FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

LOG BRIDGE CONSTRUCTION HANDBOOK

1980

Second Printing 1989

M. M. Nagy J.T. Trebett

G.V. Wellburn

Stringer Designs by L.E. Gower

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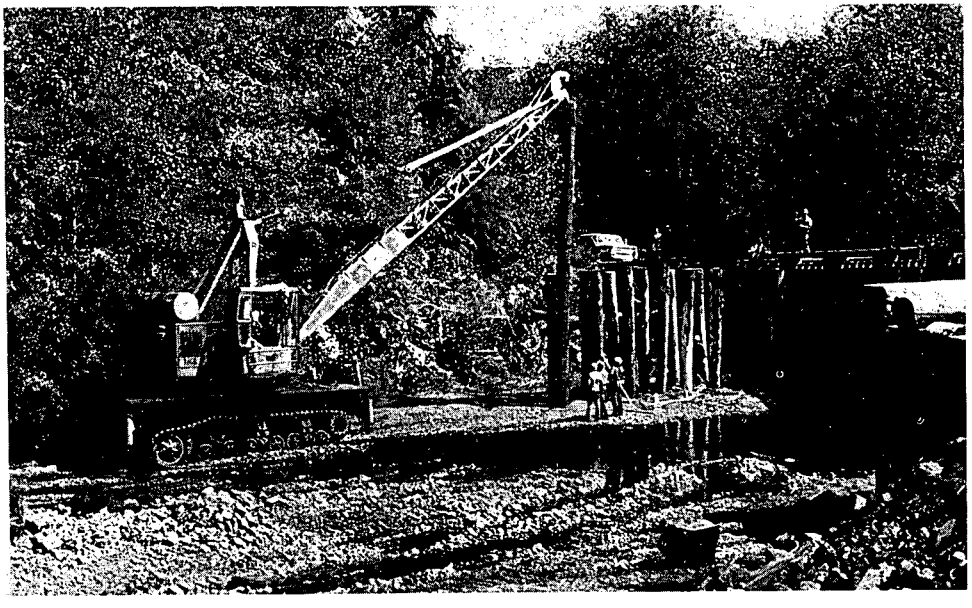

FERIC *FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA*
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

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PREFACE

FERIC is an independent non-profit research organization, organized to improve the efficiency of wood harvesting operations. It is jointly funded by member companies within the forest industry and the federal government of Canada. Membership is open to any corporation, partnership, individual or organization engaged in harvesting, transportation or the use of wood in Canada. Membership fees are assessed on the volume of wood used.

FERIC research and development activities are directed to three basic areas:

a) Improvement of present harvesting and forest transportation practices

b) Development of new harvesting systems and machines

c) Application of research and development results

FERIC is governed by a board of directors representing the membership and the federal government, and is managed by a chief executive officer. The organization has two research divisions, one in Montreal, Quebec and one in Vancouver, British Columbia.

This handbook was prepared at the request of a number of people in the British Columbia forest industry and approved by the FERIC Advisory Committee. The data and construction techniques were compiled over a period of three years. Many loggers, bridge builders and engineers were interviewed. The authors are indebted to the following people who gave their time and knowledge generously: L.L. Adamovich, R.M. Brock, C. Deminger, Bill Dunlop, C.B. Dybuik, L.E. Gower, E.G.A. Grimmer, K.A. Hallberg, C.A. Hollgren, D.C. Holmes, J.T. Johnson, Dennis Langtry, R.D. MacDougall, Ed Milligan, G.B. Milligan, J. Ronyecz, D.E. Smith, B. Thornton.

The authors would like to express their appreciation to the reviewers, whose comments and advice were most valuable. The draft was reviewed by

L.L. Adamovich, P.Eng., R.P.F., M.A., University of British Columbia
L.E. Gower, P.Eng., Gower, Yeung and Associates Ltd.
D.C. Holmes, R.P.F., P.Eng., M.F., B.C. Institute of Technology
G.B. Milligan, P.Eng., West Shore Contractors Ltd.
J.L. Power, P.Eng., R.P.F., B.C. Forest Products Ltd.
M. Stewart, P.Eng., The Canadian Portland Cement Association

R.S. Scarisbrick, P.Eng., M.Sc., and the staff of the Engineering Division of the B.C. Forest Service.

The authors are grateful to the FERIC staff for their help. Paul Leong prepared the drawings and Marjorie Bain typed the manuscript. Special thanks is due Agnes Thom, editor, who worked so diligently through all the draft copies and revisions.

CONTENTS

PAGE

PREFACE v
INTRODUCTION xv
HOW TO USE THIS HANDBOOK xvi
LEGAL DISCLAIMER xvii

I. BRIDGE TYPES AND DEFINITIONS 3

A. BRIDGE LIFE 4
B. BRIDGE SITE 4
C. BASIC BRIDGE COMPONENTS 4
1. Substructure 5
a) Abutments 5
b) Piers 8
2. Superstructure 10
a) Stringers 10
b) Trusses 12
c) Decking 13
d) Guardrails and shear logs 13
D. COMMONLY-USED BRIDGE TYPES 13
1. Culvert-Type Log Bridges 13
2. Log-Stringer Bridges with Tie-and-Plank Decks 14
3. Multispan Bridges with Piers 14

II. BRIDGE LOCATION 19

A. STREAM CHARACTERISTICS 19
1. Stream Channels 19
a) Stream bank stability 20
b) Stream bends 20
c) Meandering channels 21
d) Braided channels 21
e) Gravel and sand bars 21
f) Old channels 21
g) Straight channels 21
h) Log jams 22
2. Stream Size at Peak Flow 22
a) Peak flow 23

PAGE

b) Probability of peak flow recurrence 23
c) Bridge size and design peak flow 26
3. Scour 27
B. ENVIRONMENTAL PROTECTION 32
C. TENTATIVE SELECTION OF BRIDGE SITE 32
D. FIELD RECONNAISSANCE 34
E. PRELIMINARY SURVEY 36
F. CHOOSING THE FINAL BRIDGE SITE 37
G. DETAILED SITE SURVEY AND SITE MAP 38

III. BRIDGE DESIGN 43

A. PRELIMINARY DESIGN 43
B. STRINGER DESIGN 45
1. Design of Simple Log Stringer Bridges 45
2. Eccentric Loading 45
3. Design Stresses 46
4. Design Graphs for Simple Log Stringer Bridges 47
5. Design of Culvert-Type Log Bridges 52
6. Design of Trussed Log Bridges 54
C. PREPARATION OF BRIDGE PLANS 65
D. MATERIAL LIST 65

IV. BRIDGE CONSTRUCTION 69

A. CONSTRUCTION ORGANIZATION 69
B. SITE PREPARATION 69
C. ABUTMENTS 71
1. Simple Abutments 71
a) Single sill log 72
b) Simple sill log with mud sills 73
c) Foundation logs under mud sills 74
d) Multiple sill log abutments 74
2. Log Crib Abutments 74
a) Simple log crib 77
b) Open-end log crib 77
c) Closed-end log crib 78
d) Box cribbing 78
e) Precast concrete cribbing 83

PAGE

3. Crib Planning and Design 83
4. Crib Construction Technique 90
   a) Log preparation for cribbing 90
   b) Notching or dapping 92
   c) Sequence of crib construction 92
   d) Lashing and drifting 94
   e) Filling the crib 95
   f) Types of crib-log notching 95
5. Pile Abutments 99
   a) Pile abutment types 99
   b) Pile bents 103
   c) Types of piles in abutments and piers 112
   d) Pile bent design 113
   e) Pile selection 118
   f) Preparation of wood piles for driving 118
   g) Ground preparation and spotting pile location 120
   h) Pile drivers 123
   i) Pile driving and penetration 127
   j) Pile cutoff 129
   k) Bracing pile bents 129
   l) Caps 131
   m) Lining pile abutments 131
   n) Pile-anchoring systems 132
   o) Fastening cable to deadmen 136
   p) Fill-retaining cribbing 141
   q) Stump anchors 141
   r) Rock anchors 142
   s) Filling pile abutments 142
   t) Protection of pile abutments 143
6. Concrete Abutments 145
   a) Advantages of concrete 145
   b) Construction materials 146
   c) Site preparation for concrete structures 150
   d) Drainage 151
   e) Concrete slab foundation 151
   f) Design of concrete abutments 154
   g) Forms 163
   h) Shoring 169
   i) Preparation of formwork surfaces 169

PAGE

j) Final alignment of forms 170
k) Mixing concrete 170
l) Placing concrete 172
m) Compaction 172
n) Finishing the top 173
o) Curing concrete 173
D. PIERS 174
1. Pile-Bent Piers 175
2. Post-Bent or Frame-Bent Piers 200
3. Log Crib Piers 211
4. Concrete Piers 213
E. CAPS AND SILLS 221
F. STRINGERS 224
1. Stringer Selection 225
2. Falling 227
3. Ground Transportation of Stringers 227
4. Transportation of Stringers 228
5. Stringer Storage and Seasoning 228
6. Stringer Preparation 231
a) Debarking 231
b) Preparation area 231
c) End cuts 232
d) Marking the stringer ends 233
e) Marking the side of the stringer 235
f) Flattening the stringer top 238
g) Preparation of the stringer seat 239
7. Placing Stringers 242
8. Stringer Configuration and Load Distribution 250
a) Needlebeams (queen logs) 252
b) Stringers serving as guardlogs 256
c) Double-tier stringers 257
d) Culvert-type log bridges 262
e) Trussed-log bridges 269
G. BRIDGE DECKS 284
1. Gravel Decks 285
2. Tie-and-Plank Decks 287
a) Laying the crossties 287
b) Planking 294
3. Laminated Decks 297

PAGE

4. Specialty Decks 303
H. GUARDRAILS AND GUARDLOGS (SHEAR, FENDER, BUMPER) 306

V. WOOD PRESERVATION 317

A. WOOD PRESERVATIVES 317
1. Coal-Tar Creosotes 317
2. Pentachlorophenol and Copper Napthenate Solutions 318
3. Water-Soluble Preservatives 318
B. USE OF PRESERVATIVES 318
1. Plant Treatment 318
2. Field Treatment 319

VI. BRIDGE INSPECTION AND MAINTENANCE 327

Construction records and inspection inventory 327
1. Inspection tools 335
2. Visual Inspection 336
3. Deflection Test 337
4. Inspection Areas 338
a) Approaches 338
b) Waterways 339
c) Abutments and piers 339
d) Stringers 340
e) Needlebeams 340
f) Cables and hardware 340
g) Decks 340
h) Guardrails 341
i) Signs 341
j) General 342
5. Inspection Reports 342
6. Repairs 343
a) Stream channel 343
b) Repairs to cribbing, abutments and piers 345
c) Repairs to pile bents 349
d) Repairs to concrete abutments and piers 352
e) Repairs to caps and sills 353
f) Repairs to stringers 354

PAGE

g) Repairs to steel and wire rope trusses 356
h) Repairs to crossties 357
i) Repairs to planking 358
j) Repairs to guardrails and guardlogs 358
k) Repairs to painted surfaces 359

APPENDICES

I SCHEDULING AND COST ESTIMATING 361
COST ESTIMATING 363
II ENGINEERING CHARACTERISTICS OF SOILS AND SOIL TESTING FOR BRIDGE CONSTRUCTION 367
III SAFETY FACTORS, DURATION OF LOADS, OVERLOADING 377
IV TOOLS 379
V TIMBER CONNECTORS 383
VI WEIGHT OF STRUCTURAL TIMBERS 387
VII WEIGHT OF FILL MATERIALS 389
VIII MOISTURE CONTENT OF WOOD IN AIR-DRY CONDITION 391
IX CONVERSION FACTORS 393

GLOSSARY 397
BIBLIOGRAPHY 411
INDEX 419

TABLES

I-A GUIDE TO MAXIMUM SPAN LENGTH USING LOCAL WOOD 11
II-A PROBABILITY OF PEAK FLOW RECURRENCE 23
II-B RELATIONSHIP OF PEAK FLOWS WITH DIFFERENT RETURN PERIODS 24
II-C DESIGN PEAK FLOWS 26
II-D CLEARANCE REQUIREMENTS 27
II-E PERMISSIBLE STREAM VELOCITY 28

PAGE

II-F LOCAL SCOUR DEPTH OF PIERS 30
III-A CULVERT-TYPE LOG BRIDGES TYPE "A" 5 STRINGERS 53
III-B CULVERT-TYPE LOG BRIDGES TYPE "B" 7 STRINGERS 54
IV-A BASIC CONTACT AREA BETWEEN FACE LOGS AND TIEBACK LOGS 85
IV-B ADDITIONAL CONTACT AREA BETWEEN FACE LOGS AND TIEBACK LOGS 85
IV-C SAFE BEARING-CAPACITY OF ROCKS AND SOILS FOR CRIBBING 86
IV-D CRIBBING FACE FOUNDATION WIDTH 87
IV-E RECOMMENDED MINIMUM NUMBER OF LOAD-CARRYING WESTERN RED CEDAR FRICTION PILES FOR AN ABUTMENT 115
IV-F MAXIMUM BEARING-CAPACITY FOR END-BEARING PILES 116
IV-G PILE AND HAMMER SIZE RELATIONSHIP 117
IV-H DEFORMED BAR NUMBERS, UNIT WEIGHT AND NORMAL DIMENSIONS 150
IV-I MATERIAL LIST FOR CONCRETE 172
IV-J MINIMUM CAP SIZES IN INCHES 222
IV-K A TEST RESULT OF STRESSES IN GREEN AND DRY WOOD 229
IV-L SHRINKAGE IN PERCENT BASED ON GREEN WOOD DIMENSION 230
IV-M MOISTURE CONTENT OF GREEN WOOD 230
IV-N CABLE SIZE REQUIREMENT FOR LASHING 250
IV-O LOG NEEDLEBEAM SIZES 253
IV-P NEEDLEBEAM REQUIREMENT BETWEEN DOUBLE-TIER STRINGERS 260
IV-Q WIRE-ROPE SIZES FOR CULVERT-TYPE BRIDGE LASHING 264
IV-R LASHING FREQUENCY FOR CULVERT-TYPE BRIDGES 264
IV-S STRUCTURAL CHANNELS FOR STRONGBACK 271
IV-T CROSSTIE SIZE GUIDE 288
IV-U NAIL SIZES GUIDE 296
IV-V DEPTH OF LAMINATIONS 297

PAGE

IV-W CHECKERED STEEL PLATES 306
IV-X WASHERS TO FIT 3/4-INCH DIAMETER BOLTS 310
V-A SEASONING PERIOD 321
VI-A INSPECTION INVENTORY 328
VI-B FUMIGANT CAPACITY OF HOLES 352

A-II-a Engineering Characteristics of Soils for Bridge Construction 370
A-II-b Load-Bearing Capacity of Rocks and Soils 373
A-II-c Approximate Skin Friction Values 373

Appropriate photographs and line drawings accompany each section.

INTRODUCTION

This book was written to give practical help to loggers, foresters, forest engineers, and students, as well as the experienced bridge builder who may not be familiar with every construction technique. Not all sections will be of interest to all readers but we think that it is important for those involved in building a bridge—locator, designer and builder—to have a general knowledge of the total process. This book is not a substitute for experience or training and should be used with caution. Most of the bridge location, design, and construction information in this handbook has never been published under one cover before, although some of these subjects have been discussed in various journals and reports.

Wood is the basic construction material discussed and the one that is familiar to loggers. It is available locally and therefore cheaper; it is both reliable and versatile; and with preservative coating it has a durability equal to that of other materials.

Almost all the information in the book was collected in British Columbia and Western Alberta by interviewing bridge builders and others involved in bridge construction at logging operations. The structures and techniques described will be most useful in the two Western provinces but they can be adapted to other areas. The designs may also be adapted even though many of the tables are based on large log sizes. We have included some general design examples; an experienced designer may be able to improve these designs for specific sites by using smaller structural members at a lower cost.

During the transition period from imperial to metric, we have used imperial units where we think they will be most easily understood and metric units for surveying and for sections concerning material requiring SI specifications.

If users of this book indicate a need, we will update this material in three or four years and add and correct sections after the transition to the SI system is complete. We also plan to show designs using smaller logs. In the meantime, we invite your comments and suggestions.

HOW TO USE THIS HANDBOOK

To make it easier for the reader to work with a book this size, we have arranged the information into six major sections.

Section I, Bridge Types and Definitions, outlines basic knowledge about bridge types and structural components.

Section II, Bridge Location, discusses the selection of bridge sites, environmental considerations, channel investigations, peak flows, scour problems and preliminary site surveys.

Section III, Bridge Design, describes final plans and superstructure design.

Section IV, Bridge Construction, explains construction techniques, and gives 'how to do it' examples of bridge building. The techniques are limited to abutments and piers no higher than 20 feet and concrete abutments no higher than 10 feet. Only simple spans or spans reinforced with simple trusses are included.

Section V, Wood Preservation, lists preservatives and methods of field treatment.

Section VI, Bridge Maintenance, deals with bridge inspection, deflection tests, and when and how to repair the various structural members.

The handbook includes appendices, a glossary, references, and an index.

We have tried to emphasize practical structure types and construction techniques for different site conditions. To avoid repetition, we have cross-referenced information which pertains to more than one section. Textbook material such as derivation of member sizes and formulas is not included —readers are not expected to be familiar with engineering procedures.

The authors feel that the decision to build a bridge can be made only after full consideration of the economic and environmental factors. It is important to look at all options and to consider the need for professional advice and help. Once you have made the decision to build, this handbook gives you practical advice to plan and complete the project.

You are cautioned to get the advice of a qualified bridge engineer if any of the following conditions apply.

1. You lack confidence in your ability to build the bridge.

2. Single-length reinforced stringers may not be strong enough.

3. Piers and abutments are higher than 20 feet, or excessive earth pressures are involved.

4. Complex concrete structures or concrete abutments over 10 feet high are required.

5. The bridge is being built for more than one lane of traffic.

6. Difficult foundation problems exist—such as fractured rock, very soft soil, or underwater construction.

LEGAL DISCLAIMER

The support data for this book was collected from a great number of sources and believed to be reliable and true. Care has been taken during the compilation and writing of this book to prevent error or misrepresentations but neither the Forest Engineering Research Institute of Canada nor the authors make any warranty with respect to the accuracy, completeness or usefulness of the information contained in this book, or assume any liabilities with respect to the use of any information, method or process disclosed in this publication.

The use of trade names is for the information and convenience of the user of this book and does not constitute an endorsement by the Forest Engineering Research Institute of Canada or the authors.

I. BRIDGE TYPES AND DEFINITIONS

I. BRIDGE TYPES AND DEFINITIONS

This section defines and describes basic bridge terms and components. It explains the terms used later in this book to readers involved in bridge planning, locating, design and construction. The glossary includes additional terms not covered in this section.

Bridges and culverts are road-drainage structures that channel water from one side of the road embankment to the other. A culvert may be either a bridge less than 20 feet in length or a structure with enough fill over it so that little of its strength is needed to support the traffic load (Figure 1). Culverts may have their inlet submerged under flood conditions but bridges must have clearance even during a flood. In the context of this book a bridge is a weight-bearing structure with an earth fill or timber deck, and with a span of more than 20 feet. The designs in this book are for bridge and culvert-type (gravel-decked) bridges.

FIGURE 1. A log culvert

A. BRIDGE LIFE

The cost of a bridge depends on its design life. A bridge that is needed for only a short period can be built quickly with inexpensive materials, but a bridge used for a long period must be carefully constructed from good quality material.

We discuss three classes of bridge structure classified by expected life duration.

- Temporary bridge: a life of less than ten years
- Semipermanent bridge: a life of ten to twenty years
- Permanent bridge: a life of more than twenty years

B. BRIDGE SITE

The best bridge site forms a crossing for the road at an acceptable location, gradient, and curvature. It is located in a narrow, straight section of the stream where the banks give firm, scour-free and safe support for the foundations. There must be a clear passage for water and debris with minimum potential for obstruction or diversion of the stream. The bridge should be built from local materials at the lowest possible cost and give satisfactory service over its expected life.

To choose the most suitable site, planners and builders should consider and evaluate road and traffic requirements with great care.

C. BASIC BRIDGE COMPONENTS

Bridges have three basic components (Figure 2). The substructure supports the weight of the superstructure and the traffic on the bridge. It is made up of abutments at the ends and piers in the centre.

The superstructure is the part of the bridge which spans the opening and carries the load. It consists of decking, stringers and trusses. The span of a bridge is the clear opening between the abutments.

The approaches are road sections at both ends of the opening which guide the traffic on and off the bridge. Often abutments form part of the approach.

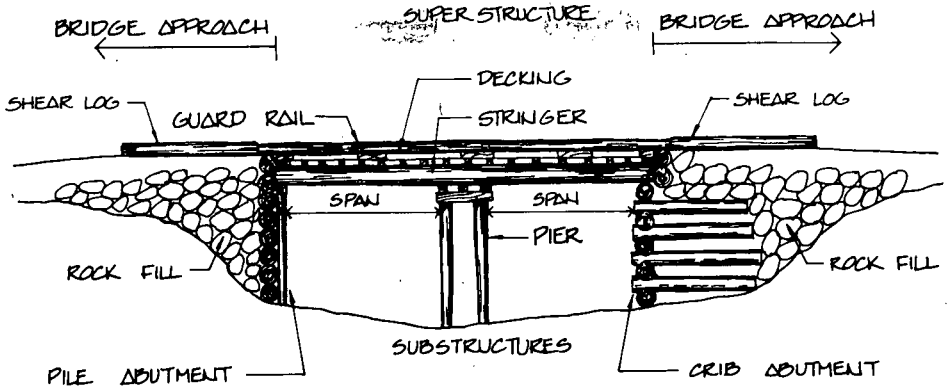


FIGURE 2. Basic bridge components

Any type of substructure may be combined with any type of superstructure to form a bridge. The designer must choose the best combination. For example, the span can be reduced by moving the abutments closer together. This may make the abutments higher and force them into a poor location in the stream. On the other hand, the span between ideal abutment locations may prohibit the use of local stringers or require the use of trussing or centre piers.

1. Substructure

The choice of substructure depends upon ground conditions, abutment height, availability of material, life of the bridge and to some extent the type of superstructure. Equipment availability may also be an important factor. For example, a pile abutment may be appropriate but if a pile driver is not available another type of abutment must be used.

a) Abutments

- Simple abutments

Simple abutments (Figure 3) may be used if the ground is firm and bridge clearance can be low. They are often used for small crossings and with culvert-type log bridges if no great clearance is required above the water. They are characterized by simplicity and low cost. Several examples, ranging from simple ground support to multiple sill log abutments, are illustrated in Section IV.

FIGURE 3. A simple abutment

- Cribbing abutments

Log crib abutments can be constructed for stream banks that are not at the same elevation, or for raising the level of the bridge to permit adequate flow (Figure 4).

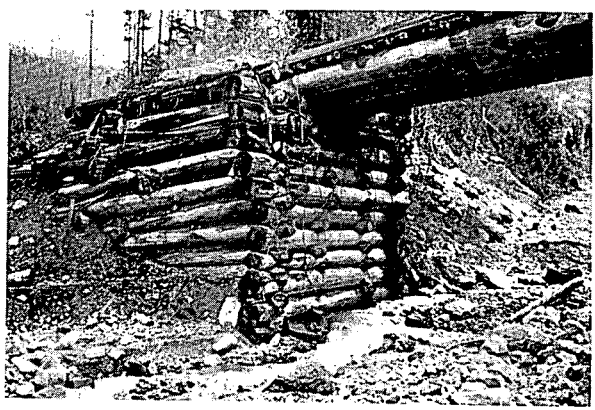


FIGURE 4. A log crib abutment

Crib design and construction methods vary to suit necessary crib height, type of soil or rock available for fill, and exposure to scour. Crib logs should be larger than 20 inches in diameter to make a stable structure and reduce the

effect of rot. (Log cribs higher than 20 feet must be designed by a qualified bridge engineer.) Only cedar cribbing is recommended for semipermanent or permanent bridges. Treated wood is not often used for cribs but precast concrete logs have been successfully used.

If the crib is to be built away from the stream channel where it is not subject to scour, it can be built directly on level hard ground. If the surface is soft and likely to scour, however, the crib site should be excavated to firmer ground or to a depth where the crib foundations will not be undermined by water. Cribs should not be located where they obstruct the flow of the stream and should not be built on steep, rocky slopes, unless a concrete pad foundation is provided. Cedar log cribs are relatively easy to construct from local materials, are easy to maintain, and support any type of superstructure.

- Pile abutments

Consider pile- or post-bents for bridge abutments

- if it is necessary to put the foundation in a stream
- if the stream bank is too steep to build a log crib
- if the soil is soft and deep enough to allow pile driving
- if wood is scarce for cribbing
- if pressure-treated materials are to be used for longer life (treated cribbing would normally cost too much).

Wooden piling is normally the most common type, but steel piling is becoming a popular alternative if longer life, resistance to ice, and difficult driving conditions are factors.

Pile-driving requires special equipment and experience. You can rent pile-driving attachments for logging machines and experts may be available for short-term contracts.

You can construct framed bents placed on mud sills on the site. These can be made from local materials and can often be used in place of driven piles but they cannot be used where the sill will be subject to scouring.

- Concrete foundations and abutments

Concrete pads are often placed on rock foundations to form sills for stringers for frame- or post-bents, or to provide level surfaces and fastening points for wood crib abutments. Concrete abutments can be constructed to retain the approach fill or to divert the stream. In either case the foundation must be secured to the rock and reinforcing is needed.

Concrete abutments

- are most expensive and most difficult to build
- are most resistant to impact damage
- have the longest service life

(Note: this handbook covers only those concrete abutments and foundations less than 10 feet in height. Consult a competent bridge designer if abutments or foundations exceed this height.)

b) Piers

When the distance between abutments is too great for the available stringers to span without intermediate support, piers are needed. Piers may be constructed of piling, log cribs or concrete (Figure 5).

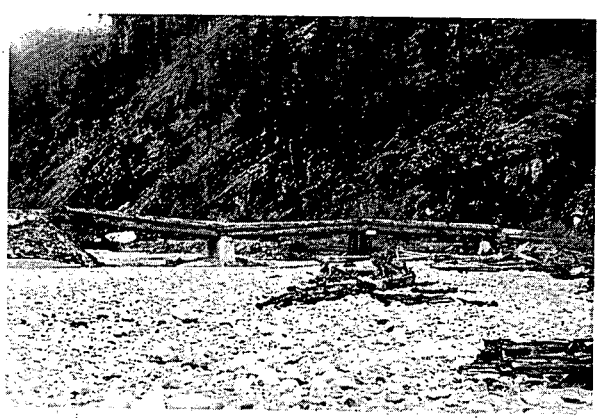


FIGURE 5. Piers

The following criteria must be met.

- Piers higher than 20 ft require full engineering design.

- Water depth should be less than 4 ft for easy construction.

- The Fisheries Department may require special conditions to be met when piers are built in the stream channel.

- Piers should not be placed in streams carrying ice floes or heavy debris.

- Unless the pier is fastened to rock, its base must be below the anticipated scour level.

Piers should be built in small islands or natural rock outcrops in the centre of a stream and should be built to be as slender as possible to minimize the obstruction to the stream flow.

Post-bent or frame-bent piers

- are used on hard ground where piles cannot be driven and wood is not available for cribbing

- may be made from treated material, must have wood or concrete foundation

- have the advantages of pile piers but are more difficult to build and protect against scour.

Post bents are cheaper to construct than frame bents but are more vulnerable to damage. Leaning bents can be constructed to reduce the unsupported span of the bridge.

Log crib piers

- are easy to build, need no special equipment

- need a good foundation, have a short life

- reduce the channel size, are susceptible to local scour

- require box cribbing.

Concrete piers

- are difficult to build, and require special equipment.

- are resistant to impact damage.

- have a narrow structure with least obstruction to stream flow.

- have the longest service life.

2. Superstructure

Bridge superstructures consist of stringers, deck and guardrails.

a) Stringers

Stringers support the design load and are the most important and expensive part of a bridge. Because they are sensitive to overloading, decay, and damage, they are the most difficult bridge components to inspect and repair. Table I-A gives you some idea of the span length of stringers and simple trusses.

The following stringer types are discussed in later chapters:

- Unprepared log stringers: for simple small bridges, culvert-type log bridges and culverts.

- Prepared log stringers: for larger semipermanent and permanent bridges.

- Guardrail stringers: two extra stringers act as guardrails and increase the bridge strength and are often used to strengthen old bridges.

- Sawn-timber stringers are not discussed in this handbook. Although extensively used in the past they are seldom used today. Their size limits them to small spans and if they are used in short-span permanent bridges, they are pressure-treated.

- Multiple layer stringers are used if the number of stringers necessary to carry the design load will not fit into a reasonable span width.

TABLE I-A. A Guide to Maximum Span Length (in Feet) Using Local Wood

(This table is a guide only and is not to be used for design.)

Superstructure Type	Mid-Stringer Diameter (Inches)								
	20			30			40		
	Design Truck Load (Tons)								
	50	100	150	50	100	150	50	100	150
Douglas-fir, Western Larch									
Simple Stringers	38	28	22	60	48	36	78	68	58
Guard-Log Stringers	44	34	26	70	58	46	90	82	70
Double-Tier Stringers	50	40	36	78	66	60	96	86	80
Trussed-Log Stringers	80	60	50	100	100	90	100	100	100
Spruce, Pine, Yellow Cedar, Hemlock, Balsam									
Simple Stringers	30	22	18	50	38	30	66	58	48
Guard-Log Stringers	36	28	20	58	50	38	80	70	60
Double-Tier Stringers	42	32	30	68	56	52	88	74	68
Trussed-Log Stringers	70	50	40	100	90	70	100	100	90
Western Red Cedar									
Simple Stringers	26	20	15	46	34	26	52	52	42
Guard-Log Stringers	32	24	18	52	44	34	72	64	55
Double-Tier Stringers	38	28	26	60	50	46	78	68	62
Trussed-Log Stringers	55	45	35	80	70	60	80	80	80

Note: - Superstructures in this table have 'crosstie and plank' decks. Special design trusses may increase the spans shown.

b) Trusses

Trussing strengthens the superstructure. It may distribute the load evenly over the stringers or it may support part of the load. In extreme cases the trussing may be designed to carry the entire load, while the stringers only stiffen the structure.

Many truss designs are available, but only three are discussed in this handbook.

- Needlebeams (king log, king beam, queen log, crosslog, etc.). Needlebeams are crosslogs placed under the stringers and securely fastened. The function of the needlebeam is to equalize stringer deflection by giving rigid support to the superstructure at one point. Needlebeams can also be lashed to guardlogs for additional strength. Needlebeams can be placed in the bridge centre (king logs) or at the third points (queen logs). You can also use needlebeams to hold the stringers of log culvert-type bridges together. Multiple-layer stringer structures require needlebeams between the stringers.

- An inverted (underslung) king truss strengthens and binds stringers at the halfway point. Usually wire ropes attached to the ends of the stringers are stretched under a single beam at centerspan to form a simple truss. Special hardware is required to tighten the wire ropes and to protect the ends of the stringers. Loggers can build wire-rope trusses to increase the span of a temporary bridge or to strengthen old ones. Wire rope has a short life and is only recommended for temporary trusses. On higher bridges with ample clearance, a large needlebeam, double needlebeam, timber frame-bent or steel frame may be hung under the centre of the bridge.

- Inverted (underslung) queen trusses support the stringers at the one-third points to increase the effective span of log stringers. Steel rods are often used to serve the same purpose as wire rope in the construction of simple trusses. Because they are rigid they are easier to use under two needlebeams. Queen trusses provide more clearance under the bridge than king trusses.

The hardware for attaching the rods is available and installation tools can be rented.

c) Decking

Decking provides the running surface for vehicles and distributes the load over the stringers. Decking rests directly on the stringers. Because decking is visible, bridges are often classified by decking appearance and construction. We list the principal types of decking in order of increasing complexity and cost.

Gravel (shot rock)
Crosstie and planking
Laminated decking
Sectional decking
Special decking (asphalt, concrete)

d) Guardrails and shear logs

Sawn timber or round-log guardrails prevent vehicles from driving off the bridge. The guardrails may be bolted or lashed to the decking or stringers. Large guardrail logs properly secured to the stringers may carry part of the load and act effectively as stringers.

Shear logs funnel the traffic from the approaches onto the bridge and may be laid on the ground and connected to the guardrails, or you may replace shear logs by ridges of gravel or blasted rock at the road edge.

D. COMMONLY-USED BRIDGE TYPES

1. Culvert-Type Log Bridges

The cheapest bridge is the culvert-type bridge with log sill abutments, log stringers and a gravel deck (Figure 6). If large cedar logs (red cedar or yellow cedar) are available, bridges of this type can be built to carry 150-ton loads on spans up to 60 feet. Cedar log bridges have a life of 10 years or more and can be built almost entirely from local material. Any wood species can be used for temporary bridges. Construction of these bridges is similar to that for log culverts.

Gravel decks generate larger dead loads than other decks and reduce the allowable span length for any given diameter of stringer. For this reason culvert-type log bridges with simple abutments are usually used to cross small streams if both stream banks are solid and high enough above the creek to permit adequate flow. The gravel deck is easy to maintain with a

grader and blends into the landscape. The life of a gravel bridge with a log crib abutment is governed by the life of the stringers. Bridge life can be extended by using stringers that are larger than the design minimum for the span.

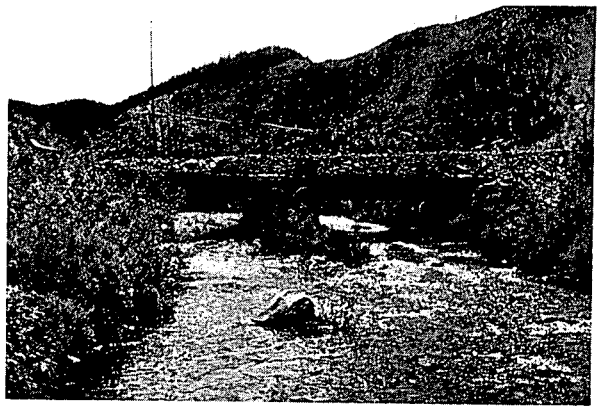


FIGURE 6. A culvert-type log bridge

2. Log-Stringer Bridges with Tie-and-Plank Decks

Use tie-and-plank decks on permanent or semipermanent bridges and on longer spans where deck weight is important and stringers are not available to support gravel decks. Tie-and-plank decks are seldom made locally and may require special fastenings. Bridge planks require considerable maintenance.

The advice of an expert is needed on the use of other materials such as asphalt, concrete or plywood.

3. Multispan Bridges with Piers

Multispan bridges are necessary when stringers are not long enough for a single span bridge or when a long low approach is necessary and a fill would restrict flood water (Figure 7).

The superstructure for these bridges is designed as two single spans connected to common piers.

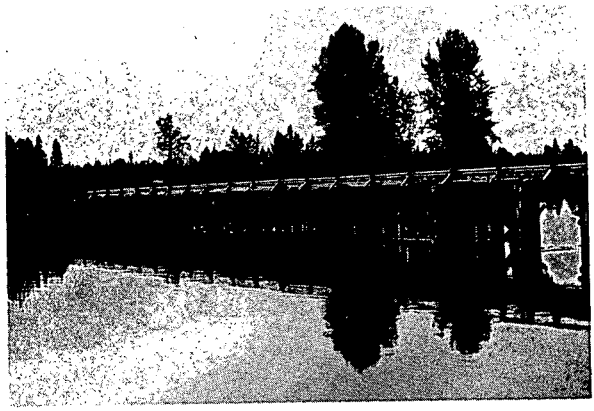


FIGURE 7. A multispan bridge

II. BRIDGE LOCATION

II. BRIDGE LOCATION

This section will familiarize the locator with the basic information he requires to choose a bridge site. It will discuss river characteristics and their effect on a bridge. It will guide the reader through the problems of tentative site selections, what to look for during the field reconnaissance, and the data needed to compare sites. We will also discuss a detailed site survey. This survey will be necessary for the bridge design and preparation of the construction plans.

Locating the bridge is not always so complex. At some sites it is sufficient to specify the size of the structure to the road construction crew and they can build a simple bridge with no further preparation. On other sites where an expensive structure is required it may be necessary to follow the detailed survey and evaluation procedure outlined. In this book we classify crossings as either 'minor' or 'major.'

- Minor crossings: Simple, easy to relocate, and cheap. Alignment to the road is the prime consideration, since bridge cost will not be critical.

- Major crossings: Expensive. The selection of the bridge site has priority over road location and alignment. Roads are located in order to cross at the selected bridge site.

A. STREAM CHARACTERISTICS

Stream characteristics are the most important factors to consider when you choose a bridge site. These characteristics are discussed in three groups.

1. Stream Channels

The characteristics of the stream bank are the most important factors affecting a bridge crossing and must be considered during both preliminary investigation and reconnaissance. Sites with a straight narrow channel, even gradient, and few potential debris-jams make an ideal location; they should fit the road pattern and cross where the banks will not erode, even at peak flood levels.

The locator must investigate the stream channel and stream banks thoroughly to judge the area for a suitable location for abutments and piers and the equipment and machines required for the construction of the bridge.

Soil conditions may be very different for each abutment and pier. Streams may follow geological transition zones so that the formation of one side differs from the other. Figure 8 illustrates an example.

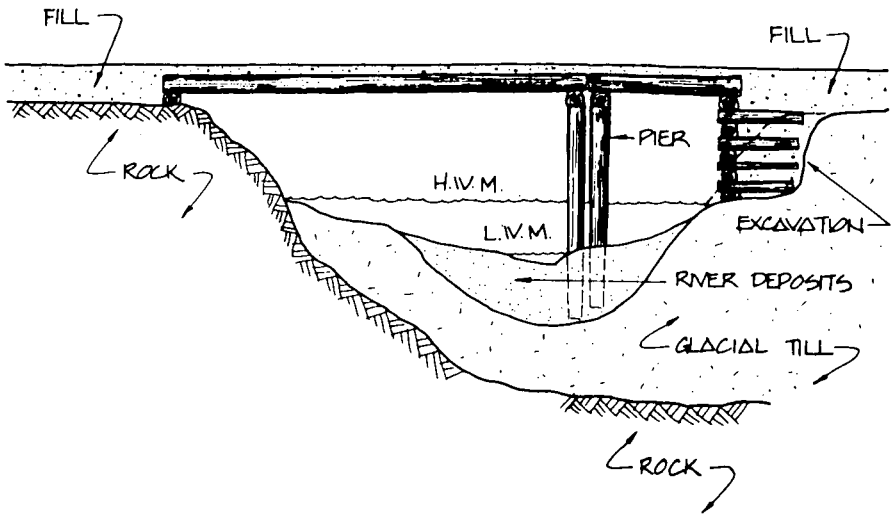


FIGURE 8. Bridge adapted to different ground conditions

a) Stream bank stability

Footings are usually placed on the stream bank. If the bank is easily erodible, special protection is required for the abutments. (Indicators of active erosion are undercut banks and partly washed-out overhanging stumps.)

b) Stream bends

Look at the flow of water around a bend or a curve in the stream and you will see that the inside of the curve has a buildup of sand or light material while the outside is deeper and usually well-scoured. If the bridge must be located in a stream bend, check the reason for the bend.

Bends might form to detour around an obstacle blocking the watercourse. These blockages may be a rock hump or other non-erodible material (hardpan) which will provide excellent footing for the abutment. Bends may also form when one side of the channel is not as easily eroded as the other.

Even in straight channels, slow stream-flow might be blocked by sediment or debris deposited by the stream itself. If the water is forced from one side to the other it will speed up and if this side is erodible, scour will start. Protect bridge abutments against scour damage on the outside of a bend.

c) Meandering channels

A meandering stream with oxbows and abandoned flood channels is relatively slow-flowing and the stream bed is erodible. Protect abutments and banks.

d) Braided channel

A braided stream has fast stream-flow with heavy runoffs and low banks which overflow. A braided stream bed is usually paved with large stones or small boulders. It may be difficult to drive piles. Protect abutments, banks and approach-fills to prevent bank erosion.

e) Gravel and sand bars

The content of gravel and sand bars can give you an indication of water speed. A swift current moves boulders, cobbles and large gravel. When the stream slows down it will deposit the large stones first and the small particles last. Slow floodwater carries only sand and silt.

Gravel and sandbars grow larger and eventually force the stream to erode its banks and to change channels. (The resulting dry bars may not make good crossing sites, but are a good source of gravel for road construction.)

f) Old channels

Old channels may reflood at extreme high water or if blockage occurs in the active channel. Keep the stream channel free from blockage under the bridge. Install a culvert where roads cross old channels to provide temporary overflow for the stream.

g) Straight channel

Water has the highest velocity in unobstructed straight channels where speed depends on the gradient. Water may back up in a narrow channel at high flood. Protect piers in the stream from fast-moving floating debris and ice.

A straight stream channel on a fairly even and steep gradient will have a well-scoured surface containing boulders that are stable during most conditions. These may sometimes float submarine-fashion during the heaviest runoff and be deposited where the river levels off. Further downstream there will be gravel, sand and silt bars. The river will normally be shallower and broader in the level stretch and although it may be easier to drive piling here than in the boulders upstream you will probably need a longer bridge. The stream bed here may be less stable in flood than the more bouldery sections.

h) Log jams

Log jams near a bridge must be removed or the bridge protected. A log jam below a crossing will cause water backup during a flood, and above a crossing it can suddenly release floating logs or a flood of water.

Logging carried out after the bridge is built may allow the formation of log jams where none existed previously. Jams are almost impossible to predict but the bridge locator should investigate any potential cause of log jams.

2. Stream Size at Peak Flow

Peak flow is the largest flood which can be expected in any given time period. The bridge opening must be large enough to accommodate 'peak flow.' The amount of water in a stream may be computed by using the stream channel cross-section and the water flow speed. Cross-section (m^2 or ft^2) multiplied by the water speed (m/sec or ft/sec) will give the figure for the volume of water (m^3/sec or ft^3/sec) passing in a period of time. Stream size calculated at peak flow will determine the size of the bridge. Water velocity depends on the channel gradient and smoothness and the head water pressure. Velocity does not fluctuate during floods because gradient, smoothness and head water pressure do not normally change. (Head water pressure could change suddenly if log jams or debris jams burst upstream, however. If unusually high water and speed combine with floating debris, their scour effect on the bridge could be disastrous.) You can judge the length of a bridge span and the height of the abutments by the amount of water that must flow under the bridge, the elevation of the road and the required clearance under the bridge.

See 'Surveys for Drainage Structures on Forest Roads'—a guide by the Ministry of Forests, Forest Service, Province of British Columbia, for additional information.

a) Peak flow

Peak flows result from a combination of many factors:

- Heavy rain and storms
- Rapid snow melt
- Bursting of temporary dam
- Watershed area
- Watershed topography
- Ground conditions: roughness
  soil types and conditions
  vegetation cover
- Drainage pattern

b) Probability of peak flow recurrence

Floods are referred to by their return periods. For example, a '10-year flood' is the peak flow which may occur once in every ten-year period. There is a 65% probability that these floods will return in their projected period. Table II-A shows the probability of some of the important flood return periods.

TABLE II-A. Probability of Peak Flow Recurrence

Return Period (Years)	Probability of Return in %		
	10-year flood	25-year flood	50-year flood
10	65	34	18
25	93	64	40
50	99	87	64
100	100	98	87

The flood levels at different return periods, when calculated, are based on the '10-year peak flood.' Table II-B demonstrates the relationship between the different peak flows.

TABLE II-B. The Relationship of Peak Flows With Different Return Periods

Peak Flow Return Period (Years)	Factor of Flood Intensity (10-year peak flow = 1:00)
10	1.00
25	1.25
50	1.50
100	1.80

You can calculate the flood level of different peak flow return periods by multiplying the 10-year peak flow stream cross-section by the factor of flood intensity. For example, to estimate the flood level of the 50-year peak flow, the stream cross-section (ft^2,m^2) of the 10-year peak flow is multiplied by 1.5 (factor of flood intensity from Table II-B) to establish the stream cross-section at the 50-year flood level. The height difference between the two cross-sections is marked under the bridge above the 10-year peak-flow mark to show the high water-level of the 50-year peak flood (Figure 9).

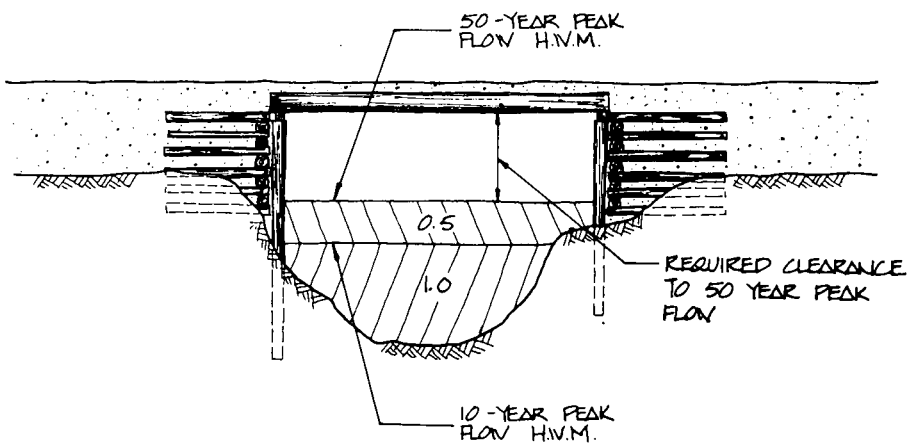


FIGURE 9. Approximate height difference between flood water-levels

There are three basic methods for estimating the high watermark of the 10-year peak flood.

- High watermark (HWM) in the vicinity of the bridge site

Examine any evidence of high water levels at the bridge site. Look in the stream bed for scour effect and soil discolouration. Scour and soil erosion found outside the stream channel on the flood plains are often caused by the 10-year peak flood and this evidence may be most visible in temporary flood channels.

Examining tree trunks and the brush in the stream channel and the flood plain may also show evidence of a peak flow. Floating small debris often hangs up on the brush. Log jams are also a good indication of the flood mark because their age can be estimated and old, high log-jams will show the high watermark on the logs.

Nearby structures can also indicate high water level.

You can learn a lot about the stream by walking through the area searching for evidence of peak flow levels and projecting the level of the stream in full flood. (This projection of full-flood conditions can often cause a locator to change his mind about a crossing which may look very good under normal conditions.)

- Collecting evidence from other sites

If peak flow evidence is difficult to find near the bridge site, it may be necessary to look for it further away from the bridge where the high watermark could be related to the bridge site.

- Examination of the same stream channel: Find the high watermark up or downstream if there is not enough evidence at the bridge site. The relationship of the cross-section at the found HWM and the present water level there may be used to estimate the peak flow at the bridge site.

- Examination of nearby streams: Examine nearby streams similar in nature and size to find the relationship to the size of peak flow and the present water level. Make sure that the stream is similar in nature to the stream at the bridge site. If they are different, then the calculated 10-year peak flow for the bridge site must be adjusted to reflect local conditions.

- Stream history: A gauged stream in the vicinity is useful, or better yet, if there is a stream gauge operating downstream, reliable records of the water level fluctuation will be available.

  Environment Canada keeps hydrometric records of some streams which they publish as a Historical Stream Flow Summary. Contact them for possible information on streams around the bridge site.

  Mining and pulp companies and hydroelectric utilities who use large amounts of water may also gauge streams.

  - Empirical formulas

Empirical formulas should be used for large or important structures to calculate the 10-year peak flow. (The C.S.P. Technical Manual from the Corrugated Steel Pipe Institute contains the most popular empirical formulas and discusses their use.) Compare the result of these calculations with other estimates.

The user of empirical formulas must have hydrological knowledge, good local experience, and familiarity with the formula requirements. Most of all he must be able to judge their accuracy.

c) Bridge size and design peak flow

The design peak flow should provide the bridge with reasonable safety at a low construction cost. The peak flow is chosen for the useful life of the bridge. (There should be less than a 40% chance of the design peak flow occurring during the life of the bridge.) The designer should consider how much extra safety can be provided at a slight increase in construction cost.

Table II-C shows the design peak flows for different bridges.

TABLE II-C. Design Peak Flows

STRUCTURES	DESIGN FLOODS
Temporary	10-yr peak flow
Semipermanent	25-yr peak flow
Permanent	50 yr - 100 yr peak flow

An old bridge in operation downstream which has stood the test of time is the best guide for the design of a new bridge. An upstream bridge may also be used as a pattern if the effect of tributaries between the upstream bridge and the proposed site is taken into account.

Keep in mind that the more ways the flood-flow is calculated and checked the more reliable the result is going to be.

Table II-D shows the clearance requirement under the stringers.

TABLE II-D. Clearance Requirements

Slow Streams	
small trees and stumps:	3 feet
large trees and stumps:	6 feet
Fast streams	
small trees and stumps:	6 feet
large trees and stumps:	10 feet

3. Scour

Scour is the erosion process resulting from the action of the stream flow when fast-flowing turbulent water removes soil particles from some parts of the stream bed and deposits them at other parts.

The scouring effect of the stream flow varies with the water velocity and the stream channel material. The size of the river deposits are an indication of the water speed as shown in Table II-E.

Lightweight soils with loose texture (silt, fine sand, organic soils) will erode easily. Bridges built in this type of soil must not constrict the water flow at all. Even the slightest increase in water velocity may have a detrimental effect on the stream channel.

Granular soils (gravel, coarse sand) will resist scouring to a larger degree because it takes fast water to work the gravel loose and to carry the particles. Only fast, turbulent water can move cobbles and boulders.

TABLE II-E. Permissible Stream Velocity

Soil Type	Permissible speed of straight channels at 1-m water depth (m/sec)
Heavy clay - low density	0.6
Heavy clay - dense density	1.5
Lean clay - low density	0.5
Lean clay - dense density	1.4
Fine silt	0.2
Fine sand	0.3
Coarse sand	0.75
Gravel	1.2
Gravel with large stones	2.4
Cobbles	3.5
Boulders	4.5

Modifying factors for water depths								
Depth (m)	0.3	0.5	0.75	1.0	1.5	2.0	2.5	3.0
Factor	0.8	0.9	0.95	1.0	1.1	1.15	1.2	1.25

Modifying factors for channel curvature				
Channel	Straight	Slightly-curved	Moderately-curved	Much-meandering
Factor	1.0	0.95	0.87	0.78

(Note: The permissible speeds in the table should be multiplied by the appropriate factor to get the permissible stream velocity.)

Impervious soils (clay, hardpan) erode very slowly, even in fast-running water. (The scouring effect of the stream is much greater when soil particles are already in the water. Scouring is caused by the 'sandblasting' effect of the water rather than its ability to loosen up soil particles by sheer force.) The scouring effect of the stream can be judged by the size of the shallow scour trenches on the channel floor.

Rock erosion due to water scouring is seldom taken into consideration. For all practical purposes rock is considered a non-erodible material.

Stream velocity is dependent on

- gradient of the stream bed

- headwater pressure—due to flood or channel constriction (natural sources or man-made structures: abutments, piers)

- wetter perimeter friction increased by channel obstacles. At low water level the rough, bouldery channel will reduce water velocity, but at peak flows it has only a small influence

Water scours are usually discussed in two groups:

- General scour occurs naturally in every stream bed. In some channels the movement of the soil particles, scour holes and gravel/sand deposits is clearly visible; in other channels the bed appears to be clean and only after close examination can scour be detected. The depth of the scouring effect of the water is an important consideration in the safe construction of abutments and piers. Measure the general scour depth of the water from the high watermark at the deepest point of the stream bed.

  At low water, some of the scour holes are filled with loose material and it is difficult to measure the correct scour depth. In fast-flowing water the depth estimate should be increased by 1 ft—in slow streams by 3 feet.

- Local scour is caused by obstructions like piers and abutments. These scours are deeper than the general scour. This extra depth must be taken into consideration. The required pile penetration, base logs and foundations must be built under local scour depth. Table II-F shows the local scour depth created by piers. The general scour depth must be increased by the local scour depth to find out the total depth of the scouring effect of the water.

Abutments are usually built at the water's edge or above the high watermark. The maximum scour depth for the abutments is not usually as deep as it is for the piers unless the stream bed is flat with nearly vertical banks on the side. If the general scour depth can be estimated, then the base log or

foundation should be at least 2 ft below it (with the exception of rock). Piling should be driven 8 ft below total scour depth.

TABLE II-F. Local Scour Depth of Piers

Open pile piers:	2 x largest pile diameter at ground line
Closed pile piers without nose:	1.5 x pier width
Closed pile piers with nose:	1.0 x pier width
Crib piers without nose:	2.0 x pier width
Crib piers with nose:	1.5 x pier width

In slow-flowing waters where the general scour depth is difficult to estimate it may be considered as being 2 ft under the undisturbed channel surface. We recommend rip-rapping to protect the abutment in fast-flowing water. Rip-rapping should be made of immovable large stones or boulders. The following rule may be used to estimate the width of the rip-rap:

$$\text{Width of rip-rap} = 1.4\,(a-c) + 2 \quad \text{where all measurements are in ft}$$

a = general scour depth $\qquad$ c = water depth at abutment base

The combined local scour of rip-rap and abutment may erode the stream bed down to the general scour depth but the protective effect of the rip-rap will prevent any further erosion (Figure 10). The rip-rap is placed in an elliptical pattern to reduce turbulence.

If abutments are inside the flood area they create local scour and constrict the free water-flow so the general scouring pattern of the stream is changed. As soon as the water leaves the bridge it slows down and creates gravel or sand bars. At lower water-levels these sand bars get bigger and bigger and creep up to the bridge (or even under it) sometimes forcing the water to the abutments with extra erosion as the result. The gravel bar may also cause a log jam under the bridge and damage the structure.

In meandering channels, gravel bars may occur naturally under the bridge and lead to the same disastrous conditions.

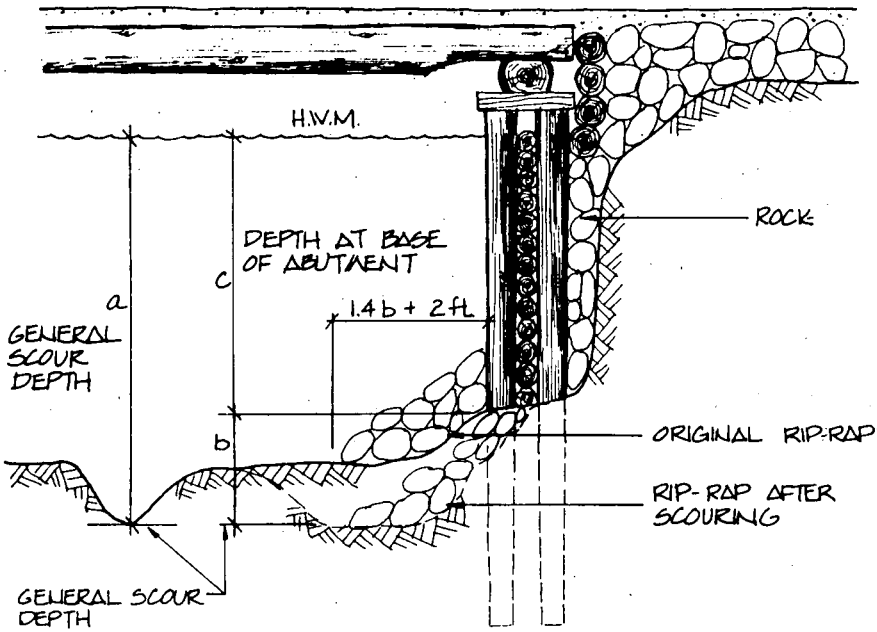


FIGURE 10. Determining width of rip-rap

If it is not harmful to fish, it may be desirable to get rid of log jams and large gravel deposits (Figure 11). Discuss channel clearing with the fishery and conservation officer before the work begins.

FIGURE 11. An improved channel

B. ENVIRONMENTAL PROTECTION

Streams and other waterways are an important resource and water quality must be protected. Bridge construction can cause siltation in downstream spawning grounds and increase the suspended sediment load. Drainage from the bridge and the approaches should not allow runoff water to carry silt directly into the stream.

Building must be done when its effect will be minimal on other users of the stream. Damage done to the stream by excavation and construction is less at low water levels, before a rainy season, or during winter before the thaw.

Discuss the location, design and construction of the bridge with the public agencies responsible for managing and protecting the stream resource. The following agencies must be contacted:

- British Columbia or other Provincial Ministry of Forests
  District Forest Ranger
  Region Engineer at the Region Headquarters

- Environment Canada: Local Fishery Officer

- Ministry of Recreation and Conservation:
  Local Conservation Officer

- Canada Transport - Coast Guard Section
  (if bridging navigable waters).

C. TENTATIVE SELECTION OF BRIDGE SITES

The choice of potential bridge sites is made by someone familiar with the area. You need good aerial photographs and maps. The actual selection starts with the general logging plan showing the approximate location of the roads. This plan is drawn on small-scale contour maps (1:5000 to 1:150000). When faced with difficult terrain, you can identify problems from a helicopter and eliminate ground work. (70-mm aerial stereo-photographs of the chosen sites may also prove valuable for the later design stages as well as for selection.) Plan difficult drainages in detail on large-scale maps with contour intervals at 2 m to 5 m. The map scale for detailed planning should not be smaller than 1:7000 (1 inch = 600 ft). The ideal scale is 1:2500 to 1:5000 (1 inch = 200 ft to 1 inch = 400 ft).

If more than one site is available for the crossing, look at each site and compare the total logging and construction cost. You must be familiar with local conditions and structures and the problems associated with them. You must know the contract requirements of the timber owner as well as environmental and government requirements. Consider the following factors during the tentative site selection.

- Logging and construction costs: To make the best crossing with good road alignment, you must know the size limits of a bridge that can be built from local material without outside help. You must know the availability of local construction material; stringer size (maximum length of a single span that can be built using local stringers); the availability of logs for the abutments and piers and the available pile length for cribbing and piling material.

- The expected life of the bridge

- The expected maximum vehicle load (Design Load)

- River characteristics, ground and soil conditions: You must be familiar with river characteristics and the local ground and soil conditions. The cost to reach different bridge sites, hauling cost, maintenance costs, and travel time on different road lengths and gradients are all important factors. Logging costs might be influenced by the amount of timber developed by the roads, seasonal closure of the road or of the bridge. You must include possible damage by bridge and road construction and future erosion problems in your environmental analysis. Consider the risk of washout.

- Environmental constraints: The timing of bridge construction is very important on some sites. Environmental and overall logging requirements may confine construction to a very short period of time.

- Access to each side of the crossing: Consider a site where construction will not be delayed by such predictable problems as a subgrading machine unable to cross a stream at a certain point.

- Survey requirements: You will need to survey some bridge sites at low water level for depth soundings, soil sampling, or exploration drilling.

- Ownership of the site

D. FIELD RECONNAISSANCE

Once the tentative selection of the bridge site is completed by map study and aerial reconnaissance, check it on the ground. Carry out field reconnaissance even if the tentative site selection appears to be the final one. This is the time to evaluate the crossing and examine the site thoroughly.

The following is a checklist for collecting information during field reconnaissance.

1. Determine where the road can cross the stream with acceptable vertical and horizontal alignment.

2. Estimate the road grade. It should be less than 5% to prevent slipping. Avoid sudden grade breaks to reduce impact loading. The bridge deck and 30 ft of the approach on each side of the bridge should have the same gradient.

3. Check the bridge approaches. The bridge should have a straight approach on each side for a distance of not less than 50 feet.

4. Find out if the bridge can be built at right angles to the direction of water flow. If it is necessary to skew the bridge to maintain road alignment, make sure that abutments and piers remain parallel to the stream flow.

5. Estimate the length of the span and decide if a single span or multispan must be built.

6. See whether or not the abutments can be placed away from normal stream flow.

7. Estimate the size of the abutment so you can make a tentative choice between building cribbing, pile bent, frame bent or concrete abutments.

8. Check the elevation of the banks. Can they be excavated or built up if necessary?

9. Check the relationship between bank height and bridge height.

10. Make sure there is enough clearance under the bridge at all times to allow the free flow of trees and stumps at high water. (Table II-D)

11. Inspect the stream channel. The stream should not change channels and the channel should be straight. The site should not be at the foot of a steep gradient where the bed load is deposited, forming islands, jams and deltas.

12. Determine the 10-year flood level by looking for the highest watermark on banks, trees, shrubs, old log jams and check the position of debris and other evidence for signs of high water.

13. Check the soil conditions of the channel. If it scours easily, the abutments and piers will need special protection from erosion and building wide crib piers will not be possible.

14. Check soil type (clay, sand, gravel, boulders) to help in choosing the right abutment.

15. Examine rock conditions of the bank where you will be putting the foundation. Does it seem solid or will it have to be protected?

16. See if piles can be driven far enough under scour level for abutments and piers—will the piles be in the fluvial layer only or will they be driven through? Can the soil layer under the river deposits support the pilings?

17. Check whether or not foundation logs for cribbing will be under scour level or on soil or rock that will not scour.

18. Find out if concrete will be needed for the foundations of abutments or piers.

19. Check to see if local materials are available.

20. See if equipment can be used to clear the site of trees and debris. Although it may be difficult to use equipment in a narrow channel, the banks are more stable and a shorter span can be built.

21. See if there is room at the bridge site for storage and preparation of the material and for the construction equipment.

22. Decide what time of the year the bridge should be constructed.

23. Decide if falsework or a temporary bridge will be necessary for construction.

24. Find out where runoff water will drain from road and ditches.

25. Make sure the bridge will be protected from floating ice. Will the channels be plugged later by logging debris?

E. PRELIMINARY SURVEY

To select the final site, you need to collect important data and carry out surveys for comparison at each location.

Examine in detail the selected bridge sites on the ground and take notes on every important aspect. The best time to do this is during the preliminary survey.

Complete the road centerline survey. The road should be laid out at the best location with centerline survey points marked with a picket every 50 ft for the length of the bridge and bridge approaches (or a distance of 500 ft on each side of the bridge). If the ground is broken the survey points may have to be closer (10 to 20 ft apart) to indicate excavation, fill and abutment problems. Depending on local conditions, this accuracy may be needed for a 100-ft distance on each side of the stream. Major ground breaks, high watermark, change in soil conditions and other points that seem to be important should also be marked. This survey is best done with a staff compass or an instrument with equivalent accuracy.

Establish benchmarks—at least two on each side of the stream—where they will not be obliterated by road construction. These benchmarks are necessary to help reestablish the centerline for the final survey and during the preparation of the site.

The last step is to level the survey points using a hand-level and levelling rod. Draw up a road profile for planning and costing the bridge. Mark cross-sections at each survey point to a distance of about 50 ft (or to cover the road right-of-way) on each side of the centerline. Use a hand compass and a measuring tape to mark the ground breaks for cross-sectioning.

Make detailed notes on local ground conditions during the survey.

Take a photograph of every important feature of the site to help office evaluation later on.

F. CHOOSING THE FINAL BRIDGE SITE

Your choice of the final site will be based on evaluation of the data collected during the field reconnaissance and economic considerations. During field examination of the site, you will have eliminated difficult crossings and those where the construction would damage fish habitat or water quality. If every potential crossing appears difficult, get the advice of outside experts.

If you feel confident in your design and construction ability, choose the final site after considering safety, economics and the environment.

We would like to emphasize again that the best bridge site is a narrow section of the stream where the reaches both above and below the proposed crossing are straight and have an even gradient. The bridge must be safe from any damage by the highest floodwater flowing under it during its planned life.

Consider all the construction costs and the cost of using the bridge for its lifespan. Costs include bridge construction, maintenance, stream protection structures and upkeep. The costs of hauling logs and personnel are the most important when the routes to the logging sites differ in length.

The routes to some sites may be closed by weather for part of the year and the costs of these closures should be projected.

For example, construction time may have to be limited to a certain period of the year, resulting in extra costs. You may need special structures built. Extra work may also be required to maintain or reestablish stream quality. All these costs must be taken into account.

Preliminary estimates of these costs are usually accurate enough for selecting the final site. If construction costs are very high, however, more than one site may be selected as a possible alternative. After surveying, mapping, and bridge design have been carried out, the total costs can be compared.

Keep public agencies involved with the final site-selection to eliminate later environmental problems and added costs.

G. DETAILED SITE SURVEY AND SITE MAP

The final bridge plans will be drawn up to complement a detailed site map prepared from a detailed site survey. (A site map is not always necessary for the bridge plans. Small, simple bridges or bridges on straightforward, uncomplicated sites could be designed from the information obtained in the preliminary survey.)

If the designer is not the same person as the locator, he should visit the site during or before the site survey to acquire first-hand information. This is also a good time for the locator, designer, builder, fishery and conservation officers to meet at the bridge site to establish the rules so the design and construction may proceed without major interruptions.

The construction of the road to the bridge site helps greatly with detailed survey and ground exploration. The last 200 feet of the road should be built as cheaply as possible because this section may be changed to adjust to the final bridge location.

The site-survey map should cover the bridge site, both approaches, and the area used by equipment working in the stream channel. Allow for unforeseen design or construction problems by including a minimum 50 feet on each side of the centerline and 50 feet on each end of the bridge.

The survey should be done at low water levels when the site is exposed for channel exploration and water measurements. The road centerline is used as the base for the survey, and it will define the location of the bridge. The designer will be able to move the bridge or the alignment to a limited degree only.

Good abutment and pier sites must be selected, and abutment, pier, and channel protection checked before deciding on the centerline.

Potential construction problems must also be considered. The banks may be too high for equipment to cross the channel. This complicates construction; perhaps a temporary bridge is needed and it should be taken into consideration in the site survey. It may be difficult for equipment to reach a site and special construction techniques may be needed to excavate below scour level.

Contour lines are important on a site map. One-foot to five-foot contours should cover the area of the foundations and the stream channel. Five foot contours are adequate for uncomplicated sites, but if complicated decisions are required, contours should be shown at one foot intervals.

Contours must also show the stream bed under water for the design of pier foundations, to establish the possible scour depth for excavation, to locate piles, and to design protection for abutments and piers. Sounding the stream depth is especially important when the construction equipment will be working in the water.

In addition, the site map should show the present, the high, and the low watermarks, soil condition and soil types, and indicate depth. Check and record rock outcrops for foundation design.

Mark scour holes, scour-hole depths, and bank scours. Show vegetation and mark the size of trees and potential 'danger trees' which may have to be removed.

Water-flow direction and speed potential are useful on the site plan. This information is used to align the piers and abutments with the water flow. In deep canyons or ravines where there is ample clearance during flood you need only prepare site surveys of the bridge approach and foundation sites.

Among the many survey methods available, the grid system provides a good way to collect the survey data for the site plan. A 10-ft x 10-ft grid system should be marked on the ground and these points levelled by a hand level and levelling rod. The stream may be covered by establishing a baseline on each side of the water with 10-ft survey marks for 50 feet. Keep a survey chain tight between the opposite survey marks on the two baselines and level or sound the points every 10 feet along the chain.

Make a detailed sketch of the vicinity of the bridge outside the surveyed area. This sketch should be based on visual observation. Take notes to describe this area.

The visual survey should cover the stream and the stream banks upstream and downstream from the bridge centerline. It should cover a distance of 5 to 7 times the channel width upstream and 3 stream-widths downstream. This survey should list the following:

- stream and stream channel, including soil and stream deposits
- flood area and apparent flood damage, including the size of trees or material moved or damaged by the water
- scour and soil erosion of the channel and flood plain

- size of logs and debris found in the channel or possibly moved by the stream

- size of large boulders moved by the flood water

- rock outcrops, or the rockiness of the stream banks and floor

- high watermark

- timber description: species, size, age, health, nature, its resistance to wind and washout

- deepest scour-hole compared to the high watermark

- flow-pattern and current

It is important to have reliable soil description at the bridge site. Indicate different types of soils and their depth. (Local experience is usually a good guide.) If there is any doubt, the soil should be tested. It may be advisable to bring a test drill to the site and sample the soils to the ncessary depth if you are building an expensive bridge with a deep foundation.

Take flow measurements again and recalculate the peak flow. (Flow measurements are more accurate at higher water levels, however, and if it is possible they should be repeated during the runoff caused by the next storm.)

Take photographs covering every aspect of the site and describe their location and purpose. They will be helpful during the designing of the bridge or in discussing problems with people not familiar with the site.

All the collected information should be shown on a site map based on the site survey. This topographic map should be drawn to a scale of 1:100 for difficult sites or designs, or 1:200 for easier sites or simpler designs. This map will be the base for planning the bridge.

A larger-scale (1:500) map should also be prepared to show the surroundings of the bridge. Transfer your notes to this map but there is no need to mark contours.

Prepare a profile at the centerline on the same horizontal scale as the site plan and on exaggerated vertical scale of 1:50 or 1:20. This profile will be used to calculate the bridge height and span.

III. BRIDGE DESIGN

III. BRIDGE DESIGN

This section will guide the reader through the necessary design steps based on the information provided by the site maps and survey. We also discuss the design and preparation of bridge components to match the stream size and type; the traffic density; the cost restraints; and the preparation of a materials list and construction schedule.

Details of the design of abutments and piers are discussed in the construction section and costing suggestions are included in Appendix I.

A. PRELIMINARY DESIGN

The designer must compare the advantages of different heights and types of abutments with the advantages of different lengths and types of superstructures to determine the basic bridge type.

He must consider the following requirements:

- Life of the bridge. Bridges expected to last for a long time without major structural repairs cannot be constructed from local materials. By using some preservatives, as much cedar as possible, and being careful with construction you can make timber bridges from local material to last twenty years. Temporary bridges built with no special precautions will usually last ten years. Bridges on lightly travelled roads may be built with permanent abutments. The stringers and deck can be untreated, however, and replaced periodically. This reduces the initial cost and may be the cheapest long-term investment.

- Volume and type of traffic. Bridges can often be shortened by going up the stream or by going down the bank closer to the stream. In the first case, the bridge approaches will contain sharp curves, and in the second, steep grades. The designer should estimate the cost of bridge construction at various locations and balance this against extra hauling costs, inconvenience, and safety over the life of the bridge.

- Type of stream. The choice of abutments and piers depends on the type of stream. Consider the effects of any future logging planned in areas above the bridge and the effect of ice during spring breakup.

- Cost. The bridge built from local materials with local labour will usually be the cheapest. The designer must know the availability of local

materials and the competence of his crews to take full advantage of the local situation.

The span length and abutment height are determined as follows:

The design peak-flow is marked on the profile. This elevation is then raised by adding the required clearance on it. A level line is drawn here to indicate the bottom of the superstructure. If a bridge has a grade in the superstructure, the clearance requirements indicate the elevation at the low end.

A vertical line at the high water-level will indicate the desired front of the abutments. The distance between the two high watermarks will indicate the span of the bridge.

Now you can choose the type of superstructure. Consider a simple span first. The number of stringers can be decided by knowing the available wood size. If the available wood is not big enough for stringers, then trussing should be considered. Sometimes even a trussed superstructure may not span the necessary distance. In this case see if the abutments can be moved within the high watermarks to shorten the span to the available size. This should be done with consideration of the consequences of restricting the water flow.

When the high watermarks are too far apart for a single-span bridge and the stream cannot be safely narrowed, then consider a multispan structure. The depth of water in a single-span structure may not be important during construction, but when you build a pier the stream bottom must be within working range of the equipment and it should also be visible. In many instances the channel depth will rule out pier construction.

Check the profile and site plan to see if you can build a pier. If piers cannot be built then bridge designers should be consulted for a bridge plan that will span the stream.

Abutment and pier height must include allowance for the required 3-ft to 10-ft clearance of the superstructure above the design peak flow. The bridge deck elevation will often be well above the road. Bridge approaches will have to lead the traffic up to the bridge and off at the other end.

The selected superstructure will define depth of the bridge and the height of the abutments. After you know the height of the abutments and piers you can choose superstructure type.

Often in a narrow valley the road alignment requires the bridge to be placed at an angle. In such circumstances even the crossings of a small stream can require a long span.

If the designer does not feel confident in his ability to design a reliable bridge for the crossing, he should seek the advice of an experienced bridge designer.

B. STRINGER DESIGN

1. Design of Simple Log Stringer Bridges

One must realize that log stringers have many inherent structural shortcomings. Logs are inefficient in shape, inconsistent in size, and the outer sap layer is subject to rapid decay. You must consider the wood quality, the consistency of available log size, the desired service life and the possibility of overload.

It is difficult to assess the strength and load sharing of several unequal logs placed top to butt. There is no practical way to calculate this accurately but a suitable approximation of performance can be made if the designer can picture how the load-sharing takes place.

The stiffest members of a structural group do most of the work since all members must deflect the same amount. The more elastic members will not deflect enough to develop their potential fibre stresses, but they do make some contribution. If the mid-diameters of the stringers are similar, a design based on the average mid-diameter will be reasonably accurate.

The designer must also consider how well the load is distributed laterally. The logs directly under the wheels are obviously loaded. The logs immediately adjacent must also be loaded, due to the spreading effect of the deck ties and decking. How far this spreading effect will be distributed depends on the stiffness of the ties and decking and the security of fastenings. Experience suggests that the tie and planking will spread the load adequately over 14 ft, limiting the total bridge width to 16 feet.

2. Eccentric Loading

An equally perplexing problem is how to allow for off-centre trucks and for unbalanced loads. Again, there is no satisfactory solution. The road may be on a curve, forcing the trucks to one side. Depending on such

factors as the width of the truck, the deck and stringers, the number and spacing of the stringers, and the ratios of the live and dead loads, an eccentric load can overstress some stringers.

A reasonable design approach is to assume that only certain stringers resist live load (though all resist dead loads) and to make an appropriate increase in the live load. A 20% increase in the live load is assumed in the design tables to allow for eccentricity.

To avoid excessive off-centre loading, a bridge design should meet these criteria:

- The bridge deck should be kept as narrow as possible (about 14 ft between guard rails).

- The stringers should be grouped under the wheels as much as is practical but large gaps should not be allowed at the centre to overstress the crossties or needlebeams. (Sixteen ft to 17 ft outside-to-outside of the stringers is a reasonable standard).

- The ties should be adequately sized and spaced to spread the load to the stringers.

- The road approaches should be designed to encourage trucks to use the centre of the bridge.

3. Design Stresses

The choice of a design fibre stress is related to the degree of conservatism used in providing for log deterioration, load-sharing and load imbalance. If the effective log diameter is restricted to the heartwood (allowing for sapwood rot), and generous allowances are made for overload and load imbalances, it is appropriate to use high fibre-stresses. On the other hand, if these factors are disregarded, lower fibre-stresses should be selected. Using the suggested assumptions, we selected bending fibre-stresses of 1350 psi for Douglas-fir and 950 psi for Sitka spruce. These stresses are less than those recommended by the Canadian National Lumber Grade Association. The design is based on the average mid-diameter of the stringers being placed top to butt. A reduction in diameter should be made to allow for anticipated rot.

4. Design Graphs for Simple Log Stringer Bridges

The following series of graphs are guides to the design of simple span Douglas-fir and spruce log-stringer bridges, using a standard timber deck (Figure 12). They are not applicable to gravel decks. Instructions for use of the graphs are as follows:

(a) Select the graph that applies to the desired number of log stringers and the desired species (spruce or Douglas-fir).

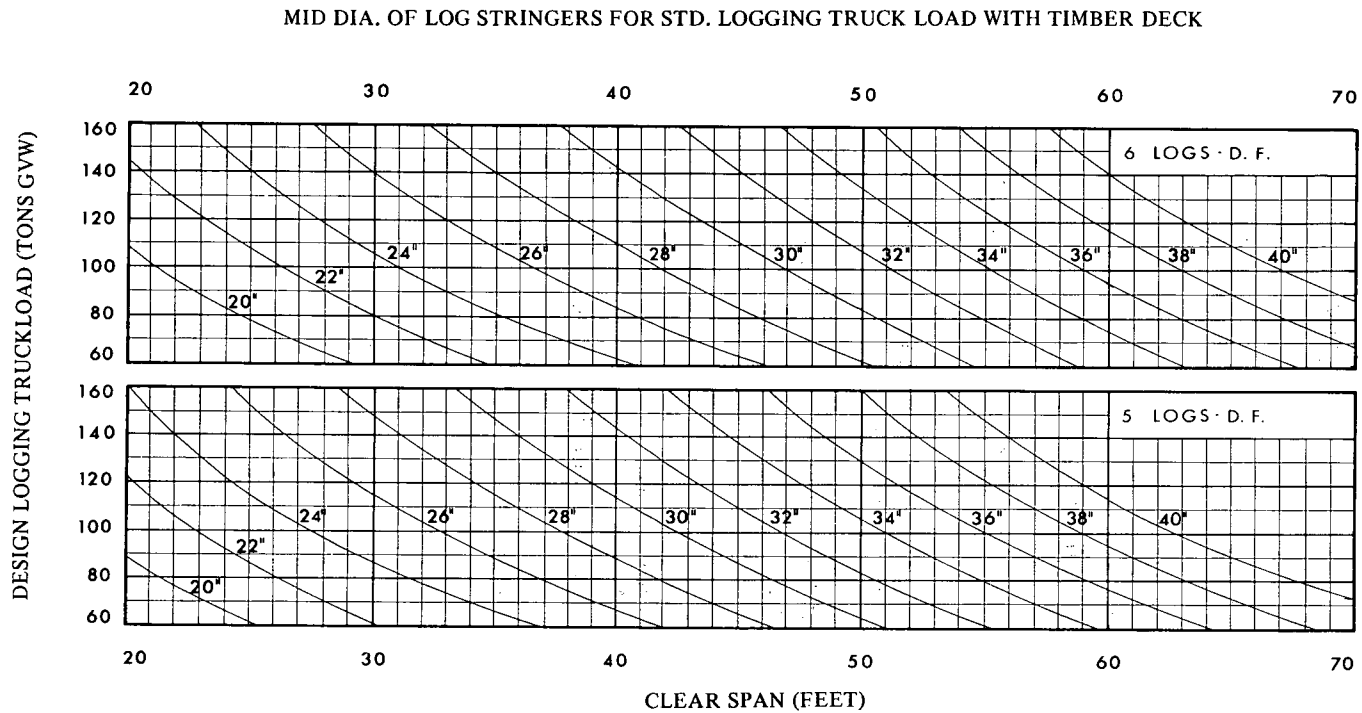
(b) Find the desired span along the baseline of the graph and extend a line vertically upward from this span.

(c) Find the desired total truckload along the side of the graph and extend a line horizontally through this load.

(d) The intersection of these two lines indicates the required average mid-diameter of the logs.

Example

For a 40-ft span and a 140-ton logging truck, the required mid-diameter of Douglas-fir stringers is 34 in. (34.1) for a four stringer bridge, 32 in. (31.7) for five stringers and 30 in. (29.8) for six stringers.



NOTE: Mid-stringer diameters are shown for bridges where the stringers are placed with alternating butts. When stringers are placed with butts at the same end of the bridge, then these diameters apply at 0.27 x span length measured from the cap (or sill) supporting the small stringer ends.

FIGURE 12 Part 1. Mid-diameter of Douglas-fir for a bridge with crossties and planks to support standard logging truck loads

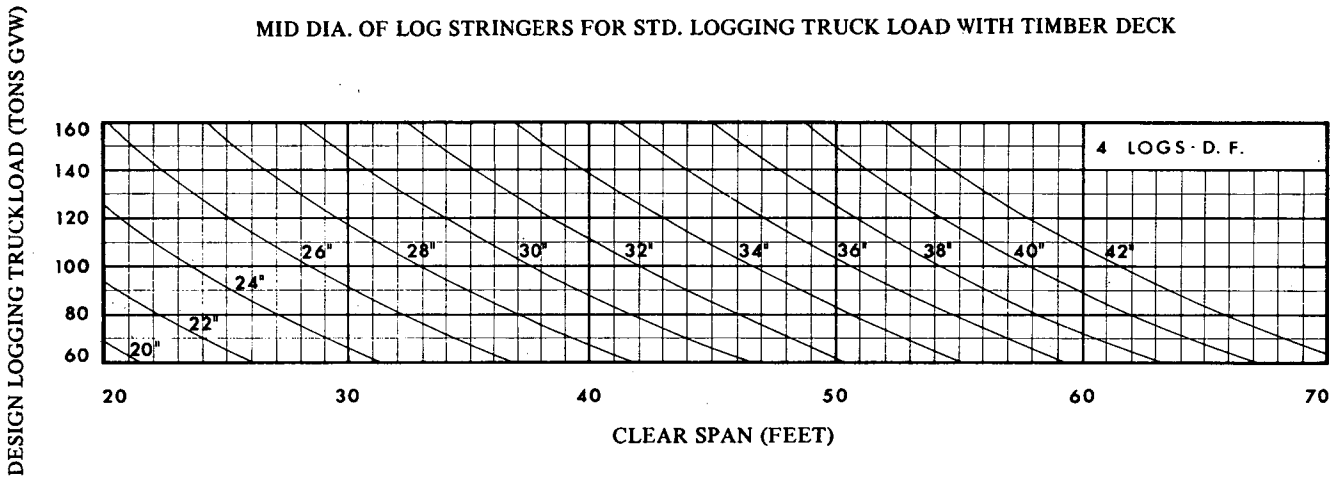


FIGURE 12 Part 2. Mid-diameter of Douglas-fir for a bridge with crossties and planks to support standard logging truck loads

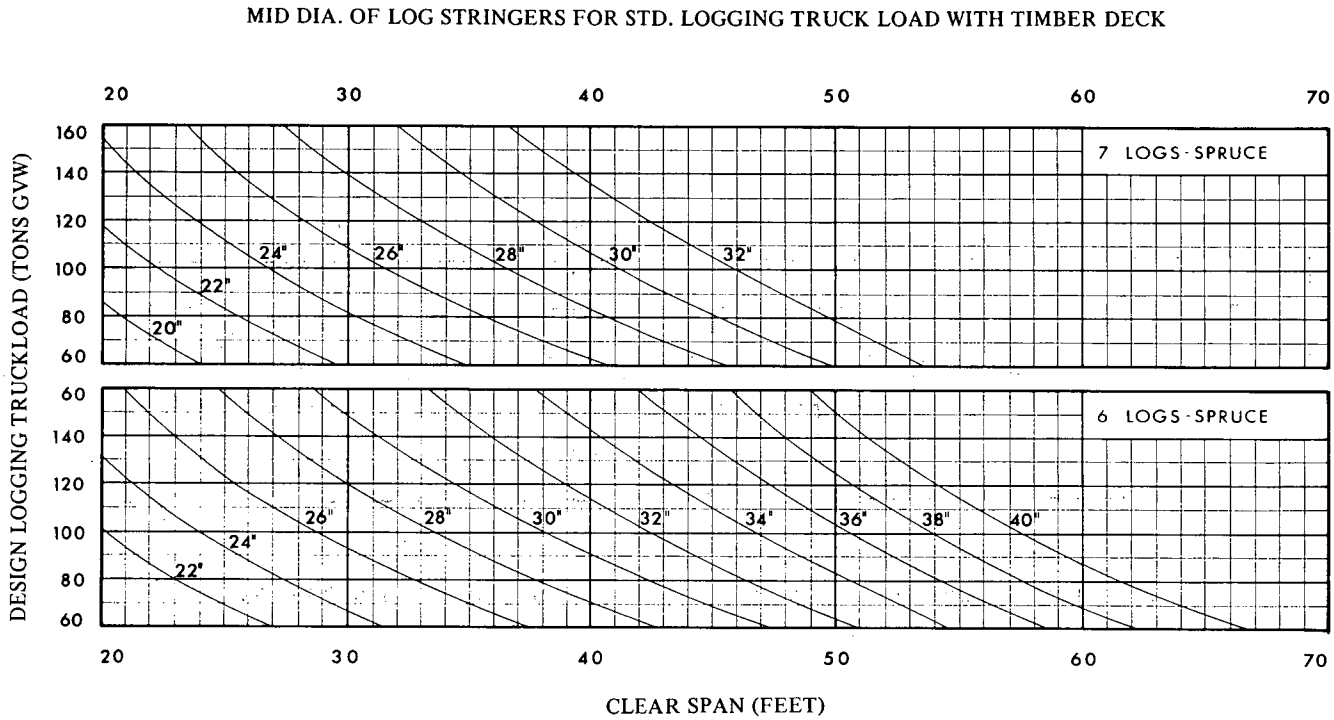


FIGURE 12 Part 3. Mid-diameter of spruce for a bridge with crossties and planks to support standard logging truck loads

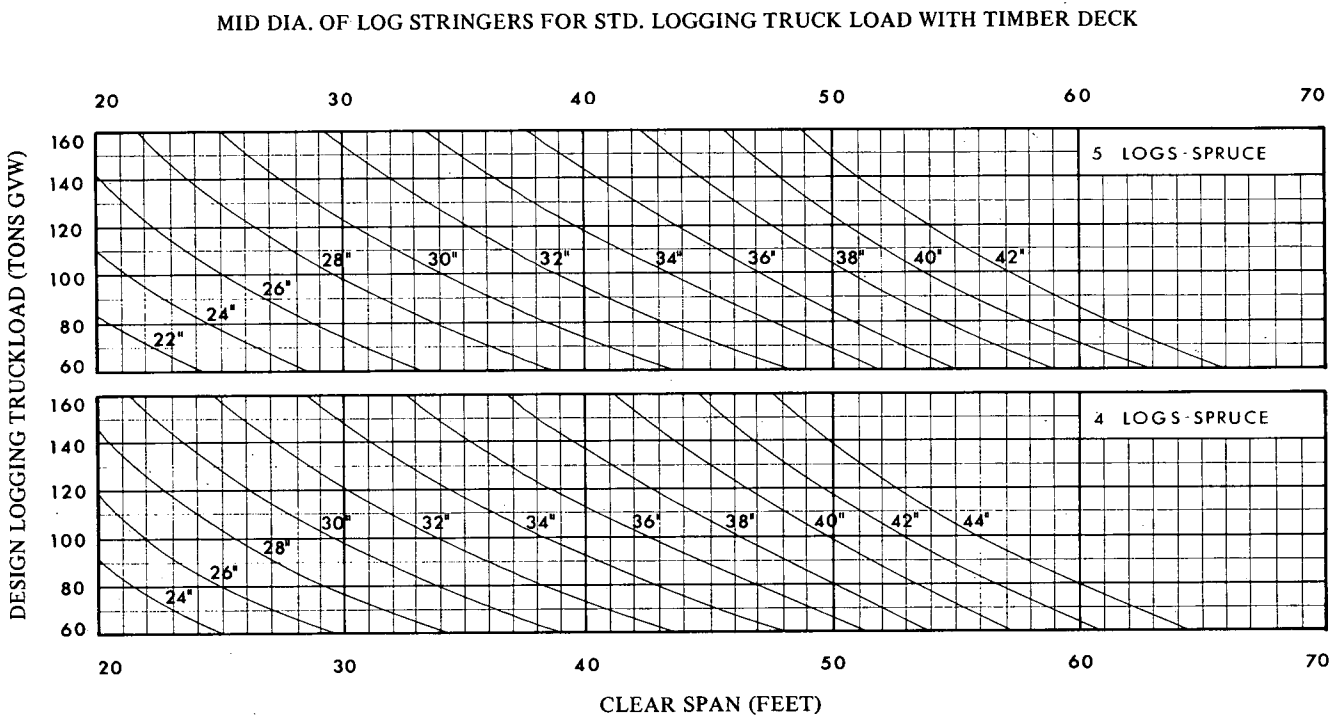


FIGURE 12 Part 4. Mid-diameter of spruce for a bridge with crossties and planks to support standard logging truck loads

5. Design of Culvert-Type Log Bridges

This type of bridge has some of the characteristics of a culvert, particularly in a shorter span. The opening is spanned by a solid layer of log stringers firmly lashed together. The deck is made from nearby gravel or other material and forms a continuous road surface.

The basic principle underlying its construction and performance is that the logs be sufficiently large and well-secured and that the gravel deck be sufficiently thick and well-compacted so components work together as a unit under the load. To prevent gravel from working out due to uneven stringer deflection, it is absolutely essential for the cables to be tight and for the deck gravel to be confined between the guard logs.

It must be recognized that a gravel-decked bridge may become hazardous with time, since unnoticeable rot may develop in the upper sections of the logs.

An accurate analysis of this complex type of structure is almost impossible, because it is difficult to anticipate and to control the depth and weight of the gravel deck and the extent of load-sharing between the stringers.

Reasonable standards for the design of cedar log-culvert bridges are as follows:

- Base the design on the average mid-diameter of the stringers.
- Use an allowable design bending fibre-stress of about 1100 psi for cedar.
- If a bridge is so short that only one pair of axles will be on it at one time, estimate the design load by the heaviest pair of axles.
- Increase this load 30% to allow for eccentric wheel loads and unequal axle loads.

Tables III-A and III-B show the relationship of span, design load and average stringer diameter for 12-in. and 24-in. gravel decks. The thickness of the gravel deck has a marked effect on the capacity of the bridge and should be either conservatively estimated or carefully controlled.

TABLE III-A. Culvert-Type Log Bridges (Western Red Cedar)

Type 'A' (Minimum: 5 Load-Carrying Stringers)

Span	Average Mid-Diameter	Design Truck Load (Tons GVW)	
		24-in. thick Gravel Deck	12-in. thick Gravel Deck
20 ft	30 in	190	215
25 ft	30 in	125	150
	32 in	160	190
30 ft	30 in	75	105
	32 in	110	140
	34 in	145	175
	36 in	180	210
35 ft	32 in	70	105
	34 in	100	135
	36 in	130	165
	38 in	165	200
40 ft	34 in	60	100
	36 in	90	130
	38 in	120	160
	40 in	150	190

TABLE III-B. Culvert-Type Log Bridges (Western Red Cedar)

Type 'B' (Minimum: 7 Load-Carrying Stringers)

Span	Average Mid-Diameter	Design Truck Load (Tons GVW)	
		24-in. thick Gravel Deck	12-in. thick Gravel Deck
20 ft	24 in	125	145
	26 in	170	190
25 ft	24 in	70	95
	26 in	105	130
	28 in	145	170
30 ft	26 in	65	95
	28 in	95	125
	30 in	130	160
	32 in	175	205
35 ft	28 in	55	90
	30 in	85	120
	32 in	120	155
	34 in	160	195
40 ft	30 in	50	90
	32 in	80	120
	34 in	115	155
	36 in	155	195

6. Design of Trussed Log Bridges

When suitable logs cannot be found for simple stringer bridges, it is possible to design inverted (underslung) steel trussing that will greatly increase the capacity of the available logs.

The design of such a structure is complex because it performs in a combined bending-and-truss action, sharing the forces between the various members in proportion to their relative stiffness.

Needlebeams may be used to provide the necessary depth for shallow trusses. Use framed struts in place of the needlebeams for deeper trusses. The trussed stringers, needlebeams, and rods function as a composite structure, with the rods taking pure tension and the stringers taking combined bending-and-axial compression.

Many types of trussing may be used, such as steel cable (see Maintenance Section), rolled sections and circular rods.

The trussing described in this section is based on the assumption that 1 1/4-in. diameter Dywidag steel rods would be selected for the tension members, using two rods per stringer. (Other types of steel rods may also be used in the place of Dywidag rods, but they and their connectors must have equivalent strength.) The practical width limit was assumed to be about 17-ft outside-to-outside of the stringers.

The graphs were based on a logging truck with the axle loadings and spacing shown in Figure 13. To provide for eccentricity, these axle loads were increased 20 percent. The following series of graphs (Figure 14) indicate the required number of logs and average midspan diameters for a limited range of types of structures and spans. No provision was made for sapwood rot.

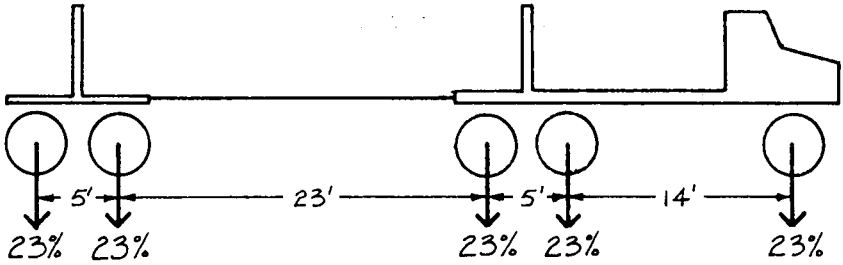


FIGURE 13. Axle spacing and loading for a 100-ton design load

The graphs were limited to crosstie and plank-decked structures consisting of Douglas-fir or spruce stringers, and two 1 1/4-in. diameter Dywidag truss rods per stringer. Two truss depth-to-span (H/L) ratios are shown: 1 to 11

and 1 to 16. See Figure 229. The depth is measured from the centerline of the design stringer to the centerline of the rods. Since the load capacity of a trussed-log bridge is greatly reduced with any decrease in the depth-to-span ratio, it is very important to provide depths which are no less than the design dimensions.

The graphs are used as follows:

(a) Select the graph that applies to the desired span (L), truss depth (H) and timber species.

(b) Find the design load in tons in the vertical column. Extend a line horizontally from this point to the line for the required number of stringers.

(c) From this point, extend a line vertically downward to find the required diameter.

Example

For a 70-ft span with a depth-to-span ratio (H/L) of 1 to 11 and a 150-ton truckload, the required mid-diameters of Douglas-fir stringers are

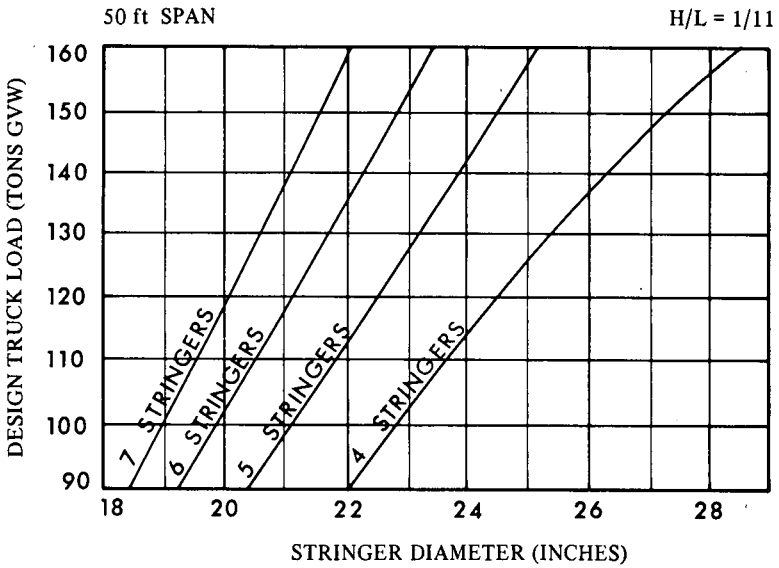
31.2 in. for 4 logs;

28.7 in. for 5 logs;

26.7 in. for 6 logs;

25.1 in. for 7 logs.

