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

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

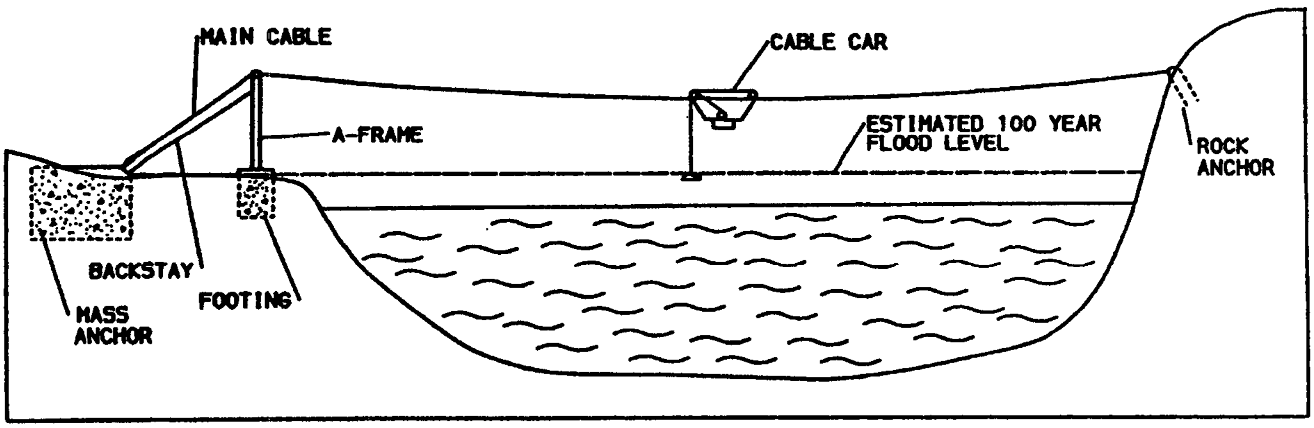


Figure 1. Typical cableway.

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 connection 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°
Friction angle of concrete on soil (δ) = 20°
Unconfined compressive strength (q_u) $\geq$ 0.5 ton/ft^2
Moist unit weight (γ) = 100 lb/ft^3
Submerged unit weight (γ') = 55 lb/ft^3
Moist soil allowable bearing pressure = 3,000 lb/ft^2
Submerged soil allowable bearing pressure = 2,100 lb/ft^2

SOIL TYPE B

Description

Loose granular soils
Wet confined silt
Soft clay

Strength characteristics

Angle of internal friction 20° $\leq$ (ϕ) < 30°
Friction angle of concrete on soil (δ) = 14°
Unconfined compressive strength 0.25 ton/ft^2 $\leq$ (q_u) < 0.5 ton/ft^2
Moist unit weight (γ) = 100 lb/ft^3
Submerged unit weight (γ')= 55 lb/ft^3
Moist soil allowable bearing pressure = 1,700 lb/ft^2
Submerged soil allowable bearing pressure = 1,200 lb/ft^2

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]

	Structural strand		6 × 19 IWRC EEIP		6 × 19 IWRC EIP		6 × 19 IWRC IPS	
Diameter (in.)	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

[1]From 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 reduc tion is deemed acceptable because integrity of the terminations is easily inspected.

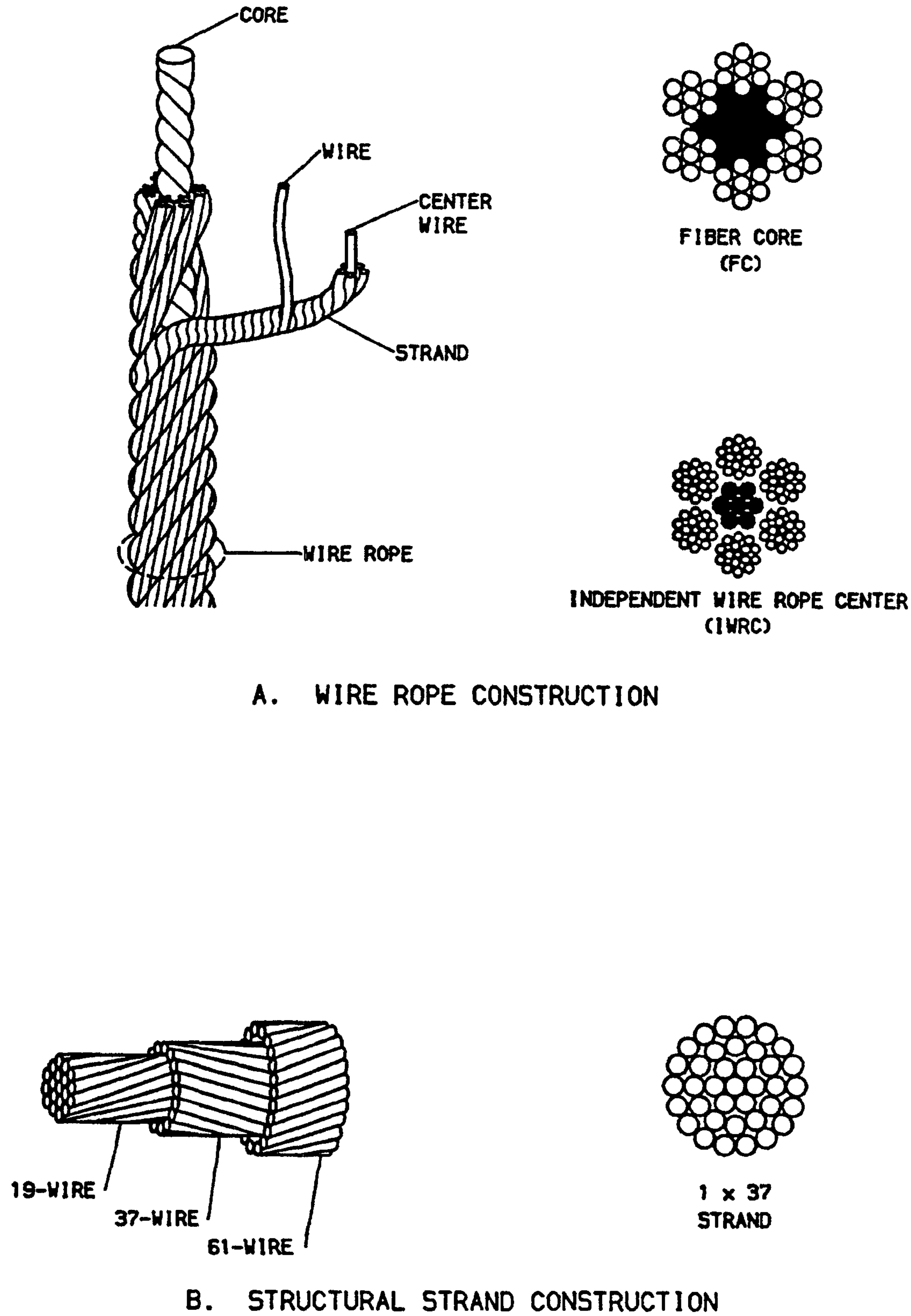


Figure 2. Construction of *(A)* wire rope and *(B)* structural strand.

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.

