



Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A21

STREAM-GAGING CABLEWAYS

By C. Russell Wagner

Book 3

APPLICATIONS OF HYDRAULICS

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY
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PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called "Books" and further subdivided into sections and chapters. Section A of Book 3 is on surface water techniques.

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TECHNIQUES OF WATER-RESOURCES INVESTIGATIONS OF THE U.S. GEOLOGICAL SURVEY

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- TWRI 1-D1. Water temperature—influential factors, field measurement, and data presentation, by H.H. Stevens, Jr., J.F. Ficke, and G.F. Smoot. 1975. 65 pages.
- TWRI 1-D2. Guidelines for collection and field analysis of ground-water samples for selected unstable constituents, by W.W. Wood. 1976. 24 pages.
- TWRI 2-D1. Application of surface geophysics to ground-water investigations, by A.A.R. Zohdy, G.P. Eaton, and D.R. Mabey. 1974. 116 pages.
- TWRI 2-D2. Application of seismic-refraction techniques to hydrologic studies, by F.P. Haeni. 1988. 86 pages.
- TWRI 2-E1. Application of borehole geophysics to water-resources investigations, by W.S. Keys and L.M. MacCary. 1971. 126 pages.
- TWRI 2-E2. Borehole geophysics applied to ground-water investigations, by W. Scott Keys. 1990. 150 pages.
- TWRI 2-F1. Application of drilling, coring, and sampling techniques to test holes and wells, by Eugene Shuter and Warren E. Teasdale. 1989. 97 pages.
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- TWRI 3-A2. Measurement of peak discharge by the slope-area method, by Tate Dalrymple and M.A. Benson. 1967. 12 pages.
- TWRI 3-A3. Measurement of peak discharge at culverts by indirect methods, by G.L. Bodhaine. 1968. 60 pages.
- TWRI 3-A4. Measurement of peak discharge at width contractions by indirect methods, by H.F. Matthai. 1967. 44 pages.
- TWRI 3-A5. Measurement of peak discharge at dams by indirect methods, by Harry Hulsing. 1967. 29 pages.
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- TWRI 3-A11. Measurement of discharge by the moving-boat method, by G.F. Smoot and C.E. Novak. 1969. 22 pages.
- TWRI 3-A12. Fluorometric procedures for dye tracing, Revised, by J.F. Wilson, Jr., E.D. Cobb, and F.A. Kilpatrick. 1986. 34 pages.
- TWRI 3-A13. Computation of continuous records of streamflow, by E.J. Kennedy. 1983. 53 pages.
- TWRI 3-A14. Use of flumes in measuring discharge, by F.A. Kilpatrick, and V.R. Schneider. 1983. 46 pages.
- TWRI 3-A15. Computation of water-surface profiles in open channels, by Jacob Davidian. 1984. 48 pages.
- TWRI 3-A16. Measurement of discharge using tracers, by F.A. Kilpatrick and E.D. Cobb. 1985. 52 pages.
- TWRI 3-A17. Acoustic velocity meter systems, by Antonius Laenen. 1985. 38 pages.
- TWRI 3-A18. Determination of stream reaeration coefficients by use of tracers, by F.A. Kilpatrick, R.E. Rathbun, N. Yotsukura, G.W. Parker, and L.L. DeLong. 1989. 52 pages.
- TWRI 3-A19. Levels at streamflow gaging stations, by E.J. Kennedy. 1990. 31 pages.
- TWRI 3-A20. Simulation of soluble waste transport and buildup in surface waters using tracers, by F.A. Kilpatrick. 1993. 38 pages.
- TWRI 3-A21. Stream-gaging cableways, by C. Russell Wagner. 1995. 56 pages.
- TWRI 3-B1. Aquifer-test design, observation, and data analysis, by R.W. Stallman. 1971. 26 pages.
- TWRI 3-B2.² Introduction to ground-water hydraulics, a programed text for self-instruction, by G.D. Bennett. 1976. 172 pages.

¹This manual is a revision of "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing," by E.F. Hubbard, F.A. Kilpatrick, L.A. Martens, and J.F. Wilson, Jr., Book 3, Chapter A9, published in 1982.

²Spanish translation also available.

- TWRI 3-B3. Type curves for selected problems of flow to wells in confined aquifers, by J.E. Reed. 1980. 106 pages.
- TWRI 3-B4. Regression modeling of ground-water flow, by Richard L. Cooley and Richard L. Naff. 1990. 232 pages.
- TWRI 3-B4, Supplement 1. Regression modeling of ground-water flow—Modifications to the computer code for nonlinear regression solution of steady-state ground-water flow problems, by R.L. Cooley. 1993. 8 pages.
- TWRI 3-B5. Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems—An introduction, by O. Lehn Franke, Thomas E. Reilly, and Gordon D. Bennett. 1987. 15 pages.
- TWRI 3-B6. The principle of superposition and its application in ground-water hydraulics, by Thomas E. Reilly, O. Lehn Franke, and Gordon D. Bennett. 1987. 28 pages.
- TWRI 3-B7. Analytical solutions for one-, two-, and three-dimensional solute transport in ground-water systems with uniform flow, by Eliezer J. Wexler. 1991. 193 pages.
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- TWRI 3-C2. Field methods of measurement of fluvial sediment, by H.P. Guy and V.W. Norman. 1970. 59 pages.
- TWRI 3-C3. Computation of fluvial-sediment discharge, by George Porterfield. 1972. 66 pages.
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- TWRI 5-A3.³ Methods for the determination of organic substances in water and fluvial sediments, edited by R.L. Wershaw, M.J. Fishman, R.R. Grabbe, and L.E. Lowe. 1987. 80 pages.
- TWRI 5-A4.⁴ Methods for collection and analysis of aquatic biological and microbiological samples, by L.J. Britton and P.E. Greeson, editors. 1989. 363 pages.
- TWRI 5-A5. Methods for determination of radioactive substances in water and fluvial sediments, by L.L. Thatcher, V.J. Janzer, and K.W. Edwards. 1977. 95 pages.
- TWRI 5-A6. Quality assurance practices for the chemical and biological analyses of water and fluvial sediments, by L.C. Friedman and D.E. Erdmann. 1982. 181 pages.
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- TWRI 6-A2. Documentation of a computer program to simulate aquifer-system compaction using the modular finite-difference ground-water flow model, by S.A. Leake and D.E. Prudic. 1991. 68 pages.
- TWRI 6-A3. A modular finite-element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 1: Model Description and User's Manual, by L.J. Torak. 1993. 136 pages.
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- TWRI 6-A5. A modular finite-element model (MODFE) for areal and axisymmetric ground-water-flow problems, Part 3: Design philosophy and programming details, by L.J. Torak. 1993. 243 pages.
- TWRI 6-A6. A coupled surface-water and ground-water flow model (MODBRANCH) for simulation of stream-aquifer interaction. 1994. 90 pages.
- TWRI 7-C1. Finite difference model for aquifer simulation in two dimensions with results of numerical experiments, by P.C. Trescott, G.F. Pinder, and S.P. Larson. 1976. 116 pages.
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- TWRI 8-A2. Installation and service manual for U.S. Geological Survey monometers, by J.D. Craig. 1983. 57 pages.
- TWRI 8-B2. Calibration and maintenance of vertical-axis type current meters, by G.F. Smoot and C.E. Novak. 1968. 15 pages.

³This manual is a revision of TWRI 5-A3, "Methods of Analysis of Organic Substances in Water," by Donald F. Goerlitz and Eugene Brown, published in 1972.

⁴This manual supersedes TWRI 5-A4, "Methods for collection and analysis of aquatic biological and microbiological samples," edited by P.E. Greeson and others, published in 1977.

CONTENTS

Preface.....	III
Glossary	X
Abstract	1
Introduction.....	1
Purpose and Scope	1
Site Selection	1
Hydraulic Considerations.....	1
Logistical Considerations.....	2
Legal and Regulatory Considerations.....	2
Easements	2
U.S. Army Corps of Engineers Requirements	2
Federal Aviation Administration Requirements	2
Other State and Local Laws and Regulations	3
Design Criteria.....	3
Determination of the 100-Year Flood Stage	3
Measurement of the Span.....	3
Loads.....	3
Soil Characteristics	4
Soil Type A	4
Soil Type B.....	4
Design Procedures	4
Cables.....	5
Characteristics and Application	5
Wire Rope	5
Tramway or Structural Strand.....	5
Design Load Selection	5
Design Sag	6
Design Factor.....	6
Calculation of Sag.....	8
System Hardware Design.....	8
Support Structures.....	22
Footings.....	22
Footing Design.....	23
Steel A-Frames.....	23
Wood A-Frames	25
Steel Beams.....	25
Trees as Supports	25
Platforms, Walkways, and Ladders.....	29
Grounding for Lightning Protection	30
Anchorage.....	30
Concrete Mass Anchors	30
Sidehill Anchors.....	31
T-Anchors.....	31
Rocks as Anchors.....	31
Trees as Anchors	34
Buried Deadmen	34
Aircraft Warning Devices	34

Cable Cars.....	34
Construction.....	42
Excavating for Anchors and Support Structures.....	42
Preparing Concrete for Anchors and Support Structures.....	43
Installing Rock Anchors.....	44
Installing Tree Supports or Anchors.....	44
Erecting A-Frames and Cable.....	44
Installing Grounds.....	46
Grounding Rods.....	46
Wire Grounds.....	46
Cableways Conforming to Circular 17 Specifications.....	47
Documentation.....	49
Security.....	49
Inspection and Maintenance.....	49
Anchors and Footings.....	49
Main Cable Supports.....	50
Main Cable.....	50
Backstay.....	50
Cable Connections.....	50
Cable Car.....	50
Miscellaneous.....	51
Nondestructive Testing.....	51
Selected References.....	51
Appendix I. Notice of Proposed Construction or Alteration.....	54
Appendix II. Cableway Design Summary.....	55
Appendix III. Painting and Preservation Guidelines.....	56

FIGURES

1, 2. Sketches showing—	
1. Typical cableway.....	2
2. Construction of (A) wire rope and (B) structural strand.....	7
3–14. Sag diagrams and selection guides for—	
3. 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 1,500 lb.....	9
4. 6 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 1,500 lb.....	10
5. Class A structural strand and cable-car load of 1,500 lb.....	11
6. 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 2,000 lb.....	12
7. 6 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,000 lb.....	13
8. Class A structural strand and cable-car load of 2,000 lb.....	14
9. 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 2,250 lb.....	15
10. 6 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,250 lb.....	16
11. Class A structural strand and cable-car load of 2,250 lb.....	17
12. 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 2,500 lb.....	18
13. 6 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,500 lb.....	19
14. Class A structural strand and cable-car load of 2,500 lb.....	20
15–37. Sketches showing—	
15. How to measure (or caliper) a wire rope.....	21
16. Various dimensions of a sheave and the use of a groove gage.....	21
17. Cross sections of sheave-groove conditions.....	21
18. Typical cast-iron cable saddle block.....	22
19. U-bar and bearing block.....	24
20. Single footing reinforcing bar placement.....	26
21. Combined footing reinforcing bar placement.....	27

22. Steel A-Frame 28

23. Wooden A-Frame 29

24. Anchorage for cableway positioned at 30° 32

25. Anchorage for cableway positioned at 45° 33

26. Sidehill anchorage for 10,000-lb design load 35

27. Sidehill anchorage for 15,000-lb design load 36

28. Sidehill anchorage for 20,000-lb design load 37

29. Sidehill anchorage for 25,000-lb design load 38

30. Sidehill anchorage for 30,000-lb design load 39

31. T-anchor 40

32. T-anchor details 41

33. Vertical rock anchor 42

34. Horizontal rock anchor 43

35. Wire-rope seizing technique and final product 45

36. Hammer-type cable cutter 45

37. Correct way to attach wire rope clips 46

38, 39. Sag diagrams showing—

 38. Improved plow steel 6 × 7 wire rope (cable) 47

 39. Extra high strength tramway track strand of various diameters 48

TABLES

1. Strength comparison for various cable materials 6

2. Hardware component sizes 23

3. Bearing areas of footings 25

4. Anchorages for 30° and 45° cables 34

5. T-anchor dimensions 42

6. Recommended number of clips, torque, and dead-end turnback for wire rope 46

METRIC CONVERSION FACTORS

Multiply inch-pound	By	To obtain metric unit
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square foot (ft ²)	0.09294	square meter
cubic foot (ft ³)	0.02832	cubic meter
cubic yard (yd ³)	0.7646	cubic meter
pound, avoirdupois (lb)	0.4536	kilogram
pound, force (lbf)	4.4482	newton
foot-pound (ft·lb)	1.3558	newton meter
pound per square inch (lb/in ²)	6.895	kilopascal
pound per cubic foot (lb/ft ³)	16.01846	kilogram per cubic meter

GLOSSARY OF TERMS

[The following terms are defined as they apply to stream-gaging cableway system]

- A-frame.** A structure to elevate and support a cable.
- Anchor.** A structure connected to end of cable to hold cable in place under tension. Usually concrete or rock.
- Area, metallic.** Sum of the cross-sectional areas of all the wires in a wire rope or strand.
- Backstay.** A wire rope guy used to support an A-frame, or other support structure, leading from the top of the support to an anchorage.
- Breaking strength.** The ultimate load at which a tensile failure occurs in the sample of wire rope being tested. (Note: The term "breaking strength" is synonymous with actual strength.)
- (1) **Minimum acceptance strength** is that strength that is 2 1/2 percent lower than the catalog or nominal strength. This tolerance is used to offset variables that occur during sample preparation and actual physical test of a wire rope.
 - (2) **Nominal strength** is the published (catalog) strength calculated by a standard procedure that is accepted by the wire rope industry. The wire rope manufacturer designs wire rope to this strength, and the user should consider this strength when making design calculations.
- Bridge socket.** A wire rope or strand end termination made of forged or cast steel that is designed with baskets—having adjustable bolts—for securing rope ends. There are two styles: (1) the **closed type** has a U-bolt with or without a bearing block in the U of the bolt and (2) the **open type** has two eyebolts and a pin.
- Bright rope.** Wire rope fabricated from wires that are not coated.
- Cable.** A term loosely applied to wire rope, wire strand, and electrical conductors. In the context of a USGS stream-gaging cableway, it refers to the system's main support rope for cable-car operation.
- Cableway.** Aerial conveying system for transporting personnel and equipment along a suspended cable above a river.
- Catenary.** A curve formed by a strand or wire rope when supported horizontally between two fixed points; for example, the main spans on a cableway.
- Certification.** Documentation provided by manufacturer that demonstrates that wire rope meets minimum acceptance strength.
- Circumference.** Measured perimeter of a circle that circumscribes either the wires of a strand or the strands of a wire rope.
- Clip.** Fitting for clamping two parts of wire rope to each other.
- Concrete anchor.** A large block of concrete used to hold a cable in place under tension.
- Constructional stretch.** The stretch that occurs when the rope is tensioned. It is due to the helically laid wires and strands creating a constricting action that compresses the core and generally brings all of the rope's elements into close contact.
- Core.** The axial member of a wire rope about which the strands are laid.
- Corrosion.** Chemical decomposition of the wires in a rope through the action of moisture, acids, alkalies, or other destructive agents.
- (1) **Light corrosion.** Rust showing without pitting of the material. Strength loss is less than 1 percent.
 - (2) **Mild corrosion.** Rust with minor pitting; less than 5 percent surface pitted. Strength loss is less than 5 percent.
 - (3) **Moderate corrosion.** Rust showing, with 10 to 30 percent of surface pitted. Strength loss is less than or equal to 10 percent.
 - (4) **Severe corrosion.** Rust showing, with 30 to 60 percent of the surface pitted. Strength loss exceeds 10 percent and possibly is as high as 25 percent.
 - (5) **Extreme corrosion.** Rust showing, with 100 percent of the surface pitted; no original surface remaining between pits. Strength loss in many cases exceeds 50 percent.

- Design factor.** In a wire rope, the ratio of the nominal strength to the total working (design) load.
- Design load.** Nominal (catalog) strength divided by the design factor. Also known as **Working load**.
- Diameter.** A line segment that passes through the center of a circle and whose end points lie on the circle. As related to wire rope, it is the diameter of a circle that circumscribes the wire rope.
- Dog-leg.** Permanent bend or kink in a wire rope caused by improper use or handling.
- End termination.** The treatment at the end or ends of a length of wire rope, usually made by forming an eye or attaching a fitting, designed to be the permanent end termination on the wire rope that connects it to the load or anchor.
- Extra extra improved plow steel rope.** A specific wire rope grade.
- Extra improved plow steel rope.** A specific wire rope grade.
- Factor of safety.** In the wire rope industry, term originally used to express the ratio of nominal strength to the total working load. The term is no longer used because it implies a permanent existence for this ratio when, in actuality, the rope strength begins to reduce the moment it is placed in service. See **Design factor**.
- Fatigue.** As applied to wire rope, term usually referring to the process of progressive failure resulting from the bending of individual wires. These fractures may and usually do occur at bending stresses well below the ultimate strength of the material; it is not an abnormality although it may be accelerated due to conditions in the rope such as corrosion.
- Fiber core.** Cord or rope of vegetable or synthetic fiber used as the axial member of a rope.
- Filler wire.** Small spacer wires within a strand that help position and support other wires. Also the name for the type of strand pattern using filler wires.
- Fitting.** Any functional accessory attached to a wire rope.
- Galvanized.** Zinc coating for corrosion resistance.
- Galvanized rope.** Wire rope made of galvanized wire.
- Galvanized strand.** Strand made of galvanized wire.
- Galvanized wire.** Zinc-coated wire.
- Grade.** Wire rope or strand classification by strength and (or) type of material, such as improved plow steel, type 302 stainless, phosphor bronze. It does not imply a strength of the basic wire used to meet the rope's nominal strength.
- Guy line.** See **Backstay**.
- Improved plow steel rope.** A specific grade of wire rope.
- Independent wire rope core (IWRC).** A wire rope used as the axial member of a larger wire rope.
- Inner wires.** All wires of a strand except the outer or cover wires.
- Lay.** (1) The manner in which the wires in a strand or the strands in a rope are helically laid or (2) the distance measured parallel to the axis of the rope (or strand) in which a strand (or wire) makes one complete helical convolution about the core (or center). In this connection, lay is also referred to as **Lay length** or **Pitch**.
- Lay, types.**
- (1) **Right lay.** The direction of strand or wire helix corresponding to that of a right-hand screw thread.
 - (2) **Left lay.** The direction of strand or wire helix corresponding to that of a left-hand screw thread.
 - (3) **Cross lay.** Rope or strand in which one or more operations are performed in opposite directions. A multiple operation product is described according to the direction of the outside layer.
 - (4) **Regular lay.** The type of rope wherein the lay of the wires in the strand is in the opposite direction of the lay of the strand in the rope. The crowns of the wires appear to be parallel to the axis of the rope.

- (5) **Lang lay.** The type of rope in which the lay of the wires in the strand is in the same direction as the lay of the strand in the rope. The crowns of the wires appear to be at an angle to the axis of the rope.
- (6) **Alternate lay.** Lay of a wire rope in which the strands are alternately regular and lang lay.
- (7) **Alberts lay.** An old, rarely used term for lang lay.
- (8) **Reverse lay.** Another term for alternate lay.
- (9) **Spring lay.** Not definable as a unique lay; more properly, it refers to a specific wire rope construction.

Lay length. See **Lay** (2).

Messenger cable. Galvanized rope used as support for aircraft warning markers or other special purposes.

Modulus of elasticity. Mathematical quantity expressing the ratio, within the elastic limit, between a definite range of unit stress on a wire rope and the corresponding unit elongation.

Nominal strength. Values calculated by standardized, industry-accepted procedures. Also known as **Catalog strength**. Designers should base calculations on these values.

Prestressing. An incorrect reference to **Prestretching**.

Prestretching. Subjecting a wire rope or strand to tension prior to its intended application for an extent and over a period of time sufficient to remove most of the **Constructional stretch**.

Rated capacity. The load that a new wire rope may handle under given operating conditions and at an assumed **Design factor**.

Regular lay rope. See **Lay, types**.

Reserve strength. The strength of a rope exclusive of the outer wires.

Reverse lay. See **Lay, types**.

Right lay. See **Lay, types**.

Safety factor. See **Design factor**.

Safe working load. Potentially misleading term, now in disfavor. Essentially, it refers to that portion of the nominal rope strength that can be applied either to move or to sustain a load. It is misleading because it is valid only when the rope is new and the equipment is in good condition. See **Rated capacity**.

Sag. (1) The sag of a rope in a span, usually measured at midspan as the distance from the chord joining the tops of the two supports or (2) any deviation from a straight line.

Seize. To make a secure binding at the end of a wire rope or strand with **Seizing wire** or other means.

Seizing wire. A wire for seizing. See **Seize**.

Shackle. A U- or anchor-shaped fitting with pin.

Sheave. A grooved pulley for wire rope.

Socket. A type of end termination that provides attachment to an anchor or load. The most common types are—

- (1) **Poured zinc (spelter).** Molten zinc is used to bond the wire rope to the socket.
- (2) **Poured resin.** Thermo-set resin is used to bond the wire rope to the socket.
- (3) **Swaged.** Mechanical force is used to forge or press the socket tightly around the socket. Sockets may be closed, having one extending ear or bail with a hole or opening for attachment, or open, having two extending ears or bails with a hole or opening for attachment. Usually two cables may be attached if one has a closed and the other has an open socket. See **Bridge socket**.

Strand. A plurality of round or shaped wires helically laid about an axis.

Stress. The force or resistance within any solid body against alteration of form; in the case of a solid wire, the load on the rope divided by the cross-sectional area of the wire.

Stretch. The elongation of a wire rope under load.

Structural strand. A plurality of wires formed as a single strand, also known as **Tramway track strand** or **Bridge strand**.

Thimble. Grooved metal fitting to protect the eye or fastening loop of a wire rope.

Track cable. On an aerial conveyor, it is the suspended wire rope or strand along which load carriers move.

Turnbuckle. A right and left screw link to tighten a cable.

U-bar. A U-shaped iron bar embedded in concrete or rock to which a cable is attached.

Wire. (1) **Round**, a single, continuous length of metal, with a circular cross section that is cold-drawn from rod, or (2) **Shaped**, a single, continuous length of metal with a noncircular cross section that is either cold-drawn or cold-rolled from rod.

Wire rope. A plurality of wire strands helically laid about an axis.

Stream-Gaging Cableways

By C. Russell Wagner

ABSTRACT

This manual provides a series of standard designs for stream-gaging cableways used by the U.S. Geological Survey. It also provides helpful information on construction, inspection, and maintenance of cableways. Users of design recommendations are cautioned to follow sound engineering practices in the selection of system components for a specific site. Accepted industry standards are referenced to facilitate procurement of materials where appropriate.

INTRODUCTION

Cableways have been used for many decades by the U.S. Geological Survey (USGS) and other organizations involved in the measurement of streamflow and collection of water-quality samples. In 1988, the USGS operated approximately 1,600 cableways. Properly constructed and maintained cableways are dependable and convenient platforms for obtaining water-resources data. Highway bridges are becoming more dangerous due to high vehicle use, and some jurisdictions are either banning their use as a measuring platform or requiring prohibitive traffic control measures. The use of cableways eliminates the need for USGS personnel to work from dangerous highway bridges. Cableways also allow the selection of sites that offer optimum hydraulic characteristics for measuring stream discharge.

PURPOSE AND SCOPE

This manual establishes guidelines for the design, construction, inspection, and maintenance of stream-gaging cableways for use with manned cable cars. A typical cableway is shown in figure 1. Remote, bank-operated cableways are frequently used in Europe but have not been popular in the United States. Discussion of bank-operated cableways is not included in this report.

This manual provides design criteria for structures having a clear span of 1,000 ft or less and support heights of 30 ft or less. These criteria are applicable to the majority of USGS structures, although the USGS has built a few structures that have spans approaching 2,000 ft with support towers as high as 100 ft. Should future cableways be required

that exceed the guidelines provided herein, it is strongly recommended that an experienced structural civil engineering organization, familiar with tramway structures, prepare complete site-specific design and construction specifications.

This manual is intended for use by USGS personnel who have limited structural design experience. Careful adherence to design, construction, inspection, and maintenance guidelines covered in this manual should result in a safe and serviceable structure.

WARNING.—This document deals with people and machines working together. When this occurs, safety (the freedom from, or limitation of, risk and danger) is of paramount importance. A cableway system is an embodiment of basic physical laws. It deals with high levels of energy, during both construction and operation. Therefore, improper construction techniques, maintenance, and (or) interpretation of the information contained in this document can result in serious injury or loss of life. Users of this document are cautioned to use the information contained herein only with the assistance and guidance of experienced engineers, technicians, construction and maintenance personnel, and trained inspectors.

SITE SELECTION

HYDRAULIC CONSIDERATIONS

The selection of the site for a cableway is based primarily on the hydraulic conditions of the river and the alignment and formation of the river banks. For current-meter measurements, the direction and pattern of the streamflow and the possible effect on the accuracy of the velocity observation are of major importance. Ideally, the channel should be straight at the place of measurement, and the river should flow smoothly, without eddies or cross currents. The flow should be confined to one channel at all stages; sites having overflow or diversions into old channels should be avoided if possible. Particles of drift in surface flotation should move in parallel straight lines and in a direction that is normal to the axis of the cableway. The site should be free of

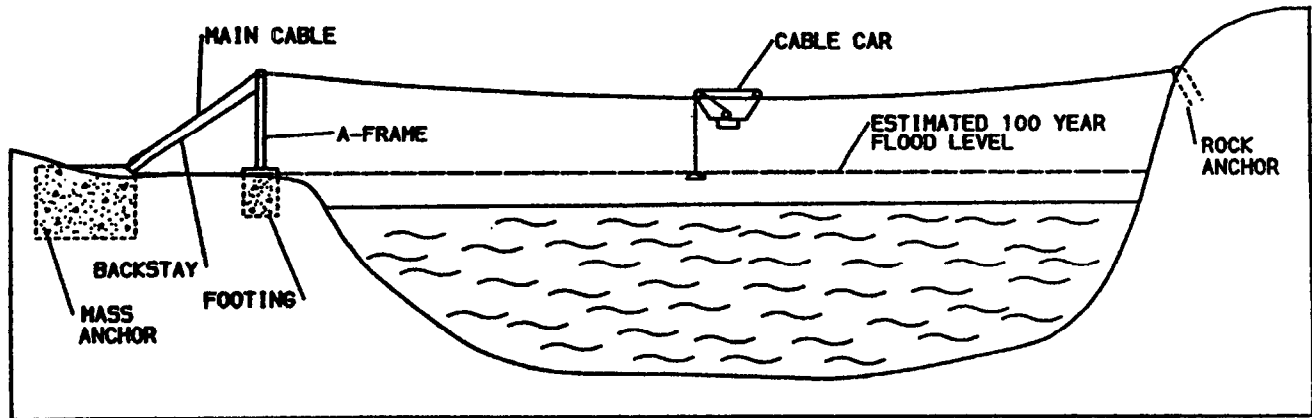


Figure 1. Typical cableway.

large rocks and boulders that cause turbulence, and the bottom should be as smooth as possible. Observation of conditions at various stages of the river, particularly at medium and high stages, before selecting a site is recommended. Reconnaissance by low-flying aircraft or boat can assist in locating good cableway sites, especially on larger rivers.

LOGISTICAL CONSIDERATIONS

Accessibility is an important consideration in the siting of a cableway. A site must be reasonably convenient for the field person who must use the structure on a frequent basis. Because most cableways will be used for making high-flow measurements, access to the site at high-water conditions is a necessity. A river stage for the 100-year flood should be estimated to determine accessibility under such conditions. A structure that is inaccessible will not serve its intended purpose.

An exception to these guidelines may be made in those situations where a cableway will be used for medium stages only and where high-water measurements will be made from highway bridges or by other means.

LEGAL AND REGULATORY CONSIDERATIONS

Attention is needed to ensure that all easements are obtained from landowners and others and that applicable permits are obtained from appropriate Federal, State, or local agencies, prior to cableway construction.

EASEMENTS

Many cableways are located on private property. Regardless of the ownership of the land, written permission to locate a cableway must be obtained before construction is begun. USGS form 9-1482 is available for this purpose.

Permission should include a right-of-way for construction, maintenance, and operation, especially if the access route crosses cultivated fields. It may take months to track down, verify, and obtain landowner permission.