FIR STRINGERS



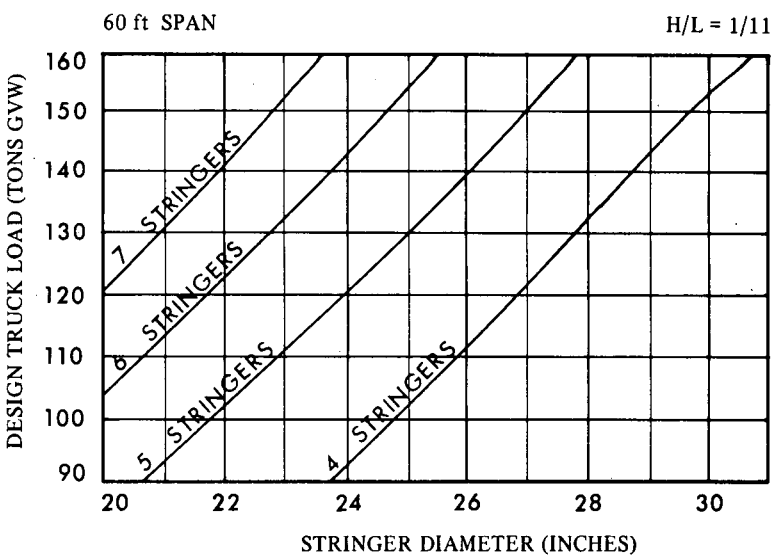
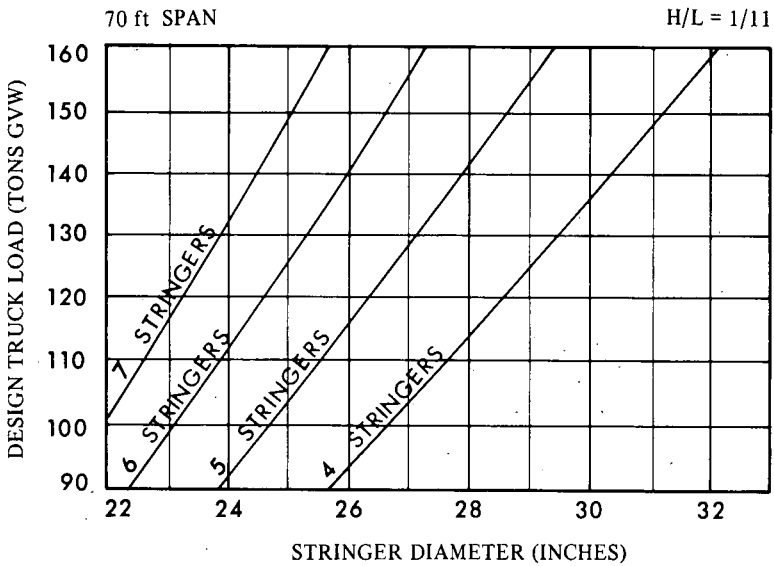


FIGURE 14 Part 1. Douglas-fir trussed log stringers

FIR STRINGERS



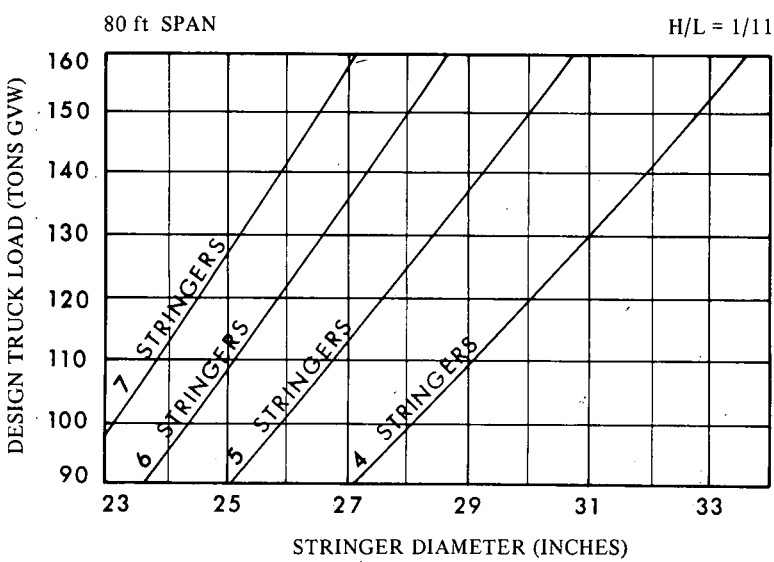
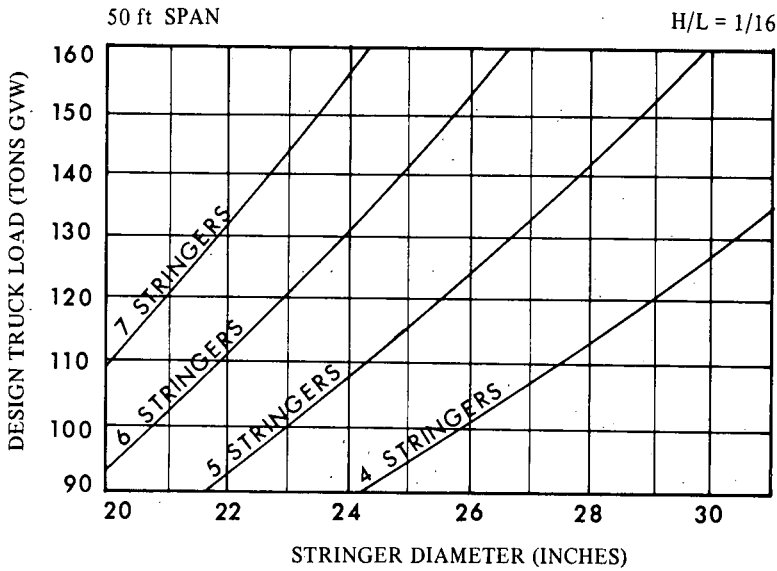


FIGURE 14 Part 2. Douglas-fir trussed log stringers

FIR STRINGERS



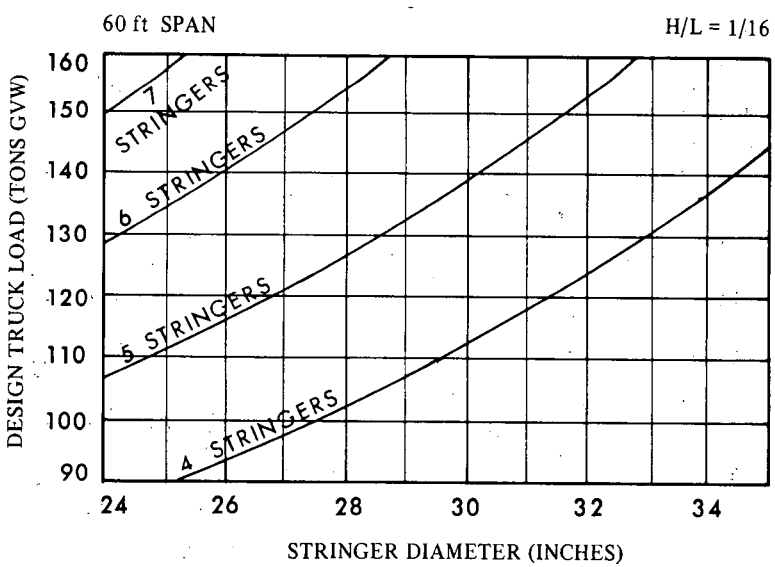
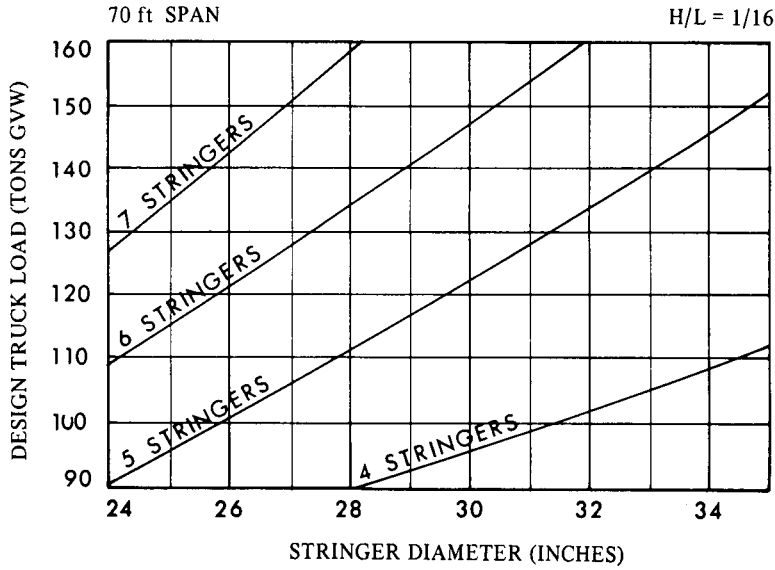


FIGURE 14 Part 3. Douglas-fir trussed log stringers

FIR STRINGERS



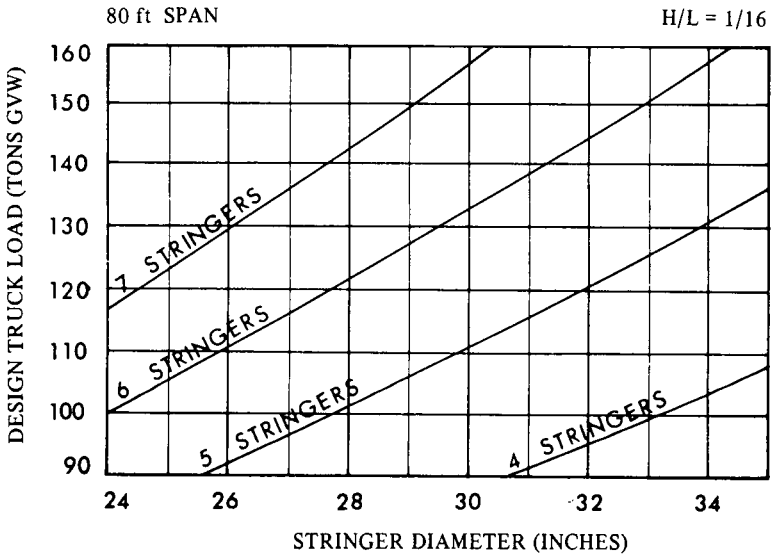
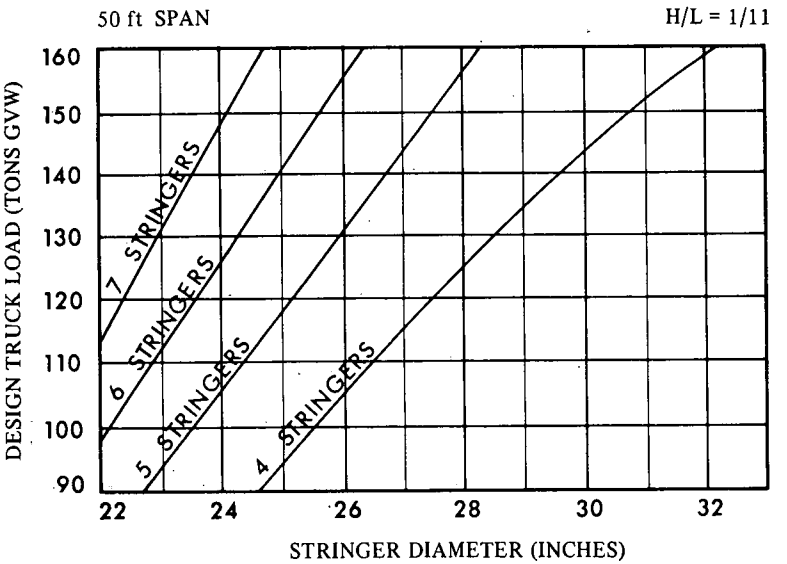


FIGURE 14 Part 4. Douglas-fir trussed log stringers

SPRUCE STRINGERS



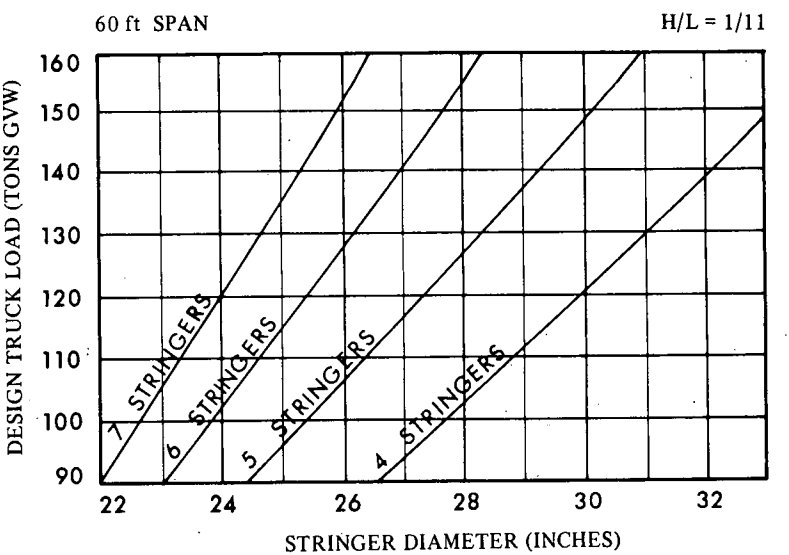
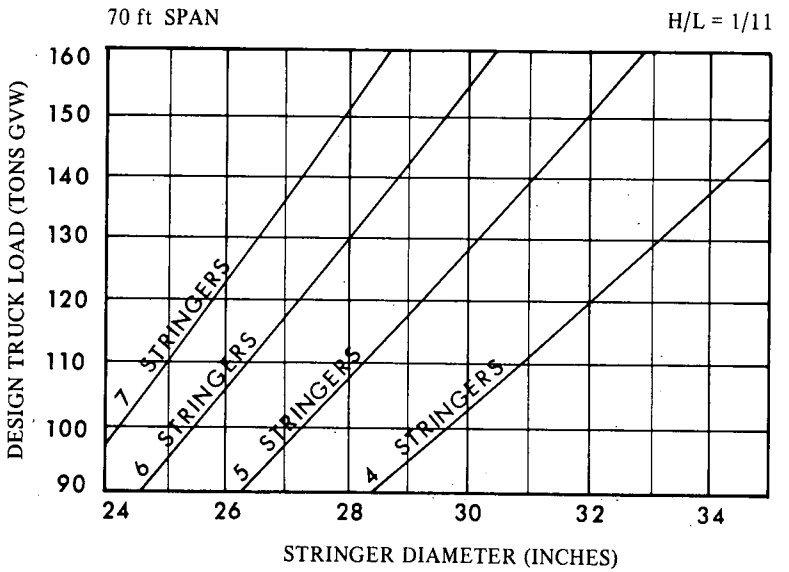


FIGURE 14 Part 5. Sitka spruce trussed-log stringers

SPRUCE STRINGERS



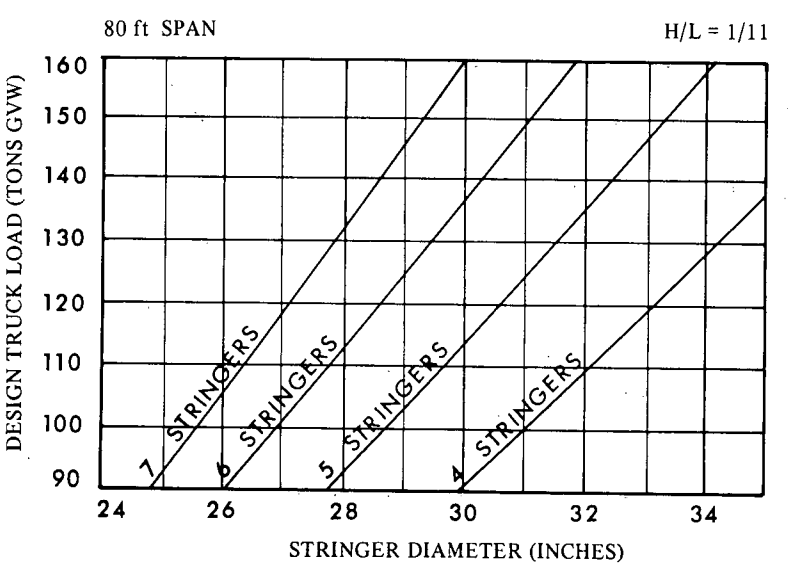
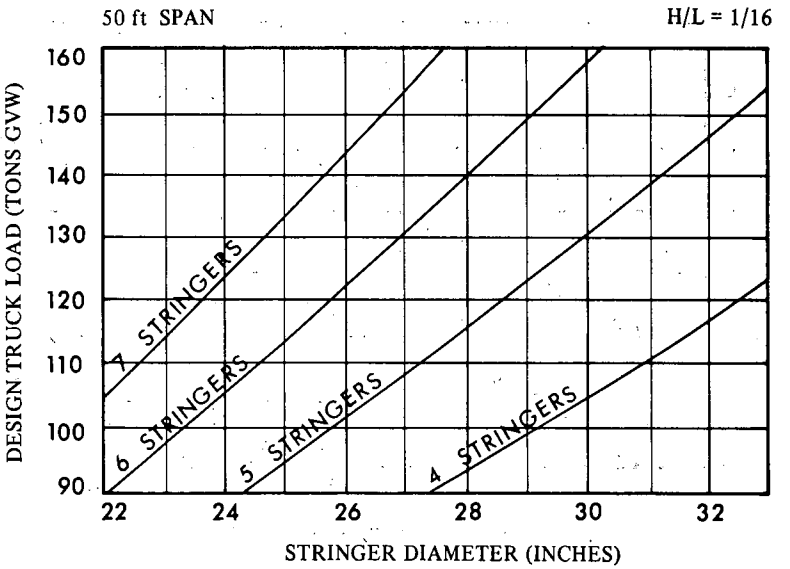


FIGURE 14 Part 6. Sitka spruce trussed-log stringers

SPRUCE STRINGERS



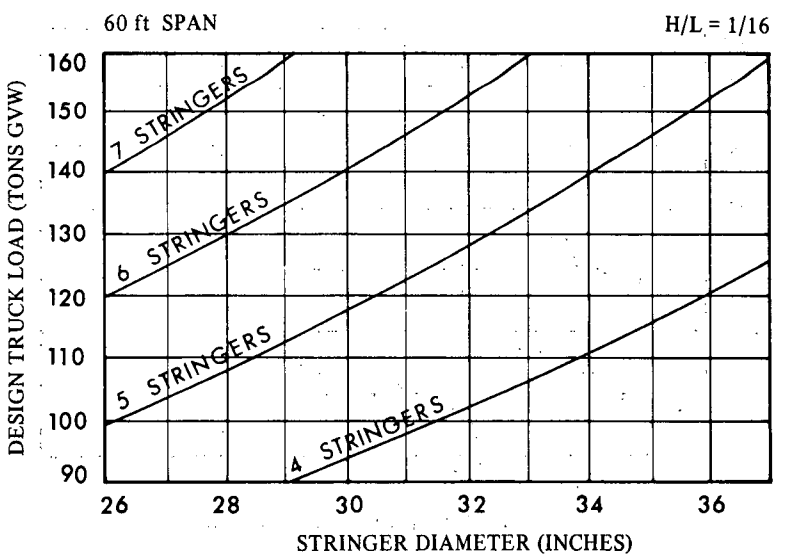
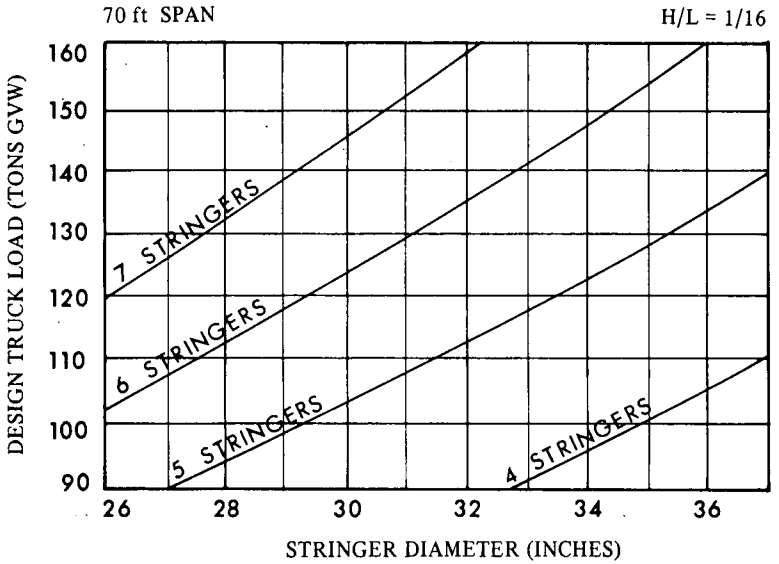


FIGURE 14 Part 7. Sitka spruce trussed-log stringers

SPRUCE STRINGERS



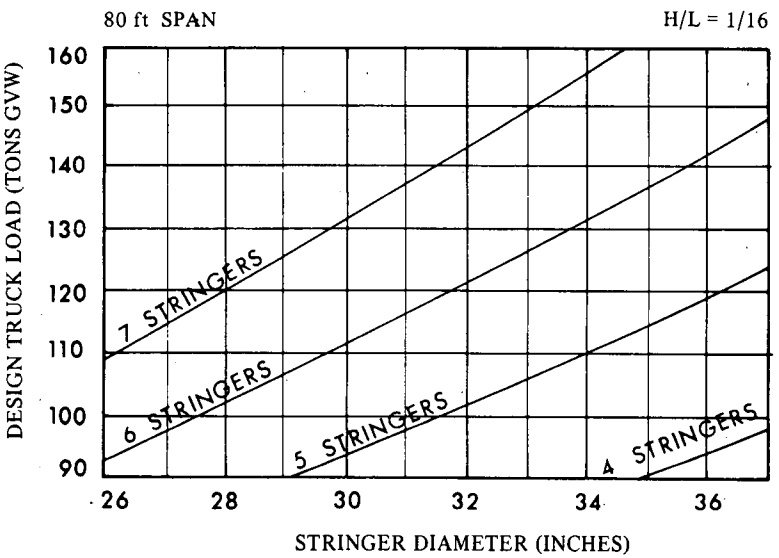


FIGURE 14 Part 8. Sitka spruce trussed-log stringers

C. PREPARATION OF BRIDGE PLANS

It is essential for every bridge (no matter how simple) to have profile and plan drawings which must show the following:

- Profile of the stream cross-section and banks
- Peak-flow level
- Height of abutments
- Deck level
- Road-approach profile
- Span length
- Stringer length
- Site plan showing the stream, road, and bridge location
- Foundation plan showing stream and abutments
- Additional details required for design or construction; these should be drawn to a large scale so that dimensions can be scaled off during construction.

D. MATERIAL LIST

Material lists should be prepared in full detail and costs and delivery schedules estimated. Careful planning and preparation at this stage will ensure that costs are controlled and construction procedes without unnecessary delays.

IV. BRIDGE CONSTRUCTION

IV. BRIDGE CONSTRUCTION

This section describes the necessary steps involved in the actual construction of the bridge, starting with organization and site preparation. Designs of abutments and piers are also included to allow the builder to make 'on-site' decisions during construction.

A. CONSTRUCTION ORGANIZATION

Prepare a timetable to coordinate the timing of deliveries and phases of construction. Design changes may be required if there is conflict between the timing of activities as permitted by various agencies and the timing of construction and deliveries of material.

After the bridge plans and material lists are completed it is necessary to determine the method of construction and to schedule the people and equipment. The final cost estimates are now prepared and decisions made on final design and the timing of activities.

It is not necessary to have a fully experienced bridge crew. It is important to have one person with management, supervisory and bridge-building experience to be in charge of the job. The main criterion for crew members is how skilled they are in the use of axes, drills and other small tools and the equipment used for heavy structural work.

B. SITE PREPARATION

The bridge site must be logged, cleared, and prepared to assure easy and continuous construction. The extent of preparation will depend upon the stream bank conditions and the complexity of the bridge. The following list will assist the builder.

- Subgrading should be completed on both sides of the crossing if possible, but finished on one side at least to provide access.

- Ballasting should be as inexpensive as possible yet good enough to carry traffic. It should be completed after the bridge is built.

- Staging area should be mud-free, big enough for material preparation, men and equipment.

- Storage area need not be at the site but should be nearby; may not need to be surfaced but the material should be kept clean. It should be large enough for building material, stringers, decking, fill, rip-rap, and surfacing material.

- Parking and turnaround area required nearby to reduce traffic congestion.

- Storage shed should be at site to keep tools and small hardware dry and safe from theft.

- Approach ramp to the stream is necessary when machines work near the stream or cross it.

- Safe temporary crew bridge is essential for high crossings or fast-moving streams. The crossing may be a footbridge with guardrails, a boat or a cable ferry.

- Anchor trees and stumps should be chosen during construction, with the selected trees and stumps left undisturbed.

- Right-of-way timber should be felled wide enough on both sides to protect the bridge site, staging and storage area during a windstorm.

- Stump blasting should be finished before bridge construction begins.

- Rock blasting should be done where rock may damage the bridge.

- Stream channel improvement may be necessary before using cranes or pile drivers. Remove log jams, earth dams or obstructions which might endanger the safety of the bridge.

- Excavation for abutments and piers should be considered the first step in the actual bridge construction, but should be done while road construction equipment is still at the site.

- Reestablish survey points before construction starts by marking the bridge on the ground.

Specific site-preparation requirements are discussed in the Abutment and Piers section of this handbook.

C. ABUTMENTS

The choice of abutments will depend on the nature of the stream bank and the length of the span: plan to put abutments away from the stream and up the bank to reduce the costs and difficulty of building. This of course increases the span length. In some cases it may be desirable to have a high abutment on one side of the bridge in order to take advantage of a rock ledge or simple sill foundation on the other side. To determine the best type of structure, consider the total cost of the abutments and the bridge superstructure as well as the safety of the bridge under stream flood conditions.

The following criteria are important in abutment and pier selection.

- The structure should be as inexpensive as possible, but it should carry the load and have a long enough life.

- The structure should be compatible with the ground conditions.

- Material should be easily available and, if practical, local material should be used.

- Construction equipment must be available and if possible it should be local construction or logging equipment.

- There must be enough room at the site for the structure and equipment.

Footings on solid ground must be deep enough for protection against scour and frost damage. Drive all load-carrying piles 8 ft under scour level.

It is important to have flow direction marked on the site plan at high water levels and to align piers and abutments with the water flow to minimize scour. Show the expected points of impact on the piers so that protection devices can be properly positioned.

There are five fundamental types of abutments used in building logging road bridges: simple abutments, log cribs, pile bents, post- or frame-bents, and concrete abutments.

1. Simple Abutments

The simplest abutment is the bank of the stream shaped to support the stringers. Place the stringers directly on the ground without a sill or any

other structure. Take care to safeguard the stringers from movement. It is difficult to prevent decay in stringers placed on the ground, and we recommend it only for bridges intended for short-term use.

Ground-support abutments can be considered on rock surfaces. For a culvert-type log bridge, clearing the rock may be all that is needed. For other structures, it may be necessary to level the rock or use concrete.

a) **Single sill log**

A single sill log is placed directly on the ground. This common type of abutment is the easiest and cheapest to make and will support any type of structure. Study the river and search for sites where simple sills can be placed. Almost all wood culverts and most culvert-type log bridges use this type of support. It may be used on soils with high load-bearing capacity rock (Figure 15).

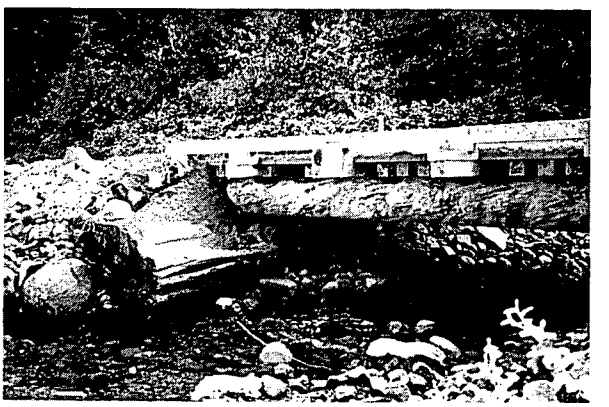


FIGURE 15. A single sill log abutment

Stability is the key element to consider with a simple abutment. The ends of the stringers must not be allowed to settle.

Usually the ground can be prepared by excavators or bulldozers to make a smooth footing for the sill log (Figure 16).

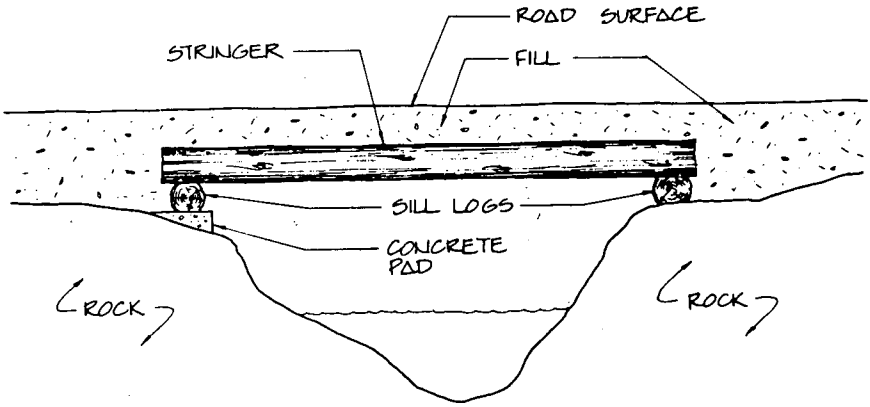


FIGURE 16. Single sill logs on rock and concrete pad

b) Simple sill log with mud sills

If the ground will not support the bridge on a single sill log, increase the load-bearing area by using mud sills. These are short logs, 10 in. (and larger) in diameter, 4 ft to 20 ft in length, placed under the sill log.

A guide to the number and spacing of mud sills needed to spread the load is shown in the Cribbing Face Foundation Width Table IV-D. The values determined can be reduced by 50% for bridges up to 40 ft long and by 25% for those longer than 40 feet.

Position the sill log half-way over the mud sills to prevent uneven settlement of the bridge (Figure 17).

Logs placed directly on the ground tend to rot quickly and even cedar sapwood rots relatively quickly under these conditions. Trimming the sapwood from the top and bottom of the sill may reduce future settlement.

Although a mud sill would not ordinarily be used where there is a chance of scour, you must allow for the possibility of erosion. Many log-bridge failures occur through settlement of the sill support. This settlement may be prevented by excavating so that the mud sills rest on solid ground. Lowering the sill may make another type of abutment necessary to provide enough height.

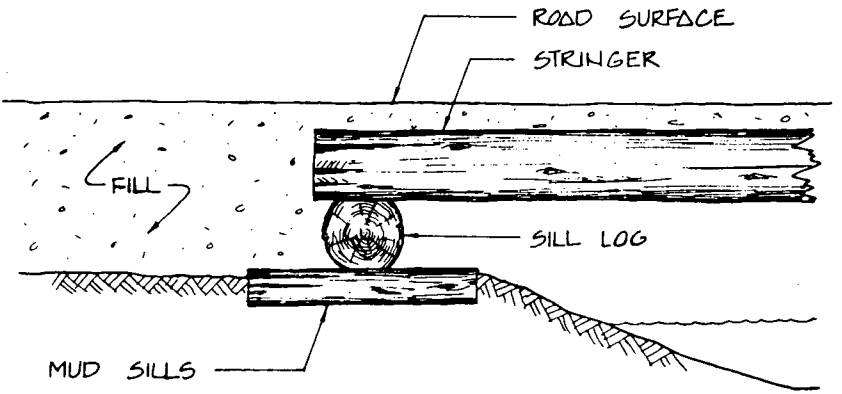


FIGURE 17. Sill log on mud sills

c) Foundation logs under mud sills

If it is necessary to make a large solid mat for a load-bearing foundation, place long logs below scour level. They should be parallel to the sill log (Figure 18). The mud sills will function as short beams spreading the load evenly over the foundation logs. Only a few foundation logs are needed, but they should be strong and large (20-in. diameter or larger). The foundation logs should be at least as long as the sill log. If long logs are not available, two shorter logs may be butted together. Mud sills and foundation logs may also be dapped to ensure good fitting. If there is any chance of undermining or erosion, then the foundation logs should be lashed together.

d) Multiple sill log abutments

If a single log is not high enough for the bridge level it may be possible to tie three or more together to get the height needed (Figure 19). Lash logs with wire rope (usually not smaller than 3/4-in. diameter) on each end and at the middle. The top log will act as the sill log. This log may be flattened to receive the stringers.

2. Log Crib Abutments

If simple abutments do not provide enough height for the bridge, you will need a more complex design. The most common is the log crib because it can be constructed from local materials. (This does not mean that the crib abutment is necessarily less expensive to build than pile bents or frame

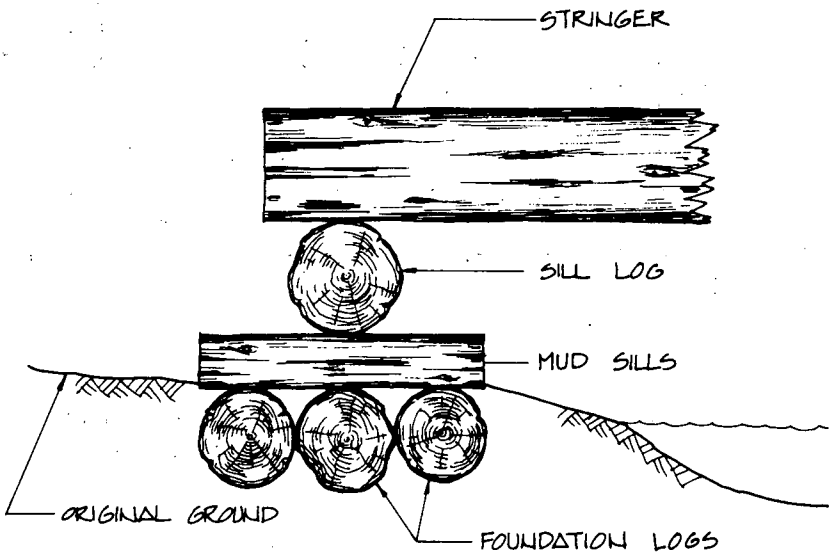


FIGURE 18. Foundation logs under mud sills

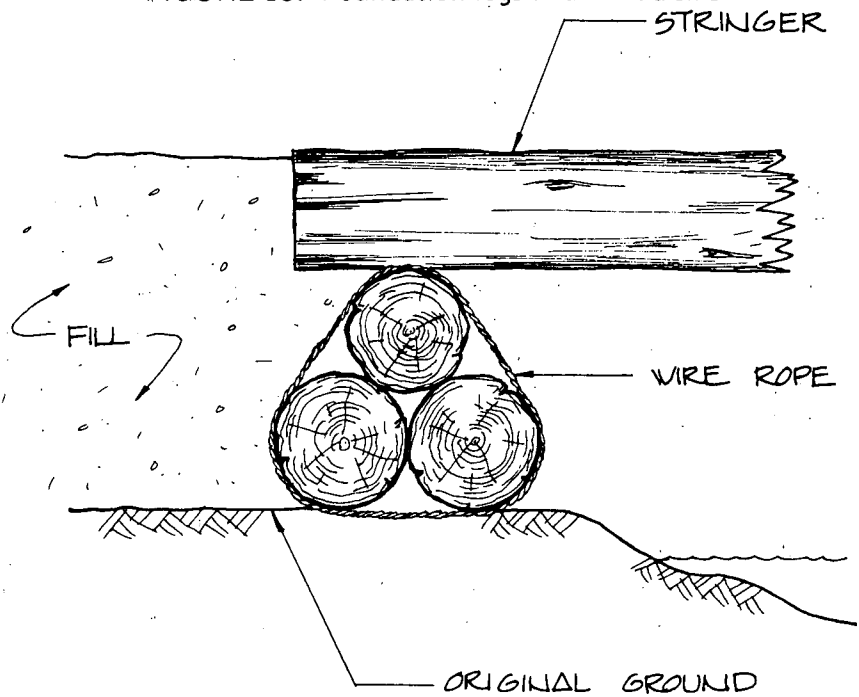


FIGURE 19. Multiple-sill log abutment

bents.) Log cribs may be grouped into four major types depending on the plan view of the structure. These are the simple log crib, the open-end crib, the closed-end log crib and box cribbing.

Build crib-type abutments from any species of logs in much the same fashion as a log cabin. The size of crib material is not critical to the design or construction, but the larger the log diameter, the fewer the logs needed. (In addition, longer life may be expected from larger logs.) The size usually depends on what material is available, what equipment will move the logs, and how large a crib is to be built.

If the cribbing will be in use for a long time, build it from cedar logs with preservatives applied on cut surfaces. A well-built cedar cribbing may be expected to last over thirty years. If the lifetime of the crib is not important, other species can be used with approximate lifetimes as follows:

	Expected Service Life
Douglas-fir	8 - 10 years
Spruce	4 - 8 years
Hemlock-balsam	4 - 6 years

These lifetimes can be extended 4 or 5 years under dry conditions with good air circulation around the crib.

Construction of a log crib abutment is easy for loggers who are well equipped to handle logs. Hard ground is specially suited for this type of structure. Simple cribbing consists of logs placed on each other with a minimum amount of dapping and then tied together with wire rope. (Higher cribbing needs well-prepared logs carefully assembled and such cribs are labour-consuming and expensive.)

There are two major disadvantages to a crib-type abutment. First, settlement might occur when the crib is built on soft ground and repairing settled cribbing is difficult and costly. Second, when green wood is used, significant shrinkage may take place—as much as 1/2-in. for each foot of cribbing height.

a) Simple log crib

This type of crib is built from face and tieback logs only. Logs are dapped where necessary and then placed on each other (Figure 20). Lay face logs parallel to the stream bed. Place tieback logs perpendicular to the face logs. (The tieback logs are usually notched where the next face log will be laid on top.) Face logs and tieback logs alternate, one on top of the other. The top log is the sill which supports the stringers.

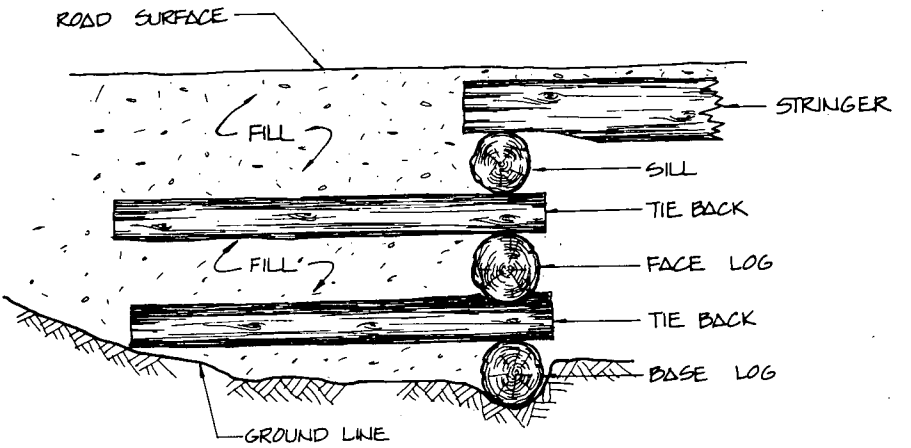


FIGURE 20. A simple log crib

A simple log crib is usually used in combination with rock fill. After every layer of tieback logs, the fill is placed and compacted. Allow the fill material to run over the side to cover up the tieback logs. At completion, the face logs are visible but the tieback logs are covered to give protection against scour and washouts.

Crib logs may be lashed together with wire rope or drifted.

You can use wood chunks or rocks to plug the openings to keep fill material from leaking out between the logs.

b) Open-end log crib

The open-end crib is made of face logs, wing logs and tieback logs. Wing logs contain the fill and form the side of the cribbing. They are visible from the outside. Place tieback logs between the wing logs to hold them in place.

Figure 21 shows the alternating nature of open-end log cribbing as the logs are piled upward. Make sure that fill material does not leak out through the joints. Place the wing logs so the structure follows the side slope of the fill.

The sketch also shows the type of cribbing support necessary for a bridge which is designed to have guardrails supporting some of the live load.

The cribbing face should be positioned parallel to the water flow to reduce the amount of turbulence and should form as small an angle as possible with the water flow. Wing walls must not be placed at more than 90° to the stream flow and a 45° angle is desirable if the site conditions permit. This type of abutment is used for small fills with coarse fill material where the tie-back logs are held in place by friction.

c) Closed-end log crib

You may have to build a crib to retain large amounts of fine fill material like gravel or sand (Figure 22). The crib must be able to stand without the fill.

Figure 23 indicates how the tieback logs are pinned together into a horizontal frame. This type of cribbing usually has large, long tieback logs which are notched, fitted and tied together where they cross. Each frame of tieback logs may be elevated by the fill material to keep it horizontal. Tieback and wing logs may be smaller than the face logs.

d) Box cribbing

Box cribbing is similar in appearance to the closed-end log crib, but shallower in depth, and each layer of wing logs is tied together by a back log (Figure 24). Tieback logs may also be tied to the back log, and they usually extend over the back log into the fill.

This type of cribbing is used when the wing walls form an angle of more than 45° to the water flow, or when the wing logs cannot support the earth pressure (Figure 25).

Fit logs precisely to keep the wing logs level; box cribbing requires careful construction.

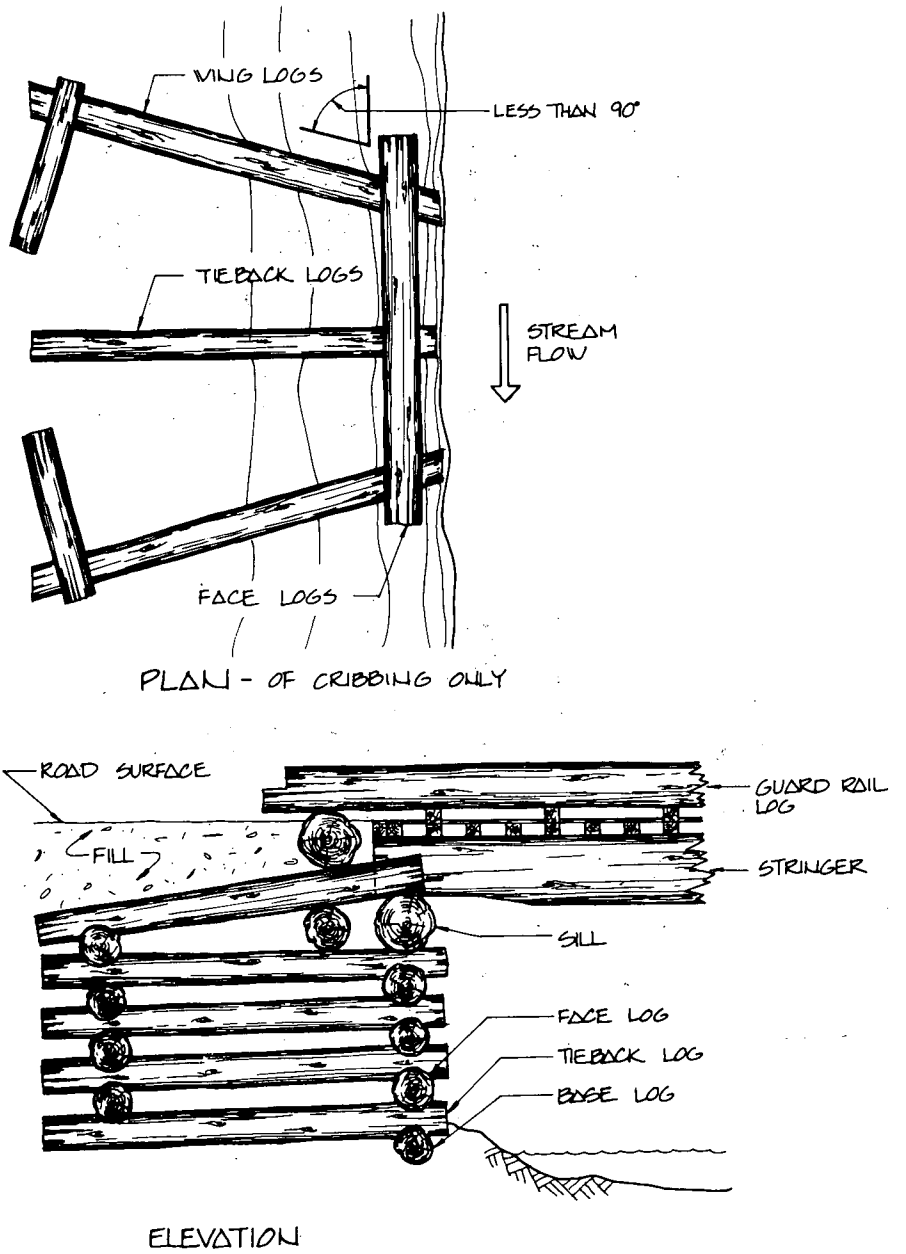


FIGURE 21. An open-end log crib

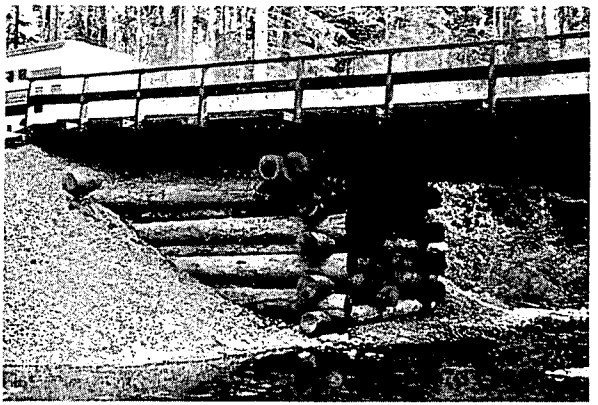


FIGURE 22. Closed-end fill-retaining crib

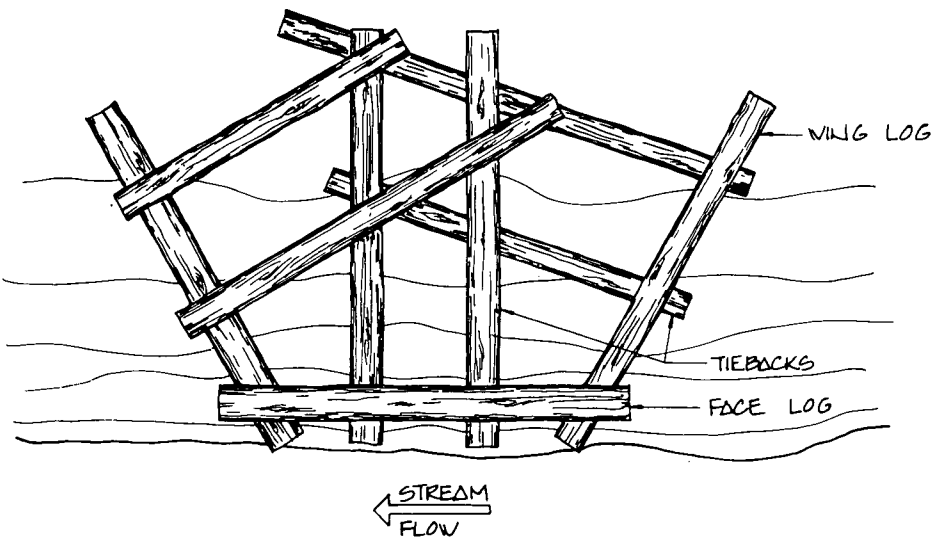


FIGURE 23. Closed-end log crib

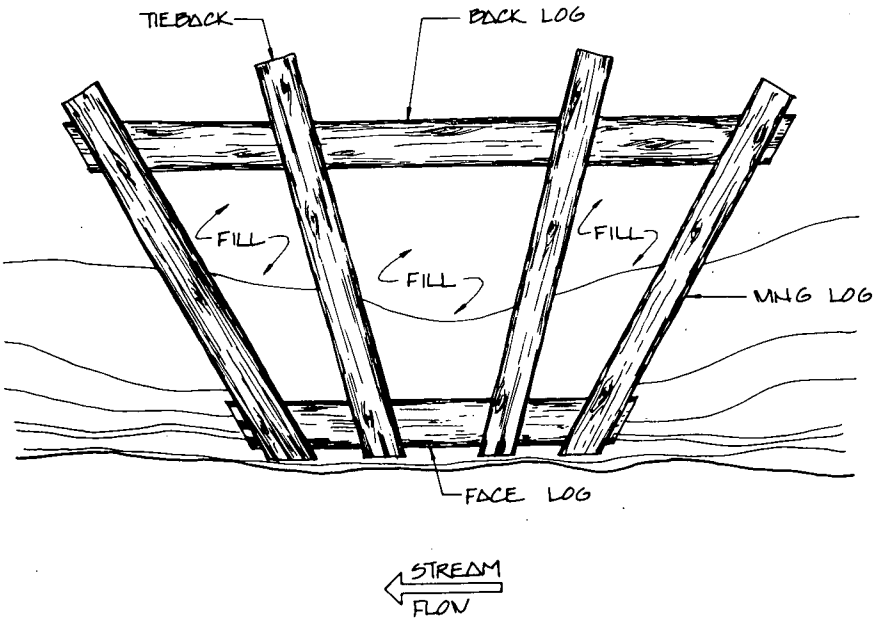


FIGURE 24. Box crib

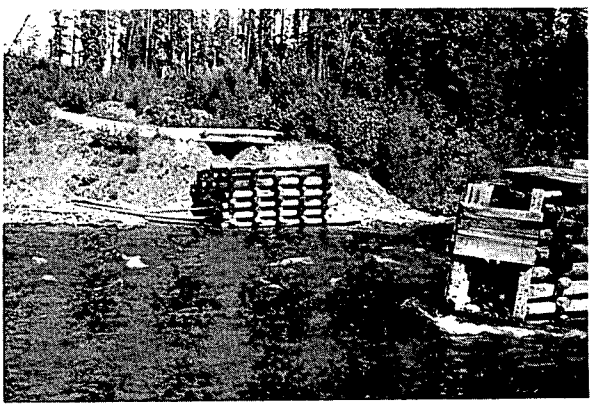


FIGURE 25. Carefully constructed box-cribbing

Figure 26 shows a variation in a box crib that is useful on soft ground or if only small logs are available.

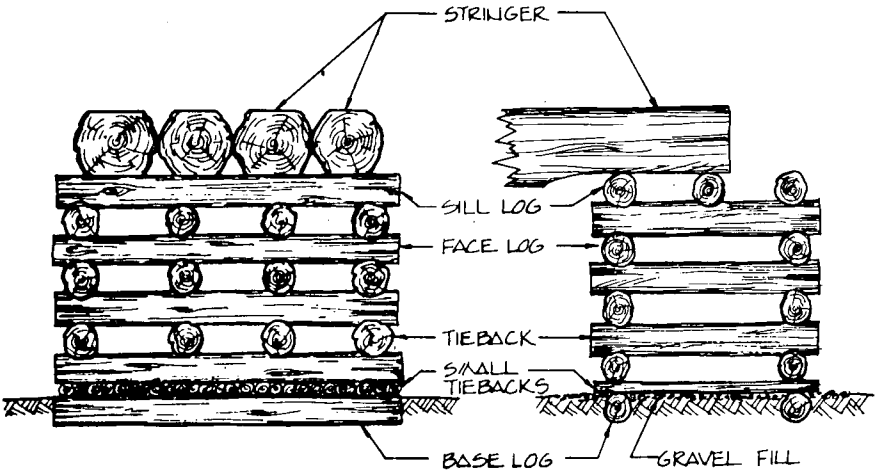


FIGURE 26. Box crib with log floor

A special type of box cribbing is used for piers rather than abutments (Figure 27). The logs form a rectangle. Usually this kind of crib is filled with blasted

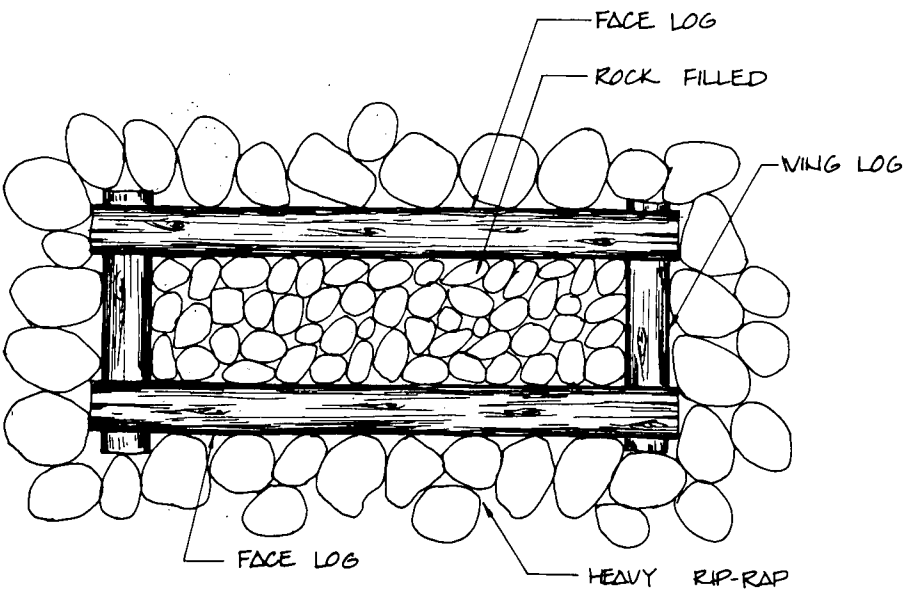


FIGURE 27. Box crib pier

rock or large stones. Use heavy rip-rap to protect it from scouring. The foundation of the cribbing must be below scour level.

e) Precast concrete cribbing

Cribbing can also be made of material other than wood. In areas where cedar is not available long-lasting cribbing can be built by using precast concrete. Forms may be built to make interlocking concrete crib members, or concrete road curbs can be used when they are avilable at a reasonable price. Box or closed-end cribbing is the best formation for this type of structure.

3. Crib Planning and Design

The design and construction procedures in this section can be used only for cribs up to 20 ft high. This assumes good foundation sites, large crib logs, well-draining fill material and low earth pressures. Consult an experienced bridge engineer for higher cribs on difficult construction sites or if only small logs are available.

Building a crib takes careful planning. Its exact location must be laid out on the ground so that the material requirements can be calculated and preparatory work carried out.

The crib must be designed and built to withstand the pressures of the earth-fill as well as bear the load of the bridge. A saturated fill of fine material will create higher earth pressures than dry rock or free-draining fill. Any crib you build will have a height limit, depending on the fill, the type of logs, and the type of construction used.

A crib built in box form with four or more sides can be built much higher than one which is not completely framed.

The length of the tieback logs should never be less than the height of the structure at the crib face. As a general rule, the tieback logs should not be shorter than 10 ft unless they are tied to a deadman (in which case there should be a minimum 6 ft between the face log and deadman).

Tieback logs should not be spaced at distances more than five times their diameter (or more than 12 ft).

Table IV-A and IV-B may be used as guides to calculate the number of tie-back and winglogs necessary for the cribbing. Table IV-A shows the contact

area required to support the superstructure and the traffic load. Table IV-B shows the contact area necessary to support the cribbing. Divide the sum of the two areas by the smallest tieback log contact area to arrive at the number of tieback and wing logs required for the cribbing. Always place tieback logs at right angles to the face or wing logs.

Example: Tieback logs - 12 in. diameter
Face logs - 18 in. diameter - 24 ft length
Span - 50 ft
Design load - 100 t
Crib height - 20 ft

In our example, notching a tieback log to one-quarter its diameter (3 in.) will create a 10-in. wide surface, while notching a face log the same depth (3 in.) will create a 13-in. wide surface. The load-bearing area for a tieback log is therefore: tieback notch-width (10 in.) x face-log notch-width (13 in.) = 130 in.^{2}.

Using the tables,

Table IV-A Basic bearing-area (using the next longest span in table — 60)	1170 in.^{2}
Table IV-B Additional bearing-area	126 in.^{2}
Total prepared tieback-log bearing area	1296 in.^{2}

$$\text{Number of tieback logs} = \frac{\text{Total required tieback-log bearing-area (1296 in.}^2\text{)}}{\text{One tieback-log load-bearing area (130 in.}^2\text{)}} = 10$$

The base log must cover enough area for the ground to support the load. The safe bearing-capacity for different soil types is shown in Table IV-C.

The table indicates the strength of dry soils only. Some soil types (sand) are adversely affected by a high moisture content and their load-carrying capability may be extremely low.

Table IV-D is a guide to find the cribbing-face foundation width.

The sill log, (the top face log) should be 6 ft longer than the width of the superstructure.

The following rule may be used to give an indication of the length of the cribbing face:

Cribbing Face Length = Sill Log Length + 1/3 Bridge Height at Cribbing

This is the shortest length and should be used to choose the right foundation area from Table IV-D.

The relationship between the number and length of mud sills can be calculated with the help of Table IV-D. Leave a space of less than 10 in. between mud sills.

TABLE IV-A. Basic Contact Area Between Face Logs and Tieback (Wing) Logs in Square Inches

Design Load	Maximum Span in Feet			
	20	40	60	80
50T	500	690	875	1,220
100T	820	1,000	1,170	1,790
150T	1,140	1,325	1,730	2,565

Note: The basic contact area is required to support the design load and the superstructure.

TABLE IV-B. Additional Contact Area Between Face Logs and Tieback (Wing) Logs in Square Inches

Height of Cribbing Above Base Log (ft)	Face Log Diameter (inches)											
	18			24			30			36		
	Face Length of Cribbing (ft)											
	16	24	30	16	24	30	16	24	30	16	24	30
4	19	25	36	26	34	48	32	42	59	38	51	71
8	38	51	71	51	67	95	63	84	118	76	101	142
12	57	76	107	76	101	142	95	126	177	114	151	213
16	76	101	142	101	135	189	126	168	236	151	202	284
20	95	126	177	126	168	236	158	210	296	189	252	355

Note: Additional contact area is required to support the weight of the cribbing. The table is based on using log sizes of 8 inches and over in diameter. If only smaller logs are available, crib height must be reduced and these tables do not apply.

TABLE IV-C. Safe Bearing Capacity of Rocks and Soils for Cribbing

Rocks and Soils	Safe Bearing Capacity psf
Massive hard volcanic rock	200,000
Massive hard limestone	100,000
Foliated rock (schist and slate in sound condition)	80,000
Sedimentary rock, hard shales, silt stones and sandstones in sound condition	30,000
*Good quality rock in average condition	20,000
Thinly-bedded limestone and sandstone, fractured rocks, dense glacial till (hardpan), exceptionally compacted gravel and sand	15,000
*Compact well-graded sands and gravel-sand mixtures	12,000
*Loose well-graded sands and gravel-sand mixtures	9,000
*Compact uniform sands	9,000
Stiff clays or sandy clays	9,000
*Loose, confined uniform sand	4,000
Soft clays and silts	2,000
Very soft clays and silts (mud)	1,000

*The crib face foundation area must be 3 ft in width. Moisture content should be very low, and the water table below the base log or mud sills. If the foundation area is less than 3 ft wide, then the Safe Bearing-Capacity must be adjusted:

Allowable Bearing Pressure $= \frac{B}{3} \times$ Safe Bearing-Capacity where B is the crib face foundation width in ft, (or base log top diameter in ft).

Example: Crib face foundation width (B) = 2 ft
Soil-compact uniform sand with a Safe Bearing-Capacity of 9000 psf
Allowable Bearing-Pressure $= \frac{2 \text{ ft}}{3} \times 9000 \text{ psf} = 6000 \text{ psf}$

TABLE IV-D. Cribbing Face Foundation Width (Base Log Diameters in Inches)

Cribbing Height: Up to 20 feet
Minimum Diameter of Face Logs: 18 inches

Safe Soil Bearing Capacity lb/ft^2	Cribbing Face Length							
	16 ft				24 ft			
	Span (in feet)							
	20	40	60	80	20	40	60	80
Design Load: 50 tons								
20,000	18	18	18	18	18	18	18	18
15,000	18	18	18	22	18	18	18	18
12,000	18	18	21	28	18	18	18	20
9,000	18	24	28	37	18	18	20	26
4,000	41	52	63	83	30	37	45	58
2,000	82	104	126	166	60	74	89	116
1,000	164	208	252	332	119	148	178	231

Safe Soil Bearing Capacity lb/ft^2	Cribbing Face Length							
	24 ft				30 ft			
	Span (in feet)							
	20	40	60	80	20	40	60	80
Design Load: 100 tons								
20,000	18	18	18	18	18	18	18	18
15,000	18	18	18	22	18	18	18	18
12,000	18	18	19	27	18	18	18	23
9,000	19	22	25	36	18	19	22	30
4,000	43	50	56	81	37	43	48	68
2,000	85	99	112	161	74	86	96	135
1,000	169	198	224	321	148	172	192	270
Design Load: 150 tons								
20,000	18	18	18	22	18	18	18	19
15,000	18	18	21	30	18	18	18	31
12,000	19	21	26	37	18	18	22	31
9,000	25	28	35	50	21	24	29	41
4,000	55	62	78	111	47	53	66	92
2,000	110	124	156	222	94	106	132	184
1,000	219	248	312	444	188	212	263	368

Use mud sills where required base-log diameter exceeds diameter of logs available.

Mud sills should be no smaller than 14-in. diameter. Eighteen-inch (or larger) logs placed at 2-ft centres are preferable. Mud sills should project at least 2 ft over the base log. Mud sills are required if soils have low strength. In cases where scour is not a problem, avoid excavation for placement of sills to allow original vegetation and root material to serve as a mat.

The face of the cribbing should run parallel to the stream. Wing logs usually form an angle of 45° to 90° with the stream flow. If sandy gravel or other poor material is used for constructing the approach road, the end of the crib wing should meet at the foot of the fill and the wing logs should be positioned to follow the slope of the fill. If coarse shot rock is used, the wing angle does not affect the fill and the fill can run outside the wings to cover them and protect the cribbing. In this case wing logs can become tieback logs.

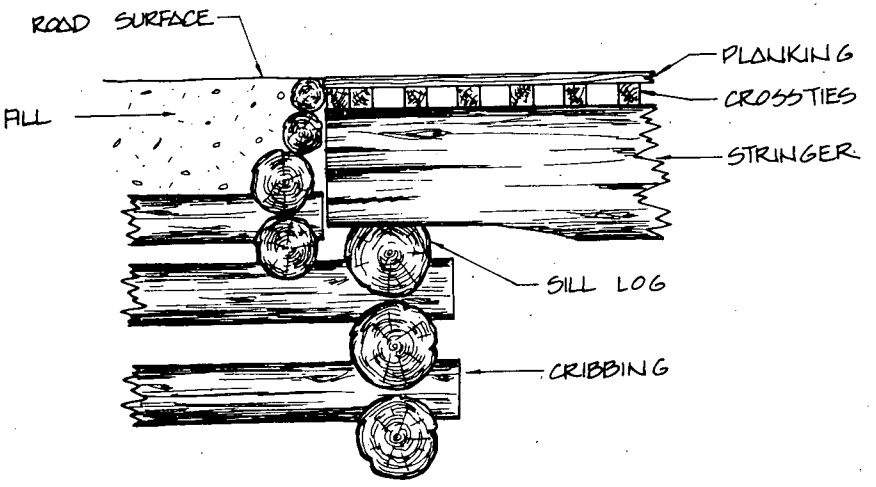
If green wood is used for cribwork, and dapping does not take out the sapwood, you can expect the cribwork to shrink up to one-half inch for every foot of height. Make allowances for this settlement in adjusting to the final finished grade.

Most notches in log cribs are not sufficient to withstand earth pressure because a flat (rather than rounded) notch is normally used, and because the protruding end of the log is normally cut short where it is subject to slabbing. The real earth-pressure resistance in these cribs comes from the drifts and lashing.

The design of the top of the crib depends on the design of the bridge. The top of the cribbing should be constructed to protect the stringer ends and connect the running surface of the bridge to the road surface. Figure 28 shows variations in cribbing tops. Note the space for air circulation at the ends of the stringers.

To contain the ballast the crib structure should be continued behind the stringers all the way up to the surface of the road. The top wing logs may be even higher than the road. Tieback logs are not necessary in the top layer.

Guardlogs are frequently designed as supporting bridge members. If this is the case, they are tied to the stringers through lashing or bolting to one or more needlebeams. The guardlog ends must bear on the abutments. They are placed above the deck level, so the abutments must be specially designed.



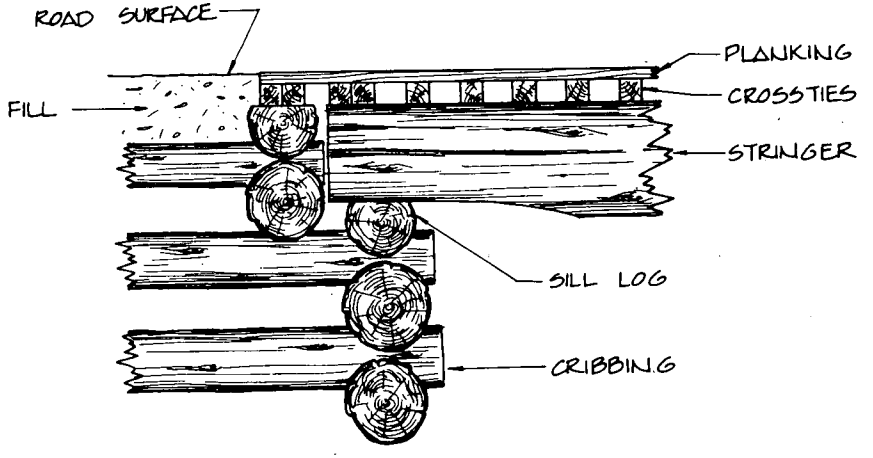


FIGURE 28. Variation in crib tops

Shear logs at the bridge approaches direct the trucks to the centre part of the bridge. They must be held in permanent position above the level of the road. They can either be spliced onto the guardrails or supported independently by cross-members of the crib. (Guardlogs, guardrails and shear logs are discussed in the bridge deck section of this book).

Low cribs seldom require anchoring or fastening. If, however, there are good stumps that will be buried in the fill, the use of 3/4-in. or 7/8-in. line lashed to the crib logs (or sill log) and tied to the stump will serve as added support (Figure 29). Placing drift pins in each joint costs little and will hold the crib together.

If there is any danger of the earth pressures being excessive, then lashing and pinning the crib is necessary, as well as tiebacks to a stump, deadman or rock anchor.

Drift the cap or sill to the crib to hold it during the placement of the stringer.

4. Crib-Construction Techniques

Planning the building of a crib is as important as planning the building of a pile pier or concrete pier. The exact location must be laid out on the ground so that the material requirements can be calculated and the preparatory work can be carried out.

First, investigate the soil condition to determine the feasibility of excavating for the base log. Fisheries' restrictions may prohibit any excavation where the excavated material may get into the stream bed. If there is any likelihood of scour around the pier base it is wise to consider burying the initial logs below the stream level.

a) Log preparation for cribbing

Green wood is usually used for building log cribs. Unless cedar is used, the face and wing logs and the exposed end of the tieback logs should be debarked.

If cedar is used in building a permanent structure, it is necessary to remove the bark only where a clean surface is required to mark the notches. Exposed bark surfaces should be stripped after the crib has been completed to reduce fire hazard and decay.

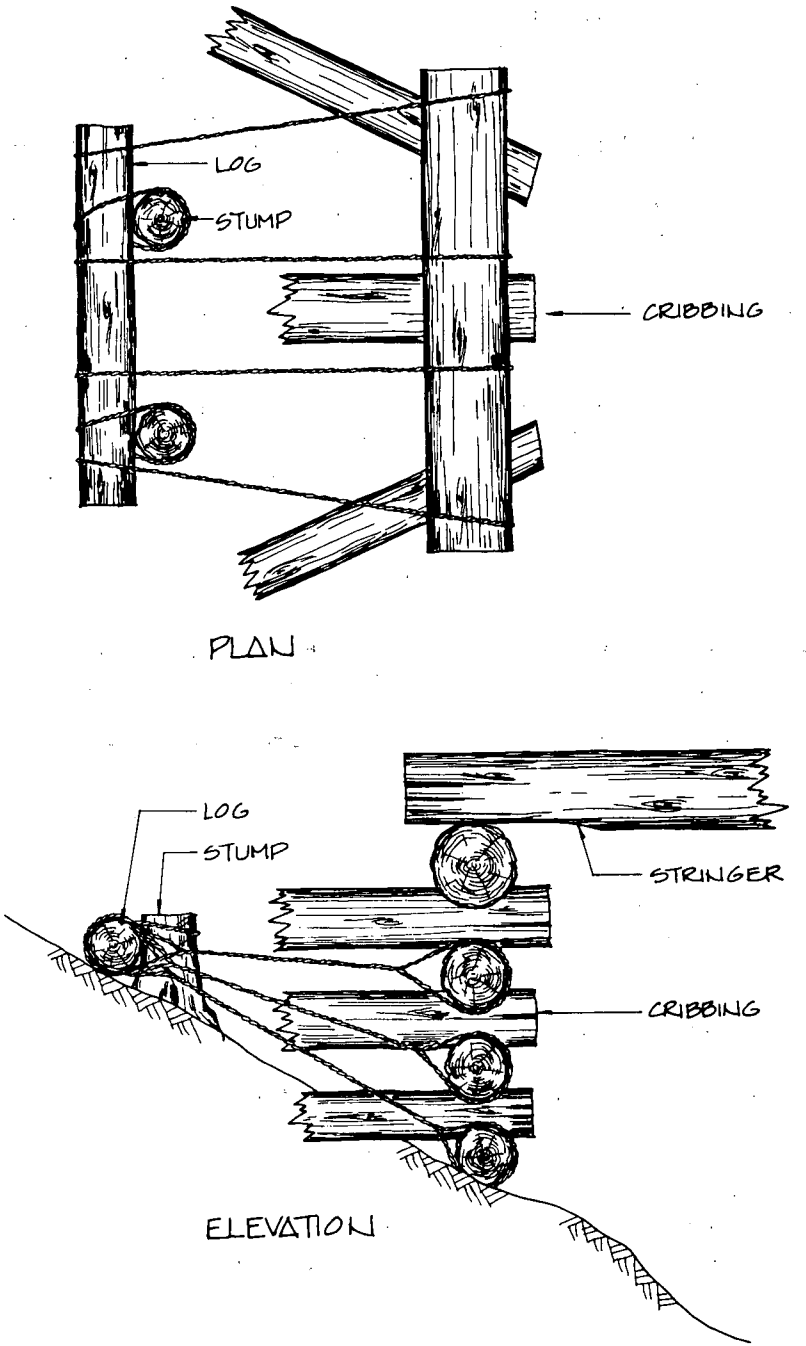


FIGURE 29. Stump helps to hold cribbing.

b) Notching or dapping

A powersaw and an axe are used for notching, but a bridge builder may also have an adze and scribers or dividers. You can chop out simple notches with an axe without marking the wood. When the fit of a log is considered 'good enough,' it is lashed or drifted to the logs underneath. If this type of notching is used (or no notching at all), limit the load-bearing section of the cribbing to five layers of logs.

Mark the notch with scribers or dividers if a proper cradle-notch is needed to fit two logs together.

Keep the scribers or dividers vertical to keep the same distance (depth of notch) for a close fit. The cut-ins are easier to make with a power saw than the angle cuts (see Figure 30). Carve out the remaining wood with an axe.

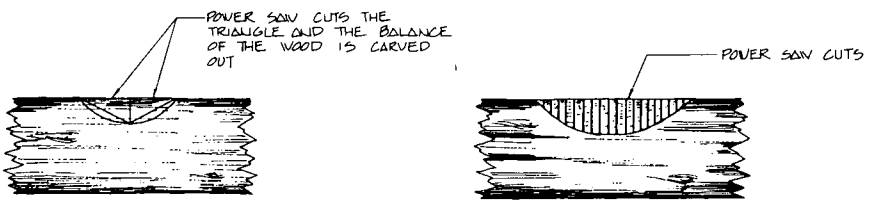


FIGURE 30. Notching methods

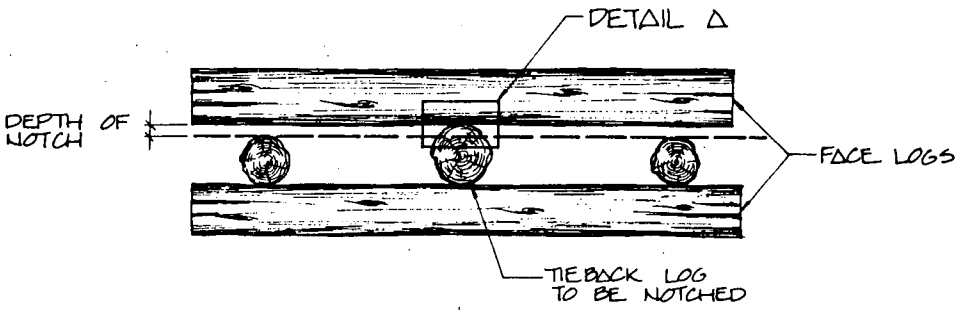
We chose a cradle notch for a partly-fitted crib in our example. Figure 31 shows the required depth for the notch, the marking of the log, and the plan view of the marking.

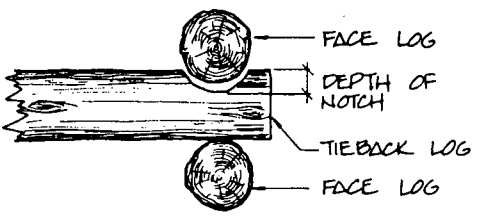
c) Sequence of crib construction

A partly-fitted crib is used in this example. Other crib construction will be similar.

STEP 1.
Excavate for the base log. Lay some small logs (about 6-in. diameter) or dig trenches that will allow room for lashing later.

STEP 2.
Position the base log.





SECTION OF DETAIL A

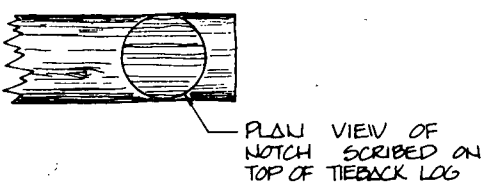


FIGURE 31. Cradle notch for partly-fitted crib

STEP 3.
Place the tieback logs. These should not exceed 8 ft to 12 ft in spacing, depending on the size of the crib logs and on the size of the crib. Table IV-B could be used as a guide to estimate the number of tieback logs required to carry the load.

STEP 4.
Lash the tieback logs to the base log using 3/4-in. to 1-in. wire rope.

STEP 5.
Place the second face log on top of the tieback logs.

STEP 6.
To get a close fit, balance the face log on the tiebacks and estimate the notch depth for proper fit.

STEP 7.
Using scribers, dividers (or eye measurement), inscribe with a lumber crayon or indelible pencil the position and shape of notch.

STEP 8.
Roll the face log back out of the way and hew out the notch.

STEP 9.
Roll the face log into position and lash it to the tieback logs.

STEP 10.
Backfill the cribbing and compact the fill.

STEP 11.
Work upward to the level required.

STEP 12.
Place rip-rap, if there is a chance that the crib will be undermined.

A hydraulic backhoe is the best machine for placing rip-rap at the base of abutments and piers as well as for shaping the banks and straightening stream channels before placing the bridge stringers.

d) Lashing and drifting

Lashing and drifting is described later in this book.

If there is any chance that the crib will move during settlement, lash—as well as drift—the base log to the tieback logs.

e) Filling the crib

Filling the crib should procede with construction. Take care not to dislodge the logs. Lashing is not absolutely necessary, but it will help to hold the crib for filling.

f) Types of crib-log notching

Five variations for joining crib logs are discussed.

- Crude crib

Crude crib construction is used for building culvert-type log bridges with a short service life when settlement, fill pressure, and shrinkage are not considerations. Use blasted rock or large stones to fill up the crib.

Place large logs without attempting to create a large contact surface and tie them together with wire rope (Figure 32). There are usually no more than three face logs and two tieback logs between every two face logs. The top face log (the sill log) is used in its natural state and is seldom flattened to receive the stringer.

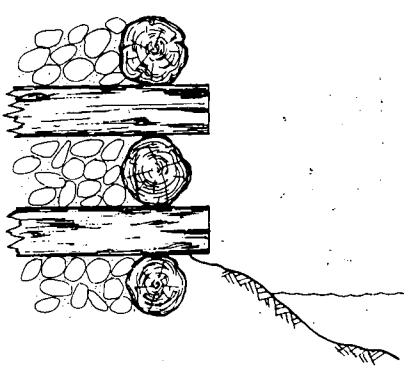


FIGURE 32. Crude cribbing

- Loose cribbing

Loose cribbing is similar in construction to crude cribbing except that more than two tieback logs are used (Figure 33). It is used for bridges built for a

short service life. Place the base log on the ground and lash the tieback logs to it. Place the second face log on the tieback logs. Some of the tieback or wing logs are hewn enough to make sure that the face log touches each one of them. Every face log is tightly lashed to every tieback and wing log above and below.

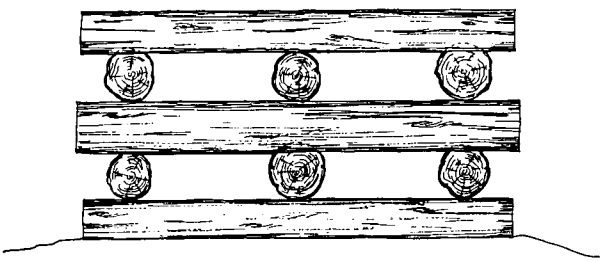


FIGURE 33. Loose cribbing

- Partly-fitted cribbing

This construction technique is described in Section IV-4-c.

Carve or dap the top of every log to make a cradle for the log above (Figure 34) and provide a larger load-bearing surface to keep the logs in place.

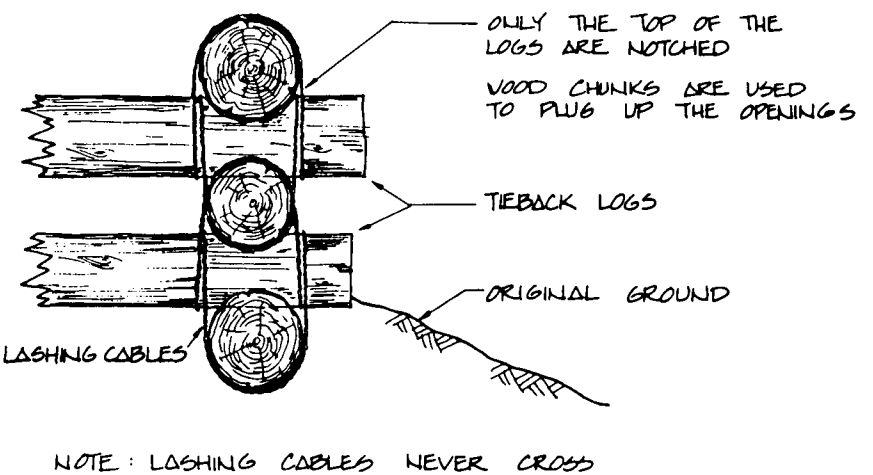


FIGURE 34. Partly-fitted cribbing

Decay may occur if stagnant water accumulates in the notches. To prevent this, the notches are sometimes made at the bottom of the logs only. This is difficult and may not reduce rot to any appreciable degree.

- Flat-face log cribbing

Flatten the face logs to their full length on the top and bottom, and notch the tieback and wing logs to fit (Figures 35 and 36). Flatten the logs with a power saw using the chalkline technique or an Alaskan sawmill. This method is often used when the face logs are large and the tiebacks are smaller; the logs should always be drifted when tieback logs are closely spaced. Use of these techniques is described in the section on preparation of log stringers.

This construction allows precise fitting. Removing the sapwood leaves a large load-bearing surface with minimal shrinkage potential.

Rot-resistance may be increased by using cedar logs and applying preservatives on the cut surfaces and drift holes.

Cedar slabs and filter fabrics can be used to plug the openings to prevent the fill from leaking out.

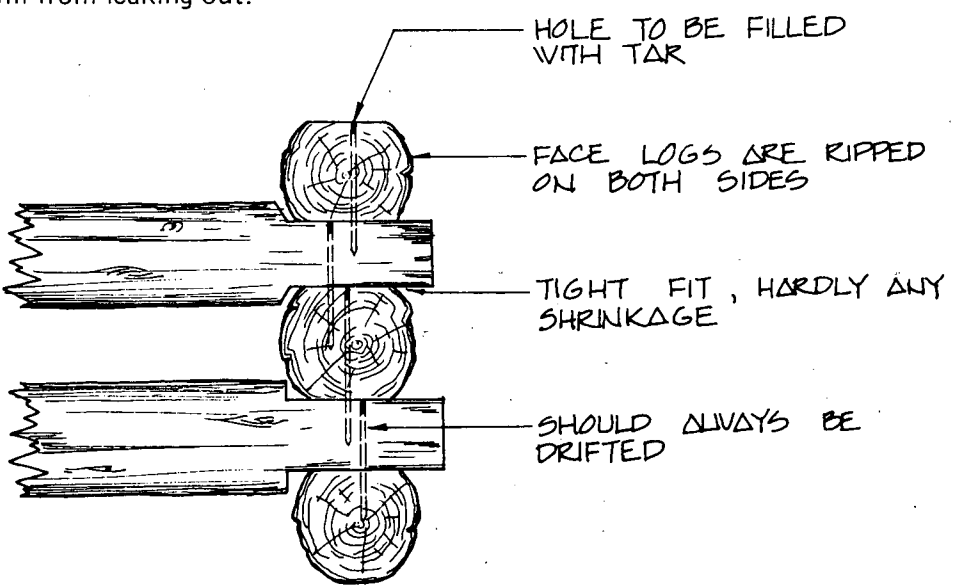


FIGURE 35. Flat-face log cribbing

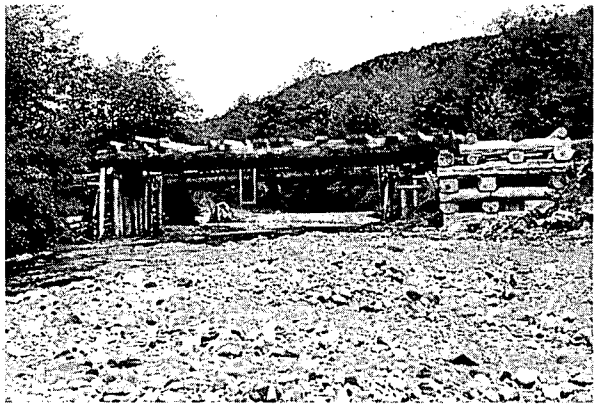


FIGURE 36. Side view of a flat-face log crib

- Tight-face cribbing

Tight-face cribbing is usually constructed when it is necessary to have the face logs close together (Figure 37). It can be used to resist scouring from fast-running water when shot rock is not available and the fill material could wash out. It is important to use the same size face and wing logs.

The style of notch employed is identical to that of the "Lincoln Logs" used as toys. Each log is dapped about one-quarter its diameter on top and bottom to produce a tightly-locked notch.

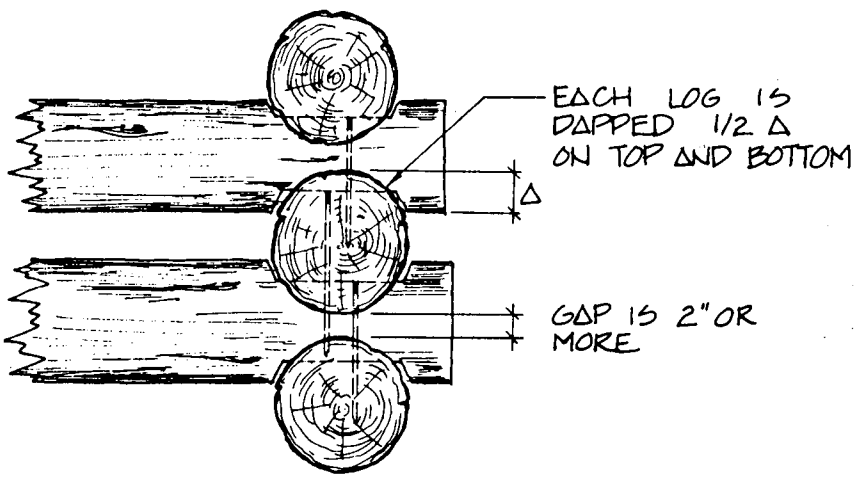


FIGURE 37. Tight-face cribbing detail

It is better not to close the space between the face or wing logs. The wood will eventually shrink, and if the gap is too small the face logs may roll or split.

Tight-face cribbing requires more material and is more labour-consuming than open-face cribbing (Figure 38).

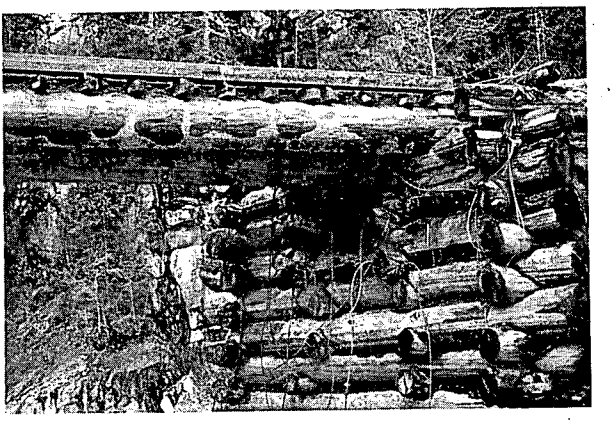


FIGURE 38. Tight-face crib

5. Pile Abutments

Pile bents are used for abutments because driving piles may be faster and cheaper than building a log crib. Piles are the best wooden load-supporting structures. Timber is five times stronger parallel to the grain than across the grain. The ground must be soft and free of large stones or any other obstacles that would prevent pile penetration. Soils with 2,000 to 10,000 psf safe bearing-capacity are suitable for pile driving.

a) Pile abutment types

Pile abutments are divided into two major groups according to their fill-retaining function.

- Pressure-free pile bent abutments

Pressure-free pile bent abutments are usually built on soft ground where cribbing may settle under the load. The pile bent or bents in this type of abutment do not sustain large fill pressures. Their only function is to support the superstructure and the traffic load. Usually these are low structures (less than 8 ft in height) with rip-rapping in front of the piling (Figure 39).

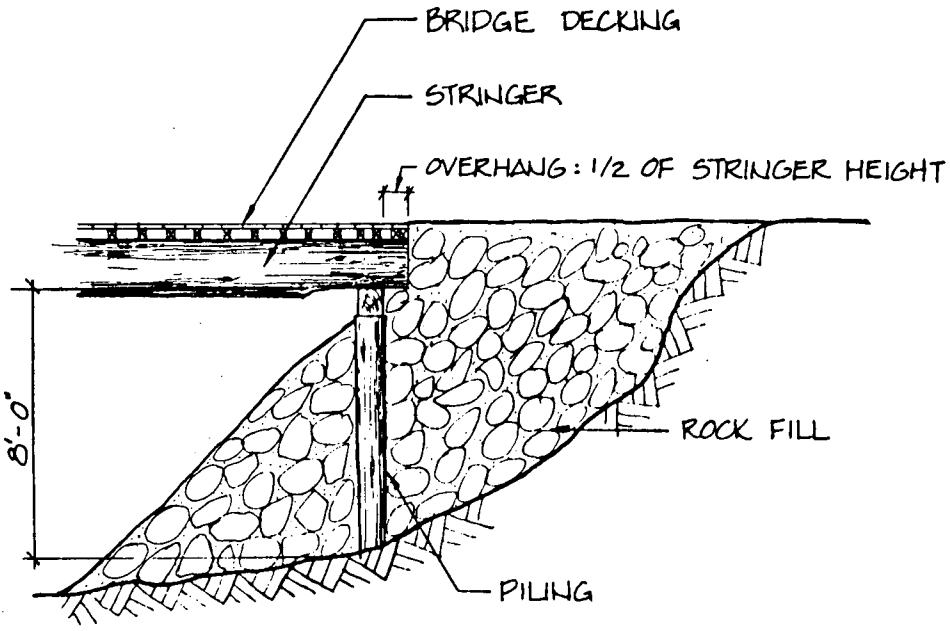


FIGURE 39. Low pressure-free pile-bent abutment

There may be cribwork behind the pile bent which retains the fill (Figure 40). Use shot rock or very coarse gravel around the fill to protect the cribbing.

- Fill-retaining pile abutments

Some pile bents are able to support considerable fill pressure while others require special structures inside the abutment. The first group is built without wing walls and the second group can be identified by fill-retaining wing walls and tiebacks.

- Fill-retaining pile abutments without tiebacks

Multiple bents are able to resist considerable earth pressure without tiebacks (Figure 41). Always place logs or planks behind the piling to prevent direct contact with the earth, to prevent damage to the piles, and to permit air circulation to reduce decay.

Use coarse material for fill, and allow the fill to cover the side of the pilings. Use rip-rap in fast-running water.

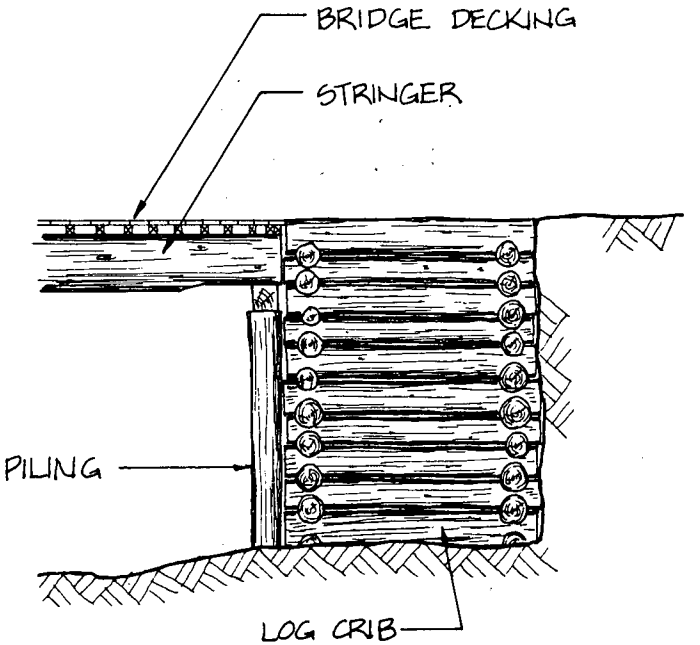


FIGURE 40. A pressure-free pile abutment with fill-retaining cribwork

- Fill-retaining pile abutment with wing walls

You need a tieback system and wing walls to retain the fill in a fill-retaining pile abutment with wing walls because the pile bents in these abutments are not able to resist earth pressure.

To form wing walls, drive a row of pilings in a straight line with planks or small logs lining the inside to retain the fill (Figures 42 and 43).

The end of the wall usually follows the slope of the fill. The end of a plank in the wing wall must always be supported by a pile. (Planks should not end halfway between two piles.) Place piles close enough so that the planking or logs are able to sustain the fill pressure, and tie them back. (Tiebacks are described later in this text.)

- Pile abutments with straight wing walls

Straight wing walls are extensions of the load-bearing pile abutment. They are easy to construct and require only a simple tieback system. They are suitable for slow-flowing streams or if rock fill is used and there is no danger

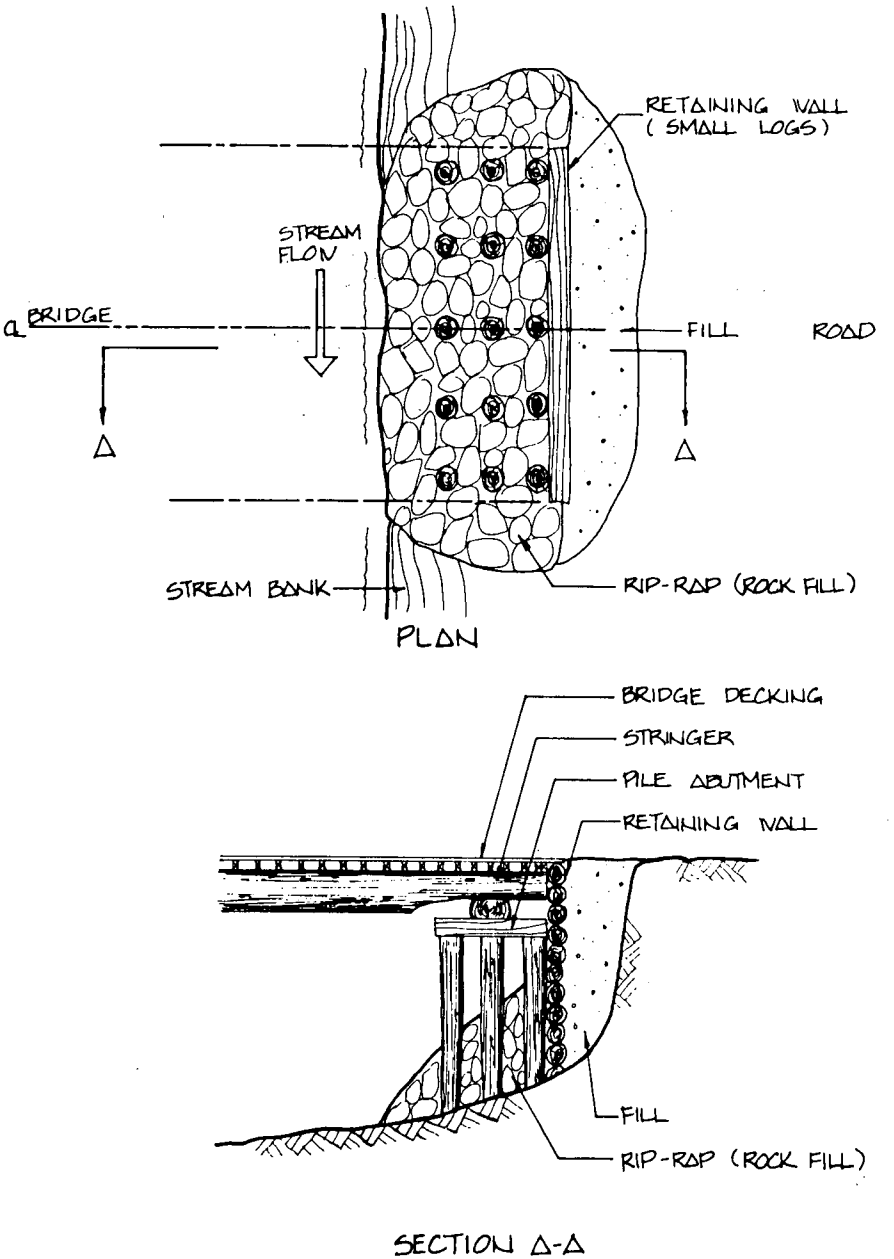


FIGURE 41. Fill-retaining pile abutment without tieback

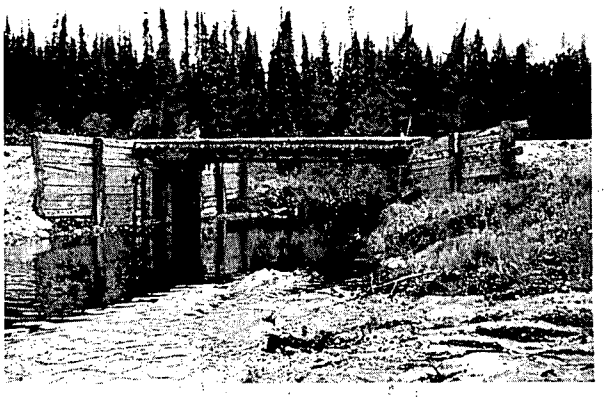


FIGURE 42. Planking to retain fill

that the fill will be damaged by the water flow. This type of structure is excavated below the scour level and the front is aligned with the original stream bank.

Straight wing walls may be used with any type of pile bents (Figure 44), but row and sheet piling lend themselves to this type of construction.

Place small logs between the two rows of a double-bent pile abutment and extend on both sides to form a wing wall. These logs serve as sway bracing and fill-retainer (Figures 45 and 46). (Cedar logs should be used for longer life.) If you use treated material, put planking behind the second row of piling and not between the piles.

b) Pile bents

A pile bent is a line of 5 or more piles. Only those piles which share the load of the superstructure are considered members of the bent.

In the following pages we will discuss some of the ways that piling forms pile bents or pile abutments.

- Single bent

Use when only a few piles are needed. Align pilings to accommodate the cap or sill (Figure 47). Careful construction is required because piles may have a batter. The bent will not support the fill unless it is tied back.

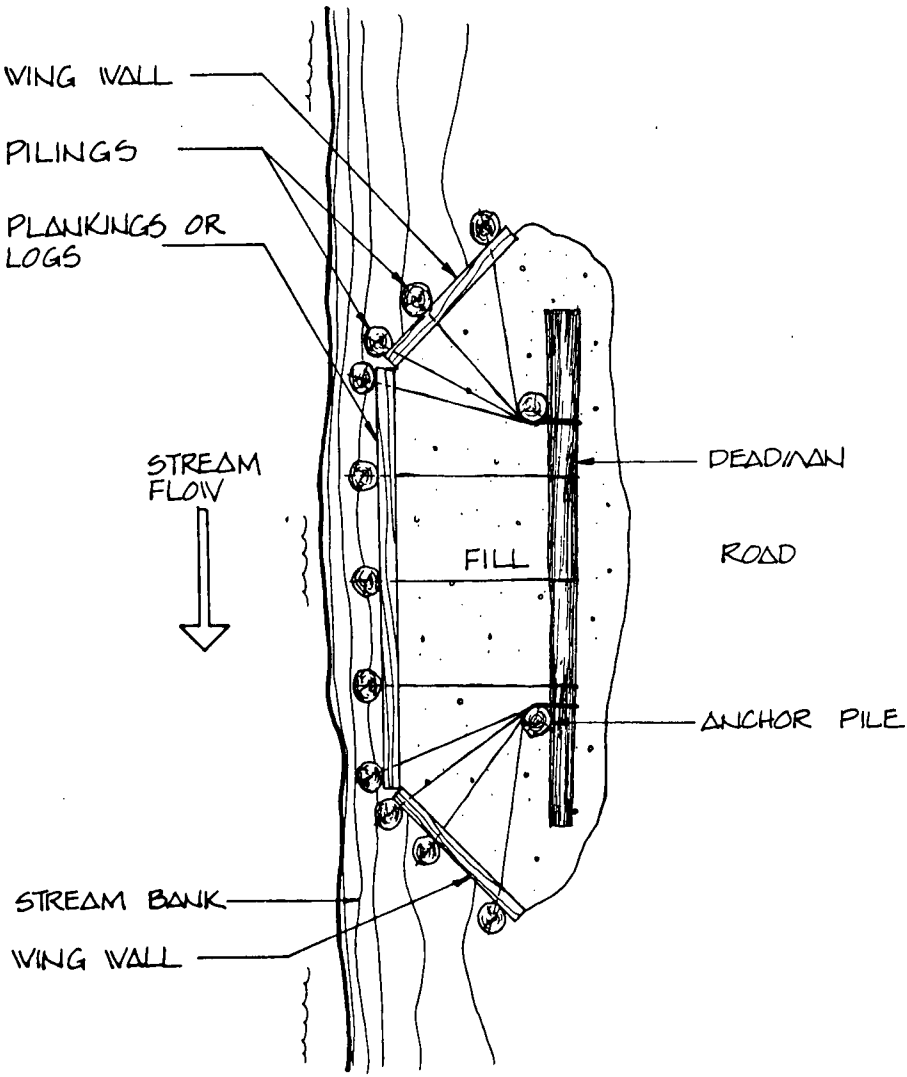


FIGURE 43. Fill-retaining pile abutment with wing walls

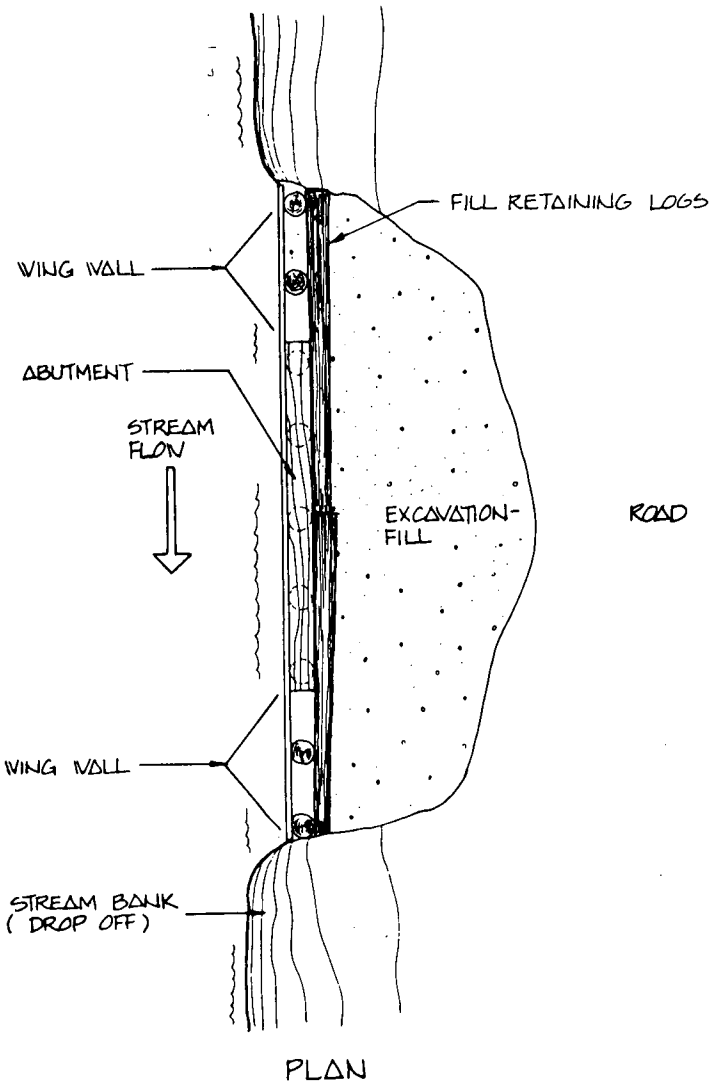


FIGURE 44. Pile abutment with straight wing walls

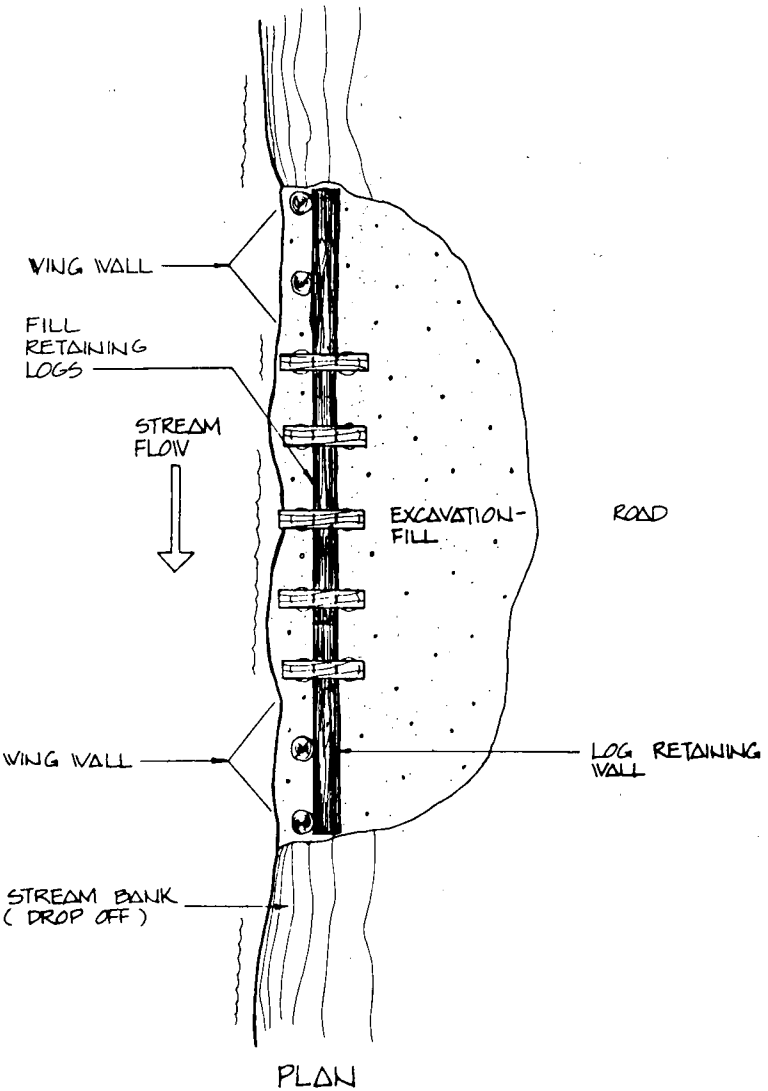


FIGURE 45. Log wall between rows of piling

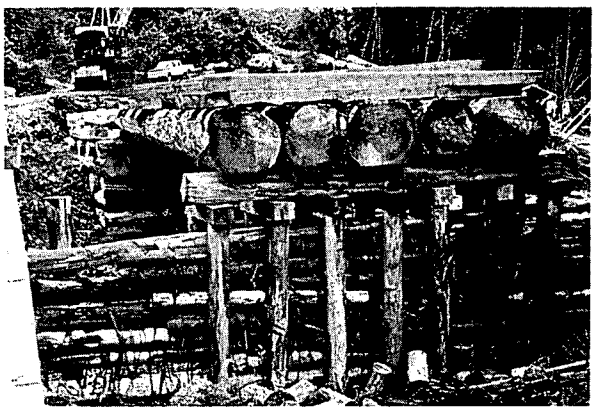


FIGURE 46. Small logs to retain fill between piling

- Double bent with short caps

To construct a pile abutment, drive piles in two rows, using the same number in each row. Fore-and-aft short caps span each pair of pilings and tie the two rows together. A large sill installed on the top provides the support for the stringers (Figure 48).