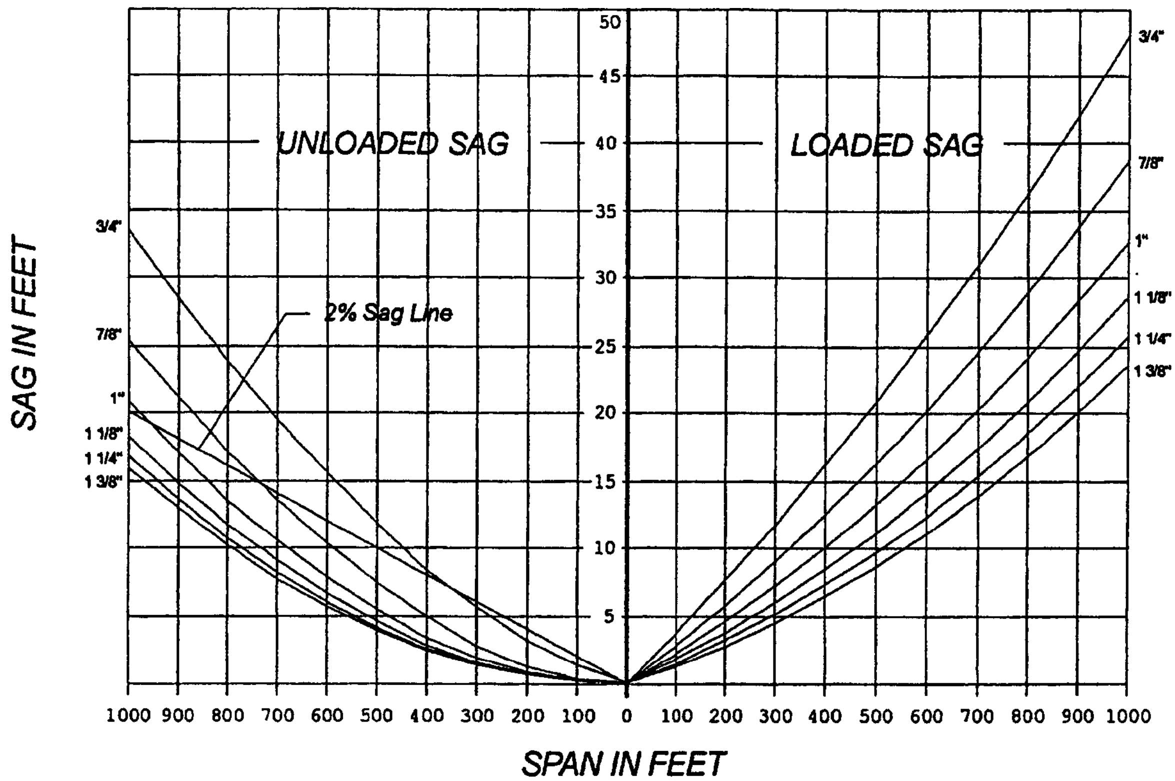
Wire rope clips must be forged steel (not malleable iron), must be galvanized to American Society for Testing and Materials (ASTM) standard A–153, and must meet Federal specification FF–C–450D, type 1, class 1. Thimbles must be heavy duty, be galvanized to ASTM specification A–153, and meet Federal specification 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/in^2. 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 gal vanized to ASTM specification A–123. U-bar and bearing block details are shown in figure 19.

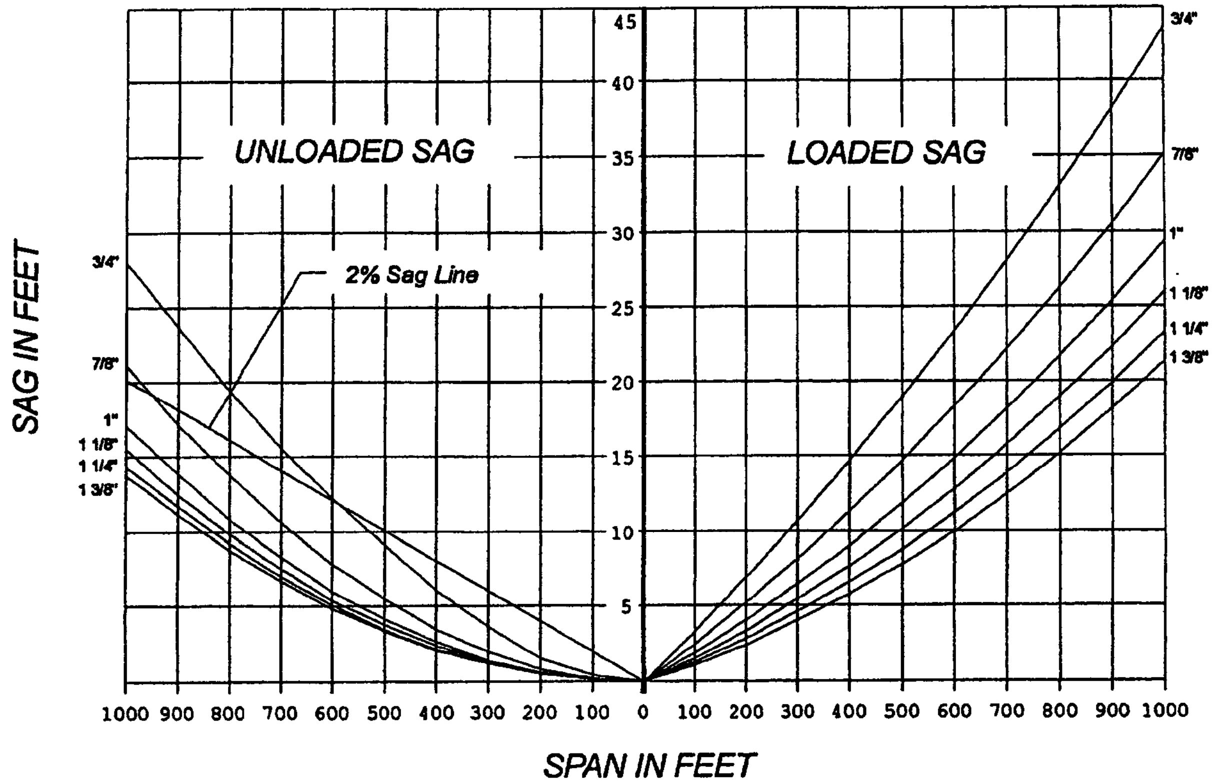
Attachment of backstay cables to A-frames or other support structures is important for the stability of the cableway structure. This can be accomplished in several ways. For steel support structures, steel plate "ears," drilled to



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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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 ×19 IWRC extra improved plow steel wire rope and cable-car load of 1,500 lb.



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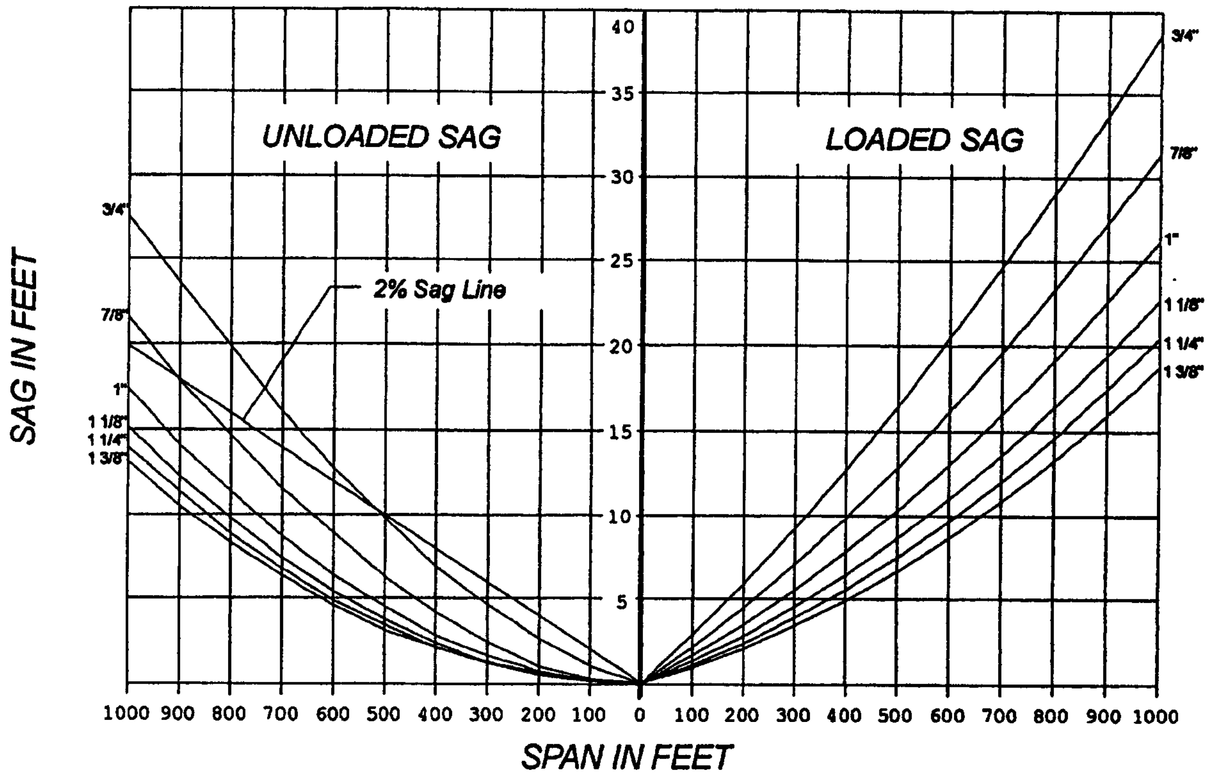
CABLE DIAMETER / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
100	OK	OK	OK	OK	OK	OK
200	OK	OK	OK	OK	OK	OK
300	OK	OK	OK	OK	OK	OK
400	OK	OK	OK	OK	OK	OK
500	OK	OK	OK	OK	OK	OK
600	OK	OK	OK	OK	OK	OK
700	X	OK	OK	OK	OK	OK
800	X	OK	OK	OK	OK	OK
900	X	OK	OK	OK	OK	OK
1000	X	X	OK	OK	OK	OK