U.S. ARMY CORPS OF ENGINEERS REQUIREMENTS

If the cableway is located on a river that is classed as "navigable," the U.S. Army Corps of Engineers (COE) may establish certain clearance requirements. Information about these requirements, as well as the necessary permits, may be obtained from the officer in charge of the local COE district. The permit from the COE usually specifies compliance with requirements issued by other departments of the Federal Government. These requirements must be ascertained as far in advance as possible and adhered to in the design and construction of the structure.

FEDERAL AVIATION ADMINISTRATION REQUIREMENTS

Under the Federal Aviation Act of 1958, as amended, the Federal Aviation Administration (FAA) must receive notice of construction or alteration of structures more than 200 ft in height, or of a height that exceeds other notice criteria found in Federal Aviation Regulations, pt. 77 (1975). While it is unlikely that the USGS will build structures exceeding these criteria, the USGS is encouraged to submit notice when cableways will be constructed in areas where low-flying small aircraft may be present. The notice should be on FAA Form 7460-1, "Notice of Proposed Construction or Alteration," and be sent to the appropriate FAA regional office. Notice information, including addresses of FAA regional offices, is found on the cover sheet of the notice form (see appendix I).

Notice affords the FAA opportunity to study the potential effects of proposed objects on safe use of navigable airspace. One result of the FAA's notification is the inclusion

on aeronautical charts of objects determined to be obstructions. Another result of the notification is the possible recommendation to mark and (or) light an obstruction to preserve air safety.

OTHER STATE AND LOCAL LAWS AND REGULATIONS

State or local jurisdictions may require building permits, inspections, or other approvals. Some jurisdictions may require approval prior to excavation adjacent to streambanks. Local USGS offices are responsible for obtaining applicable permits or approvals.

DESIGN CRITERIA

The major factors that influence the design of a cableway installation are the elevation of the 100-year or design flood, the elevation of the bank at each of the support and anchorage locations, the stream width, the expected loading on the cable, and the soil characteristics at the cable support and anchorage locations. As the several parts of the design are interrelated to a considerable extent, some preliminary computations may be required before the final decision is made as to the cable size and the necessary sag. Appropriate sag diagrams (included in this report) are used in the preliminary computations. The physiography of the river banks and the approaches to the cableway may determine the positions of the supporting structures and anchorages and, therefore, the length of the span and the size and shape of the footings and anchorages. If possible, these should be on ground not subject to submergence because reduced soil-bearing strength will occur.

DETERMINATION OF THE 100-YEAR FLOOD STAGE

Discharge measurements during high-flow conditions are the most important and difficult to obtain. Cableways should be designed to allow 10 to 15 ft clearance between the water surface and the loaded cable. An estimate of the 100-year flood stage should be made by using appropriate USGS techniques.

MEASUREMENT OF THE SPAN

Preliminary studies, such as the analysis of the relative economies of practicable span length-support height combinations, may be based on approximate measurements of the span. However, before making the final design computations, an exact determination of the distance between the supports and the horizontal and vertical distances from the top of each support to the corresponding anchorage connec-

tion must be made. For short spans, the distance between the supports may be measured with steel tapes or a tag line, but, for spans exceeding several hundred feet, the distance should be determined by triangulation from a carefully measured base line or by highly accurate electronic distance-measuring equipment. The base line should be approximately as long as the span, and all three angles of the triangle should be measured. If factory-installed socket connections are to be used, the measurements of the base line and the angles should be sufficiently exact to make it possible to compute the length of cable within an accuracy of 0.5 ft. To convert span distance to actual (catenary) cable length, multiplier factors of 1.0011 for 2 percent sag and 1.0024 for 3 percent sag are used.

An error in determining the length of the span results in an error in the length of the wire rope purchased. Consequently, compensating take-up adjustments must be made to achieve the required sag. The greater the uncertainty in the measurement of the span, the greater the provision required for take up.

LOADS

In structural design, the anticipated loads are the primary consideration. The structure is designed to carry those loads with an appropriate design factor. The maximum dead and live loads on a cableway in use for hydrologic data measurements can be determined.

The loads to be considered in the design of USGS cableway structures are (1) the dead-load weight of the cable, which may be the decisive or limiting load for long spans; (2) the concentrated load carried by the cable car, which includes the weight of the cable car and two people, the tension on the meter suspension cable attached to the car, and increased loads caused by debris snagged on the sounding line; and (3) loads caused by wind and ice.

The concentrated load that is carried by the cable car is critical to the safe design of the entire structure. As any experienced hydrographer knows, the greatest load is caused by snagging floating trees or similar debris during high-flow measurements. The breaking strength of the sounding cable, therefore, becomes an important component in the design load. The breaking strength of 0.125-in. sounding cable used on some B-56 and all E-53 reels is 1,600 lb. The breaking strength of 0.100-in. sounding cable used on A-55 and some B-56 reels is 1,000 lb. Because no control is practical on the type of reel used at a particular site, use of the strongest (0.125-in.) cable must be assumed, except in a limited number of canals or other special light-duty cases. Other weight assumptions used in this report include the standard USGS cable car, 170 lb; sounding reel, 50 lb; and two field persons, 200 lb each. Therefore, a "standard design" load is about 2,250 lb. Where a power

cable car may be used, a design load of 2,500 lb is appropriate. The concentrated design load is applied at the "worst case" location, the point of maximum sag.

The amount of allowable sag in the cable is also a critical design consideration. An unloaded sag of 2 percent of the span length is generally accepted and is used in the calculations that follow. A sag in excess of 3 percent of the span length can pose unrealistic difficulty to personnel operating the cable car and is not recommended.

Temperature changes will directly affect cable length, thus changing the sag and, indirectly, the factor of safety. The thermal effect is not as much a design criterion as an operational consideration. For most cableway systems, changes in temperature will not lower factors of safety below acceptable limits.

The snagging of floating debris on the sounding line may cause a substantial downstream "tugging" on the cable, which is transmitted to the cable supports (usually A-frames) as a rotational moment on the top of the support. This tugging results in a large downward force on the downstream leg of the A-frame and may cause a negative (lifting) force on the upstream leg. Calculations used to compute loads on A-frames and their footings are based on (1) the maximum cable-car load at a distance of 25 percent of span, (2) all (150 ft) of the sounding line having been played out, and (3) a water-surface-to-cable distance of 20 ft.

Wind and ice loadings were considered and were found to be negligible in comparison to snagging loads for cableways covered in this report. However, wind and ice loadings may be significant in the design of long spans or tall structures and should be carefully evaluated in site-specific designs where considered to be a factor.

SOIL CHARACTERISTICS

The design of anchorages and footings described in this report is based on soils classified as one of the two soil types described below. Consultation with USGS Water Resources Division (WRD) District personnel possessing a geology background is recommended.

The strength characteristics shown for each soil type are the minimum properties for which a soil's corresponding footings or anchorages may be used. In the event that the soil at a cableway site cannot be readily identified as containing the minimum strength characteristics of the two soil types below, consult an engineer with a geotechnical knowledge of the area before proceeding with construction. The soils shown in each description are determined on the basis of the angle of internal friction and cohesion of the soil as listed in "The Design of Foundations for Buildings" by Johnson and Kavanagh (1968).

SOIL TYPE A

Description

Clean, poorly graded and dense, well-graded gravels
Clayey or silty gravels
Medium and dense sand
Clayey or silty sand
Stiff and medium clays

Strength characteristics

Angle of internal friction (ϕ) $\geq 30^\circ$
Friction angle of concrete on soil (δ) = 20°
Unconfined compressive strength (q_u) ≥ 0.5 ton/ft²
Moist unit weight (γ) = 100 lb/ft³
Submerged unit weight (γ') = 55 lb/ft³
Moist soil allowable bearing pressure = 3,000 lb/ft²
Submerged soil allowable bearing pressure = 2,100 lb/ft²

SOIL TYPE B

Description

Loose granular soils
Wet confined silt
Soft clay

Strength characteristics

Angle of internal friction $20^\circ \leq (\phi) < 30^\circ$
Friction angle of concrete on soil (δ) = 14°
Unconfined compressive strength 0.25 ton/ft² $\leq (q_u) < 0.5$ ton/ft²
Moist unit weight (γ) = 100 lb/ft³
Submerged unit weight (γ') = 55 lb/ft³
Moist soil allowable bearing pressure = 1,700 lb/ft²
Submerged soil allowable bearing pressure = 1,200 lb/ft²

DESIGN PROCEDURES

This section provides standard designs for cableway system components. In the design of a cableway system, different factors of safety are used for its several parts. This diversity of factors is due to uncertainties in the nature of the material and the methods of its fabrication, the conditions of loading, and, in some instances, the physical conditions at the site. The parts of the structure for which individual designs are necessary are (1) the wire rope or strand, commonly called the cable; (2) the supports, which are usually A-frames; (3) the anchorages, usually embedded in the ground; (4) the footings for the supports; (5) the anchorage connections; and (6) the backstays and guys. Local conditions and uses may require special consideration in the design such that standard plans can be used only to a limited degree. A Cableway Design Summary provides documentation of these selections and must be retained in USGS WRD District files (appendix II).

CABLES

In the design process, it is necessary to consider the characteristics of each cable type in relation to the intended application. There are many cable configurations, each designed for specific purposes. The design process must include the selection of adequate design load, acceptable loaded and unloaded sag, cable and hardware size, and an economic analysis of alternatives.

CHARACTERISTICS AND APPLICATION

The material commonly referred to as “cable” within the USGS is technically known in the industry either as wire rope or as structural or tramway strand. These two types of cable differ significantly.

WIRE ROPE

Wire rope consists of three basic components; while few in number, these vary in both complexity and configuration so as to produce ropes for specific purposes or characteristics. The three basic components of a standard wire rope design are (1) the wires that form the strand, (2) the multiwire strands laid helically around the core, and (3) the core.

Wire, for wire rope, is made of several materials, including steel, iron, stainless steel, and bronze. By far the most widely used material is high-carbon steel, which is available in a variety of grades.

Steel wire strengths are appropriate to the particular grade of wire rope in which they are used. Grades of wire rope are referred to as traction steel (TS), mild plow steel (MPS), plow steel (PS), improved plow steel (IPS), and extra improved plow steel (EIP). Some manufacturers offer an even higher strength—extra, extra improved plow steel (EEIP).

The most common finish for steel wire is “bright” or uncoated. Steel wires may also be galvanized; that is, zinc coated. “Drawn galvanized” wire has the same strength as bright wire, but wire “galvanized at finished size” is usually 10 percent less in strength. In certain applications, “tinned” wire is used, but it should be noted that tin provides no sacrificial (cathodic) protection for the steel as zinc does and should not be used for USGS cableways.

Strands are made up of two or more steel wires, or a combination of steel and other materials such as natural or synthetic fibers, laid in any one of many specific geometric arrangements.

The core is the foundation of a wire rope; it is made of materials that will provide proper support for the strands under normal bending and loading conditions. Core materials include fibers (hard vegetable or synthetic) and steel. A steel core consists either of a strand or an independent wire

rope. The two most commonly used core designations are fiber core (FC) and independent wire rope core (IWRC). Catalog descriptions of the various available ropes usually include these abbreviations to identify the core type.

Lay is the term that defines the direction in which the strands pass around the core. Lang lay and regular lay are commonly used in wire rope. They can be fabricated in left or right lay; however, 90 percent of wire rope is right lay. If not fixed, the ends of lang-lay wire rope will untwist, which makes this type of wire rope unsuitable for most USGS applications. Either right- or left-regular-lay wire rope better fits USGS needs, although right-regular lay is more commonly available. Standard wire rope clips are designed for right-lay ropes.

Fiber core ropes are important for retaining lubricating oils for moving ropes. However, for USGS applications, this type of rope is not recommended; the fiber may collect and hold moisture, which may cause internal corrosion and early failure.

The preferred wire rope for most USGS cableways of 1,000 ft or less is 6 × 19 IWRC EIP (or EEIP, if available) right-regular-lay galvanized wire rope. This type of wire rope offers the best balance of durability, availability, strength, and cost for USGS applications. Other types may be used, but all features should be given careful consideration in the design process.

TRAMWAY OR STRUCTURAL STRAND

Tramway or structural cable consists of a single strand of wires. Typical construction features 19, 37, or 61 individual wires. Because the wire diameters are slightly larger than those used in typical wire rope, this type of cable is approximately 10 percent stronger than wire rope for comparable cable diameters. (A comparison of the strengths of various cable materials is presented in table 1.) However, tramway strand is less flexible than wire rope, and its supporting structures require large-radius saddle blocks. End termination must be poured spelter or resin sockets or swaged sockets. Factory installations are strongly recommended for spelter or resin sockets and mandatory for swaged sockets. The cost of tramway strand is substantially more than the cost of 6 × 19 IWRC wire rope. USGS usage of this type of cable is generally restricted to larger structures. Wire rope and structural strand construction are shown in figure 2.

DESIGN LOAD SELECTION

The selection of adequate design load is critical to reduce risks to field personnel. In addition to the obvious factors, the possibility of subsequent cableway enhancements and of major flooding must also be taken into account in the selection process. Many cableways are built

Table 1. Strength comparison for various cable materials.

[IWRC, independent wire rope core; EEIP, extra extra improved plow steel; EIP, extra improved plow steel; IPS, improved plow steel. Design load (D.L.) = catalog breaking strength (B.S.) of various galvanized materials ÷ design factor of 5]

Diameter (in.)	Structural strand		6 × 19 IWRC EEIP		6 × 19 IWRC EIP		6 × 19 IWRC IPS	
	B.S. ¹ (lb)	D.L. (lb)	B.S. ¹ (lb)	D.L. (lb)	B.S. ¹ (lb)	D.L. (lb)	B.S. ¹ (lb)	D.L. (lb)
3/4	68,000	13,600	58,100	11,600	53,000	10,600	46,000	9,200
13/16	80,000	16,000						
7/8	92,000	18,400	78,000	15,800	71,600	14,300	62,200	12,400
15/16	108,000	21,600						
1	122,000	24,400	102,400	20,500	93,000	18,600	80,800	16,200
1 1/6	138,000	27,600						
1 1/8	156,000	31,200	128,700	25,700	117,000	23,400	101,700	20,300
1 3/16	172,000	34,400						
1 1/4	192,000	38,400	158,200	31,600	143,800	28,800	125,000	25,000
1 3/8	232,000	46,400	190,800	38,200	172,800	34,600	150,400	30,100

¹From Wire Rope Users Manual (Wire Rope Technical Board, 1981) and catalogs of Bridon American Corp. and Wire Rope Corporation of America, Inc. Similar values are available from other manufacturers' catalogs.

for streamflow measurement only; additional heavier or power equipment for sediment or water-quality work may be added later and should be considered in the design. Major flooding necessitates the use of heavier sounding weights and significantly increases the risk of snagging debris. If there is any doubt as to the optimal design, consideration should be given to selection of the larger cableway system.

Cableway design load criteria are as follows:

- 1,500 lb Suitable only for cableways spanning slow-moving streams or canals with light suspension systems (A-pack or A-reels) and negligible possibility of floating drift.
- 2,000 lb Suitable for small-to-medium streams with low velocity and little chance of floating debris during peak runoff periods.
- 2,250 lb Suitable for most streamflow conditions. This system is designed for safe operations with two people in the cable car, with forces to failure (that is, the load that will break reel sounding lines (about 1,900 lb)) in suspension systems on B-56 and E-53 reels.
- 2,500 lb Suitable for heavy-duty sediment and water-quality sampling or streamflow measurements with powered cable cars.

Cableways will be designed for 2,250-lb loads except in unusual conditions. Station documentation must include justification to support installation of lighter load systems.

DESIGN SAG

Sag is defined as the vertical distance between the low point in a cable measured from a straight line between two points of support. Unloaded, or erection, sag is this distance

taking into consideration only the weight of the cable, and loaded sag is this distance with the design load applied at the point of maximum sag. In the application of a cable stretched horizontally between two anchors, the amount of allowable sag becomes a major design consideration. Decreasing the sag greatly increases the cable tension, resulting in the need for stronger cables and support and anchorage structures. Increasing the sag requires taller supports and imposes difficult operating conditions for personnel operating the system.

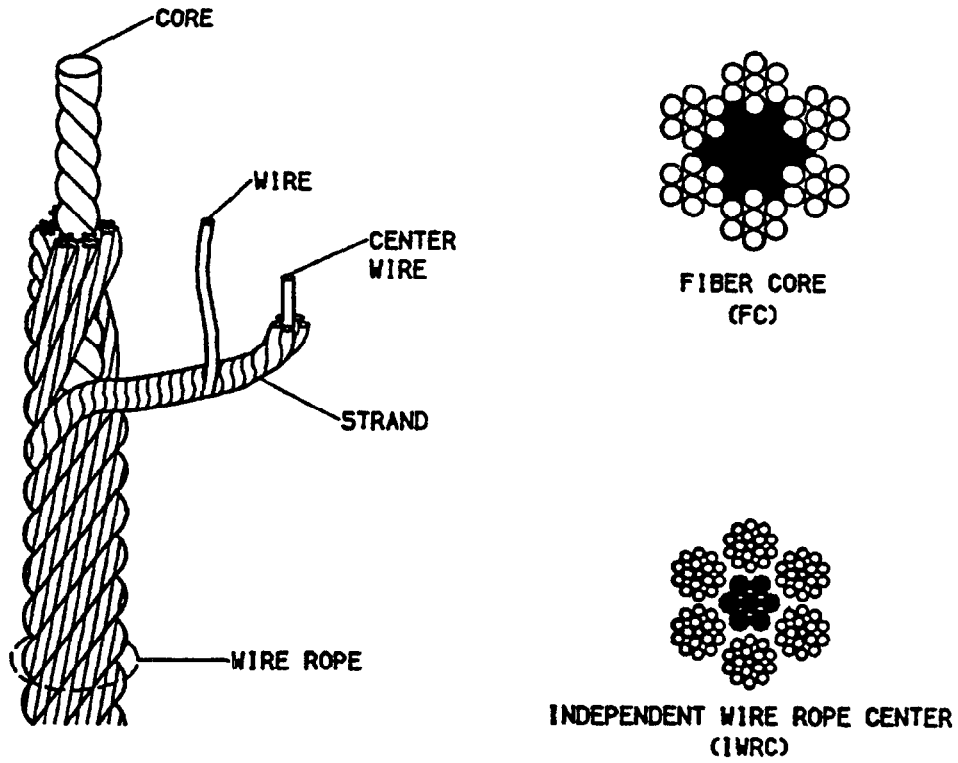
Recommended sag for cableways designed according to this report is based on an unloaded sag of 2 percent of the span. The 2 percent sag is consistent with International Organization for Standardization (ISO) (1983) recommendations and has also been adopted by the Water Survey of Canada.

NOTE.—Reducing the sag can significantly increase the tension and reduce the factor of safety.

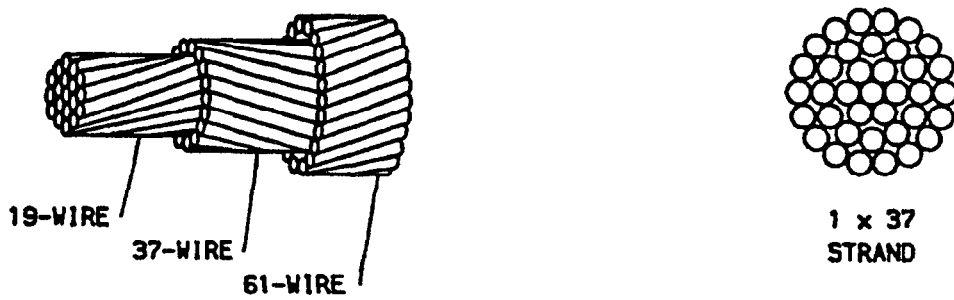
DESIGN FACTOR

Design load (tension) is defined as the cable's breaking strength divided by the design factor, previously known as safety factor.

Appropriate design factors for static cable have been suggested as 3 to 4 (Industrial Press, 1979, p. 84) and 3 to 5 (Baumeister, Avallone, and Baumeister, 1978, p. 10-35). A design factor of 5 is used in this application because of the potentially long service life—50 years or more. In the case of thimble-and-clip terminations, the strength of the termination is given as 80 percent of that of the cable. This reduction is deemed acceptable because integrity of the terminations is easily inspected.



A. WIRE ROPE CONSTRUCTION



B. STRUCTURAL STRAND CONSTRUCTION

Figure 2. Construction of (A) wire rope and (B) structural strand.

CALCULATION OF SAG

Loaded sag was calculated with the formula used by Pierce (1947). The formula is—

$$\text{Loaded sag} = \frac{(SWS + 2P)}{8H},$$

where

S = Span, in feet;

W = Cable weight per foot (from manufacturers' catalogs);

P = Concentrated load at center span; and

H = Horizontal component of tension.

This is the parabolic approximation of the basic physics relation between the cable and the load that it supports.

The calculation of unloaded sag was performed by a public domain computer program developed by the U.S. Navy (Knutson, 1987). This program has the advantage of solving the true catenary solution rather than the parabolic solution used in previous reports.

Calculations of unloaded and loaded sag were made for loads of 1,500, 2,000, 2,250, and 2,500 lb and 3/4-, 7/8-, 1-, 1 1/8-, 1 1/4-, and 1 3/8-in. diameters. The results of these calculations are presented as sag diagrams and selection guides in figures 3 through 14.

SYSTEM HARDWARE DESIGN

Sheaves, saddle blocks, and attachment hardware such as sockets, thimbles, and wire rope clips must be matched properly to the size of wire rope being used. The measurement of the size of a cable may be done with a caliper, with a wire rope gage, or by measuring the circumference and dividing by 3.1416. New wire rope may be 0 to 5 percent oversize. As cable is stretched, it will decrease slightly in diameter. A recommended measurement procedure is shown in figure 15.

A sheave must be sized for the wire rope that will be used with it. The size of a sheave's groove can be measured with a groove gage. The various dimensions of a sheave are shown in figure 16. A sheave groove that is too large or too small will not properly support the wire rope, and crushing of some wires and loss of strength will result. A properly sized sheave will support the wire rope over about 150° of its diameter. Correct, too tight, and too loose sheave-groove conditions are shown in figure 17. Bending wire rope over a small diameter sheave reduces the strength of the wire rope. The wire rope industry refers to the D/d ratio, where D is the sheave tread diameter and d is the rope diameter. A D/d ratio of less than about 10 is not recommended for stream-gaging cableways. The new standard A-frame design accommodates a sheave having an outside diameter of 12 in. and tread diameters of 9.5 to 10.5 in.

Saddle blocks must be sized to match the cable. Measurements are made in a manner similar to those described for sheaves. Industry recommendations are not published

for D/d ratios for use with structural strand. One manufacturer estimates that a D/d ratio of 100 is appropriate for application on stream-gaging cableways. The length of a saddle block must be such that the strand enters and leaves tangentially with the arc of the saddle block groove. A typical saddle block is shown in figure 18.

Turnbuckles, U-bar anchors for insertion in concrete or rock anchors, bearing blocks, and backstay cables must be sized to the main cable. This information is summarized in table 2.

There are several levels of quality of wire rope clips, thimbles, turnbuckles, eyebolts, shackles, and other attachment hardware. Field inspection indicates that poor-quality hardware has frequently been used in past installations. High-quality hardware usually is not available at hardware stores but is easily available through industrial supply houses or directly from several manufacturers. The following specifications are based on accepted industry standards for high-quality products.

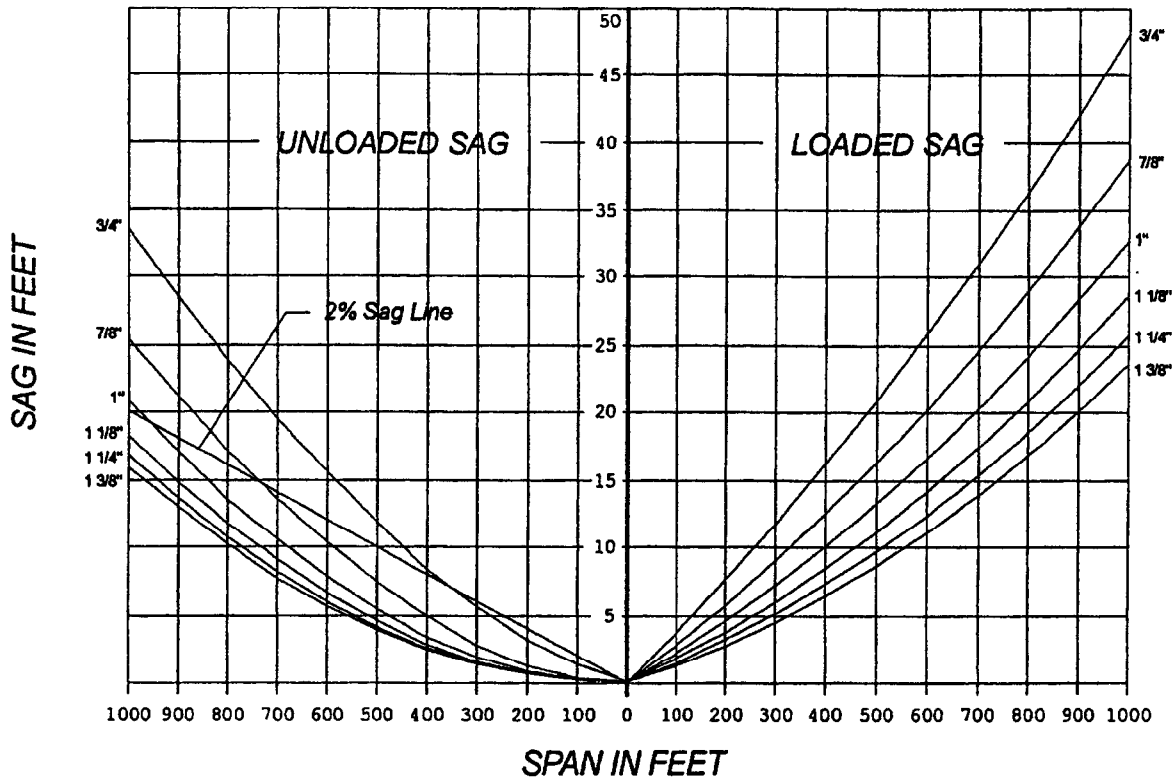
Wire rope clips must be forged steel (not malleable iron), must be galvanized to American Society for Testing and Materials (ASTM) standard A-153, and must meet Federal specification FF-C-450D, type 1, class 1. Thimbles must be heavy duty, be galvanized to ASTM specification A-153, and meet Federal specification FF-T-276b, type III.

Sockets for spelter or resin attachment must be forged; meet Federal specification RR-S-550D, type A (open) or type B (closed); and be galvanized to ASTM specification A-153.

Turnbuckles must be forged steel (not malleable iron), be galvanized to ASTM specification A-153, and meet Federal specification FF-T-791b, type 1.

U-bars must be hot formed at temperatures not to exceed 1200 °F to prevent deterioration of structural strength. Round stock must meet ASTM structural steel specification A-36, modified to 55,000 lb/in². A material certification including a certified mill test report should be obtained from U-bar fabricators. This document should be reviewed prior to acceptance to assure that correct material was used. U-bars should be X-rayed to identify material flaws. When a quantity of U-bars are purchased from a fabricator, X-ray analysis of a representative sample is considered adequate. Postforming galvanizing must meet ASTM specification A-123. Steel bearing blocks are recommended because they spread the forces over a greater area and increase the U-bar load capacity. However, U-bars have been designed to have adequate design factors without bearing blocks. Bearing blocks must be sized to U-bars and galvanized to ASTM specification A-123. U-bar and bearing block details are shown in figure 19.