The pilings in the bent do not have to be perfectly aligned unless planking is used on the outside. Use the double bent when large piling is available or the necessary number of piles will require two rows. One advantage is that it can act as a retaining wall.

If the front row has enough pilings to support the vertical load the sill may be positioned over it (Figure 49). If not, the sill must bear on all the piles.

Two single bents tied together side by side with short fore-and-aft caps may also form a double bent (Figure 50).

- Multiple bent

If a large number of piles is needed, drive them in multiple rows. Tie them together with short caps and keep minimum spacing between them (Figures 51 and 52).

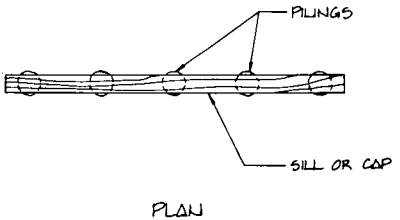


FIGURE 47. Single bent

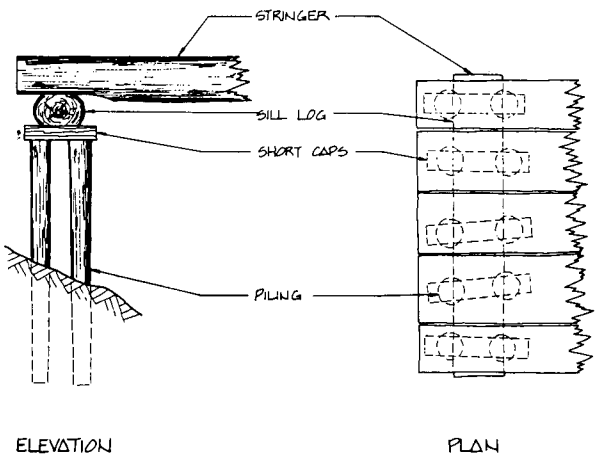


FIGURE 48. Double bent with short caps

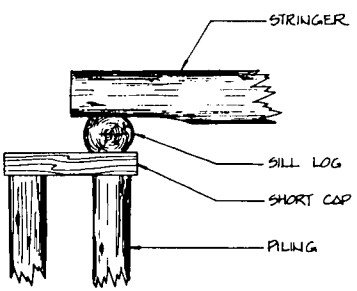


FIGURE 49. Sill log positioned over first row of piling

To simplify this procedure, align the centre row and place a long cap over it. Tie the outside rows and the long cap together with short fore-and-aft caps (Figure 53).

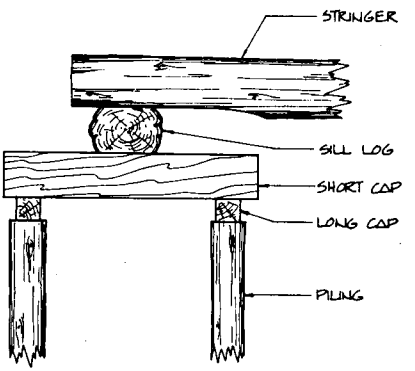


FIGURE 50. Two single bents form a double bent

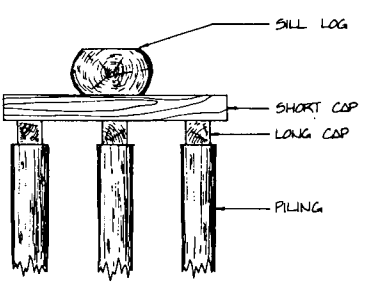


FIGURE 51. A multiple bent

Multiple bents are used for pile piers. You can drive as many as five rows of piling when extra strength is needed to resist side loading. Each row of pilings is tied together with a long cap first, and then short caps are used to tie the simple bents.

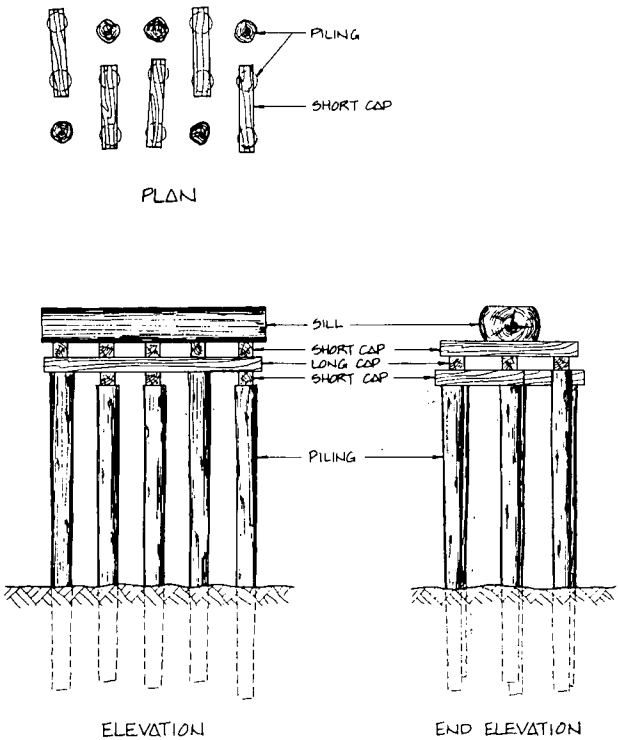


FIGURE 52. Multiple bents plan

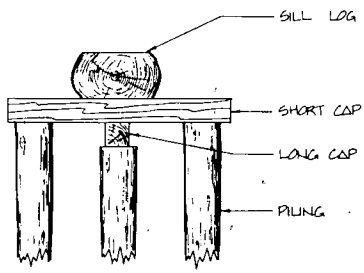


FIGURE 53. Multiple bent with a long cap over the centre row

- Single-line group bent

Drive the piles in a straight row to form a bent (Figure 54). The bent is tied together with a long cap. Make sure the cap rests on every pile and distributes the load evenly.

Use single line pile groups

- if large numbers of piles must be driven in a narrow space
- if group piling is required in sandy soils
- if piles driven into bouldery soils are insecure
- if stream scouring might occur
- if piling acts as a retaining wall

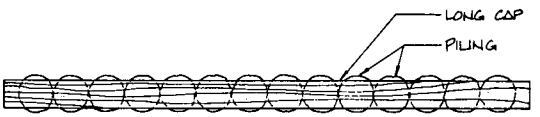


FIGURE 54. Single-line group bent

- Multiline-group pile bent

Use the multiline-group pile bent to achieve the group-pile effect in sandy soils. It is the most resistant to debris damage and can also support back pressure (Figure 55 and 56).

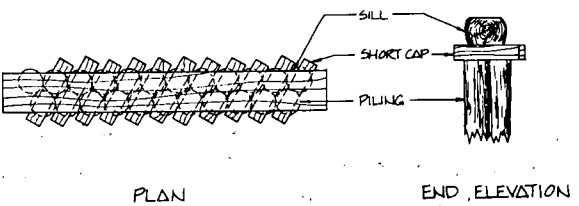


FIGURE 55. Multiline-group pile bent with short caps

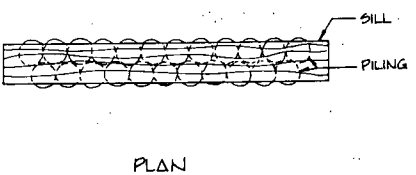


FIGURE 56. Multiline-group pile with large sill

- Independent-group pile bent

The independent-group pile-bent abutment is capable of sustaining a large backloading (Figure 57).

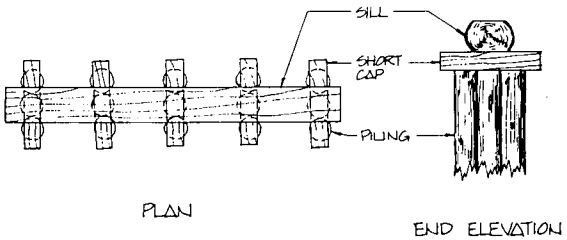


FIGURE 57. Independent-group pile bent

Arrange the piles in groups in the abutment and drive them in rows for the cap.

c) Types of piles in abutments and piers

Piles support the load by soil friction along the surface of the pile, or by having the tip of the pile resting on solid material, or by a combination of the two.

- Friction piles

The load is supported by friction and surface cohesion in clay soils. Drive tapered piles with the small end first. The moisture content is increased around the pile and the soil loses some of its strength during driving. This loss is only temporary. After the moisture content drops to its normal level, the soil regains its original strength. This process may take several weeks and the bridge cannot be loaded to full capacity during this time.

The abutment tables in the design section showing pile size and number of piles required refer to friction piles.

To maintain high friction, space the piles a minimum of 3 ft on centre or 3 times the pile diameter at ground level, whichever is greater. This spacing should be increased in soft clay.

- End-bearing piles

The top layer of the soil is not able to provide enough friction to support the load in some organic soils, loose sands or silts, but it is often possible to drive the pile far enough to reach a solid stratum. You may have to splice two piles to reach solid ground. Simplify splicing by driving the first pile butt first to allow the splicing of the top ends. The tip of the pile must be capable of supporting the load. A minimum spacing of 2 1/2 feet or 2 1/2 times the pile diameter is recommended.

- Combination end-bearing and friction piles

Penetration is difficult if a hard soil mantle is reached before refusal of a friction pile. Most of the load will be supported by end-bearing and only part by friction. These piles are still considered friction piles.

- Group piles

The load capacity of friction piles in cohesionless sandy soils depends on the density of the soil. Driving a group of piles next to each other will compact the soil. Use the design table for friction piles to calculate the number of piles necessary for the bent (Table IV-E). The table gives the appropriate number of piles for loose cohesionless soils. This number should be increased for dense cohesionless soils.

The group acts as a deep footing-foundation for friction group piles in cohesive (clay) soils. The friction pile tables are not applicable. The required square footage may be derived by using the cribbing foundation tables. This square footage is outlined by the outside perimeter of the pile group at the pile tips.

Calculate the load capacity of the piles by the method described in the following section. Multiply the capacity of one pile by the number of piles in the group to determine the load capacity of a pile group in loose cohesionless soils. In denser, cohesionless soils, however, the group may have less load capacity than one pile times the number of piles involved.

d) Pile bent design

Placing piling in the bent and driving the bent depends on the bridge design. The standard truck bridge for a single-lane 100-ton loading would have five or six pilings under a 16-ft cap. The outside piles are usually driven

straight but may be placed on an angle or 'batter' of 1 1/2 in. to 2 in. in every foot. The centre piling is vertical. Use more piling if necessary—depending on the load to be carried, the size of the available piling, and the width of the bridge (Figure 58). For example, some bridges have to be wide at the end to allow for a curved approach or clearance of unique loads such as boomsticks, cedar poles, or a mobile spar. Use at least one large cedar pile for each 20 tons of load. Engineering and piling design involves fairly complex factors and design tables are included in this section for guidance.

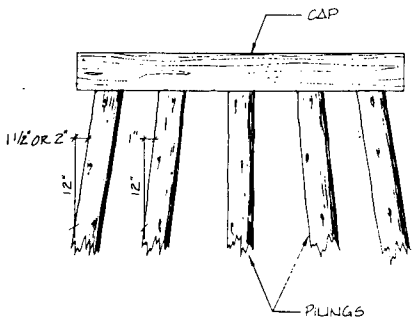


FIGURE 58. A pile bent

The contact area between the piles and the cap must be large enough to prevent crushing the cap under full loading. Remember that the bearing area of the pile will be reduced when the sapwood rots. The use of oversize pilings is the best safeguard and allows for an increase in design load.

The type of soil determines whether the pile is to serve as a friction pile or as an end-bearing pile.

The following tables provide some guidance for the design of pile bents for simple log bridges (Tables IV-E, IV-F, IV-G).

The vertical load-bearing capacity of the end-bearing piles is usually limited by the compressive strength of the wood parallel to the grain.

TABLE IV-E. Recommended Minimum Number of Load-Carrying Western Red Cedar Friction Piles for an Abutment

Design Truck Load	Maximum Pile Length Above Ground in Feet								
	17	19	20	20	20	20	20	20	20
	Pile Diameter at Small End								
	6 in	7 in	8 in	9 in	10 in	11 in	12 in	14 in	16 in
	Bridge Span 60-80 Feet								
50T	29	19	13	8	5	5	5	5	5
100T			22	14	9	7	5	5	5
150T				20	13	9	7	5	5
	Bridge Span Up to 60 Feet								
50T	20	14	9	6	5	5	5	5	5
100T		25	16	10	7	5	5	5	5
150T			23	14	10	7	6	5	5

Note: This table is based on an abutment with cross-braced piles driven to refusal and minimum spacing maintained.

Table IV-F is a guide to the maximum capacity of end-bearing piles supported by different soils and rock types.

TABLE IV-F. Maximum Bearing Capacity of End-Bearing Piles

Soil and Rock Types	Maximum Bearing Capacity lb	
	Minimum Pile-point Diameter	
	10 inch	7-10 inch
Igneous and Gneissic Rocks	300,000	200,000
Limestone (sound)	200,000	100,000
Foliated rock (schist and slate) in sound condition	160,000	80,000
Dense, Hard Glacial Till	160,000	75,000
Hard Shales, Mudstones and Sandstones	110,000	30,000
Dense Glacial Till	75,000	25,000

TABLE IV-G. Pile and Hammer Size Relationship

Ideal Pile Size in ft^3						
Cedar	40	48	56	64	72	81
Fir	29	35	41	46	52	58
Ideal Pile Dimensions						
Cedar: Length (ft)	25	27	28	29	30	34
Diameters: Large/ small end (in.)	18/16	19/17	20/18	21/19	22/20	23/19
Fir: Length (ft)	27	29	29	29	33	33
Diameters: Large/ small end (in.)	15/13	16/14	17/15	18/16	19/15	20/16
Pile Weight in lb	1250	1500	1750	2000	2250	2500
Hammer Size in lb	2500	3000	3500	4000	4500	5000

Note: For good driving, pile weight should be 50% to 75% of hammer weight.

Weight of Green Cedar: 31 lb/ft^3

Weight of Green Douglas-Fir: 43 lb/ft^3

e) Pile selection

The piling selected must be strong enough to support the load, as straight as possible, and able to resist driving forces. The purchasing agent should make sure the wood meets CSA Standard 056-1962 specifications for all permanent structures. Pressure treatment should be in accordance with CSA Standard 080-1962, Wood Preservation. The following points are useful to the builder cutting his own pilings.

- Only live trees should be cut.
- The following defects are not permitted: decay, holes, cracks, splits, insect damage, short crooks, knot clusters, large knots and abnormal changes in taper.
- The taper should be gradual, and the flare at the butt should be cut off.
- The pile must be straight so that a line between the midpoint of the ends will stay inside the heartwood.

All pilings (especially those forming a bent) should be uniform in size to permit neater and easier finishing and bracing.

Untreated wood varies in expected service life. Western red cedar or yellow cedar should be the first choice for pilings. (Many cedar log pilings are still in service after 30 years. If these species are not available for a permanent bridge, other materials such as treated timber, steel or concrete pilings should be considered.)

Most species are adequate for temporary bridges.

f) Preparation of wood piles for driving

It is not necessary to season green wood before driving. Green wood is not as brittle as dry wood, and it has better cushioning to stand up to the hammer. The strength of green wood, however, is less than that of the seasoned woods. Unless preservatives are used, pilings should be stored with the bark on or during hot weather.

Before you drive the pile, remove all bark to permit airing the sapwood and to expose any flaw in the wood, including falling breaks and cracks. Airing the wood is important to reduce insect attacks and rot.

Clean knots and branch stubs from the piling. Remove or trim oversize butt flares. The surface should be smooth and the pile must fit in the leads.

Normally the piling is driven top down. The butt must be protected from splitting or shattering under the continuous blows of the hammer. Unless a driving cap is used, a chamfer cut with an axe or power saw is usually adequate for this protection (Figure 59). If the piling is to be driven butt-down, a mild-steel ring may be fitted over its top (Figure 60).

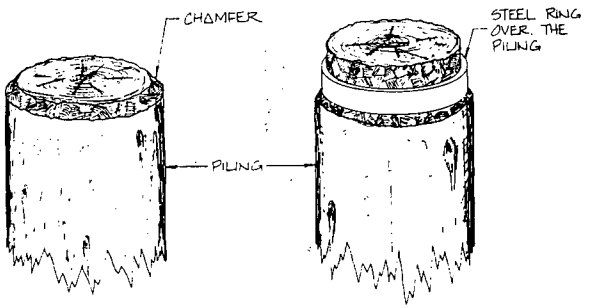


FIGURE 59. Chamfered top

FIGURE 60. Steel ring protecting a pile top

Creosote-impregnated wood is brittle and chips or splits under a hammer, so it is customary to cut off the creosoted end and the top outer shell before driving.

If a driving cap is used, the pile top must be prepared so it fits inside the cap. Usually chamfering is required to fit a socketed driving cap. Some driving caps have square sockets to prevent the pile from twisting during driving (Figure 61).

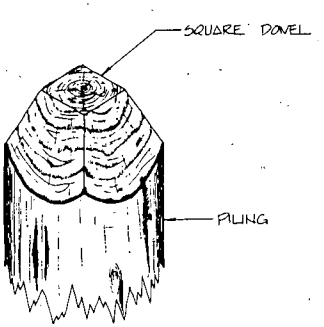


FIGURE 61. Pile top cut to fit a square socket

The pile end that enters the ground must also be prepared. Leave a square cut or light chamfering where the soil is uniform and soft enough. The piles may be pointed in hard ground if driving is slow and it is difficult to achieve the required penetration. Decide on the pile point required after driving a test pile. Cut a pyramid point with a powersaw to prevent turning the piles in the ground (Figure 62).

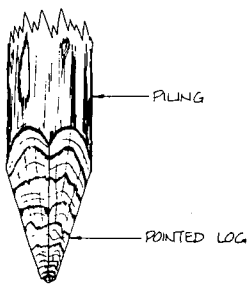


FIGURE 62. Pointed pile tip

If the soil is full of large stones or if there is a likelihood that the pile will split, use a metal guard called a 'point' or 'shoe' fitted and spiked to the end of the pile. Figure 63 shows two variations.

Fit the point carefully and check the welding for best results.

g) Ground preparation and spotting pile location

All excavation, bulldozing and surveying is done before the pile driver moves in. It is important for fire protection and safety that the driving area be clear of brush and debris. Mark the centerline of the bridge and the location of the bent. (Marking and surveying are discussed in the Survey section.) Marking should be done so the points are easily reestablished during driving. The location of the spot where each pile is to be driven can be marked from this survey. Prepare the ground for each piling. If the ground slopes off and a layer of hardpan is close to the surface, it is good practice to prepare a small pocket or depression to hold the end of the piling (Figure 64).

The prepared piling can be laid out in groups of various lengths for ease in selection as the driving procedes.

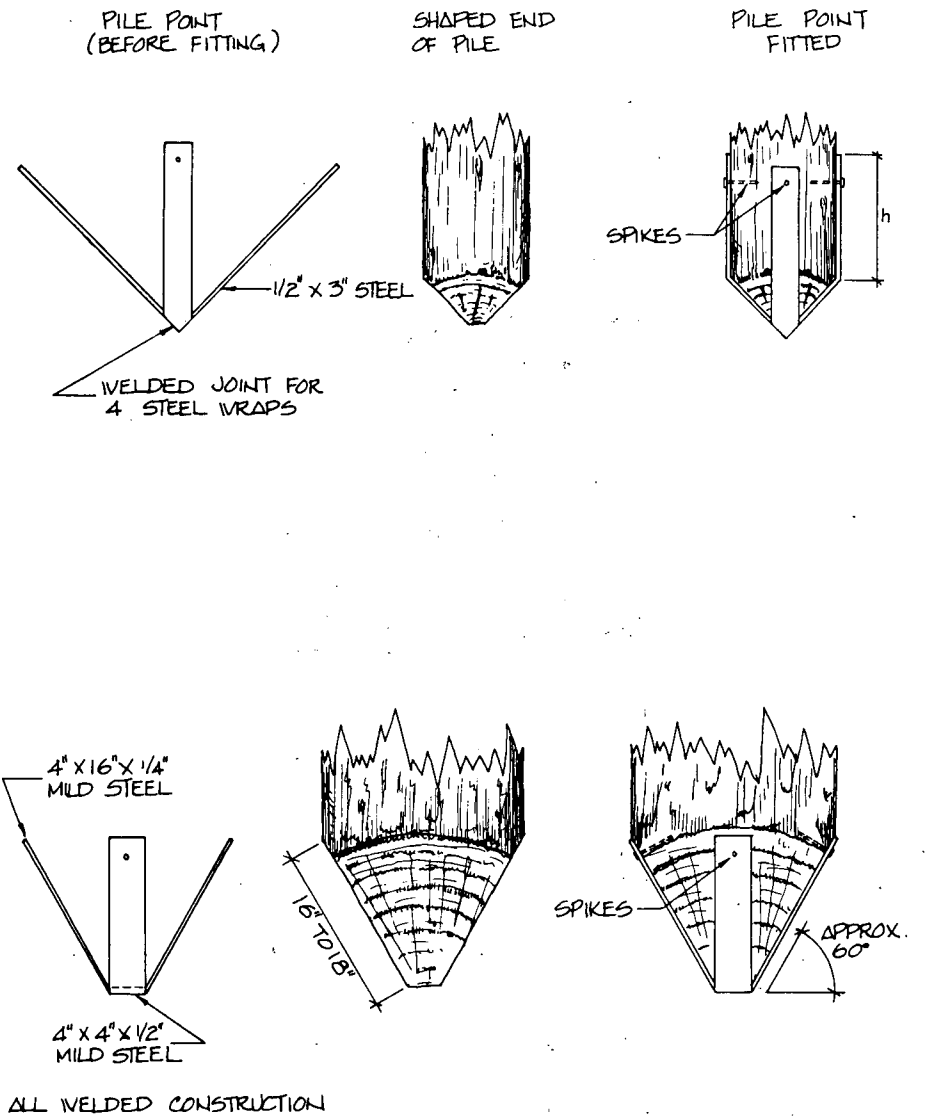


FIGURE 63. Pile shoes

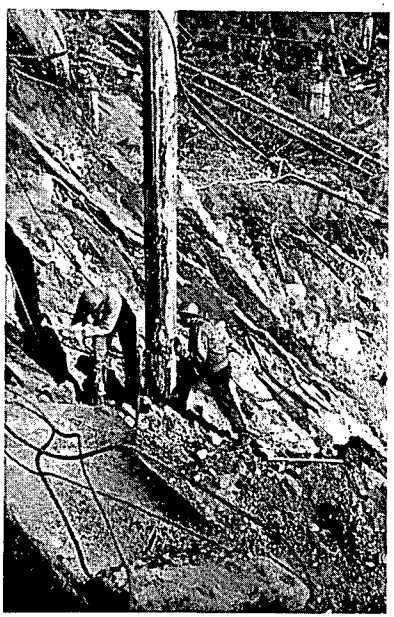


FIGURE 64. Spiking on the steel point. Note the pocket dug for starting the pile.

Mark pile locations to align either the front or rear faces of the piling or the centres. These locations may make a difference of several inches in alignment with pilings that vary considerably in dimension. (Proper alignment is important if the bent is to be planked on one or both sides or if the piling will be bearing a long cap.)

Here is a step-by-step technique for spotting pile locations.

1. Locate centerline of bridge and bent.

2. Locate position of two outside pilings.

3. Drive outside piles.

4. Mark locations of inside piling, either by sighting along the face of the two driven piles and measuring distance (Figure 65), or by placing targets and measuring distance and depth from the target string (Figure 66).

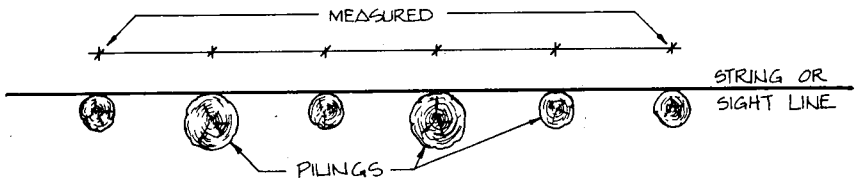


FIGURE 65. Aligning the front of the bent

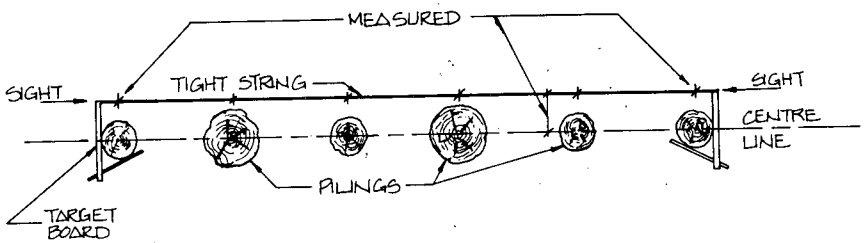


FIGURE 66. Aligning the centre of the piling row

h) Pile drivers

Some years ago most logging camps had experienced bridge crews. The permanent bridge crew became unnecessary with the arrival of modern logging and construction machinery, and the use of pile drivers all but disappeared. Pile-driving equipment is not difficult to use, and although it is no longer readily available, there are still "hammers" and even a few pile drivers or sets of pile-driver "leads" in some logging camps.

The more sophisticated pile-driver equipment—such as the diesel or air/steam hammer—is rarely needed in the woods except for large projects. These mechanical 'hammers' are efficient if you're driving more than 50 piles.

The key element to the simple pile driver (Figure 67) is a cable winch with at least two drums. One line lifts the hammer and the other hoists the pile into the leads and holds the piling in position while it is driven. The two lines can also be used for setting up a yarding system to pull piling and other bridge material into place.

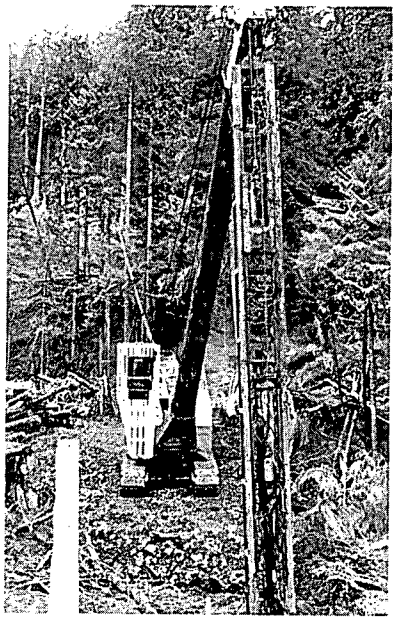


FIGURE 67. A pile driver

The leads serve as rail guides for a hammer (Figure 68). They are suspended from a boom or frame on the pile driver and placed in position directly over the spot where the pile is to be driven. The pile is placed inside the leads under the hammer.

Both the top and bottom of the leads are fixed on a sled-mounted or water-borne pile driver. A set of leads can be suspended from the boom of a log-loader or crane to make a pile-driver (Figure 68). The penetration and height of the bent determine the required length of the lead.

Leads should be at least 25 ft long to allow the hammer its initial travel (1 ft) and to allow another foot for cutoff at the top of the piling.

A cast-steel hammer weighs 2500 to 6000 lb with sides moulded so they slide on the rails of the leads (Figure 69). It has an eye in the top to shackle the line from the winch. Double-loop the line through the hammer's eye and join the lines with wire clips. The eye and the shackle should be frequently inspected for wear. The hammer has a wide, slightly concave base that comes in contact with the pile.

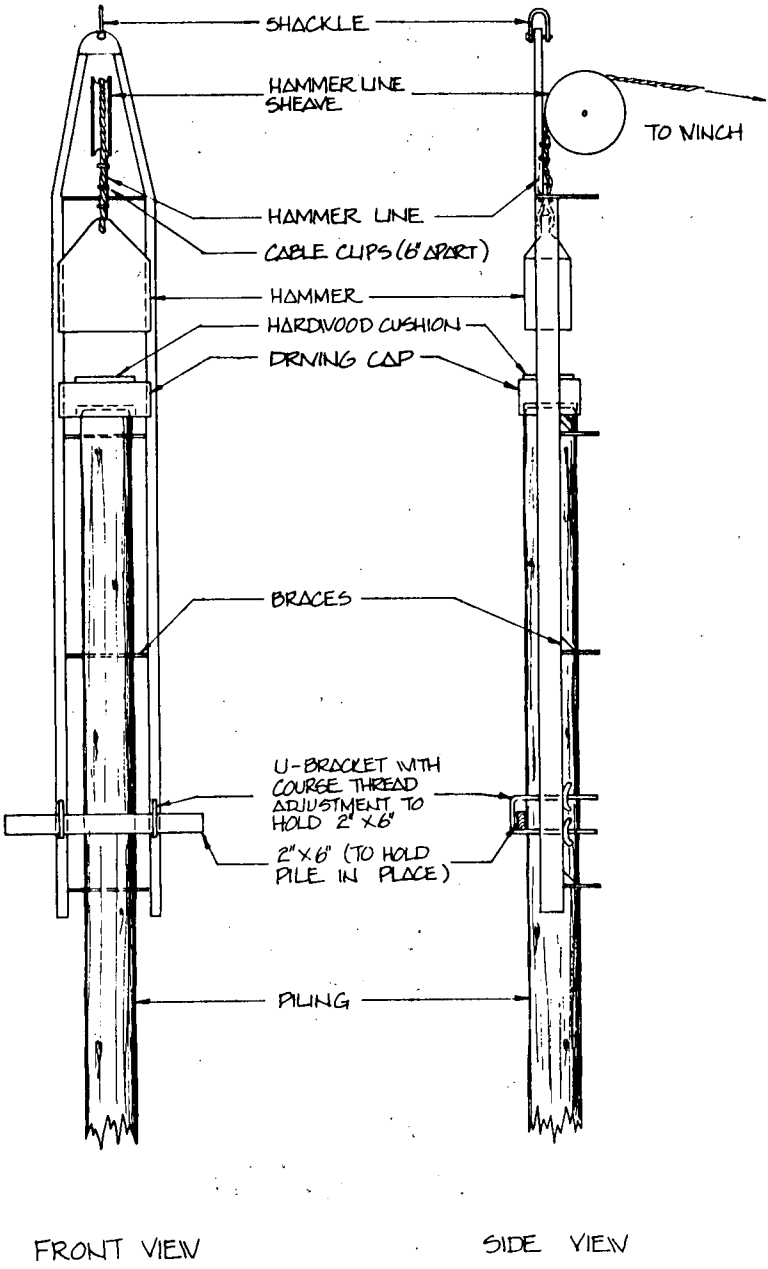


FIGURE 68. A set of suspended leads

FIGURE 69. A cast-steel hammer

The driving cap is a piece of heavy steel that slides up and down on the leads and has pockets on both the top and bottom (Figure 70). The bottom pocket houses the top of the piling and the top pocket serves as a socket to hold a piece of hardwood or other cushioning material. The driving cap is used to steady the top of the pile when suspended leads are used.

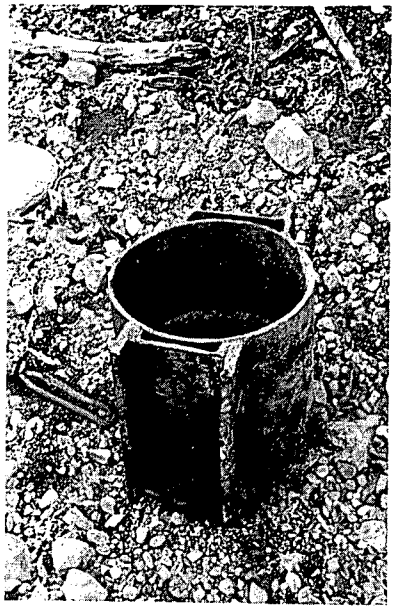


FIGURE 70. A driving cap

i) Pile driving and penetration

At least three men are needed in a pile-driving crew: an engineer to run the machine, a pile man to prepare the piling and attach the hoist line to it, and a leadsman to place the pile into the leads and direct the driving. If the machine does not have a driving cap, the crew uses pike poles to keep the top of the pile in the leads and under the hammer. They should wear hip or chest waders in shallow water or stand on a small float in deep water.

Swing the crane-type machine to face the pile sort. The driving cap is tied safely to the hammer, hoisted to the top of the leads, and held.

The pile (hoist) line (a cable from the winch) is attached to the top end of a pile and the pile is manoeuvred into the leads. Use a pass-chain or a heavy rope with a hook to tie the hoist line on a pile. (A small choker may also be used.) Occasionally the pile has to be rolled by hand or by a peavey in order to line up well in the leads. Once it is lined up, a keeper (a short piece of 2x6 plank) slides through the 'U' bolts to hold the pile. A rope or chain may be used in place of the keeper but must be removed after the pile is driven a few inches.

Once the pile is in the leads, the driving cap and the hammer are lowered on top of the piling. Then the pile is positioned on the ground and the tops of the leads are adjusted. Unhook the driving cap from the hammer. The pile is now ready to drive.

Seat the pile in the earth with a few gentle taps. The hoist line should be left hooked onto the piling during the initial driving to ensure control of the piling.

It is good practice to place a heavy-gauge wire screen on top of the piling to prevent it from burring or mushing out when the driving is hard and a driving cap is not used. Usually it will not be necessary to drop the hammer more than a few feet. If penetration of 1/2-in. (or more) is obtained under a 5-ft to 10-ft drop, drive until penetration stops or is reduced to a barely noticeable level called 'refusal.' Close observation of the penetration and the pile top is important during driving, and if the top shows signs of being damaged, then make shorter drops. Ropes or peavies are necessary to hold the piling in the leads while it is being driven. If the pile starts leaning and it cannot be corrected by adjusting the leads, pull it back with a cable. It is important to stop driving the pile when it reaches a solid base or is damaged by increasingly higher drops of the hammer. It is also important that the

piling be driven far enough. Penetration of 1/8-in. per blow with a 3600-lb hammer is usually considered 'refusal' for a drop from five to six feet. The pile must be driven into the ground not less than 6 ft unless solid rock is encountered. For many British Columbia situations the soil mantle is shallow and frequently heavily-compacted or bouldery. Penetrations greater than 15 feet are rare.

The continuous impact of logging trucks travelling over the bridge will act as a pile-driver hammer and uneven pile-settlement will occur if piling is not driven to refusal.

The load-bearing capacity of the piles in the bent must be checked during driving. At least one pile in each abutment should be tested. The following formula may be used to determine the safe pile-bearing values:

$$P = \frac{2\,WH}{S + 1}$$

where P = Safe-bearing value (in pounds)

W = Weight of hammer (in pounds)

H = Height of fall (in feet)

S = Average penetration (in inches) for the last six blows.

For example, if a 3600-lb hammer and 5-ft drop gets a 1/8-in. average penetration, the safe-bearing value becomes 32,000 pounds.

$$P = \frac{2\,(3600)\,(5)}{1/8 + 1} = 32000 \text{ lb}$$

This test pile will support 32,000 pounds. If the design calls for a total load of 240,000 pounds on the bent, then 8 pilings will be required.

This formula applies only to friction piles and is not reliable in clay soils where refusal cannot be achieved. The abutments should be designed with a large safety factor for these soils, and the bridge should not be subjected to heavy vehicular traffic for at least 10 weeks. (If possible, the abutments should not be loaded at all for a period of two weeks.)

If the top of the pile splits badly during driving, it may only be a flaw in the wood and you can cut it off and continue. On the other hand, it may be a sign of a problem at the other end where the pile tip is on bedrock and is being crushed one-quarter inch with every blow of the hammer. The inexperienced man might continue driving until he runs out of piling. The experienced man can usually tell by feel or sound when he hits bedrock. The hammer should not bounce after the blow.

The use of a cast-steel hammer provides complete flexibility for the bridgeman who wants to vary the energy transferred to the pile end. This is different from air or diesel hammers which generally transmit a given energy with each blow.

j) Pile cutoff

After all the piles in a bent are driven, they must be cut off at the correct height. The construction plan will show the difference in elevation between a field benchmark and the pile top. When only the elevation of the bridge deck surface is shown on the plan, deduct the depth of the superstructure to determine the pile elevation.

Drive a small nail in a pile at the cutoff elevation already established with a surveyor's level and rod. Nail 2x6 (or larger) straight planks on both sides of the piles in the bent. The tops of the planks are at the cutoff elevation. Cross-level them with a carpenter's level (Figure 71).

Another method for establishing pile elevations is to have the engineer establish targets on opposite sides of the bent. The construction crew sights across the targets to position the straightedges (Figure 72). Targets may be used for more than one bent.

Using the straightedge as a guide, cut off the pile tops with a powersaw.

k) Bracing pile bents

Pile abutments and bents over 10 ft in height (particularly those with small diameter pilings which are not supported against side loading) must have sway bracing as well as waling on both sides. Bracing normally consists of sawn boards of at least 3x8 inches. (See also Bracing in the Piers section.) Bracing is held with bolts not less than 3/4 in. in diameter. Malleable washers and spiked grid-connectors are used. (The spiked grids have one curved surface to fit the pile.)

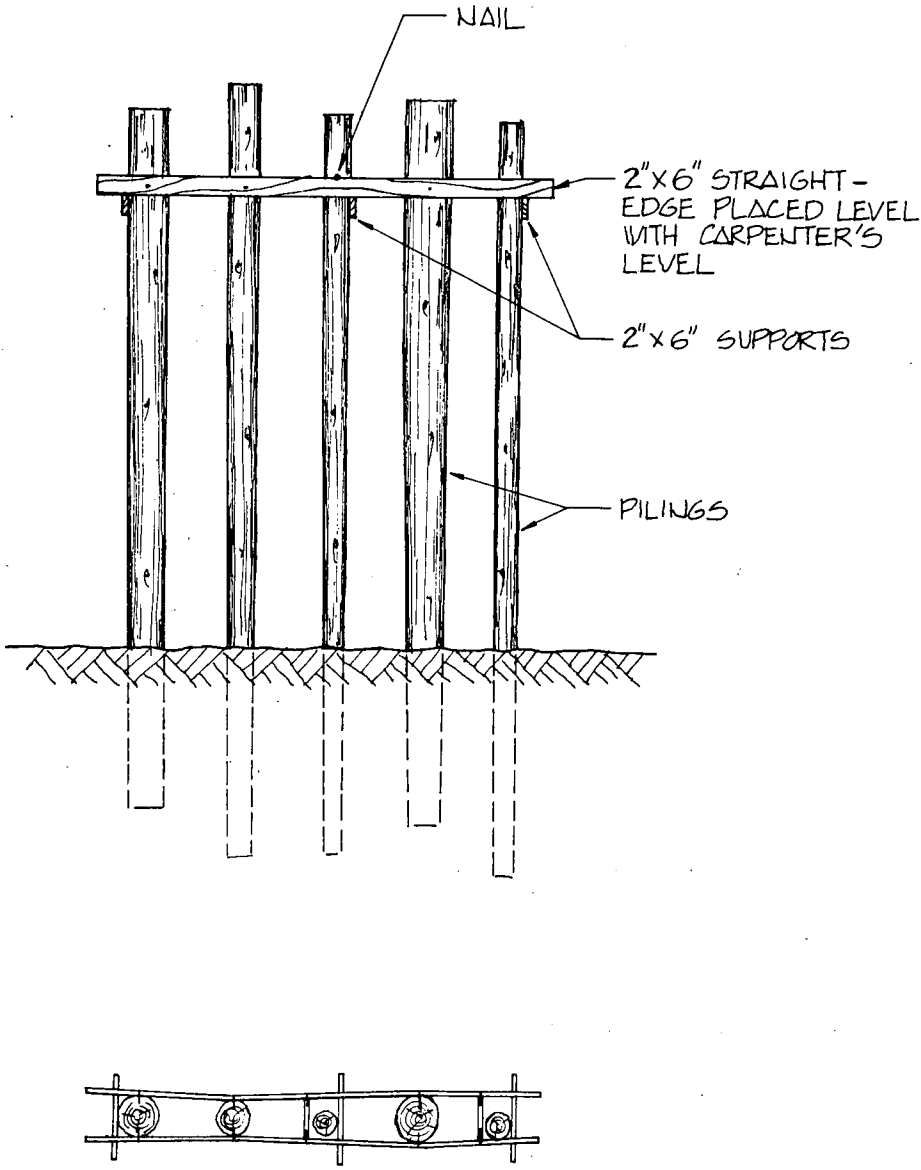


FIGURE 71. Straightedges for pile cutoff

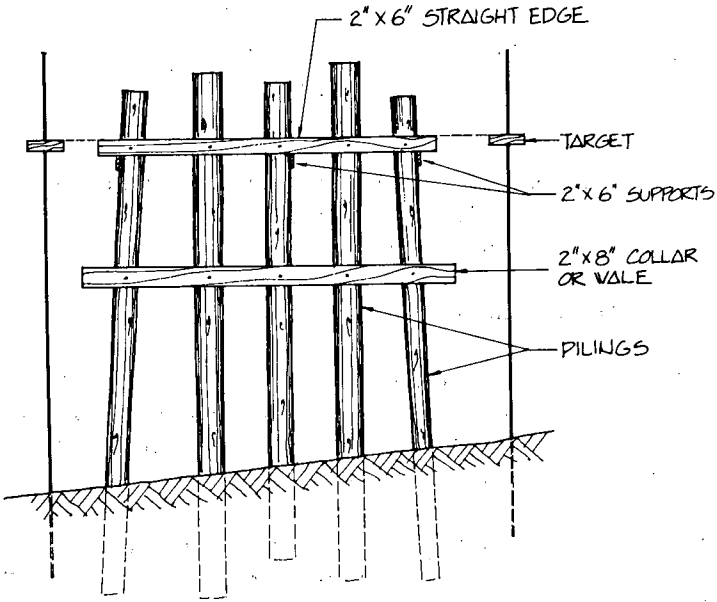


FIGURE 72. Target to establish pile cutoffs

l) Caps

Caps are discussed in the Caps and Sills section. (See also Caps in the Pier section.)

m) Lining pile abutments

Planking is usually nailed with 6-in. galvanized nails to the piling inside the bent and wings. (Nail holes are damaging to treated piles and make the pile susceptible to decay so nails should be used sparingly. Their purpose is to hold the planks in place until the abutment is filled.)

Planking should not be less than 3-in. thick and should be joined so the ends overlap or are supported by a piling.

Small logs (but larger than 6-in. diameter) may be used without nailing to line the abutment. This lining material should last as long as the piling. Use treated planking with treated piling and cedar logs or piling with cedar piling.

Abutment lining not only retains the fill but it allows the air to circulate and reduces piling rot by keeping the fill away from the piling. It is a good idea to line the abutment even when row piling is used.

Cover the lining of the abutment with layers of filter fabric to stop leakage of fine fill material (sand, silt). Water should always be able to run out of the abutment to reduce earth pressure.

n) Pile-anchoring systems

Piles are capable of carrying large vertical loads but are not able to sustain large horizontal forces. Multiple rows and independent groups may be able to stand without help but if there is any doubt about the abutment's ability to retain the fill, then use a tieback system.

(Many materials such as small logs, concrete-reinforcing steel, steel rods or angle iron can be used for the tiebacks but wire rope is most common. Piles are tied back to a deadman, piling, or to some natural anchors found around the abutment like stumps or rock.)

Figure 73 shows the desired position of a deadman. The cable angle should not exceed 45° and the deadman should be kept as deep in the fill as possible.

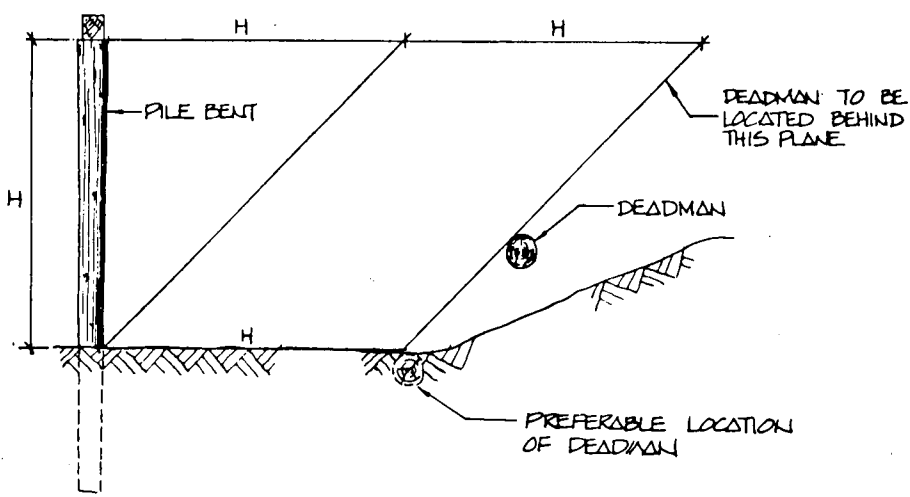


FIGURE 73. Position of deadman

If deadmen also need to be tied back, position them parallel to the pile bent and to the wing walls. These logs must be held in position while the cables are tied and the abutment filled. Anchor them to stumps or rock, or drive pilings in front of them. Two pilings are enough to anchor a deadman. Piles can also be used as anchors with the tieback lines tied to the foot. If more than one layer of line is used to tie back the bent, each layer should have its own anchor.

Use natural anchors (whenever you can find them in the fill area) to accommodate a proper alignment of the tieback cables.

Tieback cables should run in a vertical plane perpendicular to the line of pile bents or wing walls to reduce side pressure on the pile (Figure 74).

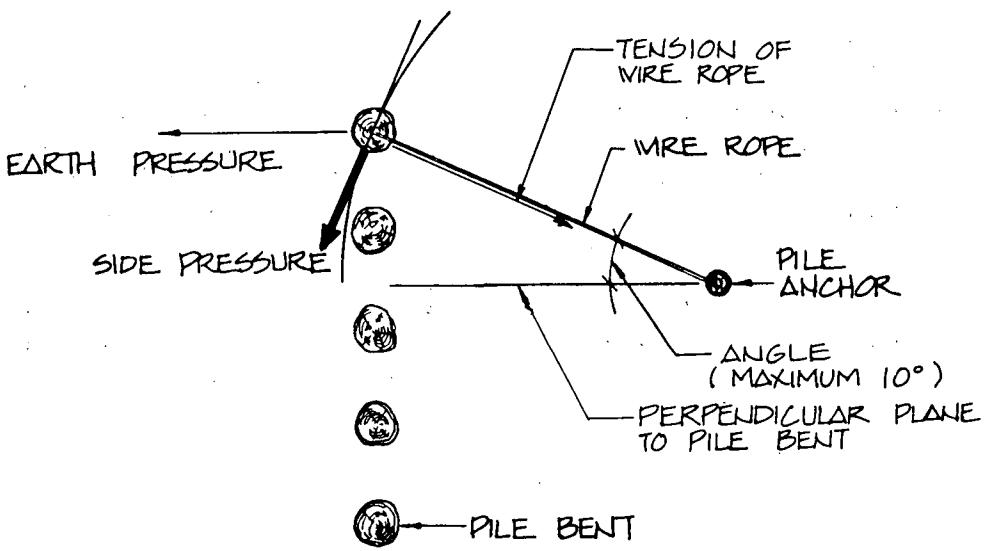


FIGURE 74. Side pressure from anchoring

If it is difficult to keep the cables in a plane perpendicular to the bent, reduce the side pressure on the piling by tying the cables to a large longitudinal brace in front of the piles (Figure 75). The bracing should be 10x10 sawn timber or a straight log not less than 12-in. diameter at the small end. Bolt it to every pile without exception.

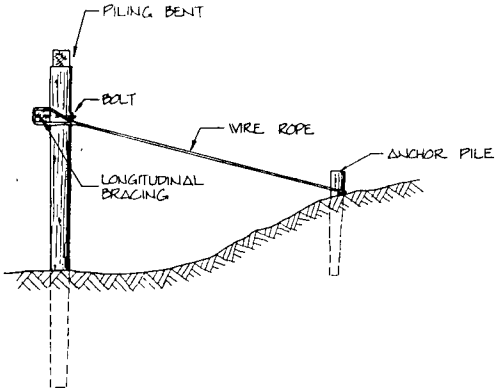


FIGURE 75. Cables tied to timber bracing

Height determines the number of tieback layers in a pile bent. A bent 4 ft to 8 ft high should have one layer of tiebacks fastened 2 feet below the pile top. If it is over 8 ft there should be a second layer in the centre. Use galvanized wire rope at least one inch in diameter. The cable should always be much stronger than the bolts because a stretched or broken cable is difficult to detect during inspection but a broken or loose bolt is readily seen.

Bolting through the pile (Figure 76) is the most common and least-damaging method for fastening the cable. Wire rope around the pile may crush the outside wood and expose untreated wood, resulting in strength loss. The galvanized layer on the wire rope around the pile may also be worn off.

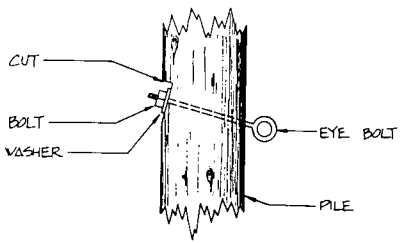


FIGURE 76. Bolting through the pile

The following sketches illustrate some of the ways to attach the cable to the piling (Figure 77).

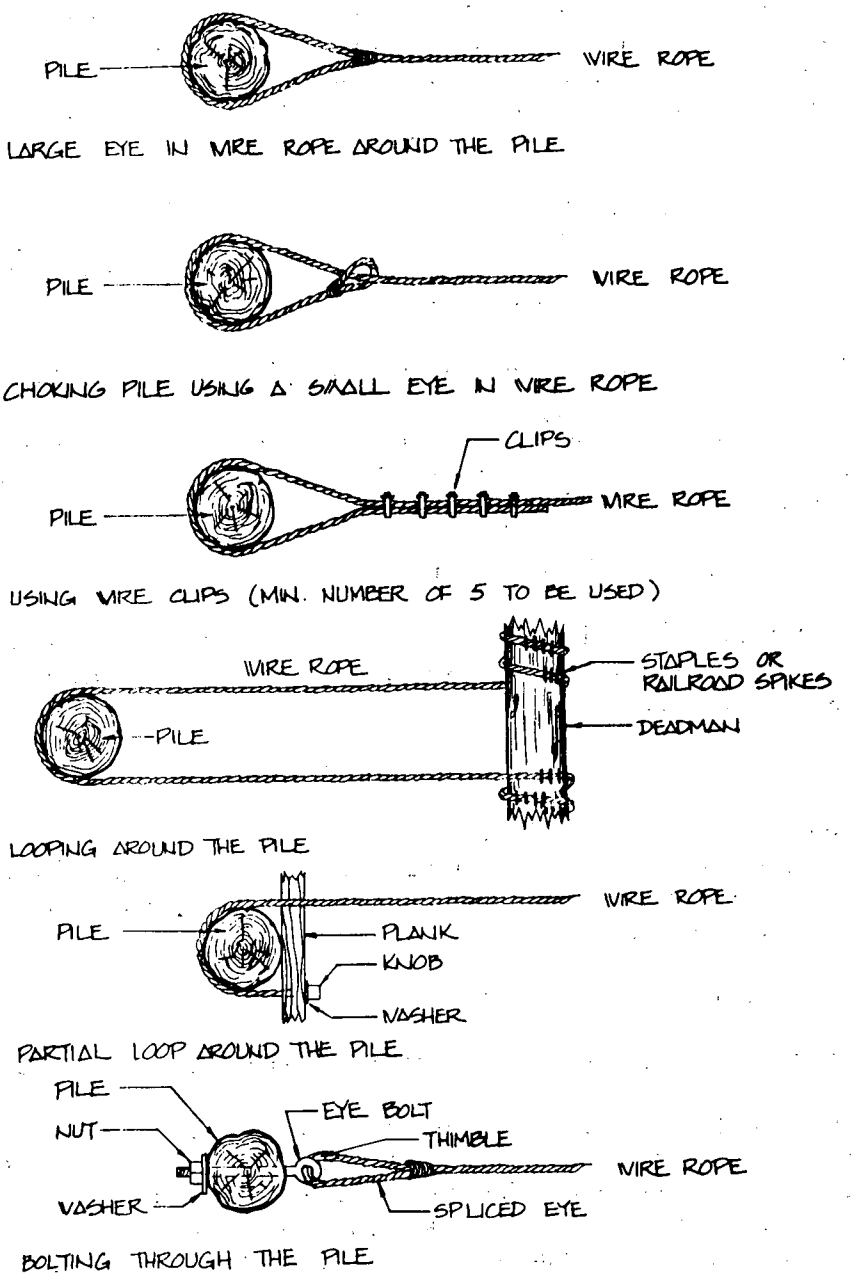


FIGURE 77. Fastening cables to pilings

Use 3/4-in. galvanized eyebolts with large galvanized washers if you use 1-in. diameter wire rope. Bolts smaller than 3/4 in. should not be considered. Holes should be drilled in the direction of the pull to avoid twisting or splitting the pile. It may be necessary to fit the washer on the pile where the bolt-hole forms a large angle with the horizontal.

The hole size in untreated piles should be the same as the bolt size. The hole in treated piles should be drilled 1/16-in. to 1/18-in. larger than the bolt size and should be heavily treated with preservatives. It is important to have a thimble in the eye of the wire rope.

Figure 78 shows anchoring details and bracing for two layers of tiebacks.

If the lines are horizontal, place the bracing between the planking without fastening. See that the direction of the pull is perpendicular to the pile bent or wing walls (Figure 79).

o) Fastening cable to deadmen

Prevent movement of the deadman or anchor when tightening the cable. Tightening the cables should start at the centre and progress to the wing walls on both sides.

- Wire clips

Using wire clips is one of the easiest methods for fastening cables (Figure 80). Use four clips 6 in. apart with a 1-in. diameter wire rope. The cable can be partly tensioned by tightening the clips one after the other as you move toward the deadman.

- Staples and railroad spikes

Staples and railroad spikes can be used to fasten a cable to a deadman.

The cable should always go around the deadman two complete wraps. The wraps should not cross. After the first wrap is completed, the cable should be pulled tight and stapled by four staples at each end (Figure 81). Staples should be 6 in. apart. If railroad spikes are used, drive 3 or 4 so that the friction and the pinching effect of the spikes will stop the rope from sliding (Figure 82).

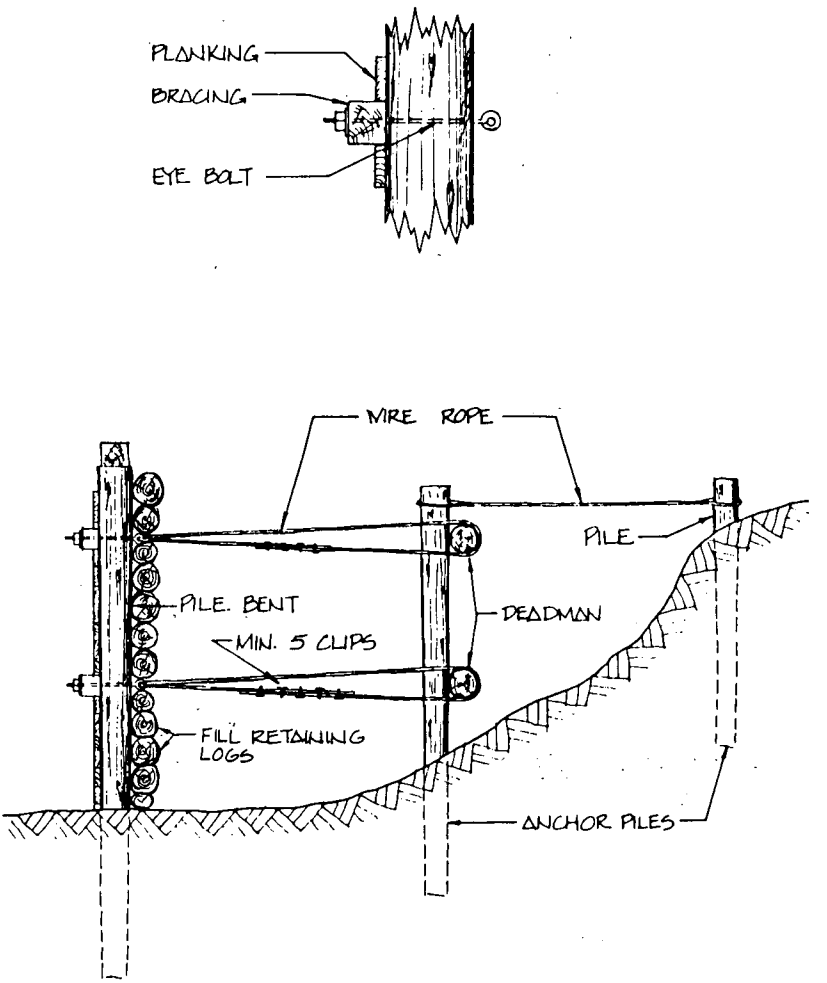


FIGURE 78. Anchor details for two tieback layers

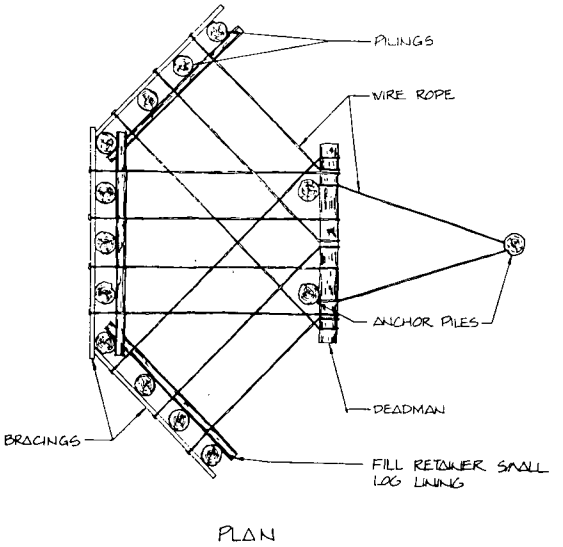


FIGURE 79. Plan view of a bracing and tieback system

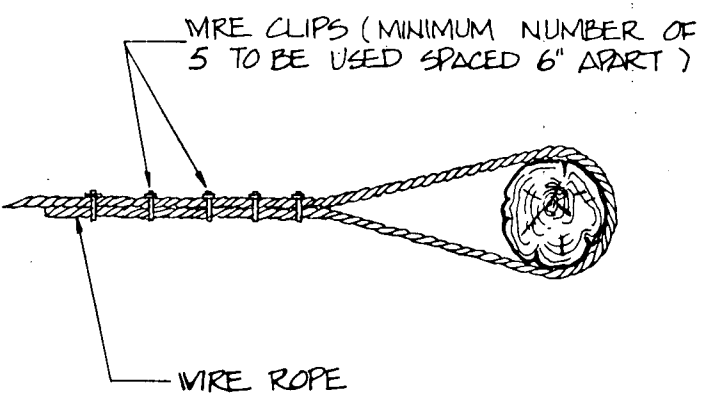


FIGURE 80. Fastening a cable with wire clips

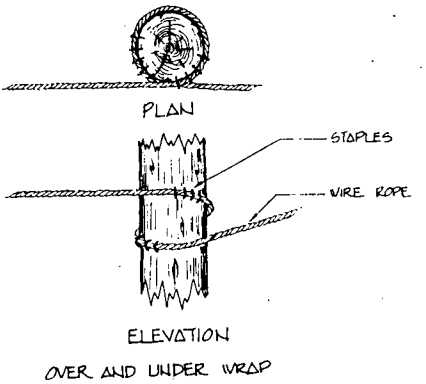


FIGURE 81. Fastening a cable with staples

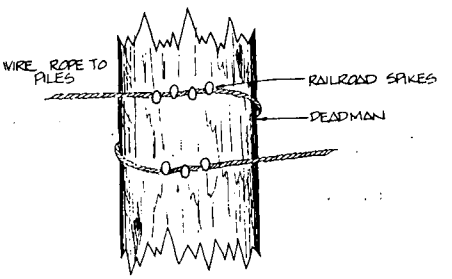


FIGURE 82. Fastening a cable with railroad spikes

Now the second wrap can be tightened and fastened (Figure 83).

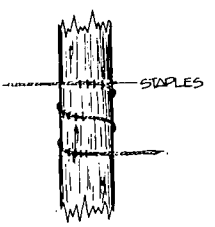


FIGURE 83. Completed wraps

The easiest way to hold the end of wire rope is with a farmer's-eye splice or a pass-chain. If a chain is used, wrap it around the cable at least three times and then hook it back so it stays tight.

When more than one tieback line is used, lead the wraps from alternate sides of the log anchor to prevent rolling.

If the tieback is not perpendicular to the log, the over-and-under wrap is easy to use (Figure 84).

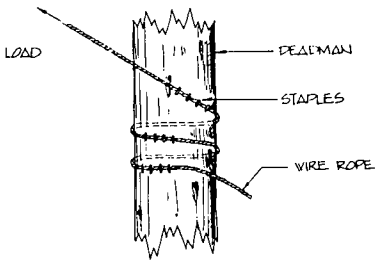


FIGURE 84. Fastening a tieback at an angle

The line may also be guided around the anchor pile and wrapped around the deadman (Figure 85). An under-and-over wrap is preferable to permit stapling on top of the deadman.

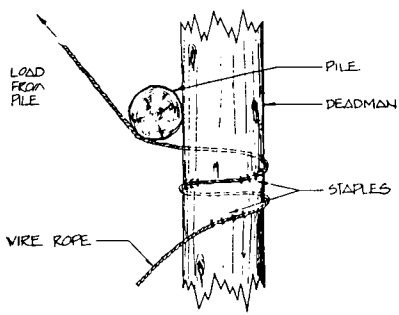


FIGURE 85. Wire rope attached to a deadman at a pile

If the line slips off the end of the deadman, cross the lines (Figure 86). (This method should not be used to tie the load-carrying pile bent.)

The looping tieback line does not end at the deadman but returns to another pile for fastening (Figure 87). The line should have a complete wrap around the deadman. It is easier to tension the line if it is stapled to the deadman. Eye bolts or wire clips allow easy tensioning.

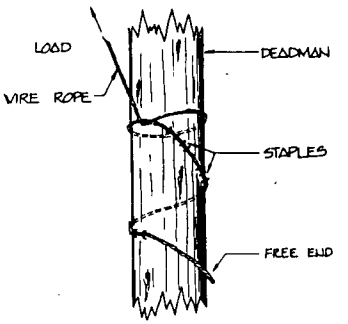


FIGURE 86. Lines crossed to prevent slipping

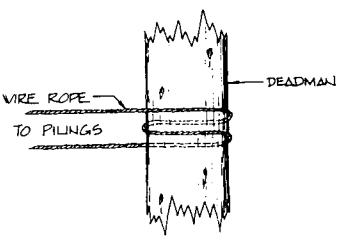


FIGURE 87. Looping tieback

p) Fill-retaining cribbing

Fill-retaining cribbing may replace the tieback system described in the cribbing section. Cribbing is easy to put together and it is usually cheaper if the wood is available. Any species can be used for crib construction with no danger of rotting if the fill material completely covers the logs.

Build the cribbing as close as possible to the pilings in the bent, but leave room for a worker between the cribbing and the piling. This system has the advantage of permitting pile-bent replacement without replacing the rest of the abutment.

q) Stump anchors

Stumps can be used in place of deadmen. One disadvantage of using stumps, however, is that only a few of them are available within the abutment area and it is often difficult to keep the tieback lines perpendicular to the pile bent.

r) Rock anchors

Use rock anchors for tiebacks on steep banks.

You can make anchors with split-wedge steel pins (Figure 88).

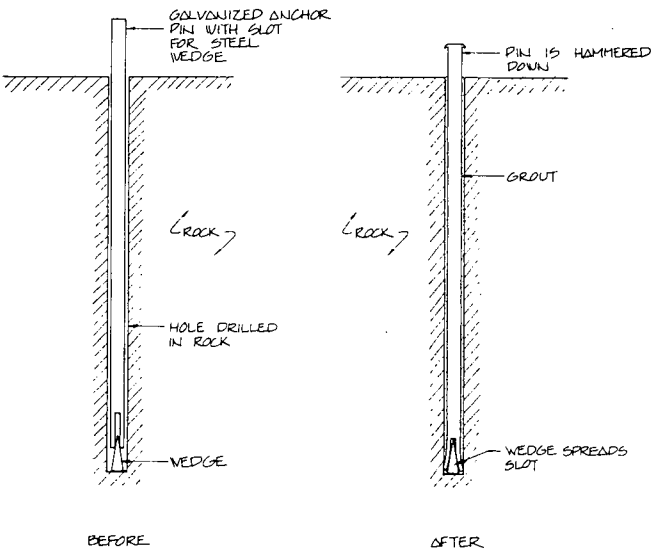


FIGURE 88. Setting rock anchors

After the pin is fixed in place, fill the hole with molten sulphur which will solidify without shrinkage. There are also chemical compounds such as 'Rok Lok.' If concrete is used as grout, the aggregate must be relatively fine sand with a rich mixture of portland cement. The concrete should be well vibrated and tamped.

s) Filling pile abutments

After the tieback system is completed, pile abutments should be filled with material that drains well—preferably gravel, shot rock or sand. Take care not to damage the cables and the piles. Sand and gravel can be dumped slowly but freely into the abutment. Use a small backhoe to place shot rock. The fill should be carefully compacted. A fill-retaining cribbing should be filled as the construction progresses. Use a bulldozer for compaction. Fill the abutment completely to help stabilize it before placing the stringers.

t) Protection of pile abutments

Pile bents are susceptible not only to movement from earth pressure, but to damage from scouring and from flood waters carrying floating debris.

If it is not possible to build abutments outside the stream channel, consider other kinds of protection.

- Prepare a smooth stream bed in a slow-flowing stream by removing all the obstacles around the bridge that would direct the water flow against the abutments, reduce the cross-section of the stream bed, or cause the stream to move. This must be done in consultation with local authorities.

- Plank the face and wing walls of the abutment. 2x12 or 3x10 planking is usually adequate for this purpose, but another method should be used if planking larger than 4x12 appears to be necessary. Solid planking is a good substitute for bracing. Nail every plank to every piling at least twice with 8-inch galvanized nails.

- If it appears that planking could not resist scour, use heavy steel sheeting instead (not less than 1/4-in. steel sheets). Nail these sheets to the piling using 8-inch galvanized nails. If pre-hole punching is desired, then 5x10 planking could be bolted to the piling in the appropriate locations and then the sheeting nailed to the planks. The sheeting should be used lengthwise and it may even be welded at the seams to form a continuous plate cover.

- Drive wood or steel sheet piling below scour depth. It must be driven at the time of driving the main bent.

- Drive row piling around the abutment instead of sheet piling. These row pilings are braced and tied to the bent. Lining the inside of the abutment is not necessary.

- Build protective cribbing around the abutment. This cribbing also replaces the wing walls, simplifies construction, and reduces the number of piles required for the abutment. Cribbing must start below the scour level. Using piling and cribbing protection enlarges the size of the abutments and reduces the size of the stream channel.

- Use concrete to protect pilings. It reinforces and preserves the bent. The concrete casing should start below scour depth and the finished bent should be one slab of concrete around the piling. At least 6 inches of concrete should cover the piling. You can build simple, maintenance-free concrete abutments by covering the pile tops with at least 12 inches of concrete.

- Put floating shear logs around the abutment to channel all the floating debris away.

- Drive a dolphin at a strategic location upstream to provide adequate protection against floating debris and ice. This method can be combined with the use of shear logs.

- Protect against undermining by lining the perimeter of the abutment with good quality rip-rap. The material must be so coarse that even the most turbulent water will not move it. The area lined with rip-rap should be approximately 1.5 times the scour depth measured from the foot of the bent.

- Build rock dykes in an oval shape to reduce turbulence (Figure 89).

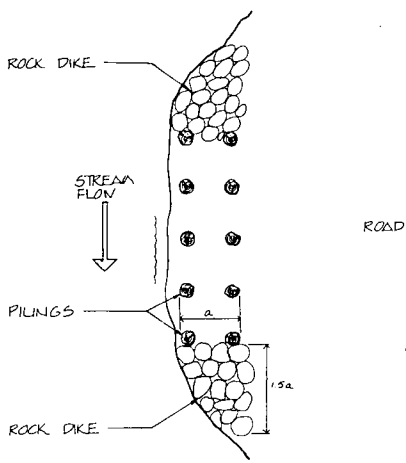


FIGURE 89. Rock dyke protection

6. Concrete Abutments

The abutments we discuss here have concrete walls no higher than 10 ft and foundations resting on material (usually solid rock or larger boulders) with a load-bearing capacity of more than 15,000 psf.

Concrete abutments used in place of log cribs or piling require extensive design to make sure the concrete can support the earth pressure from the fill. All concrete abutments must be secured against movement. You can use the designs in this book to build simple concrete footings as partial abutments.

a) Advantages of concrete

- It forms a long-lasting abutment if durable wood is not available and piles cannot be driven.
- It provides a foundation on steep, rocky ground (Figure 90).
- It can be anchored to a rock surface to support a crib or frame bent.

FIGURE 90. Concrete pad foundation

b) **Construction materials**

Concrete is artificial stone shaped to a required form. It is a mixture of cement, water, and aggregates. In some cases admixtures are added to influence the chemical reaction. The aggregate particles are held together by hardened, dry, cement paste. Reinforcing steel is often used in the poured concrete to increase its strength.

Shortly after the concrete is mixed, a chemical reaction (hydration) begins. Curing time depends on the type of cement, temperature, and the mixture's combination. Concrete generates heat during the early days of hydration. In cold weather it is necessary to cover the structure to prevent heat loss.

- Cement

Cement is the bonding agent used in concrete. Portland cement Type 10-Normal is used under most bridge construction conditions. Concrete mixed with this cement reaches its design strength in 28 days. (Design strength is approximately 90% of maximum strength.) Portland cement Type 30-High-Early-Strength is used if fast setting is required; if the concrete structure is flooded; if the construction must be completed quickly; if the concrete is used for such underground repairs as underpinning, or if the concrete is poured in cold weather. It will reach design strength faster than normal cement. Concrete mixed with Type 30 cement produces more heat than normal concrete and is not recommended for use in temperature conditions over 21°C during the curing period.

Using air-entrained portland cement Type 10 or Type 30 will improve the concrete's resistance to freeze-thaw and chemical attacks (i.e., salt) which cause scaling. It will also improve the workability of the concrete, although a slight loss in concrete strength may be expected. Air content due to air-entraining in the concrete must be 4% to 6% by volume. All ready-mix concrete should be ordered with air-entrained portland cement.

The ultimate strength of the concrete depends on the water/cement ratio. The recommended ratio is 0.45 to 0.5 by weight.

$$\frac{\text{WATER}}{\text{CEMENT}} = 0.45 \text{ to } 0.5$$

The cement content should be over 255 kg/m^3 but must never be less than 216 kg/m^3. The recommended ratio for bridge construction is 356 kg/m^3 or 600 lb/yd^3.

A 0.5 water/cement ratio will make a watertight concrete, provided the concrete is cured under moist conditions. If a very abrasion-resistant concrete is needed for turbulent water, this ratio should be reduced to 0.45.

The minimum strength acceptable for any concrete work in bridge construction is 2500 psi. A 0.5-water/cement ratio will ensure a strength of 3600 psi for air-entrained concrete and 4600 psi for non-air-entrained concrete (using 356 kg cement in 1 m^3 of concrete).

The concrete mix must be pliable so it can be easily placed and worked to achieve a good finish. The mixture may be made drier or softer by adding more or less aggregate.

- Aggregates

  i) Fine aggregate

Fine aggregates are clean sand with less than 4% silt and clay content. Some sands react with alkalis in cement to induce deterioration of the concrete. Local experience usually helps identify these impurities.

  ii) Coarse aggregate

Coarse aggregates are gravel or crushed rock, ranging from 1/4 in. (6 mm) to 4 in. (90 mm) in size, depending on the type of concrete mixture planned. Some larger stones may be allowed in the mix, and in some cases the use of larger boulders may be useful to fill out the space and save on concrete (French concrete). The aggregate must be well graded in size to make a good mixture.

* * * * * *

Some rocks react with the alkalis in the cement. Material which deteriorates easily should not be used. (Most shales and chert are not suitable for concrete.)

Maximum aggregate size:

- Floor slabs: if only compressive strength is required and reinforcing is not used, the aggregate may be any size (including boulders) as long as

it is within the slab and properly covered with finer aggregate and cement paste. A maximum size of one-third the slab thickness is recommended.

- Walls without reinforcing: no piece larger than one-fifth the width of the wall.

- In reinforced concrete: no piece larger than three-quarters of the minimum clear spacing between reinforcing bars or outer surfaces.

- Admixtures

Two groups of admixtures are important to bridge builders. The first group speeds up the hydration process; the second group increases the concrete's resistance to damage and makes it more pliable. Both are sold in liquid or powder form with the content identified and the mixing instructions printed on the package.

Admixtures should be dissolved in the mixing water to achieve a homogeneous mix.

Calcium chloride (an accelerating admixture) reduces the curing time of the concrete. Concrete mixed with the maximum amount will reach 100% design strength in 20 days. Calcium chloride is sold in flake, pellet or solution forms. It will not change the workability of the mix but it reduces its strength slightly. It is mixed with normal cement when High-Early-Strength (Type 30) cement is not available. The concrete has the same characteristics as that mixed with Type 30 cement.

Air-entraining admixtures are used to improve the workability of concrete when air-entraining portland cement is not available. These admixtures will also improve the durability of concrete which has been exposed to moisture during freezing and thawing. They reduce or eliminate bleeding. A slight loss in concrete strength (up to 20%) may be expected when using these admixtures.

Air-entrained concrete contains very small air bubbles (4% to 6% by volume) uniformly distributed throughout the cement paste. These air bubbles remain in the concrete even after vibration. Air-entraining admixtures are available in powder or liquid forms.

Admixtures should be used according to manufacturers' instructions.

- Reinforcement

Only deformed reinforcing-steel or wire fabric specially manufactured for concrete-reinforcement should be used. The steel should be clean, free from chemicals or organic material, oil and grease. Badly soiled steel should be washed with clean water and scrubbed with a wire brush. Steel with a light rust coating can be used without any treatment but heavily rusted steel should be brushed off first. If deterioration is so advanced that it is difficult to clean and the steel is pitted, it must be rated to a smaller size.

Reinforcing steel is identified by bar numbers which represent the normal diameter of the bars measured in one-eighth inches (i.e., No. 8 = 1 inch). The normal dimension of a deformed bar is equivalent to that of a plain round bar having the same weight-per-foot as the deformed bar. Table IV-H shows the normal dimensions and weights of the different-sized bars.

When you place the bars in the forms, keep a minimum clearance of 3 in. from the sides of the form. Leave enough clearance for the largest stone in the concrete to move freely when the concrete is poured. Rebars must not be spaced further than 18 in. apart.

Join bars by welding. If the steel has to be spliced, overlap the parallel running bars 33 inches. Weld them together in the middle of the overlap for a length equal to 1.5 times the diameter of the smaller bar. If a small bar joins perpendicular to a large bar, it can be hooked to the large bar. The hook end must extend at least 1 ft above the large bar, parallel with the small bar. You can also join the rebars with a 90° bend one-foot long on the small bar, place it along the large bar, and then spot-weld it.

Rebars can be bent cold. The diameter of the bend should not be less than 10 times the diameter of the bar.

Reinforced wire fabrics are made of welded plain wire, deformed wire, and welded deformed-wire sold in sheets or rolls. The wires in the fabric form a mesh with a square or rectangular opening. The opening size should be at least one-third larger than the size of the largest aggregate in the concrete. Wire fabrics can be joined by overlapping two mesh squares or rectangles. They should be clean and should have a minimum clearance of 3 in. from any outside surface of the concrete.

TABLE IV-H. Deformed Bar Numbers, Unit Weight and Normal Dimensions (Imperial Units)

Bar Number	Unit Weight lb/ft	Diameter in	Cross Sectional Area in^2
3	0.376	0.375	0.11
4	0.668	0.500	0.20
5	1.043	0.625	0.31
6	1.502	0.750	0.44
7	2.044	0.875	0.60
8	2.670	1.000	0.79
9	3.400	1.128	1.00
10	4.303	1.270	1.27
11	5.313	1.410	1.56
14	7.650	1.693	2.25
16	10.413	1.975	3.06
18	13.600	2.257	4.00

Deformed Bar Numbers, Unit Weight and Normal Dimensions (SI Units)

Bar number	Unit Weight kg/m	Diameter mm	Cross Sectional Area mm^2
10	0.785	11.3	100
15	1.570	16.0	200
20	2.355	19.5	300
25	3.925	25.2	500
30	5.495	29.9	700
35	7.850	35.7	1 000
45	11.775	43.7	1 500
50	19.625	56.4	2 500

c) Site preparation for concrete structures

Once you have completed the site survey and decided on the location of the abutment, mark the site. Pickets and target boards must be placed where they will not be hit by the machines. Take care that before a target board is moved it can be easily reestablished. Our sketch shows a simple site layout (Figure 91).

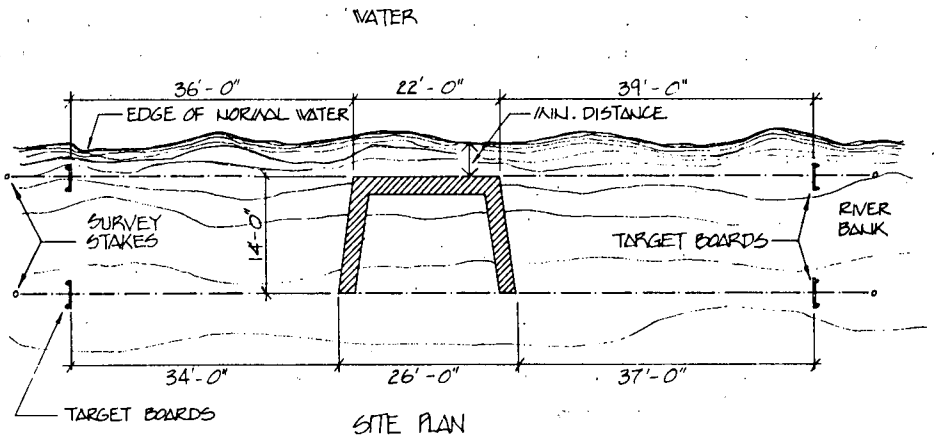


FIGURE 91. Site plan of concrete abutment

Clear the site and excavate the foundation down to rock or hard ground. In hard ground (hardpan), the foot of the foundation must reach below the stream's scour depth and must extend at least 6 ft into the subsoil. Excavation for the foundation must be large enough for easy construction of the form.

The surface should be cleaned, washed and scrubbed if the abutment is built on rock. If the abutment is built over old concrete foundations, use a bonding agent available from cement suppliers.

d) Drainage

An abutment is like a large concrete box which must be drained when flooded. Drainage pipes may be plastic, concrete, or clay drain tiles—or steel pipes. They should be no smaller than 2-in. diameter. If the fill material is porous enough to allow water movement, the pipes should be placed in the front wall at the foot of the concrete work; if not, additional pipes should be placed higher to drain off part of the water. Position them carefully so they function for long periods without becoming plugged.

e) Concrete slab foundation

You need a concrete slab foundation if the abutment is going to move or settle or if the use of rock bolts is not practical (i.e., with weathered rock, compacted glacial till or hardpan) (Figures 92 and 93). The concrete slab forms the base for the abutment. Once hard (after a minimum 3-day period)

it is ready for the abutment to be built on it. Position the slab below scour level to reduce undermining. Abutment designs 1, 2 and 4 will fit on these slabs.

Number 18 (or larger) rebar pins must be located in the slab to fit the abutment design. All connections shown are welded.

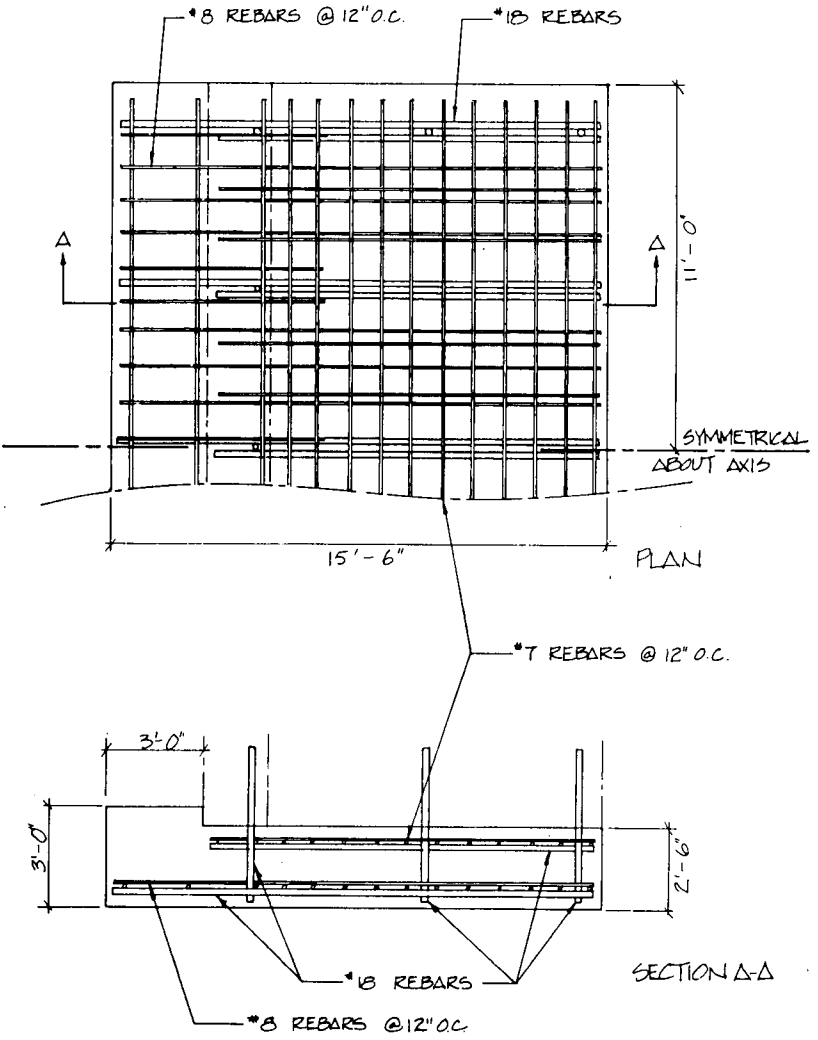


FIGURE 92. Concrete slab

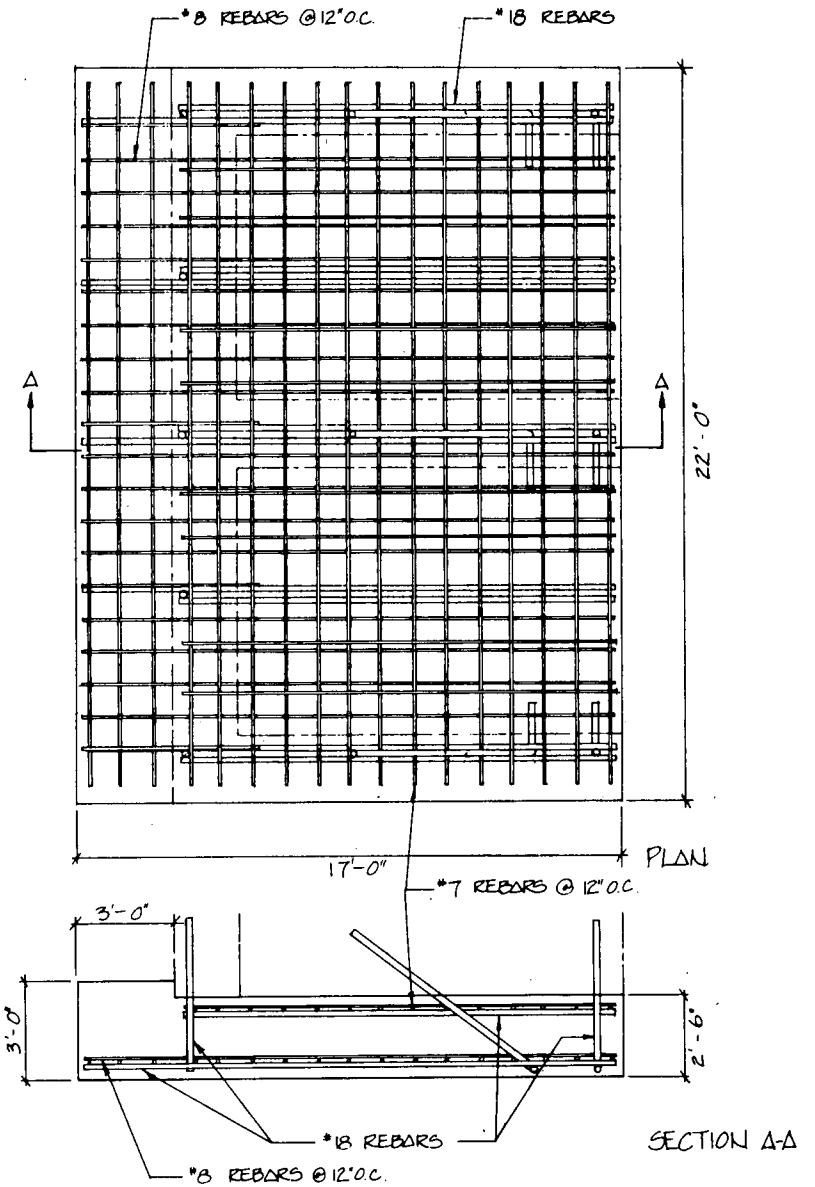


FIGURE 93. Concrete slab to fit Design 4

f) Design of concrete abutments

We show four basic designs which will support a bridge with a 150-ton design logging truckload. Height and length measurements shown are maximum and any changes in the design which increase these dimensions will require the approval of a qualified engineer. Wing walls may be angled up to 20° from those shown on Designs 1, 2 and 3.

Design 1

This design shows an abutment (Figures 94, 95, 96) with a wall thickness of 24 in. built on rock. The cap or sill rests directly on the abutment. Use fill material that will not damage the concrete. The foundation must be clean solid rock or a concrete slab that cannot settle.

The hooked reinforcing-rod connections (Figure 97) may be replaced by the welded connections shown in Figure 98. (When using welded connections, you must raise the base bar 20 in. above the ground so the reinforcing rods can run straight down with a 6-in. clearance at the ground.)

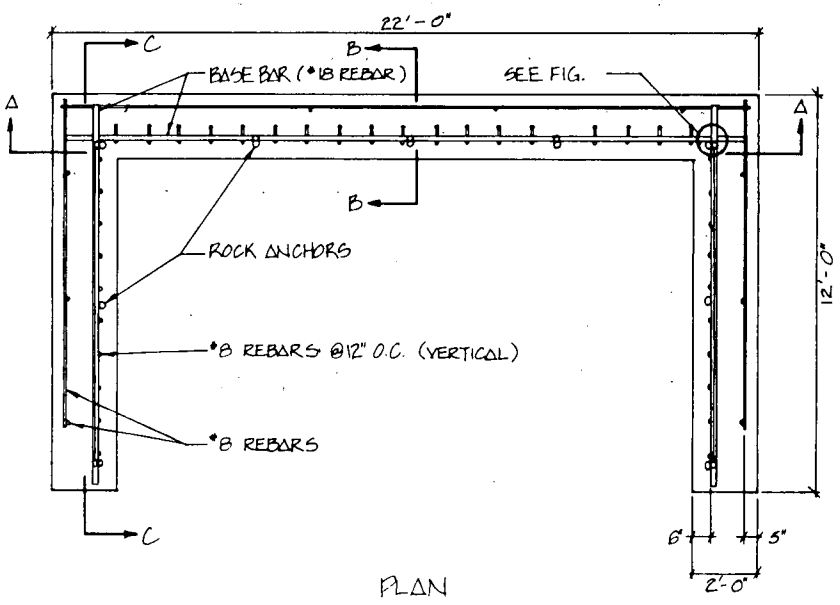


FIGURE 94. Design 1 foundation plan

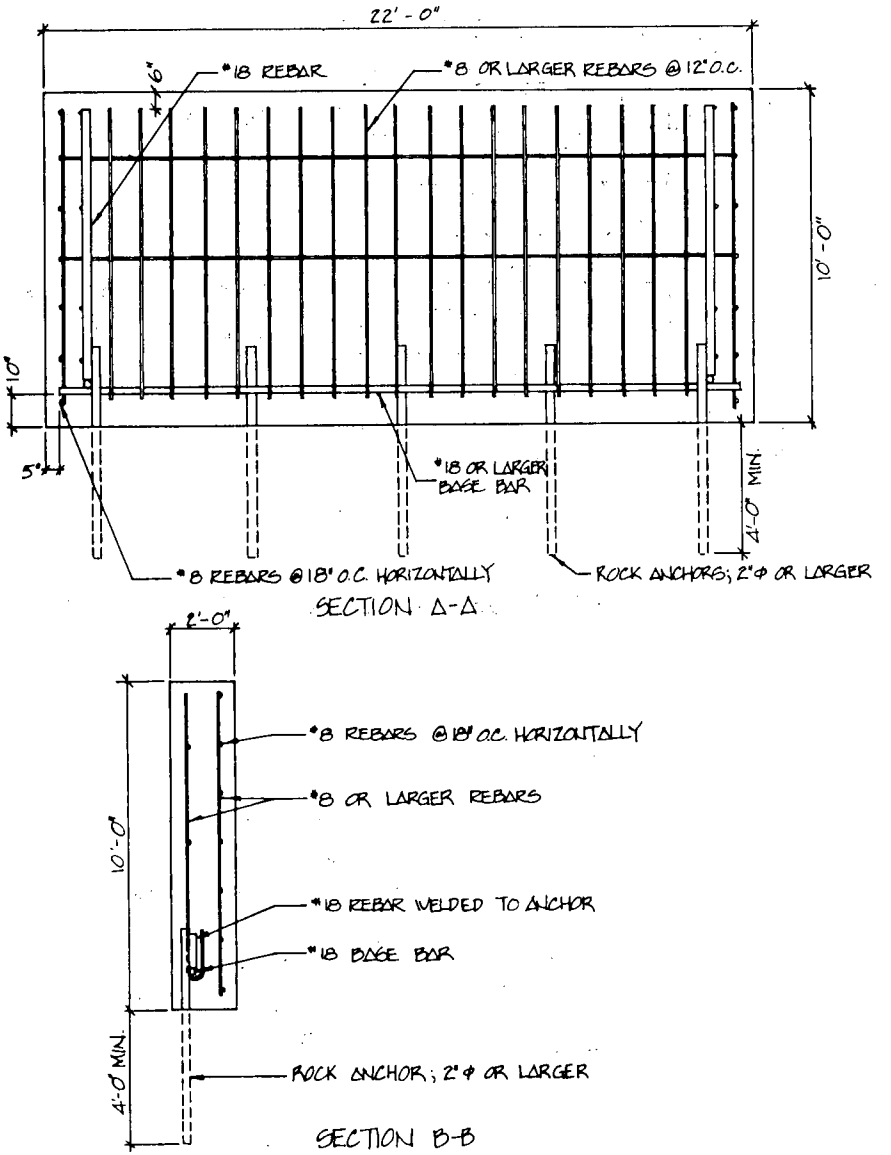


FIGURE 95. Design 1 Section A-A and B-B

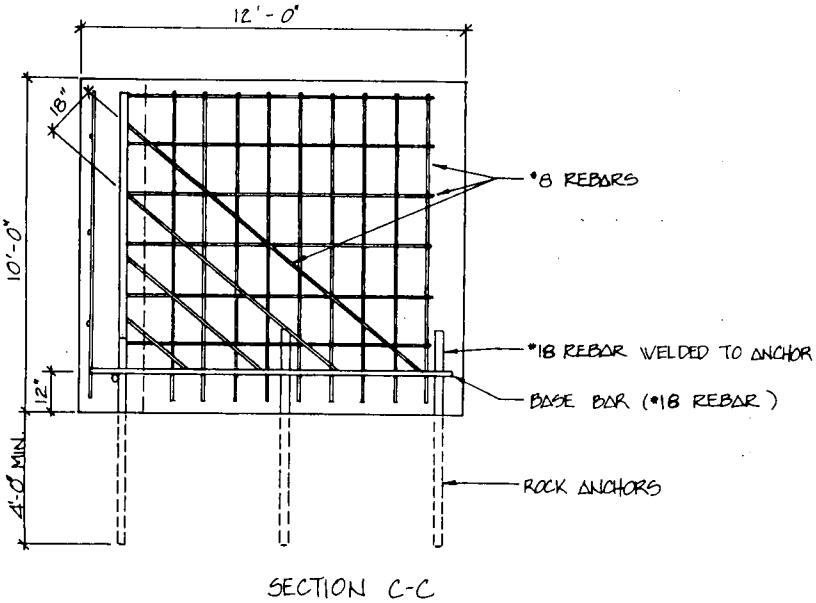


FIGURE 96. Design 1 Section C-C

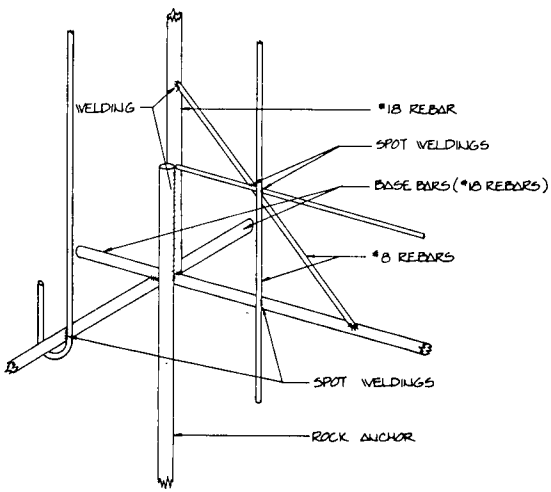


FIGURE 97. Design 1 hooked rebar connections

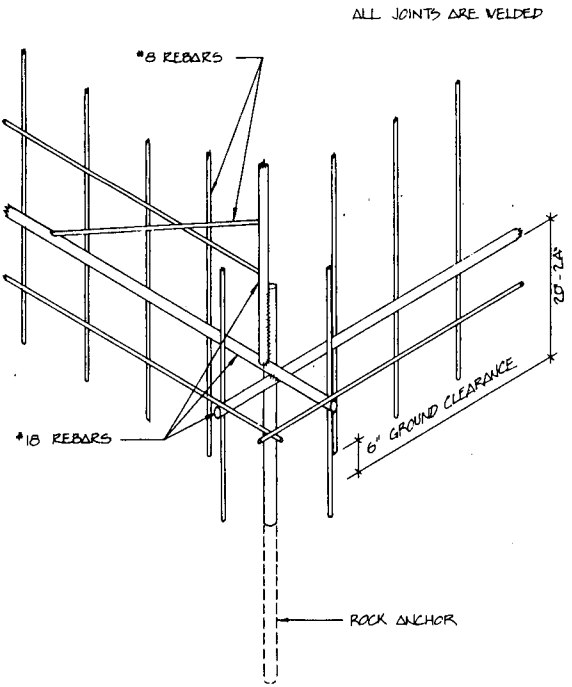


FIGURE 98. Design 1 welded rebar connections

Design 2

This design is similar in appearance to the first except that the wall thickness is 30 in. (Figures 99, 100, 101, 102). Design 2 will withstand greater earth pressures and coarser fill material. It can serve as a foundation for a low log crib and may be built on weathered fractured rock, or on a concrete slab.