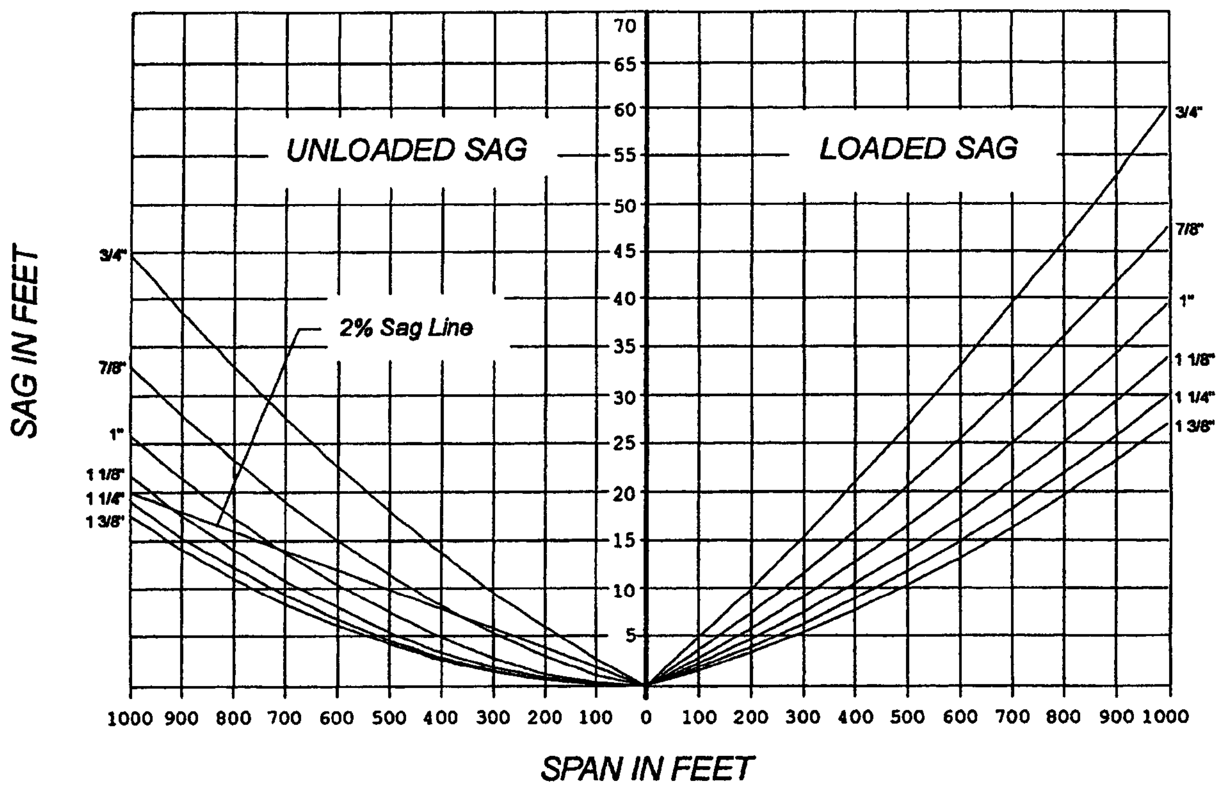
Figure 4. Sag diagram and selection guide for 6 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 1,500 lb.



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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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.

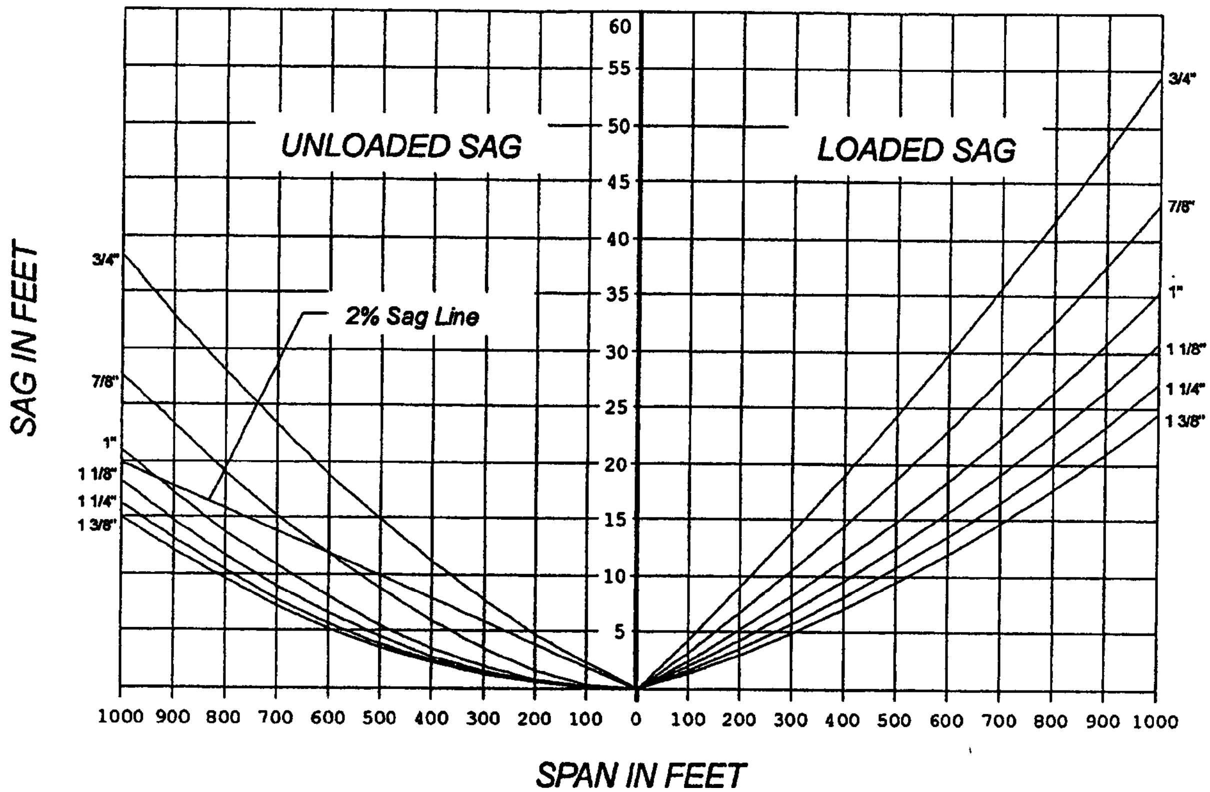


DIRECTIONS:

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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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.