Attachment of backstay cables to A-frames or other support structures is important for the stability of the cableway structure. This can be accomplished in several ways. For steel support structures, steel plate "ears," drilled to

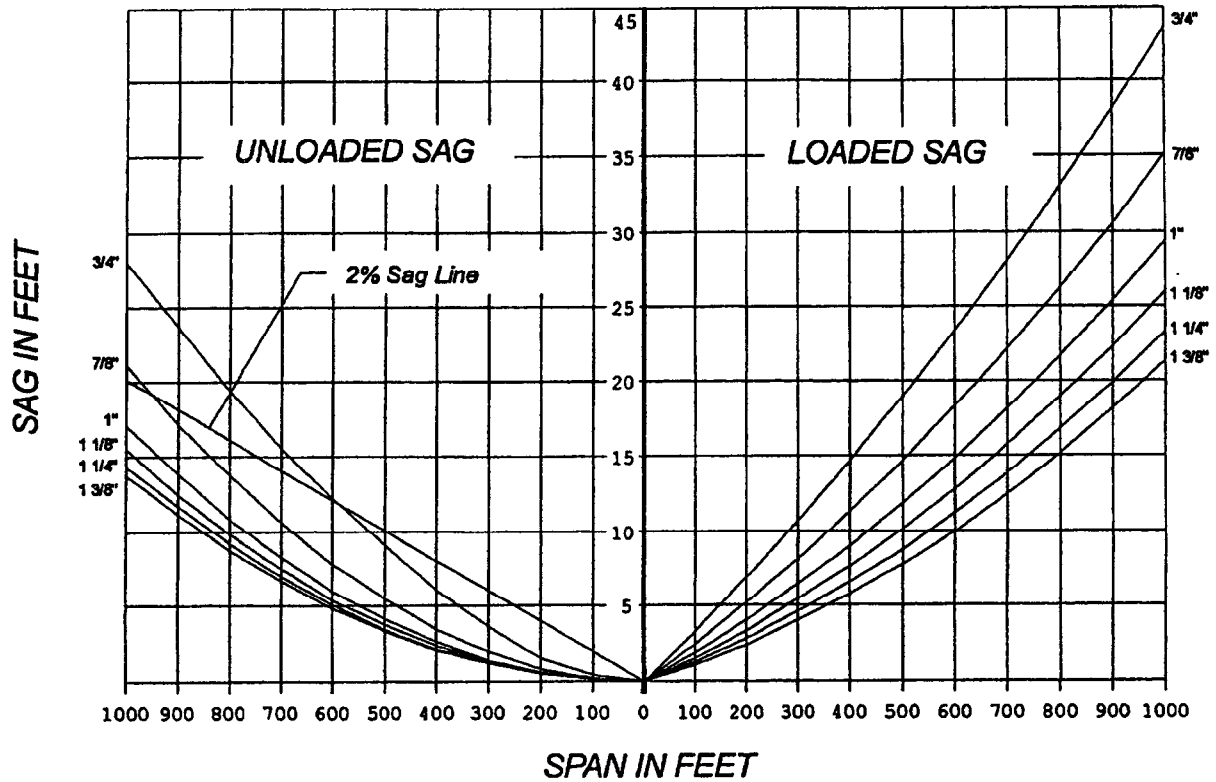


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	OK	OK	OK	OK	OK	OK
200	OK	OK	OK	OK	OK	OK
300	OK	OK	OK	OK	OK	OK
400	OK	OK	OK	OK	OK	OK
500	X	OK	OK	OK	OK	OK
600	X	OK	OK	OK	OK	OK
700	X	OK	OK	OK	OK	OK
800	X	OK	OK	OK	OK	OK
900	X	X	OK	OK	OK	OK
1000	X	X	OK	OK	OK	OK

Figure 3. Sag diagram and selection guide for 6 x 19 IWRC extra improved plow steel wire rope and cable-car load of 1,500 lb.

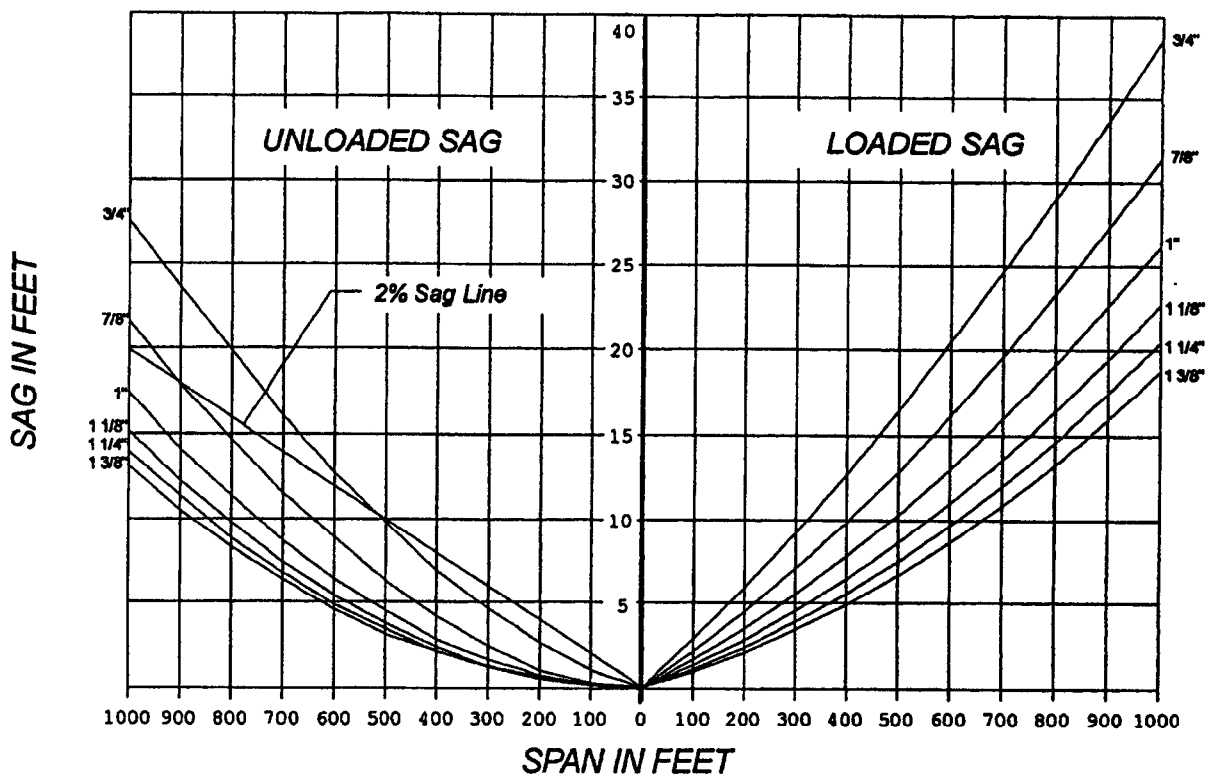


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	OK	OK	OK	OK	OK	OK
200	OK	OK	OK	OK	OK	OK
300	OK	OK	OK	OK	OK	OK
400	OK	OK	OK	OK	OK	OK
500	OK	OK	OK	OK	OK	OK
600	OK	OK	OK	OK	OK	OK
700	X	OK	OK	OK	OK	OK
800	X	OK	OK	OK	OK	OK
900	X	OK	OK	OK	OK	OK
1000	X	X	OK	OK	OK	OK

Figure 4. Sag diagram and selection guide for 6 x 19 IWRC extra extra improved plow steel wire rope and cable-car load of 1,500 lb.

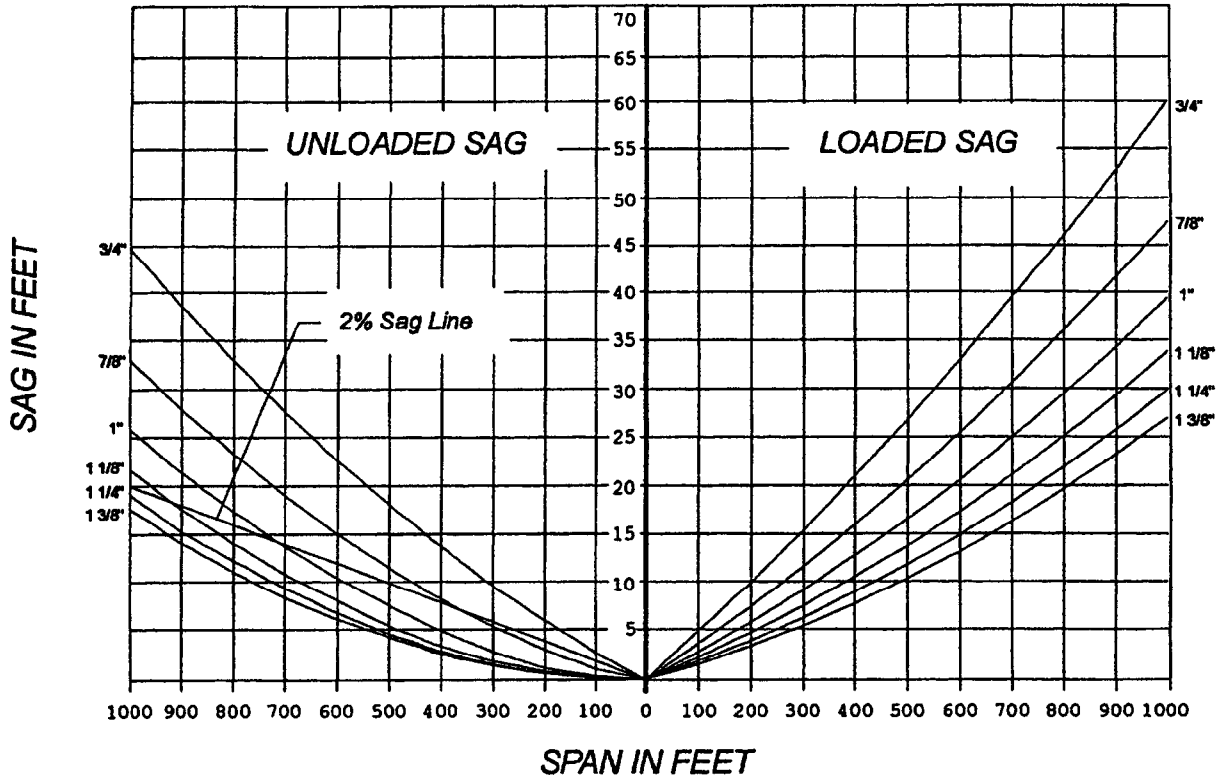


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	OK	OK	OK	OK	OK	OK
200	OK	OK	OK	OK	OK	OK
300	OK	OK	OK	OK	OK	OK
400	OK	OK	OK	OK	OK	OK
500	OK	OK	OK	OK	OK	OK
600	X	OK	OK	OK	OK	OK
700	X	OK	OK	OK	OK	OK
800	X	OK	OK	OK	OK	OK
900	X	OK	OK	OK	OK	OK
1000	X	X	OK	OK	OK	OK

Figure 5. Sag diagram and selection guide for class A structural strand and cable-car load of 1,500 lb.

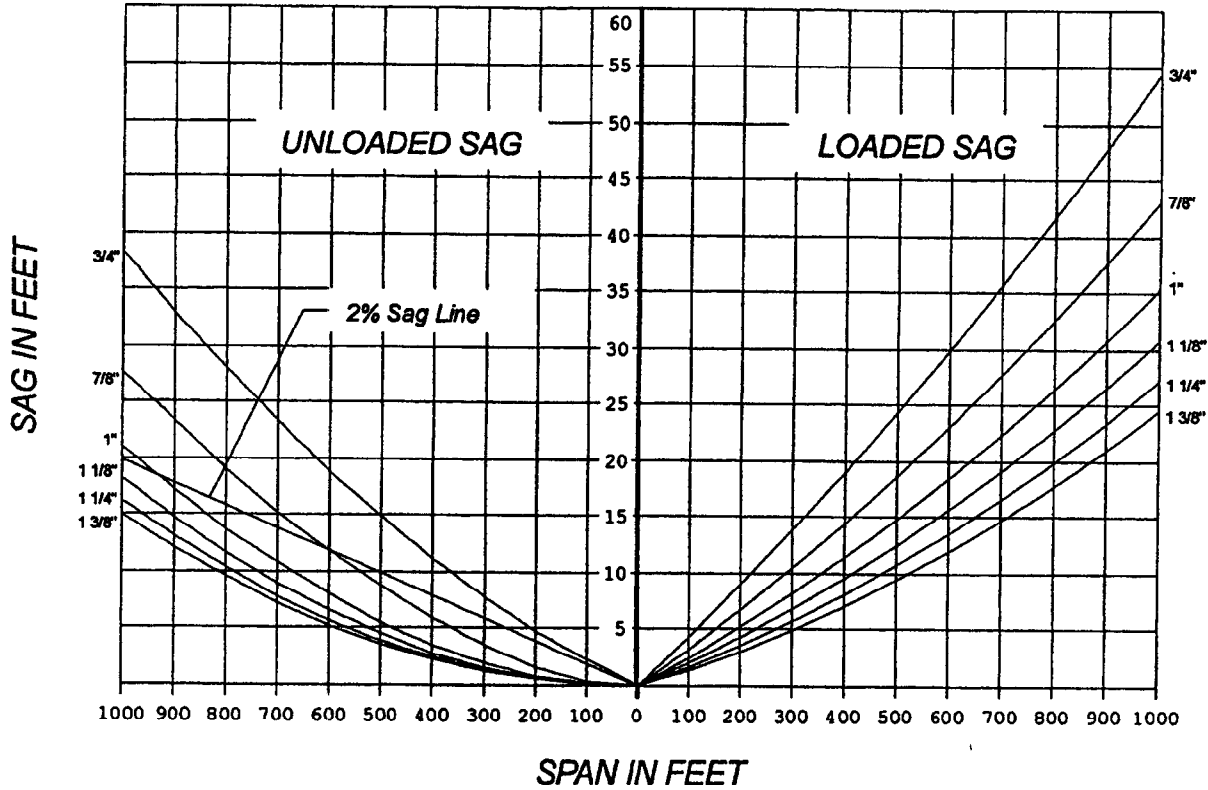


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	OK	OK	OK	OK	OK
400	X	OK	OK	OK	OK	OK
500	X	X	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	OK	OK	OK	OK
800	X	X	X	OK	OK	OK
900	X	X	X	OK	OK	OK
1000	X	X	X	X	OK	OK

Figure 6. Sag diagram and selection guide for 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 2,000 lb.

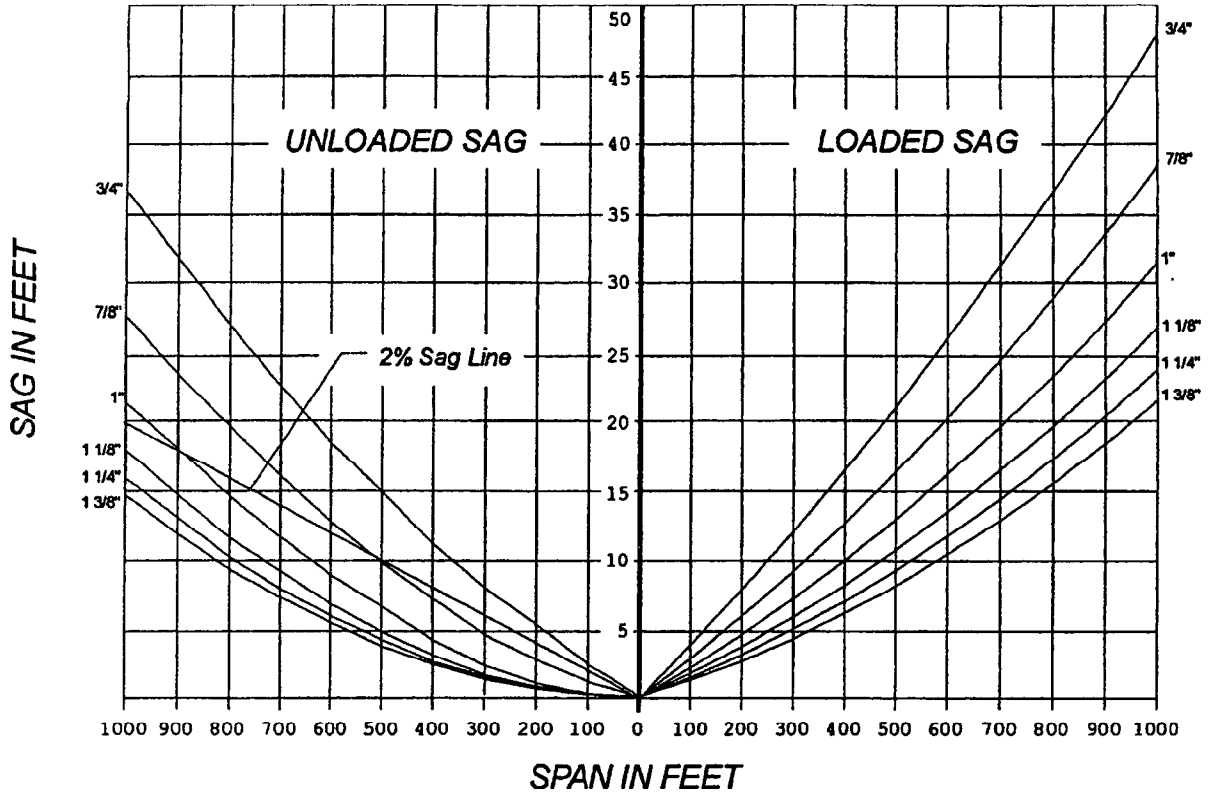


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	OK	OK	OK	OK	OK
400	X	OK	OK	OK	OK	OK
500	X	OK	OK	OK	OK	OK
600	X	OK	OK	OK	OK	OK
700	X	X	OK	OK	OK	OK
800	X	X	OK	OK	OK	OK
900	X	X	OK	OK	OK	OK
1000	X	X	X	OK	OK	OK

Figure 7. Sag diagram and selection guide for 6 x 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,000 lb.

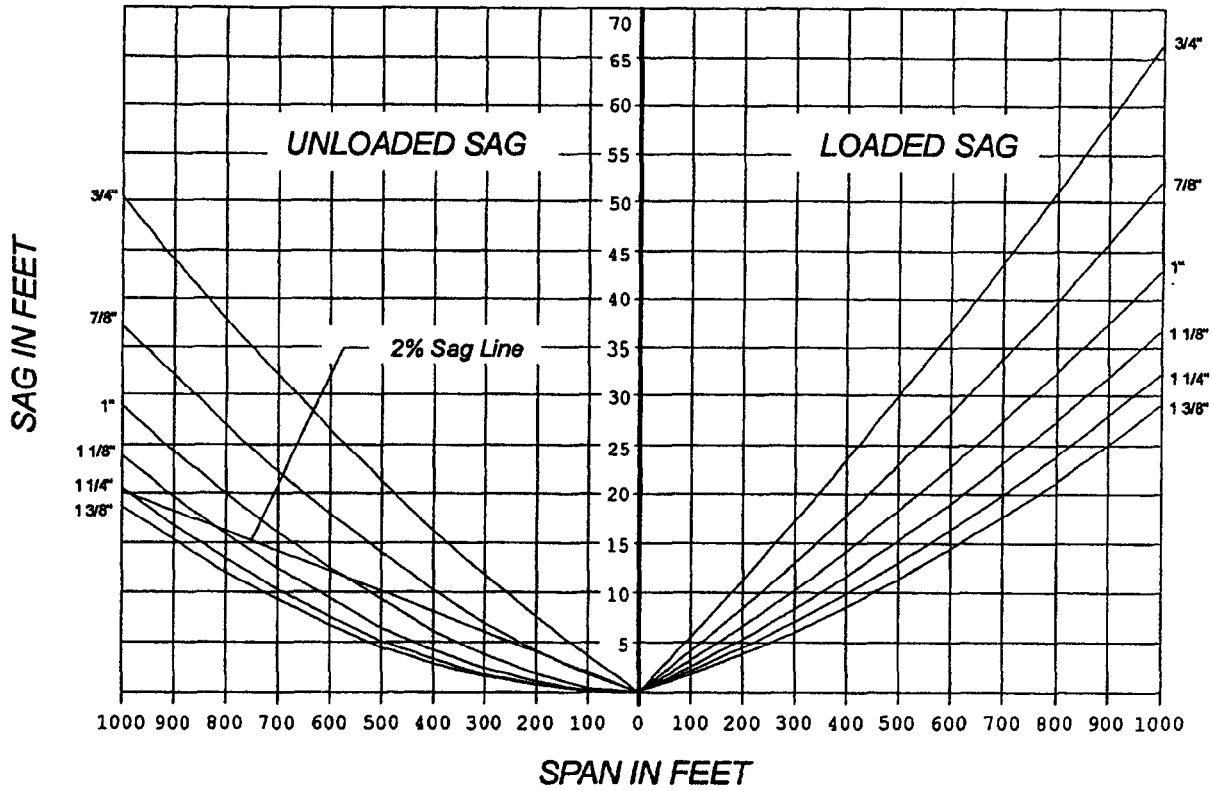


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	OK	OK	OK	OK	OK
400	X	OK	OK	OK	OK	OK
500	X	OK	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	OK	OK	OK	OK
800	X	X	OK	OK	OK	OK
900	X	X	OK	OK	OK	OK
1000	X	X	X	OK	OK	OK

Figure 8. Sag diagram and selection guide for class A structural strand and cable-car load of 2,000 lb.

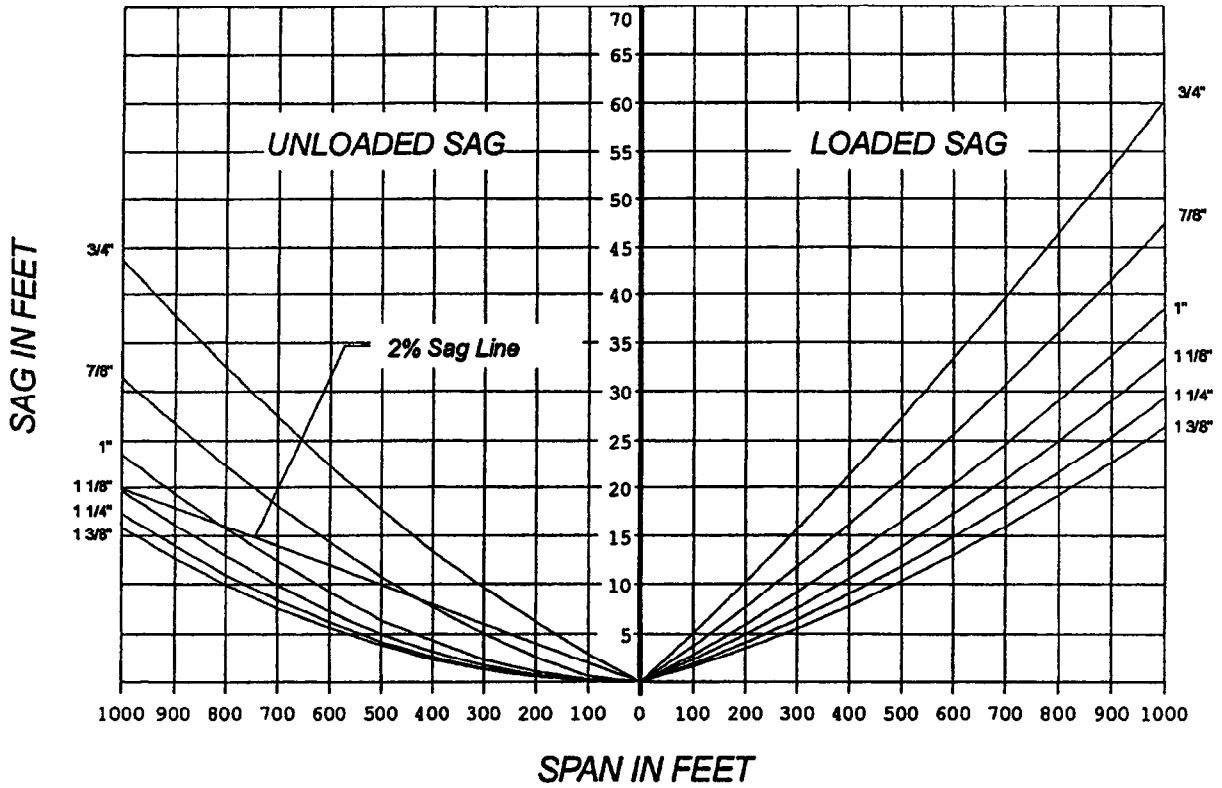


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	X	OK	OK	OK	OK
400	X	X	OK	OK	OK	OK
500	X	X	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	X	OK	OK	OK
800	X	X	X	OK	OK	OK
900	X	X	X	X	OK	OK
1000	X	X	X	X	OK	OK

Figure 9. Sag diagram and selection guide for 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 2,250 lb

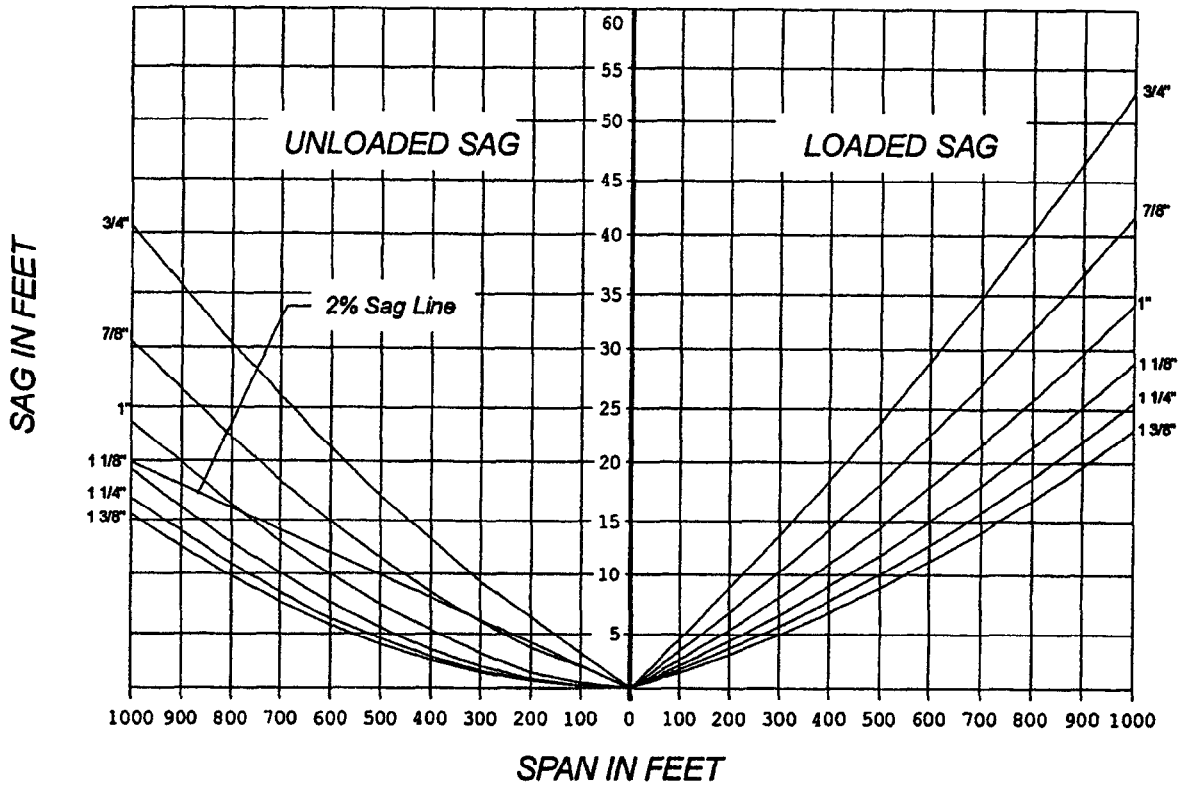


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	OK	OK	OK	OK	OK
400	X	OK	OK	OK	OK	OK
500	X	OK	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	OK	OK	OK	OK
800	X	X	OK	OK	OK	OK
900	X	X	X	OK	OK	OK
1000	X	X	X	OK	OK	OK

Figure 10. Sag diagram and selection guide for 6 x 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,250 lb..