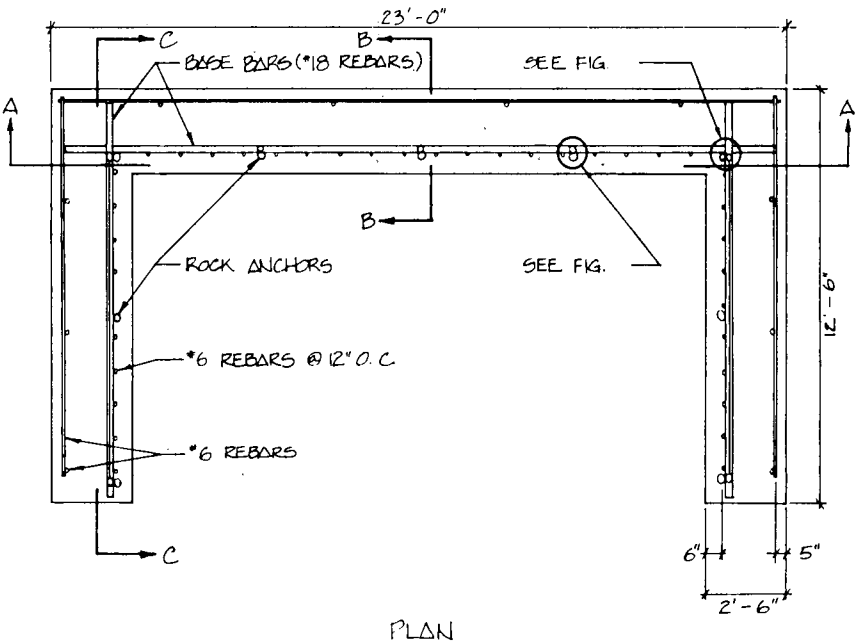
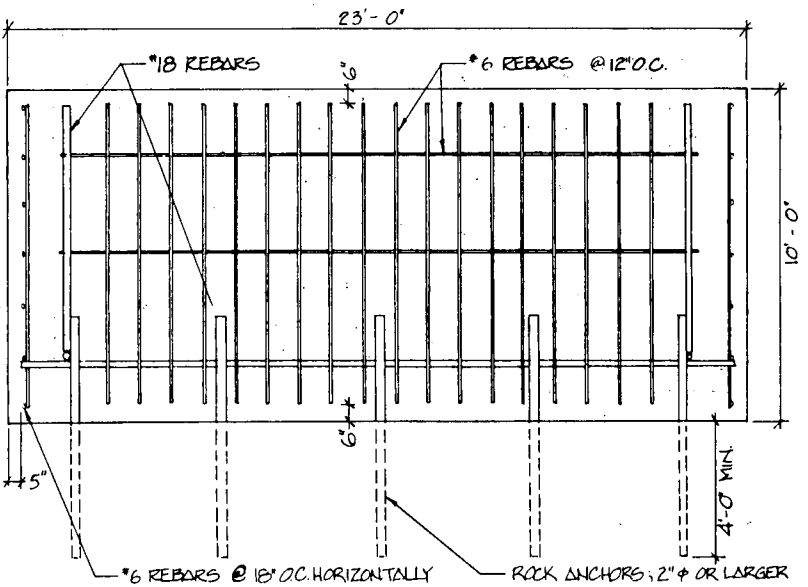
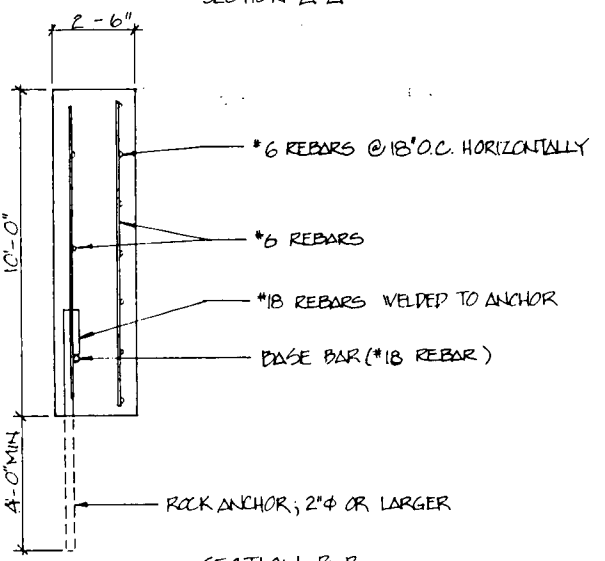


FIGURE 99. Design 2 Plan

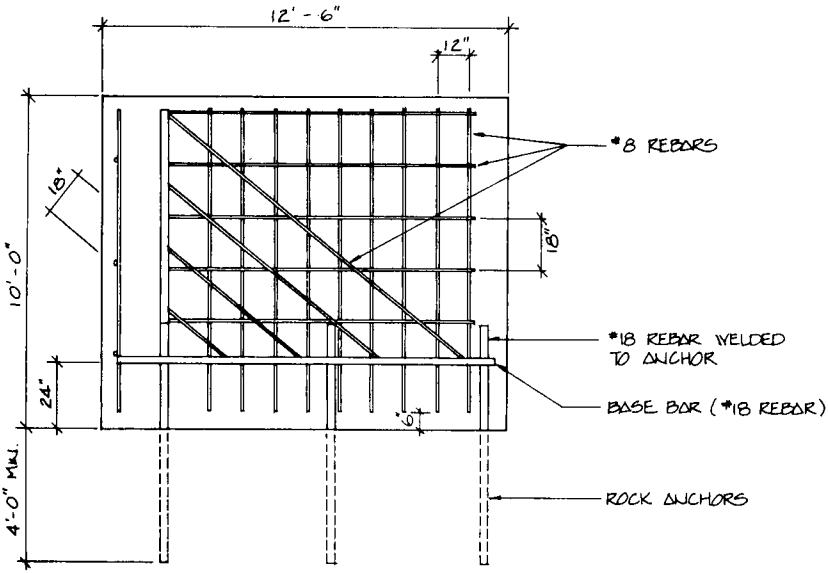


SECTION A-A



SECTION B-B

FIGURE 100. Design 2 Section A-A and B-B



SECTION C-C

FIGURE 101. Design 2 Section C-C

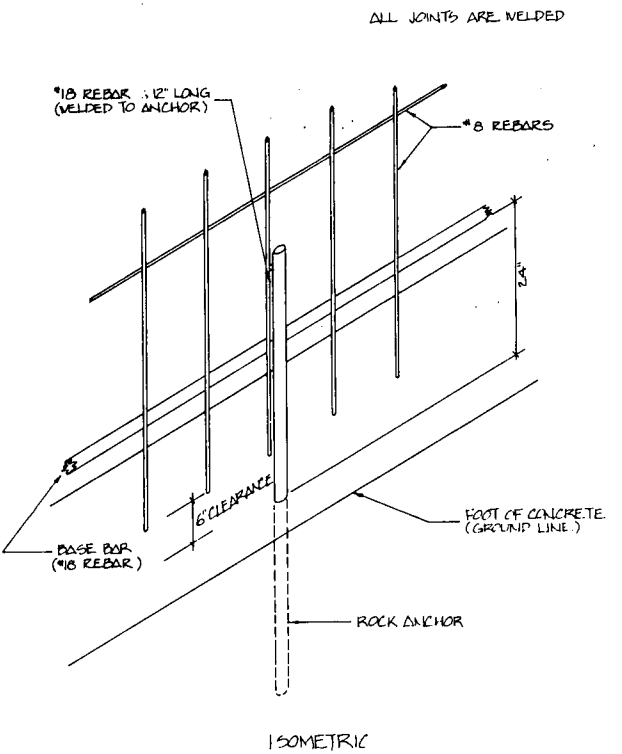


FIGURE 102. Design 2 welded rebar connections

Design 3

Design 3 is a low-cost foundation for a low log crib or a low abutment. It should be built on good rock foundation. Maximum height of the concrete work is five ft (Figure 103). Join reinforcing bars by welding or hooking.

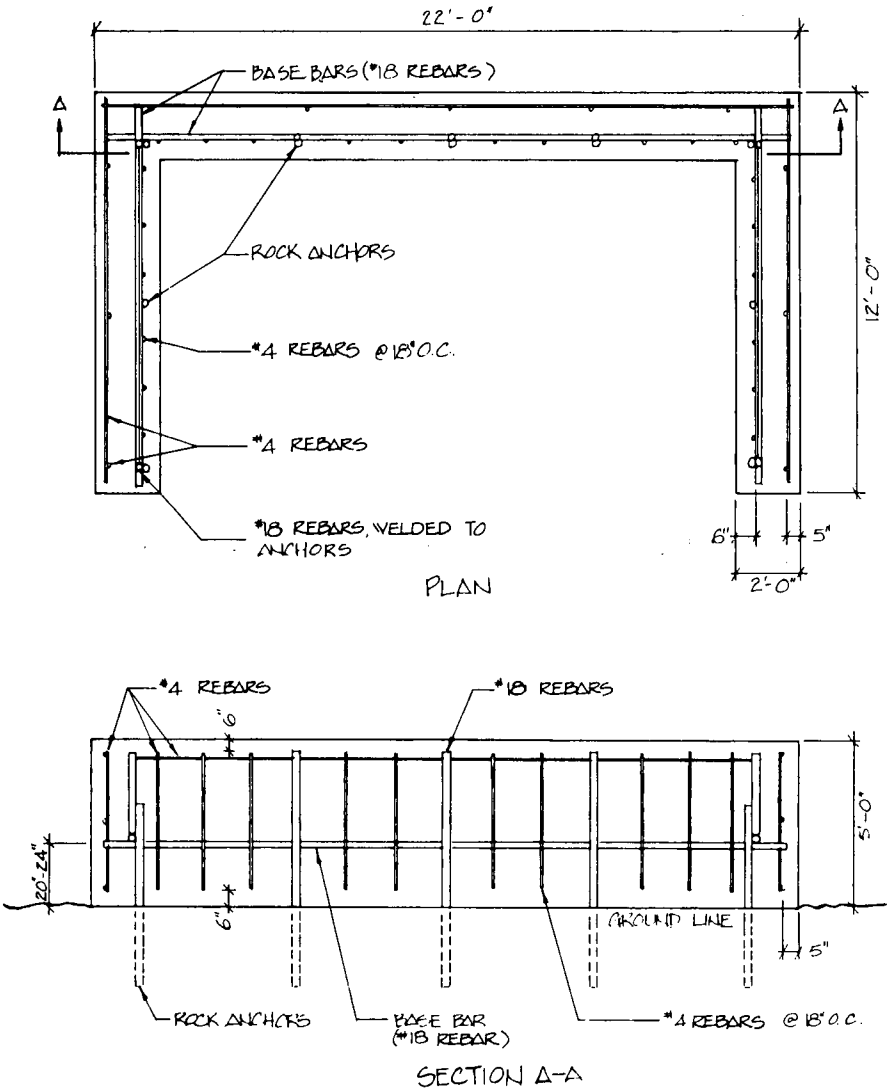


FIGURE 103. Design 3

Design 4

Design 4 has a counterfort (Figures 104 and 105). It has a wall thickness of 24 in. and a height of 10 feet. This abutment will withstand large earth pressures and is recommended if there is a chance of settlement. It may be constructed on rock or hard ground. On softer ground, the structure needs a concrete slab foundation.

g) Forms

A 10-foot-high column of fresh concrete can exert a fluid pressure of more than 10 psi on the form. Use lumber heavy enough to withstand these pressures and tie the form with bolts or tie rods.

Most concrete is poured continuously and the speed of the pour establishes the design of the form. If the job is large and the pour-ratio fast, then formwork must be massive.

Many different types of forms may be used. It may be advisable to rent the formwork to save the expense of forms built for one job only.

Here we describe a formwork up to 10-ft high which can be built locally (Figure 106). This form is made of 3/4-in. (or heavier) construction-grade plywood sanded on one side and supported by stiff members running in two directions, vertical and horizontal. The upright will usually be 2x4 lumber on 16-in. centres, and double 2x6 wales will be placed horizontally as often as necessary (Figure 107). Space these closer at the base to withstand the pressure.

Only construction-grade (or better) dressed lumber should be used. Lumber should be straight and free of twist or warp. Uprights (2x4) should not be spliced but should run to the full height of the form.

The forms are held together by steel rods or wires with end ties, wedges, or some other device (Figures 108 and 109). These internal ties should be tightened to straighten out the form and to eliminate the slack in the ties. High-tensile steel ties cannot be welded, heated or bent without losing strength. With the exception of wire ties, bending should be avoided and bent ties should be discarded.

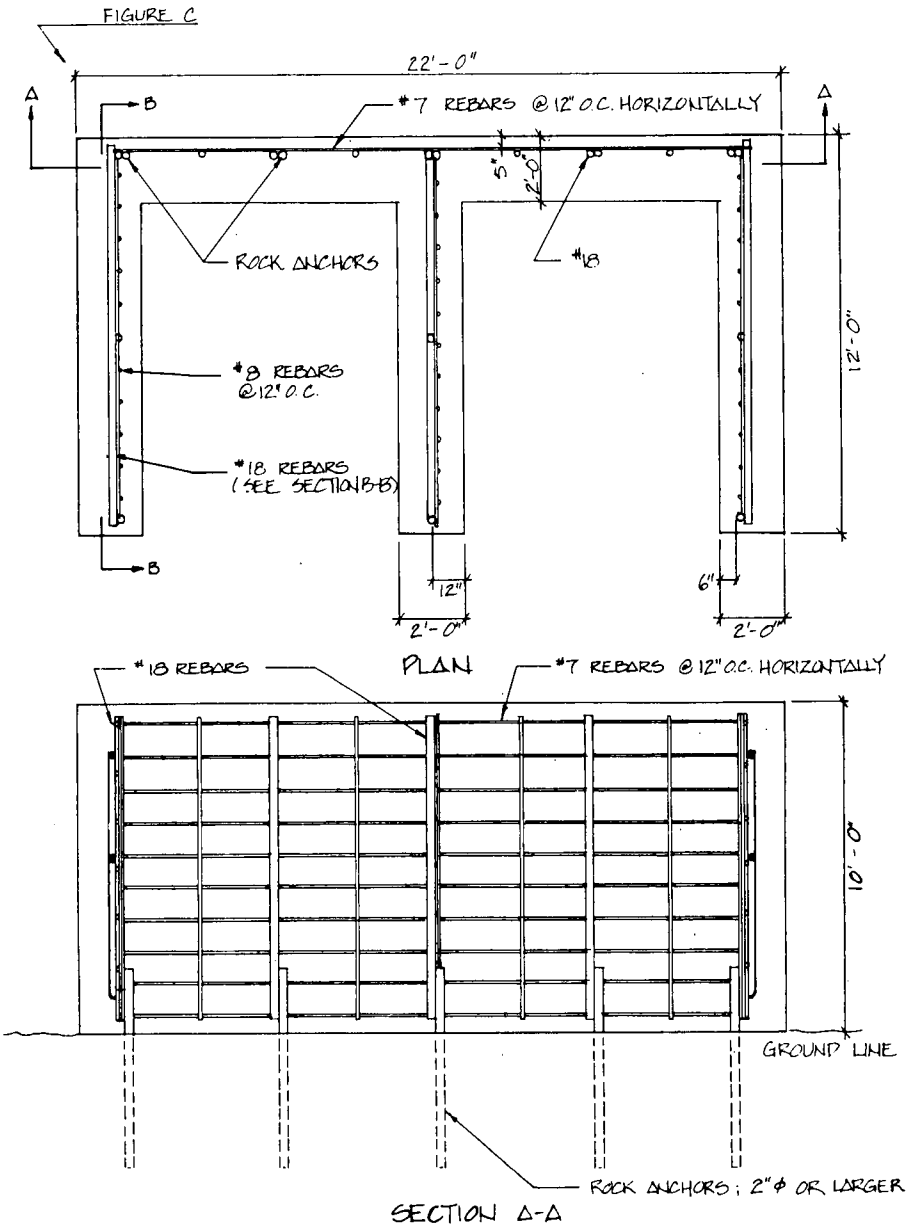
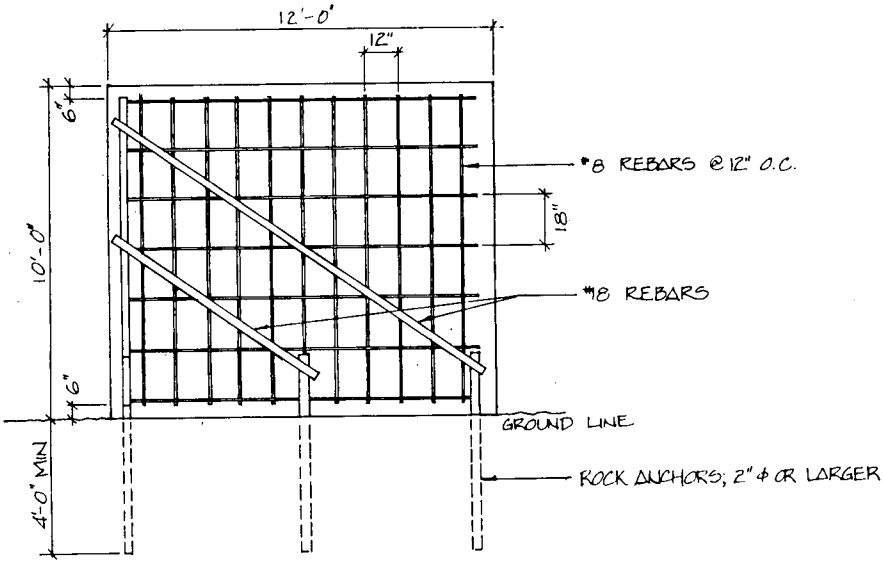


FIGURE 104. Design 4 Plan and Section A-A



SECTION B-B

FIGURE 105. Design 4 Section B-B

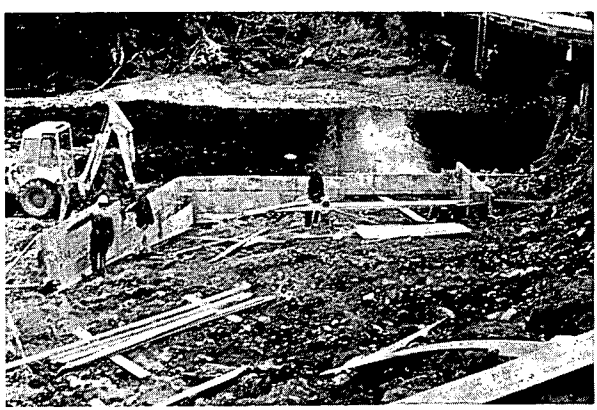


FIGURE 106. Form construction

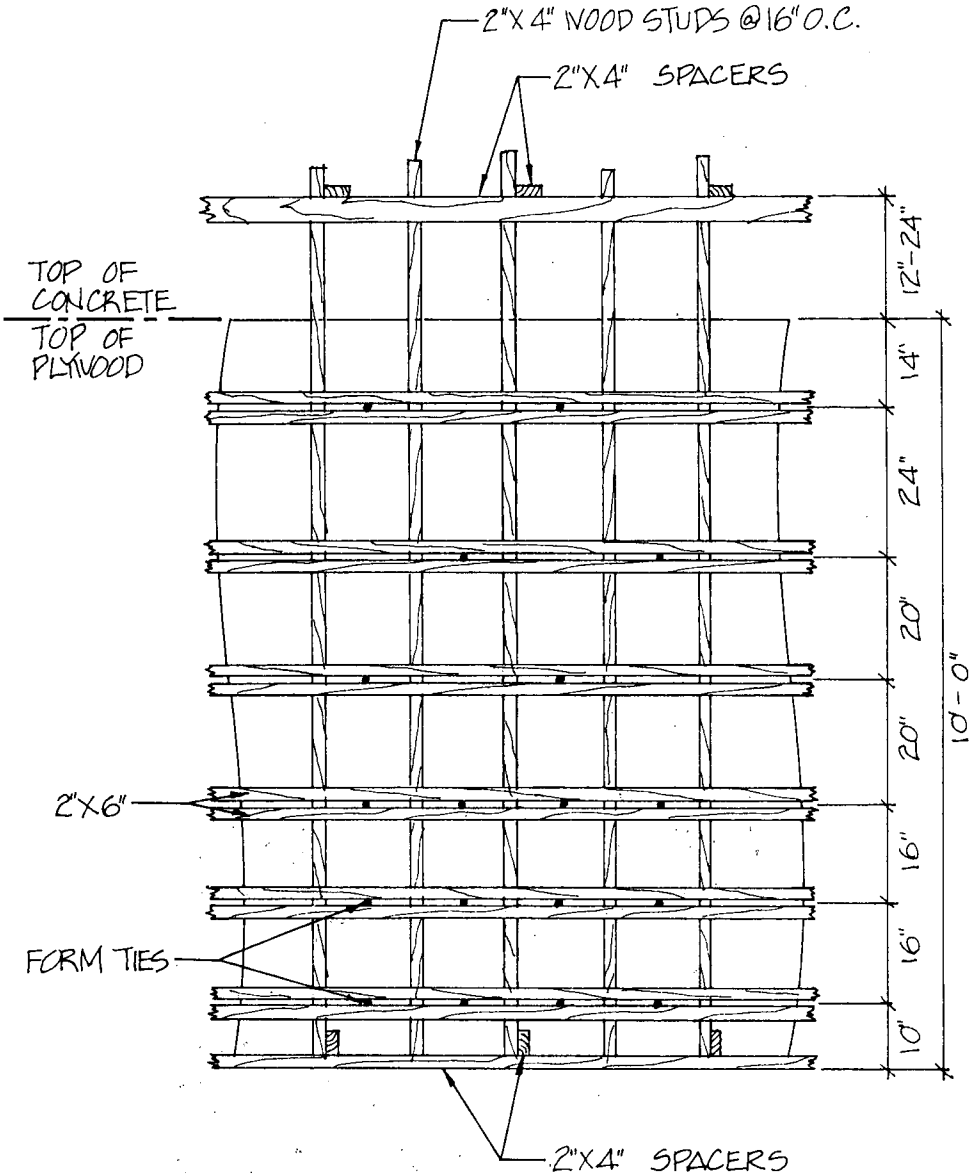
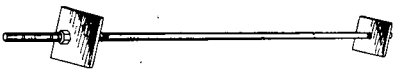
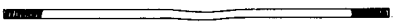


FIGURE 107. Concrete form

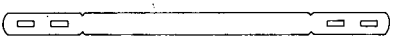
BUTTON HEADTIE
AND WEDGE



TAPERED ROD

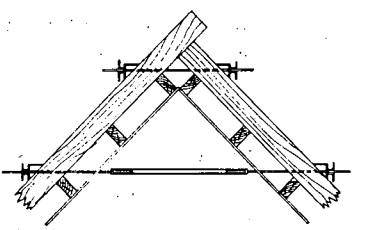


PIGTAIL



FLAT BAR TIE
AND WEDGE

SHE-BOLT AND THREADED ROD
WASHER AND WINGNUT



CONTINUOUS THREADED ROD,
COIL TIES, WASHER AND LAG NUT.

FIGURE 108. Concrete form fasteners

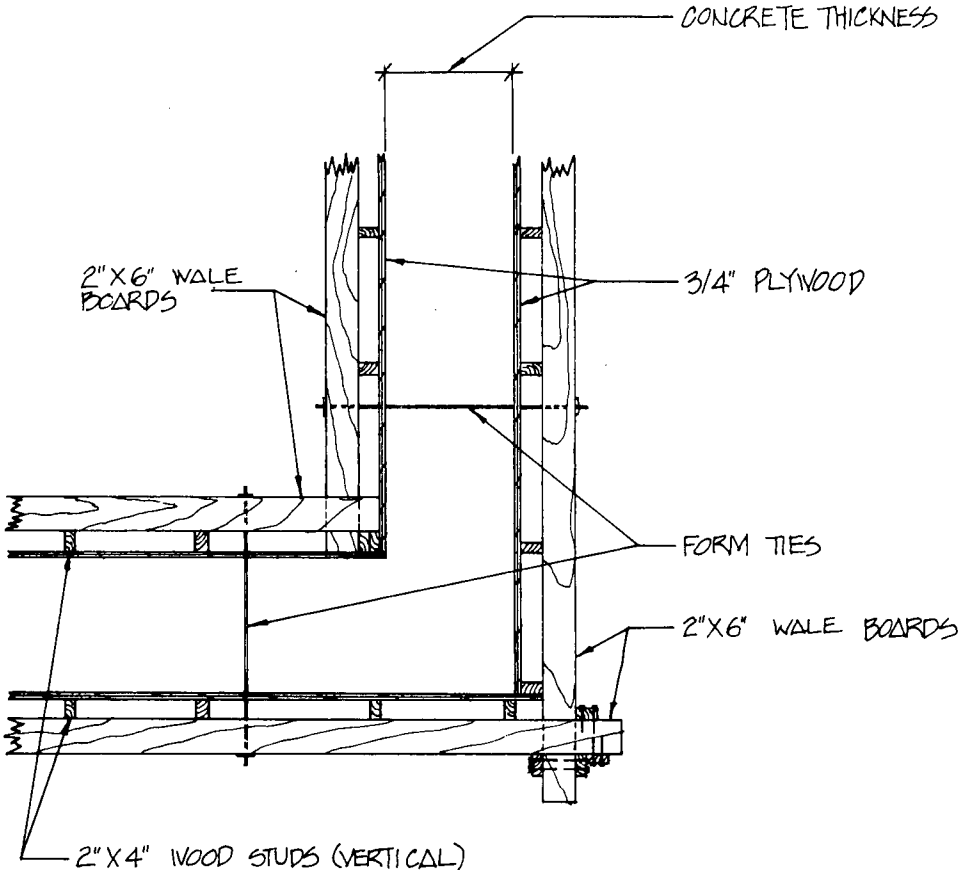


FIGURE 109. Form fasteners at corners

Spacers (spreaders) may be metal or wood. Use 2x4 pieces inside the bottom of the forms and nailed on the top. Avoid leaving wood spreaders in the concrete itself (other than at the bottom). If wood spreaders are used all the way through the forms, they should be removed one by one as the concrete level reaches them.

The foot of the form should follow the contours of the ground. Cut the lower end of the form to fit the ground approximately. Larger holes can be plugged by putting slightly larger clean stones inside the hole, or by nailing small pieces of lumber against the plywood outside and shoring them to prevent movement. (You can place gravel around the edge of the foundation from outside to prevent the concrete from running out the small holes.)

Place drainage pipes on the bottom of the form.

Place plywood vertically in the form and join it to a 2x4 upright. The lumber may be doubled at the joints using 3 1/2-in. nails, 6 in. on centre. The top two feet of the form may be leftover plywood pieces or a full sheet ripped in half and placed horizontally in the form. Nail lumber outside the seams to prevent the plywood from buckling.

Nail the plywood to the uprights, using common nails not smaller than 2 1/2 in. at 12-in. spacing (or closer) along the intermediate supports.

The steel internal ties should be no smaller than 5/8-in. diameter for the first 2.5 feet from the ground, and 7/16-in. diameter for the ties above 2.5 feet. If the space between these horizontal ties is less than 24 in. the tie sizes may be reduced to 7/16-in diameter.

2x4 lumber-spacers may be used to hold the forms in position (Figure 107). There must be enough room under the top spacers for the finishing work.

The top of the plywood in the form serves as a guide for finishing the abutment top and it should be levelled and positioned accordingly. If positioning the form is difficult, a rim made of 1-in. lumber or plywood may be nailed inside the form to serve as a pouring guide.

These strips may also support the template to hold the sill tiedown-bolts in position.

h) Shoring

Once the formwork is in the correct position, shore it up on both sides to prevent it from moving. Shoring is more important at the bottom of the forms than at the top. 2x4 or 2x6 shoring lumber is the easiest to use.

i) Preparation of formwork surfaces

Concrete sticks to untreated plywood and form-removal is difficult unless the inside surface is treated with oil or grease or other parting agents available from cement suppliers. Take care to keep the reinforcing steel clean. Remove any parting agent that spills on the steel. If no oil, grease, or parting agent is available, soak the forms with water at the time of pouring.

j) Final alignment of forms

Check the formwork just before the pouring begins to correct any misalignment. Forms must also be checked after pouring. Forms may move or bulge from the weight of the concrete and any movement must be corrected immediately.

k) Mixing concrete

The best concrete is bought from a mixing plant where the mixing is under strict control. If plant concrete is not available, use a mixer large enough for the job.

Store concrete and aggregate near the site in a clean place which is covered to prevent contamination. Use large heavy-duty buckets to load the mixer and measure the cement, aggregates and water. Plan to have enough men to complete the job in a continuous pour.

It is difficult to determine the exact water content of the aggregate when mixing concrete on site. The following method gives an approximation of the required proportions.

- Pre-mix enough dry sand (40%) and gravel for a trial batch.
- Put water in the empty mixer to the required water/cement ratio (0.45 to 0.5). If you suspect that the aggregates are not completely dry, use a 0.4 water/cement ratio.
- Start up the mixer and put in three-quarters of the required aggregates.
- Put the cement into the mixer and mix for the required time.
- Keep adding measured amounts of aggregate mixture until you have a concrete paste with the required consistency.

Good concrete is a wet paste easily worked by hand, but dry enough so a handful placed on a flat surface will not crumble. A slump-measuring tool is helpful to check the consistency of the concrete. The tester is a truncated metal cone with a height of 12 inches. The top diameter is 4 in., the base 8 inches. The tool is placed on a flat surface filled up with concrete. The paste is compacted and the top is smoothed down. The tool is carefully lifted and the height of the concrete drops. The height difference between the

cone and the concrete is measured at once. The difference in inches is called the 'slump.' The slump should be from 1 in. to 3 inches.

Once the required consistency is achieved, use the measured aggregate volume for all batches of concrete. The next trial batch will define the required volume of water.

- Empty the concrete mixer. Put in two-thirds of the water required for a 0.5 water/cement ratio. The mixer must be running continuously during the mixing period.

- Put in the aggregate as-is (the amount decided during the first test).

- Put in the cement and mix it for the required time.

- Add water little by little (and measure it) until the required consistency is achieved.

The volume of water used for mixing this trial batch is the amount that will be used for mixing the concrete. During concrete placement, the moisture content of the aggregate may change and it will be necessary to increase or decrease the amount of water. If admixtures are used, pre-mix them in a large clean container of water.

1 bag of cement = 40 kg (88 lb) = 26.57 L (5.84 gal).

Materials to make approximately 1 yd^3 or 1 m^3 of concrete with a 3500 psi compressive strength are shown in Table IV-I.

Normal concrete fresh unit weight is between 135 to 155 lb/ft^3. Multiply the required volume by 1.5 for a rough estimate when you calculate the required aggregate. The volume shrinks around one-third when mixed.

Minimum Mixing Time for Portable Mixers

1 yd^3 mixers	1 min
for every additional yd^3 or part thereof	additional 15 sec
1 m^3 mixers	1 min 20 sec
for every additional m^3 or part thereof	additional 20 sec

TABLE IV-I. Material List for Concrete

Material	Imperial Units		SI (Metric) Units		Volumetric ratio
	Weight	Volume	Weight	Volume	
Cement	600 lb	6.4 ft^3	356 kg	0.237 m^3	1.00
Sand		13.5 ft^3		0.500 m^3	2.11
Gravel		18 ft^3		0.667 m^3	2.81
Water	300 lb	29.9 gal	178 kg	178 L	0.75
admixtures					
2%	96 oz	2.4 qt		3.56 L	
1.5%	72 oz	1.8 qt		2.67 L	
Total Volume		1 yd^3		1 m^3	

l) Placing

Concrete pumps are most efficient for placing concrete in forms but may not be practical for bridge building. If possible the mix truck should dump directly into the forms. Wheelbarrows, buckets, and chutes may be used to transport concrete. Chutes should not be steeper than 1:2. Wheelbarrow ramps should be smooth and secure. Concrete should not be dropped more than 10 feet (2.5 m) to prevent separation of the aggregate.

Start at one end of the form and continue to the other so the pour is continuous. The concrete layer must be less than 2 feet deep or thin enough so that the next layer can be applied in less than 20 minutes.

It is possible to pour concrete under water but this is a special technique which requires experience. Readers are cautioned to get additional advice before undertaking this type of pour.

m) Compaction

Concrete does not flow well and compaction is necessary to remove air pockets, to get the concrete between the reinforcing, and to fill out the forms.

Use an immersion-type spud vibrator 2 in. (or larger) with a frequency of over 4500 impulses-per-minute. Let the vibrator sink by gravity into the concrete to penetrate the previous layer of concrete by one inch. Vibrate

for 5 to 15 seconds as bubbles are being released and until a fine paste with a sheen appears. Do not over-vibrate the concrete and cause bleeding. If bleeding occurs, bleed water must be removed before finishing or placing the next layer of concrete.

Remove the vibrator as gradually as it went down, immersing it at 1-ft intervals.

Use vibrating screeds to compact concrete slabs. Do not work layers heavier than 12 in. with the screeds. If vibrators are not available, use steel rods or even a 2x4 to compact the concrete. Steel rods and 2x4's do an inferior job compared to vibrators and should not be used on large jobs.

Regardless of the tools or equipment used for compacting, it is easier to work a thin layer (about 1 ft) than a thick one. Pouring thin layers and working the concrete in around the rebars and forms may be laborious, but tamping is essential for a strong and smoothly finished structure.

n) Finishing the top

Fine finishing is not required for an abutment or pier. The top should be flat and reasonably smooth to provide a good foundation for the sill or crib log. The top may be slanted slightly (not more than 1°) so water will run off.

Any required bolts should be spotted in the form and set in place in the concrete. (Holes can be drilled and the bolts grouted in the concrete later, but it is much easier to set them in the fresh concrete.) Bolts must be plumb. It is extremely difficult to set a drilled cap onto two or more bolts embedded in concrete if the bolts are not in alignment. Set a template of wood on the fresh and finished concrete with the bolts in it. (Concrete must be tightly placed around the bolts.) Leave the template in place until the concrete is hard.

o) Curing concrete

Concrete made with Normal portland cement develops its design strength in 28 days. The concrete should be cured for 3 days to 2 weeks depending on the type of concrete (Fast, Normal) and the temperature.

Curing concrete requires careful control. Keep the temperature around $21^{o}C$. Keep the surface damp. The most critical curing period is the first two or

three days. Concrete can be kept wet by covering it with a moist absorbent fabric (cotton); by using a curing compound to prevent water evaporation—or by covering the surface with a plastic sheet or waterproof paper. In hot weather the temperature can be kept down by watering the cover. Watering may also be necessary to keep the cover wet when using a moist absorbent fabric.

The minimum temperature of the concrete when it is placed should not be less than 10°C and it must not drop below 5°C. If the weather is cold after you finish placing the concrete, keep the heat in for the curing period by covering the concrete with insulation blankets. If the temperature drops to 0°C, the concrete should be continuously heated. Cover it with tarpaulins or large plastic sheets and use a heater. Circulate the air to prevent carbon monoxide buildup which could damage the concrete. In cold weather the forms should be left on the concrete during the full curing period (2 weeks or more).

D. PIERS

A pier is the independent midsupport of a bridge used when stringer material for a single unsupported span is not available or is too expensive to span the total distance between the abutments. Piers cause constriction of the stream and increase scour action unless they are built on a natural rise or island. They are vulnerable to damage from floating trees, ice and other debris. During an unusually high flood it may be impossible to determine the condition of a pier and it may be necessary to close the bridge until the water subsides and permits inspection.

Examine the alternatives before making a final decision to build a pier. An unsupported superstructure with trussing may be long enough to eliminate the need for a pier.

The following section describes four types of piers.

1. Pile piers or pile-bent piers

2. Post-bent or frame-bent piers

3. Log crib piers

4. Concrete piers

1. Pile-Bent Piers

Pile selection, preparation, driving, pile-bent types and construction techniques are discussed in the Pile Abutment section.

Pile-bent piers are used for bridge construction when ground conditions permit and the construction equipment is available. If the right type of pier is selected and aligned it will have little effect on water flow. Use single bents and open-end double-bent piers in fast-running water (Figure 110).

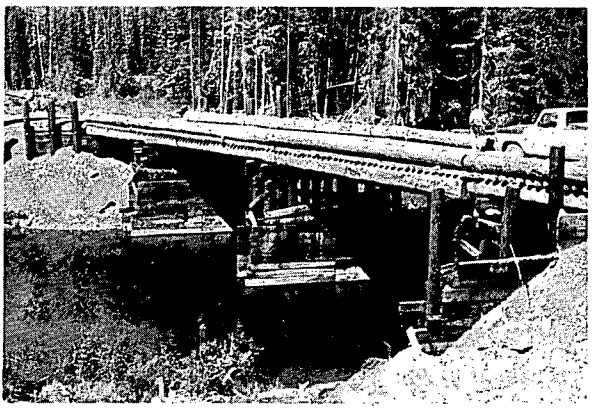


FIGURE 110. Pile-bent piers aligned with water flow

Pile-bent piers are the easiest to construct because the piles can be driven in reasonably deep water. (You may have to spot the piles from the shore and the men guiding the pile may have to work from a float and use a long boom crane for a pile driver.)

Piles must be driven at least six ft below scour depth. Estimate scour depth at low water-levels when all the holes can be seen. Probe the channel at a distance of not less than 100 ft upstream and downstream from the crossing. If the bottom cannot be seen clearly at the deepest hole, then the maximum depth will have to be estimated.

The pile piers listed in the following section are the most common.

- Single pile-bent piers

In the early days this was the main design used for logging railroad trestles and plank-road bridges (Figure 111).

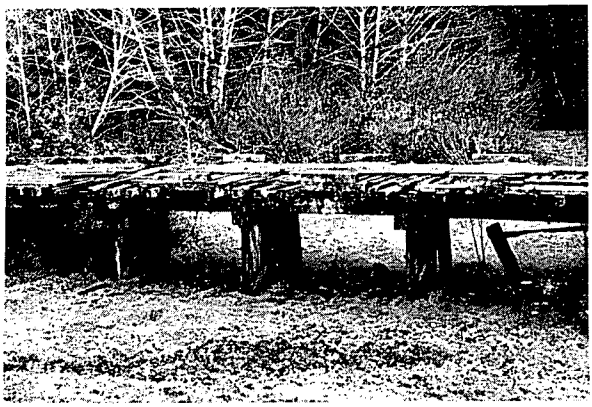


FIGURE 111. Single pile-bent piers

Single pile-bent piers are easy to use with sawn timber stringers. The ends of the stringers on the piers overlap (Figure 112). If enough long stringers are available to overlap two spans, you can place them on single pile-bent piers in herringbone fashion. This type of pier could be used to prop up long spans, but the long stringers must run the full length of the bridge. Log stringers cannot be butted over the single cap.

- Double-bent piers

This pier structure is made up of two single bents built next to each other and cross-braced at both ends (Figure 113). In a swift current, logs could jillpoke between the piles and damage the bents.

- Side-covered double-bent piers

Cover the double-bent piers on the side to prevent jillpoking by floating logs between the piles (Figure 114). Bracing is required if the cover is spiked to the piling but not if it is bolted.

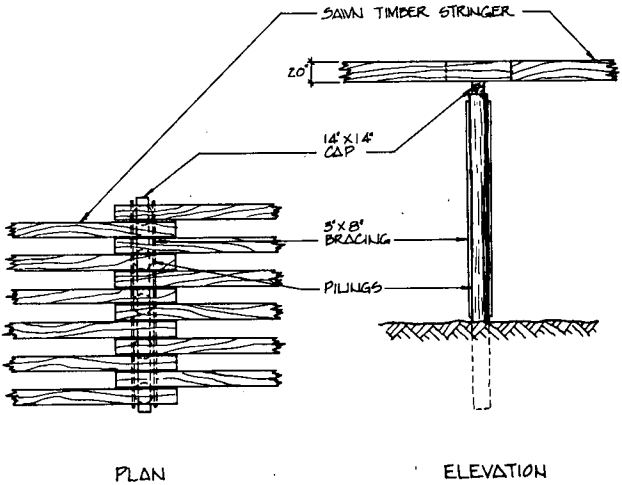


FIGURE 112. Overlapping sawn timber stringers on a single bent

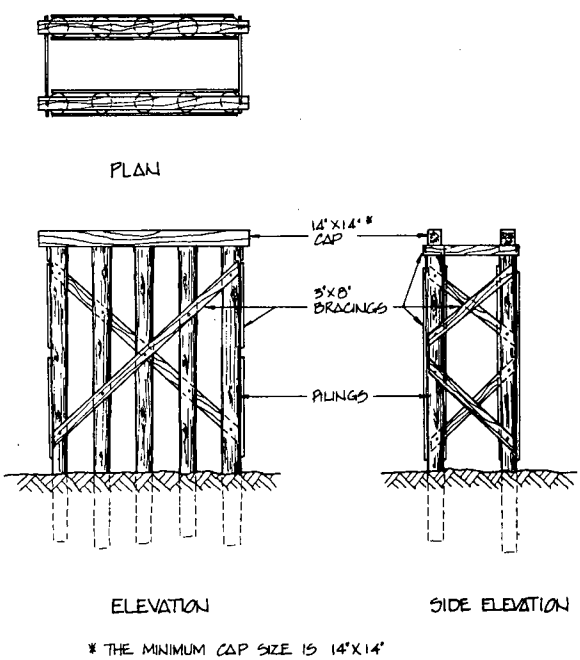


FIGURE 113. Double-bent piers

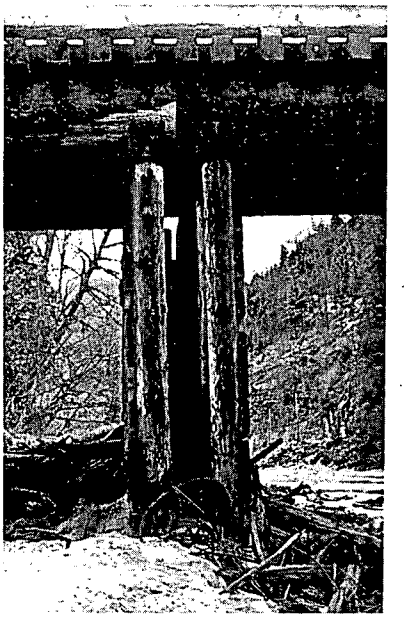


FIGURE 114. Side-covered double-bent pier

- Double-bent pier with short caps

If it is difficult to line up the pilings in the bents, it may be easier to use short caps to tie the opposing pairs of piles first and then rest the sills on top (Figure 115).

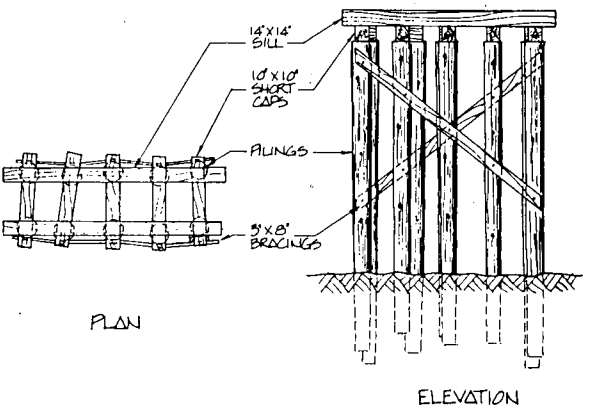


FIGURE 115. Double-bent pier with short caps

- Double-bent pier with a log spacer

You can line the piles in the bents by putting a large log or sawn-timber spacer between the bents at the top. If a log is used, flatten it to make uniform spacing between the piles. Bolt the piles tightly to the log (Figure 116).

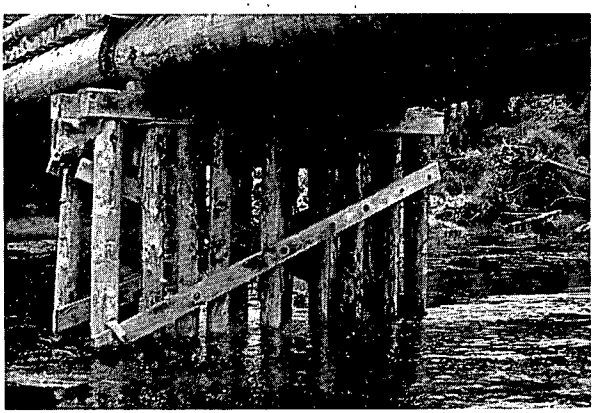


FIGURE 116. Double-bent pier with log spacer

The outside piles at both ends may be leaned (battered) to improve the rigidity of the pier (Figure 117). Common lean or 'batter' is 1 1/2 in. horizontal per vertical foot.

The spacer log must fill the space between the piles which is usually 2.5 to 3 feet (Figure 118). It is not necessary to use cross bracing on large piles 12 ft (or less) in height.

- Double-bent pier with a pile spacer

Use a pulled-over piling bolted between two closely driven pile-bents to strengthen a narrow pile pier (Figure 119).

Locate a large pile downstream and drive it between the two single bents a few feet into the ground so it can be leaned sideways without breaking. The pile is pulled down between the two rows of piling and tied to a fender piling driven at the upstream end of one of the rows.

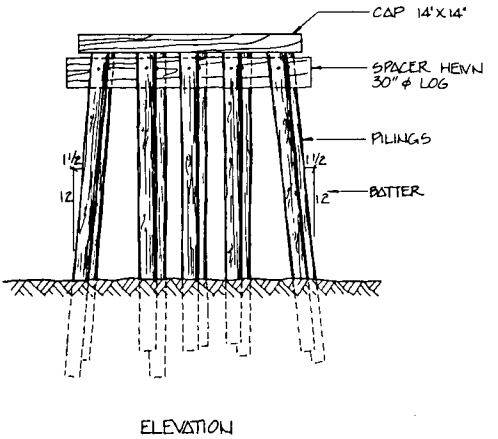


FIGURE 117. Double-bent pier details

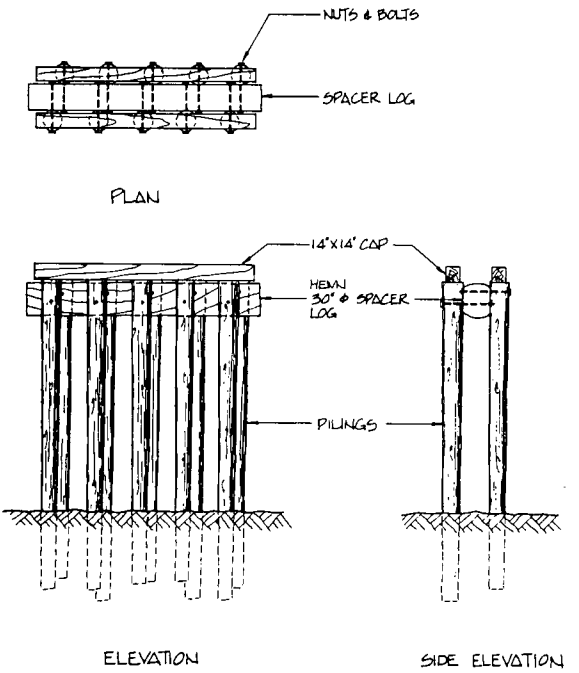


FIGURE 118. Double-bent pier with batter piles

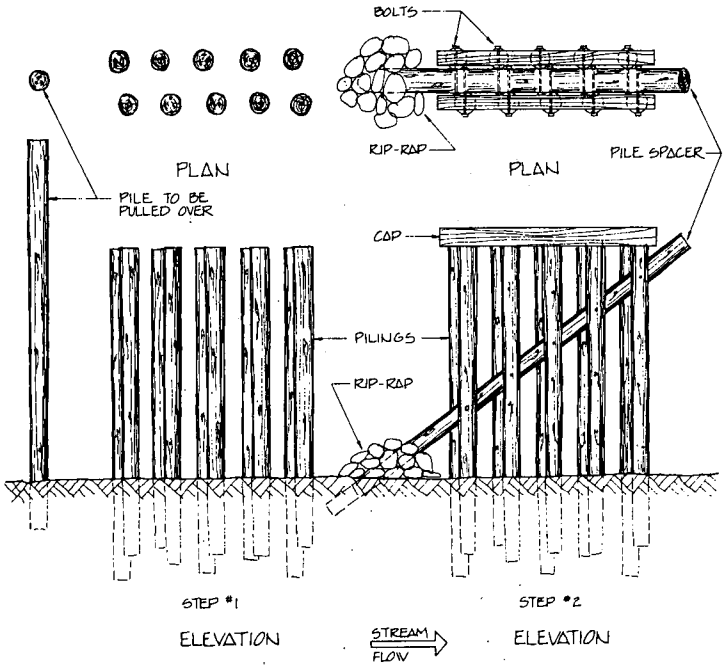


FIGURE 119. Double-bent piers with pile spacers

Bolt the leaning pile to each of the pilings in the bent, starting with the front pile closest to the fender pile. If the piles in both bents are aligned, then the two opposing piles can be bolted with a single long bolt.

The two bents must be driven close enough so the leaning pile can form a tight spacer. You may have to use short caps to position the sills. Plank the opening between the fender pile and the first pile in the opposite bent to prevent debris from jamming between the bents.

- Double-bent piers for different-sized stringers

One span of the bridge is often shorter than the other so the stringer sizes are different (Figure 120). Double-bent (multi-bent) piers can easily accommodate different stringer footings. Figure 121 shows a method for centering a sill so both bents share the load.

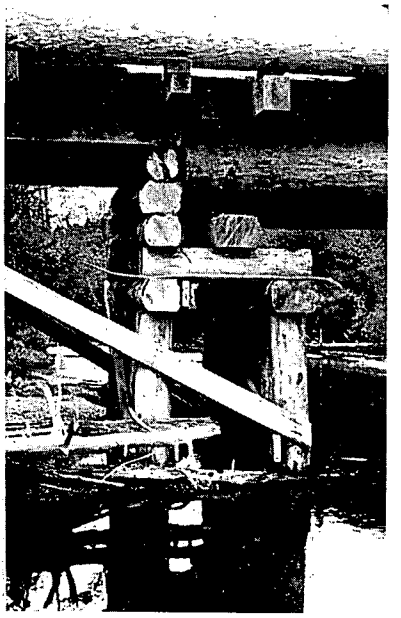


FIGURE 120. Double-bent pier with different-sized stringers

If stringers are different in size but loading on the two bents is adequate, one way of balancing them is to elevate one of the two caps (Figure 122).

Another way is shown in Figure 123. (We should point out, however, that this structure has many exposed surfaces where water can accumulate and lead to rot.)

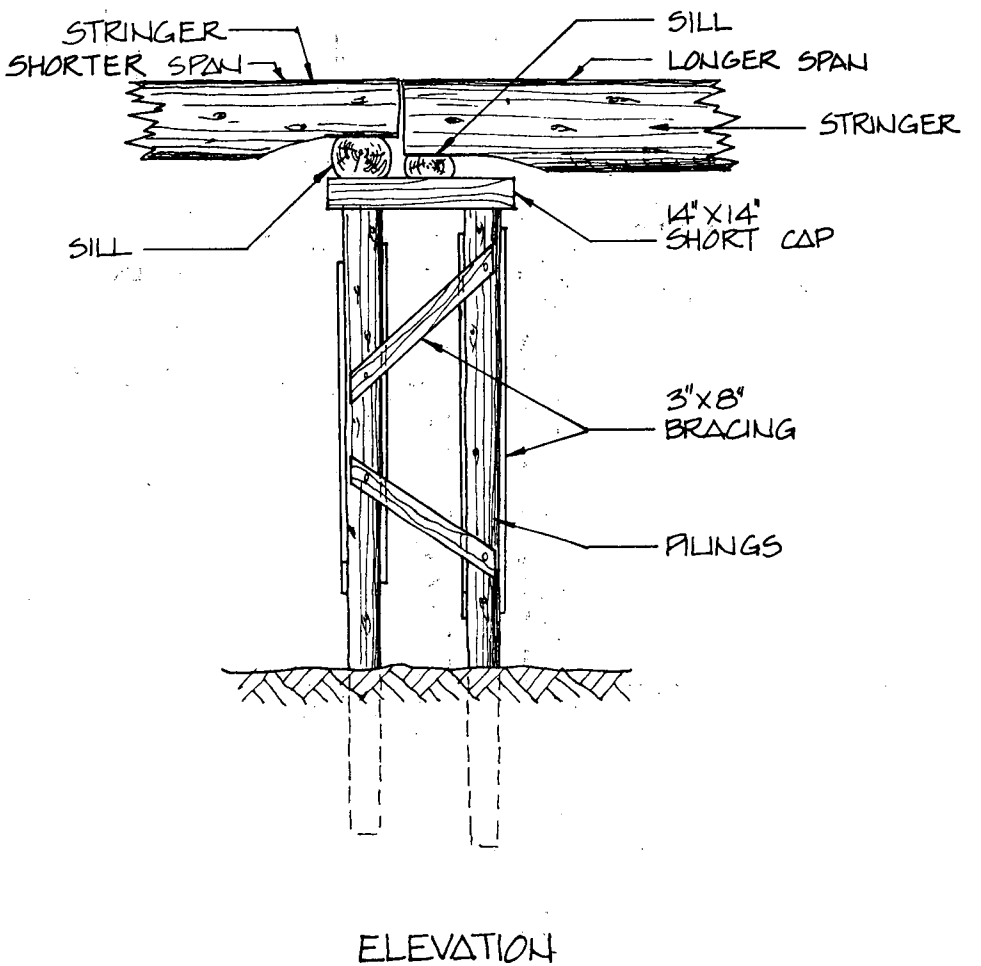


FIGURE 121. Centering the sill to share the load

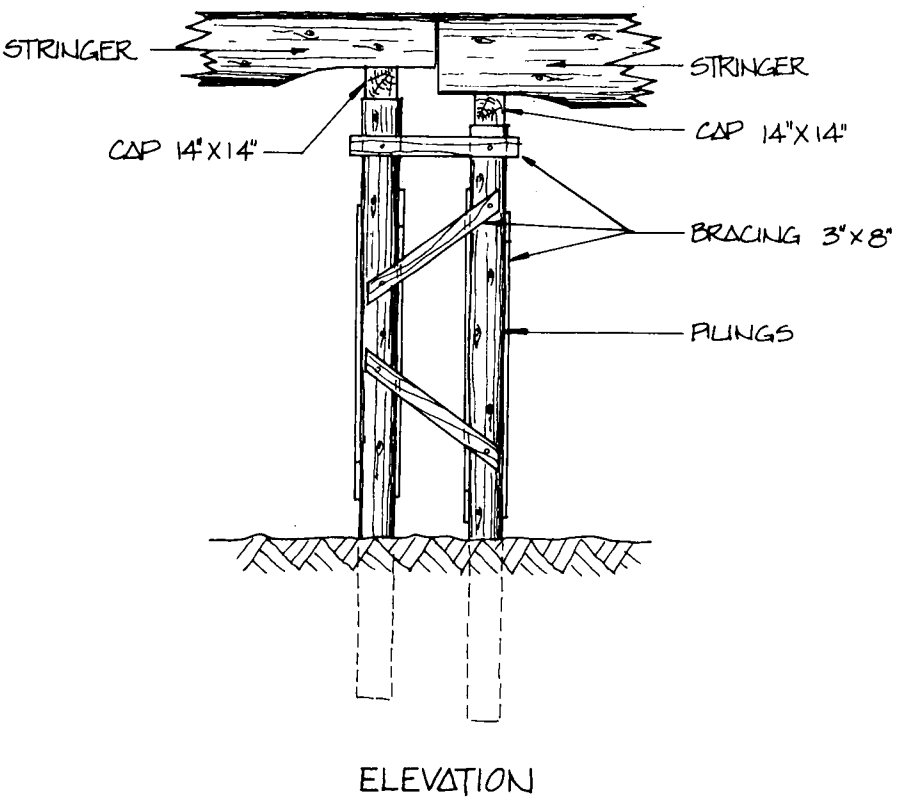


FIGURE 122. Double-bent to support different-size stringers

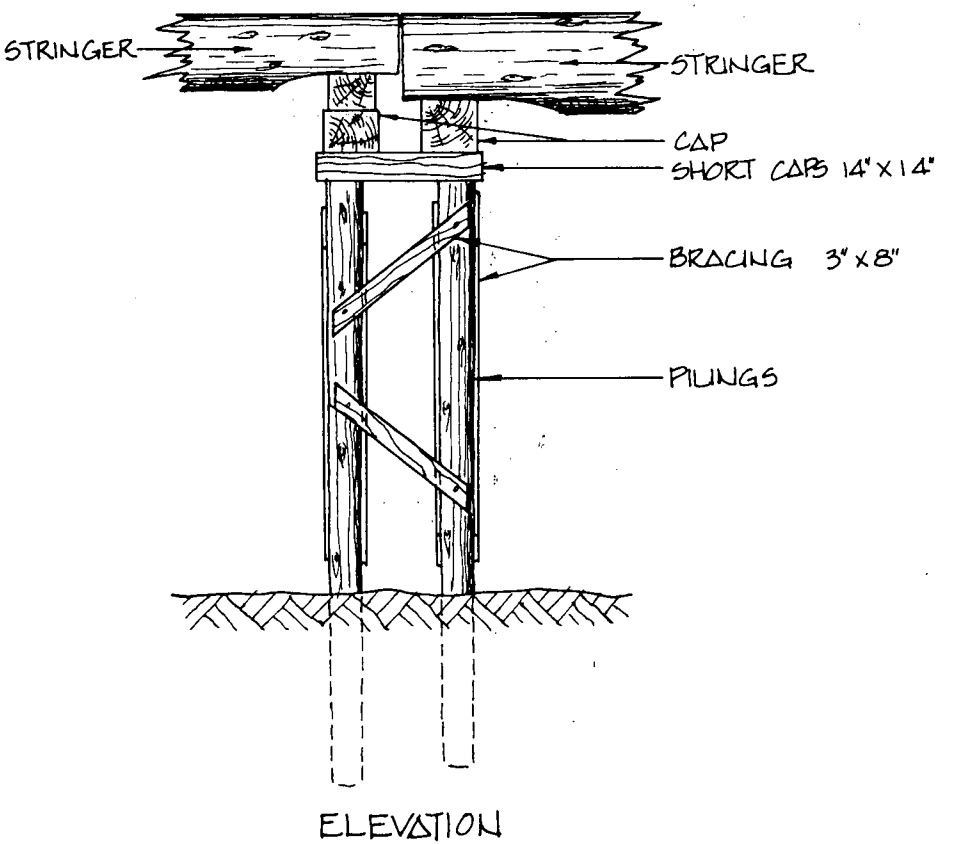


FIGURE 123. Small stringers supported by double caps

- Triple-bent pier

Three braced bents may be required to support the load (Figure 124). The two pile bents supporting the larger span should be close together. The weight is seldom distributed evenly on the cap due to the deflection of the stringers. The front row of piling may be overloaded and sink further into the ground. To solve this problem, use short caps and one sill over the two bents (Figure 125).

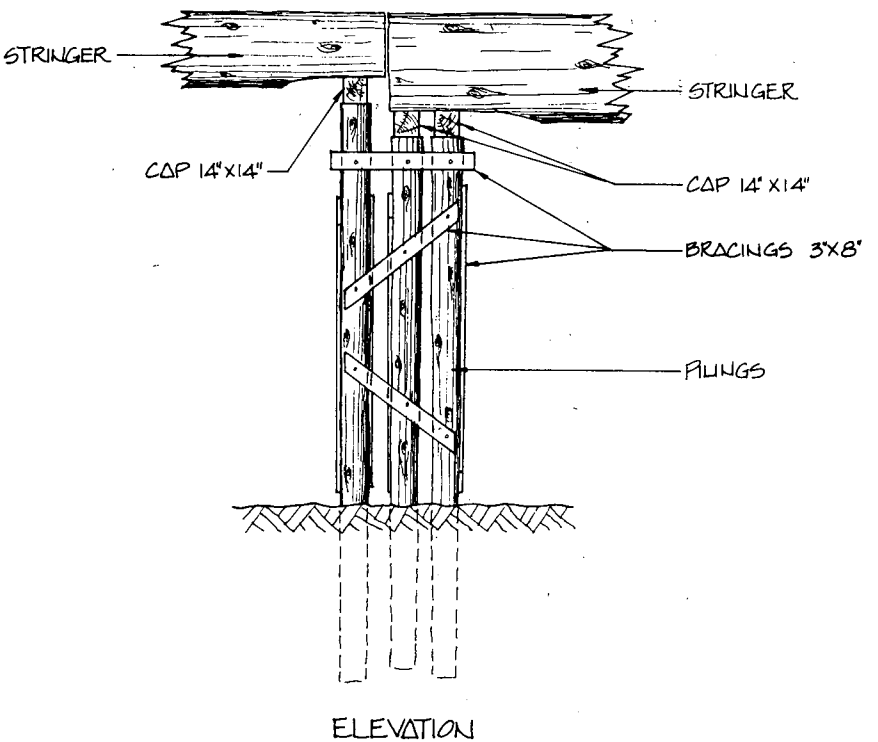


FIGURE 124. Triple-bent pier with long caps

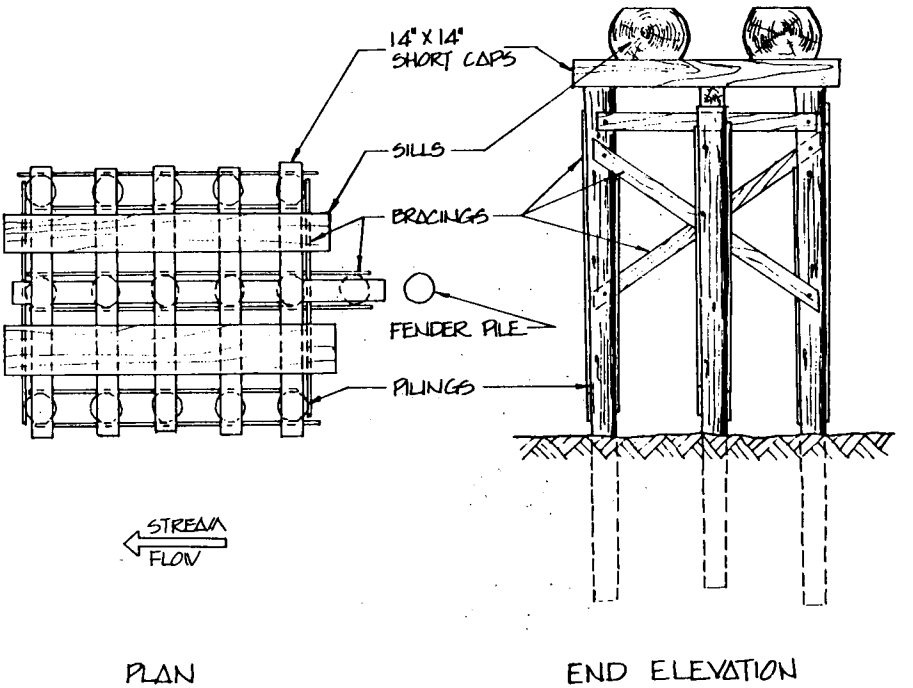


FIGURE 125. Triple-bent pier

- Multiple-bent pier

Piers with more than three bents may interfere with the water flow (Figure 126).

One of the most useful multiple-bent piers is shown in Figure 127. Drive paired rows of bents close to each other to minimize blocking of the stream channel. Bracing is required between the two tight rows of piling.

You can build this pier as two independent double piers (using short caps to span the two rows of piling) but to give it extra strength and more rigidity some or all of the short caps should span the full pier. (This structure is not recommended for fast-flowing streams.)

- Group-piling pier

Drive two rows of pilings tightly together to form a narrow pier (Figure 128). The pier needs cross-bracing on the outside only. Two caps may be

FIGURE 126. Wide multiple-bent pier

used to carry the stringers, but one large sill has the advantage of distributing the load and tying all the pilings together. If two long caps are used, tie the bents together with short caps.

If only small piling is available, drive it in small groups (Figure 129) or pair it (Figure 130), using long and short caps as in Figure 128, or using a larger sill. Protect this pier with a steel nose.

- Pile pier trestle

The pier trestle is a special structure used mainly to prop up old bridges and provide reinforcement to extend the life of stringers (Figure 131).

Usually a group of piles or one large pile is driven on each side of the bridge and capped with a large wood sill or a steel I-beam (Figure 132). The cap is placed under the stringer like a needlebeam to form the trestle.

Piling driven at both sides of the sill will prevent it from falling off the supporting piles. Drive a large pile or a dolphin in front of the pier for protection. Use blocking to minimize notching the stringers.

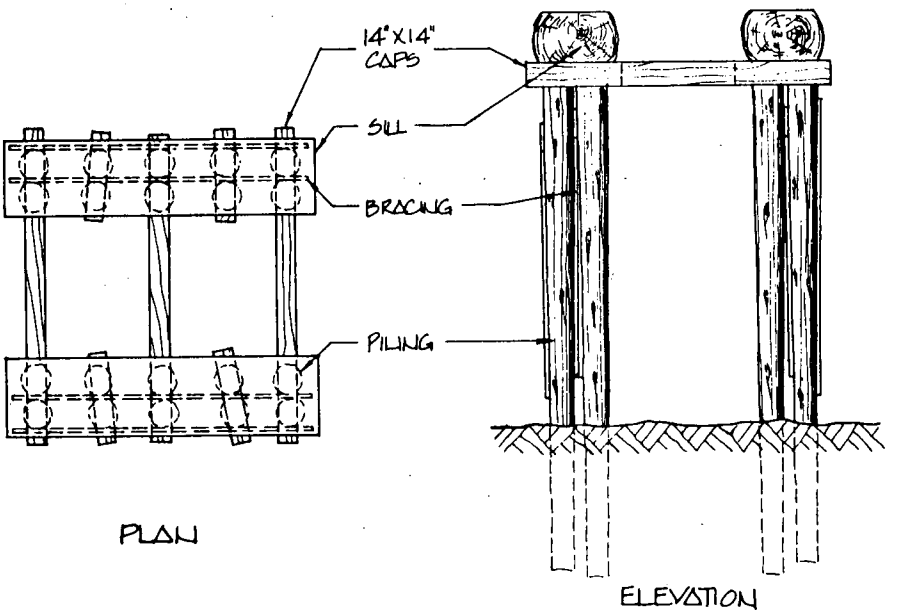


FIGURE 127. Multiple-bent pier

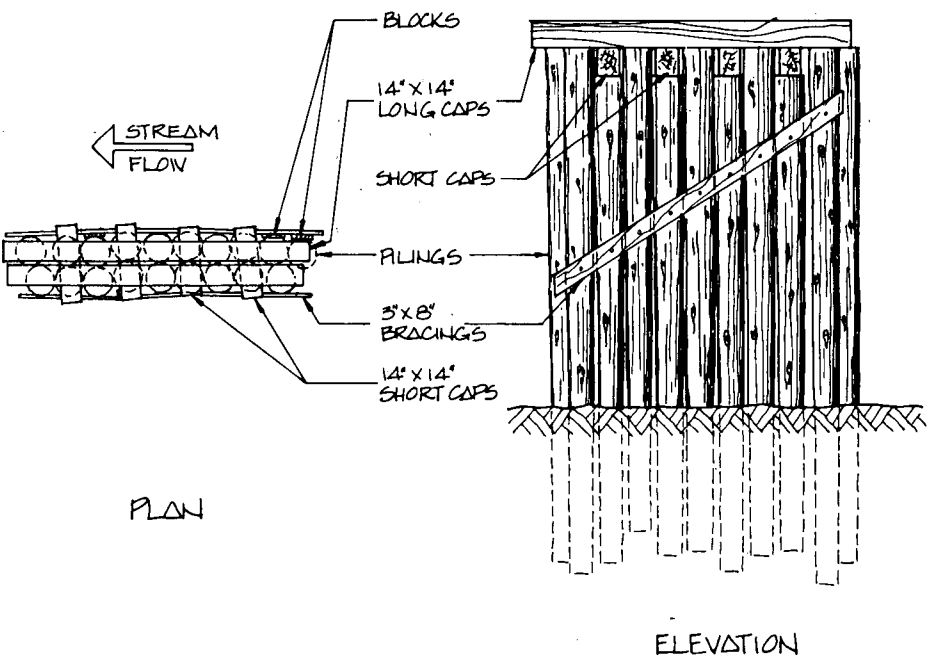


FIGURE 128. Group-pile pier using small piling

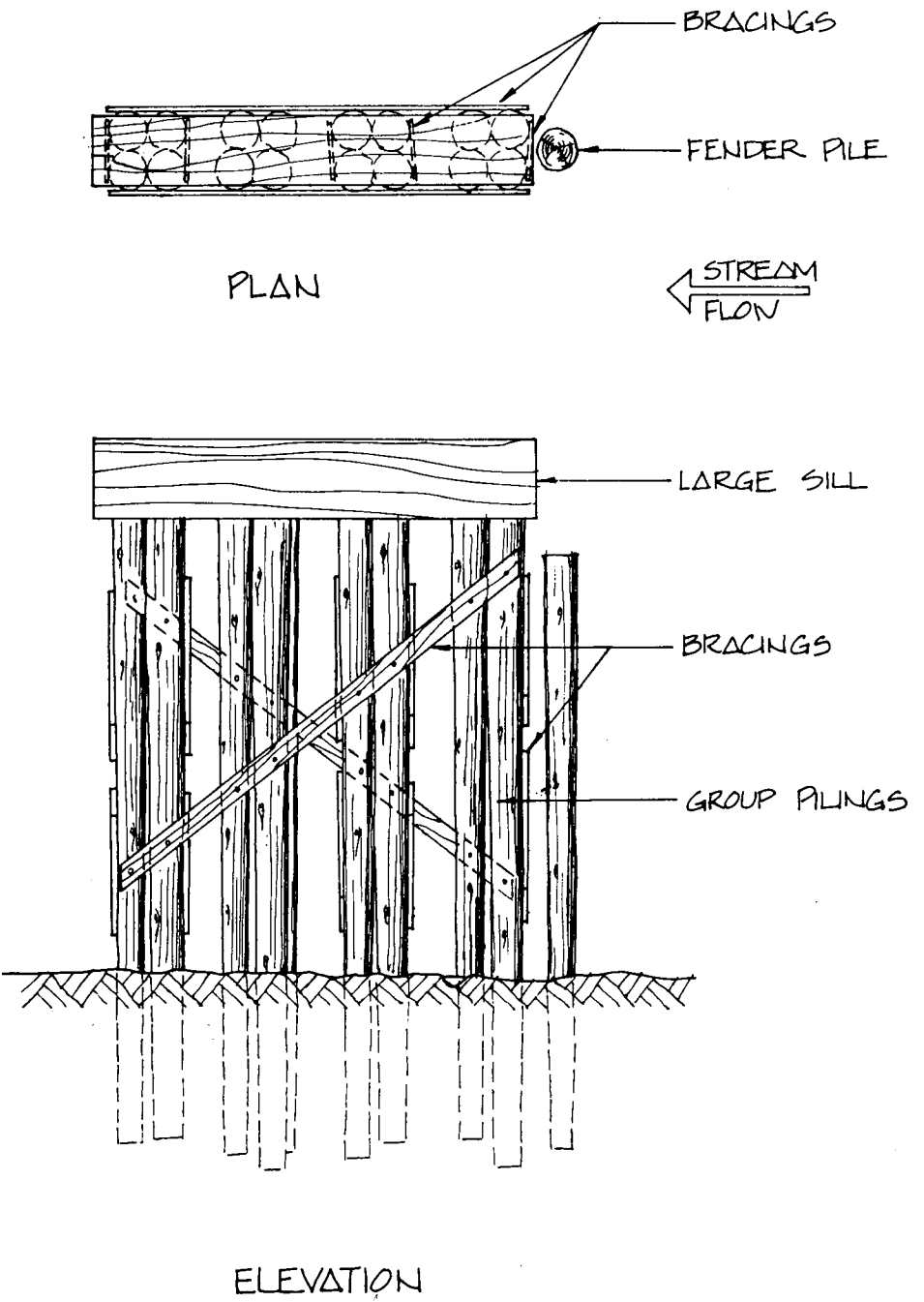


FIGURE 129. Group-pile pier with small piling

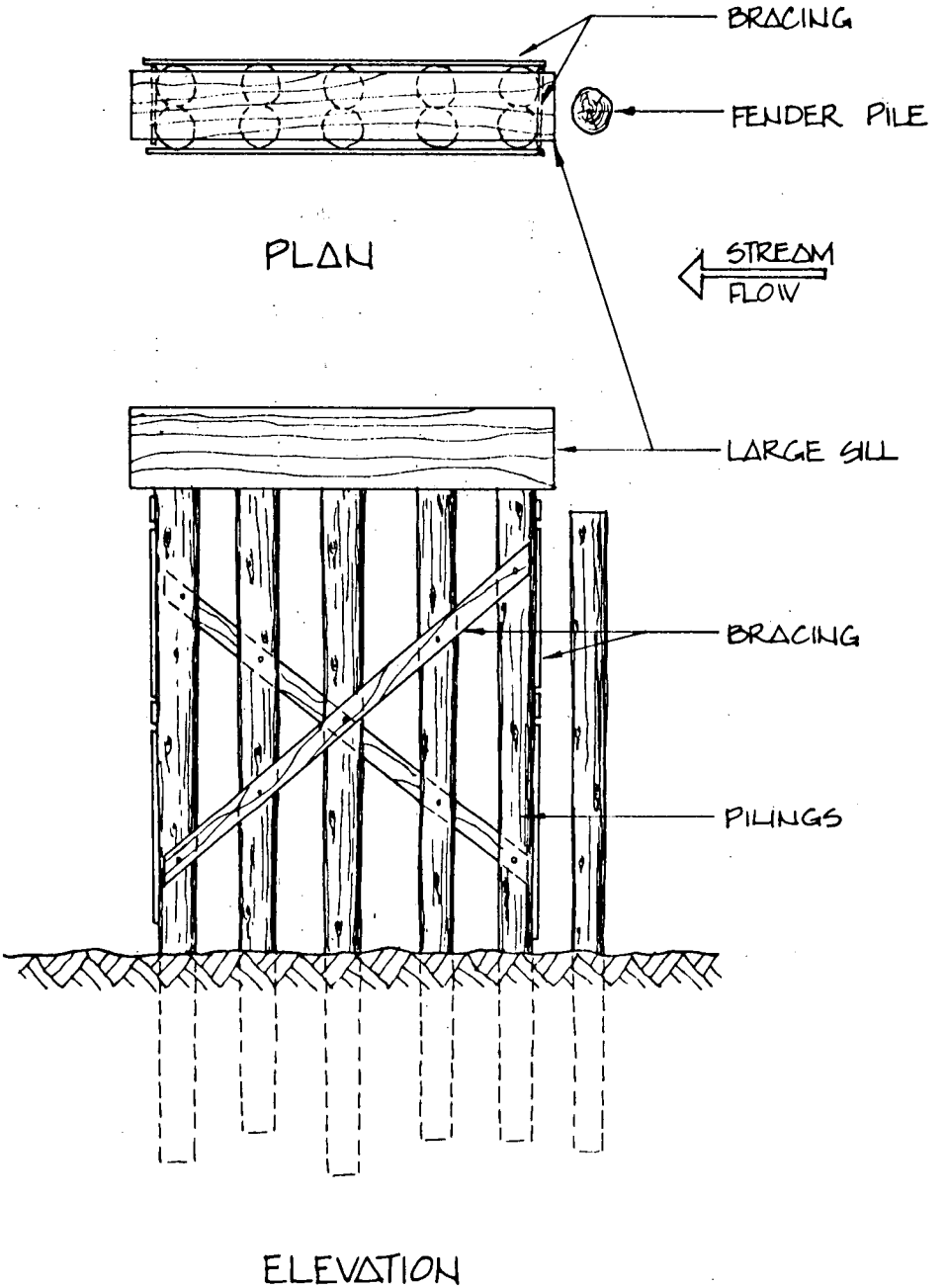


FIGURE 130. Group-pile pier with paired piles

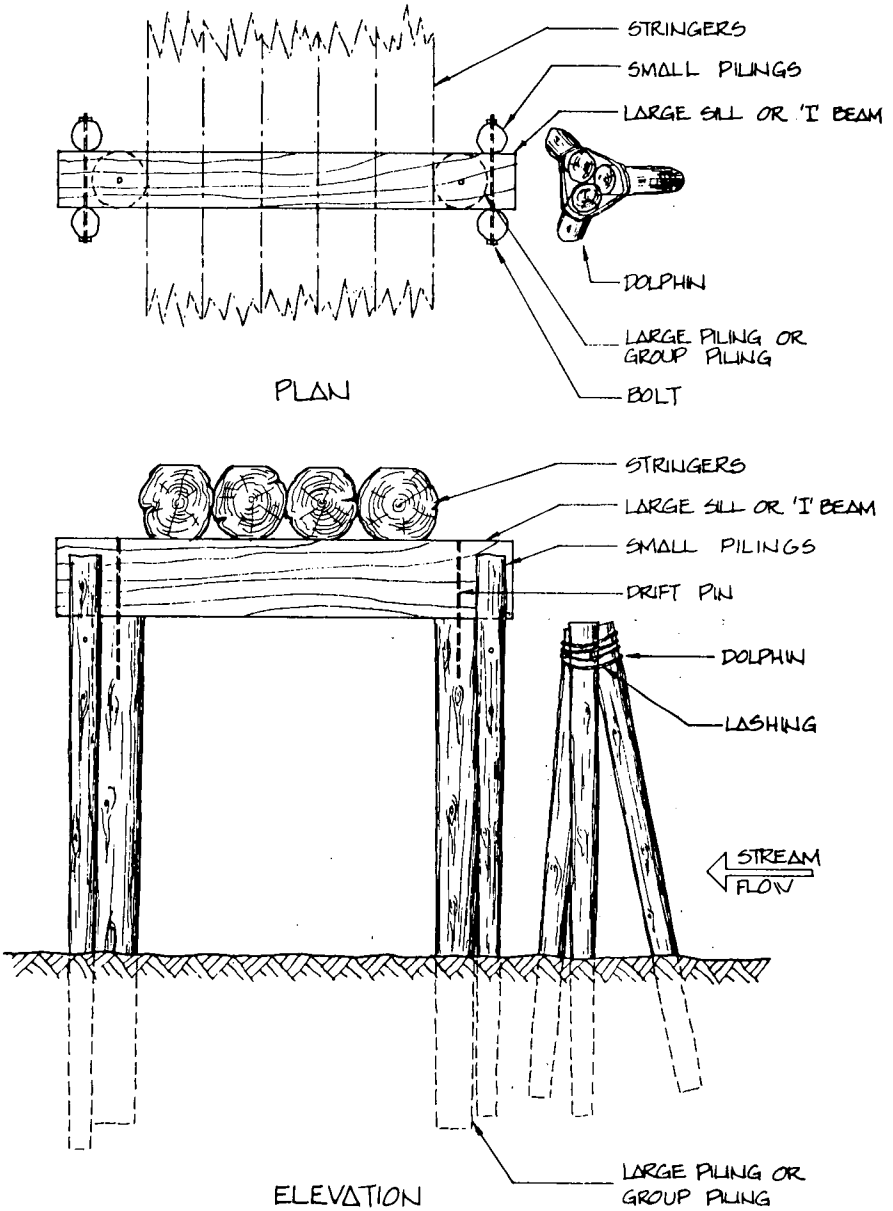


FIGURE 131. Pile pier trestle

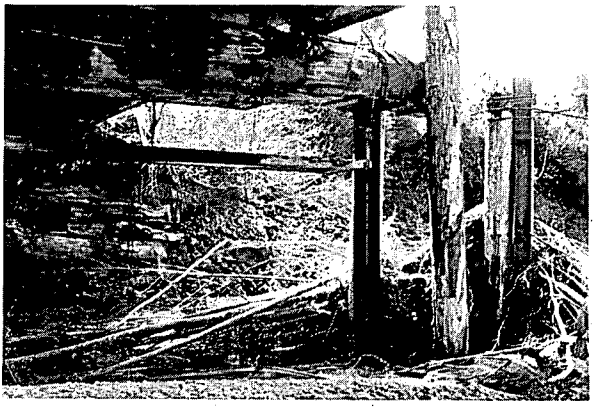


FIGURE 132. H-beam pile supporting trestle

- Protection of pile piers

Pile piers are resistant to scour, but they are easily damaged by floating debris or ice. Damage can be prevented by using the following materials.

i) Fender piles

Fender piles are the most basic protective device. Drive a single fender 5 ft to 10 ft upstream from the pier. Another pile may be driven in front of the first pile for additional protection. Figures 133 and 134 show a pier with two fender piles.

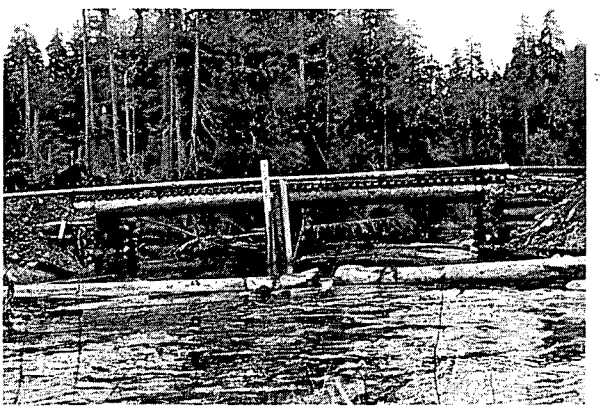


FIGURE 133. Fender-pile protection

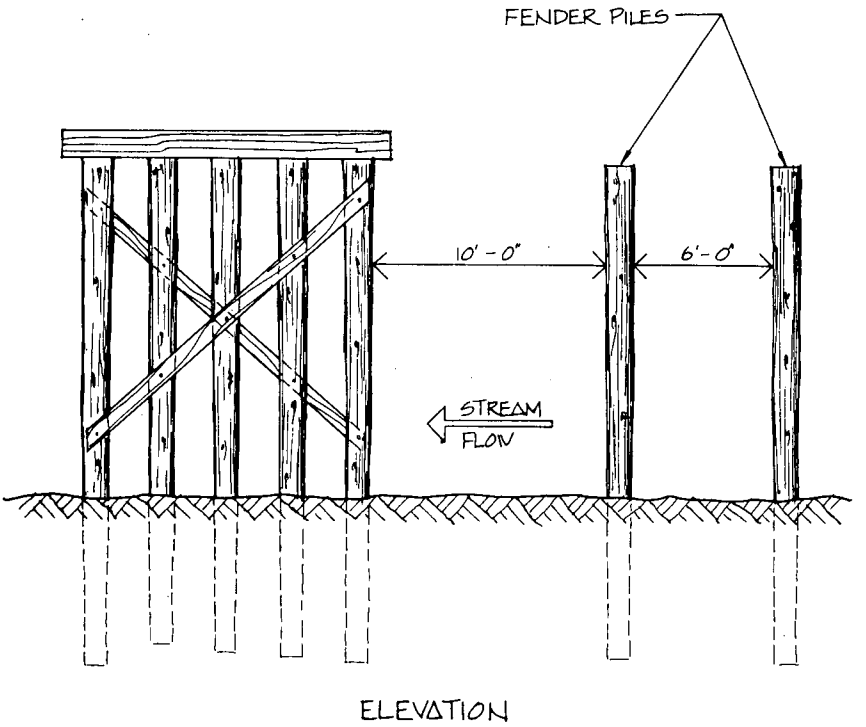


FIGURE 134. Pier protected by two fender piles

ii) Piling nose

A piling nose sheathed with planking is particularly effective if the stream is subject to severe icing (Figure 135). The nose should be just wide enough to shield the pier.

iii) Fender dolphin

A dolphin driven 5 ft to 10 ft in front of a pier will deflect any floating debris or ice. It may narrow the stream channel more than the pier but it provides protection for a wider pier (Figure 136).

Tie the tops of the piles in the dolphin so they work as a group. The usual number of pilings in a fender dolphin is 3, 5 or 6. The front pile in the dolphin is usually driven at an angle to help break floating ice.

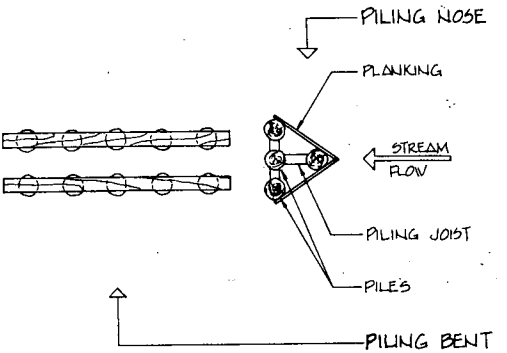


FIGURE 135. Piling nose

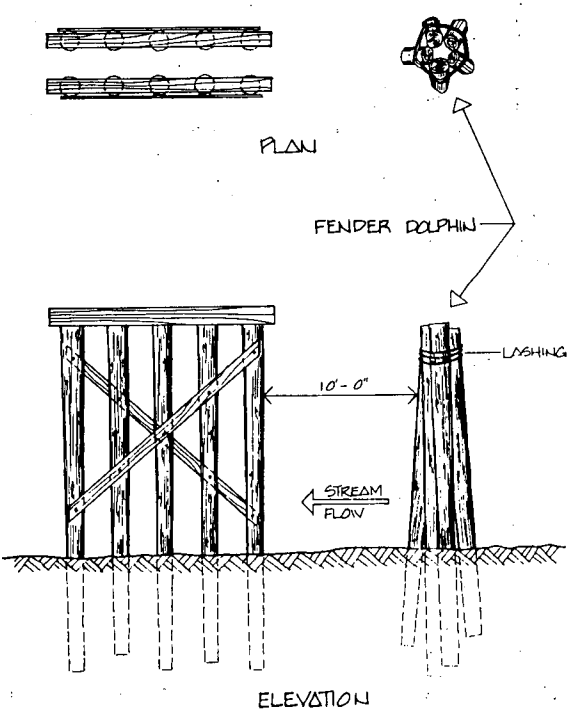


FIGURE 136. A fender dolphin

Tie the dolphin structurally to the pier to give added protection in high water (Figure 137). Drive the dolphin around a large beam or log elevated to the high water-level. This log will distribute the impact forces over the piling. All piles should be tightly bolted to this log. Spacers may be necessary for tight fitting.

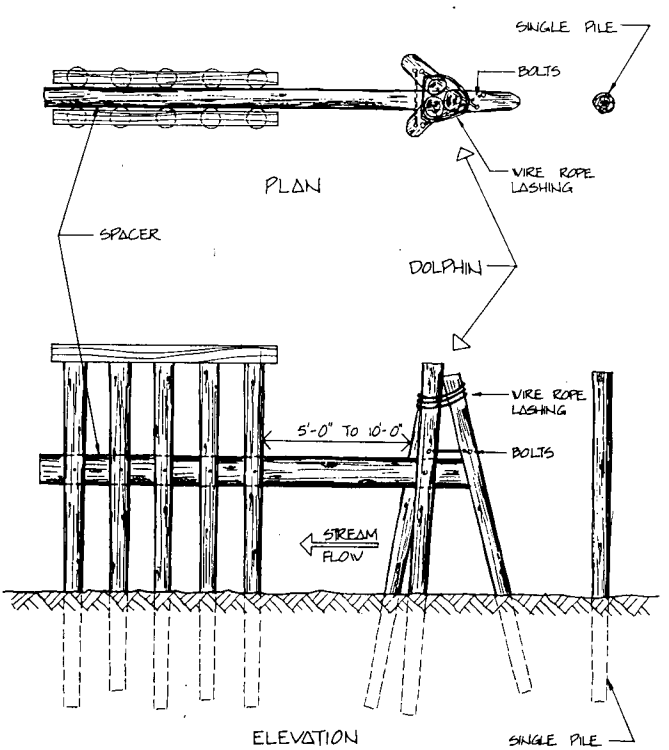


FIGURE 137. Pier with dolphin secured to spacer

To provide added protection against a direct frontal hit, drive an additional pile upstream from the dolphin.

iv) Planking

Planking is the most common protection against floating debris and logs which get stuck between the piles. If planking is needed, the piling should be in the same plane. Usually rough 2x10, 2x12, or 3x10 planking is used. Three-inch planking will not break as easily as 2-in. but is heavier for the same length. Choose planking two men can handle. Planks should span three piles. Use galvanized spikes penetrating every pile at least 5 inches.

Join the planking at a piling and nail the ends with two spikes, leaving a space 1/2 in. to 4 in. between planking.

Combining side planking with fender pilings will protect the pier without narrowing the stream channel (Figure 138).

The pile bents shown in Figure 138 should be spaced at least 4 ft between the two rows of piling to reduce water turbulence.

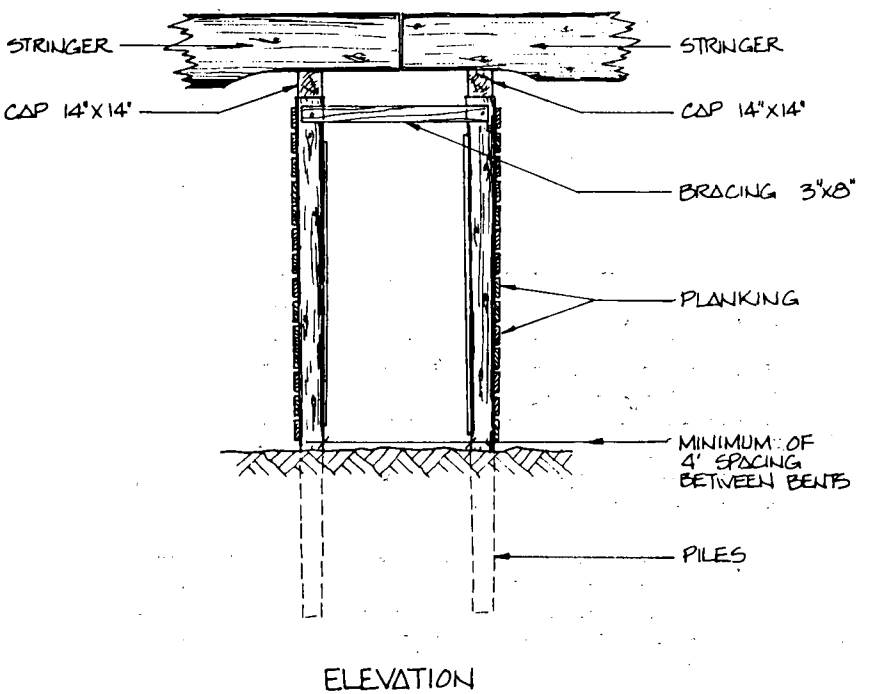


FIGURE 138. Open-front pier with sides planked

A planked nose protects a narrow pier in a stream where the flood water carries a large amount of debris. You can plate the front of the nose with steel to prevent damage to planking (Figure 139). The nose pilings and the upstream piling in each outside bent have a batter to help break up ice.

Wide planking will not lie flat on the piling because of the difference in the direction of the nose piling. Use 3x8 or 2x6 planking for the nose (Figure 140).

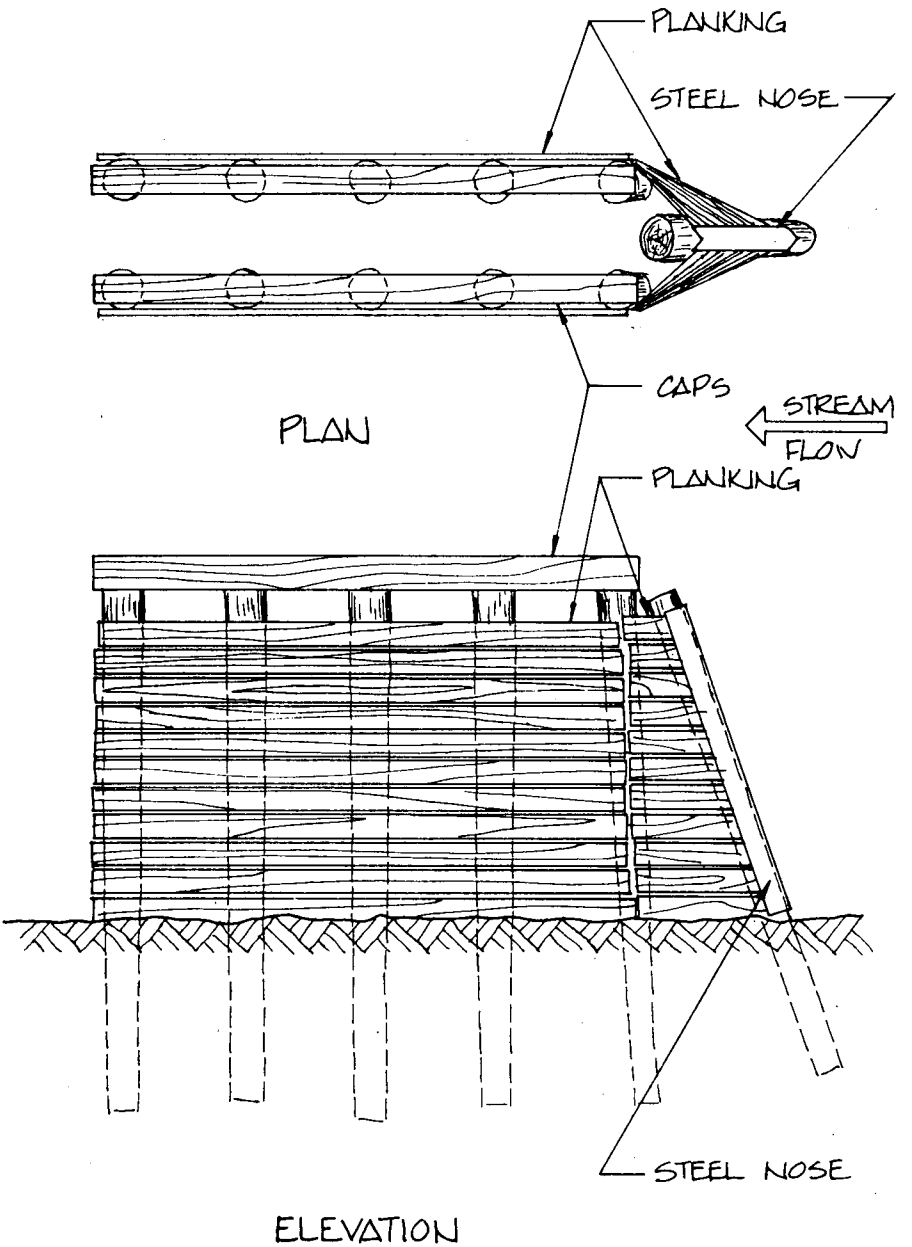


FIGURE 139. Steel-plated nose

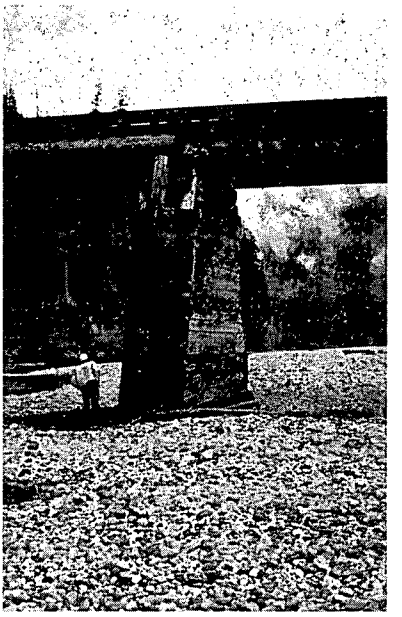


FIGURE 140. Nose covered with narrow planks

v) Steel sheeting

Use steel sheeting instead of wood planking for piers in streams with large amounts of ice or debris (Figure 141).

You can attach wood planking after the rest of the bridge is completed but steel sheeting must be mounted on the pier before the stringers so it can be easily lifted into place. Use mild 1/4-in. to 1/2-in. steel sheets. Common sheet sizes are 4x8 ft and 4x10 feet. One-quarter inch sheets may be spiked on the piles using 6-in. (or larger) galvanized spikes. Heavier sheets should be bolted or screwed on. Each sheet is fastened to each pile by three 1/2-in. (or larger) bolts or 3 screws. When wood screws are used, they should have a penetration of over 6 inches. Shim the piles to make a smooth surface for the steel sheets. Weld the sheets together to increase strength.

Light sheeting (1/4-in.) can be wrapped around a dolphin to make a pier nose. The nose may be reinforced by welding an extra strip of heavier gauge angle-iron over it.

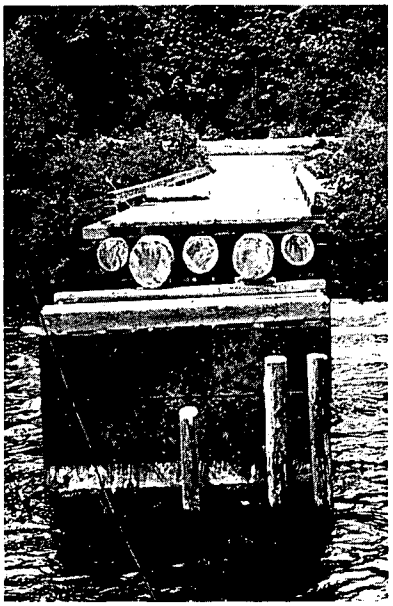


FIGURE 141. Steel sheeting

2. Post-Bent or Frame-Bent Piers

Post-bents or frame-bents may be used for a pier when it is not practical to drive pilings or use cribbing. Frame bents can be placed on midstream islands, bedrock or boulders.

Pilings are replaced by compression columns which bear the load without penetrating the ground. Round logs are used in a post bent (Figure 142) and sawn timber is used for frame bents (Figure 143).

A minimum of 6 posts is required to form a bent. Table IV-E may be used for frame-bent design. The cross-section area may be used to convert round logs to rectangular timber sizes.

- Single post-bent or frame-bent

The most frequently used post-bent or frame-bent is the single bent used for supporting log-stringer bridges (Figure 144). Do not butt log stringers over the pier. Sawn-timber stringers can be joined over the pier by overlapping as shown in the Pile Pier section.

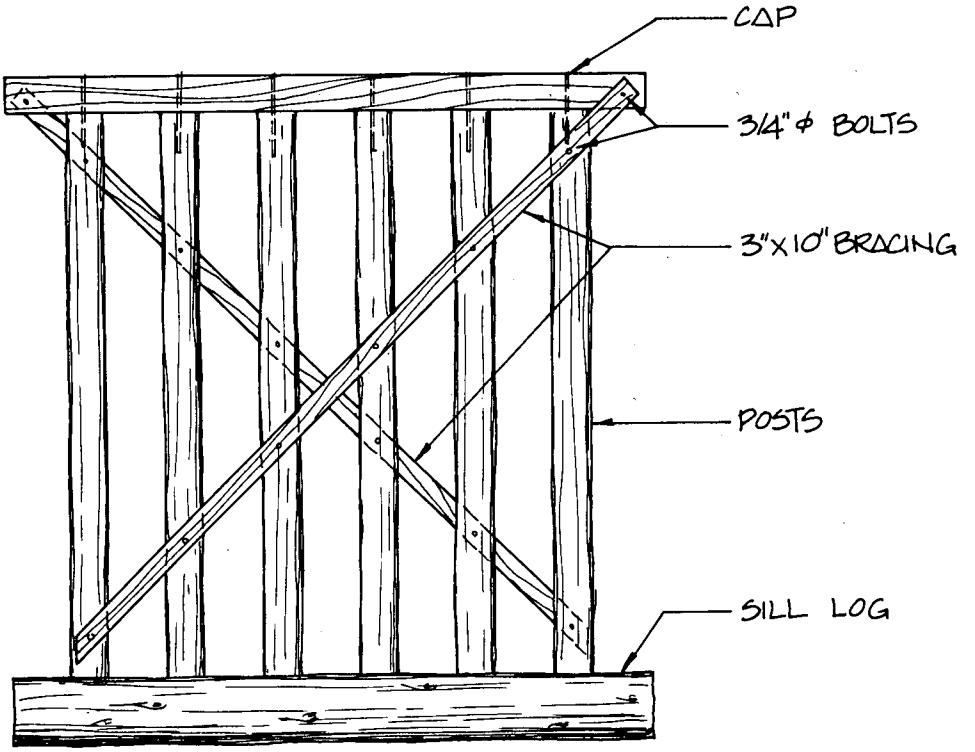


FIGURE 142. Post bent

- Leaning post-bent or frame-bent piers

Build piers outside the stream and, if possible, on dry ground. Piers can be leaned to support stringers at the right location (Figure 145).