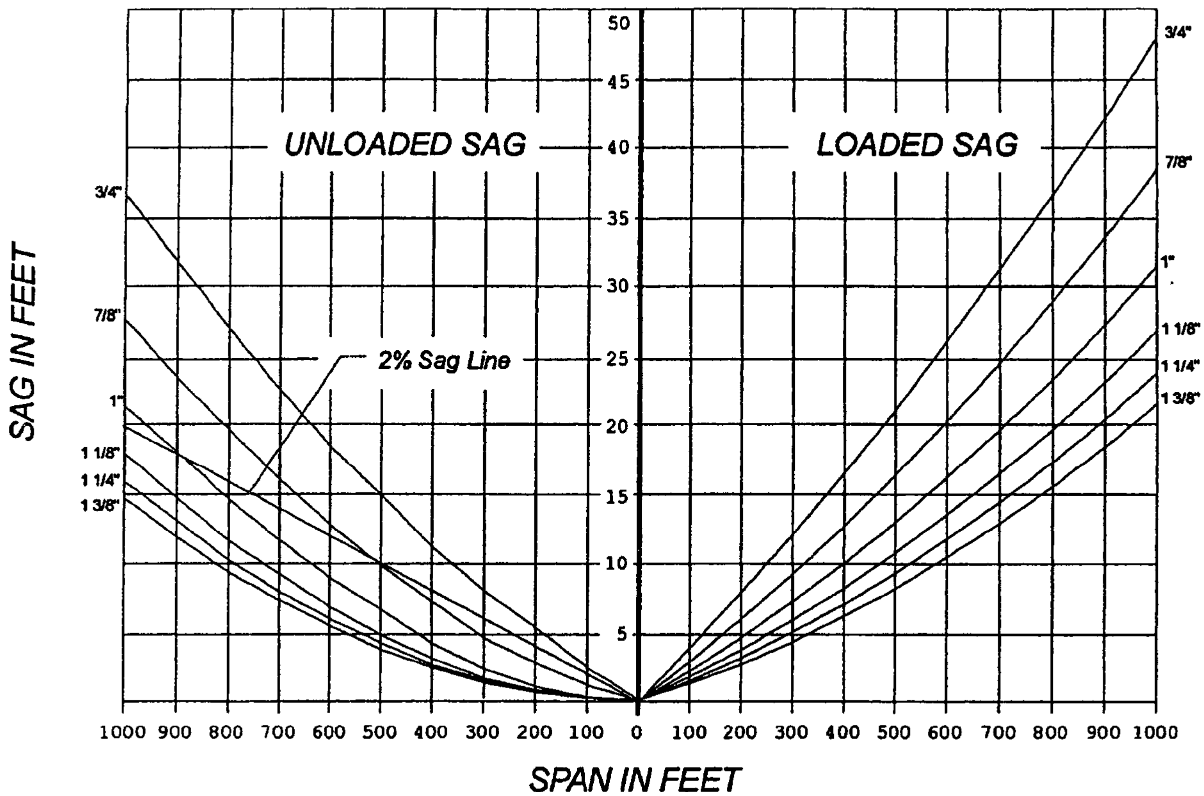


DIRECTIONS:

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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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

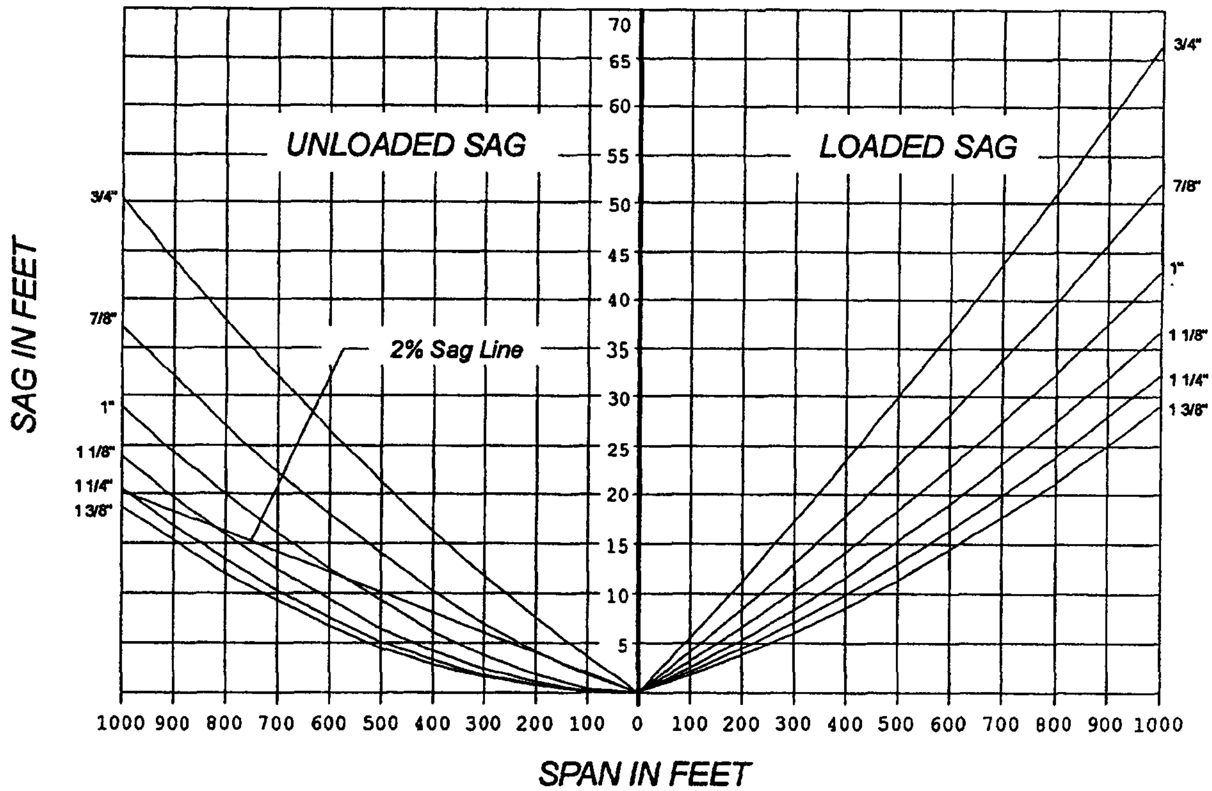
Figure 7. Sag diagram and selection guide for 6 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,000 lb.



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 SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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.

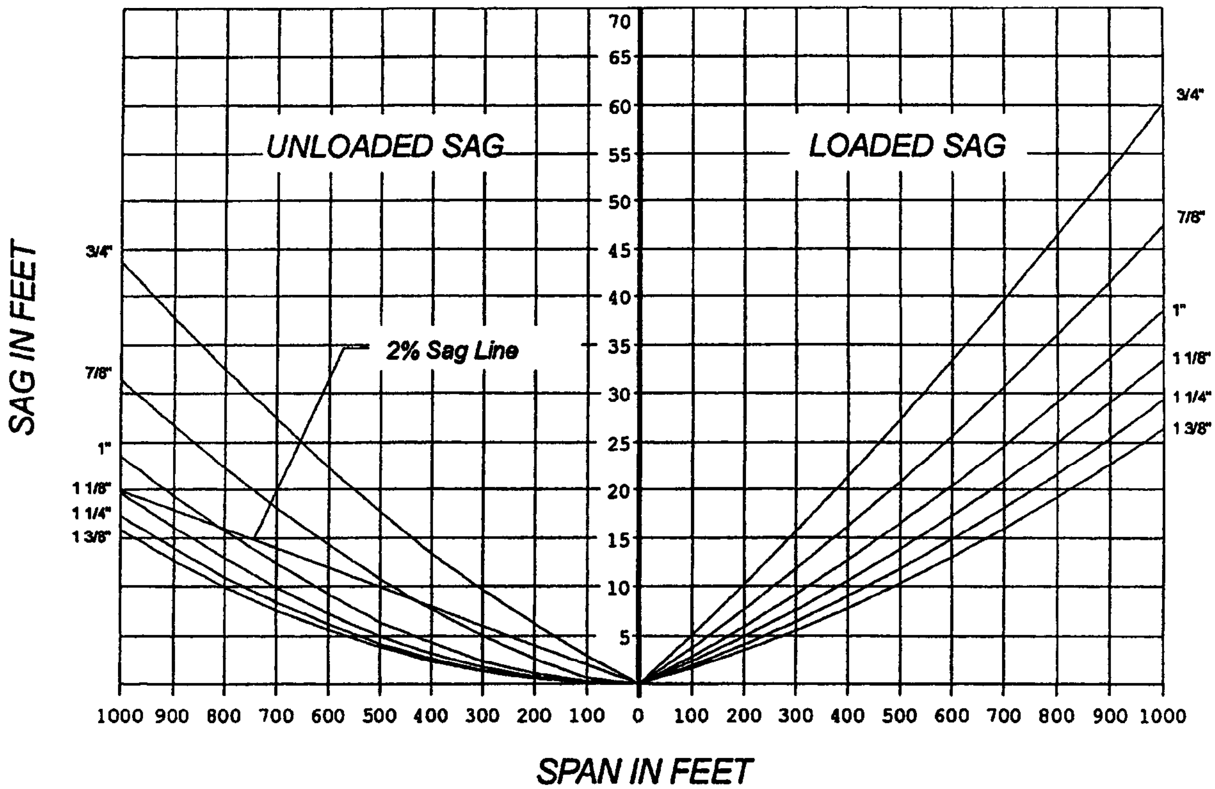


DIRECTIONS:

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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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

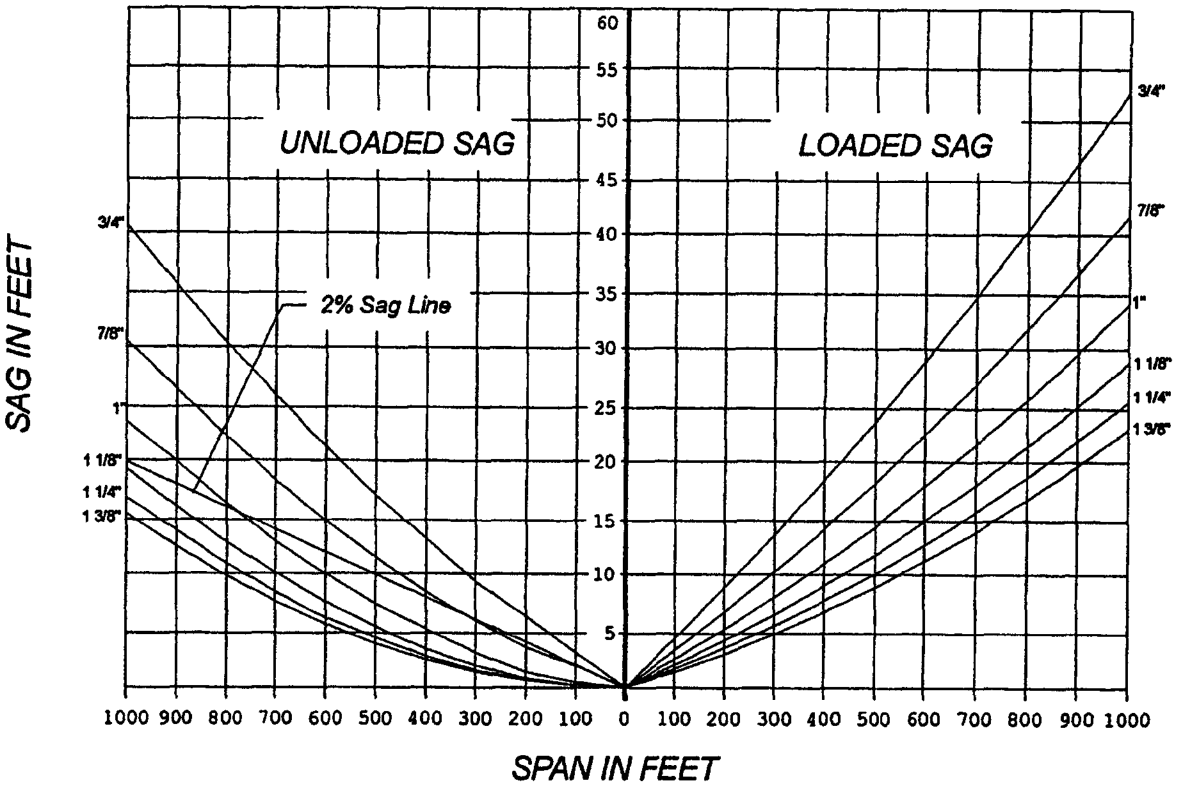


DIRECTIONS:

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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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 × 19 IWRC extra extra improved plow steel wire rope and cable-car load of 2,250 lb..

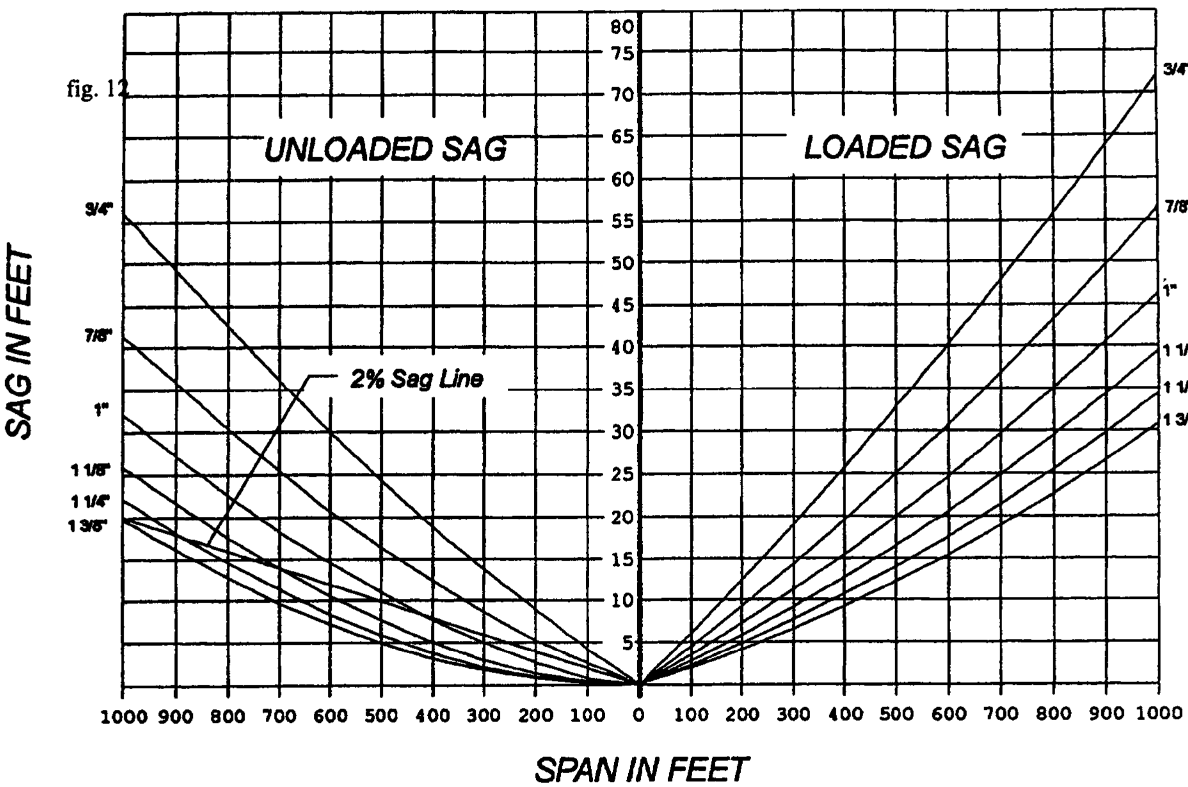


DIRECTIONS:

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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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.