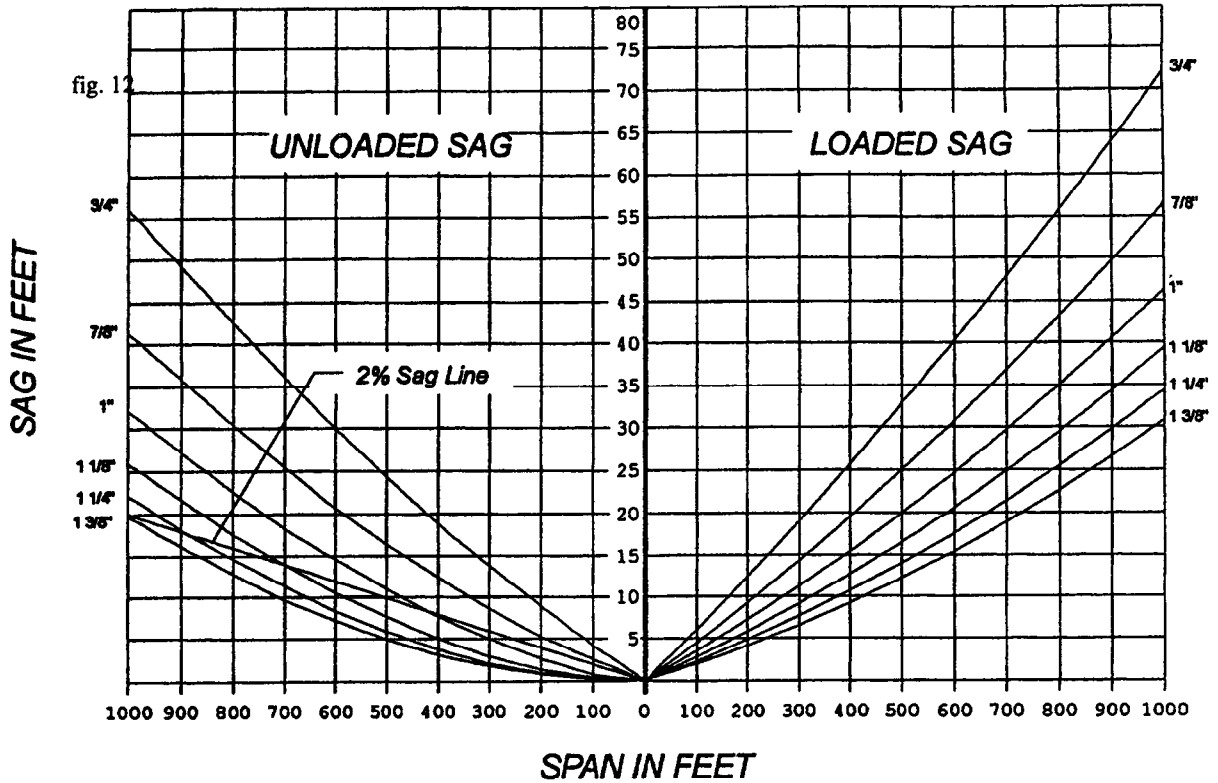


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	OK	OK	OK	OK	OK
400	X	OK	OK	OK	OK	OK
500	X	X	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	OK	OK	OK	OK
800	X	X	OK	OK	OK	OK
900	X	X	X	OK	OK	OK
1000	X	X	X	OK	OK	OK

Figure 11. Sag diagram and selection guide for class A structural strand and cable-car load of 2,250 lb.

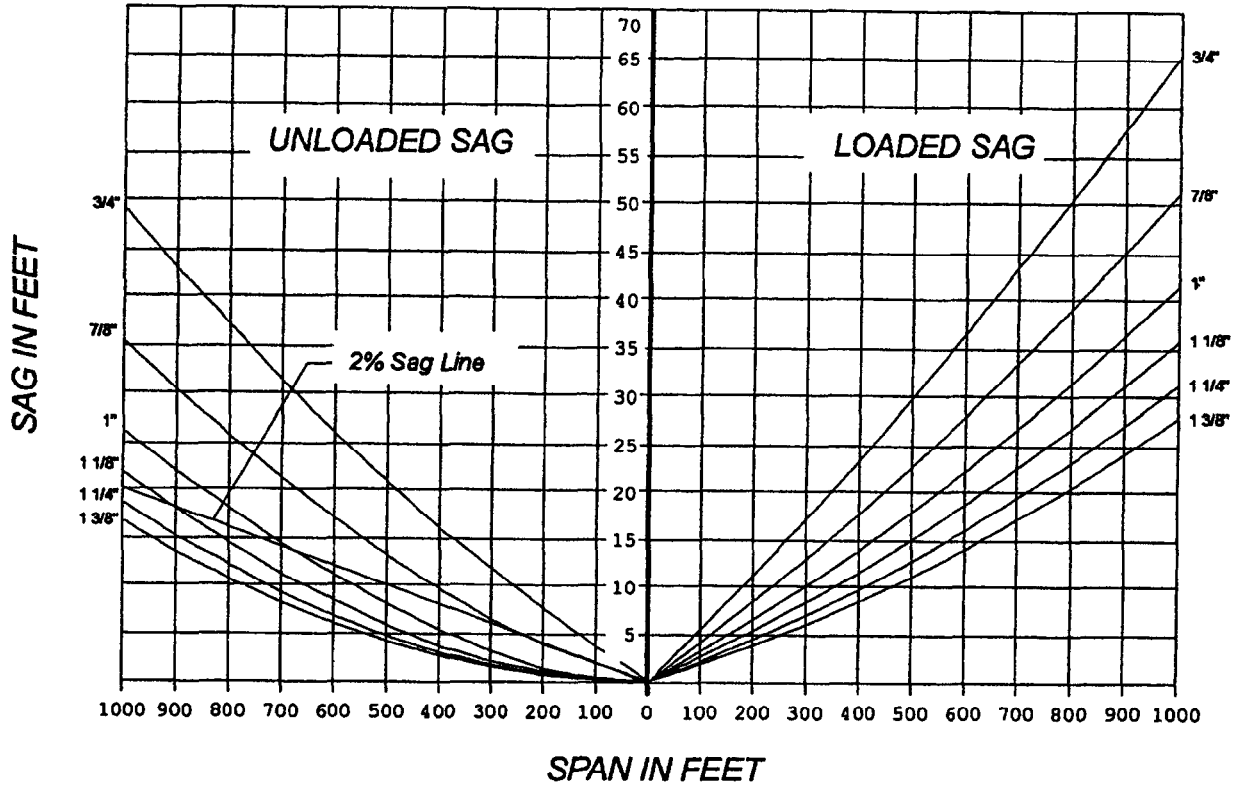


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	X	OK	OK	OK	OK
200	X	X	OK	OK	OK	OK
300	X	X	OK	OK	OK	OK
400	X	X	OK	OK	OK	OK
500	X	X	OK	OK	OK	OK
600	X	X	X	OK	OK	OK
700	X	X	X	OK	OK	OK
800	X	X	X	X	OK	OK
900	X	X	X	X	OK	OK
1000	X	X	X	X	X	OK

Figure 12. Sag diagram and selection guide for 6 x 19 IWRC extra improved plow steel wire rope and cable-car load of 2,500 lb.

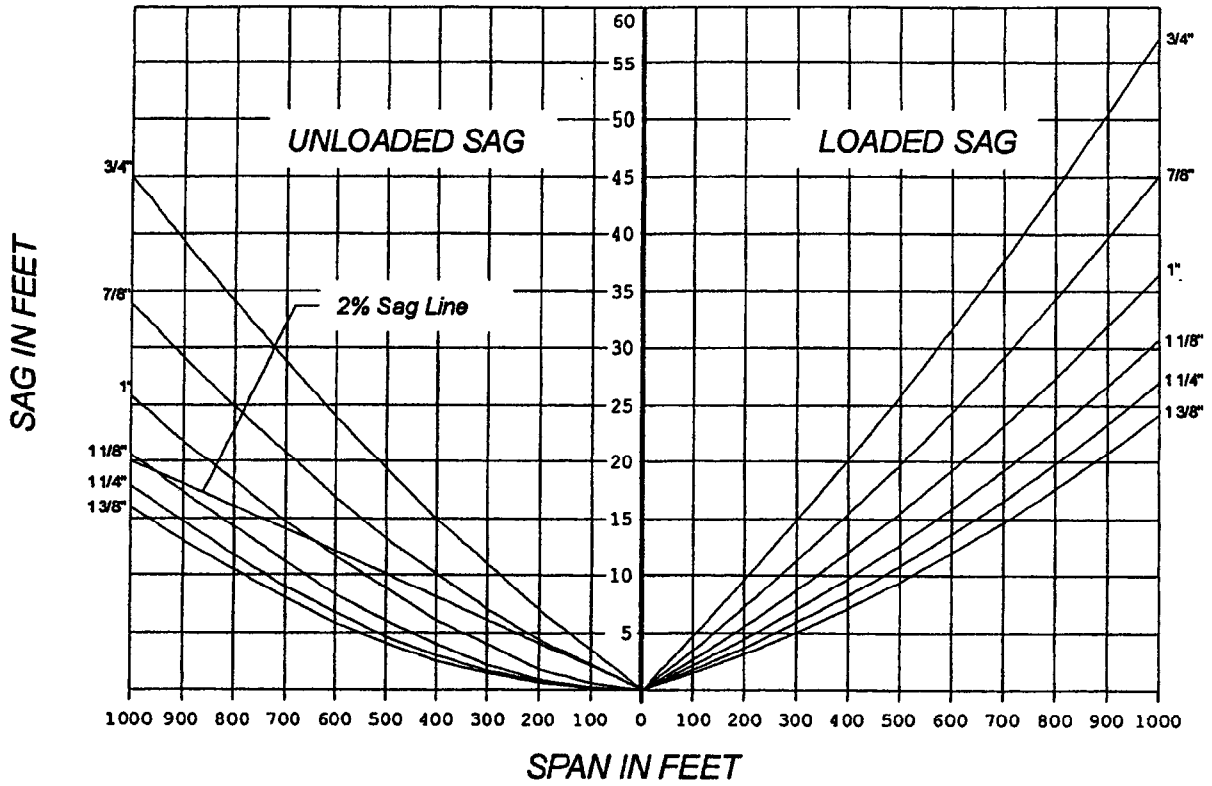


DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	OK	OK	OK	OK	OK
200	X	OK	OK	OK	OK	OK
300	X	OK	OK	OK	OK	OK
400	X	X	OK	OK	OK	OK
500	X	X	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	OK	OK	OK	OK
800	X	X	X	OK	OK	OK
900	X	X	X	OK	OK	OK
1000	X	X	X	X	OK	OK

Figure 13. Sag diagram and selection guide for 6 x 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,500 lb.



DIRECTIONS:

1. Select the desired span.
2. For unlisted spans, use the next largest span.
3. For the chosen span, use any cable diameter marked "OK".

CABLE DIAMETER	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
SPAN IN FEET						
100	X	X	OK	OK	OK	OK
200	X	X	OK	OK	OK	OK
300	X	X	OK	OK	OK	OK
400	X	X	OK	OK	OK	OK
500	X	X	OK	OK	OK	OK
600	X	X	OK	OK	OK	OK
700	X	X	X	OK	OK	OK
800	X	X	X	OK	OK	OK
900	X	X	X	OK	OK	OK
1000	X	X	X	OK	OK	OK

Figure 14. Sag diagram and selection guide for class A structural strand and cable-car load of 2,500 lb.

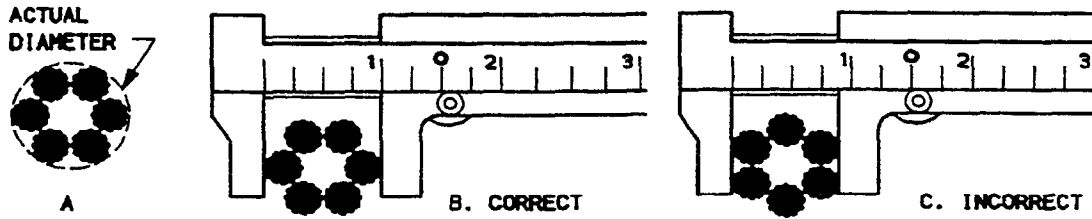


Figure 15. How to measure (or caliper) a wire rope.

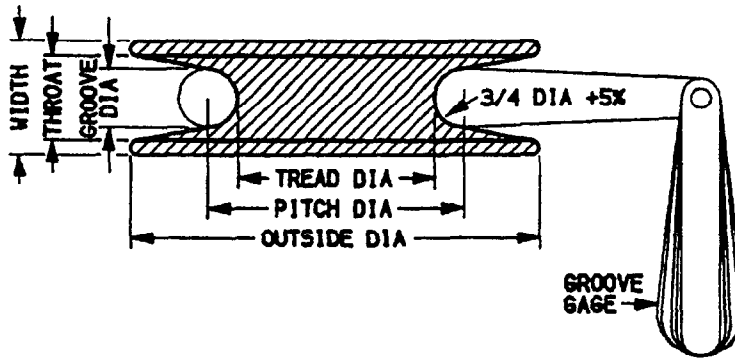


Figure 16. Various dimensions of a sheave and the use of a groove gage. DIA, diameter.

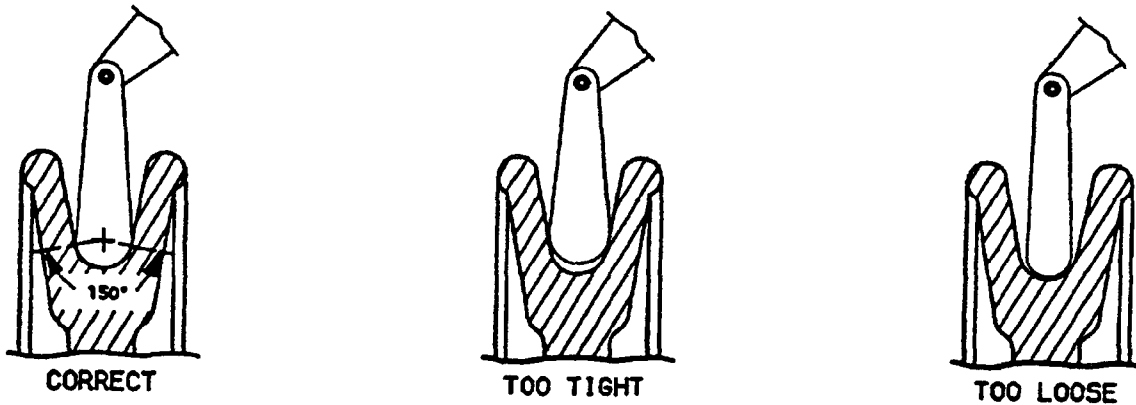


Figure 17. Cross-section sketches illustrating three sheave-groove conditions.

accommodate a steel shackle or a 1-in. or larger U-shaped round steel loop about 3 in. in radius, can be welded to a steel member below the sheave attachment. For any structure, a heavy-duty, forged, shoulder-type eyebolt may be bolted to the support structure. The eyebolt should be a minimum of 1 in. in diameter and sized to meet load requirements. (Eyebolts decrease in load capacity by 70 percent when a load is applied at 45°.) A separate attachment is required for each backstay. All fittings and connect-

ing hardware must be industrial quality and galvanized to ASTM specification A-153.

All wire rope must meet Federal specification RR-W-410. Orders for wire rope should always include a request for a "Certification of Compliance." This document certifies that a sample from the same reel or production run has been tested to breaking and that it meets or exceeds the catalog breaking strength. The certificate should be maintained with other design information in USGS WRD District files.

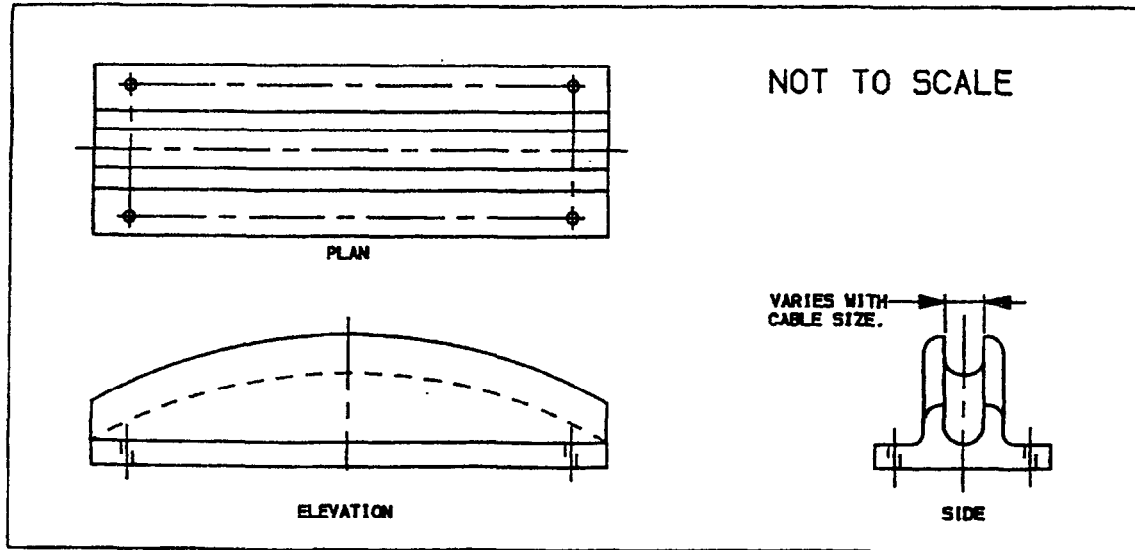


Figure 18. Typical cast-iron cable saddle block.

SUPPORT STRUCTURES

Most cableway systems require supports at each end of a cable to maintain necessary clearance above high-flow river conditions. The top of the supports should be at the same elevation. In some cases, the necessity for clearance over a railroad, highway, or other feature along one side of the river, or the desirability for greater ease of operation on the operating side, may be sufficient reason for a difference in elevation. The difference in height should not exceed 0.5 percent of the span between supports. If the support on the side where the car is stored is lower, return of the cable car will be easier. If the recommended height difference is exceeded, precautions must be taken by operators to prevent the cable car from slamming into the lower support.

A river stage for the 100-year flood should be estimated in determining the height of the structure. A structure that is too low to measure flood flow will not serve its intended purpose. The height of the cable supports should be such that, when the system is under design load and the stream is at the estimated 100-year flood elevation, there is about 10 to 15 feet of clearance between the low point of the cable and the water surface.

The type of structure most frequently used for USGS cableways is an A-frame mounted on a concrete footing. Wooden A-frames were commonly used until the 1960's when steel A-frames came into common usage.

Galvanized steel A-frames offer high strength with long-lasting and low-maintenance performance; the use of this type of A-frame is encouraged. Vertical I- or WF- (wide flange) beams are also used for vertical supports. Trees have

frequently been used, and their use is described later in this section on support structures.

FOOTINGS

Footings are required to transmit the load of the support structure, cable, and cable-car load to the ground. The size of footing required depends primarily on the total load of the structure and the bearing capacity of the particular soil type at the site. Bearing strength is diminished when the ground surface is saturated. Footings should generally extend from at least 6 in. above to 4 ft below ground surface to provide lateral stability. In areas where ground freezing occurs, the footing should extend at least 1 ft below the normal frost line. In areas of permafrost, larger and shallower footings are required to spread loads over a larger area. Where bedrock exists near the ground surface, holes should be drilled into the bedrock and pins installed to tie the footing to the rock and prevent lateral movement. At sites where ice jams or debris may be transported high up a bank or overflow channel, concrete piers may protect A-frames if the piers are several feet above ground surface and prow shaped. Anchor bolts for attaching the A-frame to footings must be set in place prior to pouring concrete. Anchor bolts must be L- or J-shaped, should not be smaller than 3/4 in. in diameter, should be galvanized to ASTM specification A-153, and should extend into the concrete a minimum distance of 30 times the bolt diameter. Concrete must meet ACI-318 (American Concrete Institute, 1984) and ASTM specification C-94. Concrete must have compressive strength of 3,000 lb/in².

Table 2. Hardware component sizes.

Cable design load ¹ (lb)	Turnbuckle size (in.)	U-bar		Auxiliary U-bar		Backstay cable diameter (in.)
		Diameter (in.)	Length (ft)	Diameter (in.)	Length (ft)	
10,000	1 1/4	1 1/8	6	1	5	7/16
15,000	1 1/2	1 1/4	7	1	5	9/16
20,000	1 1/2	1 3/8	8	1	6	7/16 (2 cables)
25,000	1 3/4	1 1/2	8	1	6	1/2 (2 cables)
30,000	1 3/4	1 5/8	9	1	7	9/16 (2 cables)
40,000	2	1 3/4	10	1	7	5/8 (2 cables)

¹Cable design load from table 1 or manufacturers' specifications.

FOOTING DESIGN

The A-frame footings that are discussed in this section are designed to provide a minimum design factor of 1.5 in saturated soil conditions. Footings were sized for soil types A and B. Footing design calculations were made for cable-car loads of 1,500, 2,000, 2,250, and 2,500 lb and for A-frame heights of 6 to 30 ft.

The footing loads for the 30-ft A-frame are not significantly greater than the footing loads for the 6-ft A-frame. Consequently, single-footing designs are given for the 30-ft A-frame for each cable size. In addition, the footings are designed for loads with the main cable at 45° from the horizontal. Footings designed for the 45° cable angle are also sufficient for the 30° cable angle.

The footing areas of the different load cases were compared. The greatest difference among the footing sizes for a given cable size is approximately 2 ft². This small variance does not warrant the use of different footings for each load case and cable size. It is recommended that the footing size be chosen on the basis of cable design load and soil type as shown in table 3.

Due to the varying base widths of the A-frames, single footings of the required sizes may be too large to remain as single footings. For this reason, combined footings were designed primarily for short A-frames. The total length of these footings is determined by adding the distance that the footing extends past each hinge of the A-frame to the base width of the A-frame.

Steel reinforcement must be used in A-frame footings for cableways. Reinforcing steel reduces cracking, which occurs due to temperature shrinkage of the concrete. Reinforcing steel placement in footings is shown in figures 20 and 21.

The shape of the footing may be square, rectangular, or round. The bearing area, however, must meet the requirements presented in table 3. The base of a rectangular footing

shall not have a side less than 2 ft 3 in. in length. Good drainage should be provided around footings to prevent erosion.

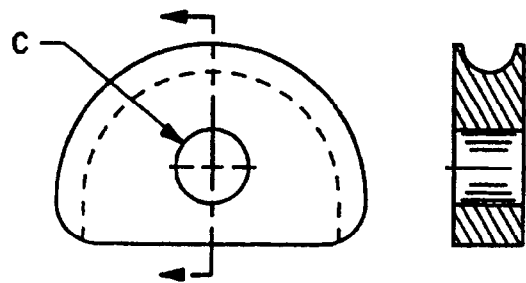
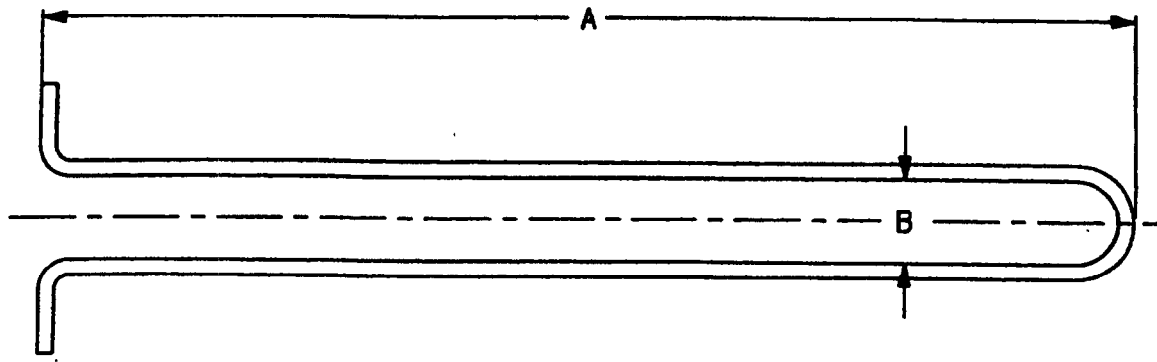
STEEL A-FRAMES

Galvanized steel A-frames are the preferred cable support device. Steel A-frames of various sizes have been developed by various offices of USGS. These designs, with minor changes, have become the USGS standard and are recommended for future installations. Drawings and specifications of USGS-approved A-frames are available on request from the Hydrologic Instrumentation Facility (HIF). A-frames fabricated from structural steel I- or WF-beams are preferred. A-frames fabricated from pipe or tubular sections are discouraged because inspection of the condition of the interior is impossible. A drawing of a typical USGS steel A-frame is shown in figure 22.

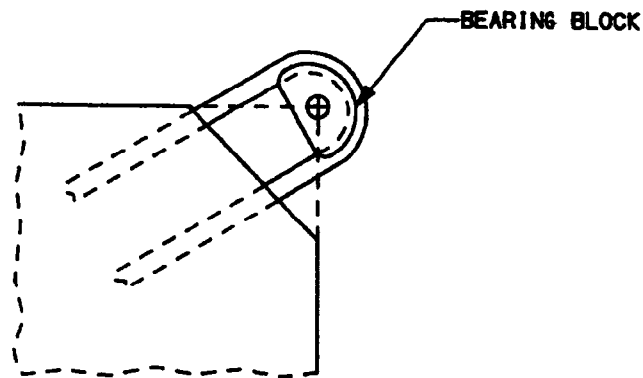
Three means of supporting the cable at the top of the A-frame may be used. The first, and recommended, method has the main cable passing over a rolling sheave and attached to an anchor. The rolling sheave is desirable because it moves as the cable moves due to use and thermal expansion and contraction.

The second method has the main cable resting in a metallic or wooden saddle. The disadvantage of this type of attachment is that movement of the cable results in sliding (with subsequent wear) between the cable and saddle. Also, the wooden saddles deteriorate relatively quickly and must be replaced. Saddles generally are used with structural strand cables because this material is adversely affected by the smaller radii of rolling sheaves.

The third method uses a main cable that is attached to the A-frame and another cable that is attached to the back side of the A-frame and also to the anchorage. The disadvantage of this third method is that the cable must be



Main Cable U-Bar Bearing Block



Anchorage Corner Assembly

Figure 19. U-bar and bearing block. Length (A) from table 2. Width (B) usually 5 to 8 in.; must match bearing block. Drill hole (C) must match turnbuckle pin diameter.

ordered with an exact length to maintain A-frames in a plumb position. This method has been used infrequently but is completely acceptable. The top of an A-frame may require modification to provide an adequate attachment for this type of connection. However, if an open socket is used for the main cable and a closed socket is used for the back-

stay segment, the A-frame sheave pin can provide an adequate attachment.

A-frames should have hinged attachments to their footings because of the considerable movement during erection and use. Fixed-leg A-frames may place extreme forces on bolts connecting the A-frame legs to the footings

Table 3. Bearing areas of footings.

[One combined footing or two single footings are required for each A-frame. For combined footings, the length is determined by adding the distance between the centers of the A-frame legs and $2 \times S$ from the table below, where S is the distance from the leg to the end of the footing. The footing width is indicated in column W . No footing shall have a side less than 2 ft 3 in.]

Cable design load ¹ (lb)	Single footing area (ft ²)	Combined footing	
		W (ft)	S (ft)
Soil type A			
10,000	5	2.5	1.5
15,000	6	2.5	1.5
20,000	7	3.0	1.5
25,000	9	3.0	1.5
30,000	10	3.0	2.0
40,000	12	3.0	2.0
Soil type B			
10,000	9	3.0	2.0
15,000	10	3.0	2.5
20,000	12	3.0	2.5
25,000	14	3.5	2.5
30,000	16	3.5	3.0
40,000	20	4.0	3.5

¹Cable design load from table 1 or manufacturers' specifications.

as the structure moves during use. A-frames up to about 15 ft in height are generally welded together in one piece. Larger sizes may be fabricated in sections and assembled on the site. All welding, drilling, punching, or other processes must be done prior to galvanizing.

Fabrication should be performed only by a shop meeting the following industry standards. Welding must be in compliance with American Welding Society Structural Welding Code AWS D1.1 (1990). Work must be performed in a shop certified by the American Welding Society or by a fabricator certified Category I, Conventional Steel Structure, by the American Institute of Steel Construction Quality Certification Program.

Galvanize steel members, subassemblies, and assemblies after fabrication by the hot-dip process in accordance with ASTM A-123. Galvanize bolts, nuts, washers, and other fasteners and hardware components to ASTM A-153. Double-dipping of components in small galvanizing tanks may yield marginal results and is discouraged. Selection of galvanizers who are members of the American Galvanizers Association is encouraged. A "Certificate of Compliance" should be requested and maintained in USGS WRD District files.

WOOD A-FRAMES

The use of wooden A-frames is discouraged because they deteriorate rapidly and must be replaced frequently. In some areas, such as national parks, wooden structures may be required to blend into a natural environment. A drawing of a typical wooden A-frame is shown in figure 23.

Where wooden structures are used, the design loads are computed similarly as done with steel. Generally 8×8-in. wooden beams will meet strength requirements for USGS structures, but calculations should be made for strength characteristics of the species of timber selected. Pressure-treated wood, which will last much longer than nontreated wood, is highly recommended. Painting of wooden structures adds to moisture retention and subsequent rotting and is discouraged. Painting may also camouflage rotted wood. Cross bracing must be bolted in place with 5/8-in. or larger bolts.