Vertical or leaning bents can be framed in place. Each post is placed on the base and the bent leaned as required and braced into final position (Figure 146).

Tie the leaning piers to the abutments and to each other to prevent any movement during placement of the stringer. Too much lean creates excessive bending in the posts, so do not lean bents more than 30° from the vertical.

Do not notch the stringers below the sapwood. Use blocking.

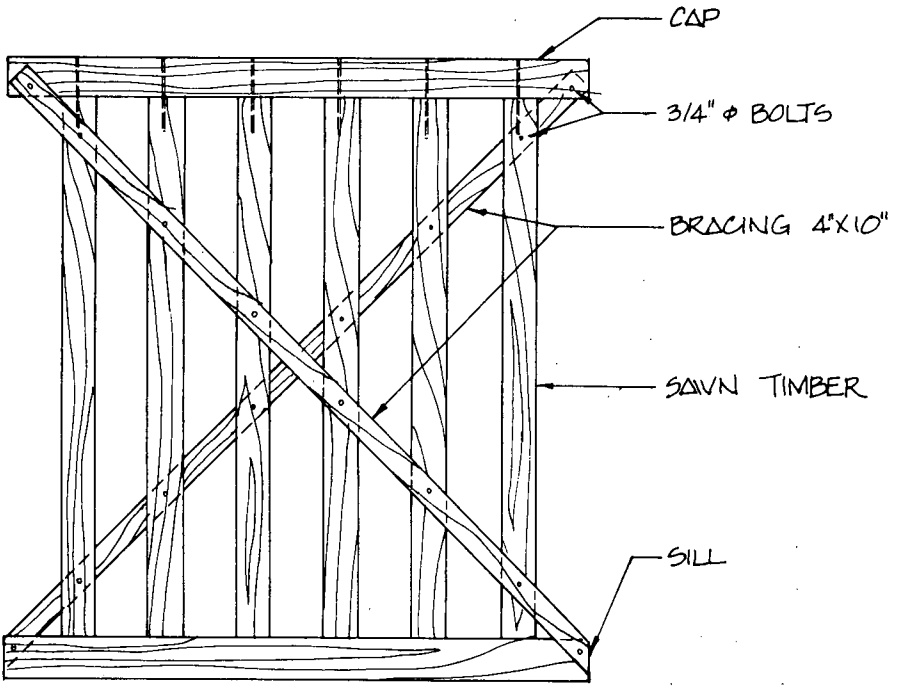


FIGURE 143. Frame bent

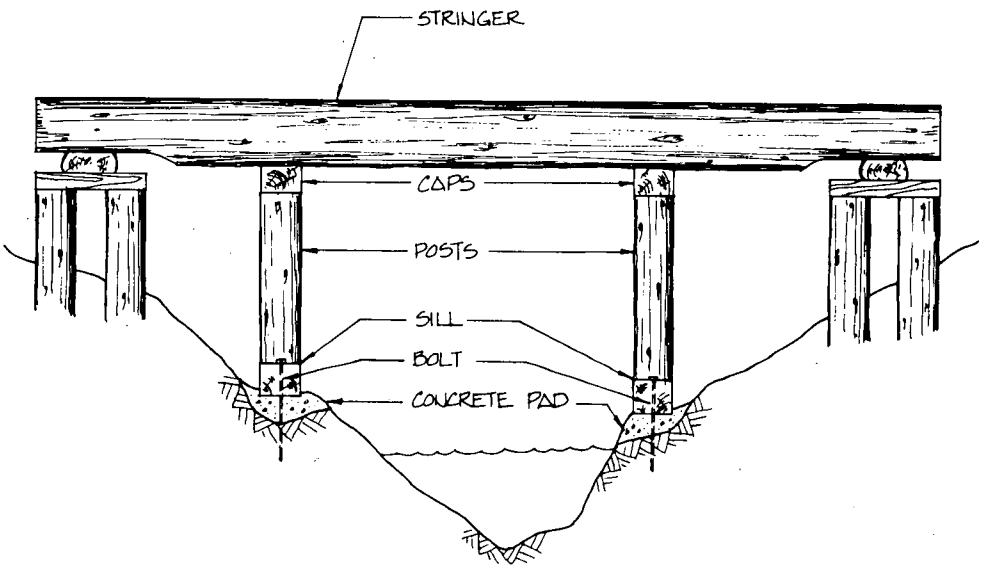


FIGURE 144. Single post-bent piers

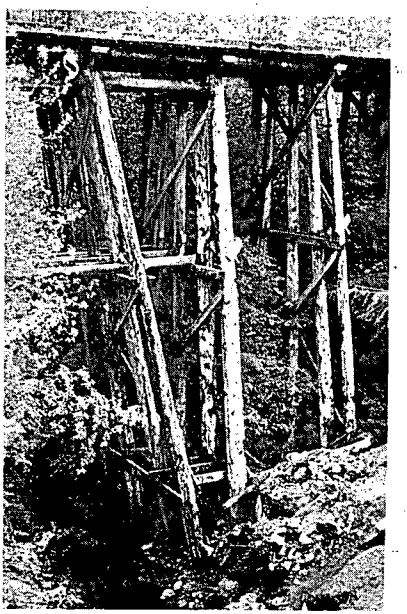


FIGURE 145. Leaning post-bent pier

*Note: The design of a bridge of this height is beyond the scope of this book.

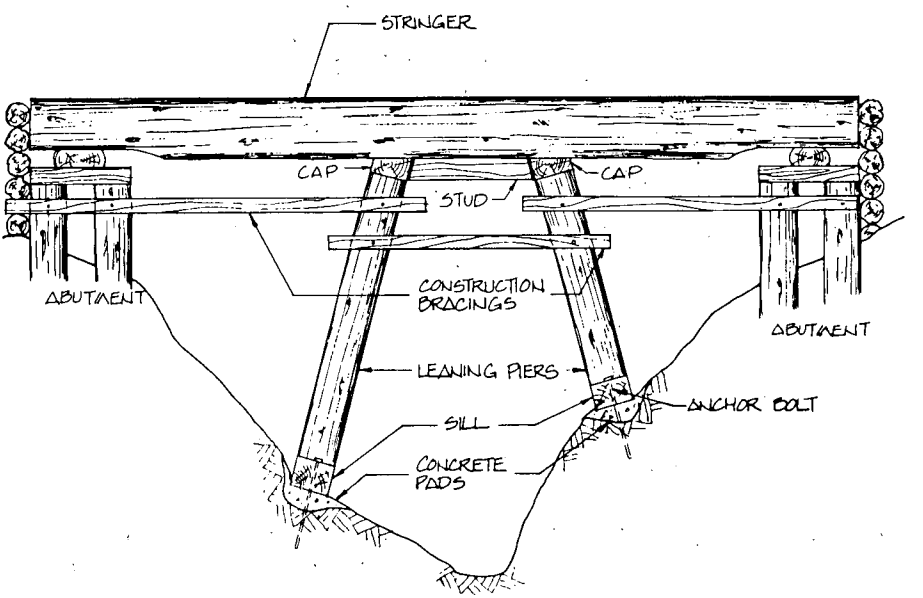


FIGURE 146. Bridge with leaning post-bent piers

- Double post-bent or frame-bent piers

Figure 147 shows the construction details of a double-frame bent pier used to support stringer ends. This construction is often used on bridges crossing tidal flats or low-lying areas, provided there is a hard subsoil.

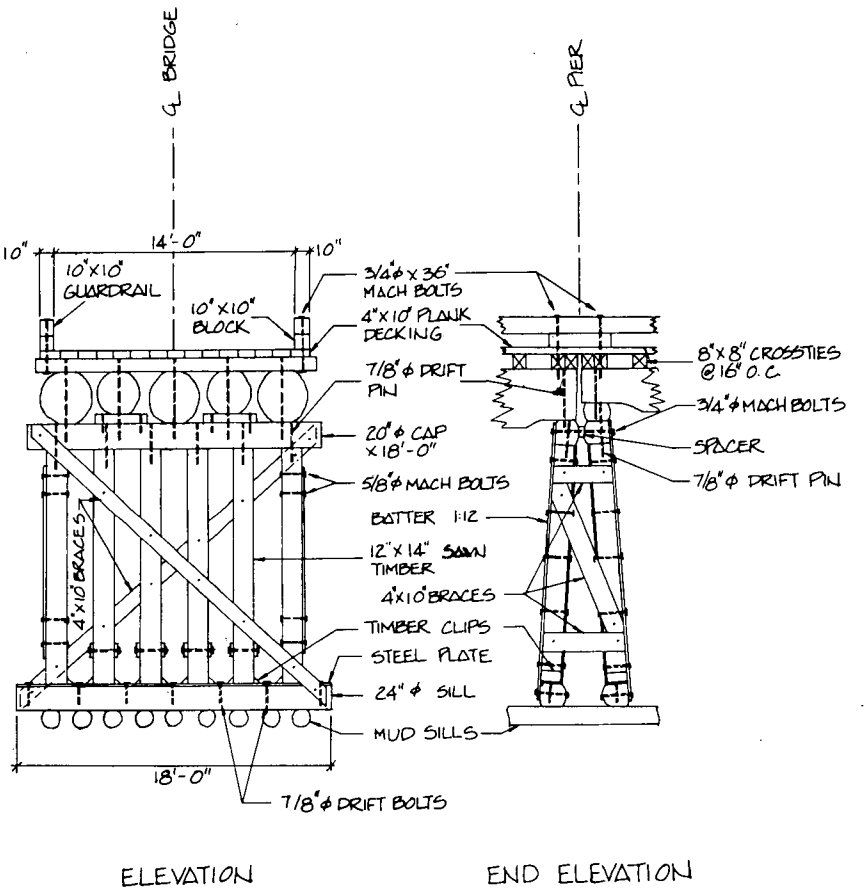


FIGURE 147. Double frame-bent piers on mud sills

- Post-bent or frame-bent trestle

The post-bent or frame-bent trestle is usually used for propping up old bridges so only 4 columns are needed (Figure 148). This type of pier usually has a large log or steel I-beam cap to distribute the load over the posts.

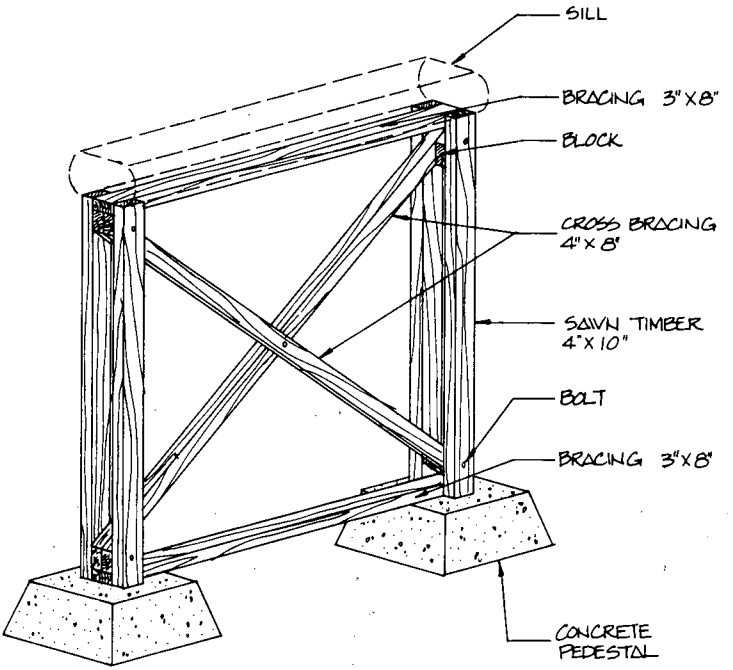


FIGURE 148. Frame-bent trestle

- Pier foundation design for post bents or frame bents

Use the crib foundation tables in the Abutment section to calculate the area of the foundation. Double the sizes indicated in the tables for piers supporting up to twice the load of most abutments. Figure 147 shows a typical double frame-bent pier with mud sills.

The sill should be no smaller than 10x14 and the width of the sill should be no less than the diameter of the largest post. Sills on other than a rock or concrete foundation should be 24 in. diameter (or larger) but under no circumstances should they be less than 18 in. diameter. Remove the top sapwood from sill logs and flatten them for posts and connectors.

- Concrete foundations for post-bent or frame-bent piers

Use concrete on solid rock to even out the roughness of the ground. Rock anchors must secure the sill if reinforcing is not used (Figure 149).

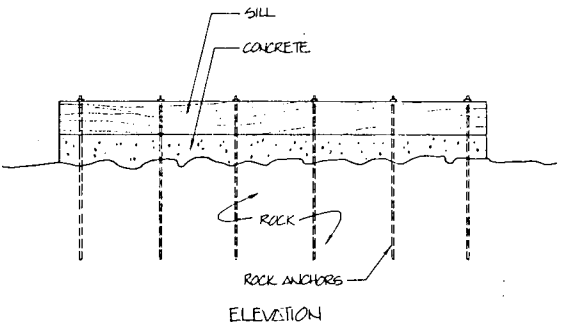


FIGURE 149. Concrete slab foundation

Posts may be set into the concrete during pouring or holes may be left for them (Figure 150). The foundation should be wide enough to allow 18 in. around the posts. The holes must be 18 in. deep. Thick concrete requires reinforcing with reinforcing bars (rebars). Place Number 8 rebars 12 in. apart around the side and bottom (Figure 151). Anchor the foundation to the rock. Posts set in concrete seldom dry out and are subject to decay.

Drain the base holes if the foundation is out of water. Use drainage pipe 2 in. (or larger) in diameter placed longitudinally in the concrete at the bottom of the holes. Slant the pipe to prevent water stagnation.

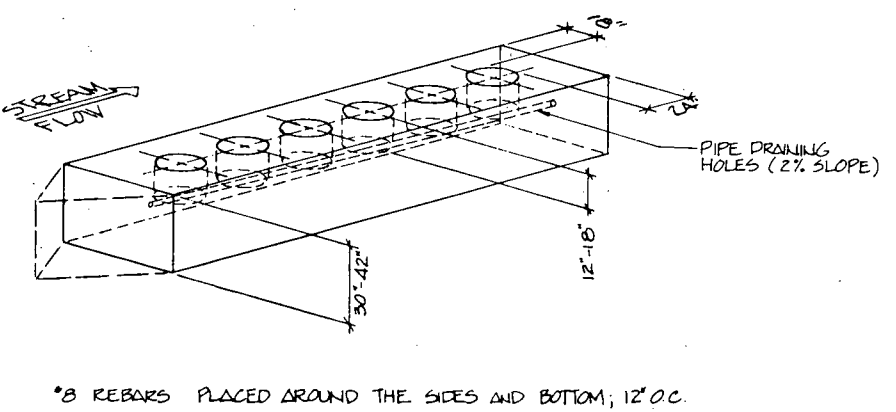


FIGURE 150. Concrete foundation with posts set in holes

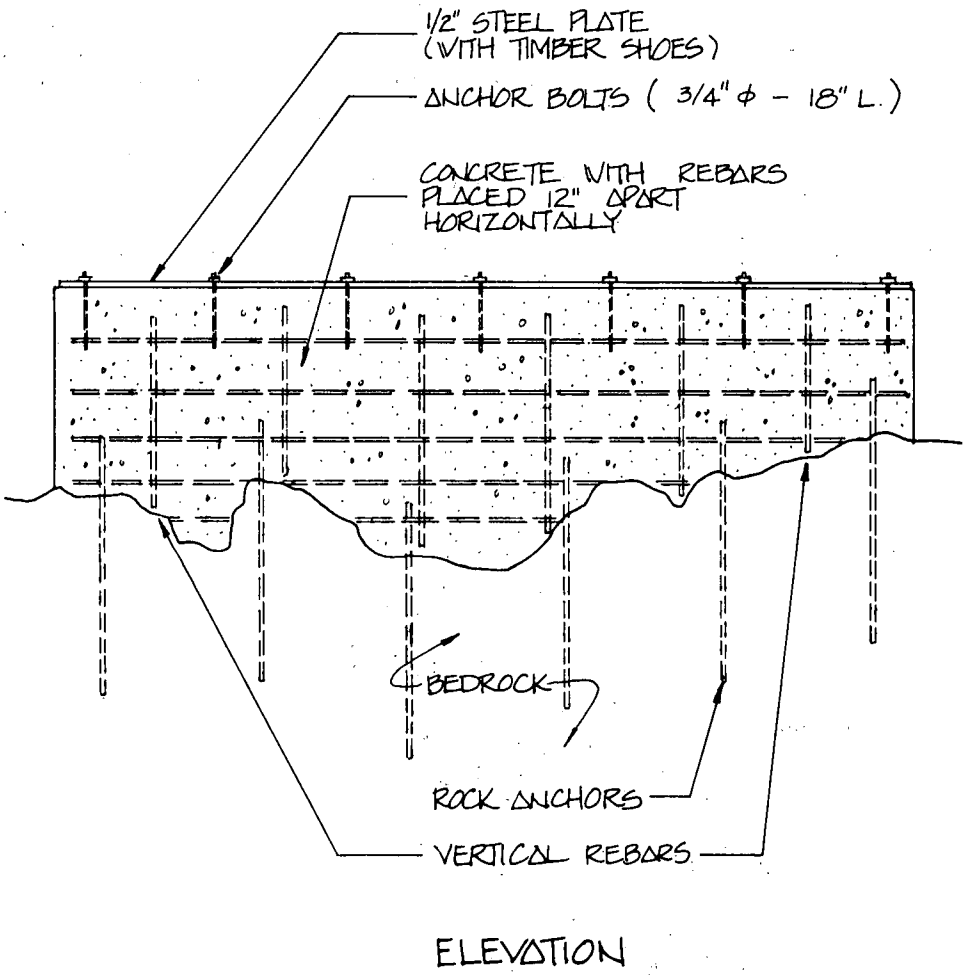


FIGURE 151. Reinforced concrete foundation

- Foundation fasteners

Rock anchor bolts should be at least 3/4-in. diameter and long enough to penetrate at least 18 in. (or to the depth of two reinforcing rods). Anchor bolts holding the sill in place should be no more than 6 ft apart.

Drift bolts must be at least 3/4-in. diameter and long enough to extend 9 in. into the post. Use one drift or drift bolt for each post.

Posts may be toe-spiked to the sill log with drift bolts. Drive two 3/4-in. drift bolts diagonally, one from each side, to extend 9 in. into both the post and sill.

Bolt clip angles to the sill using 3/4-in. diameter bolts with washers. Attach them to the posts with two 5/8-in. lag screws. Figure 152 illustrates a clip angle. Figure 153 shows a timber shoe. Timber shoes provide better security and need little preparation for use on posts.

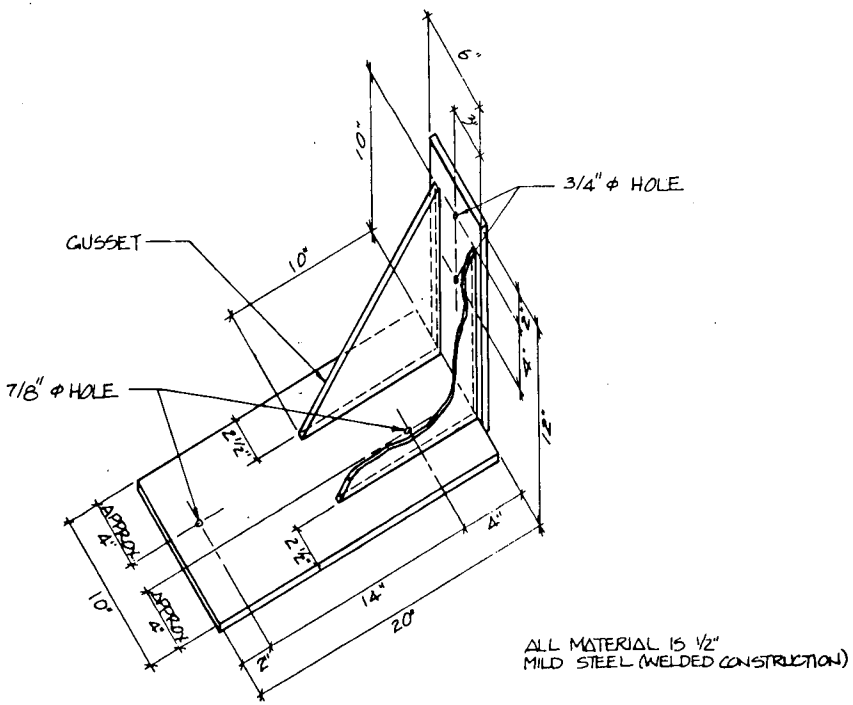


FIGURE 152. Clip angle

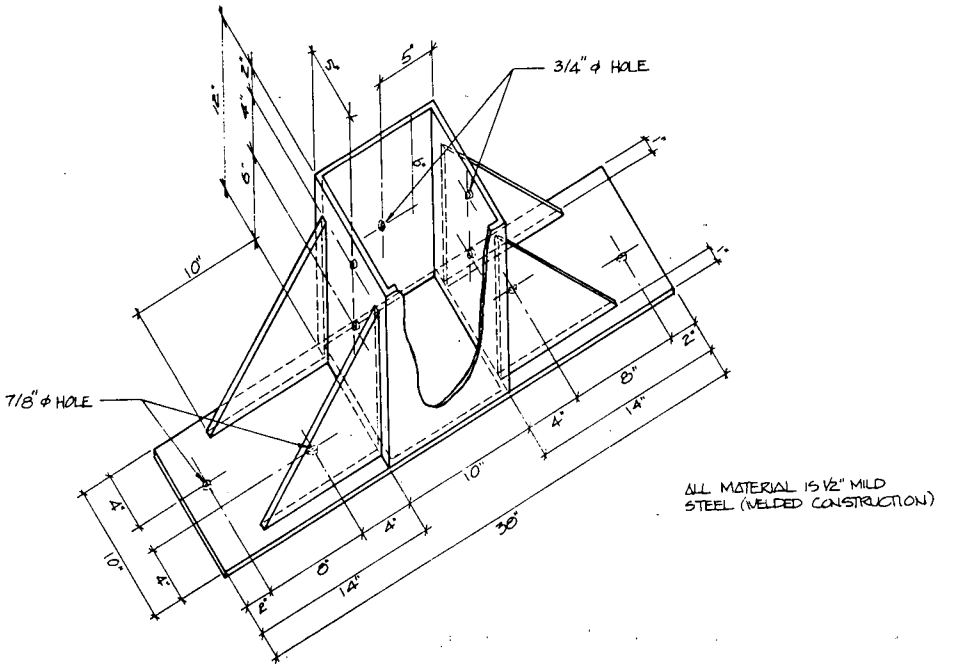


FIGURE 153. Timber shoe

Figures 154 and 155 show two types of concrete pedestals which can be used on hard ground.

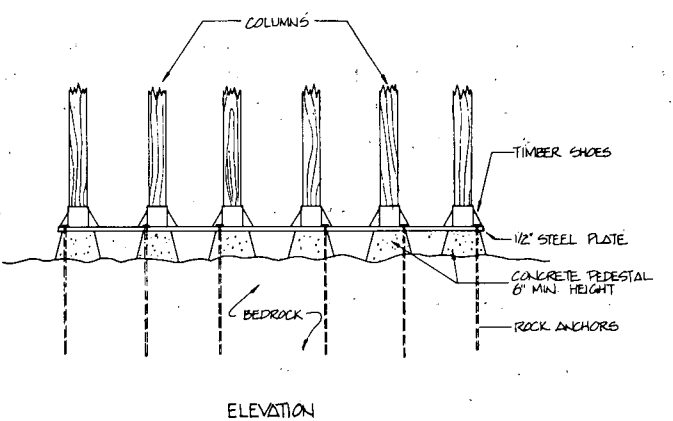


FIGURE 154. Concrete pedestal foundation

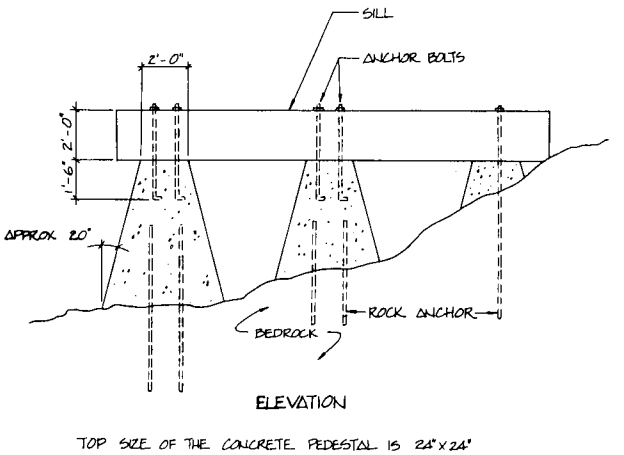


FIGURE 155. Large concrete pedestal

- Caps

Cap sizes are shown in Table IV-J in the Caps and Sills section. They may be attached to the columns by connectors (including clip angles and timber shoes) or drifted. If they are drifted, use 3/4-in. drift pins or bolts and penetrate the columns at least 9 inches. Secure the cap to prevent movement when you place a preassembled bent.

- Bracing

Use large lumber (not less than 3x8) to make strong bracing and reduce splitting. You can use deck planking provided it is at least 3 in. thick. Bolt diagonal bracing (with a slope not exceeding 45° to the horizontal) to every member in a bent. Use 3/4-in. (or larger) bolts.

Bracing should run in opposite directions on opposing sides of the bent. Take care not to loosen the bolts when you move preassembled bents.

- Protection of post-bent and frame-bent piers

It is difficult to protect post-bent and frame-bent piers against flood damage when they must be built in the stream channel. Sheeting and planking provide protection for the sides of these piers and for extra safety. They can be tied with wire rope to stumps or anchors on the shore.

Floating guardlogs can be used to protect the pier against floating debris. The guardlogs should be tied to the shore so they cannot rub against the pier.

3. Log Crib Piers

Box cribbing piers are the least expensive for soft or bouldery ground. The Log Crib Foundation Tables may be used to calculate the necessary foundation size. Multiply the figures shown in these tables by two. Build the foundation below scour level. A log crib pier built of large logs and filled with heavy rock or coarse gravel can withstand the impact of floating debris. Lash or drift the logs at the corners to strengthen the crib.

It is difficult to build a narrow log crib because of the need to allow some end room beyond the notches as well as some fill room inside the crib. The narrowest pier that can be built with 2-ft diameter logs is 8 ft wide.

Figure 156 shows a box crib pier. Tieback logs can be added, but these should be at least 6 ft apart when filled with shot rock or boulders.

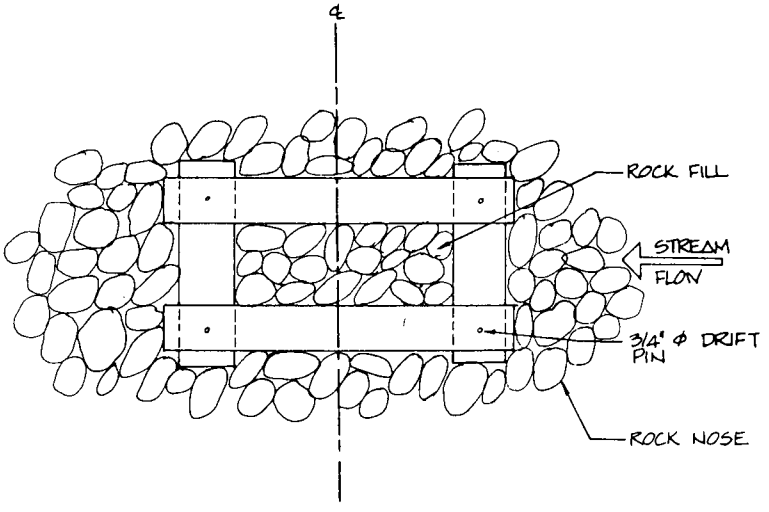
Well-placed large rocks just upstream from the crib may direct flood waters to each side of the pier. With luck, the centre pier may actually cause a buildup of rock and gravel during flood, but this is rare. As a rule, log crib piers are vulnerable to undermining and the pier must be inspected after every flood.

Build a nose at both ends of the crib for protection. Posts should be drifted to the end of the crib logs before the foundation is covered. Then erect a leaning nose-post held in place by planking (Figure 157). Place rock or gravel inside the crib solidly against the nose posts and planking. Outside rip-rapping is also placed around the pier (Figure 158).

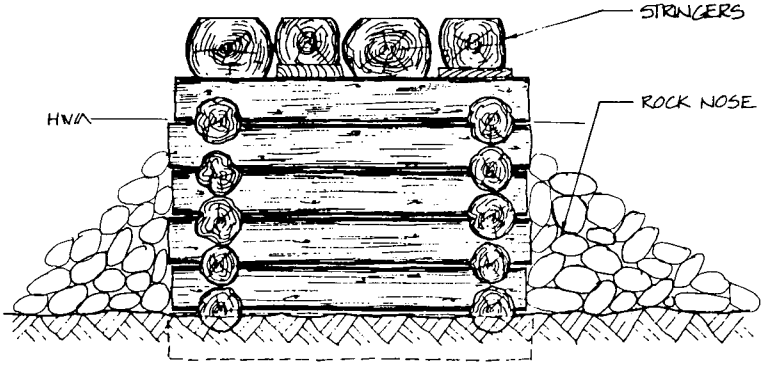
One half-inch mild steel sheeting can be used instead of planking. Steel sheeting adds strength to the nose and prevents the washout of smaller gravel.

Figure 159 shows an example of a sawn-timber nose. The nose is planked or sheeted and filled with shot rock or coarse gravel.

If ground conditions permit pile driving, a pile pier is superior to crib. If a pile driver is not available then build a crib and at a later date build protective structures as described for pile piers.



PLAN



ELEVATION

FIGURE 156. Box crib pier

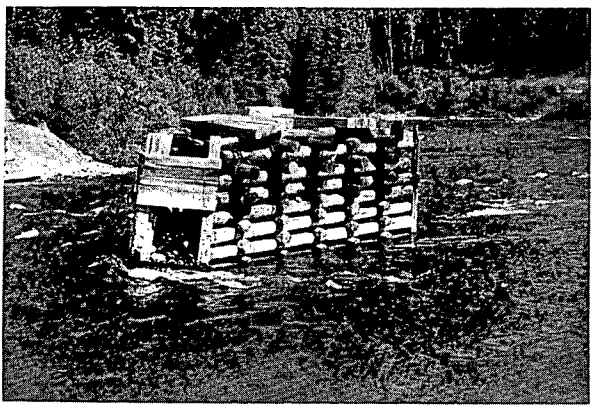


FIGURE 157. Leaning nose-post held by planking

4. Concrete Piers

We describe concrete piers used under two different ground conditions. The first group shows piers built on rock or hard ground, and the second group shows pile-based piers.

- Piers constructed on rock or hard ground

Prepare the rock surface, mount the rock bolts, erect forms, and pour concrete as described earlier for concrete abutments.

If rock is below the scour level it may be best to pour a concrete slab to use as a base for a pier. A pointed nose should be added if the rock is high enough for the slab to extend into the running water.

The rock anchors should penetrate the rock at least 3 feet. There should be enough anchors to prevent any movement of the slab under any load conditions. Rock with a fragmented, loose surface must be cleaned or blasted down to solid rock.

Figure 160 shows a typical concrete slab.

Tie down the structure above the pad with galvanized anchor bolts. They should extend as deep as the second horizontal rebar. The position of the rebars should be modified to conform to the location of the anchor bolts.

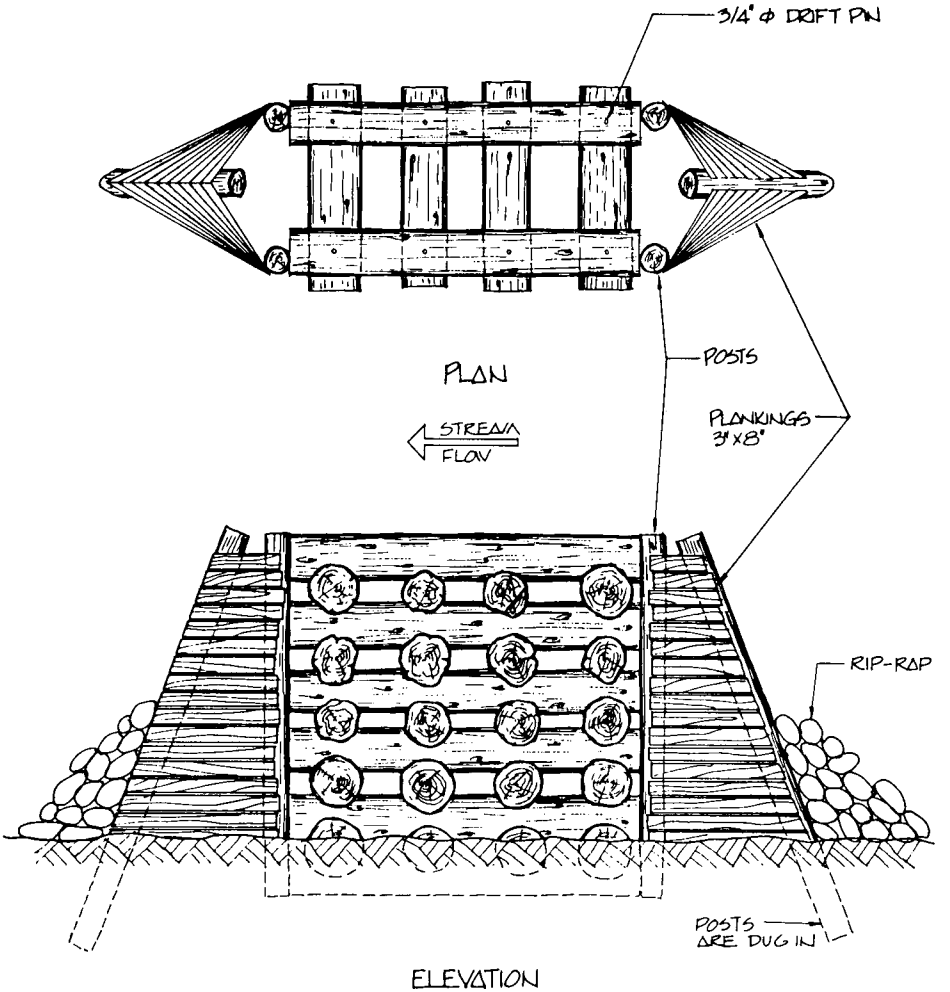


FIGURE 158. Box crib pier with rip-rapping

These bolts may be tied or welded to the bars and held in place with a template placed on top of the concrete during the curing period.

If you are building a concrete structure on the slab, replace the bolts with No. 19 rebars and tie them to at least two of the horizontal bars.

Piers described in this section may be built to a height of 20 feet (Figure 161).

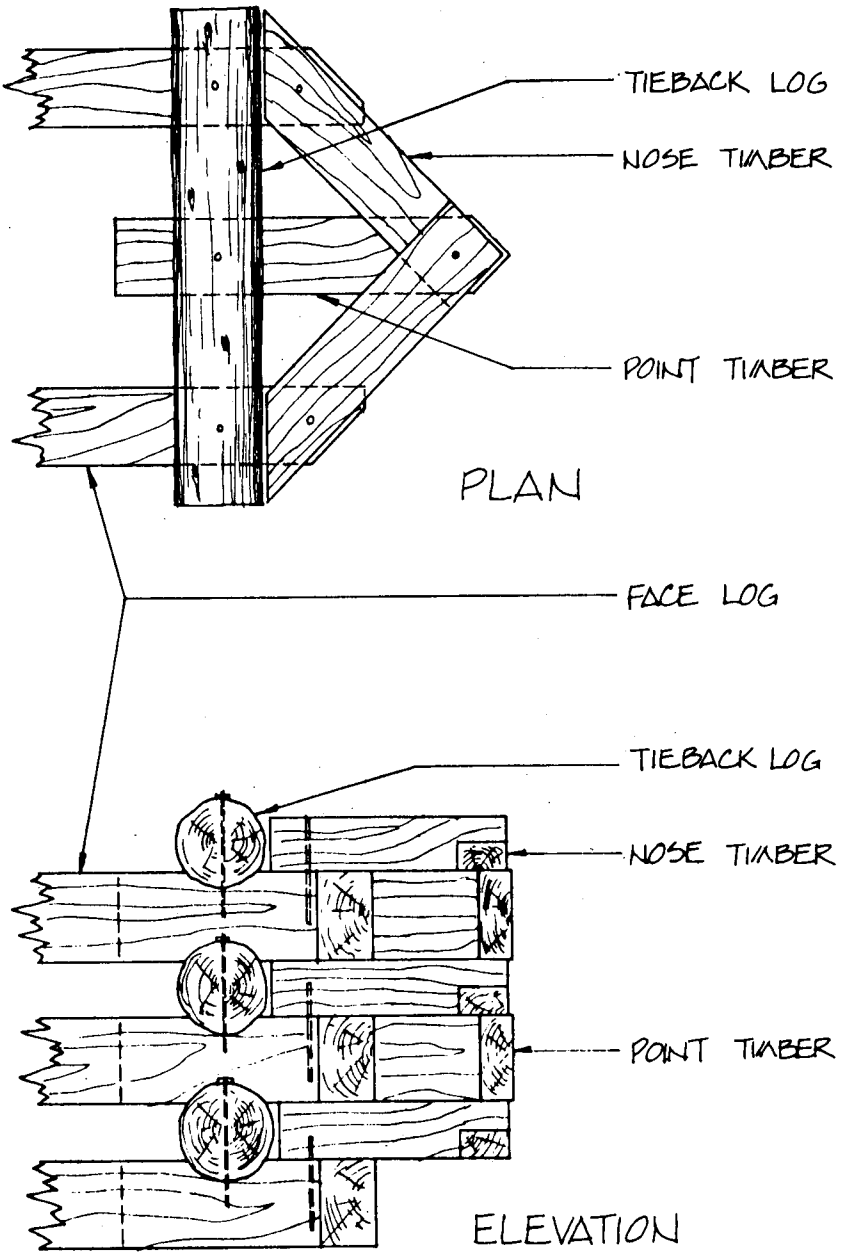


FIGURE 159. Box-crib nose built from sawn timber

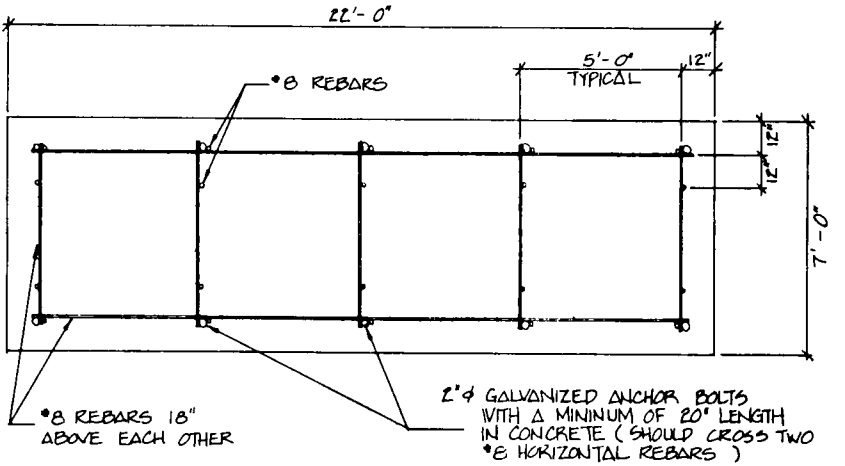


FIGURE 160. Concrete slab

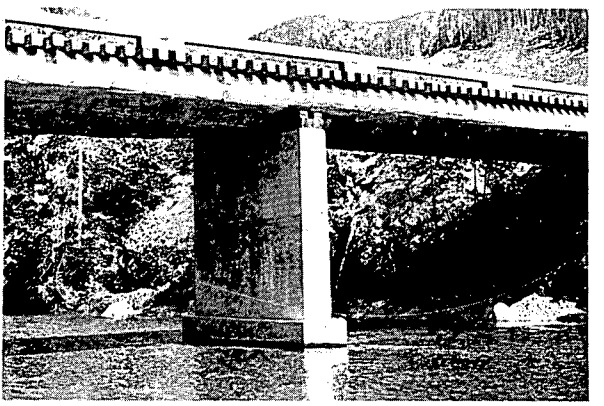


FIGURE 161. Concrete pier on slab foundation

The front and rear of the pier should be pointed to minimize water turbulence. The pier can also be protected from ice, logs and other debris by bolting large angle-irons to the pier nose (Figure 162).

- Concrete piers on soil

Occasionally it is necessary to construct a concrete pier when it is not practical to excavate to rock or hard soil. Piling driven into the soil forms a

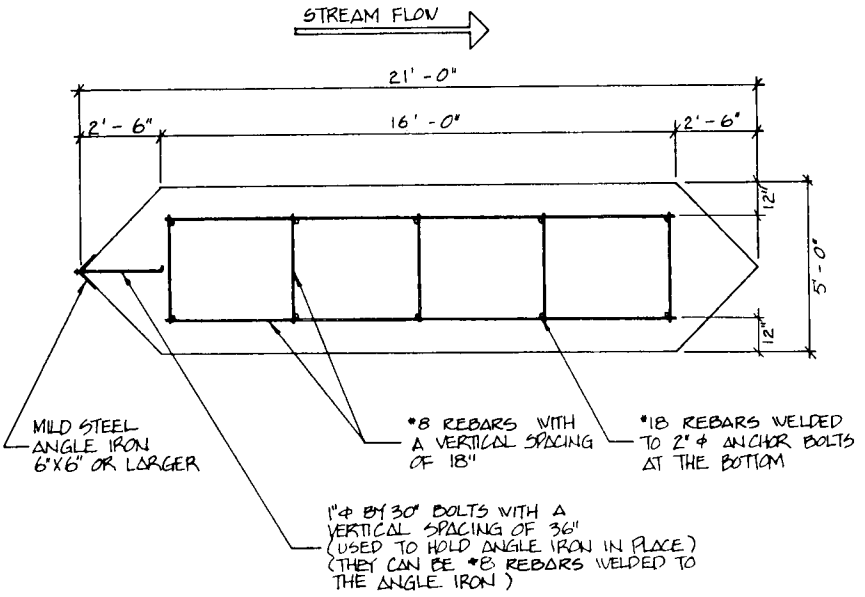


FIGURE 162. Plan of a concrete pier

suitable base for a concrete pier. It is essential to excavate to a level below the expected scour depths before driving the piling and pouring the concrete.

- Forms for concrete piers

Concrete form construction for piers up to 10 ft is similar to that for concrete abutments. If the pier is higher than 10 ft, then 1-in. plywood forms should be used. In the framework below the 10-ft level, 2x4's should be replaced with 2x6's and the 2x6's with 2x8's. The horizontal 2x8 wales should be repeated at 16-in. centres all the way to the top of the pier. If the pier is poured in sections, then a light formwork may be used depending on the height of the section.

If the forms are used in sections, they should be built so they fit over each other. The 2x4 uprights can be spliced together to extend the forms up to 20 feet (Figure 163).

Use reinforcing rods to keep the forms in position. The rods should run all the way through the forms. The rod endings must be welded to a bar so the forms can be tightened with wooden wedges (Figure 164).

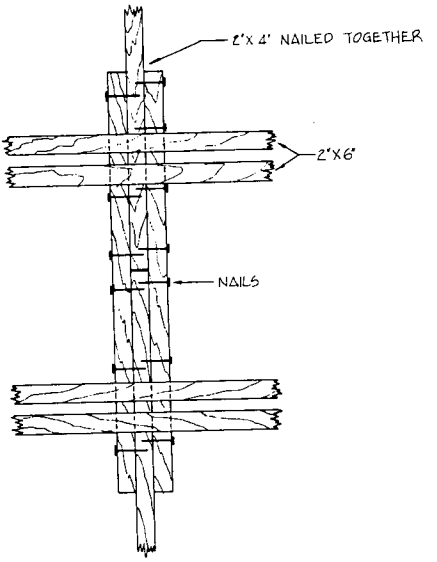


FIGURE 163. Spliced uprights for concrete form

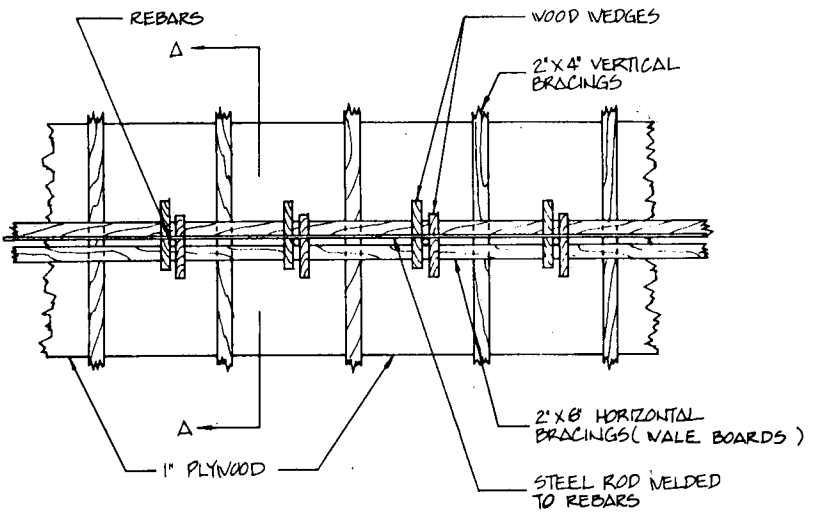
Consider sheet piling to replace wooden forms when the concrete pier is constructed in running water and placing the forms difficult. This type of construction is useful on soft ground to prevent scour. Steel sheet-piling comes in standard sections which can be delivered in required sizes and lengths. Driving sheet-piling is not difficult. The tongue-and-groove steel pilings form a solid wall (Figure 165).

Get the first pile started correctly. Some form of wood piling falsework is required to hold the first piling vertical (Figure 166).

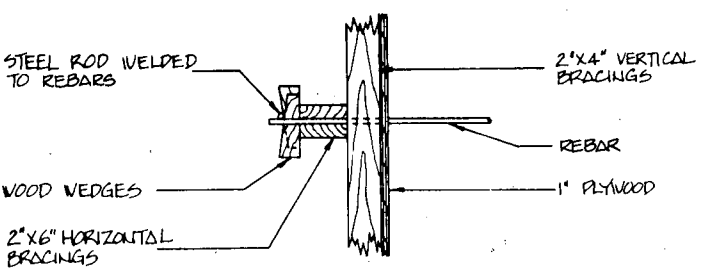
Sheet piling acts as a reinforcement in the concrete so reinforcing rods are not necessary unless the piers are more than 10 ft high. Higher piers should have No. 7 vertical reinforcing-rods spaced every 18 inches. Horizontal re-bars holding the vertical reinforcing can be fastened to the wood piling.

Small false piling may be driven 4 ft to 6 ft apart. Sheet piling should be driven deep enough so it will not be undermined.

After the sheet piling has been driven, the falsework is cut off and the pier completed by filling it with concrete.



ELEVATION



SECTION A-A

FIGURE 164. Use of wedges to tighten form

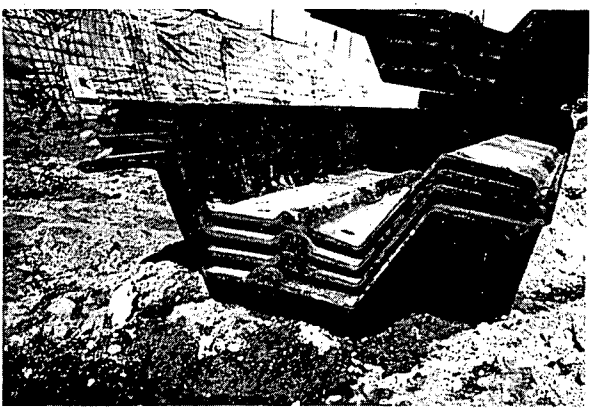


FIGURE 165. Tongue-and-groove steel sheet pilings

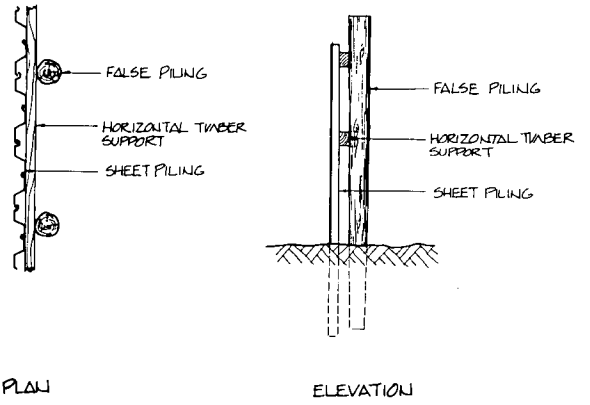


FIGURE 166. Sheet-piling concrete form with falsework

A pier can be constructed by driving 4x12 (or larger) strong wood sheet-piling in the same way as steel piling. The driven planks are bolted to a horizontal support to form a structure. Use treated timber for longer life.

- Concrete pier tops

Galvanized bolts should be placed in the top of the pier to accept the sill. You can position these bolts with a template carefully placed after pouring. Use different sizes of sills to compensate for different stringer depths (Figure 167).

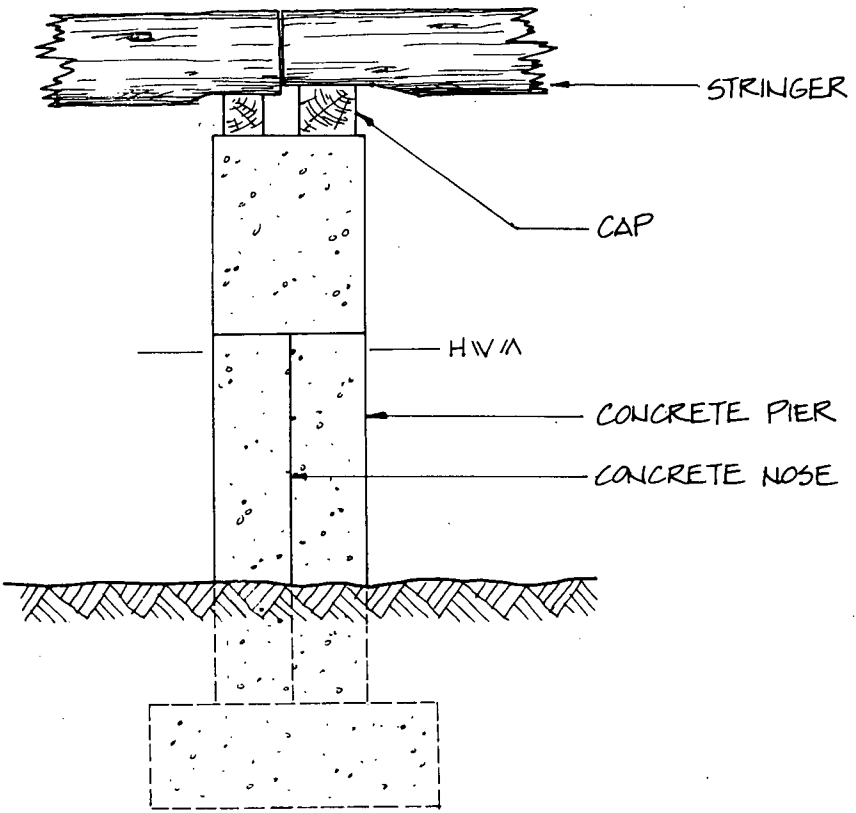


FIGURE 167. Caps on concrete pier

E. CAPS AND SILLS

The cap or sill transfers the bridge load from the stringers to the ground or the substructure. A stringer can be placed directly on solid rock or concrete but a sill provides better support. Only the best quality tight-grained material should be used for caps or sills.

Wood in the cap must support the maximum load as compression perpendicular to the grain. Good quality Douglas-fir has a 310-psi working strength in compression perpendicular to the grain, while Western red cedar has a strength of 190 psi. To design the size of cap required, calculate the minimum contact area between the stringer and the cap and between the cap and the piling or pier. Table IV-J may be used as a guide. Heartwood is the only type to consider. Make wide caps by bolting two timbers together.

TABLE IV-J Minimum Cap Sizes in Inches
(Caps lie on wide side)

Design Load (tons)	Douglas-fir	Yellow cedar	Spruce	Western red cedar
50	12 x 12	12 x 14	12 x 16	12 x 18
100	16 x 18	16 x 18	16 x 20	16 x 24
150	16 x 24	16 x 28	18 x 28	18 x 30

Sill logs should be debarked and flattened with a powersaw or broadaxe using the methods described in the section on stringers. The logs should be inspected carefully for cracks, rot or any fault or damage which will reduce their strength. Place sills so that any split which may occur will be horizontal, not vertical.

Drift pins are used to fasten the cap to a pier but lashing may be used on a crib. Lashing requires a large amount of wire rope (usually with 3/4-in. or 7/8-in. diameter) railroad spikes or staples, and some method of tightening (such as a tractor winch). Galvanized lashing should be used near tidewater. The use of wire rope larger than 1 in. is not recommended because of its weight and relative stiffness. Different types of lashing methods are discussed under 'Cribbing and Stringers.'

Fix one end of the cable to a crib log for lashing and then pass it over the sill and back under the log. Pull the line tight by using a tractor winch and drive a minimum of 3 railroad spikes or 4 staples into the tieback log (Figure 168). Lashing continues with each full loop spiked to the log. The lashing line should not cross over itself. The key to successful lashing is to have plenty of wire rope and railroad spikes. Every tieback and wing log next to the sill must be lashed to it.

Sill lashing is usually used in the construction of culvert-type bridges. Take care that the stringer seat does not rest on the lashing cables.

Use drifts with prepared stringers. Drift pins are round, mild steel with 3/4-in. diameter. Drift pins should extend at least 9 in. into the sill or cap but should never go all the way through. Holes should be pre-drilled 1/16-in. smaller than the drift pin.

Alternate log stringers butt and top on the cap, and block or shim under smaller stringers. Blocking should be firmly spiked to the cap to prevent it from vibrating out of position. (Blocking is discussed in more detail in the

Stringer Section.) If the stringers have been manufactured and the installation pattern is known before the log sill is hewn, it may be possible to hew the sill with built-in blocking. This process requires a man skilled with an adze or powersaw (Figure 169). This section of the sill is susceptible to decay.

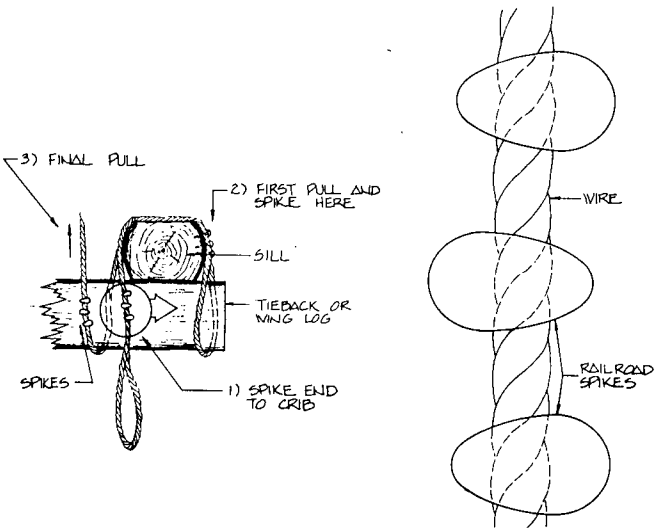


FIGURE 168. Lashing the sill

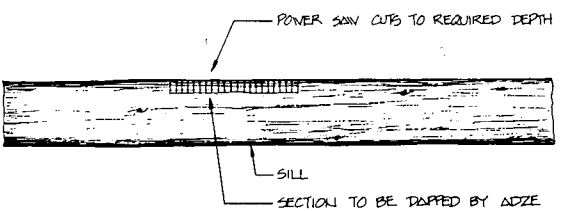


FIGURE 169. Hewing a sill with built-in blocking

- Decay prevention in the caps

Use cedar or treated timber for the cap. The cap is difficult to inspect after the bridge has been built—it is frequently in contact with water, and it has

poor air circulation. It should be field-treated with a preservative such as creosote, pentachlorophenol, copper napthenate, or fibrous asphalt. Take care to treat all ends and drill holes in contact areas. Remember that toxic preservatives require care in application and may require approval from government agencies.

Keep the pier dry by sloping the top, using a solid deck, and draining approach roads away from the bridge ends.

Keep the area around the stringers, the caps, and the pier clear of obstruction so air can circulate.

F. STRINGERS

Stringers are the main load-supporting members in the bridge. They must be designed and the design specifications must be followed. Maximum life and safety of the bridge depends on the selection, preparation and installation of the stringers (Figure 170). See the stringer-design section in this handbook.

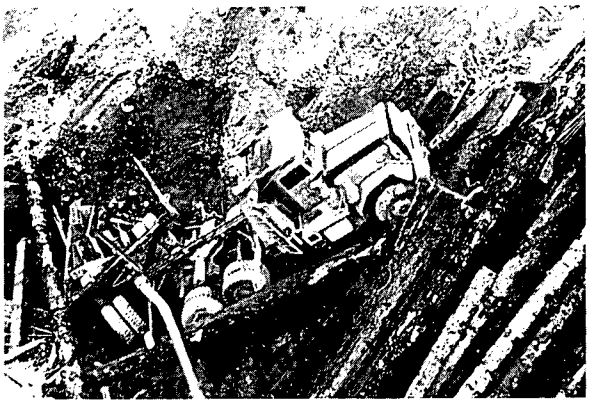


FIGURE 170. Stringer safety: overload or underdesign?

The durability of the stringers depends on the type of wood used. Douglas-fir combines strength and durability better than any other wood on the West Coast. Sitka spruce and hemlock can be used but are less durable, and Western red cedar is durable but often unobtainable in lengths required.

Remember that species found at the limits of their range may not be suitable. For example, Douglas-fir around the northern edge of its range tends to

be brittle, to split easily and to have defects. Overmature Sitka spruce usually has undetectable pocket-rot in addition to other visible defects, and cedar is susceptible to heart rot and hollow butts.

1. Stringer Selection

Before you select stringers, you must be able to recognize signs of timber defects and decay as well as any problems in falling and recovering the tree. There is no point in choosing trees from an area where the cost of recovering the large logs is excessive or where there is the danger of damage during felling or yarding. Trees standing near the bridge site are not necessarily good stringer material. Check by 'sounding' to see whether there is heart rot or the tree is hollow. Do not accept any hollow tree as a potential stringer. Even after longbutting, the rest of the tree may have incipient decay. Veteran trees left after the original logging are usually subject to ring and windshake.

A uniform stand of healthy trees should be judged by the following criteria:

- Trees should be larger than the calculated stringer sizes to allow for butt swell, long-butting, bark, and sapwood.

- Trees should provide stringers of similar sizes.

- Dominant or co-dominant trees with excellent outside appearance should be chosen.

- Old or wolf trees from a previous stand should be avoided. They usually have undetectable flaws.

- Overmature trees with dead tops and large dead branches may have decay, butt rot, hollow trunk, and loose rotten knots.

Examine potential stringer trees for the following visible defects:

- Decay: Reject trees with conk or mistletoe as these are almost certain indicators of decay.

- Cracks: Reject trees with visible cracks of any kind, partly because of the trees' susceptibility to decay.

- Large branches: Stringers should be free of large knots. Knots larger

than 3 1/2 in. on top and bottom and 5 1/2 in. along the side are not permitted in the mid-third section of the stringer.

- Suckers: These form areas of weak fibre and also permit decay to enter the tree trunk.

- Insect damage and bird holes: Surface indicators of insect damage will not normally be reason to reject a tree but if the tree has been under attack for some time it may have hidden decay.

- Forked and broken top: A broken top is an indication that the tree is overmature and decayed.

- Scars and catfaces: Short round scars may be acceptable but long scars may affect the load-carrying capability of a stringer. Catface is usually a sign of decay and should not be located in the middle of a stringer. Western red cedar is particularly subject to dryside or catface. Use an increment-borer to judge the extent of the damage and thoroughly examine the tree after felling. Powder worm may indicate decay in cedar.

- Spiral grain or spiral twist: A spiral twist to the grain is not serious in log stringers provided the tree is sound and not subject to other defects. Spiral-grain logs are more flexible than straight grain. Do no mix the two types on the bridge.

- Sweeps: Minor sweep does not affect the quality of wood. A curved stringer must be flattened on the top to support the decking and still have enough wood remaining to support the load (Figure 171). Gentle sweeps are acceptable in stringers for culvert-type log bridges.

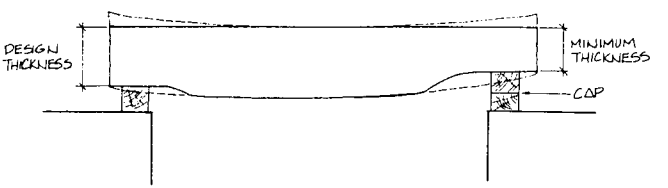


FIGURE 171. Flattening the top of a stringer with sweep

- Crooks: Many trees grown on hillsides have a crook at the butt. Remove the crook by long-butting. It is not serious if the stringer can be cut to its designed shape.

- Short crooks: These are a sudden deviation with different strength characteristics from the straight part of the tree. Reject trees with short crooks.

- Long flare and butt swell: Some trees exhibit large flare and are often hollow or rotten. The defect may be local and the tree may make a good stringer after it is longbutted.

- Insect-damaged, fire-killed or windthrown timber: Some trees killed by fire, insects, or wind are usable but you should look for decay.

2. Falling

Fell trees without damaging them. After studying the direction of fall and the ground conditions, prepare a smooth bed free of logs, stumps, and rocks. You may need a bulldozer or skidder to prepare the bed. If the natural lean prevents the tree from falling in the desired direction it may be necessary to use directional felling-devices (hydraulic jacks, pulling the tree with lines, etc.).

3. Ground Inspection of the Tree

Measure the tree to be sure that it will yield a stringer the right size. The tree may be longbutted at this stage but remember to allow for extra sizing and trimming.

The tree must be inspected before and after longbutting for the visible defects described for standing trees and for the following flaws:

- Excess taper: Taper is not a strength-reducing fault, but it may be difficult to fit all the stringers on the bridge. Taper is often the limiting factor in building long cedar spans.

- Heart rot and hollow pockets: These logs may be used for bridges with a very short lifespan, but not for other applications.

- Decay in knots: You may approve a stringer with some rotten knots but remember that the rot may progress into the wood.

- Compression wood: Compression wood appears in leaning trees, and is much weaker in tension than normal wood. It is characterized by large eccentric annual growth rings. Do not use stringers with a large proportion of compression wood.

4. Transportation of Stringers

Once the stringers are cut roughly to length, move them to a storage and preparation site. They can be ground-yarded with a bulldozer over short distances. Smaller stringers may be moved with a skidder, but a logging-arch and bulldozer combination is the best way to move larger logs short distances.

Stringers should be loaded on logging trucks for long-distance hauls and the route should be checked for clearance ahead of time. Use two trucks to handle long stringers. Face two trucks in the same direction and partially load the trucks with logs. Place crosslogs on the loads and cut notches for the stringers. The crosslog allows the clearance necessary for stringers to protrude over the cab of both vehicles. Do not fix the stringers on the crosslogs; leave the two trucks free to manoeuvre around corners.

You can also move stringers on two empty trucks back-to-back with the stringers on the bunks. This system is probably the best on curving roads, but the trucks must drive slowly and it is tiring for a driver to drive in reverse. It is important to tie the stringers to the bunks and to have both trucks equipped with two-way radio.

5. Stringer Storage and Seasoning

Stringers should always be seasoned for a few months before they are used because seasoned wood is stronger and lighter. Table IV-K demonstrates the increases in wood strength (Extreme Fibre in Bending and Modulus of Elasticity) by showing the stresses for well-seasoned and dried wood.

Logs shrink in diameter but not in length. The average radial shrinkage has been found to be 1.7% of the green dimension for Douglas-fir logs seasoned to 20% moisture content. Table IV-L shows the shrinkage of four different West Coast species.

If logs are to be stored for any length of time they must be blocked so that any natural sweep is deemphasized and no sag can develop. Logs stored for more than a month will take a permanent set. Another storage method is to let the logs sag. Each stringer is stored on two logs. These two logs support the stringers at the ends with the belly down. If they are seasoned this way they will not develop an extra sag when placed on the bridge. When the stringers are prepared they are ripped in this position to provide a level top.

TABLE IV-K. A Test Result of Stresses in Green and Dry Wood

FOR COMPARISON ONLY—DO NOT USE THIS TABLE FOR DESIGN

	Moisture Content of Green Wood	Green Wood	Air Dry (12% Moisture Content)
Coast Douglas-fir			
Extreme Fiber in Bending	38	4500	7800
Modulus of Elasticity	38	1570	1950
Western hemlock			
Extreme Fiber in Bending	74	3400	6800
Modulus of Elasticity	74	1220	1490
Western red cedar			
Extreme Fiber in Bending	37	3200	5300
Modulus of Elasticity	37	920	1120
Sitka spruce			
Extreme Fiber in Bending	42	3300	6700
Modulus of Elasticity	42	1230	1570

Extreme Fiber Stresses in Bending: psi
Modulus of Elasticity: 1000 psi

TABLE IV-L. Shrinkage in Percent Based on Green Wood Dimension

	WOOD DRIED TO 20% MOISTURE CONTENT		
	RADIAL	TANGENTIAL	VOLUMETRIC
Coast Douglas-fir	1.7	2.6	3.9
Western hemlock	1.4	2.6	4.0
Western red cedar	0.8	1.7	2.3
Sitka spruce	1.4	2.5	3.8

Logs should be stored with bark to prevent seasoning cracks. The bark prevents fast drying of the sapwood surface. Stringers should have good air circulation to allow drying and to prevent decay.

The moisture content of a tree varies greatly depending on its location, the weather and the season. Table IV-M shows the moisture content of 'green' wood for four species.

TABLE IV-M. Moisture Content of Green Wood

	Heartwood %	Sapwood %
Coast Douglas-fir	37	115
Western hemlock	85	170
Western red cedar	58	249
Sitka spruce	41	142

If the bridge is designed to be constructed out of dry wood and is actually built of green logs, there is a chance that the structure will be overloaded supporting less than the design load.

Each 1% of moisture content is equivalent to approximately 0.3 lb of water per cubic foot of wood. Water weight in green logs ranges from a low of 11.3 lb/ft^3 for fir heartwood to 74.7 lb/ft^3 for cedar sapwood. Five 'green' Douglas-fir logs (44 in. mid-diameter with a span of 60 feet) will weigh

20 900 lb more than they will after drying to 20% moisture content. In the case of hemlock this may be as much as 57 000 pounds.

6. Stringer Preparation

a) Debarking

Stringers for temporary or culvert-type bridges do not have to be debarked. Debarking may take place at the falling, storage or preparation site. Debarking seasoned logs is difficult. It is much easier to remove the bark from green logs which have been felled while the sap is up and running. On the lower B.C. Coast, this period is usually from mid-April to mid-June. Logs debarked during this period are subject to heavy checking, however, unless they are under shade continuously until seasoned—and even then checking should be expected. Remove bark by chopping and prying.

The best tool is a sharp spud or a good, heavy, swamping axe. It is easy to remove a strip of bark from the top and upper sides of the log when standing beside it. You will have to roll the log over so the logs should be set on crosslogs. Logs can be rolled with a winch-cable, or by hand using peaveys, or by a log (Gilchrist) jack. Three men are required for turning logs—two using peaveys and one setting the blocking. The skid logs should be small to make it convenient to debark, hew, and slab a large stringer. Larger skid logs should be used for small stringers to elevate them to the working height. Large stringers may require a working platform.

You may use a bulldozer blade to remove tight bark. This process requires care and should not be attempted if the log could be damaged.

Check the stringers for defects after debarking.

b) Preparation area

The preparation area is usually at the bridge site. Allow enough space in the preparation area for all the bridge material to be laid out for safe ripping and rolling and pre-fitting (Figure 172). A 4-ft diameter log requires 12.5 ft to be completely rolled over.

The work area allows the stringers to be laid out and worked in their sequential placement on the bridge. No swinging of the stringers will be required, and if the logs are set up on crosslogs they can be pulled directly into position on the bridge.

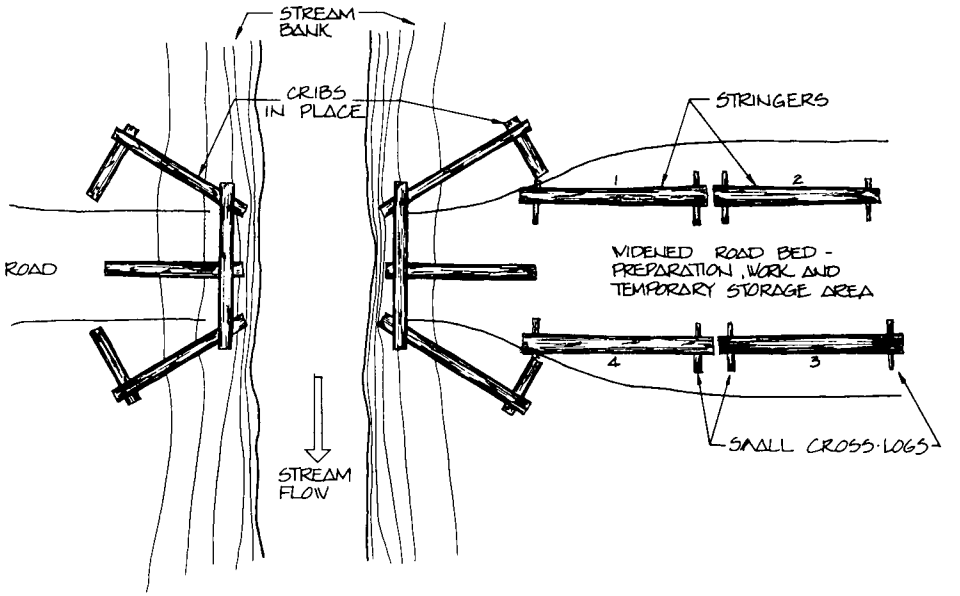


FIGURE 172. Stringer preparation area at the bridge site

Crosslogs support the stringers only at the ends. The stringer should be free of the ground and any other support. Crosslogs must be long enough so that the stringer can be rolled.

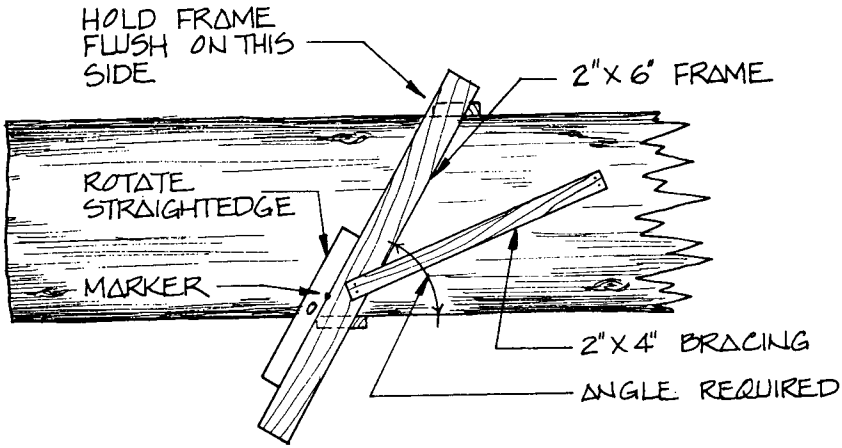
Once the stringers are on the skids ready for hewing, they must be rolled to the position they will take in the bridge.

Logs should have the natural sweep down. This will provide a wider slabbing of the top near the ends and more thickness in the centre where it is needed. (A log laid with a side sweep takes more than its share of room on the bridge and tends to twist every time a load passes.)

c) End cuts

Next, buck stringers to the exact length with a square cut. An experienced bucker may be able to do this without any help, but to be sure of accuracy, mark and frame the line to guide the cut.

Make the angle cut later. Frame for the cut with 2x6 lumber. A good way to make a line on the log after framing is to rotate a carpenter's level or other straightedge while it is held flush against the framing (Figure 173).



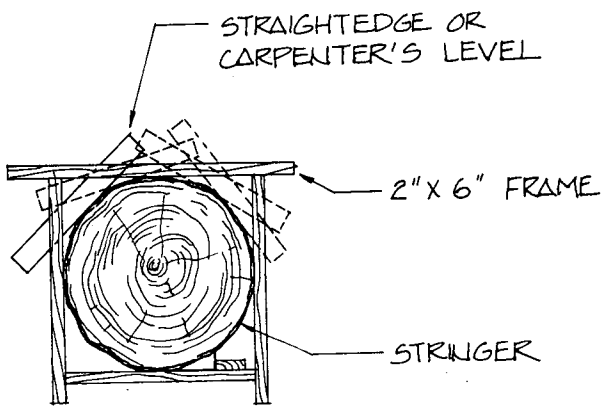


FIGURE 173. Using a carpenter's level to mark the end cut

d) Marking the stringer ends

Any carpenter's pencil or felt pen can be used for marking dry wood. On damp wood indelible pencil works best.

Once the ends are trimmed and the stringer is in position with its top up, draw a vertical line through the log centre at each end. This is a baseline that will be used for marking. Measurements will be taken from it and the stringer will be positioned by it. This vertical line is marked by using a plumb bob or a carpenter's level.

Draw the vertical lines on both ends of all the stringers and measure the butts and tops before marking any of the horizontal lines or making any further cuts. Decide on the exact location of each stringer on the bridge and plan the cuts necessary to make it fit. These measurements are especially important when the stringers are big, difficult to manoeuvre, and are to be placed close to each other. Figure 174 shows the stringers on a bridge and the area they will occupy.

FIGURE 174. Stringers on bridge and area they will occupy

Unless the stringers are oversized, only a minimum depth of wood should be removed to provide sufficient area for the ties. If the bridge contains four stringers, then a top surface width of about 8 in. (for 8-in. ties) is sufficient. This will give 64 in.^{2} of contact area for each tie on each stringer.

An 8-in. surface on a 20-in. diameter log requires a cutting depth of just over 0.8 in.; on a 24-in. diameter log it requires a cutting depth of 0.7 in.; and on 40-in. diameter logs it requires 0.4 in. cut.

A good rule-of-thumb is to limit the total cutting depth at the middle of the stringer to 2 1/2 % of its diameter size to minimize strength-reduction. This creates a flat surface of about 30% of the log's diameter. Another good rule is to limit the cut to the depth of sapwood at the middle of the stringer.

The small end of the stringer should have only a small cut. After you calculate the depth of cut, mark a horizontal line on both stringer ends with a carpenter's level. Now nail a board for sighting under this line. Stretch a string line over these boards to show the location of the cutline on the stringer. The end cutlines may require adjustment at this time.

The next step is to mark the horizontal line for the bottom cut. The butt of the stringer will always be big enough but the small end may require shimming rather than cutting. The best shims are planking and crossties, and the stringer end should be marked to allow for this depth. If a crosstie is not big enough for shimming, then the stringer is probably too small.

Measure the stringer depth from top cutline along the end baseline and mark it with a carpenter's level (Figure 175).

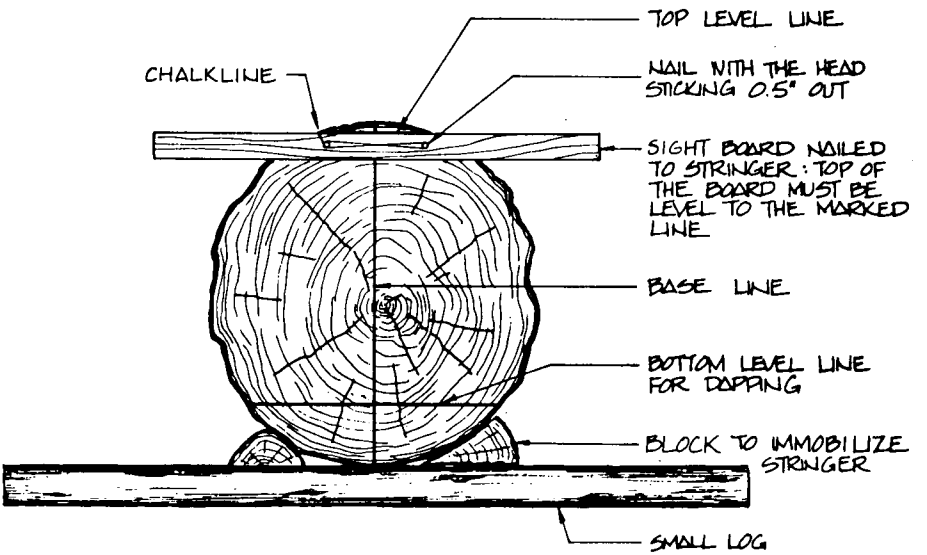


FIGURE 175. Marked stringer end

Carpenters' levels should always be checked for accuracy before starting a new job. The easiest way to check is to draw a vertical line with the level, reverse it, and check again. Do the same with a horizontal line. If the level does not show the same for vertical and horizontal, discard the instrument.

e) Marking the side of the stringer

We would like to emphasize again that before any marking is done, it is most important to have the stringer supported on cross-skids located only at the ends. Any natural sag will be allowed for in hewing and the top surface will be level and remain level when the log is on the bridge.

Mark the lines the length of the stringer, using a 'snap' or chalkline between the end boards. A chalkline can be used only in dry weather. If the line is wet or damp it will not release the chalk powder but the log must be damp to accept the chalk. The log must be clean and bark-free under the line.

The two boards on the log ends must be parallel. If they are not, all lines must be checked.

The chalkline is loaded with chalk before it is mounted on the boards. One end of it is hooked to the nail at one end of the stringer, taken to the other end of the stringer over the board, pulled very tight, and tied to the nail at that end.

A workman stands behind one end and sights over the boards while another workman pulls the chalkline away from the log (about one or two feet). See that the chalkline is in the same plane as the board tops and then quickly release it to snap against the log (Figure 176).

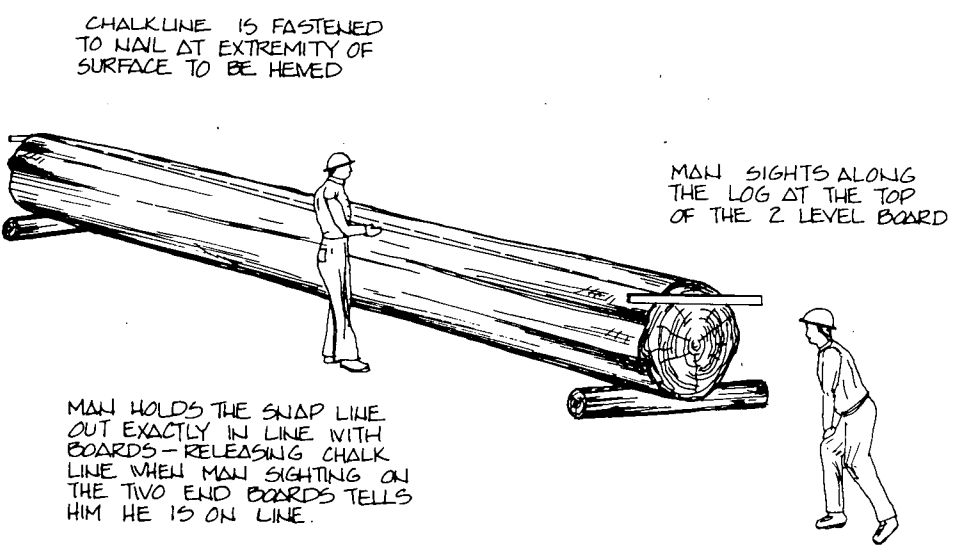


FIGURE 176. Marking the side of a stringer

After the chalk mark has been put on the log, it should be traced with an indelible pencil or lumber crayon to make sure it does not fade.

It is not customary to put any camber into a log-stringer bridge but if built in, it should never exceed 2 inches. If camber is required it can be marked on the stringers using a chalkline as follows:

- Mark the stringer ends and place a chalkline at a level that will allow for camber (Figure 177).

- Mark desired camber with a nail. Then mark one-half the camber with a nail at the one-quarter points along the stringer. Raise the sight boards to this level (Figure 178).

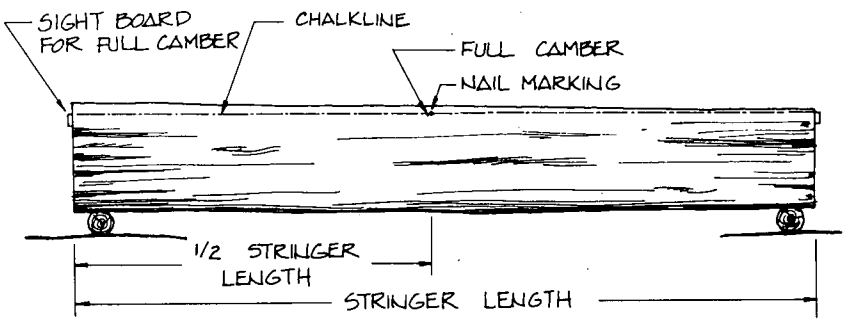


FIGURE 177. Marking full camber

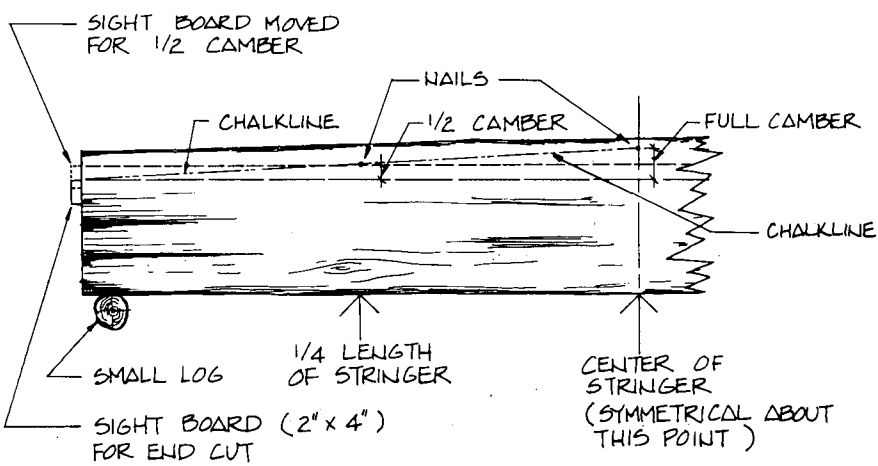


FIGURE 178. Marking 1/2 camber

Snap a chalkline between each pair of nails and use the sighting boards. (It is important to hold the chalkline exactly halfway between the nails when it is pulled for snapping—see Figure 179.)

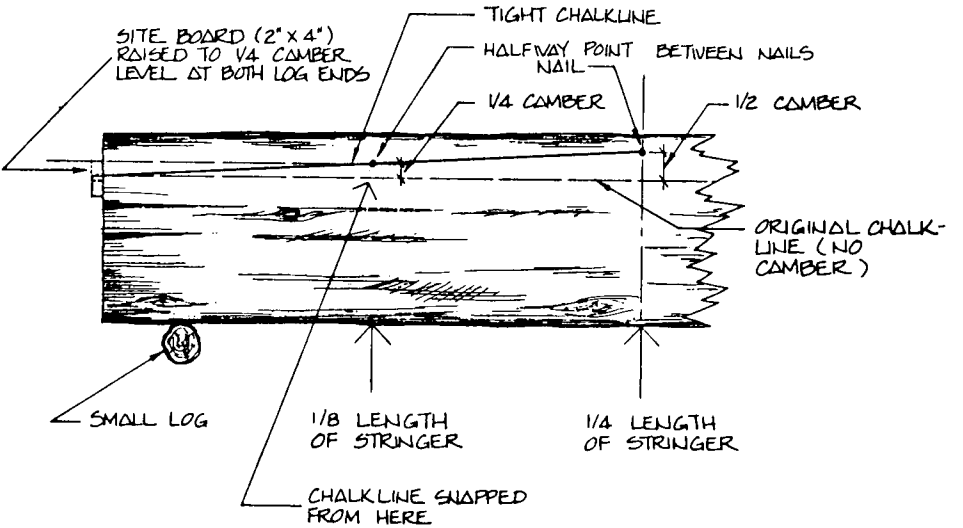


FIGURE 179. Using a chalkline to mark camber

f) Flattening the stringer top

A skilled man can hew a stringer with an axe, adze or broadaxe. Saw cuts are made every 6 inches along the stringer to the chalkline level before hewing. Ask a helper to watch the far side of the stringer to make sure that the cut does not go too deep.

An 'Alaskan sawmill' attachment with a powersaw allows two men to do an accurate job of hewing. The Alaskan sawmill requires guides or a straightedge placed level and at a measured distance above the chalkline. The rollers of the Alaskan sawmill will ride on this guide, and the saw will be suspended

underneath the guide and make a horizontal cut. A useful guide rail can be improvised using a long aluminum ladder. Straps hold the rails to the log. This works well on short stringers, but on long stringers it may be difficult to keep the guide straight.

The best way to rip a stringer is to use a large powersaw with a handle attached for two-man operation. One workman operates the saw and follows the chalkline on one side, and the other guides the end of the bar on the other side. The bar must be held level in order to make a flat cut. The saw or the bar end should be twisted to change direction rather than pushed down or pulled up. The cuts must be accurate enough so the crossties will lie flat on the stringers. If the cut leaves half the chalkline on the stringer then the job has been well done.

To start the cut with a two-man saw, nail a short piece of lumber (2x4 or 2x6) under the line. Rest the bar on this and leave the engine idling. Once the saw is in position and level, the workman operating the saw cuts into the stringer at least one-half bar-width while the other holds the end of the bar in position. When the bar cuts into the stringer, the saw operator holds the saw at that point and the pointman moves his end into the stringer. He then holds the end steady while the operator catches up. The pointman should always be ahead of the operator and only one end of the saw should be pushed for cutting at any one time.

g) Preparation of the stringer seat

Cuts on the underside of the stringer must be parallel to the top cuts or the stringer will not rest properly on the sill or cap.

Once the top of the stringer is ripped, turn it upside down on the skid logs. If the markings on the ends of the stringer are not clear, reestablish them using a carpenter's square and level. Then put a chalkline on the stringer as you would for ripping the top. The length of the cut on the bottom should be at least a foot longer than necessary for the caps. Make the mark at the ends about 6 ft long.

At the ends of the cut the saw should be turned upward and the cut finished on a gentle slope. To prevent stress concentration and slabbing never exceed a slope of 1:10 for the cut-out (Figures 180 to 182).

FIGURE 180. Correct cuts with gentle slope

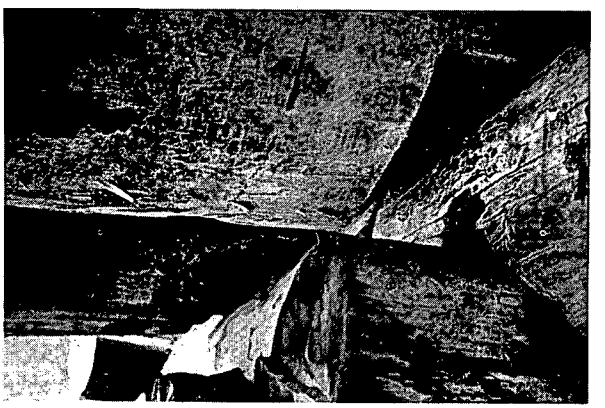


FIGURE 181. Incorrect cut

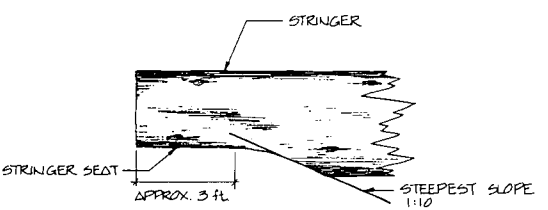


FIGURE 182. The slope of the cutout should never exceed 1:10

Figure 183 shows the reduction in cross-section if slabbing occurs.

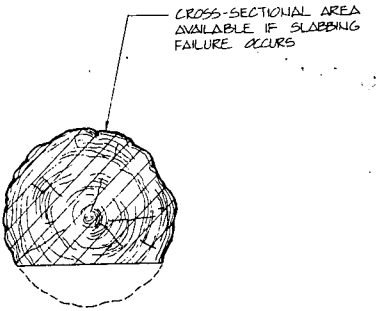


FIGURE 183. Reduction in cross-section from slabbing

Always make the sloping cut first to avoid the stress problem shown in Figure 184.

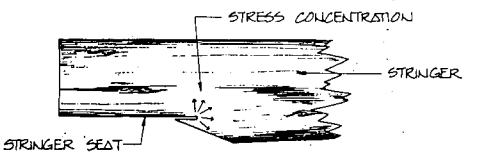


FIGURE 184. Incorrect cutting of stringer seat

When shims are necessary under a stringer, use a target to assist marking with the chalkline (Figure 185).

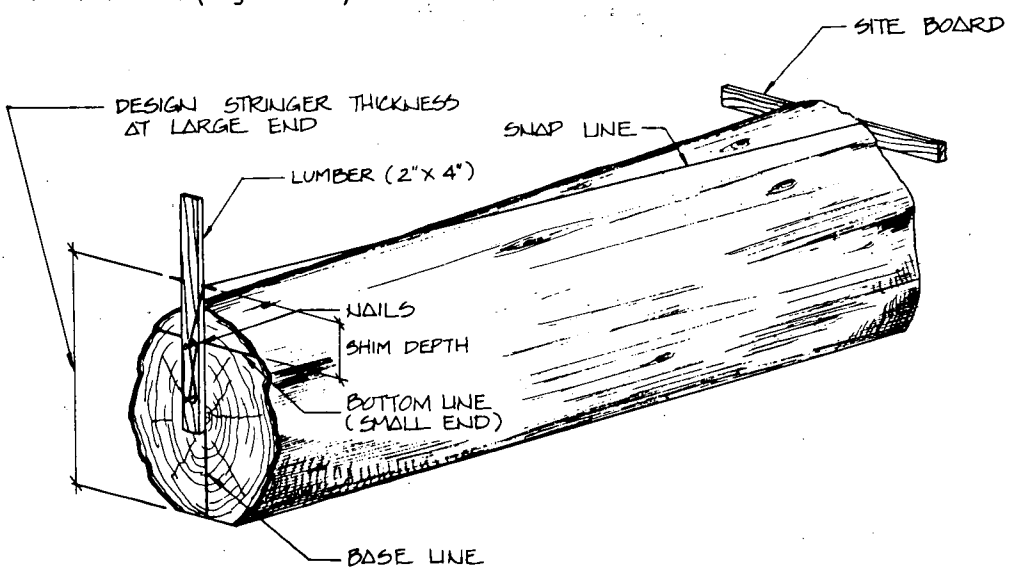


FIGURE 185. Marking the undercut (the stringer seat)

Shims should be at least as wide as the cap and should be made from sawn decking or ties, or from the same materials as the cap or stringer. If the stringers are cedar then shims should also be cedar (Figure 186). If the shims are not cedar, use preservatives or treated timber shims.

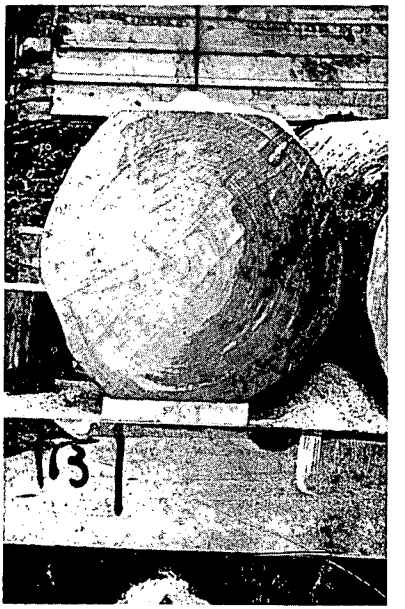


FIGURE 186. Shimming a stringer

7. Placing Stringers

Next comes the most delicate step in bridge building: placing the stringers on the abutment. If the working area was planned carefully, then placing the stringers will go smoothly.

Always remember to consult the fishery and conservation officers before using equipment in a stream.

It is important to know the exact location of each stringer on the bridge as it is specified in the design. Once all the stringers are placed, their location can be adjusted only a few inches in either direction.

If possible, place the centre stringer on the bridge first. Mark the centre of the bridge clearly on the centre stringer and also on the abutments.

If the placement must start at one side of the bridge or if the stringers are not placed tightly together, it is necessary to mark each stringer location on the abutments.

Handle stringers very gently and carefully to prevent damage. Large stringers may be moved with wire rope chokers, but large ropes or flat canvas slings are preferable for small stringers. Large cranes or crane-type log loaders are ideal for placing stringers. Two cranes, one at each end of the bridge, can manoeuvre and place the stringers.

A large crane set up in the stream can hoist the stringers by holding them near the balance point. The stringer is moved slowly, touching the ground here and there to maintain alignment. Once the stringer is resting on the caps, the hoist line is moved a few feet from the balance point toward the stringer end being positioned.

A heavy crane set up at one end of the bridge and guylined for safety may also place stringers. Long stringers are difficult to position this way, however, and it may be necessary to hand-position them by using log jacks. If a log loader is not available or if the stringers are too large to lift, slide them into position on rollers made of smooth peeled logs. Remember that once the stringer has reached its balance point over the opening, it will tend to nosedive into the hole. Two bulldozers pulling and snubbing can prevent this problem (Figure 187). The machine doing the pulling is best located on the opposite side of the bridge from the stringer, but if this is not possible, then a heavy block can be used to change the direction of the pull. The pulling machine should be well secured (Figure 188). Be sure that the machine and rope are large enough to handle the weight of the stringers.

If only one bulldozer is available, use the winch through a block system to tight-line the far end of the stringer and push the stringer with the blade. The stringer must always be tied to the blade (Figure 189).

In some cases it may be possible to float the stringers close enough for lifting into position.

The use of a false bent will ensure safety and success in placing the stringers and will add little to the cost. Basic falsework may be like the long pole shown in Figure 190. Mark the pole at a height where the stringer has to clear the sill on the far side. Lean the pole against the abutment at the machine side and push the stringer far enough so it will be in the proper position when the pole is leaning against the other abutment. The stringer may

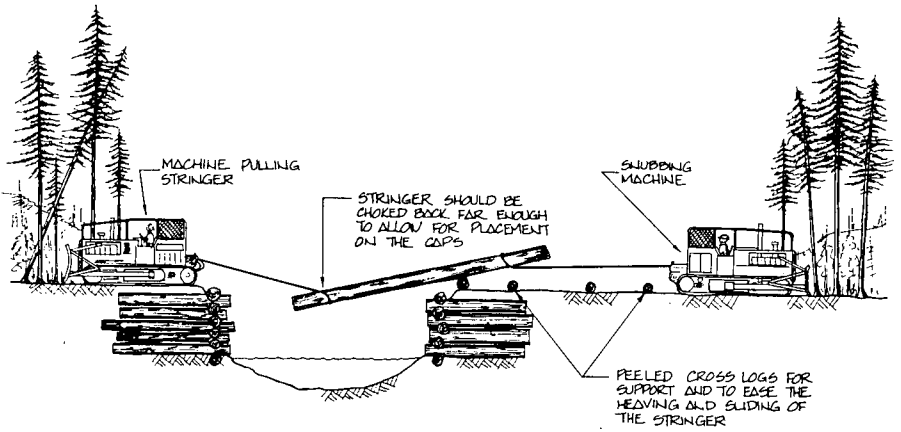


FIGURE 187. Stringer positioning using two bulldozers on either bank

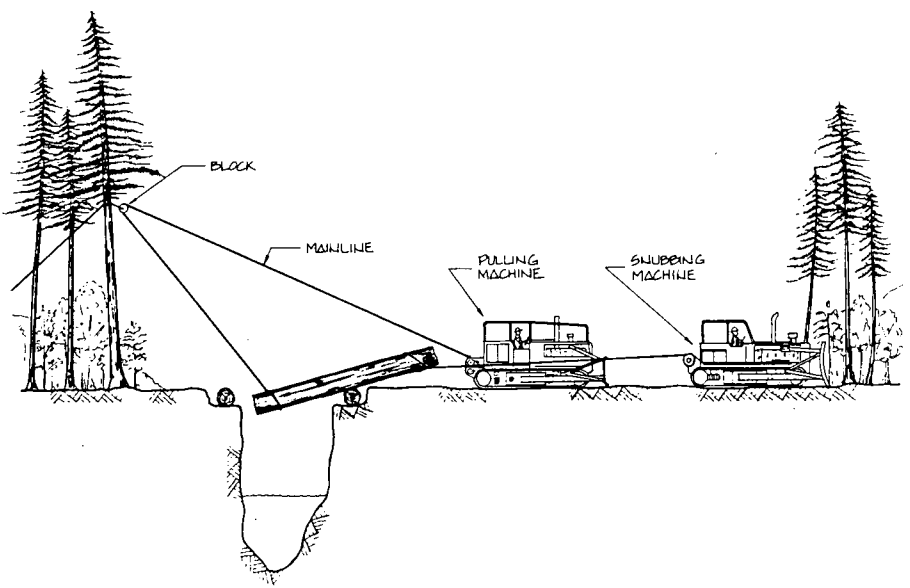


FIGURE 188. Stringer positioning with two bulldozers on one bank and a heavy block on the other bank

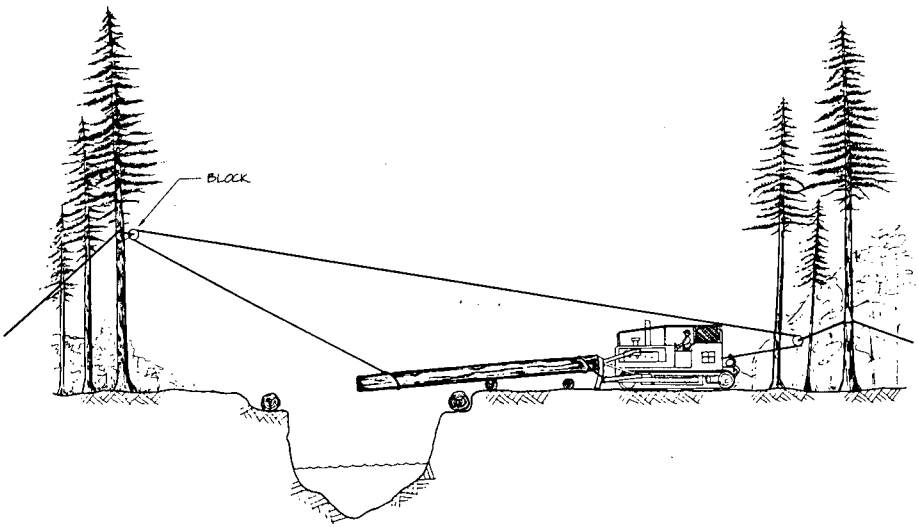


FIGURE 189. Stringer positioning using one bulldozer and a block system

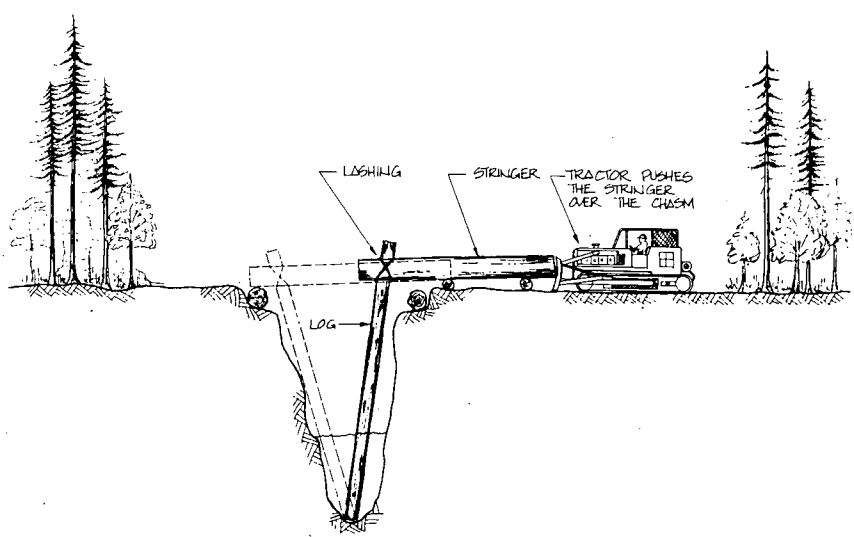


FIGURE 190 Stringer positioning using falsework

have to be raised on larger skid-logs to have it at the exact height marked on the pole. Take care the stringer does not swing sideways when pushed. It may be necessary to tie the pole to both sides of the stream. Another bulldozer can keep the lines tight.