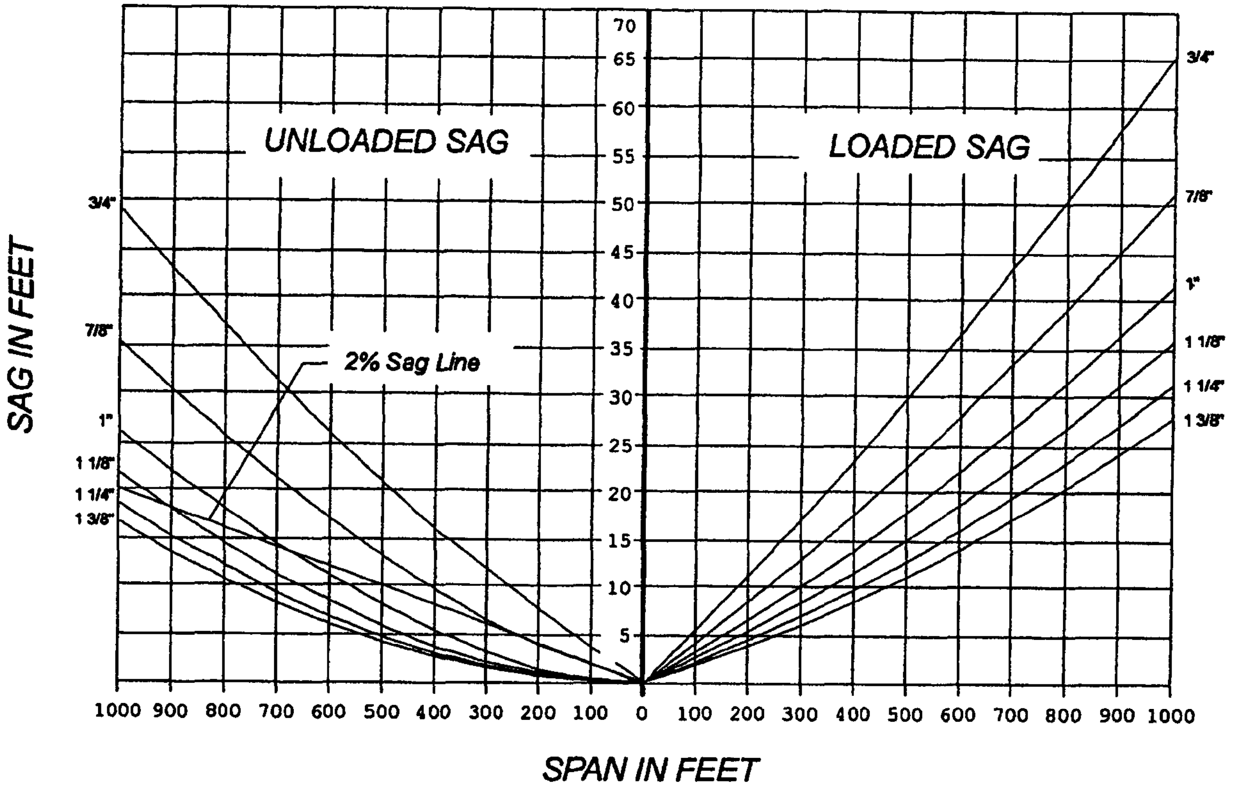


DIRECTIONS:

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 SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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

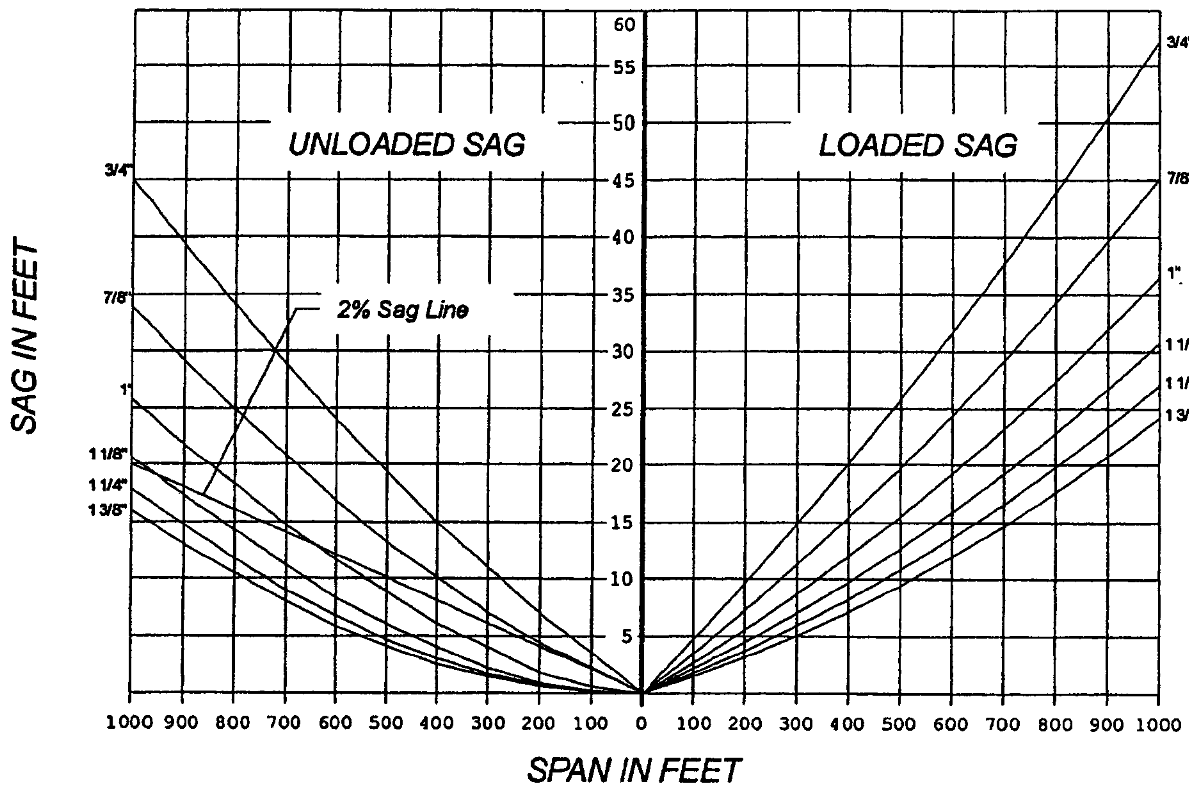
Figure 12. Sag diagram and selection guide for 6 × 19 IWRC extra improved plow steel wire rope and cable-car load of 2,500 lb.



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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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 × 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 / SPAN IN FEET	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"
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.

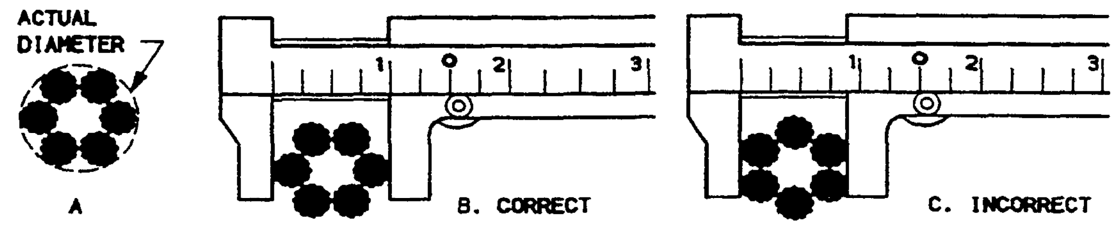


Figure 15. How to measure (or caliper) a wire rope.

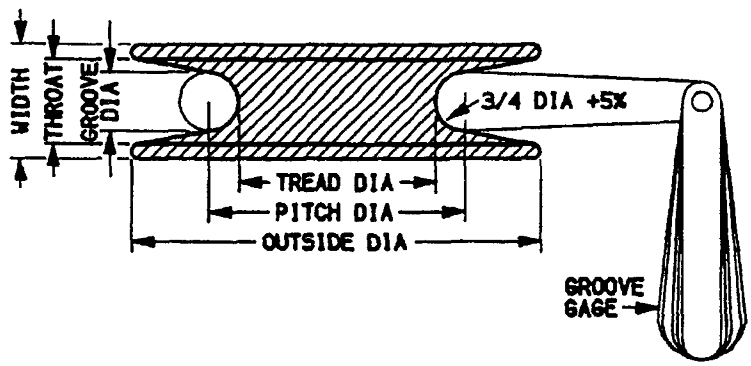


Figure 16. Various dimensions of a sheave and the use of a groove gage. DIA, diameter.