STEEL BEAMS

Steel I or WF structural shapes fabricated to single leg supports have been used as cable supports. Because these fabrications, unlike A-frames, offer no lateral stability, additional anchors must be installed on the upstream and downstream sides for guying the beam. These anchors should be approximately one-half of the length and width of appropriate main cable anchors and not less than 4 ft in depth. The entire load is carried on a single footing and, as such, requires a footing of twice the bearing area of the single footings shown in table 3. I-beam supports should be galvanized after fabrication and should meet the requirements set forth in the section on steel A-frames.

In general, the cost of this type of cable support will exceed that of an A-frame because of the cost of additional sidestays and anchorages.

TREES AS SUPPORTS

Trees have been used in many locations as cable supports. Their use is not recommended for new cableway locations. However, there may be locations where conventional structures are not practical, and large sturdy trees may be used.

Trees as supports have been used in two ways. The first is an application in which the tree supports the cable vertically and the main cable is attached to a concrete mass anchor or to the base of another tree. In this case, the loading is vertical, and little or no horizontal load is placed on the tree. A variety of sheave or other attachments have been used to attach the cable to the tree. In the second application, the cable is wrapped around the tree, and both vertical and horizontal forces are placed on the tree. The higher up

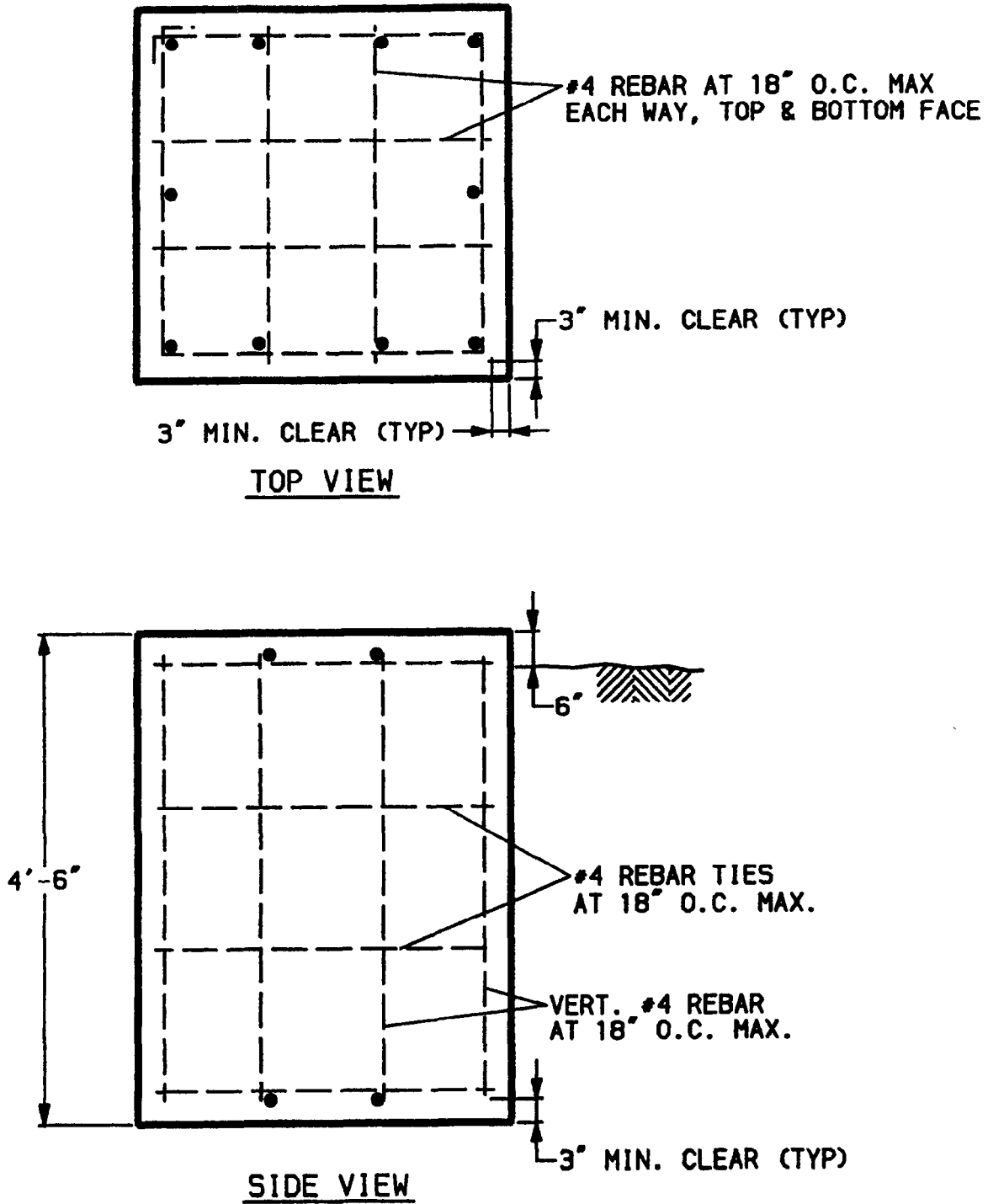


Figure 20. Single footing reinforcing bar placement. Dimensions will vary (see table 3). O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

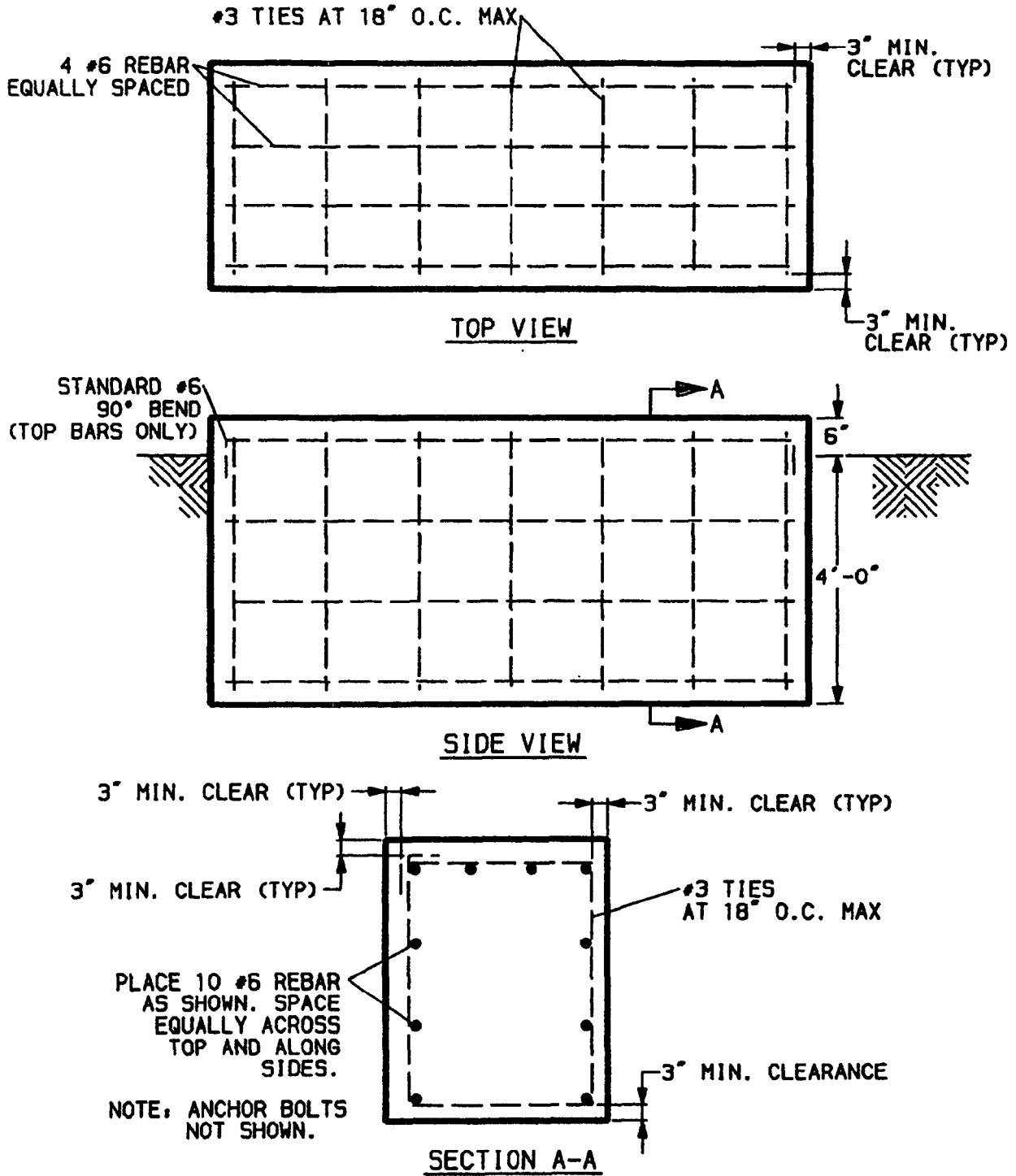


Figure 21. Combined footing reinforcing bar placement. Dimensions will vary (see table 3). O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

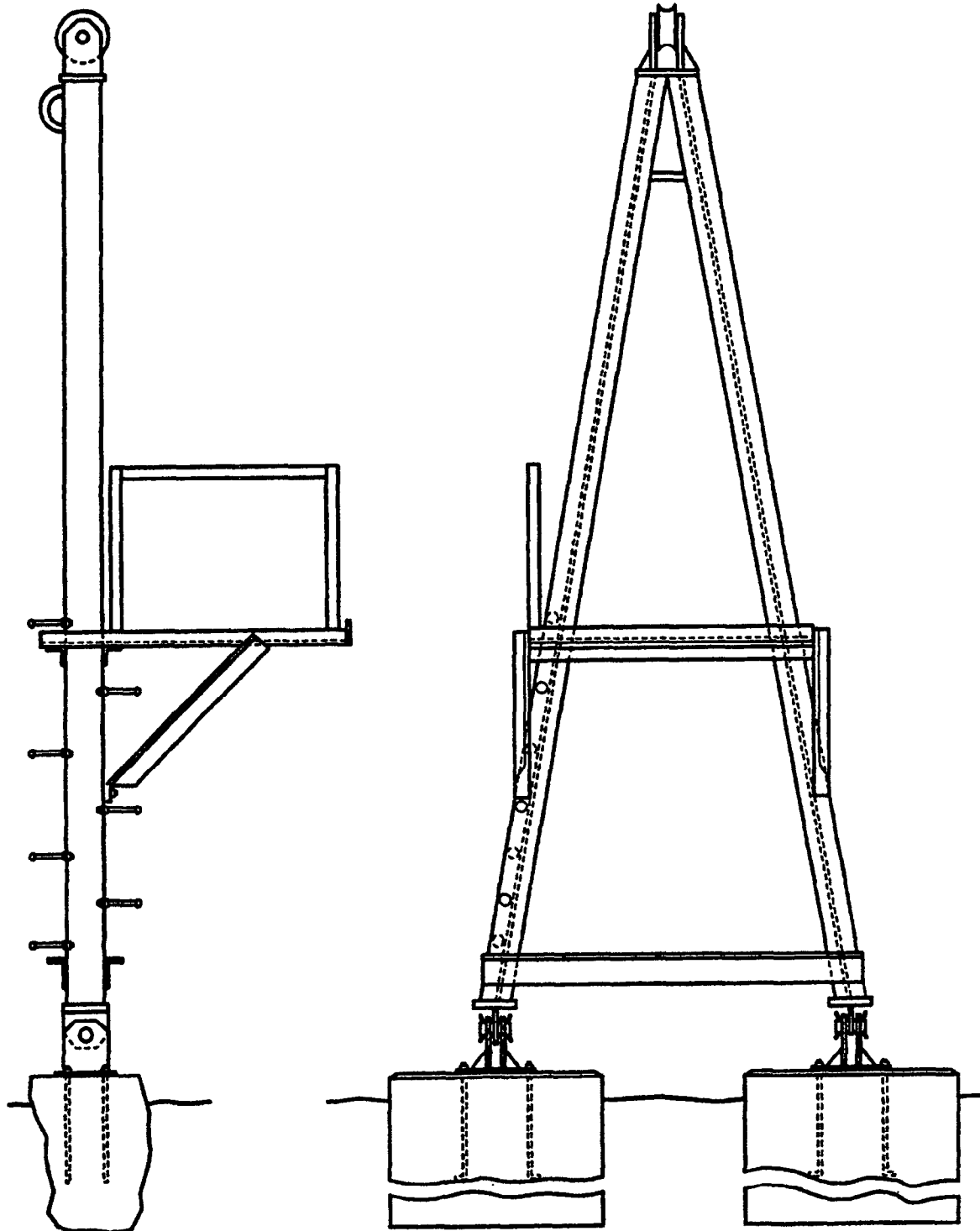


Figure 22. Steel A-frame.

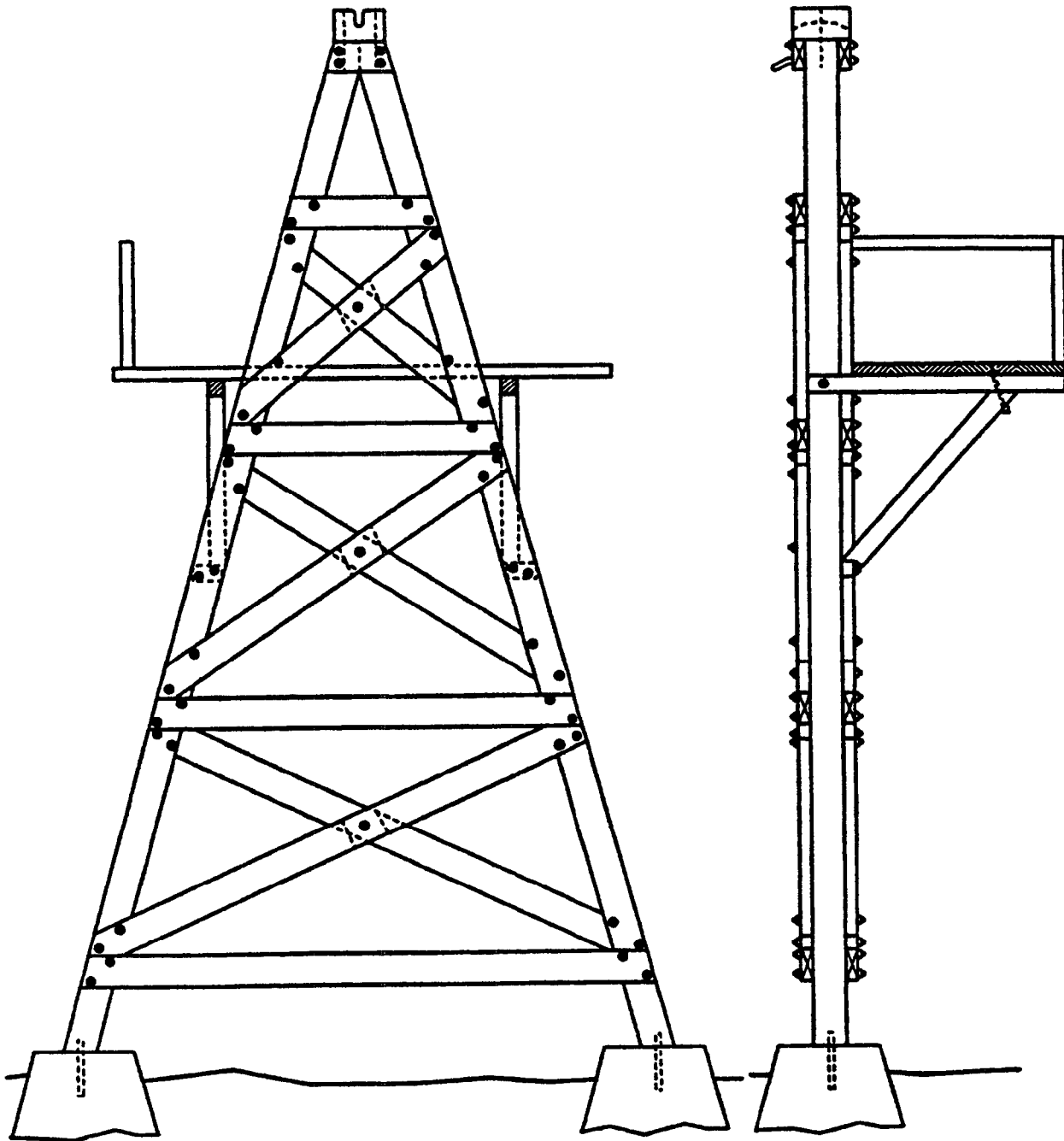


Figure 23. Wooden A-frame.

the tree that the cable is attached, the greater the bending moment that acts on the tree's root system.

When a tree is to be used as a support, there are special design considerations, which require the exercise of practiced judgment. Design and construction should be performed only by personnel with experience in using trees as cable supports. Consultation with a qualified forester may be required to evaluate a tree's health and stability. Only

large, healthy, and well-rooted trees should be considered. Care must be exercised in attachments to prevent present or future damage to the tree.

PLATFORMS, WALKWAYS, AND LADDERS

Many support structures require a ladder-type structure to reach the cable car. Platforms are required in most cases

on the cable-car storage side. The Occupational Safety and Health Act (OSHA) requires a safety railing on all platforms over 4 ft above ground level. Detailed OSHA guidelines are contained in 29 CFR (Code of Federal Regulations), pts. 1910.23 and 1910.27.

In some cases, walkways to gage shelters or down banks are required. Standard A-frame plans include properly designed platforms and railings. However, most walkways are site unique and are designed for each location. Strength and durability should be considered in the design. Galvanized steel provides long-term, low-maintenance performance. Walkways and steps should be of an open-grate, skid-resistant material. Preformed, skid-resistant, aluminum walkway material is commonly available, but caution is advised in attaching it to other metals because of galvanic action, which may rapidly deteriorate the aluminum. Wooden walkways, platforms, and ladders are discouraged, except as required for environmental or esthetic reasons. All wood should be pressure treated with preservative meeting the American Wood-Preservers' Association (1990) standard C1, designated as ACZA or CCA-C, and having retention (PCF value) of 0.40 lb/ft³ or greater. This information should be stamped on the wood or contained in a tag attached to each individual piece. Pressure-treated wood should not be painted. Fiberglass grating and support members that are light and long lasting are available.

GROUNDING FOR LIGHTNING PROTECTION

Very few USGS cableways have been grounded in the past, and lightning-induced structural damage has been negligible. Most USGS cableways use concrete anchors to provide cable tension. This mass of concrete with a long steel U-bar attached to the cable, in effect, serves as an effective ground, known as the "Ufer" ground. The Ufer technique uses foundation reinforcing bars and the moisture-retaining properties of concrete as grounds. The diameter and length of the U-bars used in USGS cable anchorages are usually adequate for carrying the energy of average lightning strikes to ground. Increased protection can be obtained by attaching the standard U-bar to anchorage reinforcement bars.

The advent of solid-state electronic sensing and recording and transmission devices in gaging stations has increased the need to provide suitable grounding procedures for instrument shelters and the electronic instrumentation. The procedures involved in protecting this instrumentation are beyond the scope of this manual. However, many cableways are near instrument shelters, and a lightning strike on the cableway system could indirectly damage electronic equipment. In these locations, or in areas of abnormally heavy lightning strikes, additional grounding procedures may be desirable. Grounding rods and wire grounds are inexpensive and effective methods of providing protection. Numerous reference materials are available that provide

detailed instructions on installation procedures for a variety of lightning-protection systems. The Standard of Practice LPI-175 (Lightning Protection Institute, 1987) provides detailed procedures.

ANCHORAGES

Anchorage are used to maintain tension in the cable. In the case of a steeply sloping topography, the anchorage may be attached directly to a cable. Most frequently, anchorages are located behind a cable support structure such as an A-frame. Anchorages must be designed to withstand safely all forces transmitted by the cableway with an appropriate design factor. Several types of cable anchors have been used and are described in this section.

CONCRETE MASS ANCHORS

Concrete mass anchors (gravity anchors) are most frequently used by the USGS. A properly designed and installed concrete anchor will last indefinitely with minimal maintenance. This type of anchor is strongly recommended. High-quality concrete can now be delivered and mixed on site nearly everywhere. However, transporting the concrete from the truck to the cableway site may require innovation on the part of the local construction crew. Even if this process is relatively costly, long-term durability and low maintenance over many years make this type of anchor desirable.

Concrete must meet ACI-318 (American Concrete Institute, 1984) and ASTM C-94 specifications. Concrete for anchors must have a minimum compressive strength of 3,000 lb/in². Reinforcing steel must have a minimum yield strength of 40,000 lb/in².

The size and shape of this type of anchor depend on the bearing and shear strength of the soil. Design considerations include the load (tension) acting on the end of the cable calculated vertically and horizontally, the coefficient of friction between concrete and various soils, the bearing strength of various soils, the weight of the concrete, and design factors against overturning and material yield stress.

In cases of submergence during high water, a buoyant effect occurs. This buoyancy dictates the use of heavier anchors. The anchor designs that follow provide for a factor of 2 for moist soil conditions and 1.5 for saturated soil conditions.

The angle of the cable from the horizontal affects the forces acting on the anchor and is therefore a significant factor in determining the size of the anchor. As the cable angle increases, the load acts downward on the A-frame and footings, and tension in the backstay increases. Angles greater than 45° are not recommended. Should angles greater than 45° be required, individual designs for foot-

ings, support structures, anchors, and backstays must be made.

The strength of various cable materials varies widely within a given cable diameter. Therefore, standard anchorages have been developed for cables of various design loads.

Standard designs for concrete mass anchors are given in figures 24 and 25 for attachment angles of 30° and 45°. Anchorage dimensions for various cable design loads are given in table 4. Spacing of reinforcing bars should be prorated depending on size but should not exceed 18 in. between bars. Placing of boundary reinforcement is critical and should never be less than 3 in. from outside surfaces. All reinforcing bars must meet ASTM specification A-615 for deformed bars designated Grade 40 or greater. U-bars in concrete anchors must always be placed in a vertical plane to minimize fatigue induced by cable vibration.

SIDEHILL ANCHORS

A sidehill anchor is a modification of a mass anchor and is designed to be built into a sloping streambank. The shape of the anchor and weight of soil on top of the concrete increase resistance to horizontal movement. The anchor must be completely buried, with the exception of the U-bar area, to work as designed. Standard designs are shown in figures 26 through 30 for design loads of 10,000 through 30,000 lb for soil type A only.

Sidehill anchors can be used only on stable slopes that have good soil and no possibility of submergence. Excavation and backfilling must be performed carefully to maintain maximum soil-bearing strength. Backfill must be placed and compacted in 3- or 4-in. layers.

T-ANCHORS

A T-anchor is a combination mass anchor and "dead-man" anchor. T-anchors are not recommended for general usage. These anchors have been used in locations where concrete placement is difficult. Excavation must be carefully undertaken to minimize soil disturbance. The placement of the forms and reinforcement bars must be precise and is therefore costly. The U-bar and main stem of the anchor must be in exact alignment with the cable. Misalignment will cause a rotational moment on the transverse load-bearing component, which then could cause cracking and a resultant strength loss. T-anchor design has been considered only for 30° applications and should never be used in locations where submergence of the anchor is likely to occur. Installations at 45° will require a deeper and larger design, which would not be practical. Standard designs are shown in figures 31 and 32. Anchorage dimensions are given in table 5 for design loads of 10,000 to 30,000 lb. U-bar diam-

eters are shown in table 2; length and shape are shown in figure 31.

ROCKS AS ANCHORS

Rock anchors are used in locations where solid rock formations are available. A rock anchor can be a steel U-bar or single-bolt-type device that either (1) is grouted into rock with expanding cement grout, epoxy or polyester resin, or other material that expands on setting or (2) incorporates a wedge-shaped expansion device that tightens as force is applied. Should the rock crack, as a result of freezing, by a change in the bond between the rock and the steel bar due to alternate loading, or by a sudden change in loading direction as a result of wind loading or a stream-gager's sounding line snagging a floating object, the connection may lose some of its strength. Many existing anchors were installed by using poured sulfur; however, this technology has generally been replaced with various resin materials.

Rock anchors generally are installed in a vertical position so that the cable tension pulls at or near 90° to the axis of the anchor. In some cases, two or more anchors are installed several feet apart, and the cable is attached to them with a metal bar or cable bridle. The design of a multianchor system requires a careful engineering analysis of all forces and selection of adequate auxiliary hardware.

Vertically installed rock anchors transmit cable tension to the rock by shear forces. Therefore, larger diameter U-bars are required than for concrete anchors. A design factor of 2 is used. Anchors should extend into solid rock for at least 3 ft, preferably 4 to 5 ft. The hole in the rock should be drilled to at least 2 in. in diameter and at least 1/2 in. larger than the U-bar or bolt diameter to allow for drilling misalignment and to allow penetration of the bonding material.

The anchor should be fabricated so that its strength is not reduced. Galvanizing of the exposed part is recommended. Grouting or epoxy or polyester resin installation must be done by experienced personnel, following the manufacturer's instructions completely. The success and safety of rock type anchors are dependent on proper installation and bonding and an accurate assessment of the stability and strength of the rock. A typical vertically installed rock anchor is shown in figure 33.

Horizontal rock anchors have been used where the cable tension pulls in a straight line. Because this type of rock anchor is in tension, it is more difficult to install and is more susceptible to failure. It is recommended that the site-evaluation, design, and installation of this type of anchor be contracted to a qualified specialist such as a mining engineering consultant. A horizontal rock anchor is shown in figure 34.