Repeat the process for each stringer. After two stringers have been placed, they can be lashed solidly together and the remaining stringers slid across them and then rolled off onto the sill. (Gentle handling is impossible here, and the abutment and stringers must be strong enough to resist the abuse.) Two small logs may be put across the opening to assist in placing the first stringer.

You can use two crossed logs to prevent the side movement of the stringer while it is being pushed (Figure 191). (The falsework must be dismantled and relocated after every stringer.)

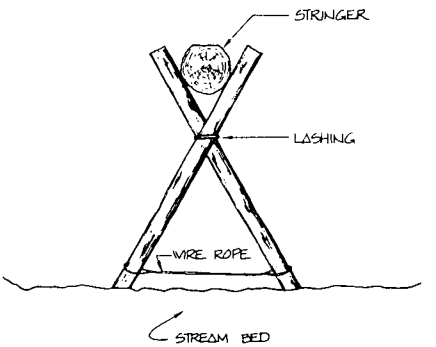


FIGURE 191. Falsework of two crossed logs is used to place a stringer.

After the stringers have been placed over the sill and shims, their position must be checked for accuracy.

Care taken in the preparation stage will pay off now. If the builder has done a good job in measuring and hewing, then shims probably won't be required. A straightedge (2x10) reaching from one side of the bridge to the other may be used to check the surface by moving it from one end of the bridge to the other. If one stringer is consistently lower than the other then it needs extra shimming. To adjust high stringers, lift the stringer up, turn it upside down and remove the appropriate amount of wood from the bottom seats. If the cap is more than 12 in. thick, the easiest remedy is to raise one stringer end and cut wood from the cap, then do the same thing at the other end. Take care to block the stringer to prevent it from accidentally falling back in place. The freshly-cut part of the sill should also be treated with preservatives.

Shim low sections in the stringer surface and remove the humps before you lay the crossties. The stringer surface should be even to within one-quarter inch, but as much as one-half inch is acceptable.

- Drifting

Tightly-spaced stringers will usually stay in place without being fastened to the abutments on a bridge with straight approach roads (Figure 192). Widely-spaced stringers (or stringers on bridges in a curve or at the foot of a hill) must be fastened to prevent movement under load. Always drift outside stringers.

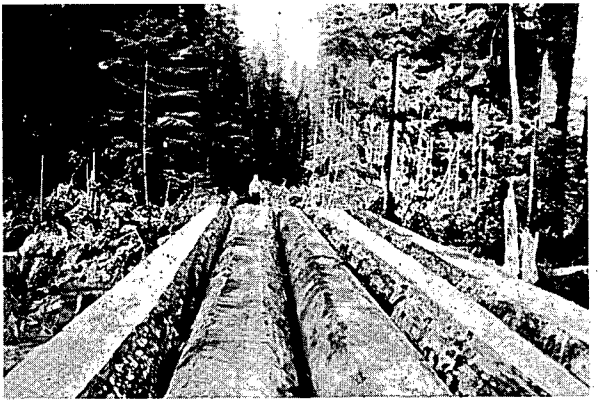


FIGURE 192. Tightly-spaced stringers

Drifts are made from round, mild steel, cut to the appropriate length and pointed at one end. Use 1-in. drifts for log stringers up to 30-in. diameter and 1 1/4-in. diameter drifts for larger stringers.

The drift hole must be pre-drilled right through the stringer and shims and at least 9 in. into the cap or sill. The holes must be deep enough for the full length of the drift. If you're using seasoned wood, make the hole 1/16-in. larger than the size of the drift in stringers with more than a 24-in. diameter. (If the wood is green, make the hole 1/8-in. larger.) Soak the hole with wood preservatives before you drive the drift. Drive the top of the drift at least 2 in. below the stringer surface. The excess space in the hole above the drift should be filled with a fibrous asphalt (not roofing cement) to prevent rot. Figure 193 illustrates drifting a stringer end. A heavy pipe 1 1/2-in. to 2-in. diameter may also be used as a drift.

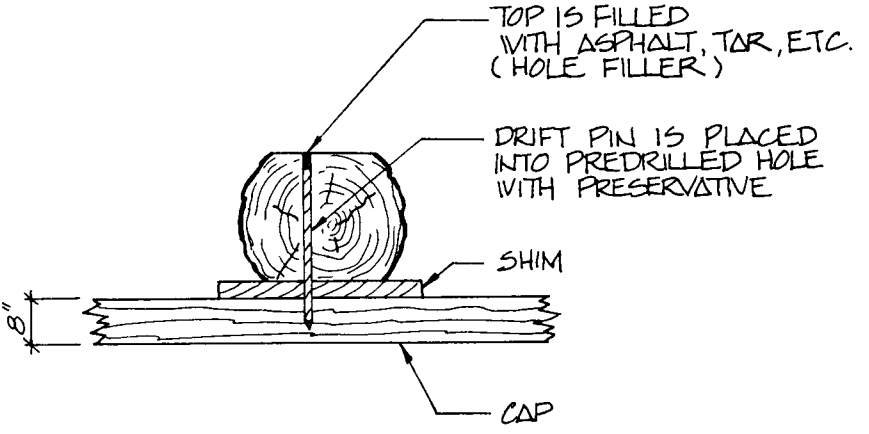


FIGURE 193. Drifting the stringer end

- Blocking

Fasten log stringers to the sill with wood blocks. If the stringers are tightly spaced, only the outside stringers need to be blocked. If not, spacers must be placed between the stringers (Figure 194). The wood blocks and spacers are wedge-shaped to support a larger stringer surface area but they can also be hewn to fit a round surface.

Pieces of crossties are usually big enough to use for blocks and spacers. Blocks are fastened with 3/4-in. round, mild steel drifts, driven in the predrilled 3/4-in. hole. After drilling, the hole should be soaked with wood preservatives once again and the top must be waterproofed.

- Lashing

If there is any danger that the superstructure could float off the piers during a flood, then it must be lashed to one end of the bridge. Three types of lashing are discussed here.

- Cable lashing is tightly wrapped around the stringers two and one-half or three times and secured by spikes or staples on culvert log-bridges—and occasionally on timber-decked bridges (Figure 195).

  Staple or spike the cable to the outside stringers at least; many bridge builders spike it to every log.

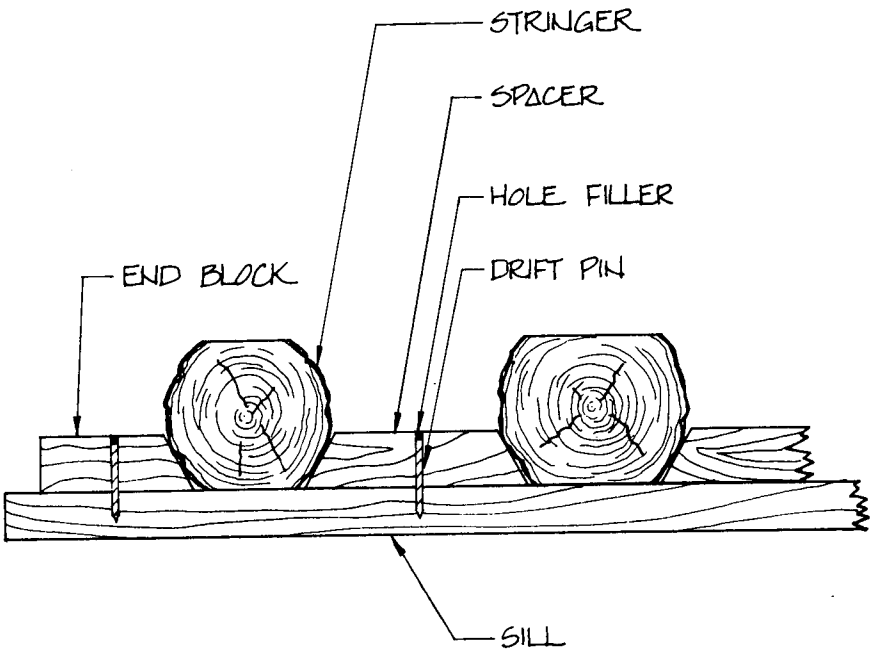


FIGURE 194. Blocking to secure stringers

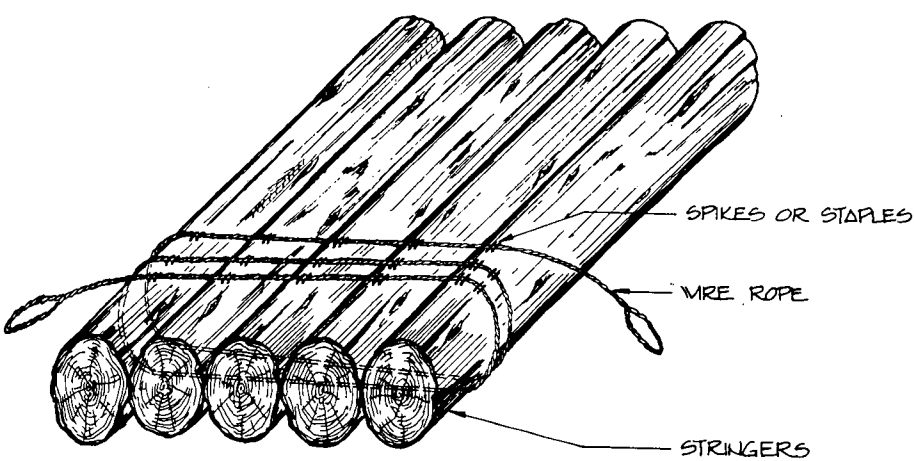


FIGURE 195. Lashing the stringers

Put the lashing on a timber-decked bridge before you spike the crossties and then fit the lashing between them. It may be helpful to hammer two guide spikes into outside stringers so the cable does not move when pulled tight.

- Needlebeams are lashed to stringers on timber-decked bridges as shown in Figure 196.

- Stringers and guardrails are lashed to a crosslog or needlebeam to support a gravel deck on a culvert-type bridge (Figure 197).

Although we've sketched only one set of lashing, in actual practice a second complete lashing line would be added. Lashing cables must always be tight and must never cross each other.

Table IV-N gives a guide for the minimum size of cables to be used when logs are lashed at least 2 1/2 times. A cable should be flexible wire rope of good quality and its breaking strength should not be less than one-third the design load.

TABLE IV-N. Cable Size Requirement for Lashing

(Improved Plow-Steel, Wire Core)

Minimum Cable Size		Design Truckload in Tons
mm	in	
25.4	1	150
22.1	7/8	100
15.9	5/8	50

8. Stringer Configuration and Load Distribution

The stringers should be grouped under the wheels to distribute the load evenly (Figure 198). On short bridges with wide running surfaces the gap between the stringers at the centre might be too wide, and the ties and inside stringers could be overstressed with an off-centre vehicle. To protect the bridge from unevenly-distributed loads, use extra stringers to fill the gap or leave the gap open without planking. (See also the Decking section of this handbook.) Another method is to lay an extra strip of planking over the decking. Any of these techniques will help to guide the wheels over the stringers.

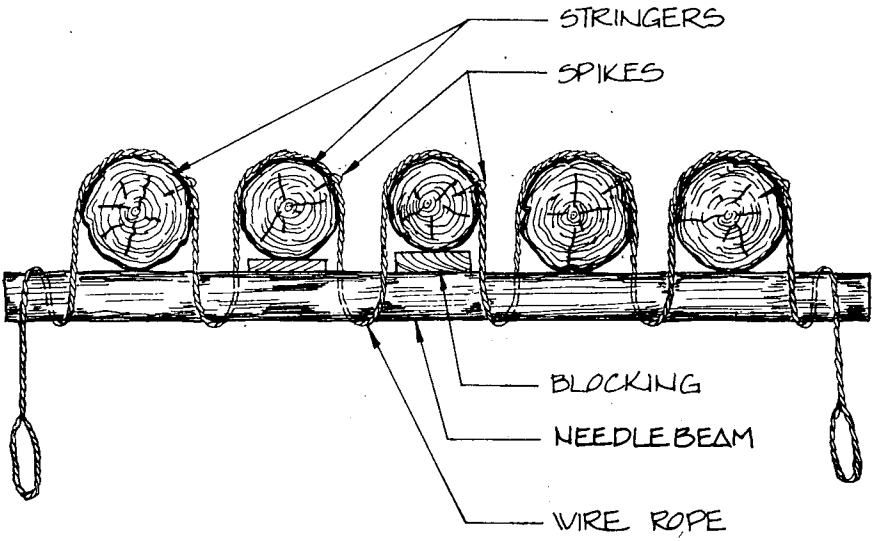


FIGURE 196. Lashing stringers to a needlebeam

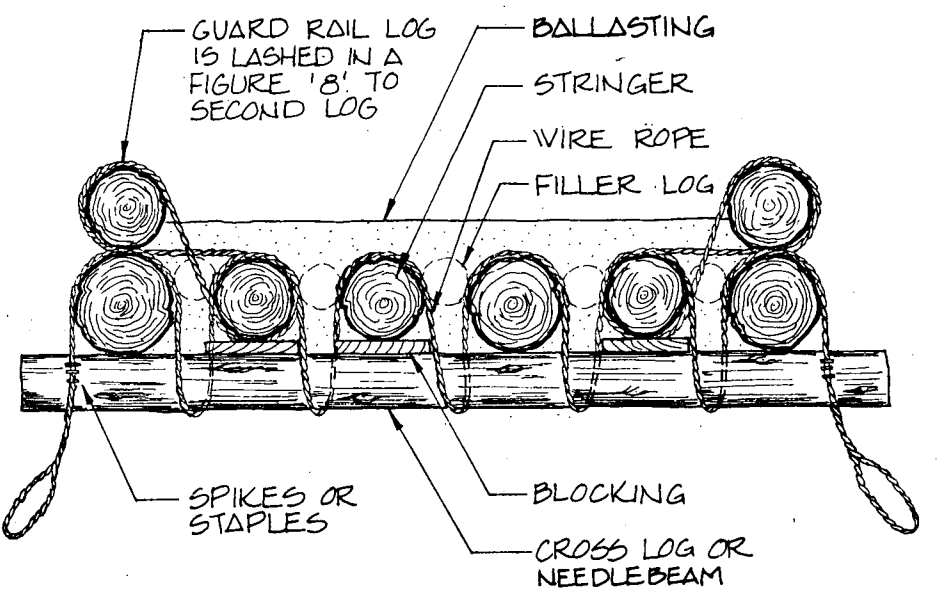


FIGURE 197. Stringers and guardrails lashed to needlebeams

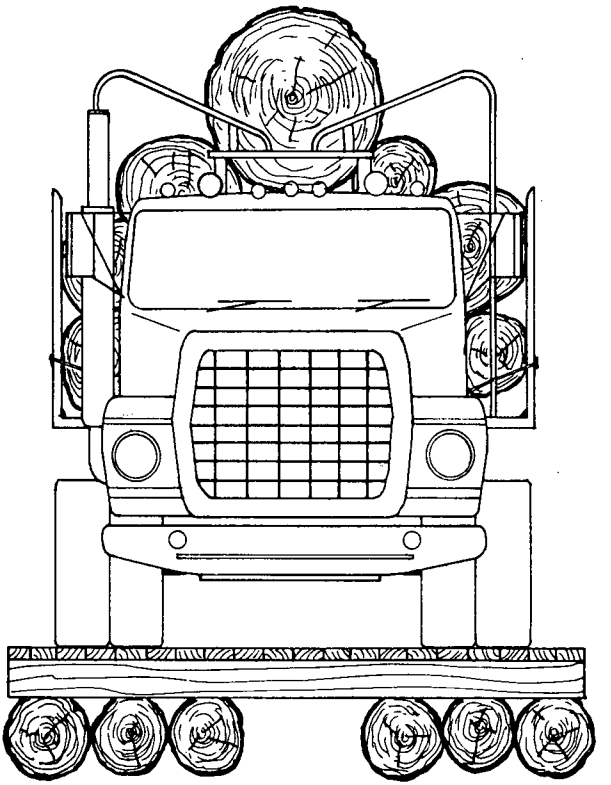


FIGURE 198. Grouping stringers to distribute weight under the wheels

Ideally, the required number of stringers should fit under the bridge deck. If the deck is wider than the necessary running surface the crossties may deflect, overstressing the stringers (Figure 199). You can reduce this problem by using needlebeams, stringers as guardrails, or double tier stringers.

a) Needlebeams (queen logs)

A needlebeam is a large log or steel beam which ties the stringers together and distributes the load. It makes the stringers work as a unit and deflect together.

Use needlebeams if evenly-spaced small logs have been used for stringers; if there is a large variation in stringer size; if the bridge has a wide running surface necessary to haul occasional wide loads; or if there is no other way

to spread the load over the stringers. A needlebeam can also be used to tie a culvert-type bridge together.

- Log needlebeams

Table IV-O may be used as a guide to establish minimum needlebeam sizes. Increase needlebeam sizes if more than six stringers are used.

TABLE IV-O. Log Needlebeam Sizes

BRIDGE LENGTH	NEEDLEBEAM DIAMETER
up to 15 ft	Same as largest stringer end
15 ft to 24 ft	Same as design stringer diameter
over 25 ft	Same as smallest stringer end

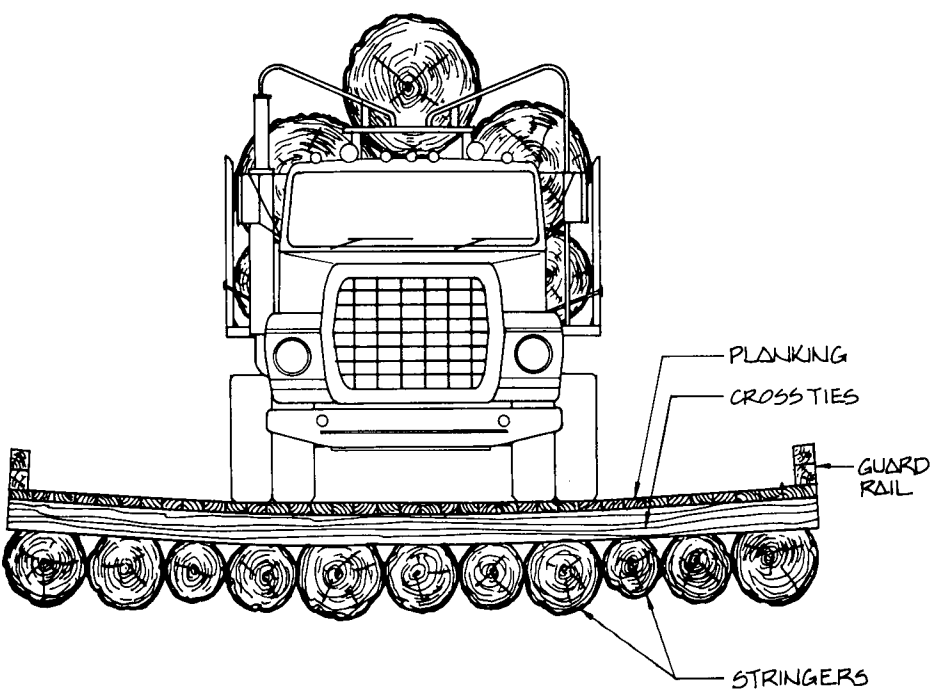


FIGURE 199. Long crossties bend under load on wide running surface

Logs may be used for needlebeams with no preparation other than removing the bark (Figure 200). Bark removal is necessary to provide a lasting tight fit. For semipermanent or permanent bridges, the top of the needlebeam should be ripped flat to make a larger contact surface and provide a surface for blocking.

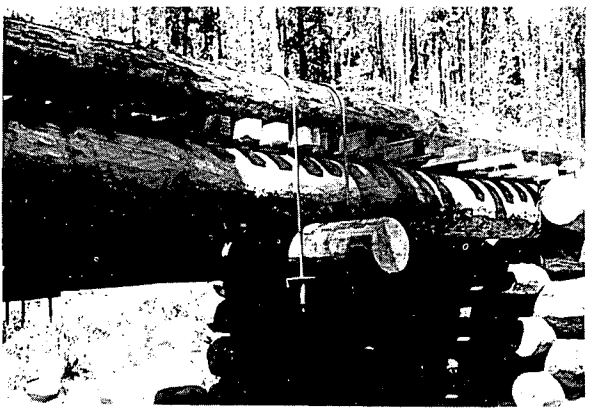


FIGURE 200. Round log needlebeam—note spiral grain in stringer.

Fasten needlebeams to the stringers with lashing, bolts or saddles. Lashing is discussed in the Log Cribs and Culvert-Type Log Bridges sections of this handbook, and saddles are shown on the following pages in conjunction with stringers as guardrails.

- Steel needlebeams

Place steel needlebeams between the crossties if clearance under the bridge is limited.

9x3/4-in. mild steel plates are welded on both sides to 8x2 1/2-in. structural channel to form a steel needlebeam for a 10-in. crosstie (Figure 201).

This fabricated beam is attached to the stringers with 1-in. to 1 1/2-in. diameter bolts, wire rope, or mild steel plate slings as shown in Figure 202.

6x3/8-in. flat, mild steel bars can be bent to the log shape like a sling. (Use 1/4-in. steel on stringers less than 24-in. in diameter.) The slings should be built so they can be tightened up later. The outside bolt may be tightened from the deck but the inside bolts should be tightened from the bottom. Weld the top of the bolt to the needlebeam.

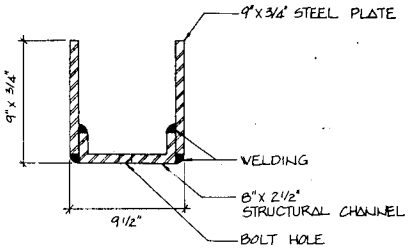


FIGURE 201. Cross-section of a steel needlebeam

Wire rope used for slings should not be less than 1-in. diameter and should be connected to the bolts with a wire-rope socket. Nail "tree plates" (cut from 4x3/8-in. flat mild steel bar 12 in. long) to the stringers to prevent the rope from cutting into the wood (Figure 202).

Use a double steel-needlebeam if additional strength is required. A needlebeam between the crossties is bolted to another under the stringers (Figure 203). All stringers rest on the lower beam. Use blocking to avoid cutting deeply into the stringers.

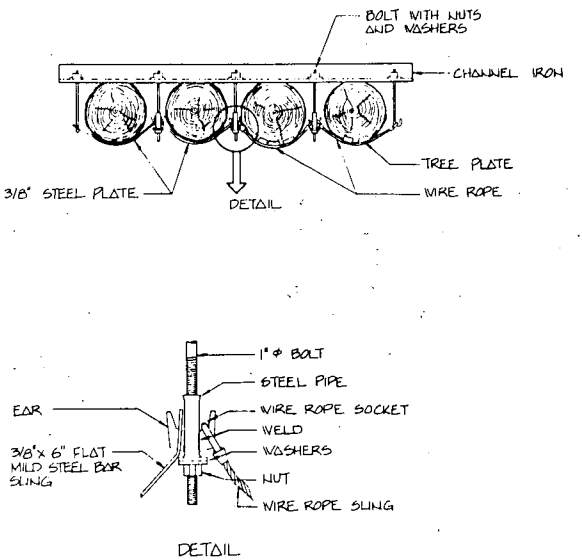


FIGURE 202. Fastening a steel needlebeam to stringers

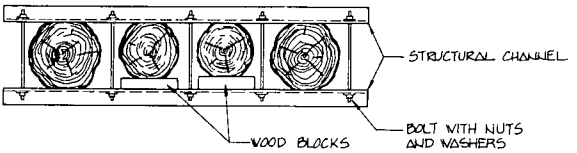


FIGURE 203. Double steel-needlebeam

b) Stringers serving as guardlogs

Two stringers may be placed on the crossties directly above the outside stringers and tied to them with a needlebeam (Figure 204 and 205).

You can use steel needlebeams for extra clearance.

Guardlog stringers must be the same size as the other stringers and must be pre-tensioned to carry their share of the dead load. Both ends of the guardlogs are dapped and blocked into position so that their top is parallel to the deck. Mark both log ends an equal distance above the deck (Figure 206). Snap a chalkline between these points. Tighten the needlebeam sling-bolts until the chalkline is parallel to the lower stringers.

The guardlogs are fastened with wire rope saddles and slings. Smaller stringers may be bolted but this results in some loss of strength and it is difficult to drill through three logs.

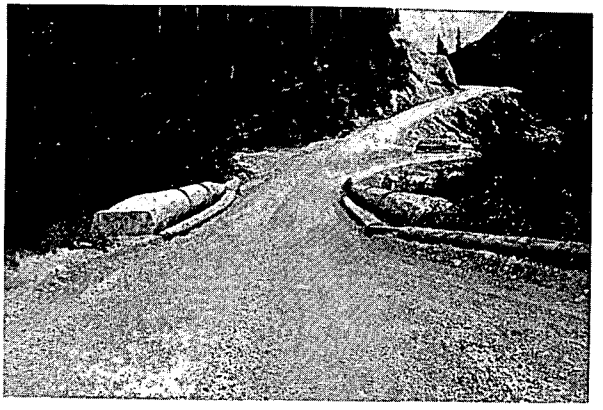


FIGURE 204. Stringers as guardlogs

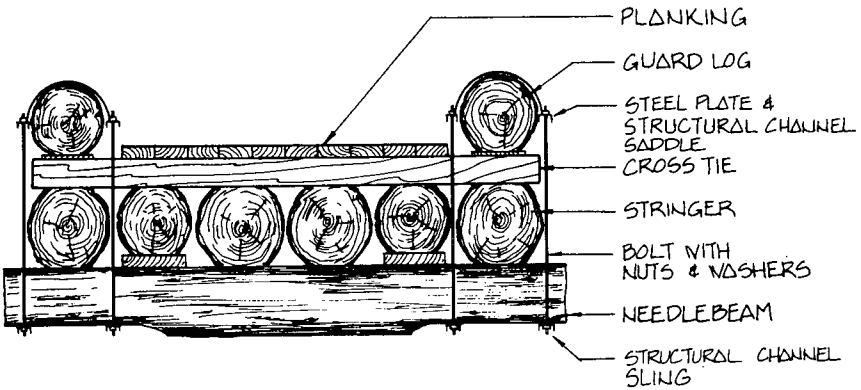


FIGURE 205. Bridge cross-section with stringers as guardlogs

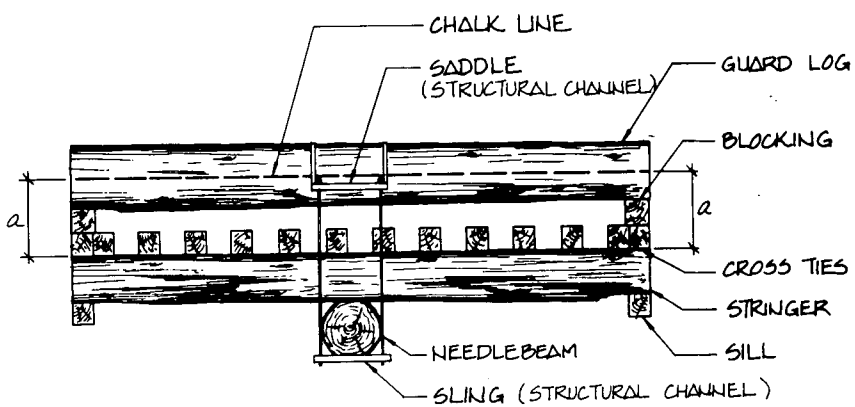


FIGURE 206. Pre-tensioning a guardlog

Figure 207 shows the needlebeam secured with lashing. It is important to keep the lashing tight and to re-lash older bridges.

Figure 208 shows double saddle-fastening and Figure 209 shows a steel double-channel with long bolts.

c) Double-tier stringers

You can see from Figure 210 that stringers are positioned in tiers so that a great many can be fitted across the width of the bridge.

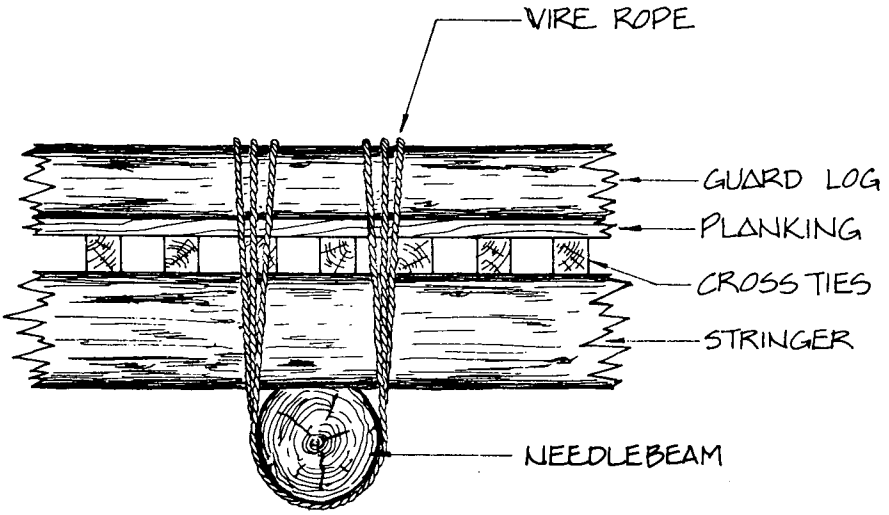


FIGURE 207. Guardlogs lashed to a needlebeam with wire rope

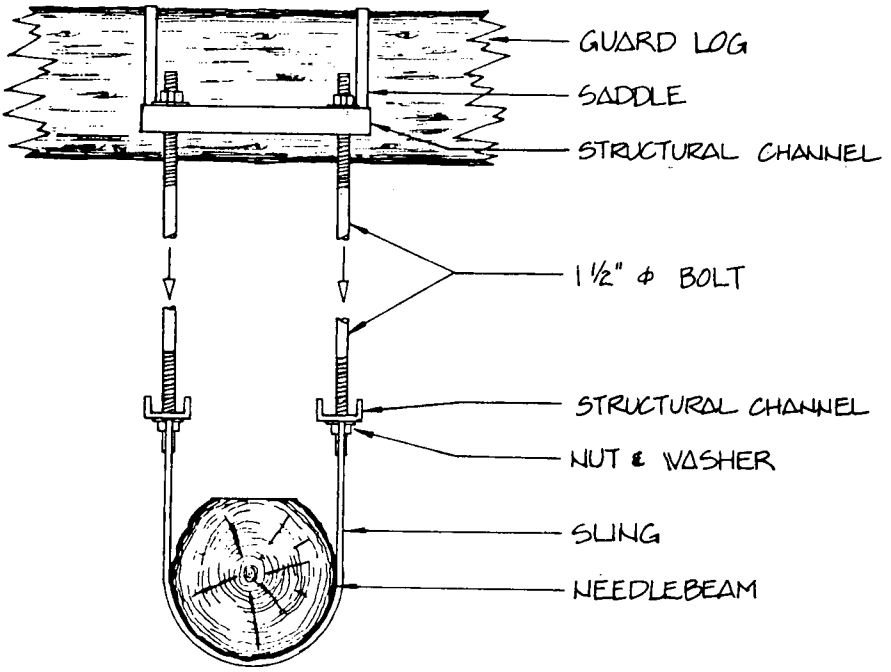


FIGURE 208. Double saddle-fastening

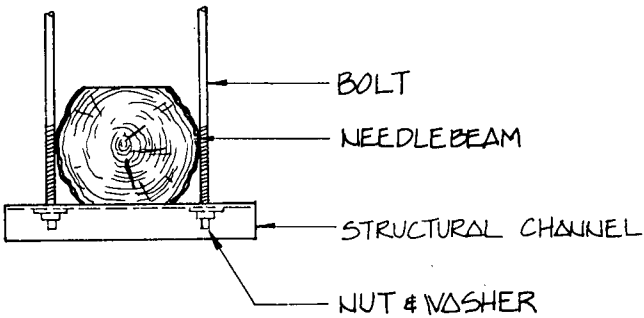


FIGURE 209. Structural channel and long bolts

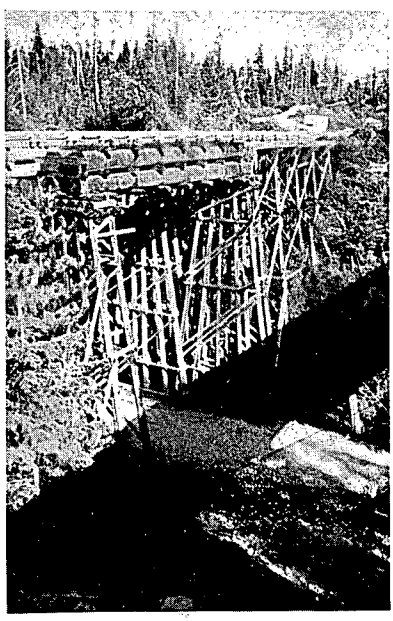


FIGURE 210. Placement of stringers in tiers

Use this design when more than four extra stringers are required or when stringers cannot be used as guardlogs. Pair bottom stringers to the top stringers. If there are fewer stringers in the bottom than in the top, a gap is left in the centre. Alternate butt and top stringer ends across the width and between top and bottom pairs.

Prepare the bottom stringers as usual. Dap both ends to sit on the sills and rip the top flat. Rip the top of the upper tier stringers. Mark the design mid-diameter on the butt of each upper stringer and rip the bottom parallel to the top at this point. The small end of the upper stringers will not be dapped. Use shims between the needlebeams as required.

Rip the needlebeams to the same thickness. Table IV-P shows the required number of needlebeams.

TABLE IV-P. Needlebeams Required Between Double-Tier Stringers

SPAN	NUMBER OF NEEDLEBEAMS
up to 20 ft	3
21-40 ft	4
over 40 ft	5 (not more than 15 ft apart)

The figures in Table IV-P include those for the two end needlebeams placed between the stringers above the caps.

Before placing stringers, mark them and the sill for the exact location. Place the bottom-tier stringers according to the design (Figure 211). Fasten the outside bottom-tier stringers to the sill.

Next, position the end needlebeams above the sills and drift or tie them to every stringer. Space the rest of the needlebeams and fasten them to the outside stringers.

Now put the top tier of stringers on the needlebeams. Block each stringer after it is in the correct position and before the next stringer is put on the bridge. Blocking should be tight, but not enough to pre-tension the stringer so that the crossties will not lie evenly (Figures 212 to 214). Shimming and blocking must cover the full width of the needlebeam's top surface.

You can use stringers on temporary bridges without ripped surfaces but the extra shimming might cost more than preparation of the stringers. The advantage of this type of structure is that long spans can be constructed with small-diameter stringers. Use only tie-and-plank decks (Figure 215).

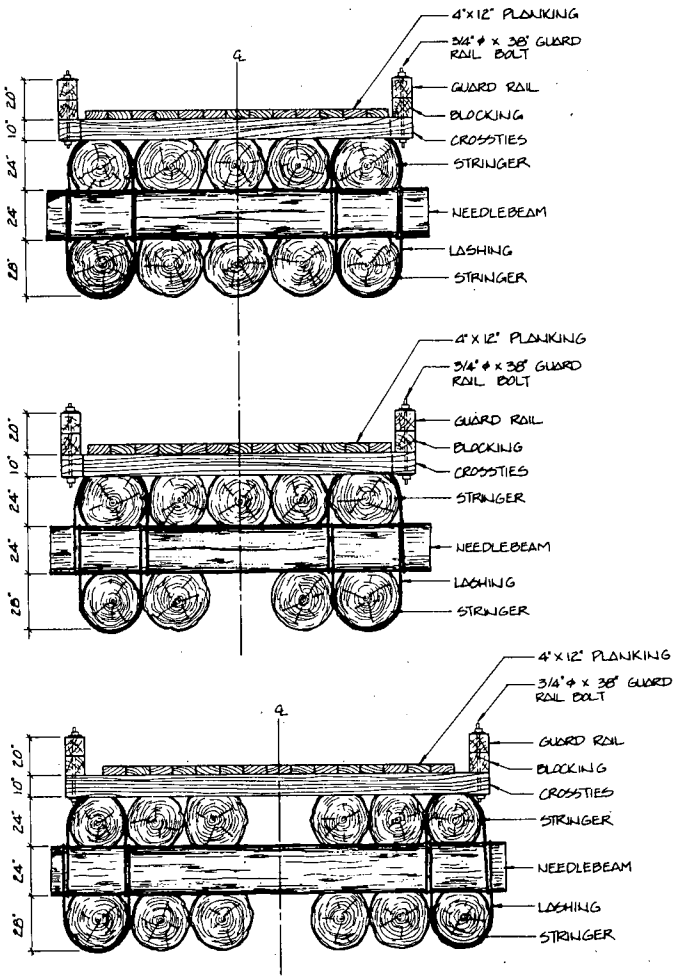


FIGURE 211. Variations in spacing stringers

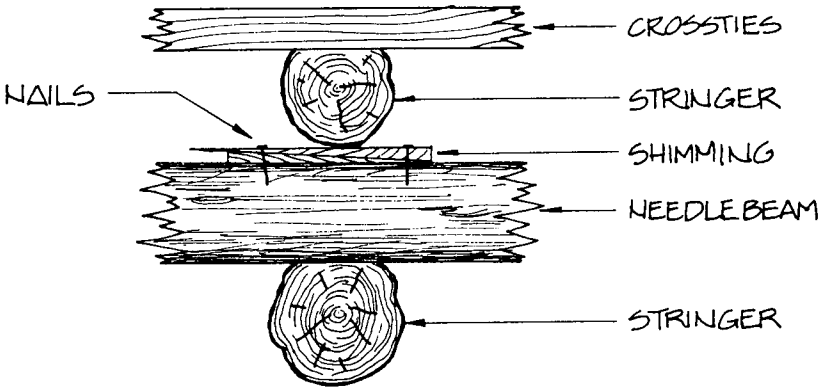


FIGURE 212. Cedar shingle shimming

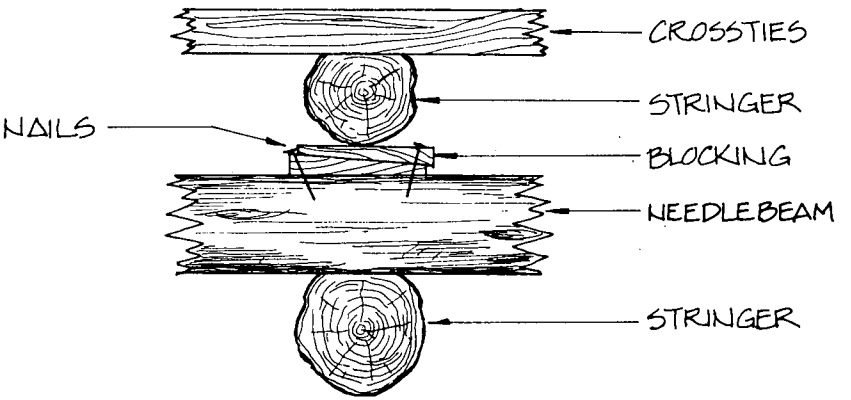


FIGURE 213. Blocking with wedge-shape blocks

d) Culvert-type log bridges

The culvert-type bridge is low-cost and easy to erect but it has a short life. Its gravel deck does not distribute the load but does help protect and stabilize the stringers. Stringers for this type of bridge are not ripped and its sill-log tops are seldom prepared.

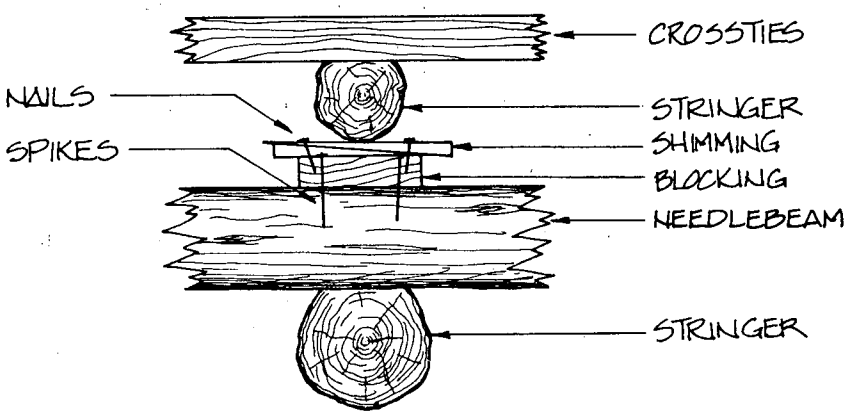


FIGURE 214. Shimming with shingles over blocks

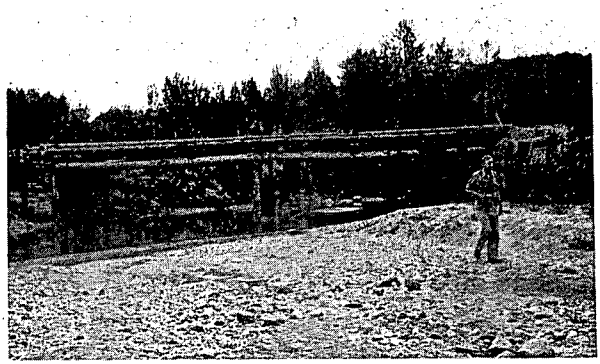


FIGURE 215. Double-tier stringers with tie-and-plank deck

It is not necessary to debark the stringers for every temporary bridge but they must be tightly lashed. As the stringers dry and shrink, the traffic forces ballast between them and keeps tension in the lashing cables. You may use green wood if the extra weight is not a limiting factor.

Although the construction technique may be very crude, take care that the stringers do not extend much over the sill logs. If they do, continuous traffic pounding on the ends will loosen the surfacing material.

It is not necessary to tie the stringers to the sill log, but the stringers themselves must be solidly tied together by lashing or needlebeams lashed to every stringer.

Table IV-Q shows the relationship between lashing diameter and stringer diameter.

TABLE IV-Q. Wire-Rope Sizes for Culvert-Type Bridge Lashing

Wire Rope Diameter	Largest Log Diameter
5/8 in	13 in
3/4 in	18 in
7/8 in	24 in
1 in	32 in

Wire rope should be wrapped 2 1/2 times (or more) around the stringer to form the lashing. Less may cause the rope to slip at the staples. Table IV-R is a guide to the lashing requirement for culvert-type log bridges.

TABLE IV-R. Lashing Frequency for Culvert-Type Bridges

Mid-Diameter of Stringer	Lashing Frequency
up to 20 in	10 ft or less
21 to 40 in	15 ft or less
over 40 in	20 ft or less

Needlebeams should be used for stringers less than 30 inches mid-diameter and for bridges with spans exceeding 30 feet. Use Table IV-R for needlebeam spacing.

Log needlebeams may be rough and unprepared for temporary structures. For durability they must be barked and flattened for blocking.

Culvert-type log bridge superstructures are usually built on simple (or crib) abutments, although some of the more elaborate gravel-decked bridges are supported by steel pipe piles with concrete caps (Figure 216).

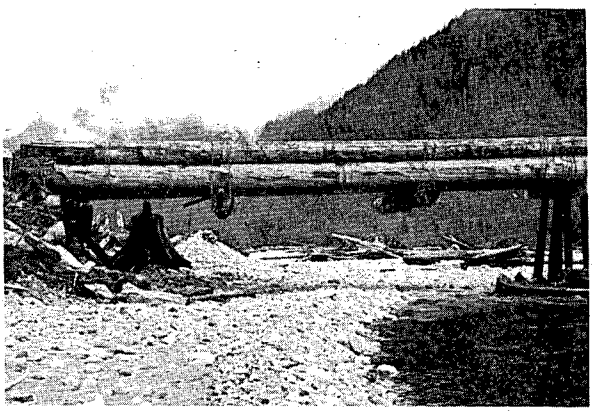


FIGURE 216. Culvert-type log bridge on a steel-pipe pile pier

Once the abutment is complete, place the stringers on the sill log and lash them together. Trim the stringers after the lashing is completed.

The stringers may be placed in a variety of configurations as follows: Figure 217 illustrates stringers without guardrails.

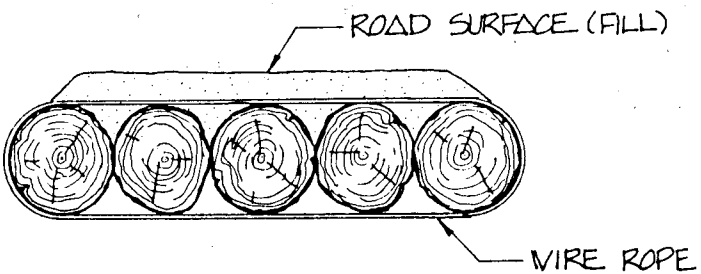


FIGURE 217. Stringers without guardrails

Figure 218 shows large stringers serving as guardrails and fill retainers. Three different sets of wire ropes are used for lashing. Two sets tie the outside stringers to the adjacent ones (solid line) and one set (open line) ties the inside stringers together to maintain friction between the logs.

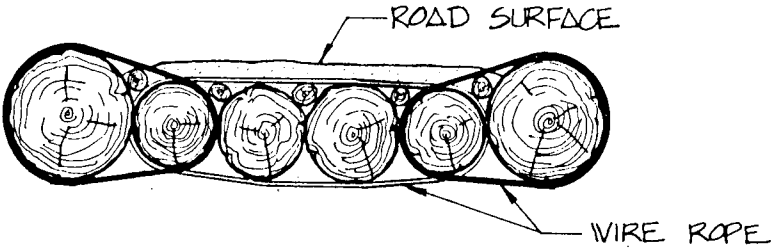


FIGURE 218. Large stringers serving as fill retainers

Figure 219 shows three stringers on the outside lashed together (solid line) to form a guardrail. A second line is wrapped around these stringers loosely to form a cradle for the inside stringers. The lashing on the centre stringer should be tight enough so that it pops out of place. Once all the lashing is complete, a backhoe or bulldozer can force the centre stringer back down before surfacing.

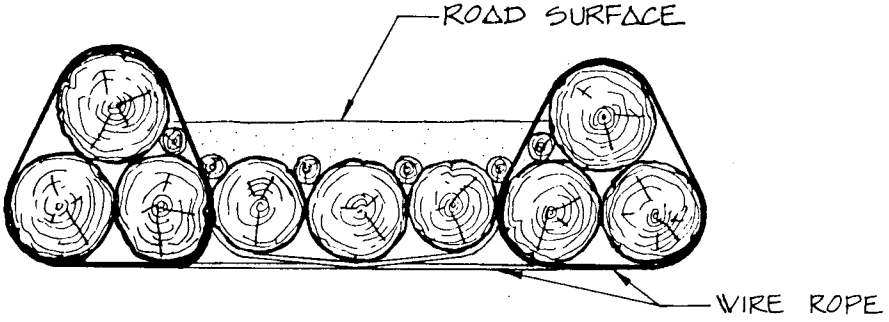


FIGURE 219. Triple-stringer guardlogs

The two outside stringers can be positioned above each other (Figure 220) and tied together with a smaller log (open line) resting on the inside stringers. Form a cradle of wire rope (solid line) to support the inside stringers. The technique shown in Figure 219 is used to tighten the cables.

Figure 221 is the same structure shown in Figure 220, but smaller logs are bolted to the outside stringers to contain the fill and serve as guardlogs.

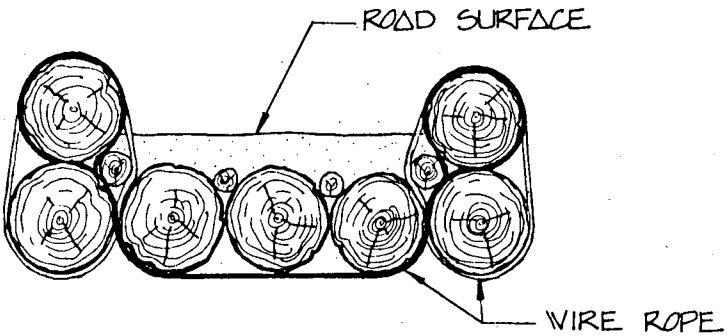


FIGURE 220. Double stringer guardlogs

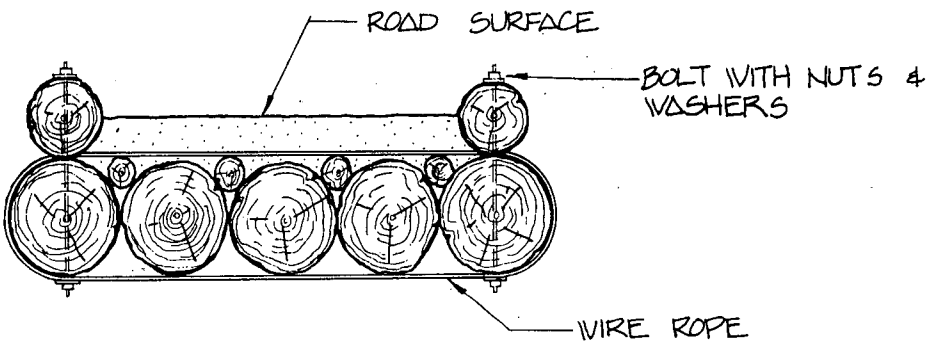


FIGURE 221. Small guardlogs bolted to stringers

The use of a needlebeam is illustrated in Figure 222. Two stringers serve as guardlogs. The two outside stringers are bolted together and the top of the bolt is tied to the needlebeam to prevent the guardlog from moving.

You can elevate the outside stringers by placing a smaller log under them, as shown in Figure 223.

Figure 224 illustrates logs lashed together as in Figure 217. Small logs or slabs are placed on top to serve as a crosstie (Figure 225). They may break during the surfacing process but will continue to distribute the load over the stringers.

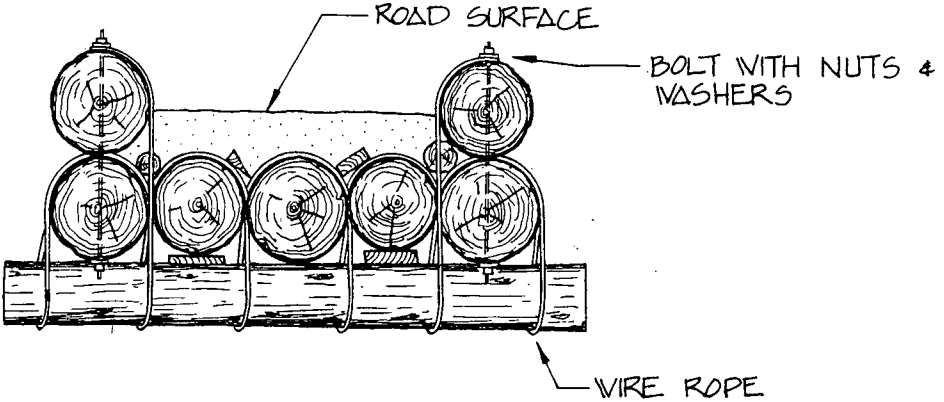


FIGURE 222. Bolted guardlogs tied to needlebeam

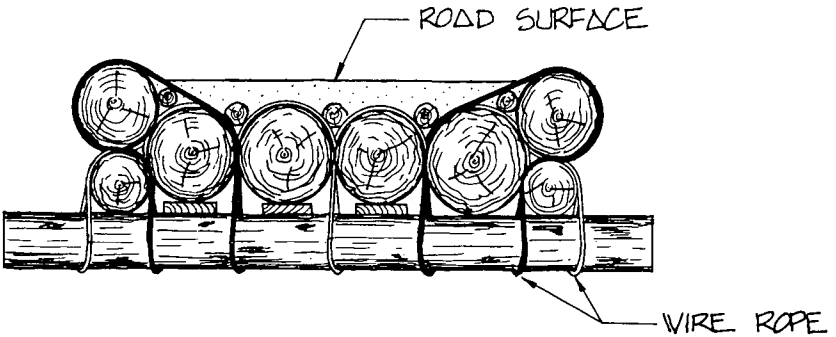


FIGURE 223. Outside stringers elevated to retain the fill

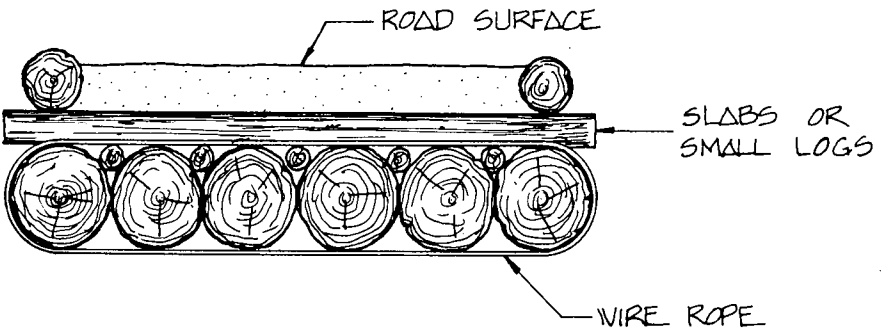


FIGURE 224. Slabs and small logs over stringers

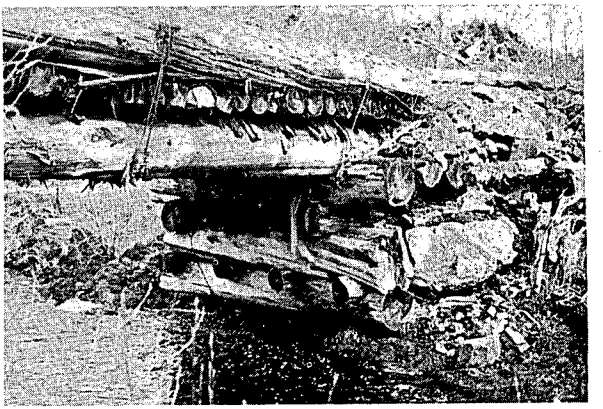


FIGURE 225. Slabs and small logs distribute the load.

Fill the spaces between the stringers with slabs or small logs, then cover the stringers and slabs with at least two layers of good quality rot-resistant filter fabric (road-construction fabric). The fabric should be loose and pushed into the holes so it adheres to the original surface and does not break. This lets the water drain but retains silt and protects the stream. It also makes it easier to remove the superstructure at some later date without dropping the gravel material into the stream.

The surface material should not contain any particles larger than one-third of the ballast thickness. Lay the ballast on the bridge in the normal way, compacting it to the designed thickness. Use a front-end loader on long bridges. Never exceed the design ballast thickness. Never take the sag out of a bridge by levelling it with fill material. Don't let the surfacing layer wear down to the point where a stringer is directly exposed to the traffic.

Culvert-type bridges need extensive surface maintenance. Road-graders should grade the bridge surface when they grade the road. Take care that the grader blade does not cut the guardlog lashing on the stringers.

e) Trussed-log bridges

Trussing is a simple and practical way to extend the span with locally-available log stringers. Theoretically it is possible to triple the maximum span length with a given stringer by using an inverted queen truss. The trussing carries the full load and the logs span only the distance between the trussing points.

Wire rope and steel rods are the standard materials used for trussing. Wire rope is expensive, difficult to tension, test and inspect, and it eventually stretches. It is readily available for temporary logging bridges, however, and

is used to reinforce older bridges. Wire trusses are discussed in the Maintenance Section.

High tensile-strength steel rods are easy to tension evenly, cheap to purchase and easy to inspect. In this chapter we discuss one type of high tensile-strength steel rod: the DYWIDAG deformed-billet steel concrete-reinforcing threadbar, which is commonly called a 'DYWIDAG ROD.'

These threadbars were developed as reinforcing bars for prestressed concrete and as anchors for rock bolts. The entire length of the bar is deformed with a continuous rolled-on thread which does not reduce its strength. Sleeves, nuts and washers are designed for use with threadbars. You can cut them any length or splice them with couplers as shown in Figure 226.

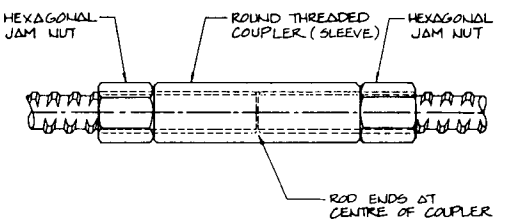


FIGURE 226. Threadbar coupler

Use an abrasive cutting tool (not a cutting torch) and avoid high temperatures which might weaken the steel. Purchase rods with black-jacket coating that is not sensitive to ultraviolet light for protection from corrosion.

Special hydraulic jacks for tensioning the rods can be rented from the dealer.

Make sure threadbars are handled carefully during fabrication and shipping. Discard bent rods or bent sections. Do not attempt to straighten damaged bars. Join cut pieces by coupling—do not weld. Round off cut ends for safe handling.

Other high-strength steel rods may be substituted for DYWIDAG but the thread deformation and the fittings must match. A qualified engineer should certify the strength of substitute rods.

Three equal panels are used for the following bridge designs. The depth of the needlebeam is L/11 and L/16 of the bridge span. Although other thread-

bars are available, we use Grade 150 in our designs—No. 10 DYWIDAG threadbars with a 1.27-in. diameter and yield strength of 150 000 psi. We use two bars with each stringer in our designs, but you may use four.

These trussed-log stringers were designed for superstructures with crosstie and plank decking; we do not recommend other deck types for this application (Figure 227).

Trussing is illustrated in Figure 228. The steel rods are fastened to the stringer ends. The truss rods must cross the horizontal centerline of the stringers above the cap or sill to force the stringers to bend upward and help support the load. Loads crossing the centerline between the abutments will deflect the stringers downward.

Threadbars pull against the stringer ends with the help of 'strongbacks,' a welded structural channel fabrication supporting the threadbar, washer and nut (Figures 229 and 230). The strongback is nailed to the stringer for temporary support during construction. Table IV-S shows the recommended specifications for the strongback.

TABLE IV-S. Structural Channels for Strongback

Design Load	Structural Channel Size (inch)	Weight/Foot (lb)	Web Thickness (inch)
150 t	8	18.75	0.487
100 t	7	14.75	0.419
50 t	6	13.00	0.437

The needlebeams and rods are joined with the help of a bracket made from half-inch steel plate (Figures 231 and 232). It is important that the vertical centerline of the needlebeam be exactly halfway between the angle formed by the rods (Figure 232).

FIGURE 227. Trussed-log bridge

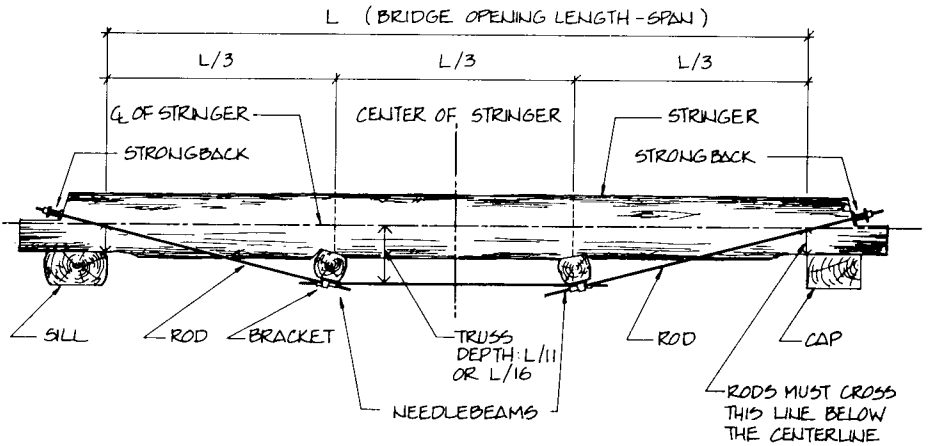


FIGURE 228. Diagram of trussed-log bridge

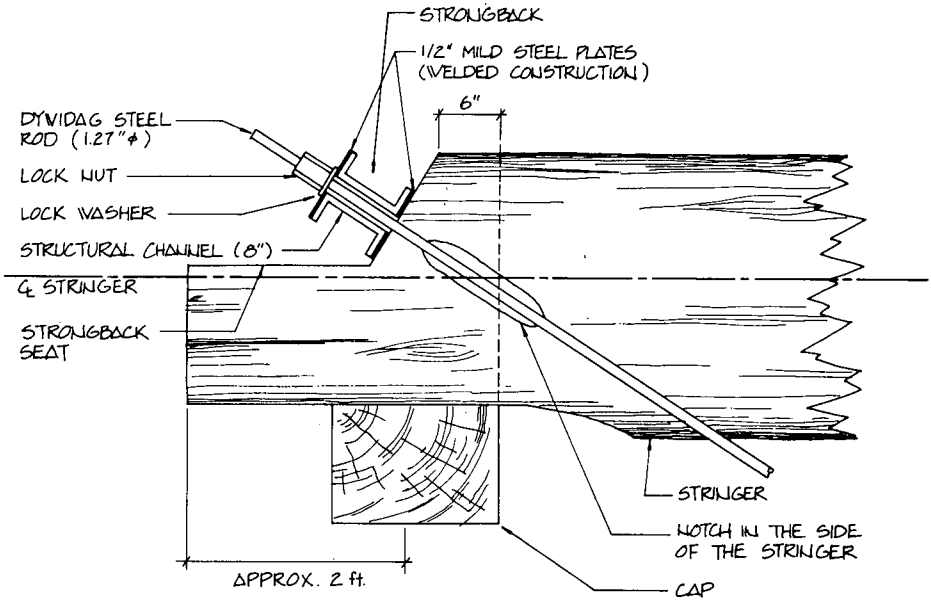


FIGURE 229. Fastening the rods to the stringer ends

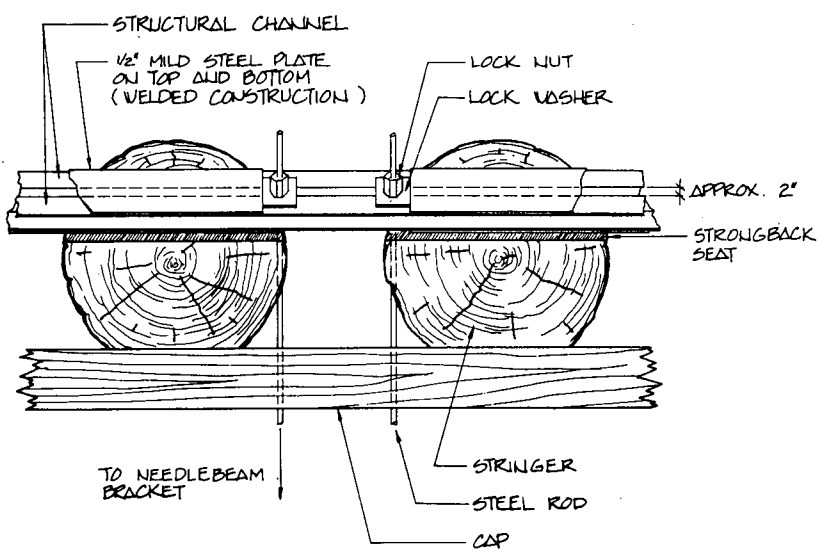


FIGURE 230. Strongback construction

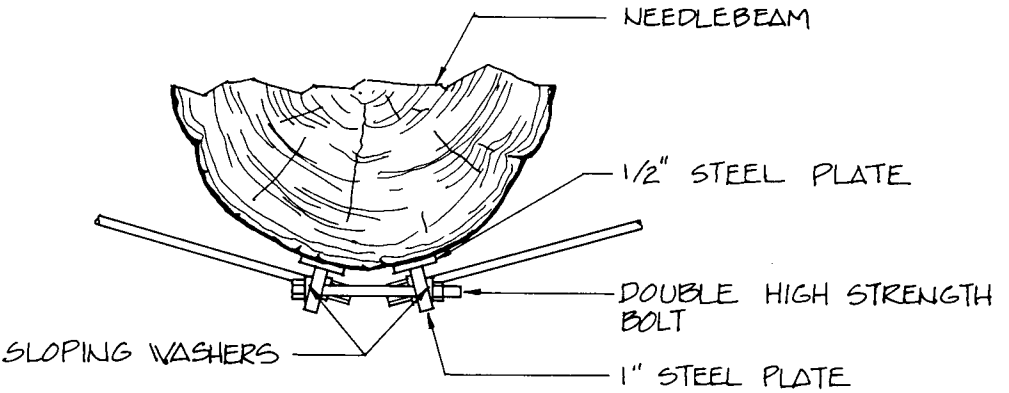


FIGURE 231. Threadbar centre-connector

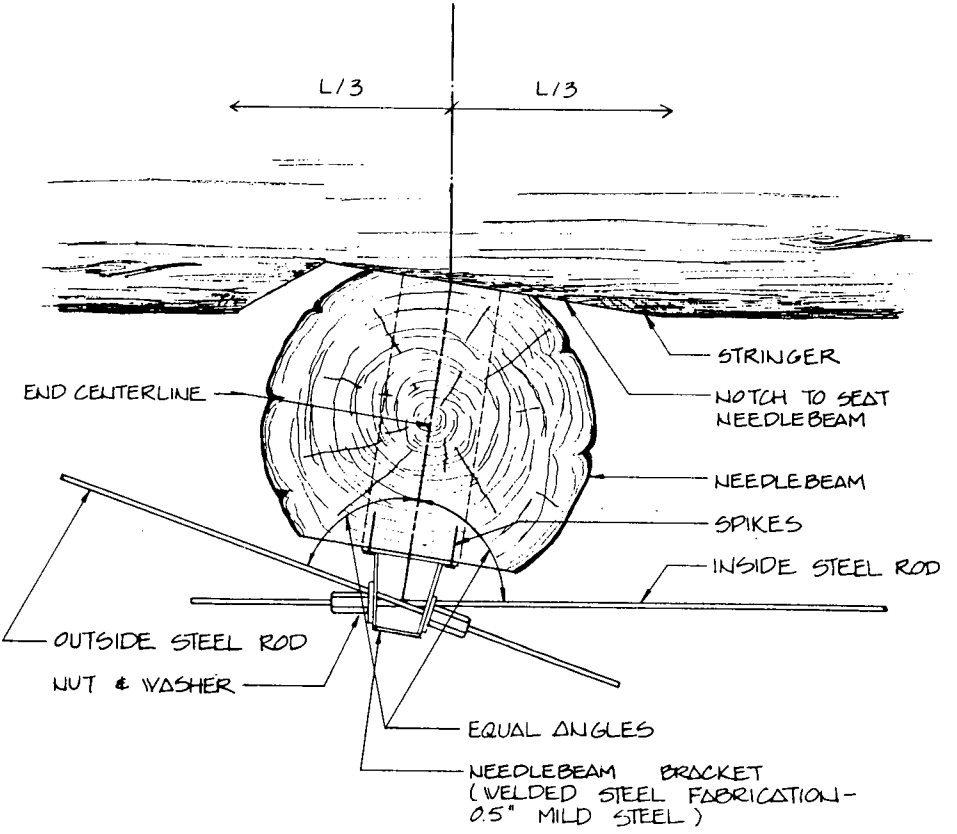


FIGURE 232. End centerline of needlebeam bisects angle formed by threadbars.

- Stringer preparation for the strongback and needlebeam support

Make a sketch of the stringer and truss system so you can place the strongback in the correct position at the planning stage. The sketch should look like Figure 228 (drawn to scale so you can take measurements). Figure 228 shows the exact stringer and needlebeam size and the size of strongbacks and needlebeam brackets.

Build the abutments, prepare the stringers, and rip them on the top as you would for any other crosstie and plank-deck bridge.

It takes special techniques to mark, cut and prepare the stringers to accept the strongback and needlebeams. Frame the stringer end by marking it with a pencil or use templates to guide the saw. Start the cut on the stringer 6 in. behind a vertical line above the front supporting-edge of the cap. The seat must be deep enough to place the strongback below the tie level and to lower the centre of the rod below the stringer centerline where it crosses the front of the cap (Figure 229).

Make a template from 1-in. plywood to simplify cutting. It must be large enough to extend above the stringer (Figure 233).

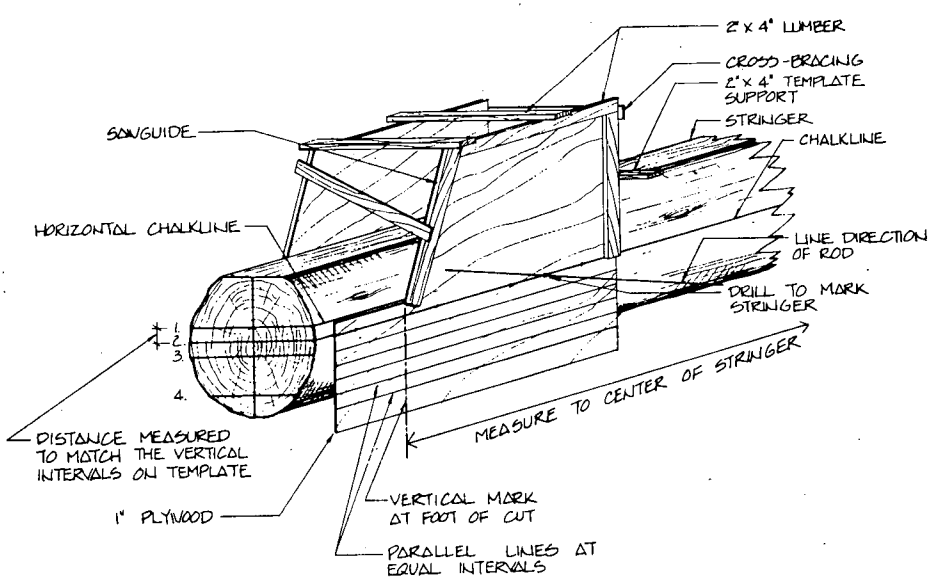


FIGURE 233. Template for strongback seat

Mark parallel horizontal lines on the side of the template in 2-in. or 4-in. intervals to help position the template on the stringers. These lines are also parallel with the bottom of the seat and the plywood edge. Mark the position of the truss rod on the template. You can reinforce the template edge with a 2x4 to guide a saw. Two sheets of plywood cut to a mirror image make a set of templates. Once the template is completed, we are ready to mark the stringer.

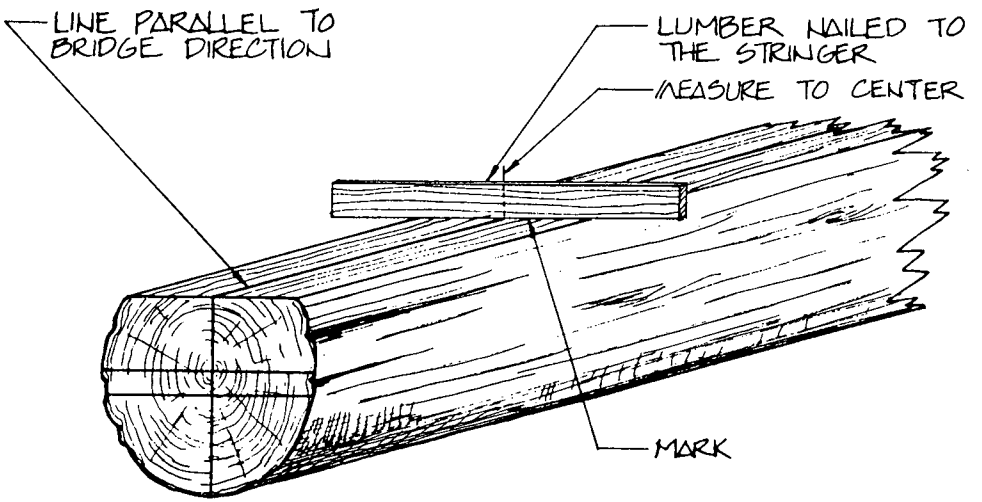


FIGURE 234. Marking the stringer for the template

STEP 1.

First mark the stringer ends with four horizontal lines as follows (Figure 233):

1. The first line marks the depth of the dap for the strongback seat.

2. The second is a guideline near the widest part of the small end of the stringer, either two or four inches (or multiples) below the dapping line so it matches a horizontal line on the template.

3. The third line marks the widest part of the large end of the stringer.

4. The fourth line is the mark for dapping the seat on the bottom of the stringer.

STEP 2.

Next, run a chalkline along the sides of the stringers far enough to mark template position (using the end marks as a guide). You can check and adjust the position of the templates on the stringers by using the parallel lines as a guide.

STEP 3.

Mark the centre of the stringer length on top with a nail. You can use the sketch of the truss and stringer to determine the distance between the template and the centre of the stringer (Figures 228 and 229). Mark this distance in both directions from the centre of the stringer (Figure 234).

STEP 4.

Mark a line on the top of the stringer parallel to the centerline of the bridge. (If the butts and tops are staggered, the stringers may not be parallel to the bridge.) Draw a line perpendicular to bridge direction at the marked template points. Nail a piece of 2x4 or 2x6 lumber beyond this line to support the template.

STEP 5.

Place the templates on the side of the stringer and nail them in the correct position. The chalkline at the wide point on the stringer must match the appropriate line on the template. Check template position again before final nailing. Use double-headed form nails to fasten each template to the stringers. The templates should be braced on top with 2x4 lumber. Check all measurements before cutting.

STEP 6.

Make the sloping cut with a 2-man powersaw. Each end of the bar can be guided by the template.

STEP 7.

If you need to make the stringer narrower for the threadbars, you can slab off 10% of stringer diameter on each side without losing significant strength. For example, you can remove 4 in. on each side of a 40-in. diameter stringer (Figure 235). Instead of slabbing the stringer, you may cut the channels

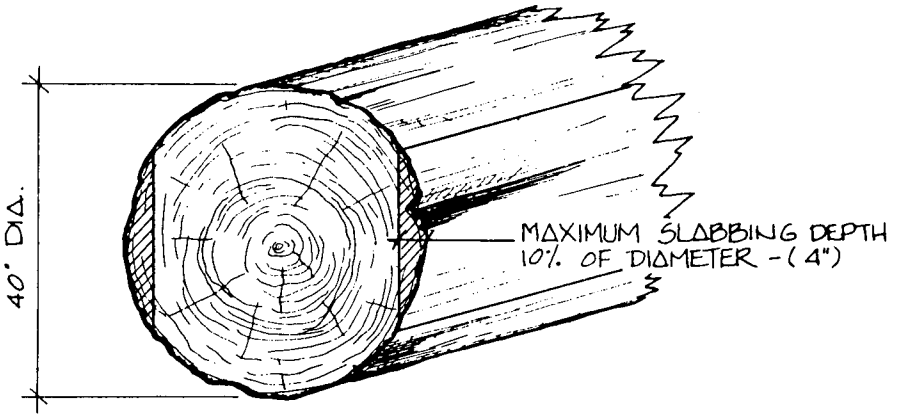


FIGURE 235. Slabbing the stringer sides

for the threadbar. Mark the side of the stringer for the location of the channels by drilling holes through the template. Then align the markers for the threadbar grooves. Notch the grooves to the correct depth by hewing or cutting with a powersaw. The grooves should be smooth and no deeper than necessary.

STEP 8.

After the template is removed cut above the chalkline to finish the bottom seat for the strongback.

Making the Needlebeam Support

Make a needlebeam-seat template as shown in Figure 236 from 1-in. (or heavier) plywood and reinforce it with 2x4's along the cutting edges and wherever bracing is necessary.

Mark the angle of the cut by referring to the large structural sketch made at the beginning of the project (Figure 228). Mark the centre of the needlebeam on the template.

STEP 1.

Mark the template position measured from the centre mark on the top of the stringer.

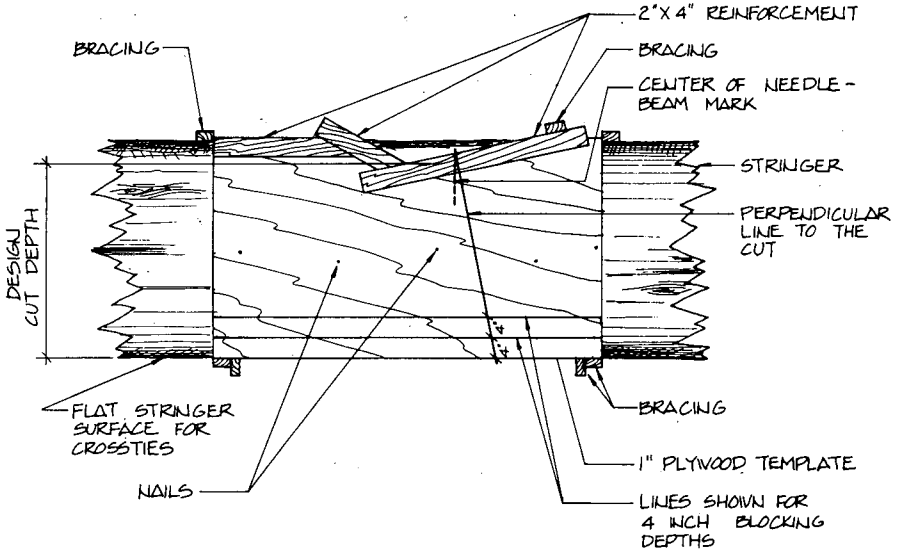


FIGURE 236. Needlebeam-seat template

STEP 2.

Mark lines perpendicular to the bridge centerline. Nail 2x4's or 2x6's on the lines within the markers. These boards will support the needlebeam-seat templates, so they must be long enough and strong enough so the templates can rest on them (Figure 236). Reinforce the boards (if required) before they are nailed to the stringer.

STEP 3.

Turn the stringer upside down without moving the boards out of position. Level the stringer end so the vertical endmark remains vertical.

STEP 4.

Place the needlebeam-seat templates precisely on the supports. Make sure that the templates are vertical. Nail them to the stringer and brace them securely on the top as shown in the sketch.

The same needlebeam-seat template is used on stringers that require blocking. Lines are marked on the bottom of the template for the appropriate block sizes. In our case, (Figure 236), lines are shown for 4-in. and 8-in. blocking.

When the stringer is cut for blocking, a 2x4 is nailed to the template on the appropriate blocking line. This 2x4 will rest on the boards nailed to the bottom of the stringers (Figure 237). The supports in this case are nailed outside the markers to allow the templates to hang between them.

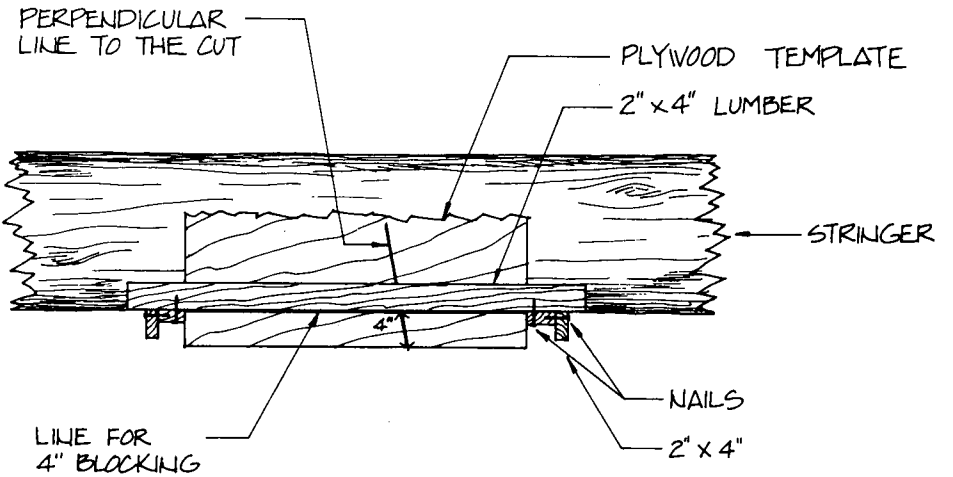


FIGURE 237. Needlebeam template positioned for blocking

STEP 5.

The stringer is now cut along the template edge. Stringers should be cut only deep enough to provide a rest for the needlebeam, and the cut must be limited to 10% of stringer diameter. Trim the needlebeam if necessary.

STEP 6.

Dap the stringer seats in the usual manner.

* * * * * *

You may use two or three small logs to form a needlebeam—as long as they are wide enough for the brackets. Bolt these logs together to simplify construction and to prevent shifting. A steel or sawn timber frame may also be used as a needlebeam to increase the depth.

If timber is used for the frames, it should be the same size as timber used for caps but none of its dimensions can be smaller than 12 inches. There must be a vertical member under every stringer (Figure 238).

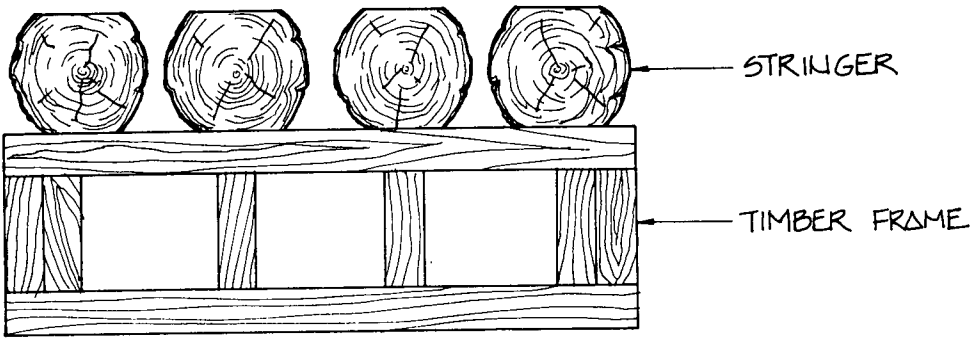


FIGURE 238. Sawn timber-frame needlebeam

The needlebeams should rest directly under at least two stringers. Instead of dapping the large stringers, use blocking between the needlebeam and the smaller stringers. It is good practice to use planking for blocking or other sawn timber already on hand.

- Placement of stringers and trussing

STEP 1.

Place the stringers in position on the caps without attaching the trussing components. Adjust them for correct location over the caps and line up strongback and needlebeam seats. If the workmanship has been inexact, it will be necessary to adjust the seats.

STEP 2.

Now fabricate the strongback to fit the stringer ends.

STEP 3.

Check the alignment and size of the grooves for the threadbars. (This will be the last chance to move the stringers.)

STEP 4.

Spike the blocking to the needlebeams and hang them under the stringers. Tie them loosely to the stringers, or to a temporary log resting across the stringers.

STEP 5.

Fit the needlebeam to its seat by shimming or cutting. Cut the needlebeam only—not the stringer. A platform under the stringers must be provided for the workmen. Take extreme care while adjusting the needlebeam.

STEP 6.

Lash the fitted needlebeam tightly to the stringers. Strong lashing is not necessary because the tension in the rods will keep it in place.

STEP 7.

Measure and mark the bracket locations on the needlebeams. Nail the bracket with double-headed form nails.

STEP 8.

Place and nail the strongbacks into position. They must be flat against the stringers. If shimming is necessary, use metal shims rather than wood.

Spray or brush the strongbacks and brackets with an anticorrosion coating before attaching them to the stringers.

STEP 9.

Remove part of the plastic jacket from the threadbar rods for the fittings before placing them into position. After the rods are in position the fittings should be hand-tight (Figure 239). The threadbars should have about 6 in. of free end behind the nut at the needlebeam brackets where the jack is used for tensioning the rods. Two in. of free end is needed at the strongback when a seal cap is used (Figure 240). One-half inch is enough if you use protective paint.

STEP 10.

Once the fittings are hand-tight, remove the nails from the brackets. Now tighten the rods so the bracket is almost touching the needlebeam. Check the alignment and location of the brackets. Continue to tighten carefully until the brackets are against the needlebeam. Now nail the brackets to the needlebeam again.

STEP 11.

After final realignment of all rods, use a single-bar DYWIDAG prestressing jack* for final tensioning.

All the rods are tensioned to the same torque. The tension is increased, little by little, one rod at a time, until all the rods are tensioned—or the stringers are raised to a slight camber (0.1% to 0.5% of the span). All the other rods are tightened to the same tension. The tensioning may be done at the needlebeams or at the strongback. If it is done at the strongback, it may be necessary to cut the rod ends. (Do not use a cutting torch.)

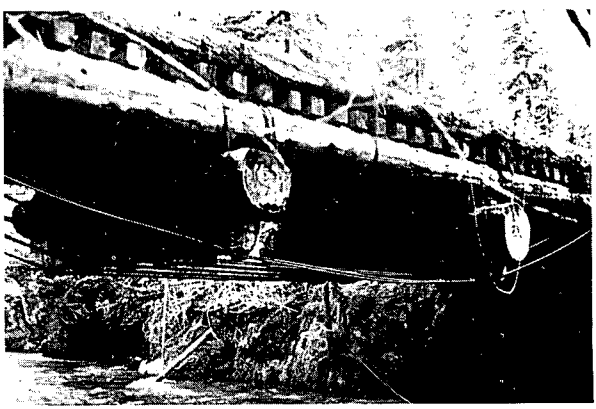


FIGURE 239. Hand-tight truss rods

**DYWIDAG Prestressing Hydraulic Jacks are designed to fit on DYWIDAG threadbars and fittings. They are attached to the end of the rod and pull the bar end away from the anchor plate or lock washer by resting against them at a controlled tension. The nut is then tightened up against the anchor plate by a wrench. This jack has a maximum 155 000-lb jacking force. Its maximum stroke is 4 in. and it weighs 96 pounds. It is powered by an electric hydraulic pressure pump with a maximum working pressure of 7200 psi. The pump has a pressure gauge for the control of the exact pressure. The pump and the jack are connected by a hydraulic hose. (They are available for rent from DYWIDAG Canada Ltd.)*

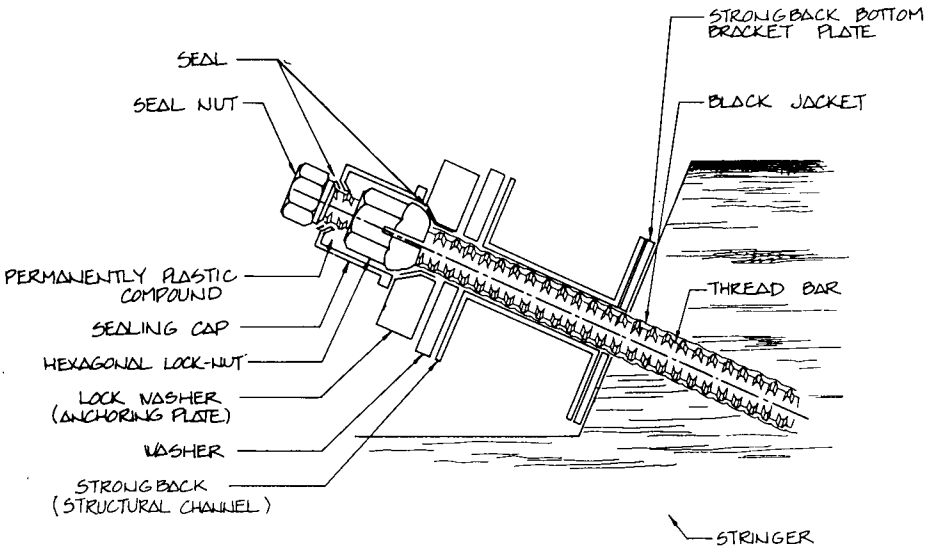


FIGURE 240. Threadbar fittings and strongback

STEP 12.

Now rustproof the fittings, brackets, and strongbacks and remove the work platforms under the bridge.

STEP 13.

Stringer extenders are put on the stringer ends and tied with drift pins to elevate the stringer ends to support the crossties (Figure 241) or to support the planking (Figure 242). The bridge is now ready for decking.

G. BRIDGE DECKS

Decking is part of the superstructure. Its function is to provide a running surface for the traffic and to distribute the live-load (traffic-load) over the stringers. The following deck types are discussed.

1. Gravel Decks
2. Tie-and-Plank Decks
3. Laminated Decks
4. Specialty Decks

1. Gravel Decks

Gravel decks may consist of any material which provides a good traffic surface and does not retain water. Some frequently-used materials are gravel (pit-run, river, crushed), rock (shotrock, fine and primary crushed-rock, ripped rock, slide rock), sand (coarse sand preferably) and coarse mineral soils (glacial till, hardpan, etc.). Even organic soil, sawdust, or wood chips could be used for a gravel deck on a temporary bridge.

Gravel decks provide a cheap, easy-to-maintain running surface for bridges with a short lifespan and for bridges built with large stringers. All culvert-type log bridges use gravel decks. Construction and maintenance costs on properly-constructed gravel-deck bridges will be lower than for other bridges and these bridges tend to blend into the landscape better.

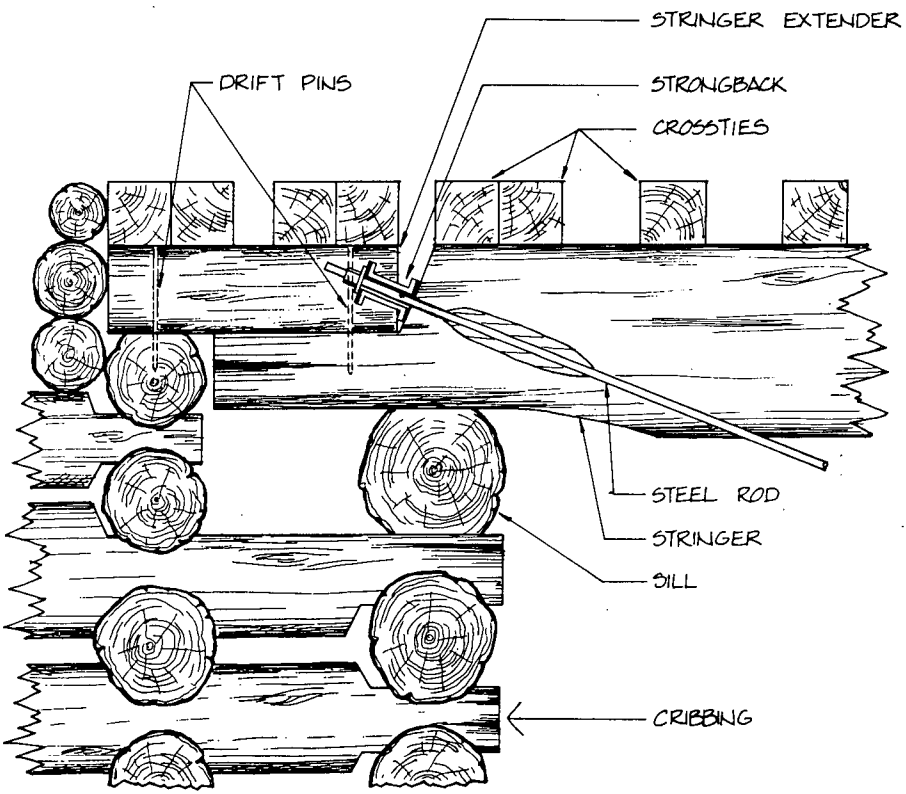


FIGURE 241. Stringer-extender crosstie support

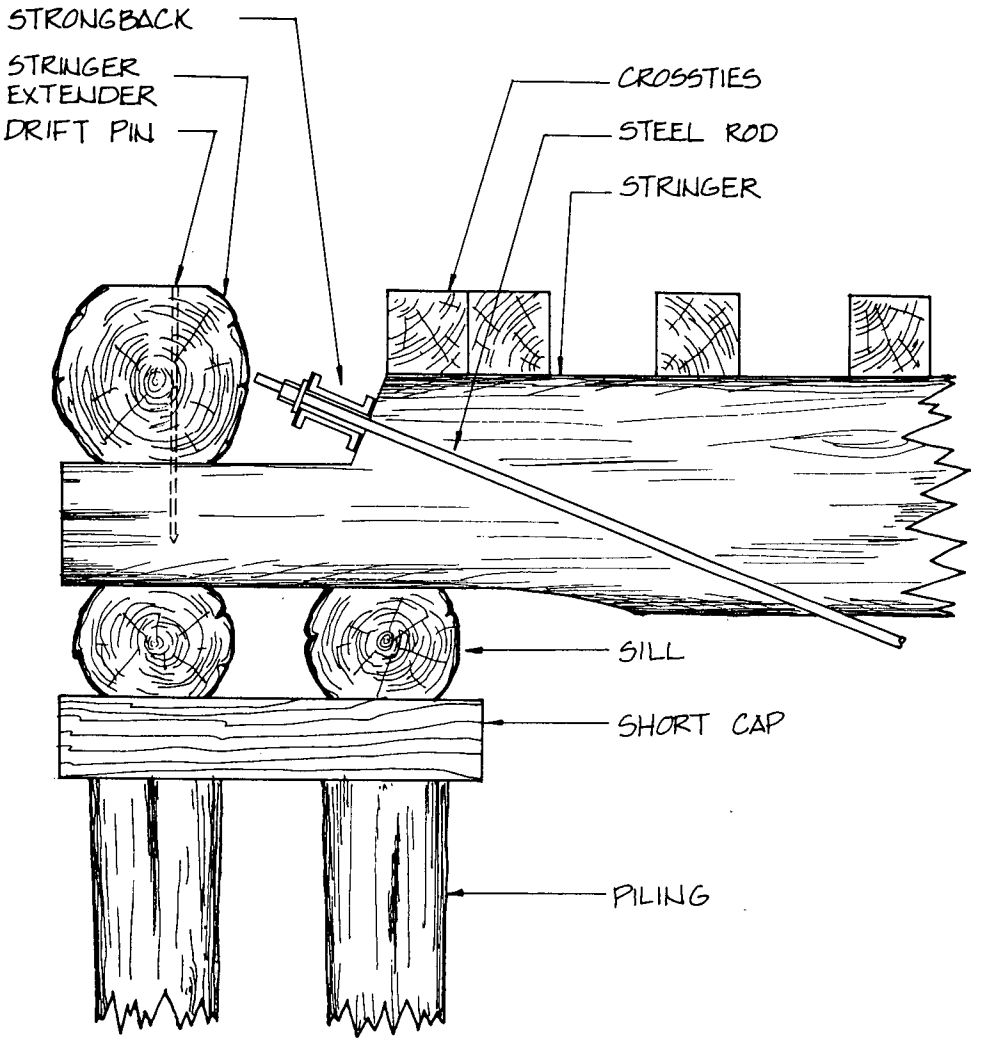


FIGURE 242. Stringer-extender planking support

A gravel deck is the only type of deck which does not distribute traffic load evenly over the stringers. It is therefore important that the stringers be fastened together to work as a unit. A minimum of 6-in. surface material is required to protect the stringers and lashing and to allow road grading the bridge. The deck thickness must be at least three times the size of the largest rock pieces.

2. Tie-and-Plank Decks

Tie-and-plank decks are light, easy to construct, contain the least amount of wood and are the best choice for long bridges. They are widely used. Prepare and position the stringers so that the top surfaces are in one plane. Put crossties across the stringers and spike them. Fore-and-aft planking is then laid and nailed on the crossties.

The deck material should be air-dried and seasoned before use to reduce its weight and to prevent it from working loose when it shrinks.

a) Crossties

Use crossties from wood species having high strength charcteristics and resistance to decay. Avoid wood that tends to deform or split during drying. Douglas-fir, cedar, spruce and pine are acceptable.

Crosstie requirements depend on stringer and crosstie spacing and the size of the design load. Table IV-T may be used as a guide for selecting sizes. Untreated crossties are seldom planed and may show as much as one-half inch variation in size. Ties with a square cross-section are preferable so that off-size ties can be turned to make an even surface for the planks.

The length of the crossties depends on the width of the stringers and the required running surface. If, for example, a 15-ft-wide load must be transported over the bridge, then the crossties must accommodate the wheel spacing and the stringers must be placed to support this load. The vehicle wheels must never run outside the stringers. Not only is there a risk of ties shearing, but serious eccentric overloads could occur on the bridge. Ties must not overhang the stringers by more than two feet. Most coastal logging operations are currently building bridges with a clearance of 14 ft, 2 in. between guardrails. Use extra stringers to prevent the crossties from overhanging more than 2 ft on an otherwise narrow bridge.

TABLE IV-T. Crosstie Size Guide (Inches)

(Crosstie sizes show rough dimensions.)

DESIGN LOAD	150 ton				100 ton		50 ton	
Planking	4 in		5 in		4 in		3 in	
SPECIES:	O.C.	Size	O.C.	Size	O.C.	Size	O.C.	Size
Douglas-fir Yellow cedar Western hemlock	16 20	10 x 10 10 x 12	18 20	10 x 10 10 x 10	16 14	8 x 8 8 x 8	12	6 x 6
Sitka spruce	16	10 x 10	16	10 x 10	16	8 x 8	12 16	6 x 6 8 x 8
Western red cedar Pine Spruce (except Sitka)	16	12 x 12	16	10 x 10	16	10 x 10	12 16	6 x 6 8 x 8

Note: O.C. = on centre

Western hemlock is used seasoned, air- or kiln-dried to prevent warping and splitting. 10x12 ties lie on 12-in. surface.

If the deck must be built to accommodate occasional wide traffic, that part of the bridge not used for normal truck traffic should be blocked off to force trucks to use the centre of the bridge when they do not need the extra width reserved for special loads. This can be done by placing small logs inside the guardrails. Put temporary fender logs on each end of the bridge to guide the traffic to the centre (Figure 243).