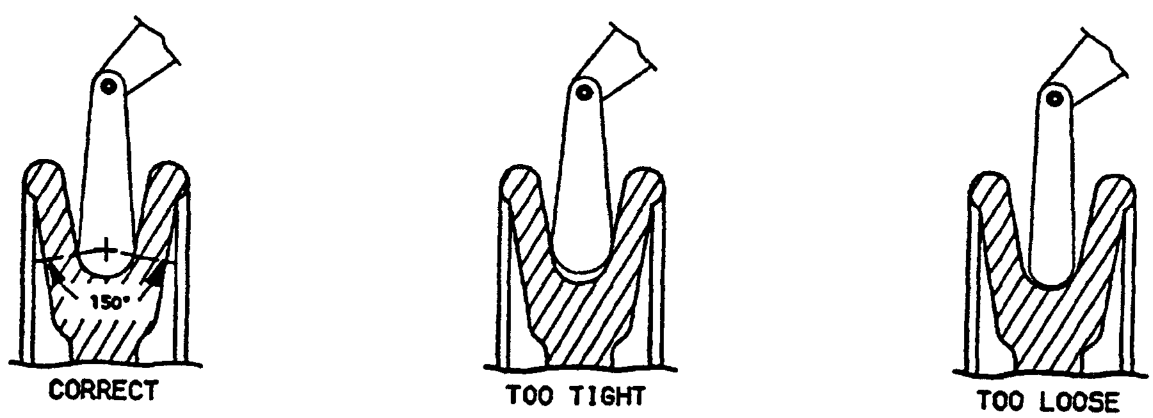


Figure 17. Cross-section sketches illustrating three sheave-groove conditions.

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 connecting 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.

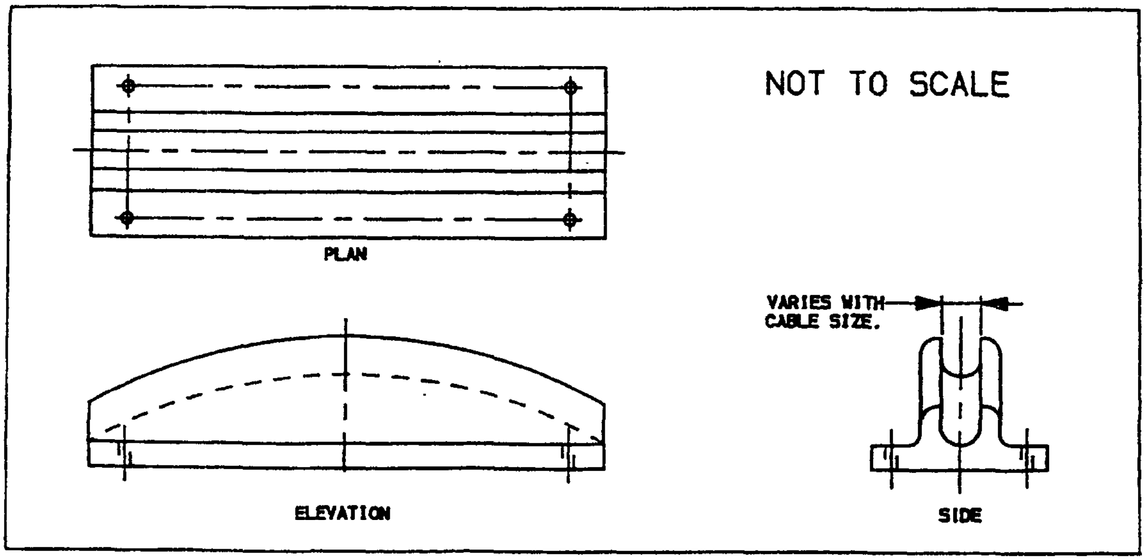


Figure 18. Typical cast-iron cable saddle block.

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/in^2.

Table 2. Hardware component sizes.

Cable design load[1] (lb)	Turnbuckle size (in.)	U-bar Diameter (in.)	U-bar Length (ft)	Auxiliary U-bar Diameter (in.)	Auxiliary U-bar Length (ft)	Backstay cable diameter (in.)
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)

[1]Cable 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 ft^2. 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

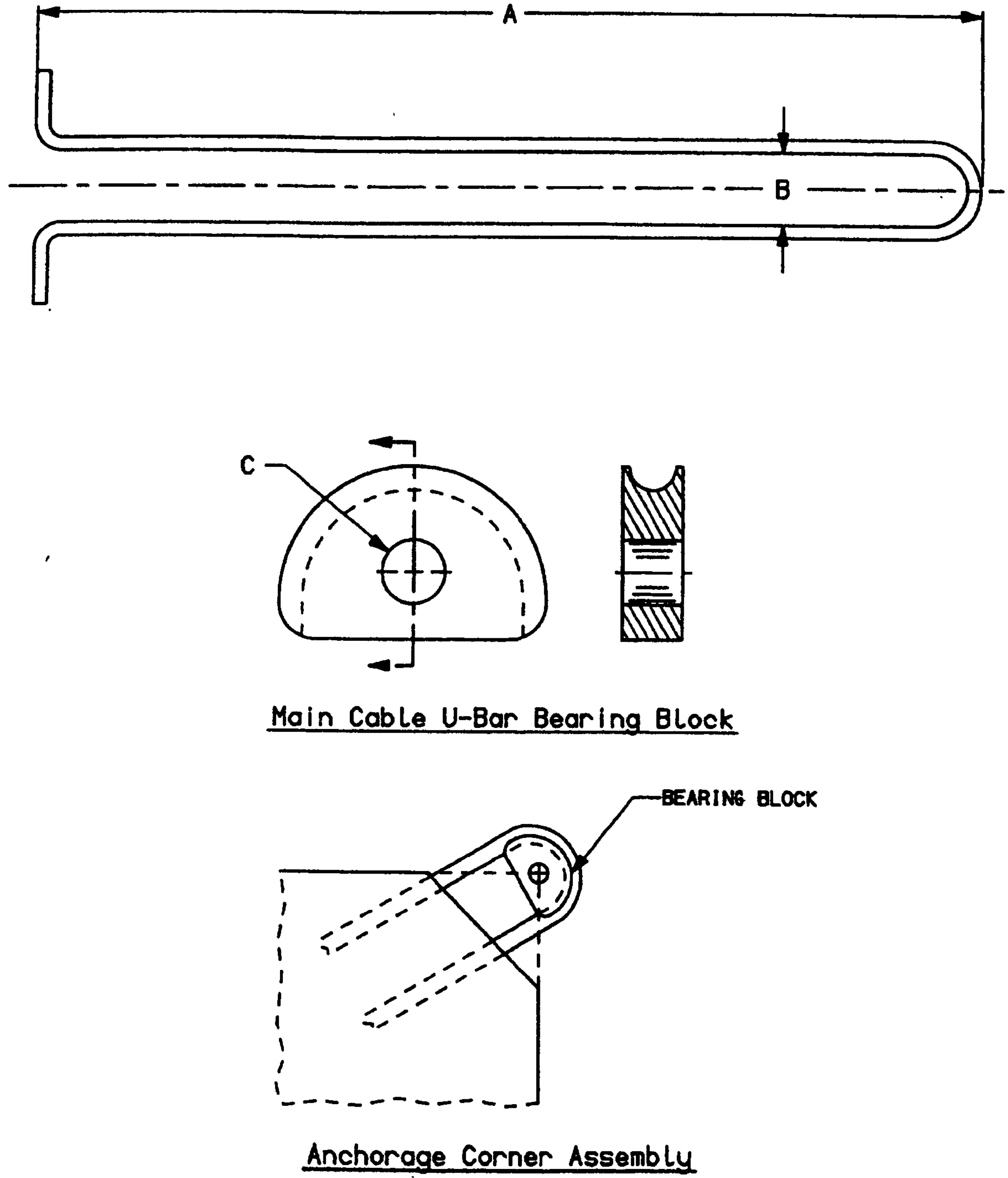


Figure 19. U-bar and bearing block. Length (A) from table 2. Width (B) usually 5 to 8 in.; must match bearing block. Drill hole (C) must match turnbuckle pin diameter.