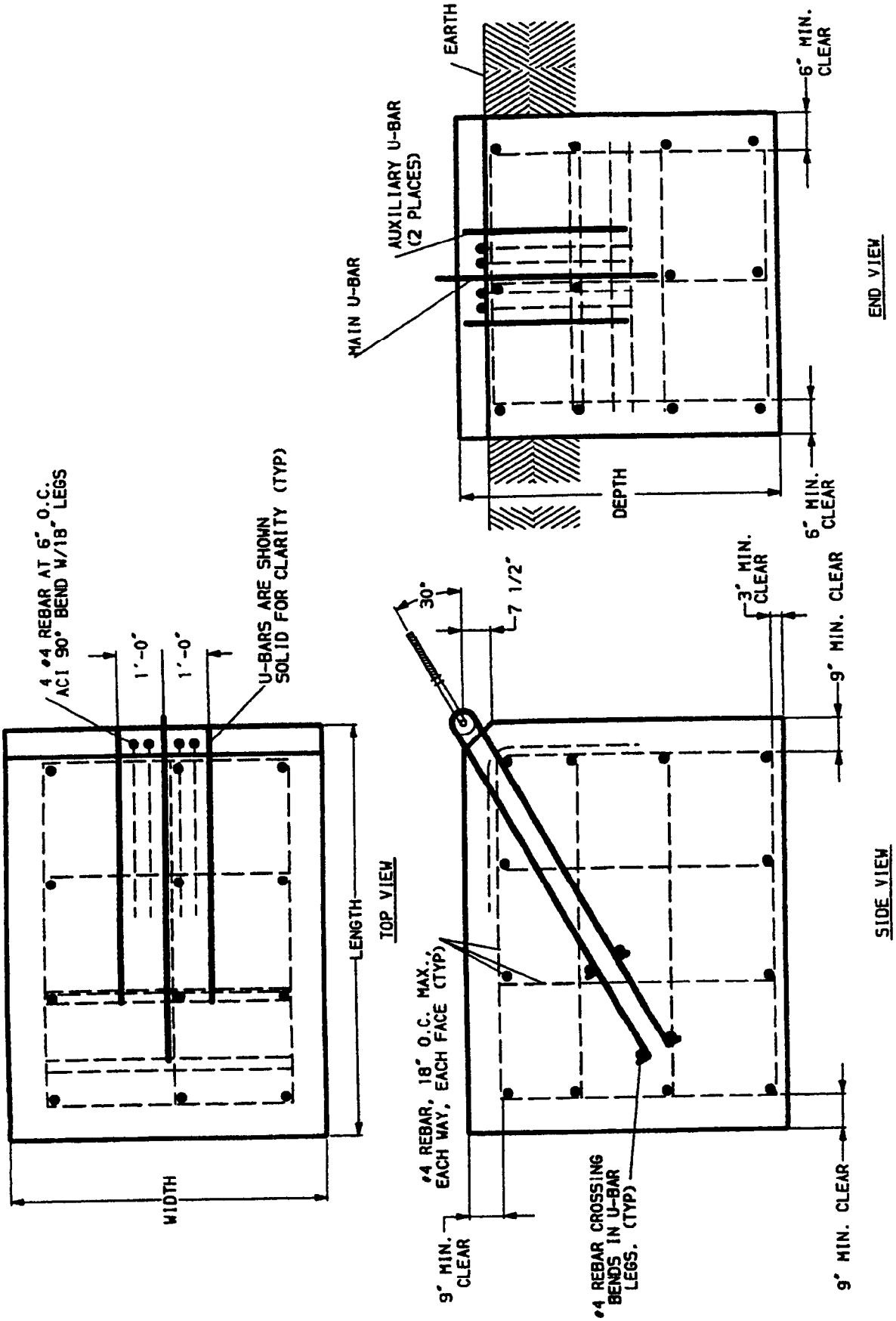


Figure 24. Anchorage for cableway positioned at 30°. O.C., on center; ACI, American Concrete Institute; TYP, typical placement; O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

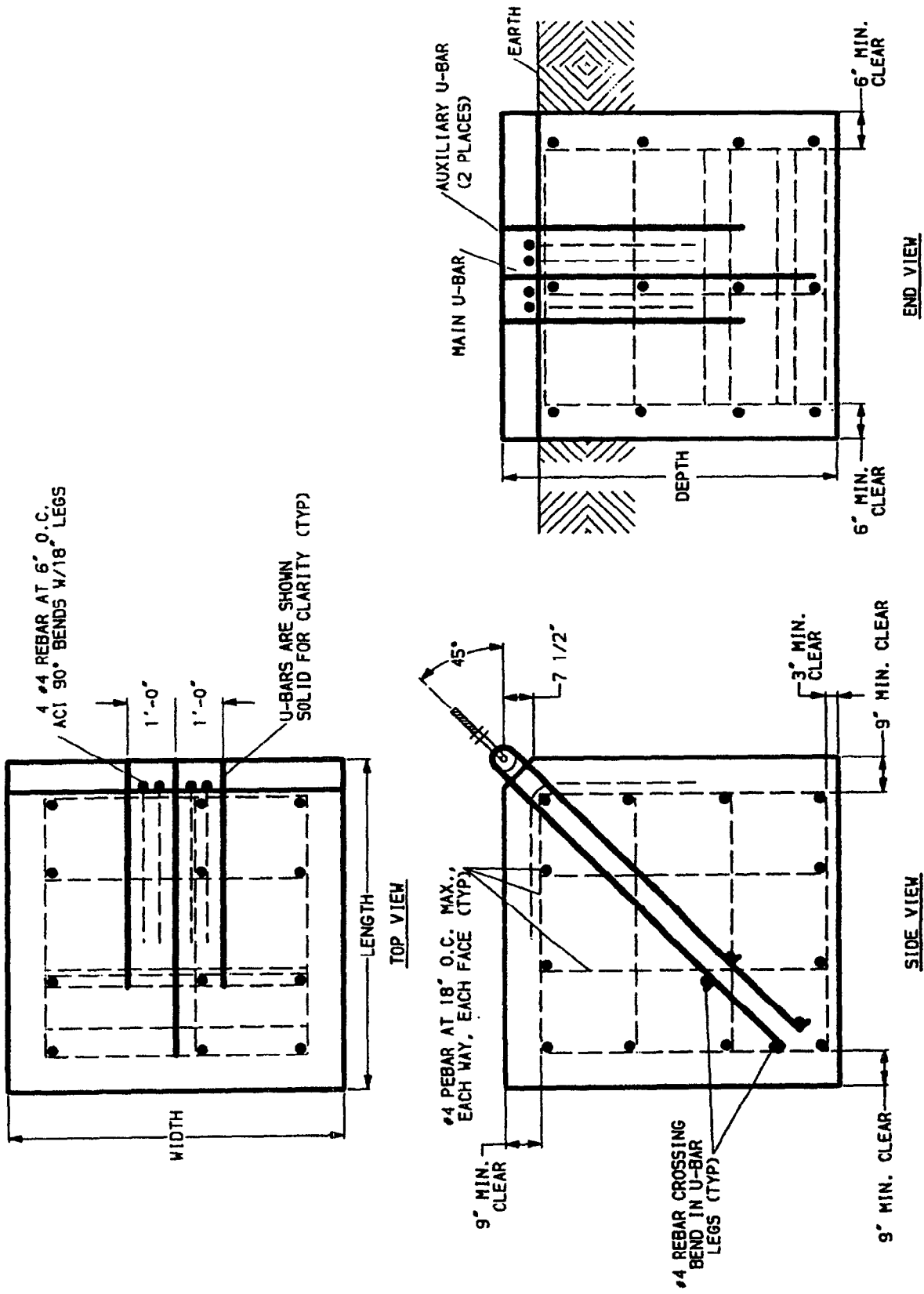


Figure 25. Anchorage for cableway positioned at 45°. O.C., on center; ACI, American Concrete Institute; TYP, typical placement; O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

Table 4. Anchorages for 30° and 45° cables.

Soil type	Cable design load ¹ (lb)	Anchorage dimensions			Concrete quantity (yd ³)
		Length (ft)	Width (ft)	Depth (ft)	
Anchorage for 30° cables					
A	10,000	6.75	5.00	4.75	6.0
	15,000	7.75	5.50	5.50	8.7
	20,000	8.50	6.00	6.00	11.4
	25,000	9.00	6.25	6.25	13.0
	30,000	9.50	6.75	6.75	16.0
	40,000	10.50	7.25	7.25	20.5
B	10,000	7.00	5.75	6.00	9.0
	15,000	7.75	6.50	6.75	12.6
	20,000	8.00	7.25	7.25	15.6
	25,000	8.50	8.00	8.00	20.2
	30,000	9.50	8.25	8.25	24.0
	40,000	10.50	9.00	9.00	30.0
Anchorage for 45° cables					
A	10,000	6.25	5.00	5.00	5.8
	15,000	7.00	5.50	6.00	8.6
	20,000	7.50	6.00	6.50	10.9
	25,000	8.00	6.50	7.00	13.5
	30,000	8.50	6.75	7.50	16.0
	40,000	9.25	7.50	8.25	21.2
B	10,000	7.00	5.50	6.00	8.6
	15,000	8.00	6.25	7.00	13.0
	20,000	8.50	7.00	7.50	16.6
	25,000	9.00	7.50	8.00	20.0
	30,000	9.50	8.00	8.50	24.0
	40,000	10.25	8.75	9.50	31.6

¹Cable design load from table 1 or manufacturers' specifications.

TREES AS ANCHORS

Trees have been used as anchors for cableways in the past. Use of trees as anchorages will be covered here only for limited applications where large healthy trees are available and installation of concrete anchors is difficult. When a tree is used as an anchorage, it may be subjected to only a horizontal force or, if the cable first passes over a structural support such as an A-frame or another tree, to both vertical and horizontal forces. Because the physics of tree root to soil have not been quantified mathematically, calculation of permissive loads on a particular tree is impossible. Differing species have root systems with substantially differing holding strength. Soil types, moisture content, and distance above ground (bending moment) that a cable is attached also affect a tree's stability.

If a tree is used, it must be a large, live, mature tree with a solid root system located in stable soil. Core borings

should be obtained if disease or decay is suspected. Since considerable judgment is required to ensure a safe installation, the design and construction should be performed only by personnel with experience in using trees as cable anchors. Consultation with an experienced forester to evaluate a tree's health and stability may be required.

BURIED DEADMEN

The use of buried timber or steel "deadmen" was once commonplace, but it is now against USGS policy to use deadman anchors because deterioration of cable and anchor material may be rapid and unobservable. Existing deadmen should be replaced with concrete anchors.

AIRCRAFT WARNING DEVICES

Aircraft warning markers usually are not required. However, some cableway locations are in remote areas where aircraft density is high and installation of markings may be desirable. Current regulations on appropriate and approved marking devices should be obtained from the FAA.

Orange spherical markers are usually suitable for USGS cableway marking. A 3/8-in. 6 × 19 IWRC or similar wire rope is adequate support for spans to about 500 ft. For greater spans, use a 1/2-in. wire rope. The support cable, sometimes referred to as a messenger cable, should be mounted about 3 ft above the main cable. This cable should have about the same sag as the main cable. An aircraft warning system places additional dead and live loads on the cable support components and anchorages and must be included as part of the design. Additional backstays and U-bars may be required. Markers should be spaced about 200 ft apart or as otherwise directed by current FAA regulations. There are no standard plans for modifications to support structures such as A-frames for aircraft warning markings.

Painting of cable supports for aircraft warning is not required except in unusual circumstances. Contact the FAA for guidance as required.

CABLE CARS

Two styles of manually propelled fabricated aluminum cable cars are commonly used by the USGS. One is a sit-down-type car with space for two field persons. The sit-down style is 60 in. long, 21 in. wide, and approximately 55 in. from footrest to cable. The other is a standup-style car, 52 in. long, 27 in. wide, and 73 in. from floor to cable. Two persons can work in the standup cable cars. Both cable car types are provided with an integral reel mount, which will accept all standard sounding reels. Both models are equipped with a follower brake to hold the car in place dur-

EXPLANATIONS.

THIS ANCHORAGE IS NOT RECOMMENDED FOR SUBMERGENCE OR TYPE B AND POORER SOILS. SUBMERGENCE AND POOR SOILS REQUIRE A SITE SPECIFIC DESIGN.

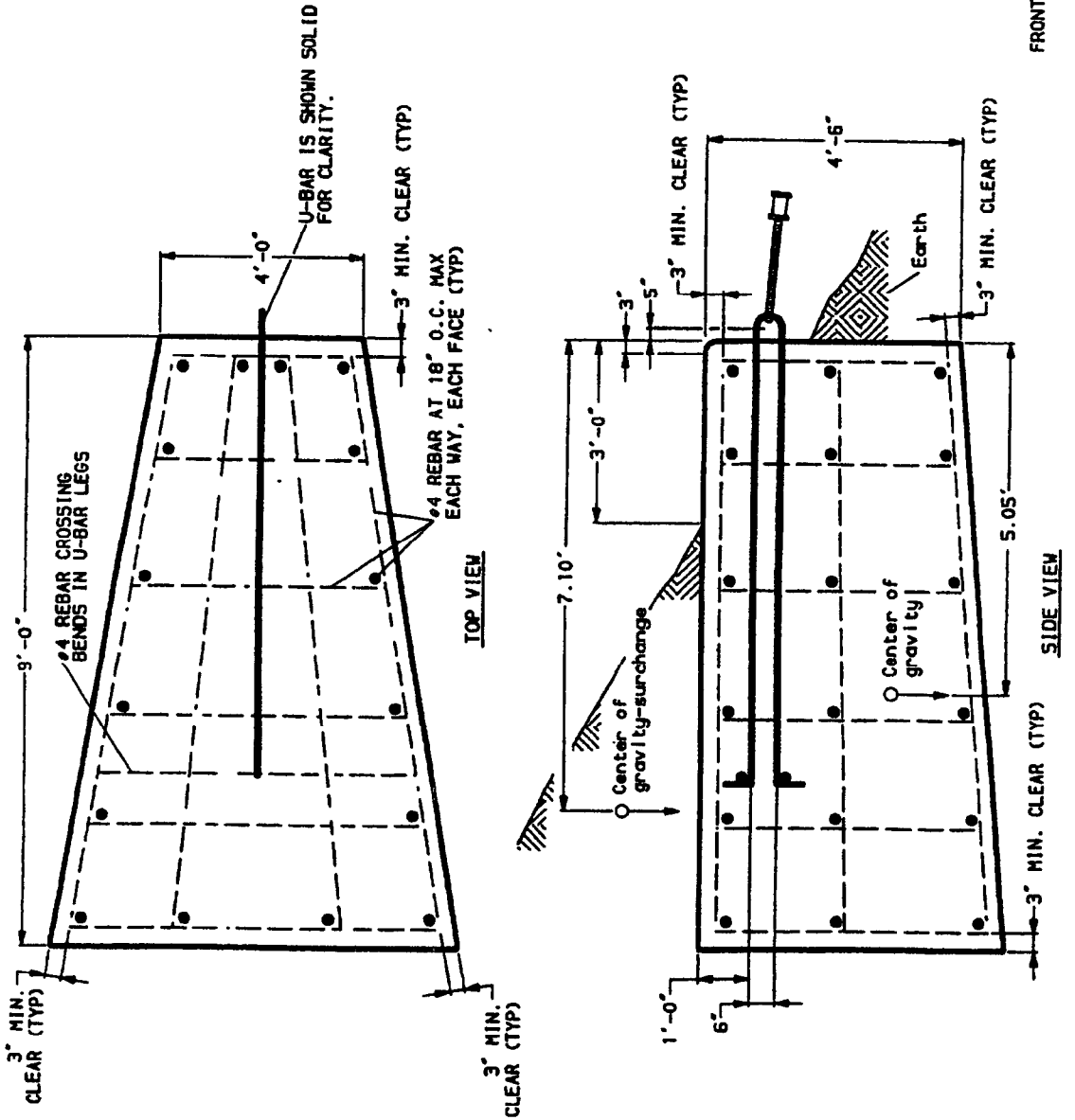


Figure 26. Sidehill anchorage for 10,000-lb design load. O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

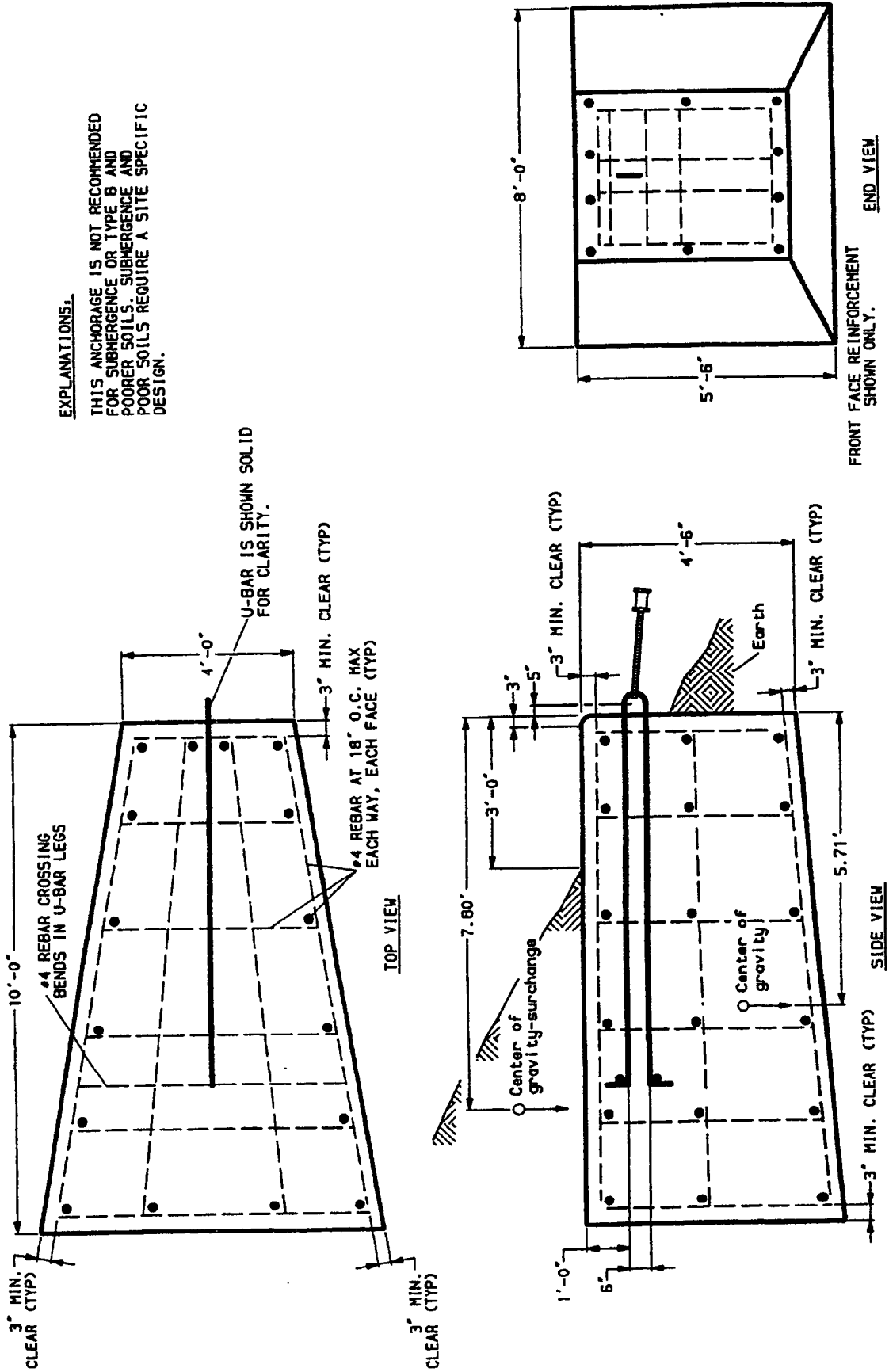


Figure 27. Sidehill anchorage for 15,000-lb design load. O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

EXPLANATIONS:

THIS ANCHORAGE IS NOT RECOMMENDED FOR SUBMERGENCE OR TYPE B AND POORER SOILS. SUBMERGENCE AND POOR SOILS REQUIRE A SITE SPECIFIC DESIGN.

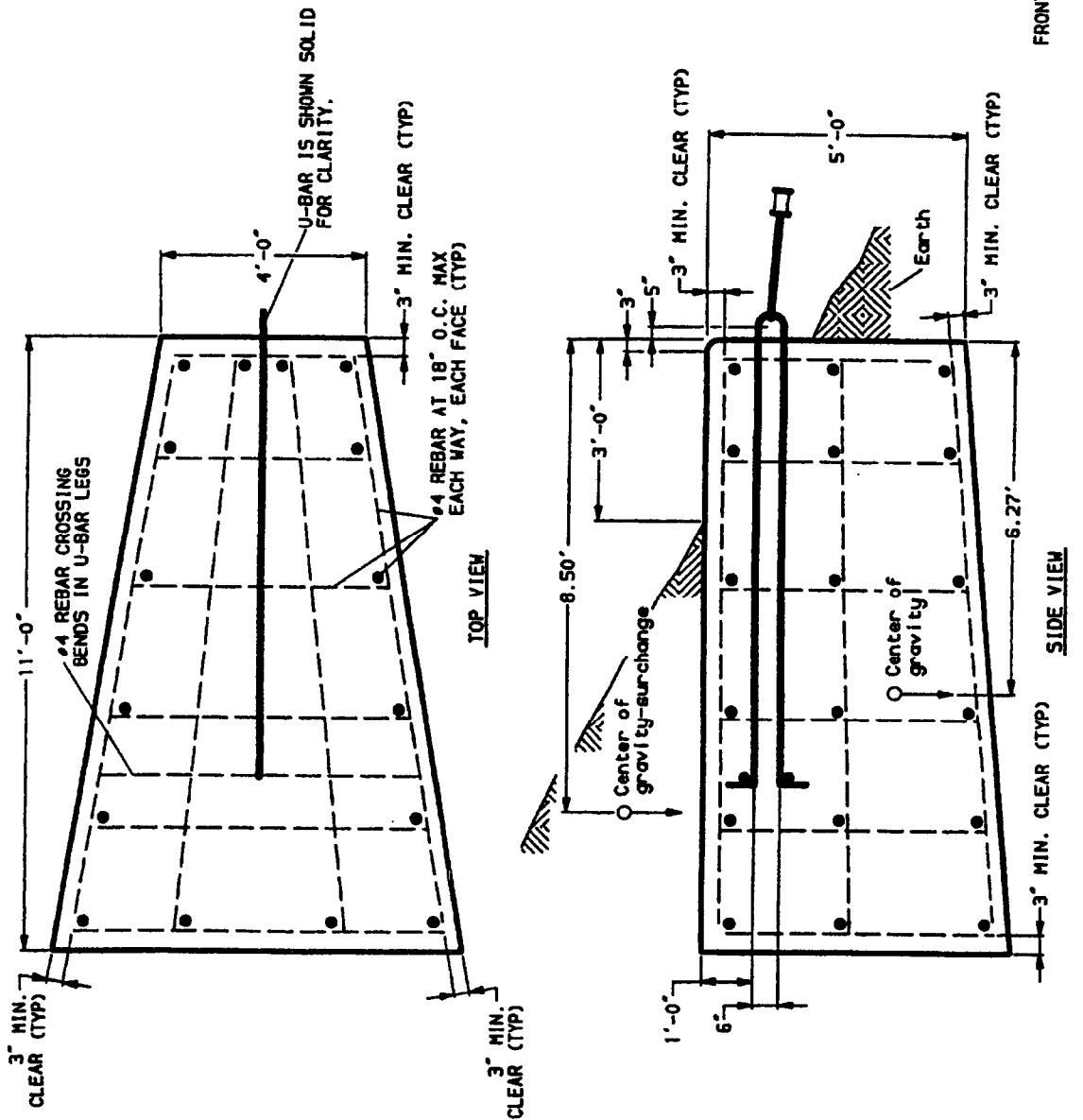


Figure 28. Sidehill anchorage for 20,000-lb design load. O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

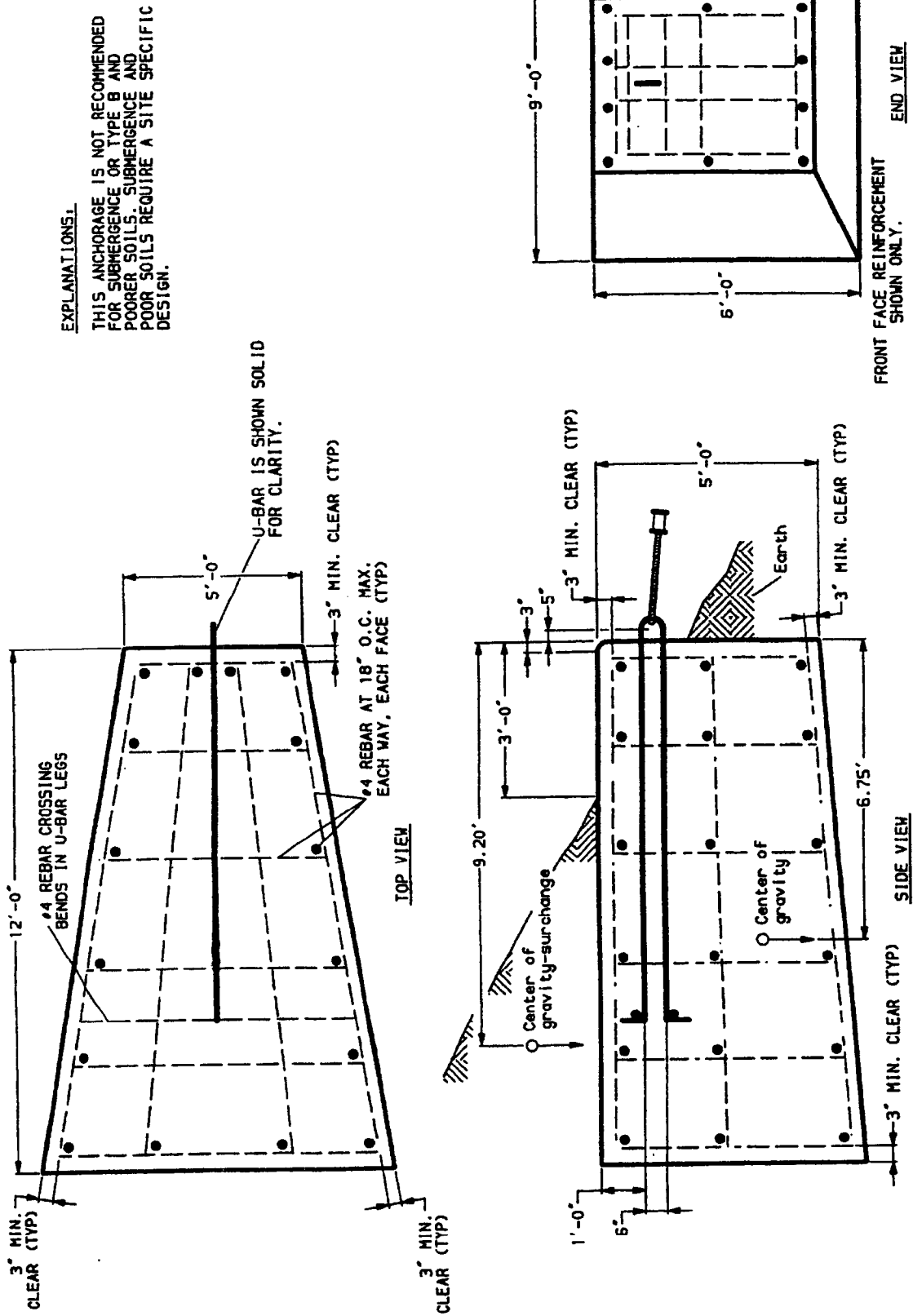


Figure 29. Sidehill anchorage for 25,000-lb design load. O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

EXPLANATIONS.

THIS ANCHORAGE IS NOT RECOMMENDED FOR SUBMERGENCE OR TYPE B AND POOR SOILS. SUBMERGENCE AND POOR SOILS REQUIRE A SITE SPECIFIC DESIGN.