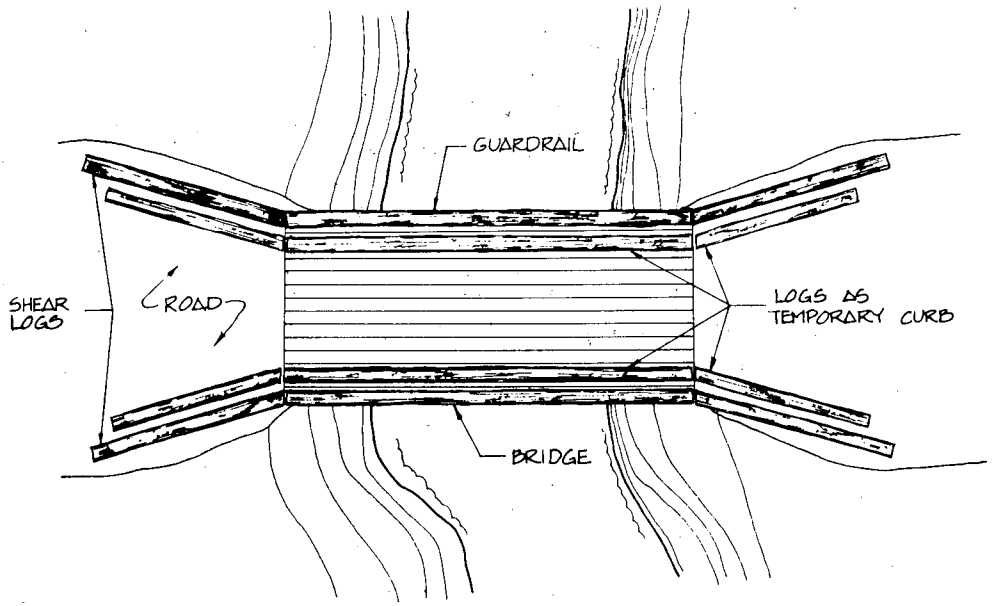


FIGURE 243. Narrowed bridge deck

Crossties which support the guardrails must be 3 ft longer than the other ties. Regular-length ties may be staggered to support the guardrail (Figure 244). Order an extra 5% for blocking and breakage when you order ties.

- Laying the crossties

STEP 1.

Lay a crosstie on each end of the stringers.

STEP 2.

The centerline of the bridge is marked at both ends of the structure. If it falls on a stringer surface, mark it with a pencil or nail. If not, nail a piece

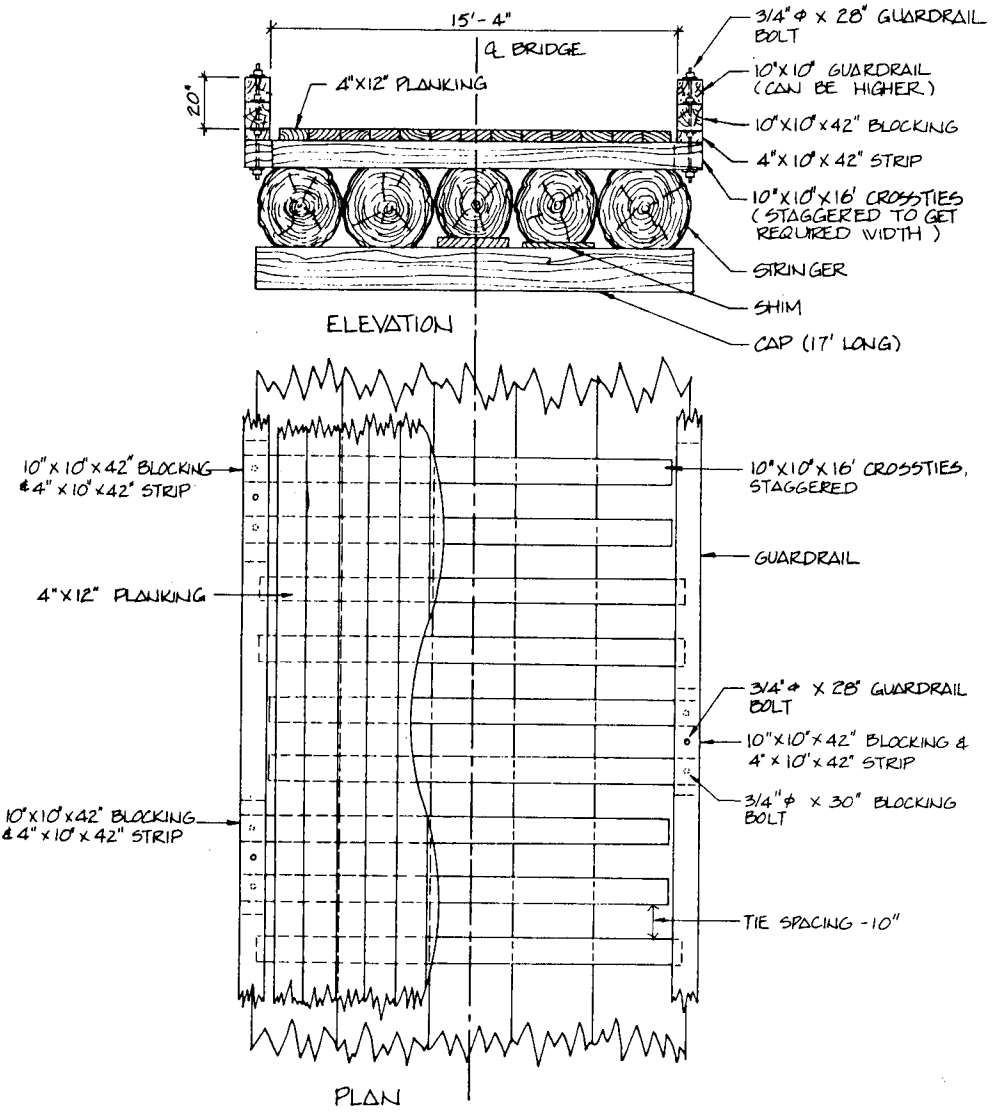


FIGURE 244. Staggered-tie guardrail support

of lumber across both ends of the stringers flush with the top, and use that for marking.

STEP 3.

Mark the centerline between the marks and centre the end crossties perpendicular to this centerline. Positioning may be done with a carpenter's square or by tape-measuring the sides of a right-angled triangle (Figure 245). (The relationship of the sides in this right-angled triangle is arranged as 3-4-5.)

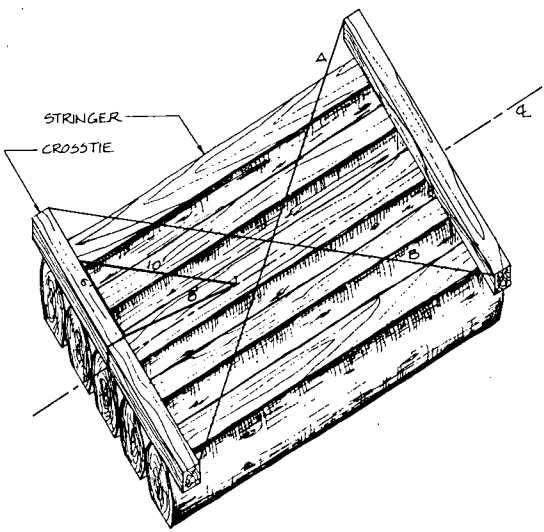


FIGURE 245. Locating crossties on the stringers

Spike these ties or mark their exact location on the stringers.

STEP 4.

Measure the distance between the ties and calculate tie spacing. Place the second tie from each end of the bridge next to the first to make a bulkhead against the pressure of the adjoining road material and to resist shockloading by traffic. The position of every tenth crosstie should be marked on the outside stringers. (Accuracy to the nearest half inch is satisfactory unless otherwise specified in the design.)

STEP 5.

Lay the crossties on the stringers. If a machine is used, start at the beginning of the bridge and lay loose planking on the ties. If it is possible to run a front-end loader directly on the stringers, start placing the ties at the far end. (Track equipment should not be allowed on the stringers.)

STEP 6.

It is not necessary to mark every tie location on the stringers if spacer templates are used. Use two templates, one at each end of the ties. Cut the templates one eighth-inch smaller than the space needed between the ties (Figure 246). Check the location of every tenth tie by checking against the marks.

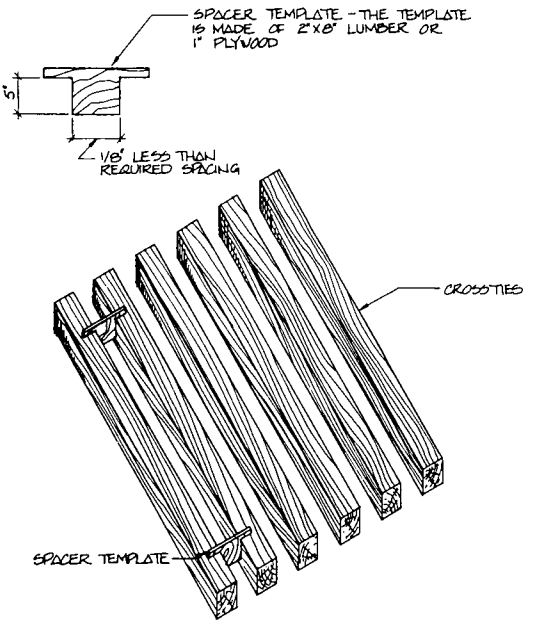


FIGURE 246. Template for crossties

STEP 7.

Lay a straightedge over the ties to check the height. Height differences should not be more than one eighth-inch on a solid deck. If height is more than one quarter-inch, the ties should be notched or turned and checked again. If they are still high (or low), they should be replaced.

STEP 8.

The crossties must lie on the stringers. Shim gaps of more than one-eighth inch. Cedar shingles used for shimming can be wedged in from both sides under the tie.

STEP 9.

Spike the first two ties in the correct position.

STEP 10.

Nail a piece of 2x4 on top of these ties and draw a chalkline to align the tie ends. Only the outside ends need to be aligned if the ties are staggered.

STEP 11.

After positioning the crossties correctly, fasten them with bridge spikes or drifts that penetrate the stringers at least four inches. To prevent splitting, pre-drill one-half inch diameter holes for spikes. The holes for drifts should be at least one-eighth inch smaller than the drift diameter. Holes should be less than full depth to allow proper fitting of the point. Use a 10-pound sledge-hammer and drive the spikes so the head is flush with the wood surface.

STEP 12.

Trim the ties along a chalkline after they have been spiked to the stringers.

* * * * * *

It is not necessary to spike the ties to every stringer on temporary bridges. You can spike every other tie between stringers. But spike every tie to every stringer on permanent bridges. Spike the guardrail supporting ties to every stringer. (This applies to all bridges.)

Bridge spikes are made from one half-inch-square galvanized mild steel with a chisel edge at one end and a large round mushroom head at the other. Drifts are 1/2-in. or 3/4-in. diameter round steel, pointed at one end and cut square at the other. We recommend the use of bridge spikes because the head helps to prevent vertical movement.

b) Planking

The size of planking depends on the design load and the traffic density. Rough 4x12 Douglas-fir or hemlock planking is commonly used for 100-ton (or larger) loads. 5x12's may be used on a bridge carrying unusually heavy traffic. Rough 3x10 fir, hemlock, pine or spruce planking is used on 50-ton capacity bridges. The planks must not be shorter than 8 ft and must span 6 or more crossties. Use random lengths.

Planking may be separated into three basic groups: tight planking, open planking and running planks for temporary bridges.

Tight planking is tightly laid to form a running surface. It will protect the stringers from mud and water to prevent decay. One disadvantage is excessive wear from gravel and dirt. To reduce this deck wear, treat the approaches with paving or soil cementing and give the decks an occasional hosing-down. (Hosing is not recommended over fish streams with normal water levels but it may be done during flood periods. Consult with local fishery and conservation officers.) This deck is easy to inspect after hosing, and worn planks can be replaced.

Open planking has a space of about one half-inch left between the planking. This type of deck tends to be self-cleaning, requires less maintenance, and its planks last longer and will be easier to replace. Dirt will cake on the stringers, however, and keep them wet—a condition conducive to rot. Open planking is recommended for temporary bridges where the deck has to last the required life of the bridge.

Running planks are used on temporary bridges—two panels wide enough to support the truck tires. Leave the centre of the bridge open. This type of decking is not recommended for roads open to the public.

- Laying the planks

Start laying the planks from the outside of the bridge and progress toward the centre. Mark the outside edge of the decked area by using a chalkline and a straightedge.

Place and nail long pieces of planking along the mark on both sides of the bridge marking their ends flush with the first crosstie. Fill in between these planks row by row. Any adjusting necessary is done in the centre with narrow planks. (Trim with a small powersaw.) Take care that neighbouring

planks do not end over the same tie. One way to make sure of this is to use the longest planks outside and progressively shorter planks inside.

Planks must join over a crosstie if the space between the ties is more than 6 in. or if the plank thickness is less than 4 inches. If the space is less than 6 in. and plank thickness more than 4 in., the planks can join between crossties to reduce end-splits from spiking (Figure 247).

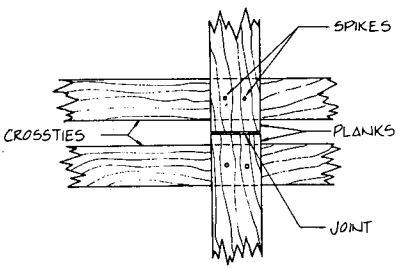


FIGURE 247. Joining planks between crossties

As you cut, take care to lift the planks from the ties to prevent damage. Trim plank ends at both ends of the bridge, flush with the outside of the first crossties. Do not drop tie and plank trimming into the stream.

Fasten ends with two spikes. Drive the spikes in a slant as far as possible from the ends to prevent splitting the plank (Figure 248). Use a 5-lb sledgehammer to drive the spikes. It may also be necessary to pre-drill holes. Drill 1/4-in. diameter holes 3 in. deep into the plank.

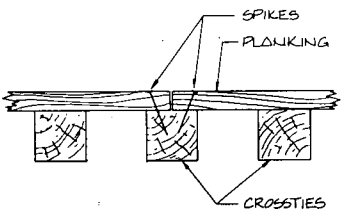


FIGURE 248. Planks joined over a crosstie

Planks are not necessarily nailed to every tie but must have one nail in every second tie. Neighbouring planks should be nailed to different ties.

Nails should be longer than twice the planking thickness. Table IV-U shows the type and size of nails recommended for different plank sizes. Order 10% to 20% more than you need to allow for inaccuracy in the count.

TABLE IV-U. Nail Size Guide

Deck Plank Thickness	5 in			4 in			3 in			2 in		
Nails and Spikes - Size	L	C	D	L	C	D	L	C	D	L	C	D
Common Round Wire Nails												
-Bright												
Flat Heads - Diamond Points												
- Standard							6	9	0.28*	6	9	0.28
- Galvanized							6	9	0.28*	5	18	0.23
Common Round Wire Spikes												
- Bright - Standard												
Flat Heads - Diamond Points	12	2.9	0.35	10	3.6	0.35	7	7	0.3	6	8	0.3
** - Galvanized	10	3.6	0.35	8	5.2	0.32	6	8	0.3	6	8	0.3
***Common Spiral Nails												
- Bright												
Flat Heads - Diamond Points												
- Standard	12	4.1	0.32	10	5	0.32	7	10.2	0.28	6	14.2	0.25
- Special										5	14	0.28

L = Length in inches
C = Count/lb
D = Diameter in inches

*May be used for bridges with a very short life span, or for decking where every crosstie is nailed to the planking.

**Diameters of galvanized nails are marginally larger than shown. The table shows the original diameter and count before galvanization.

***Diameters of spiral nails are measured across the opposing crest of the spiral.

Common round wire nails may be used for temporary bridges. Spiral or galvanized nails should be used on larger bridges to prevent the planks from working loose. Galvanized nails have more strength than spiral nails; their holding power is provided by the zinc coating. Use galvanized nails in seasoned wood and spiral nails in green wood.

3. Laminated Decks

A laminated deck is made from sized lumber placed on edge across the stringers and nailed to form a one-piece solid deck. Light fore-and-aft planks or asphalt form the running surface. Laminated decks are watertight and keep the stringers dry. They're made from treated material on permanent bridges but are seldom used on temporary bridges because of their high cost.

Table IV-V shows the required lumber size. The lumber should be pre-cut, pre-drilled and pressure-treated. Fresh cuts and holes should be field-treated. Any part of the wood damaged during transportation, handling, and construction should also be treated.

TABLE IV-V. Depths of Laminations

(Depth shown in inches. All lumber has 2-in. nominal thickness.)

Design Load	150 ton				100 ton				50 ton		
Planking thickness in inches	2	3	4	asphalt	2	3	4	asphalt	2	3	asphalt
Wood Species Douglas-fir Western hemlock Sitka spruce Yellow cedar	10	10	8	10-8	8	8	6	8-6	6	4	6-4
Pine Spruce (Interior) Western red cedar	12	10	10	12-10	10	8	8	10-8	8	6	8-6

Western red cedar and yellow cedar may be used without pressure treatment, but they should be surface-treated to waterproof the deck after the laminations are laid.

Make the deck wide enough to cover all cut stringer surfaces and to transfer the load to every stringer. It should be no wider than 16 feet.

A 2 1/2-ft section must extend 18 in. on both sides to support the guardrails. Holes for the guardrails are drilled in the field and field-treated. Figure 249 shows a laminated deck with guardrail supports.

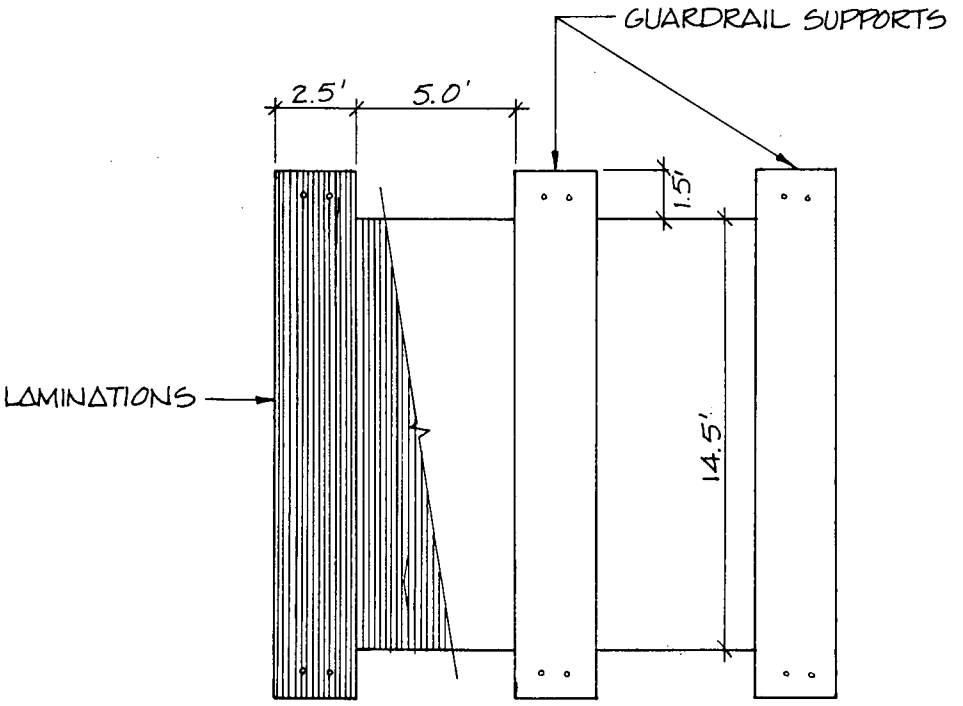


FIGURE 249. Laminated deck

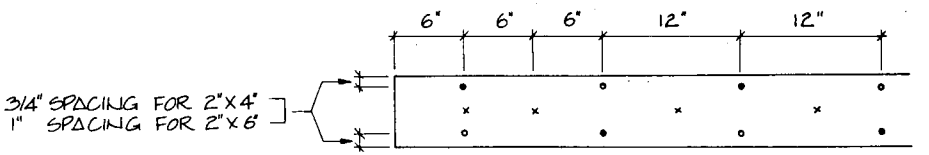
Mark the stringers as you would for tie-and-plank decks. Nail three guardrail-supporting laminations together so they form a 6-in. timber. The easiest way to do this is to lay three pieces on top of each other and nail on one side according to the nail pattern. Then turn them on the other side and nail. This laminated timber is placed like the first crosstie on a tie-and-plank deck.

Once the first three laminations are in position then the others are nailed to them and to the stringers, as indicated by the nailing pattern in Figure 250.

Nail the laminations with 5-in. common or galvanized nails. There is little advantage to galvanized nails in a dry climate but they must be used in wet areas. (Toe nails must always be galvanized.)

NAILING PATTERN

2"X4" AND 2"X6" LAMINATION :



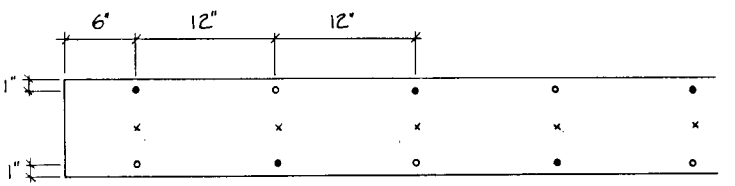
• — INDICATES NAILING OF 1st LAMINATION

o — INDICATES NAILING OF 2nd LAMINATION

x — INDICATES NAILING OF 3rd LAMINATION

TOE NAIL EACH LAMINATION TO ALTERNATE STRINGERS WITH 4" GALVANIZED NAILS

2"X8", 2"X10" AND 2"X12" LAMINATION :



• — INDICATES NAILING OF 1st LAMINATION

o — INDICATES NAILING OF 2nd LAMINATION

x — INDICATES NAILING OF 3rd LAMINATION

TOE NAIL EACH LAMINATION TO ALTERNATE STRINGERS WITH 5" GALVANIZED NAILS

FIGURE 250. Nailing pattern for laminations

Preset the nails before each lamination is placed into position. Make sure the laminations lie properly on every stringer. If not, shim after nailing. The top of the laminations should be smooth and even. Make sure each lamination is upright by checking frequently with a carpenter's square. Correct any tilting by inserting cedar shingles or treated wedges.

If stringers are not waterproofed, nail a piece of treated lumber (2x4 or 1x2 or a large moulding) to the underside at the edge of the laminations (Figure 251). This will prevent water from running under the deck and soaking the stringers. Waterproof glue, silicone, roofing cement or other waterproof material must be used between the wood strip and the laminations.

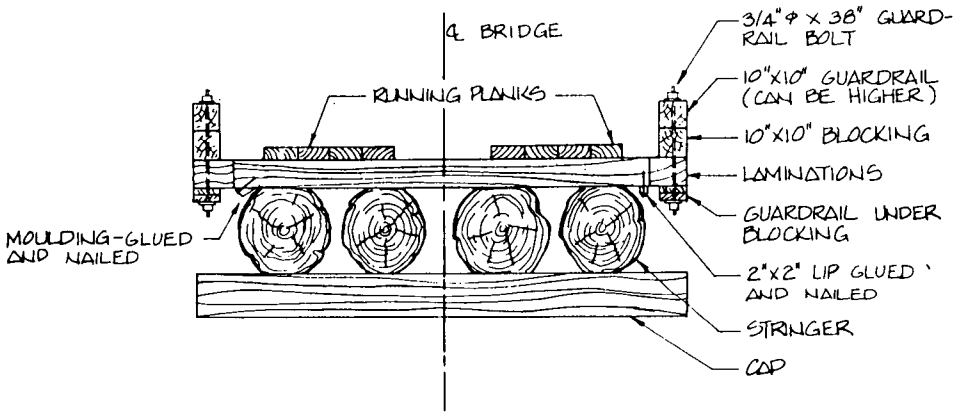


FIGURE 251. Laminated deck with running planks

Use planking over the laminations to provide a running surface on logging bridges. (Highway bridges are surfaced with asphalt or concrete.) Concrete surfacing is the most wear-resistant—and also the most expensive. If concrete is used, both the designer and builder must have experience with this type of construction. Published plans may be used for the construction and planning of 50-ton bridges. Consult MODERN TIMBER BRIDGES—SOME STANDARDS AND DETAILS, available from the Canadian Institute of Timber Construction.

Use rough untreated planking for decking (as shown in Table IV-X). The plank width is 10 or 12 inches. Planking shorter than 8-ft lengths should not be used. Nail planks to the lamination by using spiral (Ardox) nails at least twice the length of the planking thickness, taking care that the nails do not penetrate more than half the lamination thickness. Two nails are used

on both ends of the planks, but they are driven into different laminations (Figure 252). The planks are also nailed to the lamination at 2 ft intervals. (Take care to drive the nails into the laminations and not between them or through the edge.)

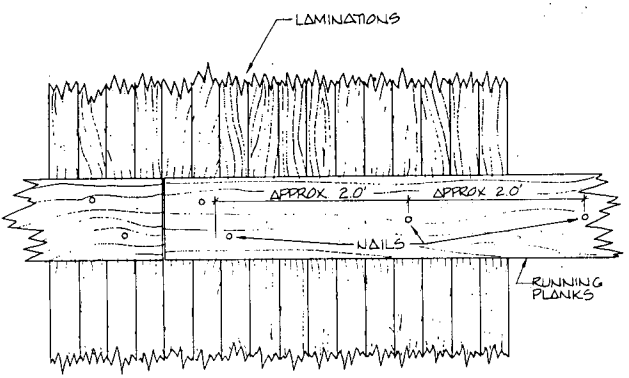


FIGURE 252. Nailing pattern for running planks on laminated deck

You can extend bridge life by using thicker planks or by doubling the planks. If you double the planks you can replace the top layer without damage to the laminations. The top layer should be nailed to the bottom layer but the nails should not penetrate the laminations. Pressure-treat—or at least field-treat—the bottom layer. A 3-in. treated base with 2-in. rough, untreated top planks will make a good running surface.

You can use running planks alone, but if public use is permitted or the planking thickness is over 2 in. the entire surface should be tightly planked.

Bituminous asphalt provides a smooth running deck for a laminated bridge. Lay at least 2 in. of asphalt on top of the laminations to prevent any damage.

Asphalt will normally be laid by a contractor but the logging engineer may be required to provide specifications. Asphalt may be put on level or it may be crowned to help water run off. The crown should not be more than 2 in. at the centre. Before paving, nail a treated 2x4 strip on the edge of the running surface to keep the asphalt on the bridge (Figure 253).

Oil the laminated surface heavily to make a bond for the asphalt. The asphalt must be a good quality hot mix. It may be laid by a paving machine or by hand, and then compacted and rolled to a smooth finish. The paving may be done in one or more layers.

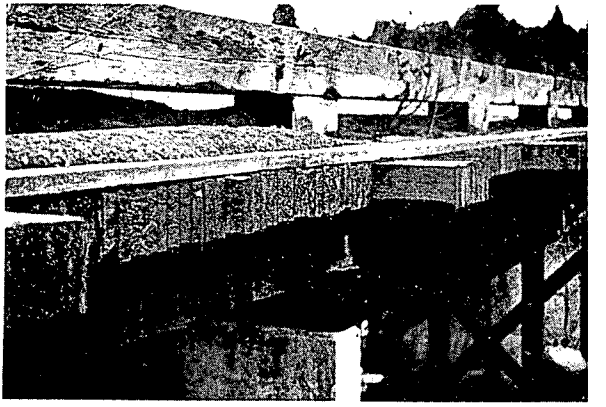


FIGURE 253. 2x4 strip to hold asphalt

Pave bridge approaches to prevent asphalt breakup at the ends of the bridge.

Asphalt will crack if the bridge deflects more than 1/360. Stringer diameter should be slightly larger (5% to 10%) than indicated by the design graphs for simple log stringers. (See Maintenance section for information about deflection testing.)

To provide a better bond between the wood on more flexible bridges, make every other lamination 2 in. higher. Pavement thickness is measured from the top of the highest laminations (Figure 254).

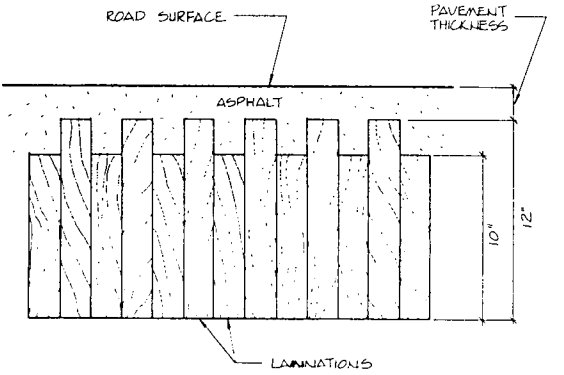


FIGURE 254. Higher laminations for better bond

4. Specialty Decks

Preconstructed deck sections can be hauled to the bridge site where it may take only a few hours to replace the deck. A well-constructed sectional deck keeps the stringers dry (Figure 255). The deck is manufactured in 6-ft panels using 12x12 cedar or other species. Join the timbers with two 6-ft long, 1-in. diameter countersunk bolts. The panels themselves are bolted to one another through the guardrail supports.

Two-inch planking or other suitable material should be used as a running surface to prevent wear.

The sectional deck is not fastened to the stringers and it may move. To prevent longitudinal movement, rest the sections against the bridge abutment at both ends. You can prevent side movement with blocking bolted under the guardrail supports to rest against the stringers (Figure 255).

For easy construction, use the same size timber for guardrails, guardrail blocking, and crossties.

The following running surfaces may be used on laminated or specialty decks:

- Two-inch running planking is commonly used to prevent wear.

- Asphalt strips come in a variety of sizes. They are made for the do-it-yourself paving project being done without any special equipment. The most common size is 1 ft x 4 ft one-inch-thick, premanufactured strip.

  Lay the asphalt strips lengthwise on the deck if the full surface is to be covered, or across the bridge if only the running surface is to be covered. Nail the strips with no fewer than eight 2-in. common galvanized nails. Lay the strips tight and fill the cracks with tar or asphalt. (It may not be necessary to fill the cracks in hot weather when the strips are soft.)

  You may use expanded metal and a gravel-tar mixture. Nail expanded metal over the running surface and be sure to nail all ends down to prevent them from curling and cutting. The sheets may be welded together to provide a continuous running surface. (Use flattened mesh with an approximate weight of 23 lb or 53 lb per sheet, and an opening of 0.75 in. x 1.81 in. or 1.0 in. x 2.49 in. respectively.)

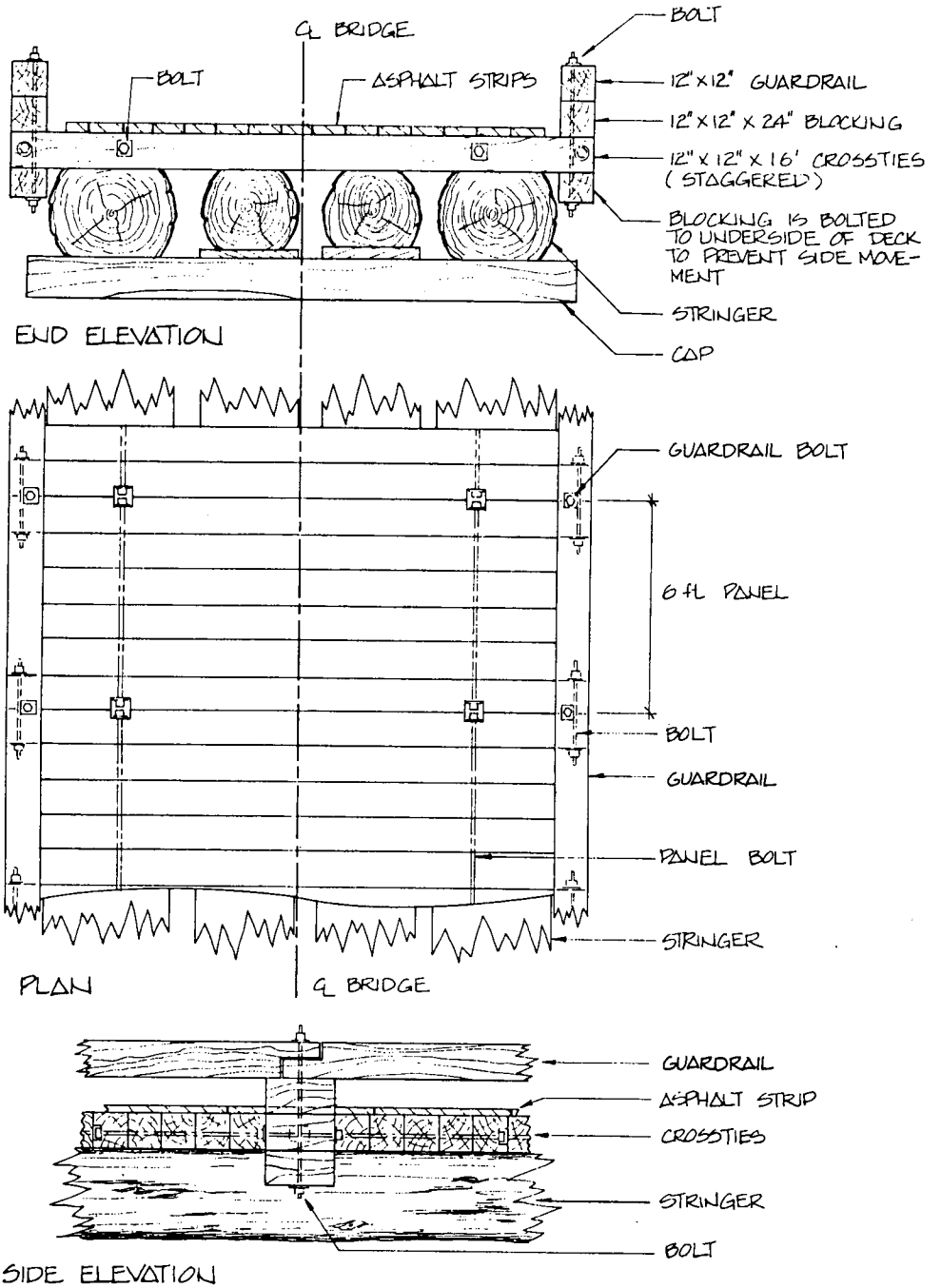


FIGURE 255. Typical sectional deck

Next, lay a thick layer of asphalt or gravel tar pavement over the metal. The pavement may break up on a bouncy bridge but the expanded metal will hold it in place (Figure 256).

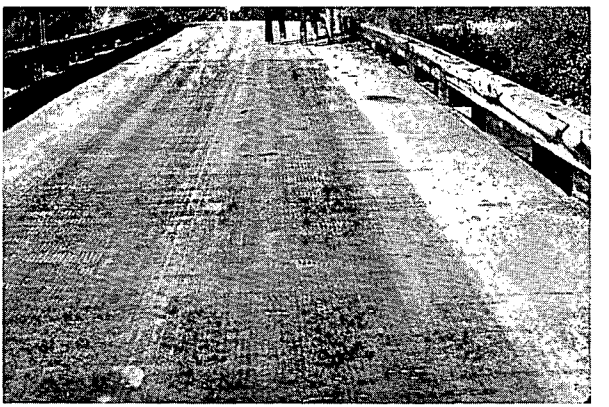


FIGURE 256. A thin layer of asphalt over expanded metal

- A tar-sand mixture may be cheaper than hot asphalt but it will not last as long or provide the same quality running surface.

- Checkered steel plates can be used when the extra weight is not significant. Weld them by placing them flat on blocks and nail them to the deck. (Welding done on the bridge deck without blocking will burn a hole in the wood and the weld may break under traffic.) Take precautions to prevent fire during and after welding.

  The size of the plate depends on the weight limitations of the bridge and traffic density. Table IV-W shows the weight of checkered steel plates.

- One-inch plywood may replace the crossties and planking on light bridges and the thickness required can be built up in layers. The total thickness of the layers should equal that of the crossties they replace. The layers should overlap and to prevent damage to the next layer the top layers should be changed when they are worn.

- Rubber belting (used conveyor belt) may be nailed to the planking to prevent damage from tracked vehicles.

TABLE IV-W. Checkered Steel Plates

Plate Size (in)	Weight/Sheet (lb)
3/16 x 48 x 96	280
1/4 x 48 x 96	360
3/8 x 48 x 96	528

H. GUARDRAILS AND GUARDLOGS (SHEAR, FENDER, BUMPER)

Guardrails keep a vehicle from accidentally driving off the bridge and they give drivers a feeling of safety.

Shear logs are placed at the sides of the approaches to guide vehicles to the centre of the bridge. They should be properly marked so motorists can see them in the dark (Figure 257).

FIGURE 257. Shear logs to guide traffic

Guardrails are usually placed on the bridge after the decking has been laid. If they are not part of the load-bearing structure they are made of sawn timber or small logs (guardlogs). They must rise above the running surface 10 in.—and 20 in. is preferable. The guardrail is elevated to the necessary height with blocking at 6-ft to 10-ft intervals.

Extra crossties may be used for the construction of sawn timber guardrails and their blocking. If extra height is needed, use double blocking.

Always splice guardrails above a block. They may be butted or dapped to overlap. Figure 258 shows a number of guardrail splices.

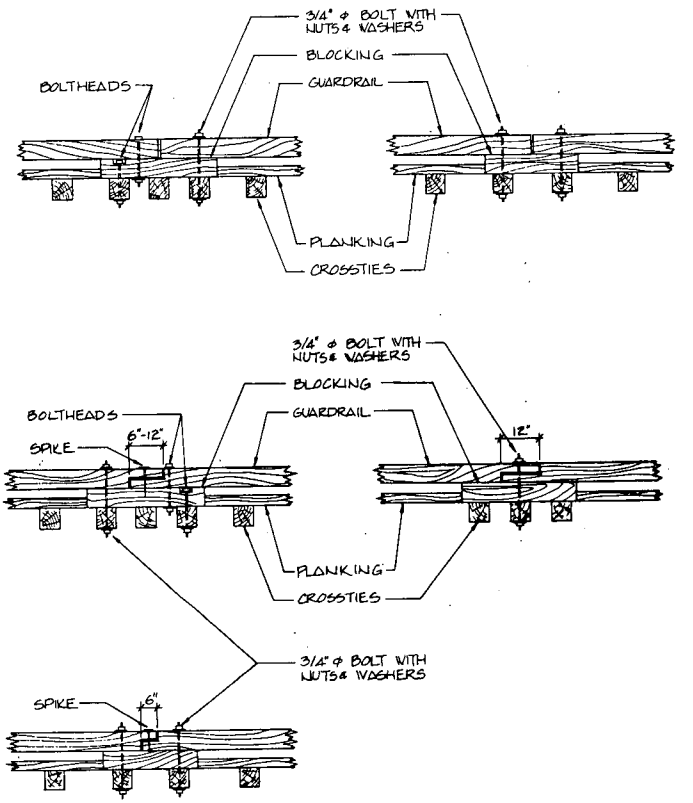


FIGURE 258. Joining guardrails

The guardrail may be bolted to the blocking, and the blocking bolted to the crosstie, or a long bolt may be used to tie the guardrail, blocking and crosstie together. If there is limited room between the stringer and the crosstie, bolts threaded at both ends allow tightening from either end.

Bolt heads between the guardrail and blocking must be countersunk onto the blocking to allow proper contact between timber surfaces.

One bolt is enough to fasten the guardrail to the crossties for a midsupport. Figure 259 shows three variations.

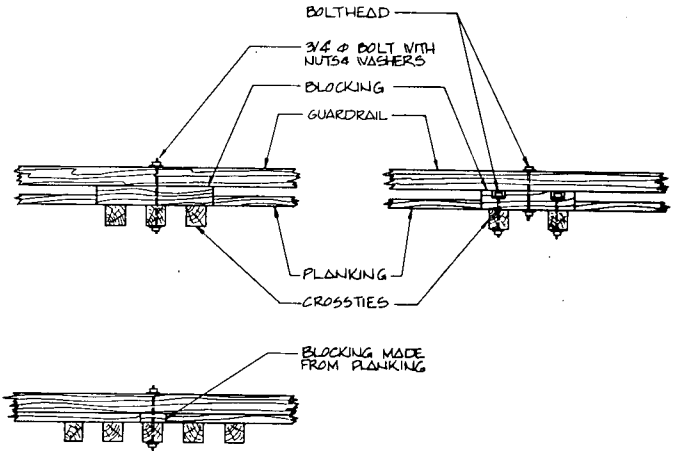


FIGURE 259. Midsupports for guardrails

Use a plate to support the guardrail bolt on laminated decks. The plate may be made from the lamination material and should extend approximately 1 ft on each side of the bolt. A continuous plate glued to the laminations may also serve to support the guardrail and act as a lip to prevent water from running onto the stringers. Figure 260 demonstrates two methods for supporting the guardrails on a laminated deck bridge.

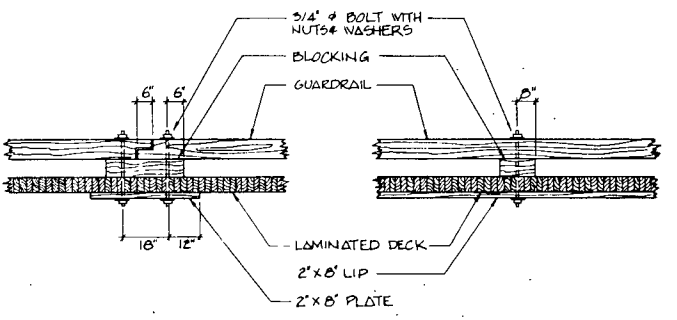


FIGURE 260. Fastening guardrails to laminated decks

Small logs are commonly used as guardlogs. They are heavier and much stronger than sawn timber, easier to put on the bridge, and safer for traffic.

If possible, choose small, round Western red cedar logs with a 16-in. top, a 22-in. butt, and long enough to eliminate splices. The guardlogs should be peeled. They should be supported with blocking where needed and bolted to the crosstie at 6-ft intervals, (or to every fifth crosstie).

Guardlogs may be spliced like sawn timbers (Figure 261). The logs are placed butt to butt and top to top.

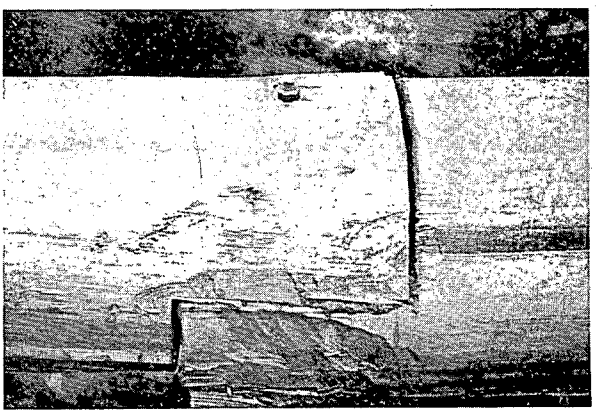


FIGURE 261. Splicing guardlogs

Guardlogs may protrude beyond the ends of the bridge to form a support for the shear logs fastened to them.

Guardrails are bolted to the crosstie with 3/4-in. bolts and washers. Table IV-X describes frequently-used washer types which fit a 3/4-in. diameter bolt.

Homemade square washers can be cut from 3/8-in. mild steel plate (4-in. x 4-in.) with a 7/8-in. diameter hole.

Shear logs (also called fender or bumper logs) are a continuation of the guardrails to channel traffic at the ends of the bridge (Figure 262). An apron of asphalt pavement at each bridge approach may reduce the risk of road graders accidentally pushing shear logs over the bank.

Figure 263 shows a method for attaching shear logs to guardlogs with a simple step notch. You can splice over the end guardlog support, where the guardlog, shear log and crosstie can all be bolted together.

TABLE IV-X. Washers to Fit 3/4-Inch-Diameter Bolts

	Diameter in	Hole Size in	Thickness in	Area of Washer in ^{2}	Weight per 100 Pieces lb
Wrought iron or steel (square plate)	3 3 1/4	3/4 7/8	1/4 5/16	6.6 7.6	59 87
Wrought iron or steel (round plate)	2 3	3/4 3/4	9/64 1/4	2.6 6.6	10 45
Malleable iron	3 3 1/2	3/4 7/8	7/16 7/16	6.6 9.0	31 37
Cast iron ogee	3 1/2	3/4	3/4	9.1	107

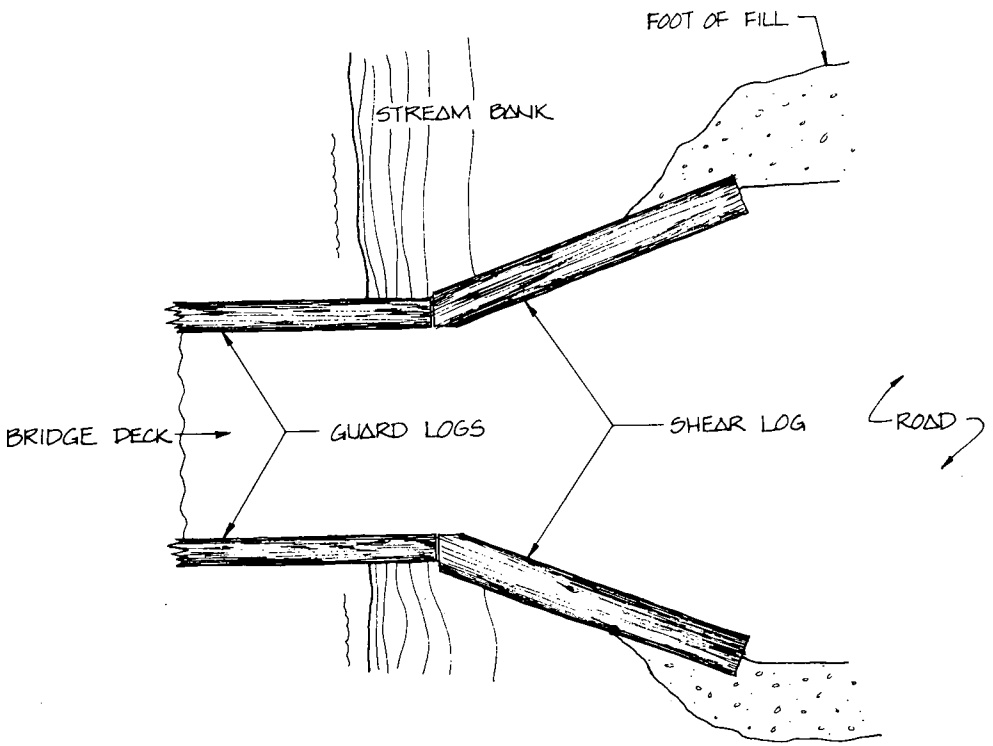


FIGURE 262. Shear logs

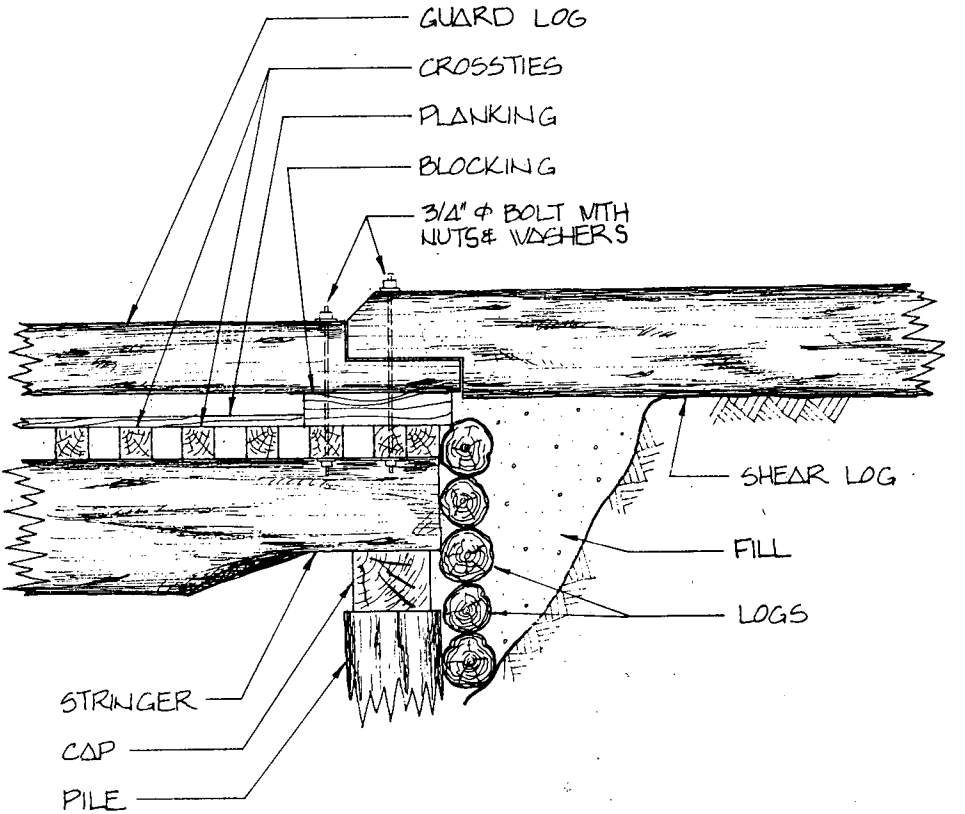


FIGURE 263. Joining shear logs to guardlogs over crossties

This is an aesthetically-pleasing connection, but it is rigid and a slight movement of the shear log may move the guardrail and damage the crossties. The splice shown in Figure 264 is more flexible. Here the guardlog is extended out from the bridge and both logs are dapped and then drifted with a 3/4-in. diameter drift-pin or bolt.

Flexible connections between the guardrail and the shear log can be made from steel strips or used cutting-edges from a grader spiked with 8-in. to 10-in. spikes.

Short pieces of wire rope may also be used (Figure 265). Each end of the rope must be fastened to the logs with at least three staples not less than 6 in. apart.

Shear logs may be placed on the ground and kept in place with a gravel berm. When there is not enough room for a gravel support behind the shear

logs, a supporting crosslog may be placed across the road at each end of the shear logs just deep enough under the road surface to allow grading without getting damaged. This may be on the top of a crib. The shear log is drifted, lashed, notched or blocked to the crosslog (Figure 266).

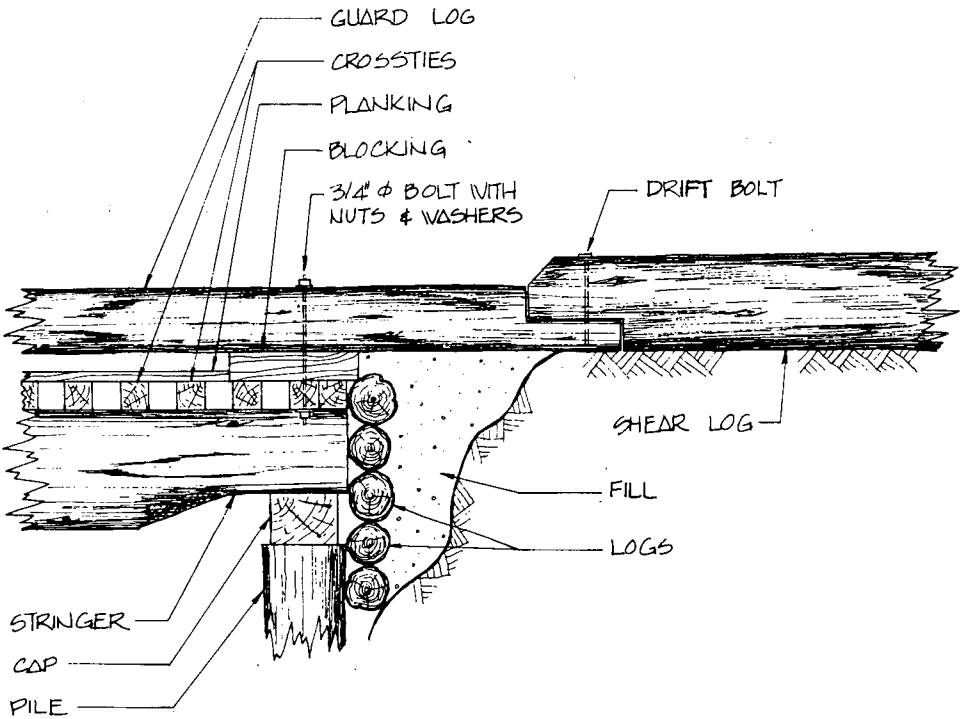


FIGURE 264. Joining a shear log to an extended guardlog

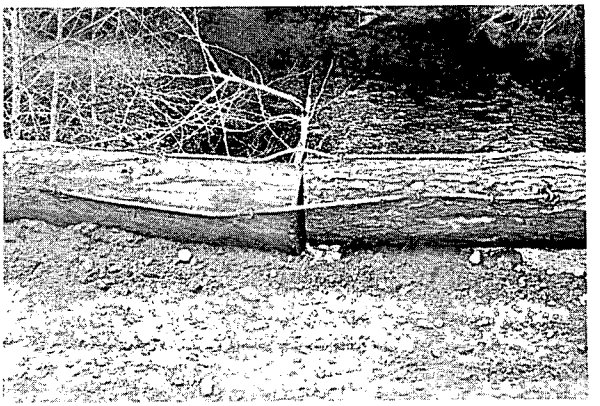


FIGURE 265. Logs spliced with wire rope

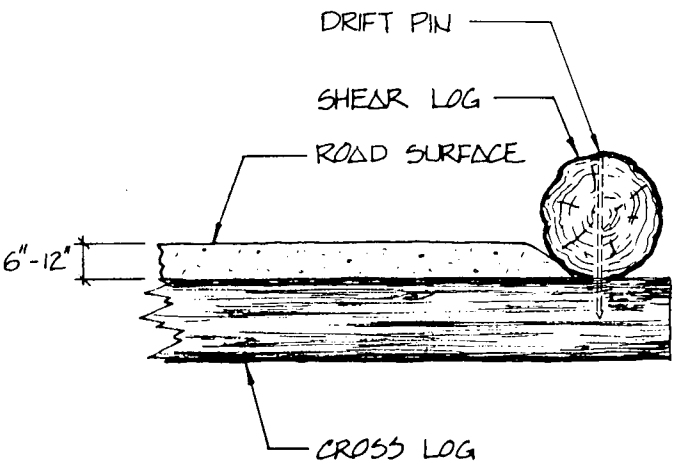


FIGURE 266. Shear log drifted to crosslog

V. WOOD PRESERVATION

V. WOOD PRESERVATION

This section on wood preservation is a brief introduction to decay problems and preservative types and includes methods for decay prevention and detailed techniques for using preservatives in the field. Your first choice for a long bridge life will be wood species with a natural resistance to decay (such as Western red or yellow cedar), which combine structural strength with reasonable cost. (True firs, alder, birch, poplar and cottonwood have low resistance to decay and must be treated.) The only part susceptible to decay in Western red and yellow cedar is a small amount of sapwood which you might want to treat with preservatives. Even with no treatment, these species will last as long as other species which have been treated—sometimes as long as 30 years.

There are two groups of fungi which cause decay. One destroys both the lignin and cellulose in the wood, causing white rot. The other destroys cellulose only, leaving brown rot. "Dry rot" has water-conducting strands and although it lives in dry wood it has a source of water. It may not be practical or possible to keep all water away from the substructure, but keeping stringers dry and providing air circulation around them is the best and cheapest way to protect their strength and extend their life.

Chemical preservatives will protect wood against decay, insect attack or marine borers. Sapwood is easily impregnated with chemicals but the heartwood of some species strongly resists treatment. The lasting quality of preservatives depends on their chemical composition, the application technique used, the wood species, and whether or not heartwood or sapwood is being treated.

Preservatives in use today are either oil-based or water-based. Oil-based preservatives are recommended for bridge construction because they resist weathering and do not leach out easily.

A. WOOD PRESERVATIVES

1. Coal-Tar Creosotes

Coal-tar creosotes are the most popular and least expensive of the preservative oils. They are easily applied in treatment plants, have good penetrating qualities, are toxic to wood-destroying organisms, and are almost insoluble in water. They can increase the life of the structure up to five times that of untreated wood. Creosote will not take paint. It can cause skin irritation, has an undesirable smell, and its oils can become toxic to fish.

As a rule, effective application of coal-tar creosote is possible only in treatment plants at high temperatures. If onsite application is necessary, crystal-free coal-tar creosote is recommended. If creosote solutions are to be used, the creosote content should be higher than 50 percent.

2. Pentachlorophenol and Copper Napthenate Solutions

Usually the petroleum oils for these solutions vary from light diesel fuel to heavy oils. Light oil solutions are recommended for onsite application. The proper mixtures for these solutions are 5% chlorinated phenols or 3% copper napthenate. Mixing pentachlorophenol with light mineral spirits results in a preservative which leaves the wood surface ready to paint. They are seldom toxic to marine life and reasonably clean to work with. Pentachlorophenol solution does not change the appearance of the wood, but copper napthenate leaves a greenish colour. Note that pentachlorophenol causes skin irritation. Wear protective clothing and avoid contact.

3. Water-Soluble Preservatives

Water-soluble chemicals are clean and easily applied by brush or spraygun and you can paint the wood surface later. Good retention can be expected when these chemicals are applied to the wood at the site while the sap is running. Some of these preservatives are highly toxic and we caution the user to check them before purchase. We do not recommend preservatives with an arsenic content to be used for the preservation of bridge material.

Two water-soluble preservatives which have good resistance to leaching are copperized chromated zinc chloride and acid copper chromate (Celcure). One of the oldest water-soluble preservatives is zinc chloride. It is easy to use, clean and inexpensive, but its leaching characteristics reduce its effectiveness. It is used only when other water-soluble preservatives are not available.

B. USE OF PRESERVATIVES

1. Plant Treatment

Small logs and timber can be treated at a plant under very strict and controlled conditions to achieve optimum penetration. Plant treatment is recommended for all bridge material except large stringers and sill logs.

Before any of the material is cut or ordered, discuss it with the treatment plant personnel.

The pressure process is better for treating bridge material in the plant. The full-cell pressure process is used for creosote. Wood is put in the treatment chambers and the air is pumped out to create a vacuum which removes the moisture from the wood. Then the chamber is flooded with creosote. Once the wood is fully submerged in the preservative, the vacuum is replaced with pressure to force the creosote into the wood and this pressure is kept on for several hours.

The empty-cell pressure process is used with oil-borne preservatives. The wood in the chambers is kept under high air-pressure for a time before being flooded with preservatives and then pressure is maintained for a few more hours.

The non-pressure process is usually an open-tank system for soaking the wood in preservatives. A hot and cold bath process is used for coal-tar creosote and oil-borne preservatives. The wood is placed into a hot preservative bath first and then the bath is quickly replaced with cold preservatives. The process is repeated often and the wood finally left to soak in the cold bath. This process is used for piling where only a portion of the pile must be treated.

2. Field Treatment

The field system is used to treat stringers and other large logs. It consists of cold-soaking the wood with crystal-free creosote or low viscosity oil-borne preservatives (using the diffusion process) or a combination of both. Field-treated wood retains much less chemical than plant-treated wood. Creosote and oil-borne preservative penetration seldom reaches 1/16 in. except at the ends.

- Diffusion process

The diffusion process is used for live wood while the sap is still running. It does not work at all on dead wood or trees cut in the dormant period. The liquid chemicals are introduced to the log at the small end immediately after felling and carried through by the sap. This is not a complete treatment, however, and should only be used to compensate for the shallow penetration of other oil-borne preservatives or creosote.

If you plan to use the diffusion process, fell the tree, buck out the stringer with extra wood left at each end, and move it immediately to a shaded location for treatment and storage.

STEP 1.

Block up each end so the log is at least 12 in. off the ground. The small end should be blocked higher so the log is sloping toward the butt.

STEP 2.

Trim the small end about 1 ft, spray water on it immediately, and keep it moist.

STEP 3.

Cover the cut with felt, cotton, or other moisture-retaining material soaked in water-soluble preservatives.

STEP 4.

Trim the butt end and repeat steps 2 and 3.

STEP 5.

Smooth the bark at each end and form containers with an aluminum sheet completely around the top and butt ends. The containers should have an inch of clearance at the stringer ends. Use silicone or other waterproofing to leakproof edges and nail the aluminum tightly to the stronger side or use a steel band to attach the containers to the stringer.

STEP 6.

Fill the containers with prepared preservative solution. Use 5% water-soluble preservative solution for this purpose.

If the weather is cool, fill the containers with preservative solution on the butt of the stringer. This container may overflow during the treatment. The extra preservative solution should be drained off and may be used to refill the top container. Make sure the solution is maintained at 5 percent.

If the weather is warm, fill the butt container with water to keep the wood moist because the solution will evaporate more rapidly in the heat.

Keep the containers full for at least three days or as long as the fluid is moving in the wood.

Once the diffusion process is completed, remove the containers and season the stringers for the time indicated in Table V-A.

TABLE V-A. Seasoning Period

Material	Species	Seasoning Time (months)
Crossties and Timber(s)	Douglas-Fir	5 - 10
	Western Red Cedar	2 - 4
	Western Hemlock	5 - 10
	Western Larch	5 - 10
	Pine	4 - 10
	Spruce	4 - 8
Piles and Stringers	Western Red Cedar	3 - 5
	Douglas-Fir	4 - 10
	Western Larch	5 - 12
	Pine	6 - 12
	Western Hemlock	2 - 12
	Spruce	4 - 10
	Yellow Cedar	4 - 10

Store timber for seasoning on skids at least 12 in. high on clean hard ground. If it is stored in layers, 12-in. skids should separate each layer. There must be good air circulation and no rotten wood or vegetation to cause decay.

Sawn timber should be stored with 3/4-in. of airspace. There should be supports between the layers to prevent deformation.

Seasoning should be done in a dry shaded place to prevent the surface from drying too fast.

- Field treatment with creosote

Apply creosote or oil-borne preservative treatment during hot weather after the stringer is air-dry. Prepare the stringers by hewing, ripping and dapping. They must be completely clean. Move the stringers to a sunny spot and brush them immediately with boiling hot preservatives. The preservative must have a temperature of at least 90°C when applied.

Let the stringer soak in the preservatives for an hour and repeat the hot application. The hotter the air and preservative, the better the treatment. Repeat the treatment and let soak overnight. Treat the stringers for at least three days or until they will not soak up any more preservatives. Never let the stringers dry during treatment.

If you don't plan to season green logs, they can be treated with creosote or oil-borne preservatives. In this case, they are peeled and prepared to receive the hot preservative treatment immediately. Further treatments are applied once a week.

Store stringers on blocks in the shade and protect them from rain as much as possible. Store piles in the shade at least 12 in. off the ground on skids.

- Treatment of cuts and holes during bridge construction

All fresh cuts and damage to the treated shell of the stringer should be brushed with preservatives at least twice.

Soak all holes with preservatives. Drift holes should be partially filled with a thinner preservative solution (creosote) before inserting the pin. The drift pins should be set one inch below the wood surface and the hole filled up with a waterproof plug (coal-tar pitch).

Keep stringers dry on the bridge. Before you place the crossties, cover the stringers with a preservative-saturated fabric—or roofing felt and aluminum sheeting. (You can also use strong roofing paper instead of aluminum sheeting but it will not last as long or give the same protection.) The aluminum

sheeting should be bought in rolls and run in one piece the length of the stringer. The felt is needed under the aluminum sheeting to prevent water condensation. The aluminum sheeting should be much wider than the ripped surface and should be bent down on both sides and over the end of the stringer to allow water runoff and to prevent the water from getting into the felt between the sheeting and the stringer. The roofing felt should be slightly wider than the ripped surface. The aluminum sheeting should not be nailed to the stringer. (It will be held in place by the crossties.) Avoid unnecessary holes in the sheeting.

Soak all the holes drilled for bridge spikes with heavy creosote solution when fastening the crossties.

- Treatment of pile tops after cut-off

After the pile tops are cut they should be soaked with creosote. Apply at least two heavy coats at intervals to soak the wood.

The next step is to cover the pile top with a heavy coat of coal-tar pitch. Place a creosote-saturated fabric, roofing or ship-felt over it and cover the top with aluminum sheeting. The sheeting should be bent down around the side of the pile at least 4 in. and nailed with galvanized shingle nails.

VI. BRIDGE INSPECTION AND MAINTENANCE

VI. BRIDGE INSPECTION AND MAINTENANCE

Forest road bridges represent the highest unit investment in the road system. Deterioration of the structure—or damage to it—not only reduces its value but also threatens bridge failure, injury and disruption of traffic flow (Figure 267). A good preventive maintenance program will increase the life and safety of bridges.

FIGURE 267. Bridge failure

First, we describe methods for inspecting and testing bridges, and show the problem areas in general bridge maintenance. We also describe ways for repairing bridge components, preventing the spread of decay and preventing further erosion or damage to the channel and structure.

Bridge inspections must be carried out regularly to determine any deterioration in the bridge material or the structure. As a rule, a full inspection is required annually in addition to inspections during and after floods.

- Construction records and inspection inventory

Each bridge must have its own file containing all the records related to the bridge. These records should include the detailed site survey, final bridge plan, cost estimates, material orders, construction costs, correspondence, detailed bridge plan "as constructed," construction records, and a detailed inventory of bridge components. At the time of construction it is important to record all the details about the buried portion of the bridge.

The records must also include inspection reports and the details of all repairs and changes made to the bridge. Pictures and sketches should be kept in the file.

It is best to have this inspection inventory in the form of a list to be used during each inspection. Table VI-A shows an inspection inventory list.

TABLE VI-A. Inspection Inventory

Bridge Number: Road: Mileage:

Date Built:

Design Engineer:

Construction Supervisor:

Design Load:

Bridge Type:

Total Length:

Length of Each Span:

Running Surface Width:

Maximum Height:

Clearance above High Watermark:

Test pile: Driving Record:

Load Capacity:

ABUTMENTS:

PILE ABUTMENTS

Type—
Species—
Depth driven—
Height above ground—
Height above rip-rap—
Treatment—
Diameter at ground level—
Diameter at top—
Condition—
Visible defect—
Recommended action—

Bracing:
Species—
Size—
Fastenings—
Conditions—
Recommended action—

SIMPLE OR CRIBBING ABUTMENTS

Type:

Mud Sills:
Species—
Size—
Depth—
Condition—
Recommended action—

Base Log:
Species—
Size—
Depth—
Condition—
Recommended action—

Crib Logs:
Species—
Size—
Condition—

Visible defects—
Recommended action—

Protection:

Planking: Species—
Size—
Height above ground—
Condition—
Recommended action—

CONCRETE ABUTMENTS

Height above ground—
Depth—
Location of drainage holes—
Size—
Material—
Condition of concrete—
Visible defects—
Recommended action—

RIP-RAPPING

Size of material—
Width—
Depth—
Length—
Compaction into ground—
Recommended action—

PIERS

Same as abutments—
Height—
Length, depth driven—
Distance between piles—
Internal ties—
Condition—

Visible defects—
Recommended action—

Dolphins:
Species—
Height—
Pile lengths, depth driven—
Distance from pier—
Internal ties—
Ties to pier—
Condition—
Visible defects—
Recommended action—

Protective Sheeting:
Type—
Species or material—
Size—
Height—
Depth from cap—
Condition—
Visible defects—
Recommended action—

Scour Protection:
Type—
Size of material—
Depth—
Width—
Recommended action—

CAPS OR SILLS

Species—
Size—
Treatment—
Ties to piles or crib—
Condition—
Visible defect—
Recommended action—

ANCHORS AND ANCHOR CABLES

Type—
Size—
Condition—
Recommended action—

STRINGERS

Type of bridge stringers—
Species—
Length—
Treatment—

Description by Stringer:	Mid-diameter—
	End-diameters—
	End heights—
	Width if side is ripped—
	Condition—
	Visible defects—
	Size of end cuts for trussing—
	Cuts for needlebeams—
Lashing:	Description—
Drifting:	Size of pins—
	Location—
	Treatment—

Recommended action—

NEEDLEBEAMS, FRAMES

Species—
Size—
Treatment—
Condition—
Visible defects—
Attachments—
Condition of attachments—
Recommended action—

WIRE ROPE AND/OR TRUSS RODS

Description—
Protection—
Tension—
Condition—
Visible defects—
Recommended action—

DECKING

Type—
Crossties—
Species—
Size—
Spacing—
Spike description—
Frequency of spikes—
Treatment—
Recommended action—
Planking—
Species—
Size—
Nail description—
Nailing pattern—
Recommended action—

Surfacing—
Type of surfacing material—
Type of filling between stringers (small logs, etc.)—
Type of filter fabric—
Ballasting depth above stringers—
Location of lashing that could easily be damaged by road graders—

Recommended action—

GUARDRAIL

Type—
Species—
Size—
Height—
Blocking—
Description of fastenings—
Condition—
Visible defects—
Recommended action—

FENDER LOGS

Type—
Location—
Species—
Size—
Fastenings—
Recommended action—

ROAD APPROACHES

Description—
Recommended action—

STREAM CHANNEL

Cross-section under the bridge—
Length and type of channel control—
Channel material (size)—
Channel condition—
Bank material—
Bank stabilization works—
Bank conditions—
Visible scour holes—
Problem areas—
Recommended action—

DEFLECTION TESTS

Test vehicles—
Load size—
G.V.W.—
Deflection for each test—
Unusual movements by bridge members under traffic—

The bridge inspector must be thoroughly familiar with the design and construction features of the bridge. He must be able to recognize any changes in the structure, judge their significance, and prescribe the necessary action to correct the problem. The inspection is best done by someone who was involved with the construction of the bridge.

1. Inspection Tools

Axe: A small 2-lb axe is one of the most effective tools used. An experienced inspector can detect rot in the wood by pounding it with an axe. A sharp ring indicates sound wood while a dull thud indicates rot. All the reachable logs should be sounded thoroughly—especially pilings. Start hitting the pilings as high as you can reach and work down to the ground line. Stringers should also be sounded. Knots, ingrowths and the distance from nearest support will all affect the sound of the wood. Skill will come with experience, but in case of doubt an increment-borer should be used for further investigation. Surface rot can be explored by using the axe to scrape or chop.

Narrow chisel, long nail, knife blade (pick test): Any of these sharp instruments could be hammered or poked into the wood surface for 1/2-in. to one inch. The probing tool should go in perpendicular to the grain with the blade surface running parallel to it. Pry the wood up with the tool and check the breakage. Sound wood has long slivers, which are rarely broken at the tool. Rotten wood has short broken chunks. The process is called the 'pick test.'

Marlin spike: This is a useful instrument to probe under ties and stringers and other hard-to-reach places to check for rot.

Increment-borer: An increment-borer is used if rot is suspected from sounding. The core will show the size of the rot pocket and the depth and quality of preservative penetration in treated wood. The bit must be long enough to

reach the centre of the stringers. The borer does not easily penetrate dry, hard wood, but you can drill a few inches at a time. To ease drilling, rub the bit with a moist bar of soap, and oil the rest. Ground-line holes should be drilled downward and all others slightly upward.

Shell-thickness indicator: This is a simple tool made of stiff wire at least 3/16 in. in diameter with a small hook at the end (Figure 268).

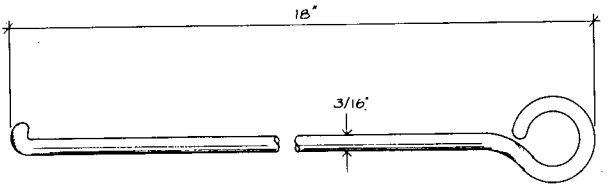


FIGURE 268. Shell-thickness indicator

Drill a hole with an electric drill, auger, or increment-borer and push the tool in it with the hook pressed against the side of the hole. You can feel the growth rings in solid wood, but if the wood is rotten the hook will go in smoothly. As you pull the tool out, the hook cuts through the rot easily but it stops when it hits solid wood and you can measure the thickness of the wood at this point.

Shovel: When you inspect piers and abutments, it is necessary to dig down periodically to check for rot under the ground line. The digging in compacted material should extend 18 in. below the ground line. It may be necessary to go deeper in well-drained gravel or sand. Cedar piling may rot 3 ft below the ground line in some areas. Scrape the pile surface with the shovel to expose the extent of outside rot.

2. Visual Inspection

Note anything unusual such as damage to the wood or attachments, heavy scour marks, or seasoning checks. Examine surface rot in untreated wood and note the condition of the treated wood. Judge the extent of undermining and check insect holes and other signs of insects. Check all loose bracing and determine why it came loose.

Treat all the holes and cuts made during inspection with preservatives (creosote, pentachlorophenol) and plug the holes with treated dowels to prevent rot.

You can detect some problems by listening for squeaking, cracking or thumping noises as a load passes over the bridge and you can check for any movement in the structure as it supports the moving load. Figure 269 shows a cross-section of a superstructure with a heavy line to indicate what is visible. As you can see, most of the areas susceptible to decay are hidden.

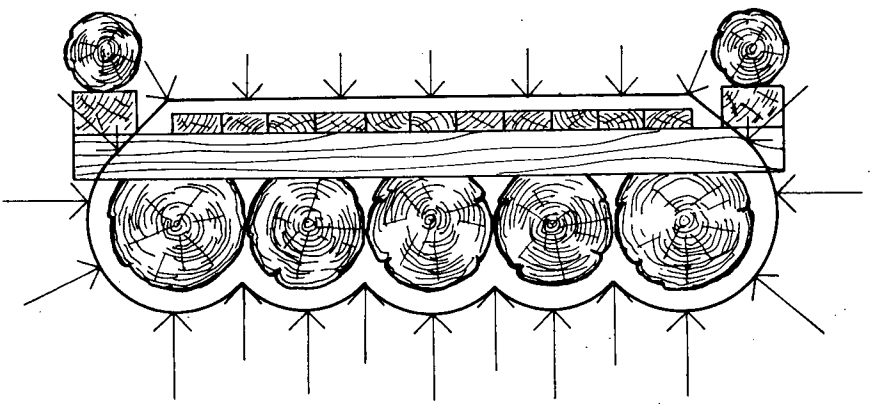


FIGURE 269. Visible areas of superstructure

Only the outside shell of a cribbing can be inspected. The tieback logs and the inside ties are invisible.

3. Deflection Test

Direct inspection can show bridge damage but it will not reveal changes in the load-carrying capacity of the bridge. It is dangerous to judge the condition of an old bridge based on inspection only. You need to use the deflection test.

During the test a heavy load of known weight is driven slowly over the bridge and the deflection is measured. (A large watertanker is a good vehicle for this purpose.)

Measure the deflection at the middle of the span with a levelling rod and instrument. (A string strung tightly between the abutments with a levelling rod hanging upside down from the middle of the outside stringers will also show the deflection.) The test should be repeated three times on each side of the bridge. The test load should approximate the design load.

Measure the deflection under the first few large truckloads to test a new bridge for safety. If one side of the bridge appears to be weaker, measure deflection with the known test load on the weaker side of the bridge.

Safe deflection is considered to be no greater than 1/200 of the span under the design load. The spiral-grain log-stringer bridge is the one exception; in this case the maximum allowable deflection is 1/100. The maximum allowable deflection for a 60-ft span is 0.3 ft, or 3.6 in.—or 7.2 in. if all logs have spiral grain.

If the strength of the bridge is approaching the maximum allowable deflection, the bridge must be strengthened or the load size reduced.

The first test with the known load may not be definitive on a new bridge because the strength of green stringers will increase as the wood becomes seasoned. It will then decrease slowly during the useful life of the bridge and deflection tests will show the extent of this strength loss.

Repeat deflection tests 5 years after construction, 10 years after construction, and annually after the structure is 12 years old. These tests must also be made whenever there is suspected settlement in the abutment or pier.

4. Inspection Areas

The bridge should be inspected in a systematic and organized way, as outlined in the Inspection Inventory Booklet. Inspection is a process for detecting and evaluating the natural aging of the structure—and more important, the damage caused by water, debris, floating ice, insects, accidental mechanical impacts, normal wear and tear, fire, wind and frost. Following are specific details to assist inspection.

a) Approaches

Is there a grade break at the bridge end? Is vertical and horizontal alignment smooth? Is the joint between the bridge deck and approach road continuous or does the bridge end in a pot-hole?

Is water draining onto the bridge or away from it? Are there frost humps at the bridge ends? What is the condition of the bridge and structure, e.g., fender logs and fastening? Are drainage structures in the approach-fill and cut functioning properly? Keep your answers to these questions so later evaluations can be made to correct the problem.

b) Waterways

Note the alignment of the bridge and approach roads to the stream. Is the alignment straight or in need of correction? Was the opening adequate during floods? Was there clearance for the floating debris and ice?

Are there new gravel or sand deposits and scour holes? Has the channel shifted significantly? (If so, a new profile of the crossing should be done.) The information should identify trouble areas, including the formation of new obstacles.

Inspect the protection devices for the bank and shore. Are they adequate in size and material? Are there new areas where bank protection is needed? Observe the influence of the bridge upstream and downstream. Are there signs of upstream flooding owing to the flow restriction by the bridge? Is there extra channel-erosion under the bridge upstream or downstream owing to the increased stream velocity created by the bridge?

c) Abutments and piers

Check these structures for scouring and undermining. Ideally, inspection should be done at low water-level. At high water, however, a pike pole is a useful tool to probe the water depth. Original pile length, pile penetration, or the abutment height above ground (and its depth in the ground) must be known at a few places. Undermining is especially dangerous for cribwork and concrete structures. If it occurs, close the bridge until the damage is repaired. Check abutments and piers for any visible damage. Check concrete for cracks and deterioration. Timber piles and crib logs must also be checked for decay. The hammer test may reveal inside rot-pockets in the piles which are not visible from the outside. Treated piles may be rotten inside. The most likely place for rot in the pile is at the ground line and at the top under the cap.

If the bridge crosses tidewater, that part of a wooden structure below the tide line may be damaged by marine borers such as teredos. Limnoria-infested piles have an 'hourglass' effect.

Examine contact surfaces between the wood members for rot, damage or looseness. Inspect the contact surfaces of wing logs, face logs, tieback logs, caps and bracing for crushing and splitting.

d) Stringers

Stringers are probably the most difficult to inspect visually (especially during flood conditions) but they show the most movement under loads. If any of the stringer movements appear to be excessive, close the bridge to heavy traffic until it can be properly inspected.

Check the stringers for decay, splitting, cracking and deflection under loads. See if any stringer has moved on the sill or cap. Check the stringer seats for crushing. Check blocking and shimming for rot, crushing and movement. Check dirt accumulation on the stringers. Check the stringer-end ventilation; is it working properly or is decay developing there?

Check for wood stains and investigate their origin. Rust around fastenings will combine chemically with wood and lower its strength.

See if the stringers work as a unit under a load. Weaker ones may have to be reinforced.

e) Needlebeams

Needlebeams should be checked like stringers although wear and tear is more evident. Check rot and crushing of the shimming. Check all the hardware for cracks, rust and looseness. The needlebeam must be tight.

f) Cables and hardware

Check wire rope, steel rods and hardware for protective coating, tension, and wear. All the ties and fastenings must be tight. Threadbar tension for steel-rod trussing is easily checked if the fittings were painted after construction. If the paint is not cracked at the nut it probably has the original tension. Steel rods and wire ropes with less tension will sag. Watch them under a load: the one with higher tension will become straight first. Rods and wire rope with higher tension will give a higher-pitched sound when hit with a piece of wood or mild steel. (One can, in fact, tune the trussing until every truss rod or wire rope gives the same note.)

g) Decks

Examine planking for wear and tear. Check the nailing. Planking wears unevenly, more under traffic and less at the guardrails. Planks must be replaced

when they start to crack. Replace planks in the wheel's path more often than other planks, and renail planks which move under a load.

It is difficult to inspect crossties, but you may find crosstie weakness when you notice a sudden drop in planking as wheels go over it.

Check gravel decks for thickness, pot-holes, and uneven spots developed by grading. Do any of the stringers or inside lashings show? Is all the visible lashing and bolting tight? Are any of the lashings damaged? Are any of the guardlog stringers damaged?

Are small logs between the lashing at the guardrails big enough to protect the lashing?

A loose surface indicates that the stringers do not work together and should be reinforced.

Laminations should be checked for decay. Are laminations tightly nailed against each other? Is the deck watertight? Is there any apparent damage to the laminations?

Does the deck need cleaning? The deck should be free of gritty material that would increase surface wear.

h) Guardrails

Guardrails, guardlogs, and temporary curbs should all be checked for mechanical damage, misalignment and looseness. Do the guardrails appear to be high enough? Are the guardrails broken or moved out of place? Are the bolts and lashings tight and in good shape? Are the guardrails split and the fittings bent? Is the blocking undamaged and in place? Are the support crossties split? Are the guardrails aligned with the fender logs?

i) Signs

Check all signs and markers posted around the bridge.

If there are none, check to see if posting the bridge is necessary. Do the bridge ends need marking for night? Are speed signs necessary? Should a load limit sign be posted? Is the bridge numbered? Is the number visible? Is the bridge marked for snow plows?

j) General

Observe the bridge under the load and give special attention to excessive vibration and deflection. The intensity of vibrations should be recorded for comparison with future inspections. Determine the cause of any excessive vibration. Carry out a deflection test if scheduled or required.

Note the general appearance of the bridge. A bridge with poor appearance does not present a good public image.

Check for fire hazards. Debris and fast-growing weeds create a fire hazard which must be eliminated. Check fire-protection equipment, especially at the beginning of summer.

If the timber structure has been treated with preservatives, see if chemicals are leaking into the stream. When the chemical content of the water reaches a certain level it can be harmful to fish. Investigate all minor complaints about the bridge, including those relating to visibility on and around the structure.

Check the concrete under the sill for surface cracks or crumbling from salt or from other causes.

Frost hump causes a problem if fine-grained soil is used for fill. Fine soil expands during freezing weather and forms a hump at the bridge end. Loaded, fast-moving vehicles hit the hump (and bridge) with considerable impact. Replace the fine-grained soil with granular soil (gravel).

Some logging bridges close to camps carry utility lines (usually water lines). Check these lines and any attachments during bridge inspection.

Photograph defects, if possible. Such photographs will be useful later in the office to evaluate the problem areas and decide on corrective action. They are also helpful in judging the rate of deterioration of the structure.

5. Inspection Reports

Make a written report of each inspection. Results of this inspection can be recorded in both narrative form or by checklist system on a suitable document.

We recommend the use of a maintenance-inventory form with three small columns and one large column on the right side of the list. Use the short columns for checkmark indications of the condition of the structure, such as 'good,' 'fair,' and 'poor.' 'Good' means that the structure requires no further attention. If it is checked 'fair' then it will require repair in the near future. Anything marked 'poor' must be repaired immediately. The large column is for comments describing the problem.

There should also be enough room after each main heading for general comments describing the condition of the structure, including what to watch for during the next inspection.

Once the recommended repairs are carried out, the inspector should update the maintenance-inventory sheet to show the present condition of the bridge components. File all inspection reports in the bridge file.

6. Repairs

In the following list, we identify a few common problems of the stream as it affects each component of the bridge and give some guidance about repairing these defects.

a) Stream channel

A major problem is channel erosion. Erosion occurs for the following reasons:

Constriction of waterflow
Misalignment of piers and abutments
Bridge built on a stream bend
Flood
Progressive natural scour
Uneven stream bed

If piers or cribs or concrete footings do become undermined, a number of corrective measures are possible.

Large scour holes or holes made by rapid water may be filled with coarse shotrock. Take care not to restrict the water flow because this will cause even more erosion at unprotected places. Be very careful when you fill the hole with rock or you may move the scour hole to the edge of the fill.

The following formula may be used to calculate the coarseness of the shot-rock and rip-rap required for different flow speeds.

$$\text{Minimum coarse rock diameter (ft)} = \frac{\text{Water velocity (ft/sec)}^2}{85}$$

Table III-E can also be used for this purpose. Stream velocities shown in the table are for flood conditions.

Rock should be well-graded to act as a solid blanket. If only large pieces are used then the water percolates through them and erodes the stream bed. On sandy soils a layer of gravel (or filter fabric) should be laid before using rip-rap or coarse rock.

Rock-filled wire baskets (gabions) can be placed in holes next to piers and abutments. If possible the ground should be smoothed so the baskets can be placed next to each other.

Row piling, wood or steel sheet piling driven deep enough will stop under-mining and will also prevent damage by floating logs and debris.

- Concrete fill

Some scour holes under abutments and piers may be filled with concrete to give support to the structure. Excavate to make sure that the concrete starts well below scour level.

- Cleaning and reshaping the channel

If the channel is plugged with gravel or debris so that the scouring effect of the water will endanger the bridge, it will be necessary to clean and reshape the channel under the bridge and downstream. This should be done with a backhoe or bulldozer at low water-levels at times when the silt movement will not affect fish-spawning grounds.

- Channel realignment

On flat areas, a meandering stream might change its channel at the bridge to the extent that the bridge appears to be built in a bend. The stream will undermine the approach fill at one side and scour the abutment on the other. Protect the structure and the fill with scour-resistant material (Figure 270).

(Realigning the channel should be the last resort. It is expensive and difficult to stop a river from meandering.)

FIGURE 270. Scour-resistant approach fill

- Lining banks with concrete

Line easily-eroded banks with concrete if the water is not expected to carry heavy debris. This is an expensive process and should be used only as a last resort. Shape the banks at low water-level and dig a ditch down below scour level. Line the banks with plastic sheets covered with reinforcing wire mesh and concrete. When the concrete sets, fill the ditch and put rip-rap at the foot of the bank. Prevent the stream from getting behind the concrete sheet.

- Removing undermined trees

Remove undermined trees which could fall into the creek.

- Ice jams

Ice jams can be a problem, so make a straight, smooth channel. If piers must be added or rebuilt, reinforce them with a sharp steel nose or steel-clad protective dolphin.

b) Repairs to cribbing, abutments and piers

Cribbing abutment failures are usually caused by the six types of problems discussed in the following paragraphs.

- Decay

Sooner or later, rot will develop in the wood, but decay is easily detected if it is visible. Scrape it off or chop it out and treat the solid wood with a heavy application of preservatives (using a brush). Preservatives seldom penetrate wood deeply and the treatment will have to be repeated often.

Treat rot pockets as you would pilings. Rot inside next to the fill is very difficult to detect and even more difficult to treat without opening the cribbing up. Usually it is allowed to run its course.

- Shrinkage

Loose fittings in the cribbing should be shimmed. When one side of the bridge starts sagging, the superstructure should be jacked up and the sill levelled out by shimming, either between the stringers and the sill, or under the sill.

- Ground settlement

This is the most difficult problem to correct without rebuilding the abutment. Ground settlement becomes a problem when the soil's low load-carrying capacity is not taken into account at the time the abutment is designed.

If settlement is gradual, raise the superstructure by re-shimming the sill whenever it is necessary. If more rapid, redistribute the load exerted on the soil by the base log. Underpin the base log with concrete to cover an area at least three times the base log's width. The concrete should be at least 2 feet thick. (Underpinning should be done in small sections. It may also be necessary to jack up the superstructure before digging.) First excavate a 5-ft section of the base log at the weakest section of the cribbing. Put a form in around the hole and fill it with concrete. If the ground is wet the forms should be lined with a plastic sheet. The pads must be centered under the base log to distribute the load evenly over the ground.

Once the concrete is strong enough, excavate another section under the base log and fill it with concrete. This process is repeated until the base log is entirely supported by concrete pads.

Another way to stop settlement is by driving group piling (i.e., dolphins at each side of the bridge) in front of the cribbing and placing a large sill across

the piling as a trestle to support the superstructure. This system narrows the stream channel but it is an easy way to extend the abutment's life and it can be done without much traffic interruption.

- Scour

The abutment or pier should be restored to its original condition or reinforced against future scour. Determine the reason for scour and prevent future erosion.

Light scour conditions may be eliminated with rip-rapping around the foundation. If rip-rapping has to be placed underwater, or the shape of it must be controlled, use rock-filled wire baskets (gabions).

If the base log is not down deep enough, it can be underpinned with concrete pads, concrete pads and posts, or concrete and another base log. Dig down far enough under the base log and fill the hole with concrete. Use the same system described for ground settlement. Dig in sections. To save on concrete in deep holes, pour concrete pads in the bottom of the excavation and place wooden posts on these pads under the base log. The area of the concrete pads should not be smaller than the area occupied by the base log. Pour a 2-ft thick pad first and wait for it to harden. Put a post on it (solidly jammed under the base log) and use shimming if necessary. Then pour 1 ft of concrete around the post. If the base log foundation is totally eroded, you will need at least six posts to underpin it.

Another method is to rip large log sections on both sides, place them on the pads, and shim them up to support the base log. After the underpinning is completed, the hole should be filled with scour-resistant gravel or well-graded crushed rock, and this in turn should be protected by rip-rapping or rock fill.

You can also prevent scour by driving row or sheet piling in front of the abutment or around the pier. Pile driving can be done only when the superstructure is removed.

- Earth pressure

Abutment failure due to earth pressure may result from the following problems.

- The logs are too small to resist the earth pressure.

- The tieback and face logs are rotten and loose.

- Anchors are pulled or the ties are broken or loose.

- The base log has moved or settled.

Angled wing-walls are easily reinforced by placing piling, rock or coarse gravel against them. You can also pile rock in front of the abutments if constriction of water flow is not important.

If you can't narrow the channel, here are some temporary solutions: dig holes for strong posts tight against the crib face, place the posts, and then tie them back to a solid anchor. Put a large log or an I-beam across the top of these posts and tie it at both ends to anchor. (You can drive piling instead of using posts.) If driving piling or digging for posts is not possible because of hard ground conditions, bolt posts against the front of the crib face and anchor at top and bottom.

- Mechanical damage

Mechanical damage is caused by floating logs, debris, ice, and rolling boulders.

To transfer the vertical loads, it is important to keep the end of a tieback in place between the face logs. If tieback logs are moved or broken, they should be moved back in position and fastened. (It is difficult to replace a tieback log unless the crib is taken apart.)

Broken face and wing logs should be reassembled and reinforced. Bolt flat bars of 1/2-in. by 4-in. mild steel to the log, using lag bolts (screws) at least 6 1/2 in. long. Use two bars (or more) for each log.

You can drive piling dolphins upstream and downstream as a quick but temporary corrective measure. Cut off the top of the dolphins and slip a heavy sill log or steel beam into place across them to support the stringers. You will need to jack or lift the stringers because it is necessary for the new sill to have a tight fit. Place sills on both sides of the pier to support the superstructure. This support may restrict the water flow and should be removed once the abutment or pier is repaired.

c) **Repairs to pile bents**

- Pile settlement

Under certain ground conditions, and if piles are not driven to refusal, the pounding effect of traffic may drive some of the piles further in and create a space between the cap and the pile top. Fill in the gap by periodic shimming. Bracing should also be tightened.

Mechanical damage: Protection piles and bracing are easily repaired or replaced but replacing a structural pile is difficult and expensive.

You can repair broken or split piles by splitting a steel pipe and bonding or lag-bolting it around the broken section of the pile. The pipe should be at least 4 ft long. Use strong banding or no fewer than six lag bolts to hold each section of pipe. Through-bolting (instead of lag bolts) may be necessary in difficult places.

If the lower part of the pile is still sound but the top is beyond repair, cut the pile below the damage. Slip a large-diameter pipe (larger than the pile) over the cut pile to replace the top part. This pipe should be at least a foot longer than the cut-out section of the piling. The pipe should have two ears on top so it can be fastened to the cap. Cut two holes 4 to 6 inches in diameter on the side of the pipe for concrete pouring, one on top and one about a foot above the pile cutoff. Once this pipe is in place and fastened to the sill, the bottom of the pipe is fixed in place (with a space around the pile butt) and sealed off. Pour fine, fairly-dry concrete into the bottom hole and tamp it so it gets down around the pile. Seal the bottom hole and continue pouring concrete through the top hole until the pipe is solidly filled. If there is a likelihood that the abutment or pier will be damaged again, protect it.

Damage from decay: If the pile is badly rotted above ground, cut it off and replace it with a steel tube. If the piling is weakened under the ground-line, dig the pile below the rotten section. Cut it off about 3 ft above the bottom of the hole.

Use a steel pipe much larger than the pile and long enough to reach from the bottom of the hole to the cap. Split the section above the pile in half lengthwise and remove one half. Weld ears to the top for bolting, jack up the cap, put the large pipe in place, and bolt it to the cap. Weld a piece of steel (at least 1/2-in. by 6-in.) inside the pipe resting on top of the pile. The weld must be strong. Fill up the lower section of the pipe with good quality

concrete, making sure it goes all the way to the bottom of the hole. Once the concrete is set, weld the cut-out section back in place and fill it up from the top with concrete. After the concrete is set remove the jack.

Piles in piers or abutments can also be repaired by replacing the top section with a new-wood pile. The pile base is dug around at least 3 ft below the rot and cut just below the rot. A makeshift jack is placed on the cut (see Figure 271). Prepare a new pile cut to size with a hole drilled for the jack bolt and put it in place. Fasten the pile to the cap and tighten the jack bolt. One-quarter-inch angles (four) are tack-welded between the jack plates after jacking is completed. Four 3/8-in. x 4-in. steel plates are bolted to the pile. Forms are placed around the pile and concrete is poured as shown in Figure 271. The top of the concrete is sloped for better drainage. Make sure that the concrete fills the void around the jack. All steel material should be treated against corrosion.

If there is only a small amount of rot on the outside of a pile or log, it can be scraped off and brushed with pentochlorophenol or creosote.

Apply the bandage treatment for rot at the ground line. Dig a hole around the piling below the rotted section. Scrape off the decayed wood and brush on water-soluble fluorides, pentochlorophenol or creosote. These preservatives may also be applied as a mixture, which quickly diffuses into wet wood. Cover the section with a very thick coat of preservatives. Wrap it with a black polyethylene sheet reaching 18 in. above the ground. Cover the hole with fine fill material but avoid puncturing holes in the polyethylene sheet. Compact the fill and place rip-rapping (if necessary) to prevent scouring.

Rot pockets can also be treated by drilling a 3/4-in. hole in the rot pocket (more than one if the pocket is large) and pouring in water-soluble fluoride preservative solution. Fill the hole with tar and plug it with a treated plug. (If ants are present the final treatment should be creosote or pentochlorophenol mixed with gasoline.)

These preservatives will not work in Douglas-fir and other wood species where the rot pockets are not defined. Liquid fumigants must be used. Some fumigants are Vapam (Sodium N-methyldithiocarbamate), Vorlex (methylisothiocyanate and dichloropropenes) and Chloropicrin (trichloronitromethane). All of them are volatile and poisonous. Follow the manufacturer's instructions and use extra care.

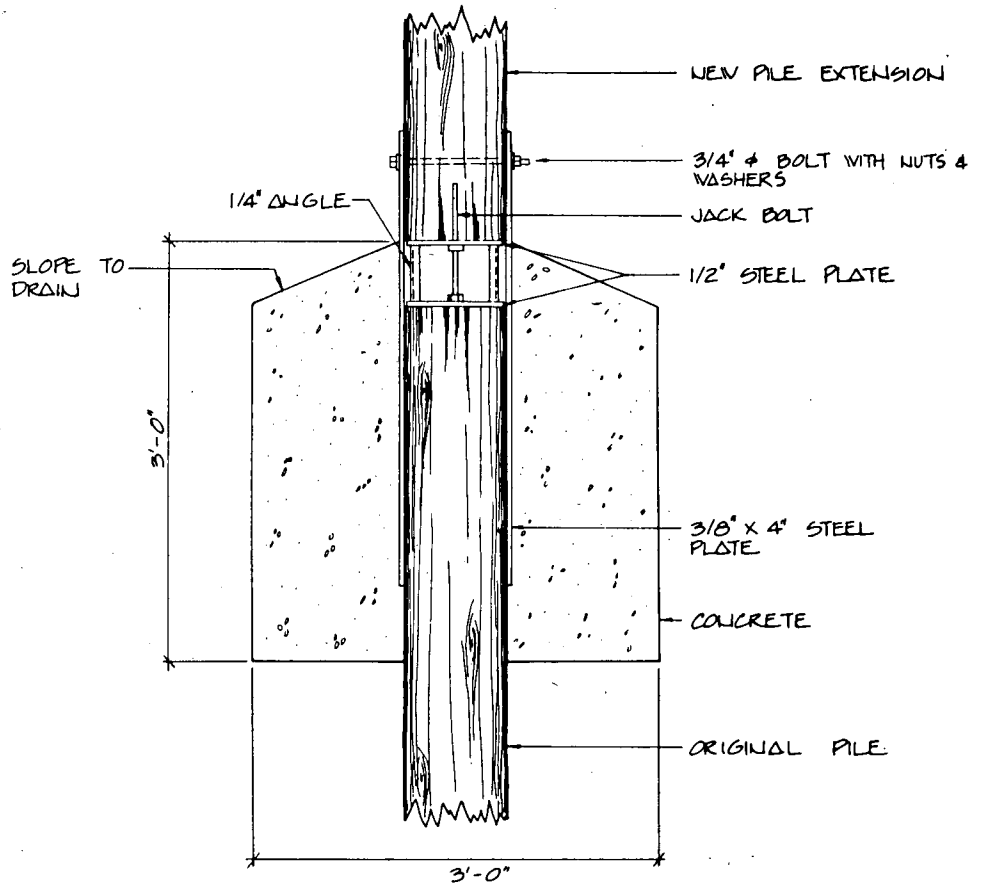


FIGURE 271. Pile repair

Drill holes downward around the pile from 6 in. to 12 in. apart. The first holes should be below the rot pocket and the last above it. Start with the bottom hole, and use a squirt bottle with a plastic hose to fill 3 in. from the end, then seal with a tight-fitting treated plug. (Cedar plugs may be used.)

Table VI-B shows the fumigant capacity of a hole.

Wear protective equipment and stand upwind during the fumigation process.

Carry out the fumigation at a time when the pile will not be flooded for at least two months. The treatments discussed in this section will last from 5 years to 9 years.

TABLE VI-B. Fumigant Capacity of Holes

Hole Diameter (inch)	Hole Length		Fumigant		Number of Holes per	
	(inch)	(cm)	per inch fl oz (Can)	per cm (cm^3)	12 fl oz (Can)	0.5L
5/8	15	38	0.18	1.98	6	8
	18	46	0.18	1.98	5	7
3/4	15	38	0.25	2.85	4	6
	18	46	0.25	2.85	3	5

- Scour damage in friction piles

Friction piles support most of the load through friction between the pile skin and the adjacent soil. They are driven in the ground until they generate enough support or reach refusal. Often the stream's scouring action lowers the original ground and reduces the original pile penetration. This reduces the pile's load-carrying capacity. To prevent failure of the abutment or pier, this hole must be filled with well-graded gravel or shot rock. If the fill is not scour resistant it should be protected by rip-rapping.

d) Repairs to Concrete Abutments and Piers

- Ground settlement and undermining

Underpin the structure as soon as possible after you notice undermining. Jack up the superstructure and shore up the damaged area. Dig out the foundation in sections (see cribbing abutments) and underpin with concrete. If ground settlement is the problem, the underpinning must be wide and start below scour level. Cover the scour-resistant material and rip-rap. Level the stringer seats before lowering the superstructure.