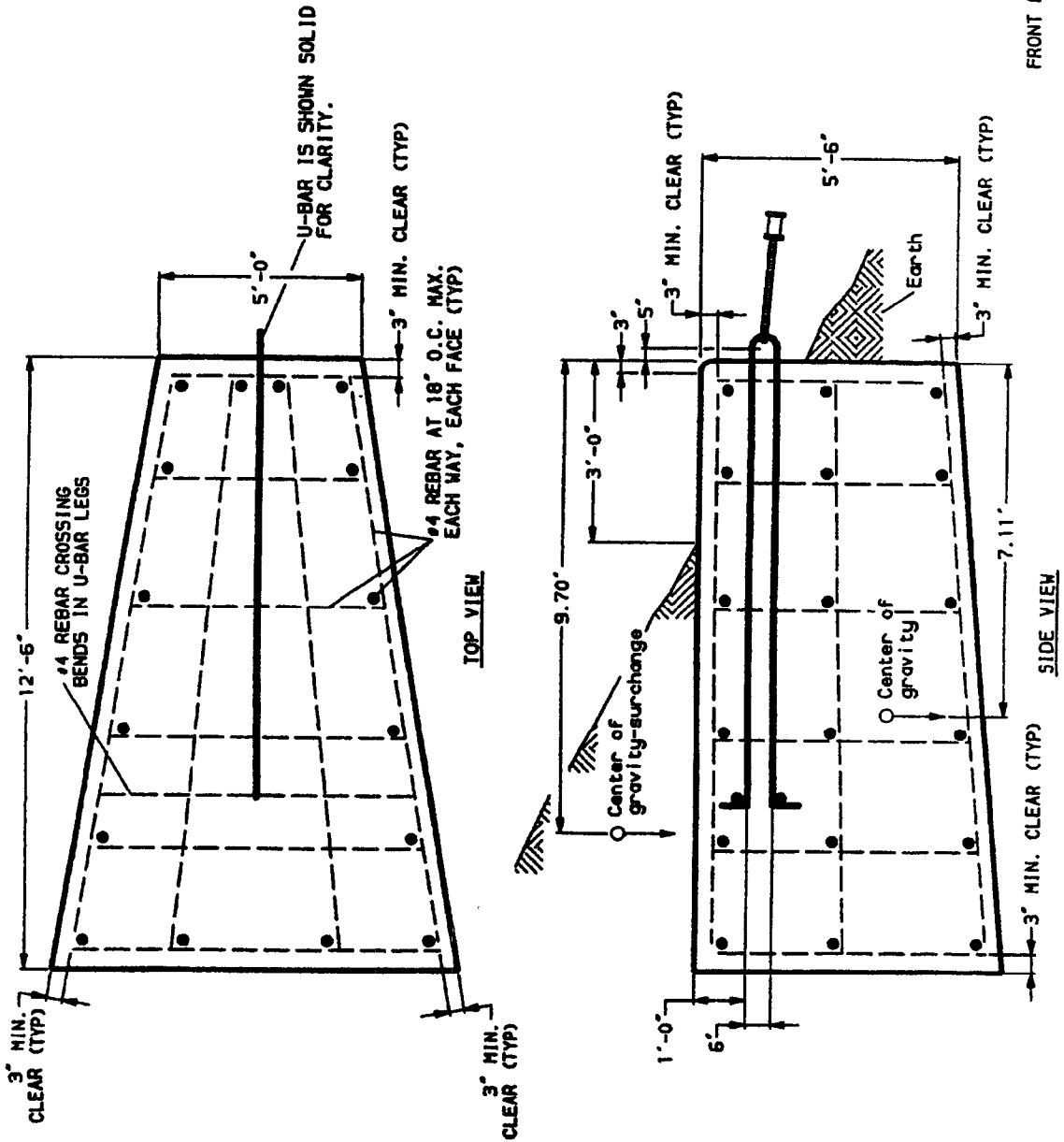


Figure 30. Sidehill anchorage for 30,000-lb design load. O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

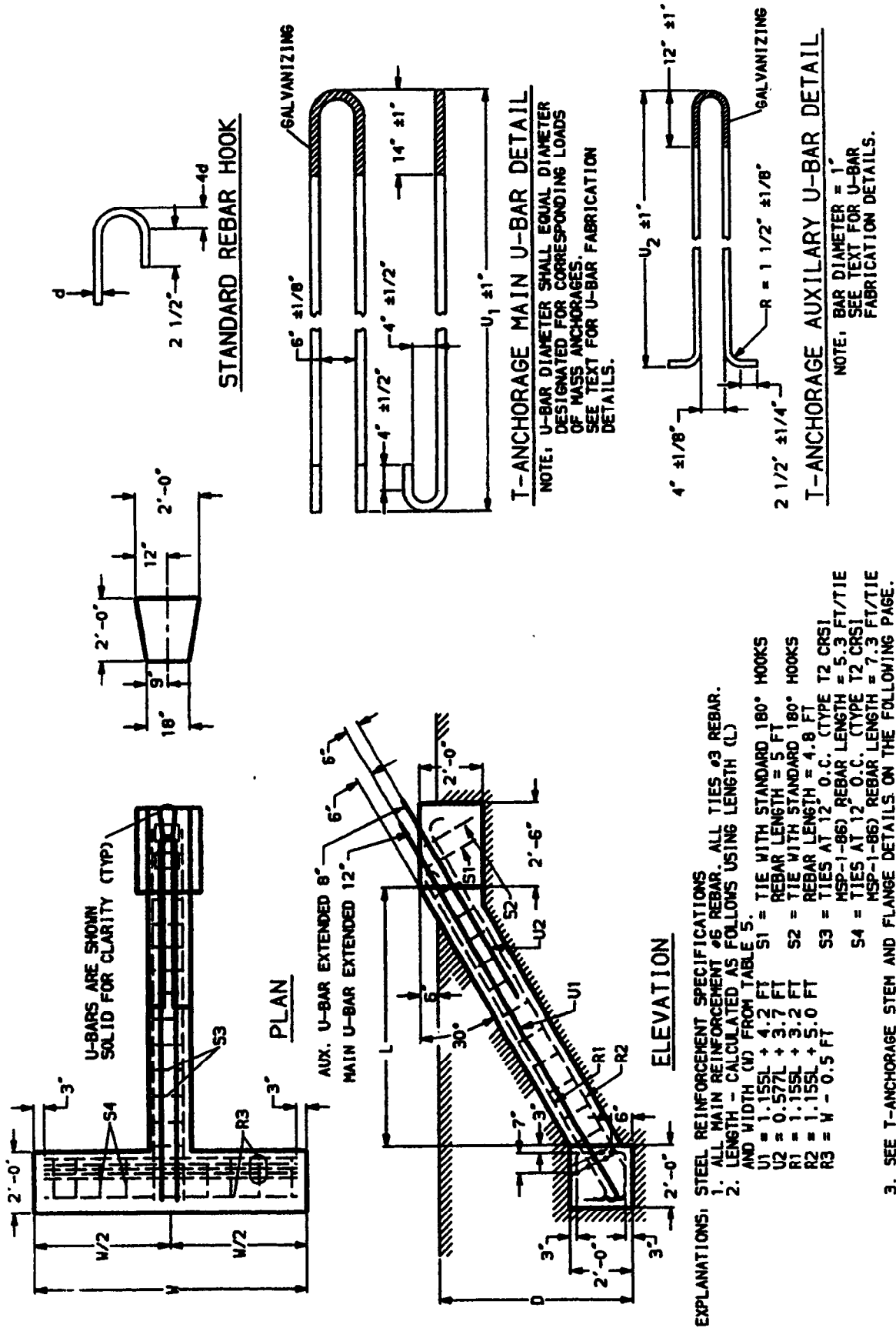


Figure 31. T-anchor. AUX, auxiliary; TYP, typical placement; O.C., on center.

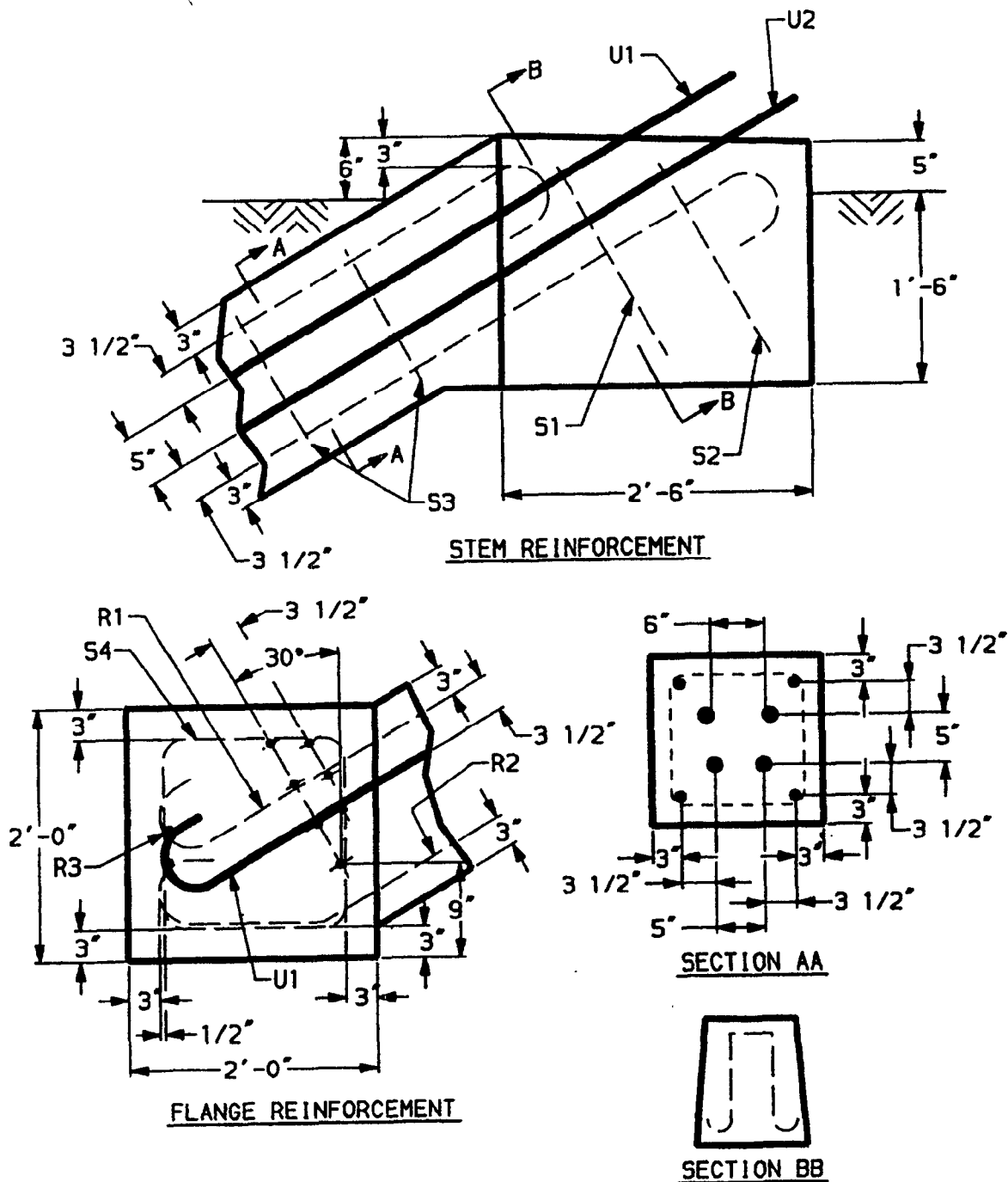


Figure 32. T-anchor details. See figure 31 for explanation of symbols used.

ing observations or sampling procedures. Several styles of car pullers are available. Exterior mounting brackets for water-sample bottles are available for both styles of cable cars.

All cable cars and accessories mentioned above are available to the USGS and other Federal agencies through the HIF. Battery- and gasoline-powered cable cars are

sometimes used at sites located on large rivers that are frequently and extensively monitored. The HIF has designed a gasoline-powered cable car with a hydraulic pump that drives two hydraulic motors, one that moves the cable car along the cable and another that operates a type E sounding reel. This cable car is available from the HIF on special order.

CONSTRUCTION

Table 5. T-anchor dimensions.

Cable design load ¹ (lb)	Dimension (ft)		
	Depth	Width	Length
Soil type A			
10,000	6	6	7.8
15,000	6	8	7.8
20,000	7	8	9.5
25,000	7	10	9.5
30,000	8	10	11.25
Soil type B			
10,000	6	8	7.8
15,000	7	10	9.5
20,000	8	11	11.25
25,000	9	13	13
30,000	9	16	13

¹Cable design load from table 1 or manufacturers' specifications.

Construction of cableway systems must be carried out by using sound construction and safety practices. USGS personnel have been injured while building or maintaining cableways. Most incidents involved poor training, inadequate or makeshift equipment, or carelessness. It is not the intent of this publication to teach a course in engineering design or construction practices, and the following information is provided only for informational purposes for those with limited experience in constructing this type of structure.

EXCAVATING FOR ANCHORS AND SUPPORT STRUCTURES

Most excavation for typical A-frame footings and anchors is done by power equipment. Small backhoes of the type frequently mounted on industrial or farm tractors are best suited for this work because of their mobility. In general, the bearing strength of soil decreases when disturbed;

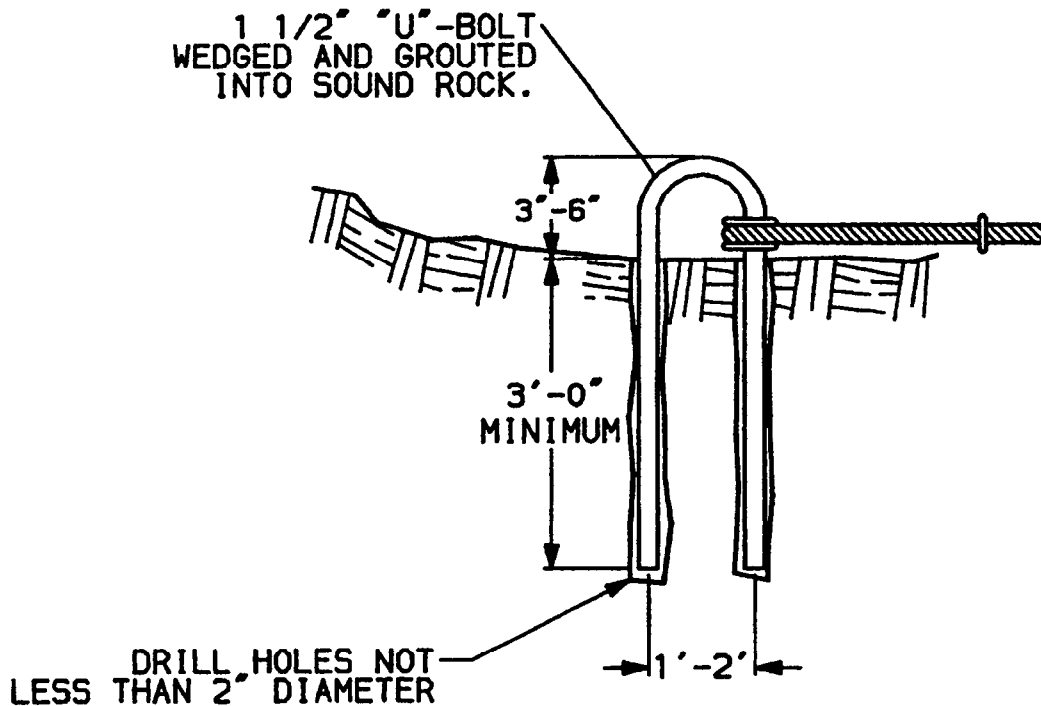


Figure 33. Vertical rock anchor. Drill holes in rock at least 2 in. in diameter or 1/2 in. larger than anchor diameter. Width normally measures between 6 and 12 in. Anchor diameter (in inches) for cable working load (in pounds) = 1 1/2 in., 10,000 lb; 1 5/8 in., 15,000 lb; 1 7/8 in., 20,000 lb; 2 in., 25,000 lb; 2 1/8 in., 30,000 lb; 2 1/4 in., 40,000 lb.

EYEBOLT GROUDED
INTO SOUND ROCK

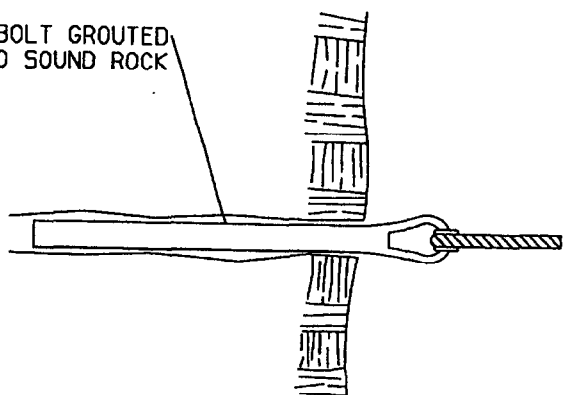


Figure 34. Horizontal rock anchor.

therefore, it is essential to dig as close to the desired dimensions as possible. In the case of concrete anchor blocks, a carefully dug rectangle may require a concrete form only for the top foot or so to provide for the above-ground portion. However, it is sometimes desirable in such cases to line the sides of the hole and adjacent ground with plastic sheeting before placing the forms and pouring the concrete to prevent dirt from falling into and contaminating the concrete. A careful and attentive backhoe operator and a little hand shoveling can result in a considerable savings of time and materials.

The use of cylindrical forms for A-frame footings is cost efficient since it minimizes excavation and labor intensive form construction. Cylindrical cardboard form materials are available commercially in a variety of sizes and can be easily cut as needed in the field. Steel culvert pipe makes an excellent form, and A-frame anchor bolts can be welded in exact positions before being taken to the site. (Neither type of form material is removed after pouring.) Careful attention to vertical and horizontal control in construction layout surveys is necessary to ensure that all components are exactly located.

The size and placement of steel reinforcement are critical to the strength of concrete structures. Concrete has excellent strength in compression but little strength in tension. Therefore, the integrity of concrete anchors depends primarily on the tensile strength of the reinforcement steel and proper bonding to the concrete.

Any space that has been excavated around formed concrete must be carefully replaced by mechanical compacting or by "puddling" before erection of A-frames and cable. Puddling involves pouring water into the void between the cured concrete and the excavation and carefully hand backfilling and tamping to ensure a soil condition as close as possible to original soil conditions.

PREPARING CONCRETE FOR ANCHORS AND SUPPORT STRUCTURES

Concrete is best procured from a local "ready-mix" vendor. Onsite hand mixing often results in a low-strength product and, in most cases, is not cost effective. In inaccessible locations, innovation may be necessary to transport concrete from the mixer-truck to the forms. If a long delay is expected, request a slow-setting mix. A temporary cableway or a cableway that is to be replaced may be used to transport concrete to a location on the far side of a stream. A washed-clean front-end bucket on a tractor may be used or, in some cases, a helicopter may be required.

Concrete for footings and anchorages must have compressive strength of 3,000 lb/in² (5 sacks/yd). All concrete should meet ACI-318 (American Concrete Institute, 1984) and ASTM C-94 and specifications. All concrete should be poured within 60 minutes after water has been added. When pouring concrete in forms, not more than 12 to 18 in. shall be poured before concrete is consolidated into all corners and around all reinforcing bars. Care must be taken to avoid disturbing the position of the reinforcing or U-bars. The process of consolidation or compaction of concrete must be done during and immediately after pouring. Mechanical vibrators are recommended; however, on small pours, hand spading (rodding) is acceptable as long as it is done thoroughly and carefully. The entire operation of depositing and consolidating the concrete must be conducted such that the finished concrete is smooth, dense, and free from honeycombs and pockets of segregated aggregate. Once started, no pour should be interrupted for more than 30 minutes. Water should never be added to the concrete mix to make it flow better because its addition seriously reduces the strength of the final product. Concrete should not be poured if below-freezing temperatures are expected within 48 hours, unless heated concrete is used or other means are available onsite to protect the curing concrete. All freshly poured concrete should be kept moist and should be protected from rapid drying by waterproof paper, plastic sheeting, wet burlap, or straw. Concrete poured during extremely hot or below-freezing conditions requires appropriate protection.

Concrete achieves approximately 75 percent strength in 7 days and approximately 100 percent strength in 28 days. Therefore, erection of A-frames and cables should never be started in less than 7 days. A longer curing time is preferable. A variety of readily available admixtures will retard or increase the setting and curing time of concrete. High, early-strength concrete achieves nearly full strength in 3 days; however, special curing procedures are required due to the large amounts of heat generated. All admixtures must meet applicable ASTM specifications (C-260 or C-494). Special mixtures should be agreed upon with the concrete supplier prior to formulation and delivery.

All placement of reinforcing bars and U-bars must be completed prior to starting a pour. The placement of anchor bars and A-frame attachment bolts in concrete must be done carefully to ensure proper connection with the steel components of the system. Reinforcing and U-bars must be free of loose rust and scale, petroleum products, or excessive dirt, any of which will significantly reduce concrete bonding. Misalignment of U-bars in concrete anchors will result in added stresses to the U-bars if the U-bars are not set at the proper angle. Even a slight misalignment of A-frame anchor bolts will result in a poor or impossible attachment to the steel A-frame. A convenient way of maintaining the proper spacing of anchor bolts is to weld the bolts for one leg of an A-frame together with reinforcing bars at the exact spacing. The bolt "cluster" is then inserted into the wet concrete as a unit. Alignment for bolt clusters for the legs of both A-frames can be maintained by drilling appropriate bolt holes in a 1- by 12-in. board, long enough to extend between the two pedestals. U-bars must always be placed vertically and at the same alignment angle as the cable. Proper placement is necessary to transmit tension forces to the entire concrete anchor.

Personnel preparing form work, installing reinforcement, and positioning anchor bolts and U-bars should have experience in construction carpentry and must follow design instructions. Concrete should have a smooth and level finish with a slight pitch to encourage water to drain away from metal connections such as A-frames and U-bars on anchors.

In locations where soil instability is suspected, inserting a gaging station reference mark or a bolt slightly above the concrete surface serves as a reference point and also allows measurements to be taken over time to determine if movement of any components has occurred.

INSTALLING ROCK ANCHORS

The installation of rock anchors must be done with great care to ensure adequate holding strength. Anchors should not be installed near fractures or near the edges of the rock formation. Installation of mechanical expansion anchors must follow the manufacturer's instructions. U-bar anchors require precise drilling of two parallel holes to accommodate the two legs of the bolt. Drill size must be selected to allow adequate clearance for grout or epoxy bonding materials. Vibrating the anchor will assist in working the bonding material along the entire anchor axis. Proper setting time is necessary prior to tensioning.

INSTALLING TREE SUPPORTS OR ANCHORS

The construction of cableways using trees as anchors or support structures should be performed only by persons who have had experience with such designs. When a tree is

incorporated into the design of a cableway, it must be a large, live, mature tree with a solid root system located in stable soil. If there is any reason to suspect that a tree is diseased or decaying, core borings should be obtained. Careful consideration of all factors must support the tree's suitability for use.

The main cable may be looped directly around the tree, or a separate cable sling may be looped around the tree and attached to the main cable with a turnbuckle or other appropriate fittings. Wooden bearing blocks (often called lagging), such as hardwood 2 × 4's, should be placed between the tree and cable to protect both the cable and the tree. The cable should be loose enough to allow for the growth of the tree. If a sheave or other attachment hardware is used to attach the cable to a tree, it must be installed in a manner to adequately carry the load and not injure the tree.

ERECTING A-FRAMES AND CABLE

The construction of a cableway must be done by experienced personnel who emphasize safe practices. Safety shoes, hard hats, and heavy work gloves should be worn. No member of the crew should work in any location that would be unsafe in the event of a slippage or failure of a cable or component.

Preparation of a cable is essential to prevent unraveling and subsequent loss of strength. Seizing is the procedure of making a secure binding at the end of a wire rope to prevent unraveling. If a wire rope unravels, it will lose strength several feet from the point of disturbance. Wire rope should be seized prior to being cut. Seizing with wire wrappings has been the traditional method; however, stainless steel crimp-type hose clamps are noncorrosive and an effective means of seizing wire rope. If wire seizing is used, the wire should be soft annealed rustproof wire or strand, about 0.075 in. in diameter for most main cable applications. Correct placement techniques are shown in figure 35.

Once a wire rope is properly seized, it should be cut, preferably with a shearing-type cutter. A number of portable manual cutters that will meet most USGS needs are commercially available. A hammer-type cable cutter is shown in figure 36. Wire rope should not be cut with acetylene torches; using a torch tends to weld together the individual wires and inhibit movement in the wire rope, reducing its strength.

The erection of A-frames about 15 ft or less and cable spans of 400 to 500 ft long can usually be performed by a 3- or 4-person team without power equipment. Larger installations may require the use of power equipment. Backhoes usually are appropriate for lifting the A-frame into place and pulling the cable tight.

Usually the A-frames are aligned and bolted into place first, with the A-frame pointing to the river. In the case of A-frames without pivoting legs or I-beam supports, the sup-

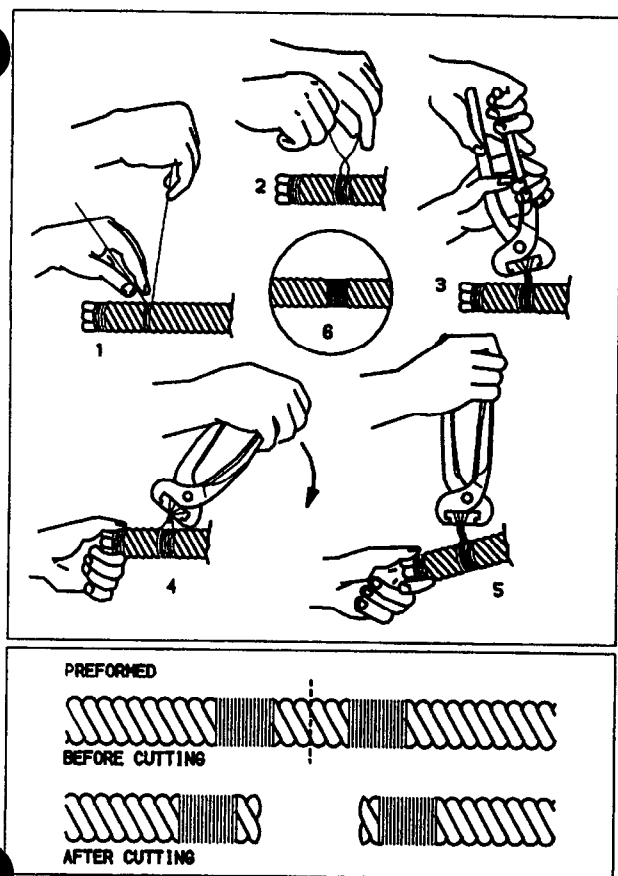


Figure 35. Wire-rope seizing technique and final product.

ports must be erected and guyed in position before the cable is installed. For pivoting structures, the cable can be pulled across the stream and raised as the A-frames are lifted into position.

Pulling a cable across a large or deep river is best accomplished by first pulling a fiber rope across the river with a boat and then pulling the steel cable with the rope. Usually, the cable is attached on the less accessible side first. The cable and turnbuckle are assembled, and the cable is laid over the sheave or bearing block of the A-frame. The A-frame is then pulled to a nearly upright position and guyed. Usually the second side is handled by lifting the A-frame into position before end connections are made to the main cable; if exact measurements are made, the end connections can be done prior to lifting the A-frame into place.

Raising and tightening a main cable present the most dangerous parts of the construction process because of the large amount of energy involved. It is strongly recommended that, prior to this activity, the construction crew take a brief break and carefully review assignments, personnel positions, and safety procedures. Also, all connections and lifting equipment should be double checked prior to final tensioning.

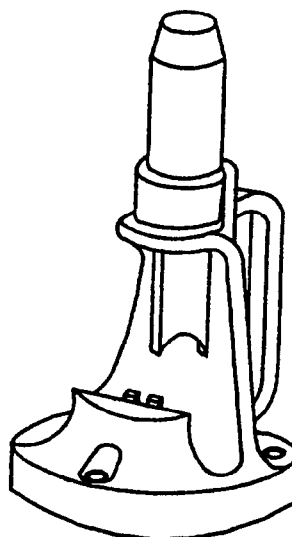


Figure 36. Hammer-type cable cutter.

CAUTION.—Various block and tackle, cable hoists (come-a-longs), and chain hoists are used to erect A-frames and tighten cables. Make certain that the lifting devices being used are rated for the loads involved. Always use a cable grip of the proper type and size to attach the lifting device to the main cable to prevent damage to the cable or avoid slippage or failure during lifting. Common sense and caution are critical. A 1/4-in. cable hoist is not capable of tightening a 1-in. steel cable. Double check connections to the main cable when chains are used to assist in the lifting. Make sure that all pulls are straight. Make sure that all personnel are clear, should something go wrong as the cable is pulled up.

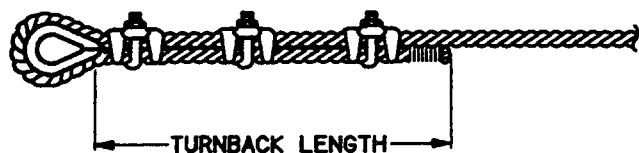
The following method is recommended for tightening a wire rope and fastening it to its anchorage. With one end of the hoisting device hooked to the anchor and the other to the main cable, take up the cable to slightly tighter than unloaded sag. Fasten the turnbuckle to the anchor and place a thimble in the cable end. The turnbuckle should be in its fully extended position. Pass the end of the main wire rope around the thimble and install clips to achieve maximum holding power. See figure 37 for proper clip placement. Follow the directions listed below to attach the U-bolts to the cable.

1. Turn back the specified amount of rope from the thimble. Apply the first clip approximately one base width (width of clip saddle) from the dead end of the wire rope (U-bolt over dead end, live end rests in clip saddle). Tighten nuts evenly to recommended torque.

Table 6. Recommended number of clips, torque, and dead-end turnback for wire rope.

Wire rope diameter (in.)	Minimum number clips	Torque ¹ (ft-lb)	Minimum turnback (in.)
7/16	2	65	7
1/2	3	65	12
9/16	3	95	12
5/8	3	95	12
3/4	4	130	18
7/8	4	225	19
1	5	225	26
1 1/8	6	225	34
1 1/4	7	360	44

¹From Wire Rope Technical Board, 1981.

**Figure 37.** Correct way to attach wire rope clips.

2. Apply the next clip as near the loop as possible. Install nuts firmly but do not tighten.

3. Place additional clips, as required, equally spaced between the first two. (Spacing between clips should be 1 to 2 base widths.) Install nuts firmly but do not tighten; back off lifting device to place a slight tension on the wire rope, and tighten all nuts evenly on all clips to recommended torque.

4. Release lifting device, placing full tension on connection, and retorque all nuts. Rope will stretch and be reduced in diameter when loads are applied. Inspect periodically and retighten to recommended torque. (A light application of spray paint over the cable and wire rope clips provides a visual indication of slippage.)

Recommendations for the minimum number of clips, torque, and dead-end turnback are given in table 6.

A-frame backstay cables are installed and tightened with the A-frame in a plumb position. Final sag adjustment should be made after the cable car is installed and several trips have been made across the cableway with a loaded car to stretch the cable and set bends and clips. One method to check sag easily is to paint a line on both A-frames at a distance from the sheave corresponding to the proper unloaded sag, then sight from one A-frame to the other with a hand level. This procedure is also applicable to structures where cable supports are at differing elevations.

It is necessary to mark the cableway to provide a width reference for discharge measurements. This is commonly done by stretching a tag line or steel tape between A-frames and painting marks at selected intervals with brightly colored paint. A convention of single marks at 5- or 10-ft intervals, double marks at 50 ft, and triple marks at 100 ft is usually used.

INSTALLING GROUNDS

GROUNDING RODS

Grounding rods can be installed for attachment to the main cable, backstay cables, and steel A-frames or other support structures. For cable grounding, drive a standard 10-ft by 5/8-in., copper-clad grounding rod into the earth under the main cable, streamward from the anchorage. Drive the grounding rod about 1 ft below ground level. Clamp a piece of 1/4- to 1/2-in. galvanized wire rope with galvanized wire rope clips to the main cable above all clamps and attachment hardware. With gentle bends, clamp this cable to all backstay cables and arc it toward the grounding rod. Just above the ground level, cut the galvanized wire rope and securely clamp it to a piece of No. 2 copper lightning-conductor cable. Clamp this cable to the grounding rod by using a commercial, bronze grounding clamp. (This procedure reduces damage to the main cable from electrochemical reaction of dissimilar metals.) All connection surfaces should be clean and free of corrosion and coatings. Drive a similar ground rod midway between the A-frame legs and under the A-frame. Solidly connect a No. 2 copper lightning-conductor cable to each leg of the A-frame and to the grounding rod. Connect the two grounding rods with No. 2 copper lightning-connector cable. The grounding rods and connecting wire should be about 1 ft below the surface of the earth. Drive the ground rods full length into solid earth. All bends in the grounding wires should be gradual with no bends less than 8 in. in radius. All cable and components must meet Lightning Protection Institute (1987) requirements.

WIRE GROUNDS

An alternative grounding system uses several 40- to 50-ft lengths of wire buried at least 6 to 12 in. below ground and, preferably, below frost level. Running the wire from the main cable and the A-frames toward the river usually provides the best ground because of the likelihood of increased soil moisture. No. 2 copper lightning-protection cable should be used. Follow all connection procedures described for grounding rods. Extraneous metal objects such as wire fences or antennas should not be connected to cableway systems.

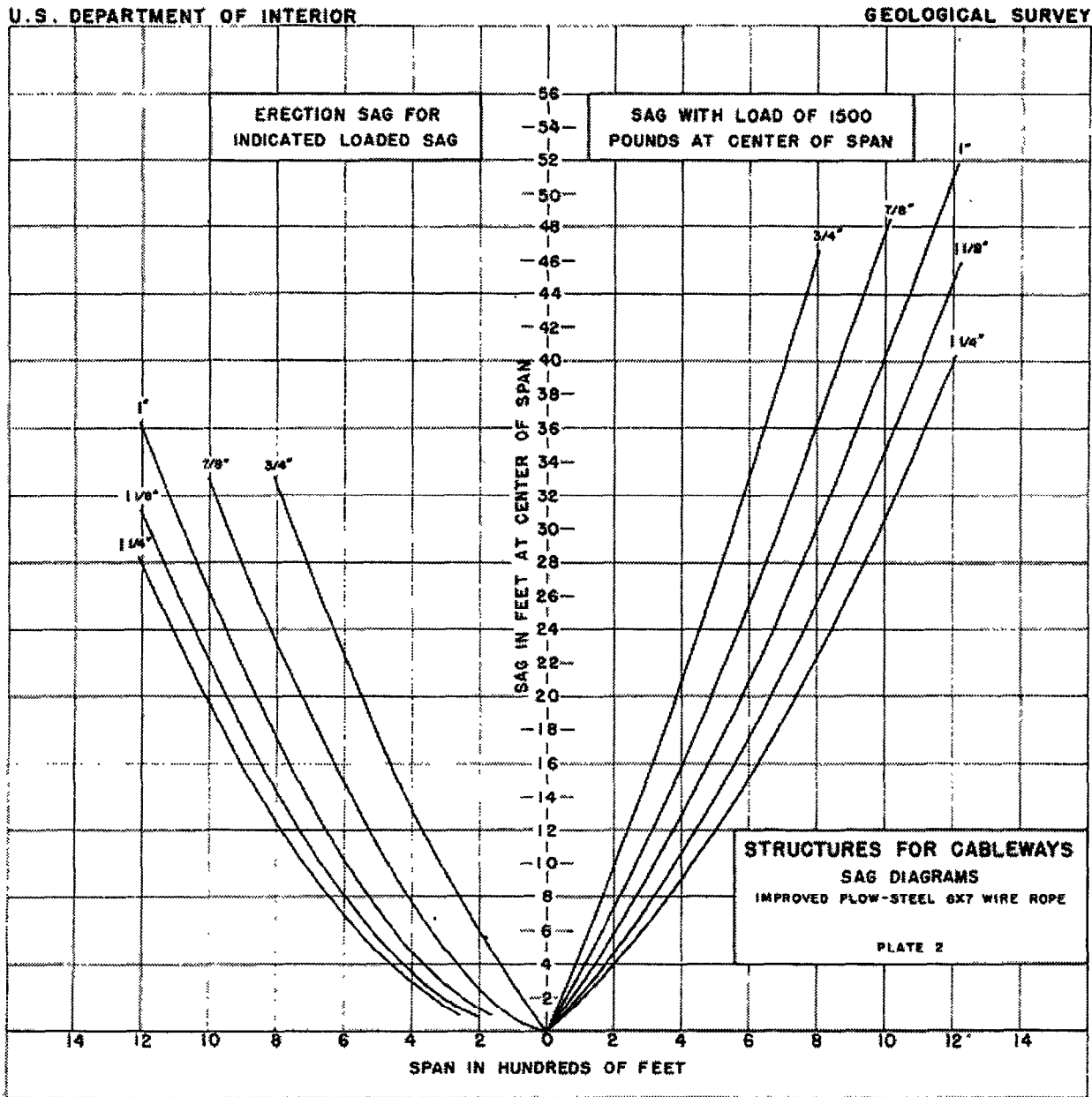


Figure 38. Sag diagram for improved plow steel 6 x 7 wire rope (cable) (from Pierce, 1947, p. 16a).

There is no effective means of protecting operating personnel from the hazards of lightning strikes. Use of cableways during periods of lightning storms is discouraged.

CABLEWAYS CONFORMING TO CIRCULAR 17 SPECIFICATIONS

Design criteria used in this manual differ slightly from those used in earlier cableway manuals. The type and

strength of available cable materials have changed since USGS Circular 17 (Pierce, 1947) was prepared, and heavier equipment is now being used.

Many of these earlier structures will be maintained in service for some time. Sag diagrams from Circular 17 are included herein and should be used for determining proper sag adjustments for cableways built in accordance with guidelines from Circular 17 (figs. 38 and 39).

Many existing cableways may be retrofitted with new higher strength cable in the future. The heavier design loads recommended in this manual and the reduced sag and

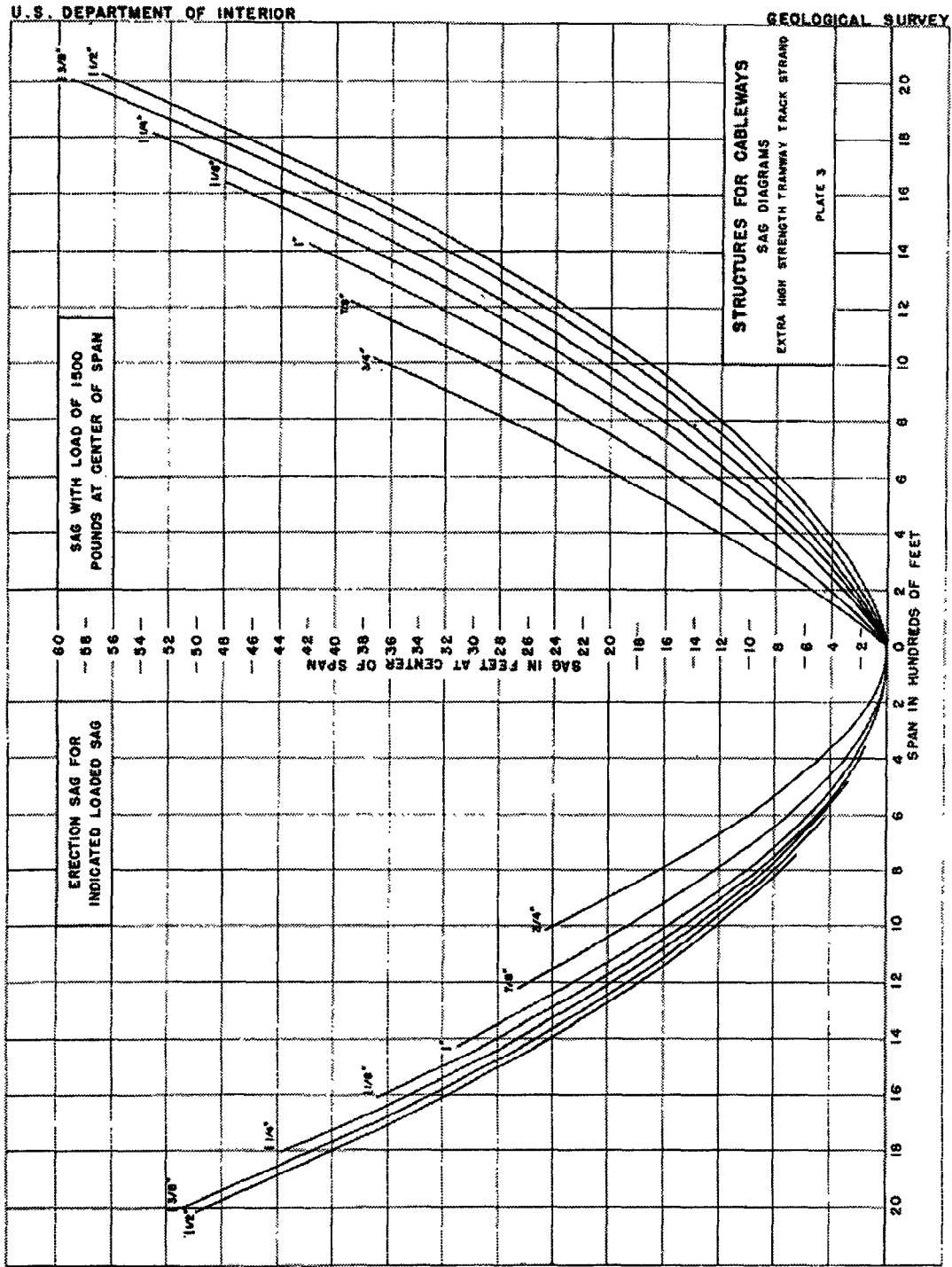


Figure 39. Sag diagram for extra high strength tramway track strand of various diameters (from Pierce, 1947, p. 16b).

higher-strength characteristics of present cable may result in a larger tension force acting on the existing anchorage. Careful inspection and evaluation of existing anchorages and attachment hardware, cable supports, and footings are necessary to determine adequacy of these components to meet increased loads. Complete inspection is also necessary to ensure that strength-limiting deterioration has not occurred. In many cases, replacement of entire systems will be necessary.

Inspection, evaluation, and redesign must be performed and documented by using the guidelines described in this report.

DOCUMENTATION

After a cableway installation is complete, all vital dimensions must be recorded for inclusion in USGS WRD District files and Field Station Description (USGS Form 9-197). Documentation should include the size and depth of the footings, the size of the anchors, the manufacturer and type of cable, and a diagram showing dimensions between components. A copy of the design information, including any special considerations, should always be retained. Any changes or repairs to the structure should be added as they are made.

As much information as possible should be obtained on existing structures. Careful field measurements of cable diameter and type, anchorage dimensions, and related information are important for evaluating the safety of old structures. Reliable information about existing anchors and footings is needed to determine whether they can safely be reused with new supports and (or) cables.

SECURITY

Cableways frequently are the target of vandals. This vandalism may involve breaking locks and using the cable cars to cross streams or just damaging the structure. Cable cars should always be locked when not in use. In most cases, a piece of chain about 4 ft long wrapped around the A-frame or anchor and a standard or high-security USGS padlock will be adequate. The preferred chain is 3/8- to 1/2-in. case-hardened and rustproofed. It is nearly impossible to saw through case-hardened chain and the USGS high-security padlock. However, vandals may cut the chain with large bolt cutters. Several types of special locking devices and lock shields have been tried with some success. "Danger—Keep Off" warning signs should be attached to all cableways.

In some areas subject to frequent vandalism, enclosing the entire anchor, A-frame, and cable car with a heavy-duty, chain-link fence protects the USGS's property and mini-

mizes potential liability for persons injured by misused equipment.

INSPECTION AND MAINTENANCE

Casual inspection and incomplete maintenance of a cableway structure may result in shortening its useful life and jeopardizing the safety of personnel using the system. Inspection personnel must have a knowledge of materials and forces acting on the systems and be properly trained in field inspection techniques. Maintenance personnel must also receive training in proper procedures. One of the major factors in deterioration of cableway systems is the improper selection of fabrication materials and subsequent preservation of components. Guidance on painting and preservation is given in appendix III.

Experience indicates that the majority of cableway system deficiencies are in the footing to A-frame attachment, backstay system, and improperly installed wire rope clips.

Every cableway system shall be inspected at least once each year, and new or modified structures should be inspected after the first several uses. The inspections shall be performed by a qualified person, and an inspection report, in approved USGS format, must be completed, signed, and submitted to appropriate USGS WRD District management. In cases where the safety of a cableway is in doubt, the structure should not be used until further testing proves it to be safe or repairs have been made. Field inspection of cableway systems is critical to the lives and safety of field personnel. USGS WRD District management and field personnel must therefore make thorough inspection and maintenance of cableways a priority of the highest order. Inspection of a cableway system should include, at a minimum, the items listed in the following sections.

ANCHORS AND FOOTINGS

1. Carefully check the general condition of concrete and steel U-bar connection to concrete. Look for crack lines in concrete or evidence of movement where the U-bar enters concrete.
2. Inspect the general condition of rock anchors for any indications of deterioration or movement of U-bar or pin. Check for fracture or other failure of adjacent rock formation.
3. Check to see that connections are free of soil and debris. Check for indications of overstress, corrosion, or damage. Clean and paint if required. Previous guidance recommended that tar should be used to seal between U-bars and concrete. However, experience has since shown that moisture frequently penetrates between the tar and metal and causes corrosion. Tar

should be removed, and metal components carefully inspected. If found to be safe, clean and paint; otherwise replace as necessary.

4. Check for movement of anchor or footings. Look for subsidence, heaving, or other signs of instability. Check dimensions between anchors and footings if instability is suspected.
5. Check for erosion or other disturbance of adjacent soil.
6. Trees used as anchors must be alive and healthy. Check bearing blocks for soundness and proper position. Root systems must not show signs of movement or damage.

MAIN CABLE SUPPORTS

1. A-frames or I-beams must be plumb. Check bolts and hardware attaching A-frames to concrete footings for rust and signs of movement.
2. All metal components must be rust free. Remove rust and paint as required. See appendix III.
3. Check wooden A-frames and walkways for rot or termite damage, especially at ends. Apply wood preservative as required.
4. Check points of contact between concrete and steel (or wood) for corrosion or rot.
5. Check sheave or saddle block for condition and proper contact with cable. Look for signs of corrosion or damage to cable at this point of contact.
6. Check ladders, walkways, platforms, and safety rails for stability and condition.
7. Check grounding of steel structures.
8. Trees used as cable supports must be alive and healthy. Check bearing blocks for soundness and proper position. Root systems must not show signs of movement or damage.

MAIN CABLE

1. Check general condition of main cable. Note rust penetration and broken wires. Particularly note condition at the point where the main cable contacts the support (sheave or saddle block) and where it connects to the anchorage. Broken wires at these locations indicate serious deterioration and require immediate replacement or inspection by a specialist.
2. Replace wire rope or structural strand when one or more of the following occur:
 - a. The number of broken wires within a rope lay length, excluding filler wires, exceeds either (1) 5 percent of the total number of wires or (2) 15 percent of the total number of wires within any strand.
 - b. On a regular lay rope, there are two or more broken wires in the valley between strands in one rope lay length.

- c. On a structural strand, there are more than three broken wires.
 - d. There are two or more broken wires at any termination.
 - e. The rope deterioration caused by corrosion exceeds that defined as moderate (see glossary).
 - f. There is loss of more than 10 percent of the rope strength as determined by nondestructive testing.
 - g. There is any unexplained distortion.
3. Check sag and adjust as required. If sag has changed frequently, find out why. Field personnel should not make sag adjustments on the hottest days or coldest days without making sure that sag is within acceptable limits. Sag adjustments should be made during periods near annual mean temperatures. In no case should the sag be set less than the unloaded sag from figures 3–14 in this report.

4. Check cable markings; repaint as needed.

BACKSTAY

1. Check general condition of cable. Note rust or damage to cable. Replace if indicated by using the criteria applicable to the main cable.
2. Check for undersized cable; replace if necessary.
3. Check tension. It should be taut but not under great load.
4. Check attachment on support structure and anchor.

CABLE CONNECTIONS

1. Check general condition of wire rope clips. Replace if rusted. Replace if improperly installed. Check for damage to wire rope if improperly installed. Check for slippage on cable. Check for loose clips. Tighten to proper torque.
2. Check sockets (bridge sockets or poured sockets) for corrosion, movement, or other signs of deterioration. Field repairs are not recommended. Report deficiencies; do not use structure pending replacement or inspection and approval by a specialist.
3. Check condition of turnbuckle. Apply grease to threads to prevent seizing and retard corrosion.
4. Check clips and fittings on backstay cables.
5. Check cable attachments to trees. Adjustments may be necessary to accommodate tree growth.

CABLE CAR

1. Check general condition. Grease sheaves if required.
2. Check for loose, missing, or corroded bolts. Replace as required.
3. Check brake system. Repair as required.

4. Check condition of wood on wooden cars. Apply wood preservative or replace as needed. Check and clean drainholes.
5. Check condition of aluminum components of aluminum cars for deterioration or corrosion.
6. Check and oil locking system.

MISCELLANEOUS

1. Check aircraft warning markers. Replace as required. Check all components of supporting cable and fittings, as described above.
2. Cut grass and brush adjacent to anchors and cable supports and under cable to water's edge. **Remove dirt or debris in contact with or close to anchor connection.**
3. Remove overhanging branches or trees that might fall on structure.
4. Note any encroachment of activity in area that might damage structures.
5. Check condition and integrity of security fences or other protective devices.
6. Check for warning signs. Replace if necessary.

Note any uncorrected deficiencies that may affect the safe use of the cableway and report to USGS WRD District management immediately.

In addition to making periodic safety inspections, field personnel should always look over the anchorages, turnbuckles, wire rope clips, and other system components for damage or vandalism prior to operating a cableway. The supporting and anchoring devices on the far side of the stream may be difficult or impossible to inspect before every use but should be visually checked from the cable car at the time of each discharge measurement. In wooded areas, trees may fall on the cable structure, and thorough inspection before use is required.

NONDESTRUCTIVE TESTING

Load testing of a cableway is performed as a method of testing the integrity of the entire cableway system. The load testing requires that a 2,000-lb deadload, or the design load of the cableway, whichever is the larger, is suspended from approximately center span. The usual deadload is a quantity of water. Various vessels and suspension systems have been developed for this purpose.

Load testing is performed ideally during conditions of saturated soil, when movement of footings and anchors is most likely to occur. Soil moisture conditions should be included on load test reports.

Anchor block and footing measurements should be taken prior to loading and again under fully loaded conditions to determine lateral and vertical movement. A simple

set of levels run to the top of A-frame footings, corners of concrete anchors, and top of U-bars and tied to a reference mark not associated with the cableway structure is adequate. Horizontal reference can include measurements from A-frame anchor bolts to a point on the U-bar or to temporary stakes driven into the ground some distance from the structure. A simple string and batterboard setup similar to the setup used in foundation construction is an easy form of reference. Where a cableway is located near a gaging station, the elevation of cableway elements should be tied to gage datum. Periodic levels could be useful for documenting structure movement.

CAUTION.—Personnel should use extreme caution during the loading, measuring, and unloading of the structure since failure of effective system components including total collapse of the structure is possible. Personnel should plan every detail by assuming that the system will fail.

Magnetometer tests can be run on the main cable to determine changes in metallic area along the length of cable. Changes in metallic area are indicative of deterioration that may not be visually detected. Unfortunately, the magnetometer can not pass over cable supports or terminations. Magnetometer tests require specialized equipment and trained operators to interpret results. Generally the USGS contracts with specialized testing firms for this work.

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APPENDIXES

APPENDIX I. NOTICE OF PROPOSED CONSTRUCTION OR ALTERATION

Form Approved OMB No 2120-0001

DO NOT REMOVE CARBONS

<p align="center">NOTICE OF PROPOSED CONSTRUCTION OR ALTERATION</p> <p>US Department of Transportation Federal Aviation Administration</p>	Aeronautical Study Number _____
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1. Nature of Proposal A Type <input type="checkbox"/> New Construction <input type="checkbox"/> Alteration B Class <input type="checkbox"/> Permanent <input type="checkbox"/> Temporary (Duration _____ months) C Work Schedule Dates Beginning _____ End _____	2. Complete Description of Structure A Include effective radiated power and assigned frequency of all existing, proposed or modified AM, FM, or TV broadcast stations utilizing this structure B Include size and configuration of power transmission lines and their supporting towers in the vicinity of FAA facilities and public airports C Include information showing site orientation, dimensions, and construction materials of the proposed structure
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3A. Name and address of individual, company, corporation, etc. proposing the construction or alteration. (Number, Street, City, State and Zip Code)

(_____)
 area code Telephone Number

B. Name, address and telephone number of proponent's representative if different than 3 above.

(if more space is required, continue on a separate sheet.)

4. Location of Structure		5. Height and Elevation (Complete to the nearest foot)	
A Coordinates (To nearest second)	B Nearest City or Town, and State	C Name of nearest airport, heliport, flightpark, or seaplane base	A. Elevation of site above mean sea level
Latitude	(1) Distance to 4B Miles	(1) Distance from structure to nearest point of nearest runway	B. Height of Structure including all appurtenances and lighting (if any) above ground, or water if so situated
Longitude	(2) Direction to 4B	(2) Direction from structure to airport	C. Overall height above mean sea level (A + B)

D. Description of location of site with respect to highways, streets, airports, prominent terrain features, existing structures, etc. Attach a U.S. Geological Survey quadrangle map or equivalent showing the relationship of construction site to nearest airport(s) *(if more space is required, continue on a separate sheet of paper and attach to this notice.)*

Notice is required by Part 77 of the Federal Aviation Regulations (14 C.F.R. Part 77) pursuant to Section 1101 of the Federal Aviation Act of 1958, as amended (49 U.S.C. 1101). Persons who knowingly and willingly violate the Notice requirements of Part 77 are subject to a fine (criminal penalty) of not more than \$500 for the first offense and not more than \$2,000 for subsequent offenses, pursuant to Section 902(a) of the Federal Aviation Act of 1958, as amended (49 U.S.C. 1472(a)).

I HEREBY CERTIFY that all of the above statements made by me are true, complete, and correct to the best of my knowledge. In addition, I agree to obstruction mark and/or light the structure in accordance with established marking & lighting standards if necessary.

Date	Typed Name/Title of Person Filing Notice	Signature
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FOR FAA USE ONLY *FAA will either return this form or issue a separate acknowledgement*

The Proposal: <input type="checkbox"/> Does not require a notice to FAA. <input type="checkbox"/> Is not identified as an obstruction under any standard of FAR, Part 77, Subpart C, and would not be a hazard to air navigation. <input type="checkbox"/> Is identified as an obstruction under the standards of FAR, Part 77, Subpart C, but would not be a hazard to air navigation. <input type="checkbox"/> Should be obstruction <input type="checkbox"/> marked, <input type="checkbox"/> lighted per FAA Advisory Circular 70/7460-1, Chapter(s) _____ <input checked="" type="checkbox"/> Obstruction marking and lighting are not necessary.	Supplemental Notice of Construction / FAA Form 7460-2 is required any time the project is abandoned, or <input type="checkbox"/> At least 48 hours before the start of construction. <input type="checkbox"/> Within five days after the construction reaches its greatest height. This determination expires on _____ unless: (a) extended, revised or terminated by the issuing office; (b) the construction is subject to the licensing authority of the Federal Communications Commission and an application for a construction permit is made to the FCC on or before the above expiration date. In such case the determination expires on the date prescribed by the FCC for completion of construction, or on the date the FCC denies the application. NOTE: Request for extension of the effective period of this determination must be postmarked or delivered to the issuing office at least 15 days prior to the expiration date. If the structure is subject to the licensing authority of the FCC, a copy of this determination will be sent to that Agency.
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Remarks:

Issued In _____ Signature _____	_____
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APPENDIX II. CABLEWAY DESIGN SUMMARY

District _____ Office _____ Region _____
 Station No. _____ Name _____
 Property Owner _____ LB _____ Signed Easement _____ Y N Date _____
 (attach)
 RB _____ Signed Easement _____ Y N Date _____
 FAA notification _____ Construction Permits _____
 Highwater Access _____

DESIGN CRITERIA—Attach cross section of cableway station

Channel width, Normal _____ Bankful _____ 100 yr flood _____
 Elevation of: 50 yr flood _____ 100 yr flood _____ Historical _____
 Cableway span between supports _____ Cable-car Type _____
 Cableway Purpose _____
 Design Load _____ lbs (if <2250, justify) _____

DESIGN—Standard USGS design based on Streamgaging Cableways, OFR 91-84

Soil Type A B _____ Frost Depth _____ ft _____ Submergence Probable _____ Y N
 Footings: LB _____ Dimensions _____
 Footings: RB _____ Dimensions _____
 Cable Support LB _____ Height _____
 RB _____ Height _____
 Anchorage LB _____ Angle _____ Size L _____ W _____ D _____ CUYDS _____
 RB _____ Angle _____ Size L _____ W _____ D _____ CUYDS _____
 Main Cable Cable Type _____ Diam _____ Termination _____
 Backstay Wire Rope Type _____ Diam _____ Number _____

Unloaded Sag _____ Distance (cable loaded sag) to 100 yr elev _____
 Walkways/Platforms _____
 Other: _____

Deviations from standard design Y N; if Y, attach design documentation

Remarks:

Designed by _____ Title _____ Date _____
 Checked by _____ Title _____ Date _____
 Approved by _____ Title _____ Date _____

APPENDIX III. PAINTING AND PRESERVATION GUIDELINES

A major cause of deterioration of metal cableway structures is failure to maintain proper protective paint coatings. A large part of this problem is lack of thorough cleaning and rust removal from metal components prior to recoating. Metal components must be sandblasted, wire brushed, scraped, and then washed to remove all loose material, grease, and soil, allowed to dry, and recoated with a two-coat paint system. Industrial enamels having oil- or alkyd-type bases are best suited to USGS field facilities. Dampness-tolerant primers, which are particularly well suited for field application, are available. These primers are formulated to bond firmly to bare or semibare metal and should be coated with a compatible top coat after a 24-hour drying time.

Preparation time will greatly exceed actual painting time. A properly applied two-coat system should last 5 or 6 years on field structures, whereas a quick cover over with improper preparation may fail in less than a year.

Touchup or repair of damaged galvanized surfaces should be done with an organic zinc-rich paint formulated for this purpose. Badly weathered galvanized structures should be painted with one of several two-coat systems of paints developed for this purpose.

Wooden structures are best preserved by fabrication from pressure-treated lumber. Where this has not been done, field treatment with a copper-sulfate-type wood preservative, paying particular attention to the members' end-grain areas most susceptible to deterioration, is an acceptable alternative.

All coatings should be industrial quality products from reliable manufacturers. Most coatings should be applied by brush during temperatures from 40 °F to 125 °F.

Painters of all types—industrial, marine, commercial, or even weekend painters—generally have one thing in common. That is, they tend to neglect the most important part of a coating job, surface preparation. The time and expense required to take this step are generally resented, creating a psychological barrier. Physical application of the coating seems to be a much more productive and therefore satisfying activity than sandblasting, chipping, scraping, or even thoroughly washing a surface. Unfortunately, if proper surface preparation methods are omitted, the whole coating program is doomed to be a waste of both the time and expense involved.