- Cracking

Vertical cracks indicate excessive earth pressure. The abutment is failing because of poor wall design or construction.

The structure may be repaired by building another wall in front of it. Jack up the superstructure and install a number of concrete anchors in the wall.

Excavate to the foot of the structure. Tie reinforcing-bar for the new wall to the anchors. Build the outside forms and pour good quality concrete.

- Surface deterioration

This may happen due to chemicals in the water, poor concrete material, poor concrete mix, or freeze-thaw damage.

Scrape off all the loose particles. Apply a bonding agent or grout to seal, and fill the holes with new concrete.

Scour holes in concrete can be treated the same way but make sure that the concrete has enough time to set before it is flooded again.

- Spalling under the sill or stringer seats

Spalling is a type of chipping, a deterioration caused by chemicals (usually road salt). The best prevention is to wash off the bridge, the abutment, and the pier tops frequently.

Clean the concrete and waterproof the surface. Fifty percent linseed oil and 50% mineral spirit make a cheap, waterproof coating.

- Mechanical damage

Mechanical damage is usually caused by floating logs. The best protection is to cover the problem areas with steel sheeting.

e) Repairs to caps and sills

The problems with caps and sills relate to decay, crushing under loads and mechanical damage. If rot shows, scrape the wood and soak it with preservatives. Under most conditions, shimming is required. Use treated or cedar shimming.

It is difficult to scrape rotten wood in confined areas. If the decay is not too advanced it may suffice to soak the rotted area with preservatives. In very advanced cases, however, the cap or sill should be replaced. A crushed cap must be replaced with a larger one.

Split caps or sills may be bolted with through-bolts or lag bolts.

f) Repairs to stringers

Rot in stringers is treated as it is for piling and cribbing. The most decay-sensitive part of a stringer is under and between the crossties. Do not allow dirt to collect on top of the stringers. If there is any doubt of the strength of the stringer, a deflection test should be done. Any time the crossties are replaced, the stringers should be cleaned off and heavily treated with preservatives.

Longitudinal deep splits and stress-concentration splits should be watched carefully. If they progress rapidly the stringer should be replaced or the structure reinforced.

Shim uneven stringers. Once they are seasoned it may be necessary to shim again.

If some stringers are weaker or springier than others, you may use needle-beams to make the superstructure work as a unit.

Increasing deflection on a bridge is a sign of old age. The bridge can be strengthened but simple solutions are temporary and give the bridge only a few more years of service life.

Reinforce a weak bridge by using two extra stringers as guardrail logs. These stringers should have a mid-diameter nearly 10% smaller than the original average mid-diameter of the old stringers. Lay the extra logs over the outside stringers on wide bridges and block up the two ends to a clearance at the middle of 1.0% of stringer length if you're using old seasoned logs, or 1.5% of stringer length for young, green, springy logs. Lash down as shown in Figure 272. This type of bridge reinforcement is temporary because the crossties are overworked. They must spread the load between stiffened outside stringers and unstiffened inside stringers.

A better solution is to place a needlebeam under the stringers and tie the guardrail logs to it (as explained in the stringer section).

An inverted king truss with galvanized wire rope provides reinforcement when extra stringers for guardrails are not available (Figure 273). The ropes should run outside the side stringers. The same number of wire ropes must be used on both sides and all must be the same size. The total allowable load of the wire rope must be at least 1.25 of the Design Load Weight. The fittings for the wire ropes must be at least as strong as the wire rope itself.

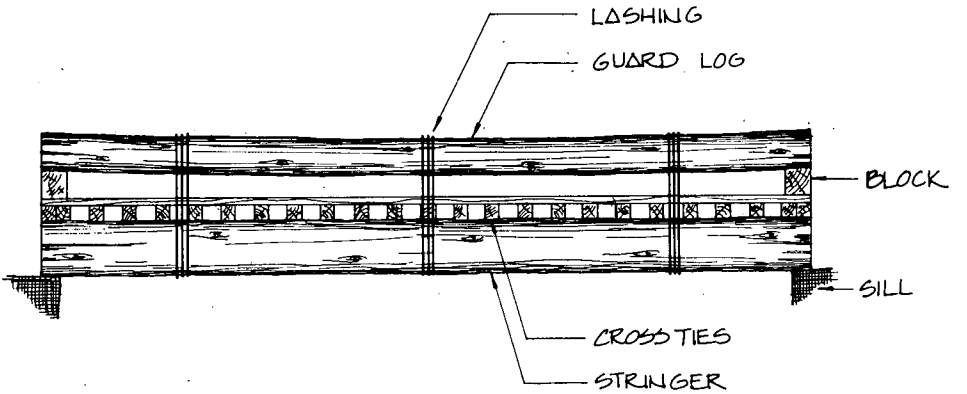


FIGURE 272. Emergency use of guardrail logs as stringers

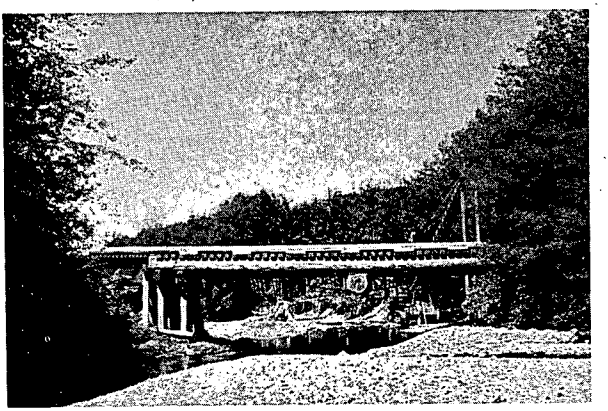


FIGURE 273. Bridge strengthened with a wire rope truss

The needlebeam must be large enough to assure an L/10 or L/8 trussing depth (Figure 274). If you don't need the bridge any longer than two years, the trussing can run under the unprotected needlebeam. If the bridge is to have a longer life, you can protect the needlebeam with tree plates or steel channels (sleeve segments). They will keep the rope from cutting into the wood, and will prevent deformation of the wire rope.

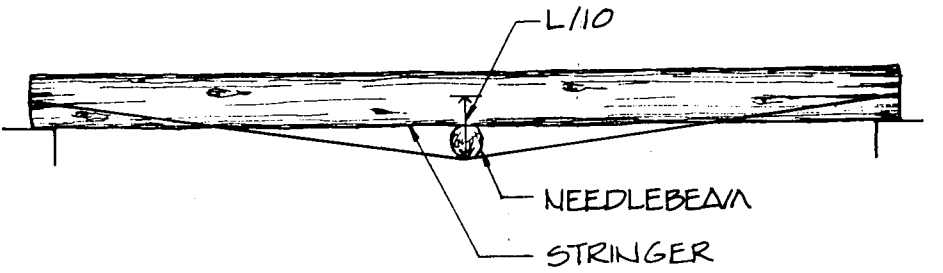


FIGURE 274. King truss

Tension the wire rope as follows (using turn buckles or other similar devices):

1. Take the sag out of the bridge up to the original deflection without live loading.

2. Run a few loads over it and tension up to the original deflection under live loads.

3. Check and adjust a few days later.

In some cases the bridge should be rebuilt, not repaired. If you plan to replace stringers, however, you should replace the sills, crossties, and planking at the same time.

If in doubt about repairing or rebuilding, consult a bridge engineer.

g) Repairs to steel and wire rope trusses

Trusses may become loose and should be tightened to the required tension. The trusses should be cleaned and painted at the first sign of rust or corrosion.

Broken strands in wire ropes indicate that the trussing is overloaded. Rubbing may have damaged the wire rope at the tree plates. These wire ropes must be replaced with either larger size rope or extra ropes.

Place either tree plates or wire-rope shoes on the beam if trusses become loose when the rope cuts into the needlebeam.

If trusses are damaged by high floods, move the members back into position, and thoroughly check the original tension. Bent rods should be replaced

or in the case of DYWIDAG threadbars, the section may be cut out and spliced with a new section.

If the needlebeam has moved, it is usually necessary to shim between it and the stringers.

h) Repairs to crossties

Remove planking and guardrails to replace the ties. When crossties are off, check the top of the stringers for rot. The stringers should be cleaned and coated with preservative before new crossties are laid.

Crosstie problems are usually associated with loose decks or poor load distribution.

- Loose crossties

There are problems if not enough bridge spikes were used, or they were too short, or they have rusted. If the original crosstie nailing pattern is known, drill larger holes through the planking without removing the planks and drive the spikes down through the planking and the crossties. If not, take off the planks and spike every crosstie to every stringer.

Always use a mild-steel sledgehammer and wear protective goggles. Remember that a hole should always be drilled through the crosstie into the stringer to prevent splitting by the spike. (See Decking section for details.)

- Crossties not distributing the load:

- Undersize crossties: The crossties will eventually have to be replaced. Needlebeams can be used as a temporary solution.

- Not enough crossties: Take off the planking and place extra crossties between the existing ones if the spacing allows it. If not, the crossties will have to be replaced with larger ones.

- Rotten crossties: Replace rotting ties if planks continue to loosen after re-spiking.

- Crossties damaged from overloads: Cracked and broken ties must be replaced. Larger ties should be used if there is a chance of future overloading. Check to see if the stringers are capable of carrying the overload.

Guardrail-support crossties may be damaged. A broken tie may be left in place and fastened until the deck is replaced. In this case the guardrail support should be moved over the sound ties. A vertical crack often develops at the bolts in guardrail-support ties. These cracks can be repaired by placing a block between the ties, and bolting it and the cracked tie to an adjacent crosstie.

Check all crossties when the planking is replaced. If there is a chance that the ties will not last as long as the new planking, then the ties should be replaced as well. The stringer top may also be treated with preservatives to check decay.

i) Repairs to planking

Planking deteriorates from wear and mechanical damage. Rotting is a problem on old, out-of-service bridges. Rotten planking should always be replaced if the bridge is expected to carry a normal traffic load. Planking should be replaced whenever new crossties are installed.

Occasionally a bridge plank will break prematurely. Quick action is necessary to replace broken planks because short broken sections have been known to jillpoke a vehicle. Use a powersaw and wrecking bar to remove the broken sections and spike a new plank in place. The cuts should be made over a crosstie if the full length of the plank is not replaced.

Planking is due for replacement when planks start cracking and heavy wear shows around spike heads and knots. It may only be necessary to replace the running planking.

When a special wearing-surface is used to extend the life of the planks, it must be kept in good repair. Replace the protection surface if repairing is difficult or has to be done frequently.

j) Repairs to guardrails and guardlogs

Guardrails may be damaged by road-graders or other vehicles bumping or rubbing against them. The guardrail may break or crack at the bolts. All or part of the guardrail section can be replaced. Bent and damaged bolts should also be replaced.

Guardrails rarely become rotten enough to warrant replacing separately, but they should be replaced along with planking or crossties. Some guardrails are painted for visibility. The paint surface should be kept clean.

k) Repairs to painted surfaces

Repainting should be part of the annual maintenance program. Never allow any exposed load-carrying metal part of a bridge to become rusted. Even the zinc coating of galvanized metal can become worn or damaged so the metal rusts. Clean it and cover it with paint.

Use a good quality zinc-rich paint for efficient rustproofing. It requires surface preparation but it is worth it. Paints which do not require a rust-free surface are useful for urgent repairs.

A good quality coal-tar Epoxy paint will protect all metal parts from corrosion. Use any paint that will do the job—but paint, and paint often.

APPENDIX I

SCHEDULING AND COST-ESTIMATING

A well thought out construction schedule will reduce delays and ensure the bridge is built on time. To prepare this schedule the planner must know the delivery times for materials and must estimate the time required to do specific jobs. He must also establish critical dates and problem areas which might restrict progress. The most obvious critical date is the completion date. Some questions to ask might be, Is the site accessible at all seasons of the year? Must some of the work be done at low water? Must the stringers be cut when the trees are dormant and how long should they be seasoned?

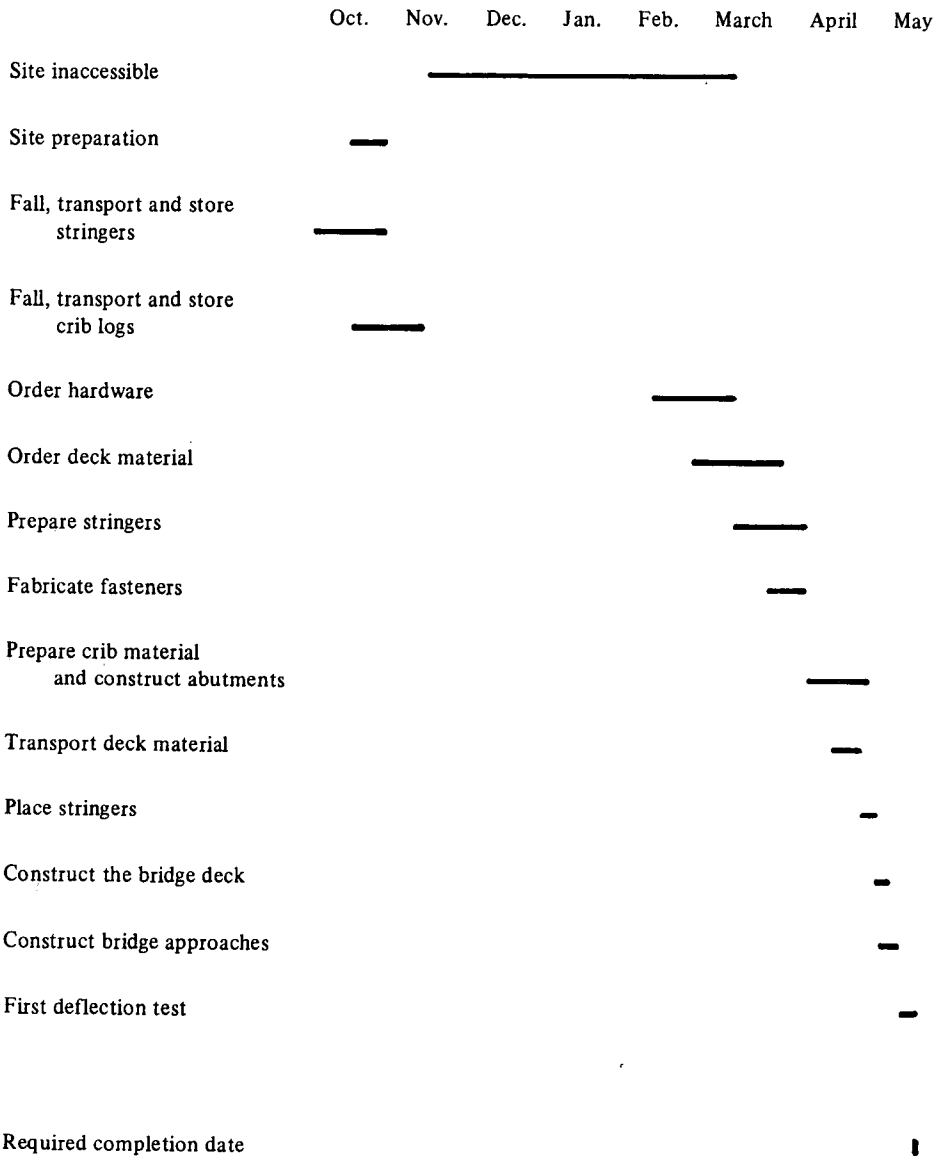
The "critical path technique" graphically illustrates the relative times between ordering supplies and between starting and completion dates of parts of the project. To make a critical path, begin with the earliest starting date of the first job and add the length of time required to complete it to find its completion date. Now consider the sequence of elements. Can one start before another is complete? When must supplies be ordered? When will they arrive on site? Continue to work through each element until the bridge is finished. If the scheduled completion date does not agree with the required date, go back and see if it is possible to shorten up or overlap certain elements.

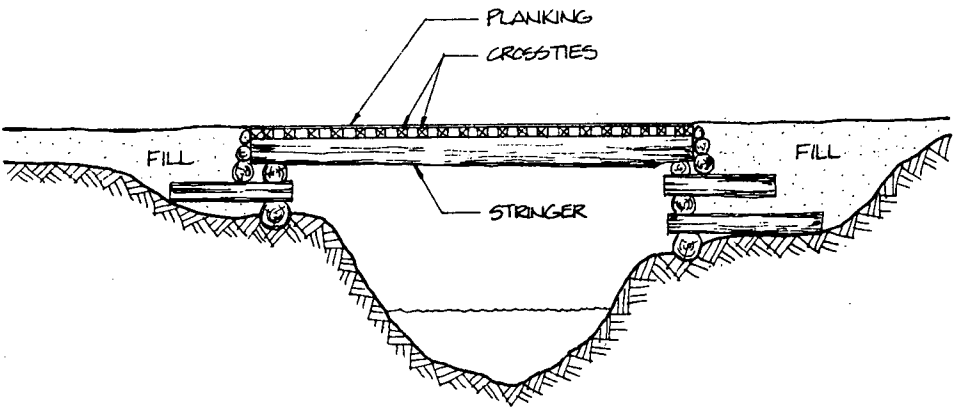
The following is an example of a work schedule and a simple critical path diagram.

SCHEDULE RESTRICTIONS
Starting date: September
Completion date: May 15
Site inaccessible: November 15 to March 15
Stringer seasoning: 2 months

TIME ESTIMATES	WEEKS
Site preparation	1
Preparation of crib logs	2
Crib construction	1
Choosing, felling, and yarding stringers	3
Stringer preparation	2
Stringer placement	1
Deck material delivery	4
Deck construction	1
Bridge and road completion	1
Hardware delivery	4

CONSTRUCTION SCHEDULE





Three types of cost estimates are necessary during the process of choosing a bridge site, determining the type of bridge and preparing a final budget.

The first is a rough cost estimate used for long-range planning—or to compare sites. The planner must know construction costs in the area and must know the life and length of the bridge and the height and foundation conditions of the abutments.

The second is the estimate used for comparing specific bridge sites or bridge types and is a refinement of the rough estimate based on more information about the stream and site. The planner makes a series of sketches of possible bridge types, using a variety of alternative components. He then estimates the cost of each proposal. The detail required depends upon the importance of the structure.

The third is the detailed cost estimate or budget which can only be made after the design, plans, and material list are complete. It consists of estimates of the time and cost of the men and machines, the cost of materials (including freight) and the supervision or administrative costs. The critical path diagram and cost estimate can be used to prepare a weekly or monthly cash-flow schedule. Here is a typical sample of a detailed cost estimate:

LABOUR AND MACHINE COSTS

Site preparation:					
Bulldozer (incl. 2 men)	16 h	@	$65.00	=	$1,040.00
Stringers: Falling, transportation and storage					
2 fallers	2 mandays	@	$150.00	=	$300.00
Log loader (2 men) (yard and load)	3 h	@	$90.00	=	$270.00
Logging truck	4 h	@	$60.00	=	$240.00
Bulldozer (2 men)	1 h	@	$65.00	=	$65.00
Other equipment and transportation				=	$150.00
Crib logs: Falling, transportation and storage					
1 faller	1 manday	@	$150.00	=	$150.00
Log loader	1 h	@	$90.00	=	$90.00
Logging truck	2 h	@	$60.00	=	$120.00
Log loader	½ h	@	$46.00	=	$23.00
Other equipment and transportation				=	$50.00
Stringer preparation:					
2 men	48 h	@	$13.00	=	$624.00
2 men	64 h	@	$16.00	=	$1,024.00
Other equipment and transportation				=	$150.00
Fabricating fasteners:					
1 man	4 h	@	$18.00	=	$72.00
Preparation of crib material, construction of cribbings:					
2 men	32 h	@	$16.00	=	$512.00
Backhoe	8 h	@	$40.00	=	$320.00
Other equipment and transportation				=	$60.00
Transportation of decking material:					
Truck	8 h	@	$60.00	=	$480.00
Loader	1 h	@	$46.00	=	$46.00

Placing stringers:					
Log loader	4 h	@	$90.00	=	$360.00
2 men	16 h	@	$16.00	=	$256.00
Transportation				=	$20.00
Deck construction:					
2 men	32 h	@	$13.00	=	$416.00
2 men	32 h	@	$16.00	=	$512.00
Loader	16 h	@	$45.00	=	$720.00
Other equipment and transportation				=	$100.00
Bridge approach construction:					
150 yd of shot rock @ $6.00/yd				=	$900.00
Clean-up:				=	$200.00
Supervision:	12 days	@	$150.00	=	$1,800.00
Total Labour and Machine Costs				=	$11,070.00

MATERIALS

Hardware:					
(¾ in. diam. mild steel, guardrail bolts, bridge spikes, spikes, etc.)				=	$350.00
Crossties:					
D.F. 10 in. x 10 in. x 18 ft rough - 70	10.5 MBM	@	$450.00	=	$4,725.00
Planking:					
D.F. 5 in. x 12 in. rough random length (min. 8 ft)	3.8 MBM	@	$450.00	=	$1,710.00
Tools:				=	$100.00
Total Material Cost				=	$6,885.00

TOTAL BRIDGE COST
(Location, planning and design costs are not included in this bridge cost.) = $17,955.00

APPENDIX II

ENGINEERING CHARACTERISTICS OF SOILS AND SOIL TESTING FOR BRIDGE CONSTRUCTION

by L.L. Adamovich

SOIL AS CONSTRUCTION MATERIAL

Bridges are in direct contact with soil in the following ways:

1. The fill materials exert an horizontal overturning force on the abutments.
2. The earth under the foundations must support the weight of the bridge and the traffic load without excessive settlement.
3. Soils around the bridge must resist erosion or scouring.

The bridge designer and builder must have a knowledge of the engineering characteristics of the soils. Soils are complex structural materials. The strength, elasticity and thermal expansion of wood, steel and concrete are defined simply for structural design. Not so with soils. Soils are mixtures of various particles, coming from physical and chemical alteration of rocks or organic matters. Engineering characteristics include not only strength but other characteristics such as drainage properties, capillarity, cohesion and friction, behaviour if frozen, expansion and compactibility.

The characteristics of soils have been classified in a similar manner to those for wood. The strength of wood is determined by its species and grades and we know for example that Douglas fir is stronger than Western red cedar and that structural grades are stronger than utility grades. The engineering properties of soil types have been tested and are known. Unfortunately most soils found in nature are mixtures of soil types. It is therefore necessary to identify the individual soil types and estimate the nature of the mixture.

The Unified Soil Classification System which is used for engineering recognizes only five major soil groups. Gravels (G), Sands (S), Silts (M), Clays (C), and organic soils or peats (P). These soil groups are described and their characteristics shown in Table A-II-a.

Soils engineers use the following sizes of particles.

Cobbles, boulders	3 in. (76 mm) or larger
Gravel	0.18 in. to 3 in. (5 mm to 76 mm)
Sand	0.003 in. to .18 in. (0.07 mm to 5mm)
Fines	less than 0.003 in. (0.07 mm)

Inorganic soils have been divided into two distinct groups: (1) gravels and sands are granular soils with visible particles and (2) silts and clays are fine textured and cohesive with particles hardly distinguishable to the naked eye.

Gravels and sands are excellent for construction. They have good drainage characteristics, do not freeze, and have good friction properties between the particles. Their strength is not appreciably affected by water content (except when pore pressure becomes high and creates quicksand conditions). They can be compacted easily by pressure and vibration. Their shortcoming is that they lack cohesion. (Potholes in front of the bridge are the result of lack of cohesion.) Due to the lack of cohesion they are easily erodible (particularly sands and fine gravels).

Granular soils are either well-graded (W) or poorly graded (P). A well-graded soil has a great variety of particle sizes distributed throughout its mass. If the sizes are uniform it is poorly graded. For example, material coming from a gravel pit is usually well graded (GW) and the sand on the beaches is usually poorly graded (SP).

Fine textured soils, silts and clays are the problem soils. They generally have poor drainage characteristics. They create frost heaves (especially silts or silty-clays), and their strength is greatly influenced by water content—(some become fluid with water). At moderate water content, however, they can be compacted to a very dense state by tampers (or sheep-foot rollers) and if they are dry (or can be kept dry) their strength approaches that of concrete. Fine textured soil particles are very small so the size sub-classification cannot be used and other distinguishing characteristics are necessary. Bone-dry fine textured soils (e.g., clays) are very tough. With little water, however, they become soft or plastic and by adding water they become sticky and finally fluid. Other fine textured soils change from plastic (moldable) to liquid (fluid) state with much less water. This characteristic is called 'plasticity' and varies from high to low. A soil referred to as 'ML' is a low-plasticity silt, and CH is a high-plasticity clay. The practical application of this knowledge is that low-plasticity soils dry out quickly and their strength increases rapidly. High-plasticity soils remain plastic and are difficult to drain. Problem soils have less than 50% granular content. They are tough when dry, sticky when wet, and feel like soap with no grit.

Soil Identification

The soils at a major bridge site (or complex soils at any site) must be identified by specialists who have access to sophisticated sampling and testing

equipment. The following procedures will assist the bridge builder to identify simple soils and will provide sufficient information for the construction of many minor bridges.

The first step is to get a representative sample of the soil. Use a shovel and a bucket to get a sample. For abutment or pier foundations, dig down to the foundation level. Soil samples may not be necessary for pile structures, when test pile results will be used for design.

- Testing and identifying the soil samples:

First, separate the fines from the granular solid particles. Use the soil sieves: remove the large cobbles and boulders from the sample. Dry the sample (e.g., on a camp stove) and shake it through standard soil sieves. Weigh the two parts separated by sieve #200 (0.003 in.). Their ratio defines the soil type as granular or fine textured. If more than 40% falls through #200 the soil is fine textured.

Another simple test to define the soil type is the settlement test. Mix the soil sample with plenty of water in a large glass jar, shake it and then let it rest. Gravels and sands settle first (in less than half a minute). The fines will settle last, but most of it will settle in an hour. Compare the depth of fines to the total settlement depth. In fine textured soils (silts or clays) the fines will be over 40 percent. For those soils it is important to know their plasticity, because low-plasticity soils make better foundations.

To check the plasticity of the fines form a small mold by adding a little water (5% to 10%). If the mold is very soft and sticky then the sample is of low plasticity. High-plasticity soils need 20% to 50% water content to reach this state.

Good gravel soils usually have 5% to 15% fines in them. Settlement of granular particle sizes will show whether or not the soil is gravel or sand. Similarly, the variation in particle size is an indication whether they are well or poorly graded.

Once the soils are classified, Table-A-II-a will show the engineering characteristics for the soil types. Only well compacted soils will provide long service life as a fill.

TABLE A-II-a. Engineering Characteristics of Soils for Bridge Construction

	Soil Type	Symbol	Value as Fill	Load-Bearing Strength	Drainage Characteristics
1.	Rock (shot or crushed), boulders	R	Excellent	Very high	Excellent
2.	Well-graded gravel, gravel sand mixtures	GW	Excellent	Very high	Excellent
3.	Poorly-graded gravel, little or no fines	GP	Excellent	High	Excellent
4.	Silty-gravel, fines with low plasticity	GM	Fair to poor	High	Fair to poor
5.	Clayey gravels, plastic fines	GC	Fair to poor	High	Poor to very poor
6.	Well-graded sands, gravelly sands, no fines	SW	Very good	Very high	Excellent
7.	Poorly-graded sands	SP	Very good	High	Excellent
8.	Silty sands with low plasticity	SM	Poor	Medium	Poor
9.	Clayey sands with plastic fines	SC	Poor	Medium	Poor to very poor
10.	Inorganic silts, very fine sands, rock flour	ML	Very poor	Very low	Fair to poor
11.	Lean clay	CL	Poor	Very low	Impervious
12.	Elastic silts	MH	Very poor	Almost none	Fair to poor
13.	Fat clays	CH	Very poor	Very low	Impervious
14.	Organic silts or clays	OH	Very poor	Very low	Impervious

Erosion or Scour Resistance	Compactibility and Best Compaction Equipment	Remarks	
Very good	Compaction if needed: grid-roller	Best material for bridge and road construction	1.
Very good	Crawler-type tractor, rubber-tired roller, vibrating roller	Best all-around soil type. Fines up to 10%, all particle sizes are present.	2.
Good	Crawler-type tractor, rubber-tired roller, vibrating roller	Voids between particles are not filled as certain particle sizes are missing.	3.
Medium	Rubber-tired roller, sheepsfoot roller, tamper	Behaviour depends on the amount of silt.	4.
Medium	Rubber-tired roller, sheepsfoot roller, tamper	Behaviour depends on the amount of clay.	5.
Fair	Crawler-type tractor, rubber-tired roller, vibrating roller	A mixture of sand and gravel. It is stable if all particle sizes are present.	6.
Poor	Crawler-type tractor, rubber-tired roller, vibrating roller	If sand particles are round, they easily erode, angular particles can be stable.	7.
Very poor	Rubber-tired roller, sheepsfoot roller, tamper	Behaviour depends on the amount of silt.	8.
Medium	Rubber-tired roller, sheepsfoot roller, tamper	Behaviour depends on the amount of clay.	9.
Very poor	Rubber-tired roller, sheepsfoot roller, tamper, close control of moisture	These soils scour easily.	10.
Medium, very good if hard	Rubber-tired roller, sheepsfoot roller, tamper	Fine soils cannot be kept dry in field, their strength is consequently very low. If protected, can hold piles and cribs reasonably well.	11.
Poor	Sheepsfoot roller, rubber-tired roller, tamper		12.
Medium, very good if hard	Sheepsfoot roller, rubber-tired roller, tamper		13.
Medium	Sheepsfoot roller, rubber-tired roller, tamper	Muck when wet, not usable for construction purposes.	14.

Load-bearing capacity of Foundation Soils

- The strength of foundation soils can be tested by a simple homemade device shown by Figure A-II-1.

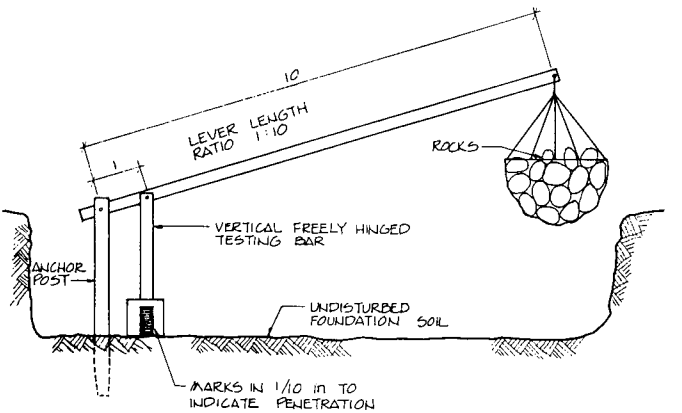


FIGURE A-II-1. Testing soil load capacity

You must know the cross-section of the testing bar to make the calculations, let's say 16 in.^{2}. You must decide the allowable settlement of the foundation under the structure—usually not more than 1/2 inch.

Load up the basket so the testing bar penetrates the ground the distance of the allowable settlement. Weigh the basket-load and multiply it by 10. Divide this figure by the area of the test bar's cross-section (in our case 16 in.^{2}) to arrive at the load-bearing capacity of the soil. This is the maximum load that the soil will carry without exceeding the allowable settlement.

- Tables can also be used for finding the load-bearing capacity of soils but with less accuracy. A good example is Table A-II-b.

- If friction piles are being considered, drive a test pile to give you the most reliable load-bearing capacity of the soil or the load-bearing ability of a pile. (See Pile Driving in the main body of this book.)

One must be careful about the possibility that the tips of the piles might have penetrated into a dense layer above softer ones. Force the test pile as much as possible to make sure that the final position has been reached.

TABLE A-II-b. Load-Bearing Capacity of Rocks and Soils

Material	Allowable Load-Bearing Capacity lb/ft^2
Massive bedrock in sound condition without laminations: granite, diorite, other granite rocks, gneiss, and thoroughly cemented conglomerates. (Minor cracks allowed.)	200 000
Laminated rocks in sound condition (slate, schist, etc.). (Minor cracks allowed.)	70 000
Shale in sound condition (minor cracks allowed), shattered or broken bedrock	20 000
Hardpan	20 000
Gravel, compact sand-gravel mixtures	10 000
Gravel, loose sand and gravel mixtures, compact coarse sand	8 000
Loose coarse sand, compact fine sand	6 000
Loose fine sand	2 000
Hard clay	12 000
Medium clay	8 000
Soft clay	2 000

If the position has been identified, the load-bearing ability of a friction pile can be approximated by multiplying the surface area of the pile in the soil with skin-friction values shown in Table A-II-c. To get the piles surface area in ft^2, multiply the pile's average diameter (ft) in the soil with the pile penetration (ft) and by 3.14.

TABLE A-II-c. Approximate Skin Friction Values

Material	Skin friction values lb/ft^2
Soft silt and dense muck	50 - 100
Silt (wet but confined)	100 - 200
Soft clay	200 - 300
Stiff clay	300 - 500
Clay and sand mixture	300 - 500
Fine sand (wet but confined)	300 - 400
Medium sand and small gravel	500 - 700

- The Penetration Test is probably the least sophisticated and most popular test used for onsite testing. A split-spoon sampler can be purchased or fabricated in a shop. You can easily make the device demonstrated by Figure A-II-2.

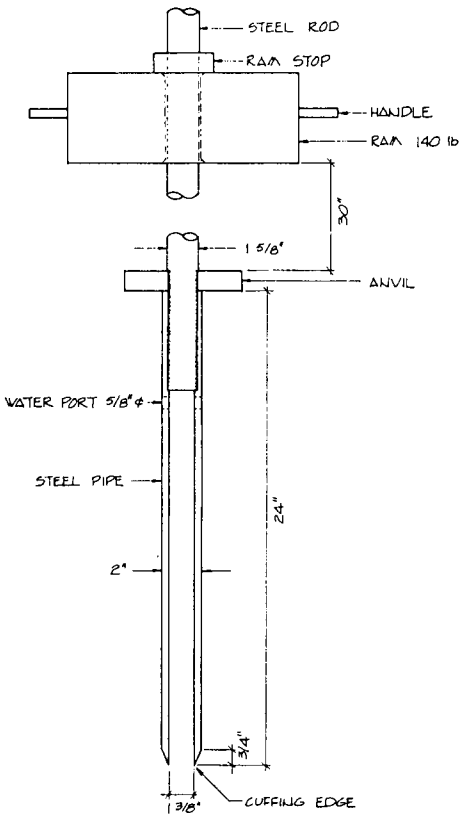


FIGURE A-II-2. A device to test soil strength

The sampler is a strong hollow pipe with one end made into a cutting edge while the other is reinforced to receive the blows of the ram. The ram is guided by a rod fitted to the sampler's top. The ram weighs 140 lb and falls a distance of 30 inches. The number of blows needed to drive this sampler into the ground for one foot (N) indicates the strength of the soil.

The sampler should be driven partly into the ground (2 in. to 3 in.) before the actual test begins. The results of many tests are summarized in the following two graphs (Figure A-II-3 and A-II-4), one for granular soils and one for fine textured soils. The graphs show the strength of the soils.

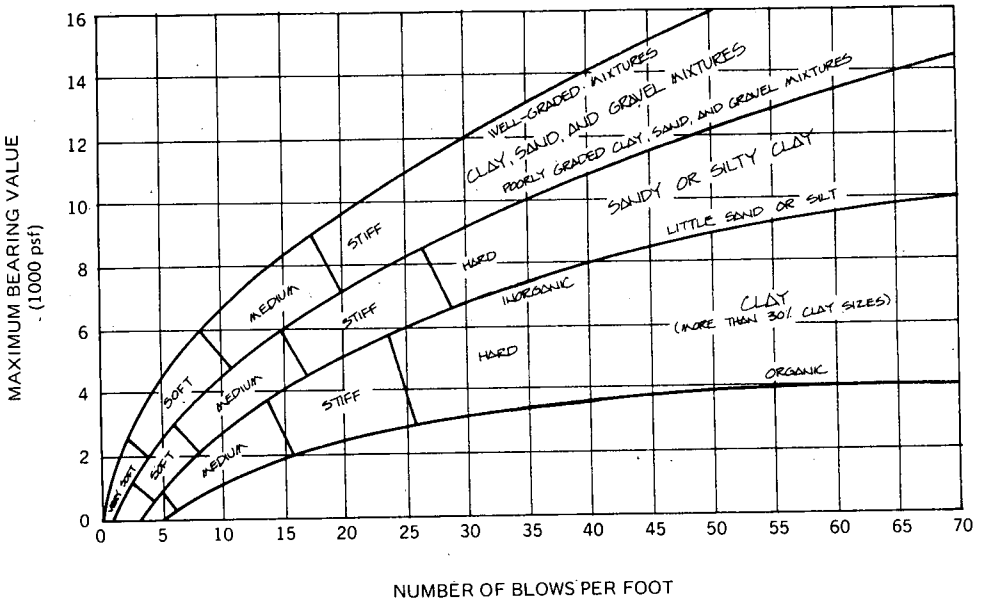


FIGURE A-II-3. Soil strength summary for granular soil

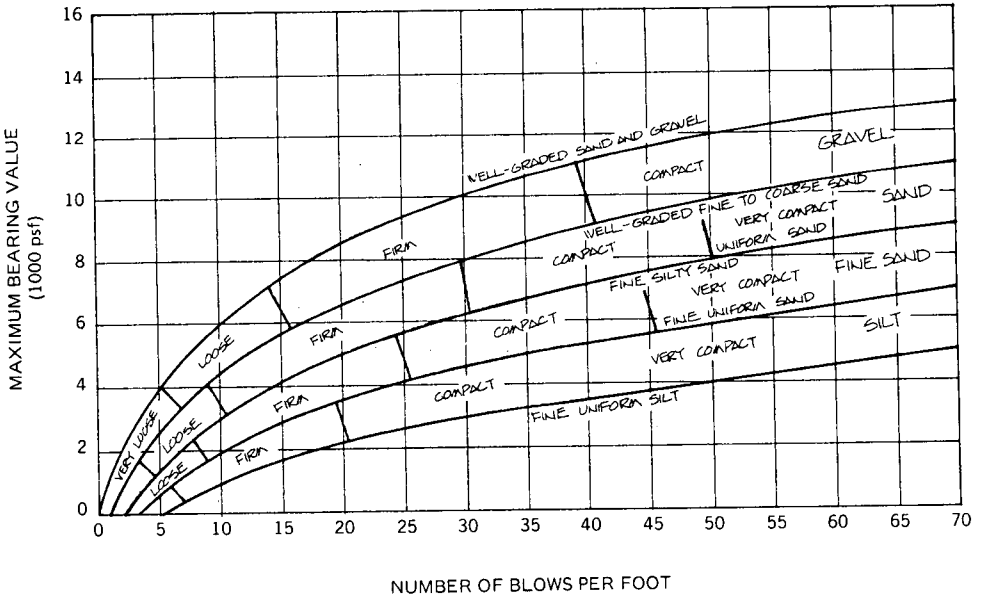


FIGURE A-II-4. Soil strength summary for fine-grained soil

Summary

Soils can be identified and their engineering characteristics determined for bridge design. Table A-11-a can be used to estimate the soil's suitability for fill. The values shown in the tables are an indication of the relationship of soil characteristics between soil types. For example "very good" scouring resistance means that this soil is more resistant to erosion than the one that has a value of "good," but this soil may easily scour depending on other circumstances. Scouring not only depends on the soil type, but also depends very much on the volume, speed, and turbulence of the water flow. The force of the water might become so large that even rip-rapping with rock will not resist it.

You must know the strength of foundation soils. If there is a doubt about the correctness of the identification then further tests must be conducted.

Soils are variable—and occasionally unpredictable—building materials. Local experience and observations of similar structures nearby are the most valuable guides to judging soil characteristics on a bridge construction site.

SAFETY FACTORS, DURATION OF LOADS, OVERLOADING

The safety factor for wood structures is between 1 1/4 and 5 depending on the individual timber strength and local conditions. To keep the safety factor above 2 1/2, it is important to select good quality stringers so the wood has better-than-average strength.

Wood is the only material which can sustain a load greater than its design strength for a brief period of time. Such an overload (or an impact load) may be twice the design load yet not harm the bridge if the duration is short. These heavy loads do not change the basic design-load capacity of the bridge.

Figure A-III-1 shows the short duration loadings. Intermittent overloads are cumulative.

Log (wood) bridges which are properly designed and constructed will safely support the design and dead load (100% loading) continuously for ten years. These bridges can stay in service for over 50 years carrying only 90% of the combined load if they are kept in good repair.

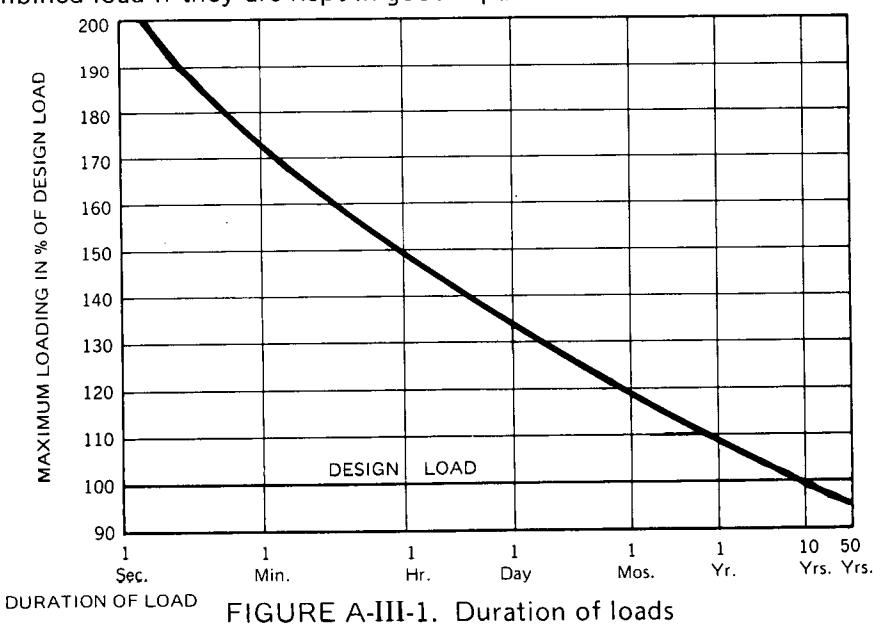


FIGURE A-III-1. Duration of loads

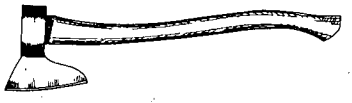
APPENDIX IV

TOOLS

Some special tools used in bridge construction are shown here.

Broadaxe

A broadaxe is used to flatten or hew a log surface. It is a heavy axe with a wide cutting edge and flat-sided blade.

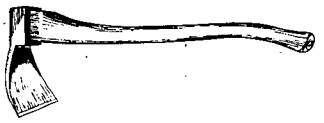


Swamping axe

A swamping axe is used for heavy slabbing, barking and brushing out. Frequently one bit is kept very sharp and the other is used for cutting knots or brush close to the ground.

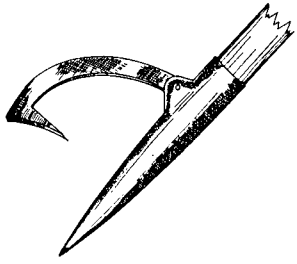
Adze

An adze is a mattock-type tool kept sharp and used to produce a smooth, hewn surface (usually horizontal). This is a dangerous tool in the hands of an inexperienced person.



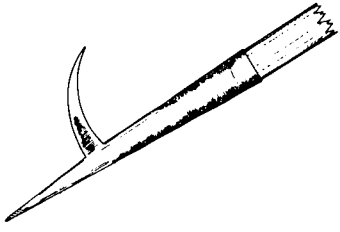
Peavey

A peavey is a heavy lever with a hook. Points are sharp. This is used for turning logs and timbers.



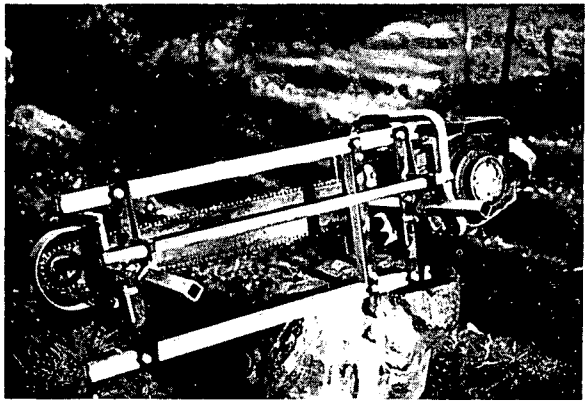
Pike Pole

A pike pole is a long pole with a spear and hook point used for probing, spearing and pulling or pushing logs. It is made to float in water.



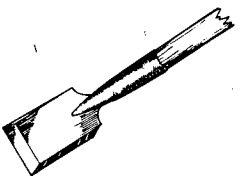
Alaskan Sawmill

This is a brand name for a device that is manufactured to allow accurate rip-sawing of lumber or slabs with a powersaw.

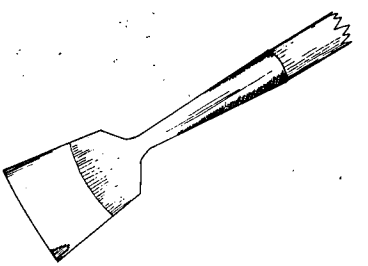


Spud

A spud is a flat, sharp tool used for peeling bark from logs. A long blade scraper is used for peeling smaller logs, while the cedar spud is used with large logs.



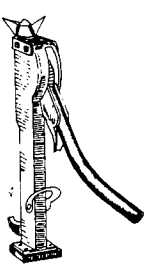
Log blade scraper



Cedar spud

Logging (Gilchrist, Hercules) jack

A logging jack is a heavy mechanical jack that is used for turning and lifting logs. A notch is cut into the log to hold the jack. The log can be placed under the jack head or the side hook for jacking.

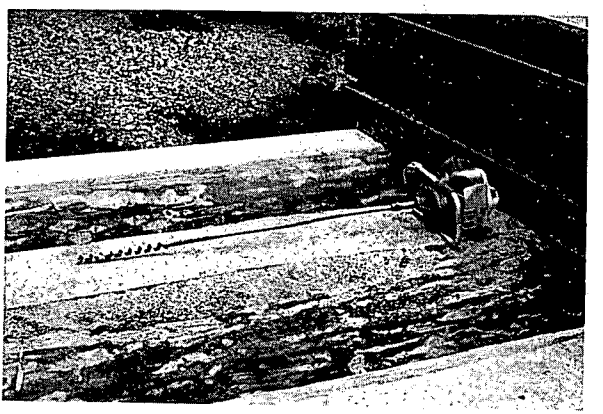


Hookeroon or Pickaroon

A hookeroon or pickaroon is a small hook tool with a long axehandle. It is used for moving logs, lumber, crossties and planking into place.

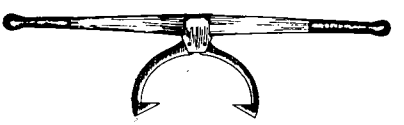
Auger

An auger is also known as a ship-builder's auger. This is a drill bit with a long shank that is used with a manual or powered drill-holder. These bits must go through several feet of wood and must be kept straight and sharp.



Timber Carrier

A timber-carrier is a large double hook used by two men to carry small logs and large lumber (crossties).



TIMBER CONNECTORS

Bridge building requires considerable use of standard forms of timber connectors as well as some unique connectors. The more common and standard connectors are listed:

Railroad Spike

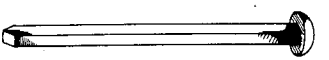
A railroad spike is a strong, square shank spike with an off-centre head used for wire-rope fastening in lashing.

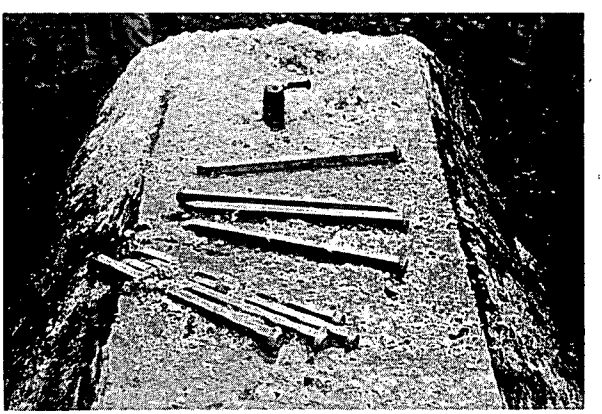
Spikes and Nails

Common, spiral and galvanized nails and spikes are used for nailing in form work, abutments and decking.

Bridge Spike

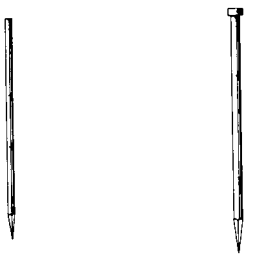
The bridge spike has a sharpened half-inch square shank with a round head. It is mainly used for fastening the crossties to the stringer.





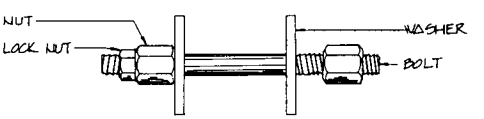
Drift Pin and Drift Bolt

A drift pin and drift bolt are round mild steel pins pointed on one end. The other end is cut flat (drift pin) or may have a head (drift bolt). It is used for holding logs or large sawn timber together.



Bolt

A bolt is a steel rod threaded to take nuts. It is normally used with washers for holding predrilled wood and steel together.

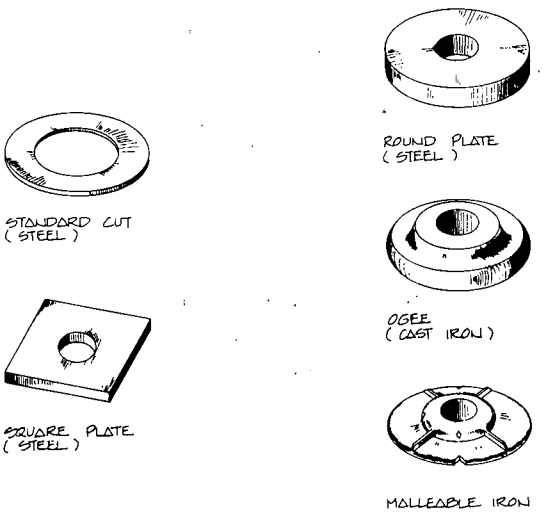


Lag Bolt or Screw

A lag bolt or screw is a large woodscrew having a screw-type thread on the bottom half only. It is used in place of a spike, where the spike might pull. Steel plates are usually fastened to wood with lag bolts. The lag bolt is screwed into a predrilled hole.

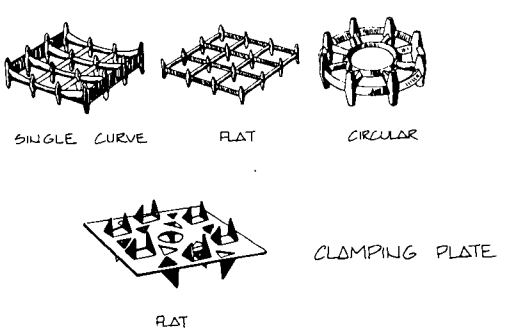
Washer

Washers are used with bolts to spread the stress caused by the tightening of the nut over a large area and allow easier turning of the nut. Standard and square-plate washers are used over steel. The others are used over wood. They are shown in order of increasing strength.



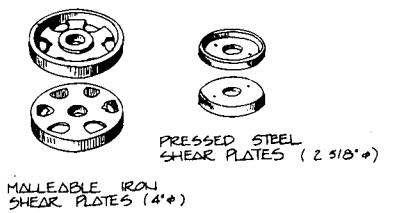
Spiked Grid

A spiked grid is a timber connector to hold two pieces of wood from sliding after it is bolted, spiked or drifted. The grid is placed between two pieces of wood and bolted through the centre.



Shear Plates

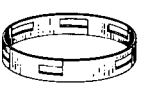
Shear plates are used in place of washers where the wood must be protected from splitting. Malleable iron shear plate is stronger than pressed steel.



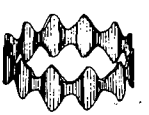
Split Ring

A split ring is a device that can be used to splice two beams together end-to-end where there is need to maintain strength against shear forces in the two beams. The split ring will distribute the shear forces over a large area to prevent splitting of the wood.

SPLIT RING



SPLIT RING



TOOTHED RING

APPENDIX VI

WEIGHT OF STRUCTURAL TIMBERS

SPECIES	Weight of Wood lb/ft^3 Green	12% Moisture content
CEDAR, EASTERN WHITE (Thuja occidentalis L.)	34	21
WESTERN RED (Thuja plicata Donn)	29	24
YELLOW (Chamaecyparis nootkatensis (D. Don) Spach)	35	30
DOUGLAS FIR, (Pseudotsuga menziesii (Mirb.) Franco)	40	34
FIR, AMBALIS, BALSAM (B.C. COAST) (Abies amabilis (Dougl. Forbes)	39	27
GRAND, WESTERN BALSAM (Abies grandis (Dougl.) Lindl.)	39	27
ALPINE, BALSAM (B.C. INTERIOR) (Abies lasiocorpa (Hook.) Nutt.)	39	27
BALSAM (EASTERN CANADA) (Abies balsamea (L.) Mill.)	46	24
HEMLOCK, EASTERN (Tsuga canadensis (L.) Carr.)	61	30
WESTERN (Tsuga heterophylla (raf.) Sarg.)	49	30
TAMARACK (Larix laricina (Du Roi) K. Koch)	48	35
LARCH, WESTERN (Larix occidentalis Nutt.)	52	40
PINE, LODGEPOLE (Pinus contorta var. latifolia Dougl.)	40	29
RED (Pinus resinosa Ait.)	52	28
WESTERN WHITE (Pinus monticola Dougl.)	36	26
YELLOW (PONDEROSA) (Pinus ponderosa Laws.)	47	32
EASTERN WHITE (Pinus strobus L.)	46	27
SPRUCE, BLACK (Picea mariana (mill.) B.S.P.)	37	30
ENGELMAN (Picea engelmannii Parry)	37	28
RED (Picea rubens Sarg.)	35	28
SITKA (Picea sitchensis (Bong.) Carr.)	31	27
WHITE (Picea glauca (Moench) Voss)	38	26

These values represent approximate weights. Weights change with wood density and moisture content. Underlined figures are estimates. Logs and stringers are also heavier owing to the large amount of sapwood in them. For stringers and logs an extra 2 to 3 lb/ft^3 should be added to the green weight in load calculations.

APPENDIX VII

WEIGHT OF FILL MATERIALS

MATERIAL	UNIT WEIGHT* lb/ft^3
GRAVEL	
Well graded gravels, gravel sand mixtures (no fines)	125-140
Poorly graded gravels, gravel sand mixtures (no fines)	110-140
Silty gravels	115-145
Gravel-sand-clay mixtures, clayey, hardpan	130-145
SANDS	
Well graded sands, gravelly sands (no fines)	110-130
Poorly graded sands, gravelly sands (no fines)	105-135
Silty sands, sand-silt mixtures	100-135
Sand-clay mixtures	100-135
SILTS AND CLAYS	
Inorganic silts, very fine sands–with slight plasticity	90-130
Inorganic clays, gravelly and sandy clays–low to medium plasticity	90-130
Inorganic clays of high plasticity	90-115
Inorganic silts, elastic silts	80-105

ROCK	FINE BLASTED OR CRUSHED ROCK (DRY)	SOLID ROCK
Basalt	132	185
Dolomite	129	180
Granite	118	165
Gypsum	125	175
Limestone	118	165
Schist	121	170
Quartz	118	165
Sandstone	107	150
Shale	114	160
Slate	118	165
Talc	121	170

*Moisture content is at natural state of "pit run" material. The weight range is an indication of "dry to wet" state range.

APPENDIX VIII

MOISTURE CONTENT OF WOOD IN AIR DRY CONDITION (%)

Air Temperature °C	Relative Humidity, %							
	30	40	50	60	70	80	90	98
0	6.3	7.9	9.5	11.3	13.5	16.5	21.0	26.9
5	6.3	7.9	9.5	11.3	13.5	16.5	21.0	26.9
10	6.3	7.9	9.5	11.2	13.4	16.4	20.9	26.9
15	6.2	7.8	9.4	11.1	13.3	16.2	20.7	26.8
20	6.2	7.7	9.3	11.0	13.1	16.0	20.5	26.6
25	6.1	7.6	9.1	10.9	13.0	15.8	20.3	26.4
30	6.0	7.5	9.0	10.6	12.7	15.5	20.0	26.1
35	5.8	7.3	8.8	10.4	12.4	15.2	19.6	25.8
40	5.7	7.1	8.6	10.2	12.2	14.9	19.3	25.4
45	5.5	6.9	8.3	9.9	11.9	14.6	19.0	25.1
50	5.3	6.8	8.1	9.6	11.6	14.3	18.5	24.6
55	5.2	6.6	7.9	9.4	11.3	14.0	18.2	24.2
60	5.0	6.3	7.7	9.1	11.0	13.6	17.7	23.7
65	4.8	6.1	7.4	8.8	10.6	13.1	17.2	23.1

APPENDIX IX

CONVERSION FACTORS

The Table shows conversion factors for converting Imperial measurements (Canadian yard/pound system) to metric (SI–International System of Units) units.

1 ac	=	0.404	ha	1 lb/ft^3	=	16.018	kg/m^3
1 Cunit	=	2.832	m^3	1 mi	=	1.609	km
1 fbm	=	2.360	dm^3	1 mi^2	=	2.590	km^2
1°F	=	1.8°C	+32	1 mi/hr	=	1.609	km/h
1 fluid oz	=	28.413	cm^3	1 N	=	1.000	mkg/s^2
1 ft	=	0.305	m	1 oz	=	28.349	g
1 ft^2	=	0.093	m^2	1 Pa	=	1.000	N/m^2
1ft^3	=	28.317	dm^3	1 psf	=	1.488	Pa
1 ft/sec	=	0.305	m/s	1 psi	=	6.895	kPa
1 ft^3/sec	=	28.317	dm^3/s	1 pt (Can.)	=	0.568	dm^3
1 gal (Can.)	=	4.546	dm^3	1 qt (Can.)	=	1.136	dm^3
1 gal (U.S)	=	3.785	dm^3	1 t	=	1 000.0	kg
1 ha	=	10 000.0	m^2	1 ton (short)	=	0.907	t
1 in	=	25.400	mm	1 ton/yd^3	=	1.186	t/m^3
1 in^2	=	6.452	cm^2	1 yd	=	0.914	m
1 in^3	=	16.387	cm^3	1 yd^2	=	0.836	m^2
1 L	=	1.000	dm^3	1 yd^3	=	0.764	m^3
1 lb	=	0.454	kg				

ABBREVIATIONS

Imperial Units			Metric Units		
ac	=	acres	C	=	Celsius
Cunit	=	100 ft^3 of wood	cm	=	centimetre
F	=	Fahrenheit	dm	=	decimetre
fbm	=	board feet (measure)	g	=	gram
ft	=	foot, feet	h	=	hour
gal	=	gallon	ha	=	hectare
hr	=	hour	kg	=	kilogram
in	=	inch	km	=	kilometre
lb	=	pound	kPa	=	kilopascal
MBM	=	1000 fbm	l	=	litre
mi	=	mile	m	=	metre
oz	=	ounce	mm	=	millimetre
psf	=	pound per square feet	N	=	newton
psi	=	pound per square inch	Pa	=	pascal
pt	=	pint	s	=	second
qt	=	quart	t	=	tonne
sec	=	second			
yd	=	yard			

SI PREFIX

Prefix	Symbol	Multiplying factor
kilo	k	1000
deci	d	0.1
centi	c	0.01
milli	m	0.001

GLOSSARY

abutment	A substructure, supporting the ends of a superstructure. Its function is to transfer the weight of the bridge and the traffic to the ground, to retain the approach fill and to elevate the bridge to the required height.
adze	An axe-like cutting tool used for dressing timbers with the cutting edge at right angles to the handle.
approach (bridge)	A road segment at each end of a superstructure (bridge)guiding and carrying the traffic on and off the bridge.
back log	The back log holds the fill end of the tieback logs together in a box crib. It is laid parallel to the face log.
back pressure	The earth pressure exerted on the vertical walls of an abutment by the fill, or the lateral loading of a piling or face log in an abutment.
base log	This is the first log in a cribbing face (face log) resting directly on the ground or on the mud sills.
batter	The lean of the pile. It is expressed as one unit horizontal to a given number of units vertical (e.g., 1:10).
batter pile	A pile leaned slightly against the usual horizontal forces to counteract them and to make the structure rigid. The outside piles of an abutment or pier may be battered.
bearing capacity	See "load-bearing capacity."
bearing surface	The sectional area of a structural member's surface which supports the load.
bent (pile bent)	A line of piling built as a structural unit, transverse to the length of the bridge and supporting the load of the superstructure.
bird hole	A small hole made in the wood by birds. Older bird-holes are accompanied by discoloration of the wood, called "mineral streak." Rot can enter a tree in bird holes.
block, wood block	A short, thick piece of wood (2 inches or thicker)used to transfer the load between two structural members. It is usually used between the small stringer end and the sill or cap to elevate the stringer.
bracing	A diagonal–or sometimes horizontal–structural member used to stiffen a structure. Bracing is required to strengthen pile bents.

bridge	In this book, bridge is a drainage structure with a span of 20 ft or more, having a designed clearance over the highest expected floods.
bridge height	The elevation difference between the deck surface and the deepest point in the channel under the bridge.
bridge location	1) The site of a bridge, or 2) The process of selecting and surveying a bridge site.
bridge locator	The person who searches for a bridge site and selects and surveys it.
bridge maintenance	The process of inspecting and repairing the bridge to reduce deterioration and insure safety.
bridge opening	The distance between two abutments. In the case of single spans it is sometimes used as a synonym for "span."
burring	Cracks on the pile top caused by hammer blows during driving. A burred pile may split during driving.
butt	The large end of a log or the trunk of a tree above the stump.
butt swell	An unusually large flare of the tree trunk above the stump.
butting up (butted)	Two logs or timber placed next to each other end to end.
camber	A rise in elevation at the middle of a stringer compared to its ends (if the stringer has a convex upper surface).
cap	A sawn timber placed horizontally on an abutment or pier to distribute the live and dead load of the superstructure. The stringers rest on the cap.
catface	A scar or deformation on the surface of a tree due to a wound which did not heal properly.
centerline	Midway between the guardrails of a bridge or edges of a road. The final survey line of a bridge or road indicating the middle of the final structure.
chalkline (snapline)	A fine reinforced cotton line bathed in chalk powder or rubbed with a cake of chalk used to mark a straight line on a timber or log surface. The chalkline is tightly fastened to two points at the ends of the required line, pulled away from the wood at the centre, and allowed to snap back. The line will release the chalk powder on impact and mark the wood surface.
chamfer	The bevelled edge on top of a pile cut to prevent splitting while the pile is driven.

channel	The bed of a stream or waterway.
channel (braided)	The large flood channel of a fast-flowing stream made up of many small stream beds crossing each other. These stream channels are associated with low stream banks. They are also associated with frequent runoffs and/or ice flows.
channel (flood)	The wetted area that the flood occupies at its peak.
channel (meandering)	The bed of a slow-flowing stream in easily erodible material, on flat ground, with many curves and abandoned channels.
clearance (bridge)	The elevation difference between the lowest part of the superstructure and the water surface directly under the bridge. The required clearance is stated at design flood.
clip angle	A connector made from steel used to fasten the post or frames to the sill in post or frame bents.
column	A vertical member (post, pile, sawn timber) bearing axial load in compression.
compression wood	Abnormal wood with unusually wide eccentric annual rings formed in leaning trees or on the opposite side of the prevailing wind direction. There is little demarcation between springwood and summerwood. Compression wood has a low stiffness for its weight and a general deficiency in most other properties.
compressive strength (soil)	The maximum compressive stress (loading) the material (soil) can withstand without failure.
counterfort	A strengthening wall in the middle of a concrete abutment.
cradle, cradle notch	The side of a log carved out to fit another log placed across it.
crib height	The elevation difference between the top of the cap or sill and the bottom of the base log at the centerline.
crook	An abrupt curvature of the tree trunk close to the stump.
crook (short)	Deviation from straight growth in a short section of a tree trunk.
crossbearers	See "mudsills."
crosstie	A sawn timber (part of the bridge deck) placed and fastened transversely over the stringers to distribute the load. Crossties provide a flat surface and carry the planking.

culvert	A drainage structure—either a short bridge less than 20 ft in length—or a structure with enough fill over it so that little of its strength is needed to support the traffic load. Culverts may have their inlet submerged under flood conditions.
culvert-type log bridge	A bridge with loose material (gravel, shot rock, dirt, sand, sawdust, etc.) decking. The deck is used as a running surface, is not a structural member and does not spread the load over the stringers.
cut-off	The top cut of a driven pile at a marked elevation.
dap	To cut or carve out the end of a log so it will have a large flat contact area with another structural member.
deadman	A log buried in the ground to serve as an anchor.
debark	To remove the bark from a log.
debris jam	Congested debris obstructing the free movement of the water in a stream.
deck, bridge deck	The top floor of a bridge providing a running surface for the vehicles and distributing the load over the stringers.
deflection	The bending-down or sag of a more/less horizontal structural member (stringer) at the midspan due to the stress of the dead load and traffic load.
design load	See "load."
dolphin	A group of piles placed together for greater strength. They are driven in front of piers and abutments as a protection device and are used as anchors and trestle supports.
dowel	A round steel pin cut square at both ends used for fastening post or frame bents.
drift	A round mild steel pin pointed at one end and cut square at the other. It is used to fasten timbers.
drift bolt	A drift with a head welded on for hammering. Its appearance is similar to that of a giant nail.
drift pin	See "drift."
driving cap	A cast-iron or steel fabrication used for pile driving. It fits over the pile and cushions the blows of the drop hammer to prevent splitting the pile during driving.

DYWIDAG rod	A trade name for a high-strength concrete reinforcing bar with a rolled-on continuous thread.
expected bridge life	The usable life of the bridge for which it is designed and maintained.
eye splice	The end of a wire rope bent back and spliced to the main stem to form a loop.
eyebolt	A bolt with a large eye fabrication to replace the head. The hole or eye is bigger than the diameter of the bolt stem. Used to fasten wire rope to wood or steel in abutments.
face log	Logs placed in a crib parallel to the stream flow.
falsework	A temporary timber structure to help support the main structure during construction or permit crossing of the stream while the bridge is being built.
farmer's eye-splice	A simple temporary splice to form an eye on the end of the wire rope. It develops less than one-half the full strength of the rope.
fender logs	Logs placed at the end of the bridge on the road shoulder as a continuation of the guardrails to guide the traffic onto the bridge, or used as floating logs protecting the piers or abutments from damage from floating objects.
field treatment	Onsite application of wood preservatives.
fluvial layer	River or stream deposits. A layer of soil deposited by a stream.
fore-and-aft	A direction parallel to the travel direction of the bridge. Fore-and-aft planking is laid parallel to the stringers.
form	A temporary lumber and plywood structure used to contain fresh concrete while it is placed and sets.
formwork	See "form."
foundation area	The area required to support the traffic and the load of the structure. ("Cribbing foundation area" is the area occupied by the base log, mud sills or foundation logs.)
foundation logs	Logs placed under the mudsills in a cribbing to spread the load over a larger area.
frame	1) Round or sawn timber cut to fit other timbers in a structure. 2) A rectangular sawn timber structure used in place of a needlebeam to increase its depth. 3) A lumber or plywood structure built around a log, stringer or pile to guide the saw.

frame bent	A bent in a pier or abutment made from sawn timber.
framed strut	See "frame." A replacement for a needlebeam.
French concrete	Concrete containing large stones or rock in order to save cement. Usually used as fill or for levelling out rock surfaces where it is not subjected to tension or bending.
gradient	The slope of a stream bed in the direction of the water flow.
guardlog	See "guardrail." Using logs in place of sawn timber.
guardrail	Sawn timber fastened to the edge of a bridge deck to prevent vehicles from running over the side of the bridge.
hardpan	A hard solid layer containing gravel particles cemented together. The hardness of this soil does not change appreciably with changes in the moisture content. The wet surfaces tend to crumble under traffic and become muddy.
hew (hewn)	To carve a timber to a specific dimension or shape, using an axe or an adze. (See also frame and dap.)
jillpoke	A log or post which is caught on one end and pivots into something. It may be a floating log with one end stuck in the stream bank and the other end jammed in the abutment. Not only will it obstruct the stream flow but it can exert enough force on the structure to damage it.
keeper (pile driver)	A piece of lumber or steel used to hold a pile in the leads.
lamination	Transverse members of a laminated bridge deck having the same function as the crossties. Two-inch nominal size lumber (usually preservative treated) tightly placed perpendicular to the traffic direction and vertically on edge over the stringers, then nailed to the stringers and to each other.
laminated decking	A decking with laminations used in place of the crossties and planks.
lash (lashing)	To fasten logs or timber together with tightly wrapped and fastened wire rope.
leads, set of leads	Pile-driver leads guide the hammer when it slides up and down and help to keep the pile in the correct position. They are made of steel or steel over wood.
leadsman	The person who directs the pile during driving.
leaning pier	A pier which is not vertical. It is usually located ashore and leaned out over the stream to support the stringers.

line	Used as a synonym for "wire rope."
load capacity	Synonymous with "load-bearing capacity"–see "load-carrying capacity."
load (dead)	A load of a long duration. The load exerted on a structure by its own weight.
load (design)	A loaded vehicle (including its weight and axle spacing) used as a live load for the design of a bridge. This load represents 100% loading of a bridge.
load (live)	A short-duration or moving load such as a vehicle or the traffic on a bridge.
load (standard truck)	See "design load."
load (traffic)	The loading that the bridge is subjected to by traffic. Often used as a synonym for "design load."
load-carrying capacity	The capacity of a material to sustain vertical (transverse) loading expressed in a unit of weight per area (psi, psf, etc.).
log jam	Congested groups of logs and debris obstructing the flow of a stream.
long cap	The cap of a pile bent that usually holds the piles of a single bent together and distributes the load over them and is placed transversely to the bridge direction.
mudsills (crossbearers)	Short pieces of horizontal logs placed transversely under the sill log or foundation log to spread loading over a large area to prevent settlement.
multispan	A bridge containing a pier or piers and more than one span.
mushing	See "burring."
needlebeam	A transverse log or timber placed under the stringers and fastened to them to make them work as a unit. Used to join the stringers and trussing system.
notch (notching)	See "cradle notch."
o.c.	Abbreviation for "on centre."
ox-box (oxbow)	The abandoned part of a meandering stream channel.
passchain	A short section of strong (4 ft to 8 ft) steel chain with a hook on one end and a large ring (eye) on the other. It is used for attaching logs to tow ropes.

peak flood-level	The water surface elevation of the design flood.
peavey (peavie)	A tool used for turning logs. See "Tools," Appendix IV.
pier	An intermediate vertical support (substructure) used to join and support the ends of two spans.
pike pole	A long pole (10 ft to 20 ft) made of aluminum tubing with a sharp twisted point and a hook or spar at one end made for hauling floating logs. See "Tools," Appendix IV.
pile	A structural column driven deep into the ground (at least 6 feet) to provide support for structures built on soft ground. Piles are used for abutments and piers and in protective dolphins and retaining walls.
pile bent	See "bent."
pile driving	The process of hammering or driving the pile into the ground.
piling nose	A fabrication of angle iron attached to the front of a fender pile or dolphin to protect it from damage by floating debris or ice.
pile shoes	A steel fabrication attached to the pile point to protect it during driving.
pile spotting	Preparing the location of the pile and placing it in the correct position.
pileman	A member of a piledriver crew.
plank	A piece of sawn lumber having a rectangular cross-section with a nominal thickness of 2 in. to 5 in., a width of 8 in. to 12 in., and a random length, usually not less than 6 feet. Used for decking or bracing.
post	A log column supporting vertical loads. See "Pile." Posts rest on sills or concrete, above the ground or partly dug in.
post bent	A bent made of posts. See "pile bent." The bottom of the post held together by a sill log or concrete.
prepared log stringer	A stringer that is barked, trimmed, hewed or ripped, ready to be placed in position.
preservation (wood)	Synonymous for "treatment." The process of using chemicals to saturate the outside shell of wood to prevent decay.
preservatives	Chemicals used for treating wood to prevent decay.
psf	Abbreviation for "pounds per square foot."

psi	Abbreviation for "pounds per square inch."
reconnaissance	The preliminary inspection of an area to gain general information useful for judging bridge sites.
refusal	The stage of a friction pile during driving when it reaches the point where further driving will not significantly improve its load-carrying capacity.
retaining wall	A vertical structure designed to resist the horizontal earth pressures of the fill or other material. The wall has a slope steeper than the angle of repose of the fill.
ripping	Cutting a long flat surface on a log or timber with a saw. Similar to hewing.
rip-rap	Protective cover made of large stones or rock. Used for covering stream banks, sides of fills, or the stream bed around abutments and piers to prevent erosion (scour).
runoff	The movement of water from a drainage area after a rainfall or snow melt.
safe bearing-capacity	The safe load-carrying capacity of the material.
sawn timber	Sawn lumber 5 inches or more in nominal dimension.
scour, general	Natural scour in the stream bed.
scour, local	The erosion around obstructions and structures built in the stream.
scour, scouring	An erosion process caused by the flow of water through a stream channel and around structures in the stream.
shear log	1) Logs placed on the side of the road as an extension of the guardrails to guide the traffic onto the bridge and to prevent vehicles accidentally driving off the bridge approaches. 2) Logs placed in the water to direct debris away from the substructures.
sheet piling	Large sawn timber or interconnecting steel sheets driven like piling to protect structures or concrete forms.
shoring	Lumber or small logs used as temporary support of concrete forms. They keep the forms in place and vertical while the concrete hardens.
short caps	The caps in a pile abutment or pier which are placed in the direction of travel over two or three piles to hold them together and to accommodate a long cap.

short crook	See "crook."
shim	A small block (usually less than 2 inches in thickness) used to even out differences in size between two structural members.
sill	A log with flat surfaces (top and bottom) placed on the top of an abutment or pier to support the stringers. It has the same function as a cap.
sill log (bed plate)	A log placed transversely under the stringer ends to form a simple abutment; the bottom log of a post or frame bent.
simple span	A superstructure with a single layer of stringers without trussing is usually referred to as the "span."
single span	A bridge without a pier.
skewed bridge	A bridge with a superstructure forming an angle other than 90° with the direction of the stream channel or the substructure.
skids, skid logs	Short, small logs laid transversely at intervals under big logs or stringers. They support logs being stored above ground, and support the end of stringers being prepared.
slender	A pile, post or upright structure is called " slender" if it has a slenderness ratio of over 10. Slenderness ratio: the length of a compression member to its least actual dimension.
slope angle	The natural angle of repose of the fill material. The angle of the fill side slope measured from a horizontal plane.
snapline	See "chalkline."
soils, cohesionless	These soils do not have cohesion between the soil particles and they stay loose (e.g., sand).
soils, cohesive	In cohesive soils the particles are held together by attractive forces between the soil particles (cohesion), including electrostatic attraction and surface tension caused by the air-water interfaces between particles. In this soil the particles stick together (e.g., clay soils).
soil strength (ground strength)	The safe load-bearing capacity of the soil. See "load-carrying capacity."
span	The distance between the caps or sills of two neighbouring structures (abutments and piers). The stringers are always longer than the span.
spike	Large nail. Spikes have a larger diameter than nails and are used for fastening large pieces of timber.

spiked grid	A timber fastener with spikes on both sides used between bolted timbers to prevent movement between the two timbers.
spiral grain	Wood grain at an angle to the length of the tree or timber. It weakens sawn timber.
splice	To connect two pieces, or two parts of a wire rope to form a continuous length.
spotting	See "pile spotting."
spreaders	Pieces of lumber or steel rods placed between the concrete forms to keep them apart while placing the concrete.
spud	A hand tool with a narrow sharp blade designed for log barking. See "Tools," Appendix IV.
spur dyke	Rip-rap or rock fill shaped as a quarter of an ellipse, built in front of or behind abutments or piers to prevent scouring. Its length is more than 1.5 times its width.
stratum	A homogeneous soil layer in a stratified soil deposit.
stream	A body of running water in a narrow, clearly-defined natural watercourse or channel. Includes rivers, creeks and brooks.
stream size	A reference to the width or depth of the channel and volume of water flowing.
stringer	A load-carrying longitudinal member of a superstructure resting on the caps or sills and supporting the decking. Stringers are made of logs, sawn timber, or other materials.
strut	A structural member subject mainly to longitudinal compression stress. The word is a synonym for "frame" in the case of trussing.
stud	A horizontal sawn timber or log between two leaning pier caps to keep them apart and in position.
substructure	Abutments, piers, their foundations and protective works which form the bridge substructure supporting the superstructure above.
suckers	Large dead or live branches on the stem of a tree, or a lone branch below the crown.
superstructure	The entire structure of a bridge resting on the abutments and piers, consisting of stringers, decking, trussing, and guardrails.
swamping axe	A double-bitted axe. One edge is usually kep sharp for wood cutting while the other is used as a utility blade (wire rope cutting, etc.).

sweep	A gentle curve in a log or tree.
taper	The decrease in thickness. The decrease in diameter of a log or tree toward the top.
target board	A wood fabrication with a point marked on it fixed to the ground or a solid, horizontal surface made of lumber. Such fabrications are used in pairs or multiple numbers to align structures or to mark the boundaries of excavations. The marks on them are used as sight points.
target string	A line tightly stretched between two target boards to align structures (e.g., the face of an abutment during pile driving).
tie rod	A steel rod used to tie concrete forms together. It passes through the forms horizontally and prevents them from moving. Some tie rods also serve as spacers.
timber	Wood suitable for bridge or heavy construction. Can be logs or sawn lumber with not less than 5 in. nominal dimension.
treatment	See "preservatives."
tree plate	Flat steel strips nailed around a log to prevent a wire rope from cutting into the wood.
trestle	A braced, framed pier to support the stringers. It may rest on sill logs (post or frame trestle) or be made of piling with a cap (pile trestle).
truss	A braced structure made of wire rope or steel rods combined with needlebeams or frames to support the stringers and to carry part or most of the load. It is part of the superstructure.
undercut bank	A bank that is undermined by the stream flow.
undermine	To erode the soil under a structure or at the foot of a bank. See "scour."
vehicle load	Synonym for "design load." See "load."
waling	See "bracing."
watercourse	1) A stream of water. 2) A natural water channel.
watermark	The water surface elevation of the design peak flow.
watermark, high (HWM)	The highest visible mark left behind by a flood. It is usually the sign of the 10-year peak flow.
watermark, low (LWM)	The average surface elevation of the expected low water.

water velocity	The speed of the stream. It usually refers to the average water speed throughout a stream's cross-section. Measurements are used for calculating the volume of water flow and the scouring activity of a stream.
wing log	The logs making up the wing walls of a crib.
wingwalls	The side walls of an abutment which is built into the bank to help contain the fill.
wire rope	A rope made of twisted strands of wire. It has strength and flexibility.

BIBLIOGRAPHY

A.B.C.P.F. and U.B.C. Seminar proceedings. Drainage Structures for Logging Roads. 1979. 238 pp.

A Course on Geology-Landform-Soils. Seminar proceeding. J. McCammon, N. Keser, L. Lavkulich, Vancouver Forest District, 1973.

Adamovich, L.L. Engineering characteristics of Canadian trees–Center of gravity and green weight of components of three confiers in Interior British Columbia on poor growing sites. Forest Management Institute, FMR-X-82, 1975.

—. Engineering characteristics of Canadian trees–Center of gravity and green weight of components of four species in Interior British Columbia. Forest Management Institute, FMR-X-74, 1975.

—. Engineering Characteristics of Canadian Trees: Douglas-fir and Western Hemlock in Interior British Columbia. FERIC TN-27, 1979. 51 pp.

Amburgey, T.L., Johnson, B.R. Comparing Ammoniation and Water-Repellent Preservative Treatments for Protecting Wood Window Units From Decay. Article. Forest Product Journal, March, 1979.

American Association of State Highway and Transportation Officials. Manual on Foundation Investigations, 1978.

—. Standard Specifications for Highway Bridges. 12th Ed. 1977. 496 pp.

—. Interim Specifications, Bridges 1978.

—. Construction Manual for Highway Bridges and Incidental Structures. 1973. 66 pp.

—. AASHTO Maintenance Manual. 1976. 319 pp.

—. AASHTO Manual for Bridge Maintenance. 1976. 251 pp.

—. Manual for Maintenance Inspection of Bridges. 1974. 85 pp.

—. Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part I. 11th Ed., Washington, D.C., 1974. 685 pp.

American Institute Timber Construction. Standard for the Design of Structural Timber Framing. AITC 102-76. 37 pp.

—. Standard for Heavy Timber Construction. AITC 108-69. 4 pp.

—. Timber Construction Manual, 2nd Ed. 1974. Wiley-Interscience.

—. Typical Construction Details. AITC 104-76.

American Iron and Steel Institute. Steel Drainage and Highway Construction Products. 352 pp.

Associate Committee on Soil and Snow Mechanics, National Research Council of Canada. Guide to the Field Description of Soils for Engineering Purposes. TM37. Ottawa, 1955. 16 pp.

B.C. Forest Service, Engineering Services Division. Data on Culverts. 7 pp.

Beaver, L.D., Gardner, W.H., Gardner, W.R. Soil Physics. 4th Ed. 1972. Wiley. 498 pp.

Bureau of Land Management, Oregon State Office. Forest Engineering Handbook. U.S. Dept. of the Interior. 220 pp.

Burroughs, Jr., E.R., Chalfont, G.R., Townsend, M.A. Slope Stability in Road Construction. B.L.M. Portland, Oregon, 1976. 102 pp.

Canadian Corrugated Steel Pipe Institute. Basic Principles for Proper Installation of Drainage Structures.

—· C.S.P. Technical Manual.

—· Solving Drainage Problems with Steel. 1972.

Canadian Industries Limited. Blasters Handbook. 6th Ed. Montreal. 545 pp.

Canadian Institute of Timber Construction. Modern Timber Bridges, Some Standards and Details. 3rd Ed. Ottawa, 1970. 48 pp.

—· Pressure Treated Timber Piles. 1962. 160 pp.

Central Mortgage and Housing Corporation. Canadian Wood-Frame Housing Construction. 1975. 200 pp.

—· A Glossary of House-Building Terms. 1976. 48 pp.

Canadian Standards Association. Abbreviations for Scientific and Engineering Terms Z85-1963. 15 pp.

—· Air-Entraining Admixtures for Concrete. Can 3-A266.1-M78. 19 pp.

—· Billet-Steel Bars for Concrete Reinforcement. G30.12-1972. 14 pp.

—· Billet-Steel Bars for Concrete Reinforcement. G30.12-M1977. 16 pp.

—· Canadian Metric Practice Guide, Can 3-Z234.1-76. 48 pp.

—· Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-up Roofs. A123.8-1953. 7 pp.

—· Code for the Design of Concrete Structures for Buildings. A23.3-1973. 123 pp.

—. Code for the Engineering Design of Wood. 086-1976. 125 pp.

—. Concrete Materials and Methods of Concrete Construction. A23.1-1973. 94 pp.

—. Design of Highway Bridges. S6-1974. 231 pp.

—. Falsework for Construction Purposes. S269.1-1975. 42 pp.

—. Guidelines for the Use of Admixtures in Concrete. Can 3-A266.4-M78. 43 pp.

—. Manual of Terms and Definitions Recommended for Use in CSA Timber Standards. 1968.

—. Methods of Test for Concrete. A23.2-1973. 112 pp.

—. Portland Cements. Can 3-A5-M77. 79 pp.

—. Round Timber Piles. 056-1962. 17 pp.

—. Softwood Lumber. 0141-1970. 48 pp.

—. Steel Railway Bridges. S1-1966. 70 pp.

—. Supplement No. 1-1976 to S6-1974. 22 pp.

—. The Physical Properties of Douglas-Fir and Western Larch Poles and Reinforcing Stubs. 015.4-1975. 22 pp.

—. The Physical Properties of Western Red Cedar Poles and Reinforcing Stubs. 015.2-1969. 22 pp.

—. Welded Steel Wire Fabric for Concrete Reinforcement. G30.5-1972. 13 pp.

—. Wire Nails, Spikes and Staples. B111-1974. 34 pp.

—. Wood Screws. B35.4-1972. 21 pp.

—. Mechanical Engineering Drawing Standards. CSA B78.1-1967. 31 pp.

—. Wood Preservation. CSA Standard 080, 1974. Looseleaf edition.

Canadian Wood Council. Canadian Wood Construction. 1978 Ed. Booklet series in 3-ring binder:
Structure and Properties, 16 pp.
Storage and Handling, 4 pp.
Design, 28 pp.
Section Properties, 16 pp.
Lumber Standards and Design Data, 16 pp.
Nails, Spikes and Staples, 8 pp.
Wood Screws, 8 pp.
Bolts, Lag Screws and Timber Connectors, 28 pp.
Metal Framing Connectors, 16 pp.
Falsework and Formwork, 32 pp.

Framing Techniques, 24 pp.
Post and Beam–Description and Design Factors, 12 pp.

Dickie, D.E. Crane Handbook. Construction Safety Association of Ontario, 1975. 304 pp.

—· Rigging Manual. Construction Safety Association of Ontario, 1975. 188 pp.

E.L.U.C. Secretariat. Terrain Classification System. 1976. 54 pp.

Engineering Division, B.C.F.S. Engineering Notes. Notes prepared for the Forest Service Training School, 1972.

Forest Products Laboratories of Canada, Forestry Branch. Strength and Related Properties of Woods Grown in Canada. F.P.L. T.N. No. 3, Ottawa, 1956.

Forest Service. Government of B.C. R.L. Davis. Log Bridge Stringers and Needle Beam Sizing. 1973. 59 pp.

Fox, S.P. Inspection of High-Temperature Manufactured Laminated Structural Members. Western Forest Products Laboratory, Vancouver, B.C., 1972. 8 pp.

Gower, L.E. Article series on bridges in the Journal of Logging Management. 1976-1979.

—· Trussed logs offered as solution for low-cost short-life bridges. Article June 1978, Canadian Pulp and Paper Industry.

Graham, Robert D., Hesing, Guy G.–Forest Research Laboratory. Wood pole maintenance manual: inspection and supplemental treatment of Douglas-fir and western red cedar poles. Oregon State University, 1979. 62 pp.

Gurfinkel, German. Wood Engineering. Southern Forest Products Assoc., 1973. 540 pp.

Hetherington, E.D. The 25-year Storm and Culvert Size. Environment Canada, Forestry Service, 1974. BC-X-102. 28 pp.

Holmes, D.C. Manual for Roads and Transportation–Volume 1 and 2. B.C. Institute of Technology, 1978. 327 pp.

Hough, B.K. Basic Soil Engineering. Ronald Press. 1957.

Hunt, M.M. Some Notes on Log Bridge Construction. Proceedings Road Seminar, Williams Lake, B.C., 1974.

Kinori, B.Z. Manual of Surface Drainage Engineering. Elsevier 1970.

Klima, I.F. Design of Log Bridges–How to design one lane, single span log bridges to meet the needs of the B.C. logger. British Columbia Lumberman, April 1969.

—· Practical Guide to Culverts and Log Bridges on Forest Roads. B.C.F.S. Proceedings Road Seminar, Williams Lake, B.C., 1974.

Lambe, T. William. Soil Testing for Engineers. Wiley, New York, 1951. 165 pp.

Laminated Timber Institue of Canada. Timber Design Manual. 1972. 458 pp.

Lapedes, D.N. Dictionary of Scientific and Technical Terms. McGraw-Hill, 1976.

Latta, W.S. Table Showing Sizes of Log Stringers. Unpublished. MacMillan Bloedel Limited.

Lyons, C.P. Trees, Shrubs and Flowers to Know in British Columbia. J.M. Dent and Sons, 1976. 194 pp.

Merritt, F.S. ed. Standard Handbook of Civil Engineers. McGraw-Hill, 1976. 1305 pp.

Metric Commission Canada. How to Write SI. 4th Ed. 1978. 8 pp.

Mifflin, Ronald W., Lysons, Hilton H., U.S.D.A. Forest Service. Glossary of Forest Engineering Terms. Pacific Northwest Forest Range and Experiment Station, 1979. 24 pp.

National Corrugated Steel Pipe Association. Installation Manual–CMPA 1162. 1973. 54 pp.

National Corrugated Steel Pipe Association. Installation Manual. NCSPA 1977.

National Forest Products Association. Wood Structural Design Data. 1970. 236 pp.

—. Supplement to 1973 edition of National Design Specification for Stress-Grade Lumber and its Fastenings. 1974. 17 pp.

National Lumber Grades Authority 1970. Standard Grading Rules for Canadian Lumber. Vancouver, 1973. 234 pp.

National Research Council of Canada. Commentaries on Part A of the National Building Code of Canada 1975. 169 pp.

Oregon State University. Forest Land Use and Stream Environment. Symposium proceedings, 1970. 252 pp.

Parker, Harry. Simplified Mechanics and Strength of Materials. 2nd Ed. Wiley, 1961. 285 pp.

—. Simplified Design of Reinforced Concrete. 3rd Ed. Wiley, 1968. 310 pp.

Peck, Ralph B., Hanson, Walter E., Thornburn, Thomas H. Foundation Engineering. 2nd Ed. Wiley, 1974. 514 pp.

Peurifoy, R.L. Construction Planning, Equipment and Methods. McGraw-Hill, 1979, New York 720 pp.

Portland Cement Association. Design and Control of Concrete Mixtures. 11th Ed. 1968. 121 pp.

—. Concrete Culverts and Conduits. Skokie, Ill., 1975. 73 pp.

Pratt, R.W. Design of Log Span Bridges. Articles, The Timberman, June 1950.

Queen's Printer of B.C. Classification (Grading) and Scaling Procedure in Current Use for British Columbia 1975. 39 pp.

Riddell, Robert. Splicing Manual, Wire Rope. Div. of Technical and Vocational Services, Dept. of Education, B.C. 1972.

Scarisbrick, R. Surveys for Drainage Structures on Forest Roads. Ministry of Forests, Province of B.C., 1979. A guide. 23 pp.

Smith, D.E. Culvert Design Guide. Unpublished, 1967. B.C.F.S.

Society of American Foresters, R.D. Forbes ed. Forestry Handbook. The Ronald Press, New York, 1961.

Society of American Foresters, F.C. Ford-Robertson ed. Terminology of Forest Science, Technology, Practice and Products. Washington, D.C., 1971. 349 pp.

Sowers, George B., Sowers, George F. Introductory Soil Mechanics and Foundation. 3rd Ed. 1970. MacMillan, London. 556 pp.

Talbot, Steven. Building Standard Woodland Roads. Nova Scotia Department of Lands and Forests, 1975. 21 pp.

Task Force on Hydrology and Hydraulics. AASHTO. Highway Drainage Guidelines. Washington, D.C., 1973. 113 pp.

The Asphalt Institue. Soil Manual for Design of Asphalt Pavement Structure. MS-10. 2nd Ed. 1969. 271 pp.

The Forest Club. U.B.C., Vancouver, B.C. Forestry Handbook for British Columbia. 3rd Ed. 1971. 815 pp.

Thompson, D. The Nuts and Bolts of Bridge Construction. Proceedings, Crown Zellerbach Canada Limited, Engineer-Foresters Seminar, 1978. Unpublished.

Timber Engineering Company (An affiliate of National Lumber Manufacturing Association). Timber Design and Construction Handbook. McGraw-Hill, 1956. 622 pp.

U.S.D.A. Forest Products Laboratory. Wood Handbook NO. 72. Forest Service, 1955. 528 pp.

U.S.D.A. Forest Service, Region 10. F.W. Muchmore. Design Guide for Native Log Stringer Bridges. 1977.

Weightman, J.C. A Brief Summary of Fish Passage Problems at Culvert Installations with Special Reference to Swimming Performance. Fish and Wildlife Branch, Dept. of Recreation and Conservation, Victoria, B.C., 1974. 14 pp.

Workers' Compensation Board of B.C. Industrial Health and Safety Regulations. Vancouver, 1978.

—· Fallers and Buckers Handbook. Vancouver, 1973. 107 pp.

Woods, Kenneth B. ed., Berry, Donald S. ed., Goetz, William H. ed., Highway Engineering Handbook, 1st Ed. McGraw-Hill, 1960.

Wrights Canadian Ropes Ltd. Wrights Ropes. 1963. 132 pp.

Abutments, 5, 71, 339, 345, 352
concrete, 8, 151
design, 43, 367
drainage, 151
failure, 339, 345, 352
log crib, 6, 74
pile, 7, 99
simple, 5, 71
Adze, 379
Alaskan sawmill, 380
Approaches, 338

Bearing capacity of rocks
and soils for end-bearing piles, 113
Bench marks, 36, 38
Bracing, 129, 210
outside longitudinal, 129
Bridge, 3, 71
abutments, 5, 71
approaches, 4
basic components, 4
culvert-type, 13, 262
life, 4
size and peak flow, 26
trussed log, 269
types, 3, 13
Broadaxe, 379

Cables and hardware, 134, 136
Caps and sills, 107, 210, 221
minimum sizes, 222
repairing, 353
Cement, 146
Chamfer cut, 129
Concrete, 145, 342, 352
admixtures, 148
aggregate, 147
compaction, 172
curing, 173
forms, 166, 217
mixing, 170
reinforcement, 149
unit weight, 171
Construction, 69
cost, 361, 363
material, 65, 365
records, 328
Cradle notch, 92, 93
Crib, 6, 74
construction, 92
design, 83
filling, 95
lashing and drifting, 94
log fittings, 92
types, 95
crude, 95
flat-face, 97
loose, 95
partly-fitted, 96
log preparation, 89
Cribbing, 74, 345
box, 78, 213
fill-retaining, 141
open-end, 77
tight-face, 98
Crossties, 284
repairing, 357
Culvert, 3

Deadman, 136
Decay, 223, 317, 346
Decking, 13, 284, 340
asphalt, 305
crosstie and planking, 287
crosstie size guide, 288
gravel, 285
joining plank ends, 295
laminated, 297
laying crossties, 289
nail size guide, 296
planking, 294
plywood, 305
sectional, 303
Definitions, 3
Deflection test, 331
Design load, 55, 377
Dolphin, 89, 194
Drift pins, 247, 384
DYWIDAG rods, 269

Eccentric loading, 45
Environmental protection, 32

Fastenings, 108, 208, 310
Fender pile, 194
Field reconnaissance, 34

Fisheries Department, 32
Foundations, 151, 205
Foundation logs, 74
Fumigants, 351

Gravel and sand bars, 21
Ground preparation, 120
Guardrails, 13, 306, 341
  repairing, 358
Guardlogs
  (shear, fender, bumper logs), 306, 341

High watermark, 25
Hookeroon, 382

Ice jams, 345
Inspection, 327
  inventory, 327
  reports, 328, 342
  tools, 335

Lashing, 248, 264
Log jams, 22
Logging (Gilchrist, Hercules) jack, 381

Maintenance, 327
  concrete abutments and piers, 352
  culvert-type log bridges, 340, 354
  decks, 340, 357, 358
  guardrails, 341, 358
  inspection limitations, 336
  inventory form, 342
  settlement, 346, 349, 352
  tie and plank decks, 357, 358
Material list, 65, 365
Moisture content of green wood, 230, 391
Mud sills, 73, 74

Needlebeam, 252, 278, 340
  repairs, 340
Notching or dapping, 92

Peak-flow, 23, 26
Peavey (peavy), 380
Pickaroon, 382
Piers, 8, 174, 339, 345, 352
  bracing, 129
  caps, 131
  concrete, 8, 213, 216
  double-bent, 176
  foundation design, 205
  frame bent, 200
  group-piling, 187
  leaning, 201
  load-distributing three-bent, 186
  log crib, 211
  multiple-bent, 187
  pile-bent, 175
  post-bent, 200
  protection, 193, 210
  simple, 174
Pike pole, 380
Pile, 7, 99
  abutment, 7, 99
    fill-retaining, 100
  bents, 103, 349
    bracing, 129
    design, 113
  drivers, 123
  driving, 127
  friction, 112
  group, 113, 187
  number in a bent, 114
  piling nose, 194, 198
  point, 120, 121
  preparation, 118
  protection, 73, 143, 210, 323
  selection, 118
  steel, 193, 217
  type of, 112
    combination end-bearing, 113
      and friction piles, 112
  wooden, 7, 118
Pile and hammer size relationship, 117
Planking, 196
  repair, 358
Preparation of plans, 65
Preservation, 371

Railroad spikes, 136, 383
Repairs (see also individual components), 343
  painted surfaces, 359
  pile settlement, 349
  scour, 347
  shrinkage, 346
  stream channels, 343
Reports, 328, 342
Rip-rap, 31, 144, 214, 344
Rock anchors and stumps, 141, 142

Scour, 27, 29, 347
Seasoning of wood, 228

Shear logs, 144, 306
Shims, 248
Shrinkage, 230, 346
Signs, 341
  traffic, 341
Simple abutments, 5, 71
Site, 4, 37, 38
  choosing, 32, 34, 37
  preparation, 69, 150
  survey and plans, 36, 38, 43
Slab foundation, 151
Span, 11
Spud, 381
Staples, 136
Steel sheeting, 199
Storage and seasoning, 228
Stream, 19, 341, 344
  bank stability, 20
  bends, 20
  channel and bank investigation, 19
  channel realignment, 343, 344
  crossings, 38
  size and peak flow, 22
  type, 19
  velocity, 28, 29
Stringer, 10, 224, 250, 340
  guardlogs, 256
  blocking, 248
  design, 45
    criteria, 45
    culvert-type log bridges, 52, 262
    graphs, 47
    stresses, 46, 229
    trussed log bridges, 54
  distribution, 250
  double tier, 257
  drifting 247,
  extenders, 284
  falling, 227
  lashing, 248
  placing, 242, 281
  preparation, 231, 275
    area, 231
  debarking, 231
  hewing or ripping, 231, 232
  marking, 233, 235
  repairing, 354
  sawn-timber, 281
  selection, 225, 227
  transportation, 228
  trussed log, 269, 278
Strongback, 271
Substructure, 5
Superstructure, 10

Timber carrier, 382
Timber connectors, 383
  bridge spike, 383
  bolt, 384
  drift bolt, 384
  drift pin, 384
  lag bolt or screw, 384
  railroad spike, 383
  shear plates, 386
  spiked grid, 385
  spikes and nails, 383
  split ring, 386
  washer, 385
Trees, 225
  defects, 225, 227
Truss, 12, 269
  designs, 54
  wire rope, steel, 54, 355
    repair of, 356

Wire clips, 136
Wood, 387
  desired species, 387
  weight, 76, 387
Wood preservation, 317
Wood preservatives, 317
  coal-tar creosotes, 317
  field treatment, 319
    with creosote, 322
    with copper napthenate and pentachlorophenol solutions, 319
  plant treatment, 318
  water-soluble, 318, 319