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 backstay 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 × *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)	Combined footing *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

[1]Cable 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

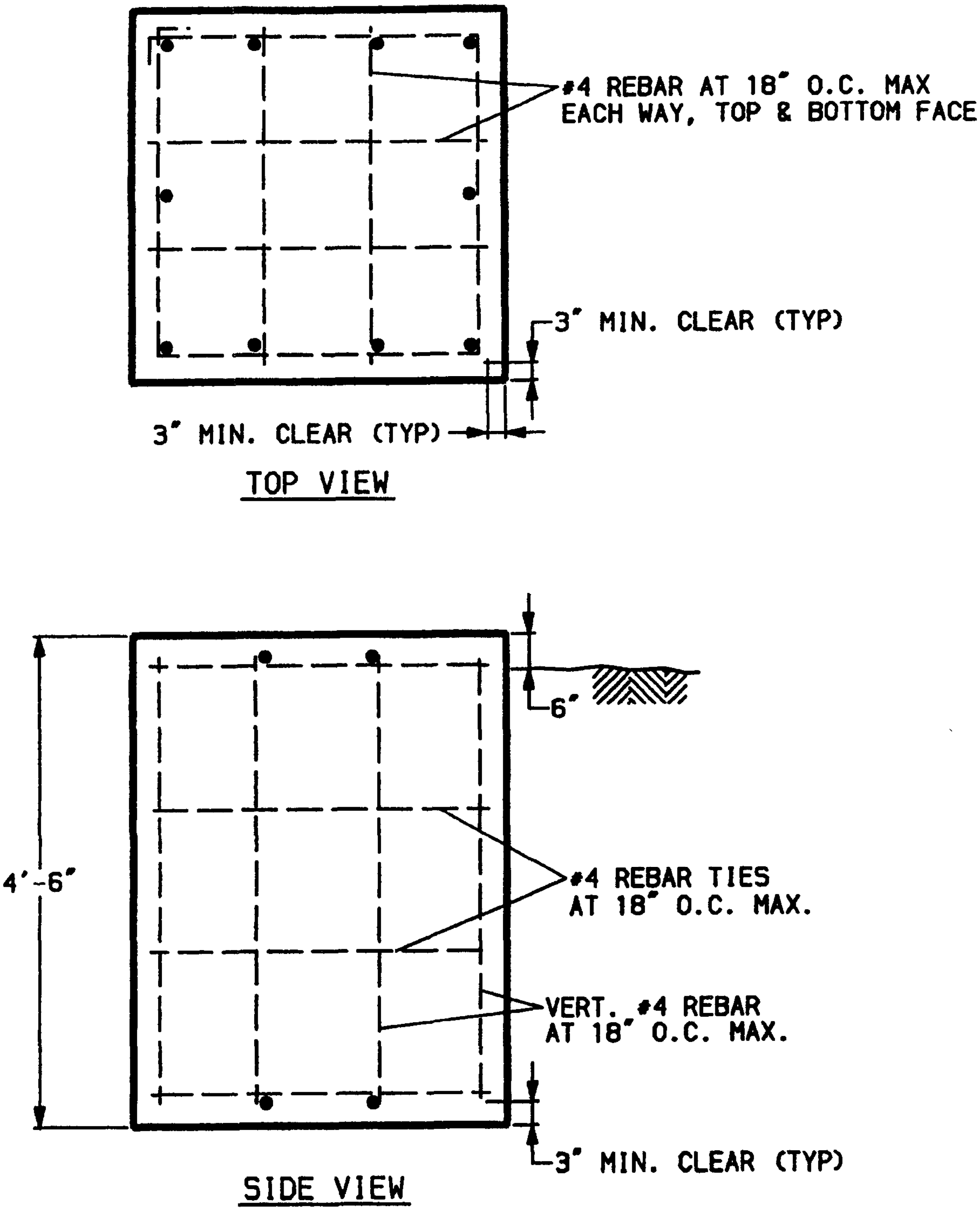


Figure 20. Single footing reinforcing bar placement. Dimensions will vary (see table 3). O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

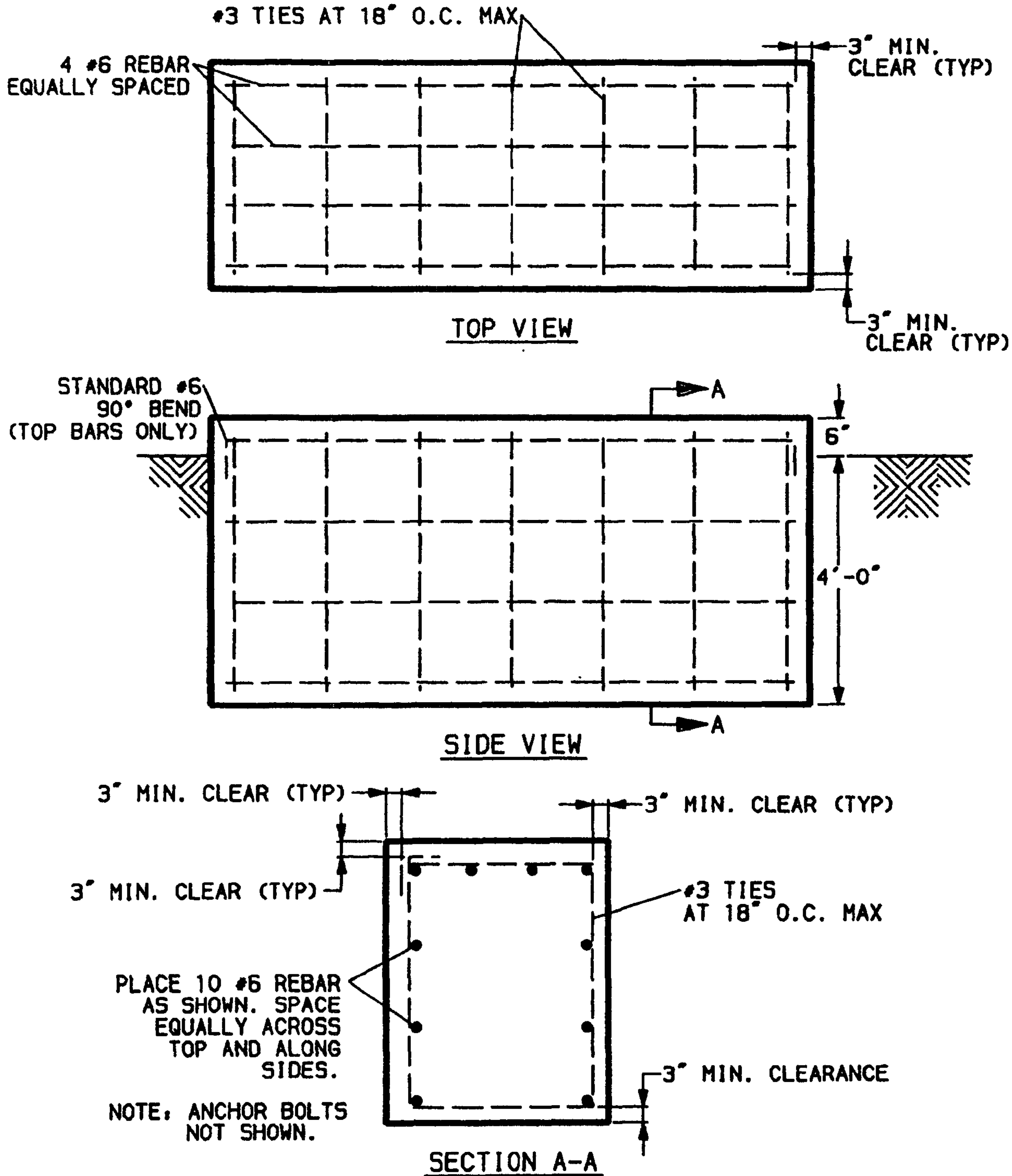


Figure 21. Combined footing reinforcing bar placement. Dimensions will vary (see table 3). O.C. MAX, on center maximum; MIN. CLEAR (TYP), minimum clearance (typical placement).

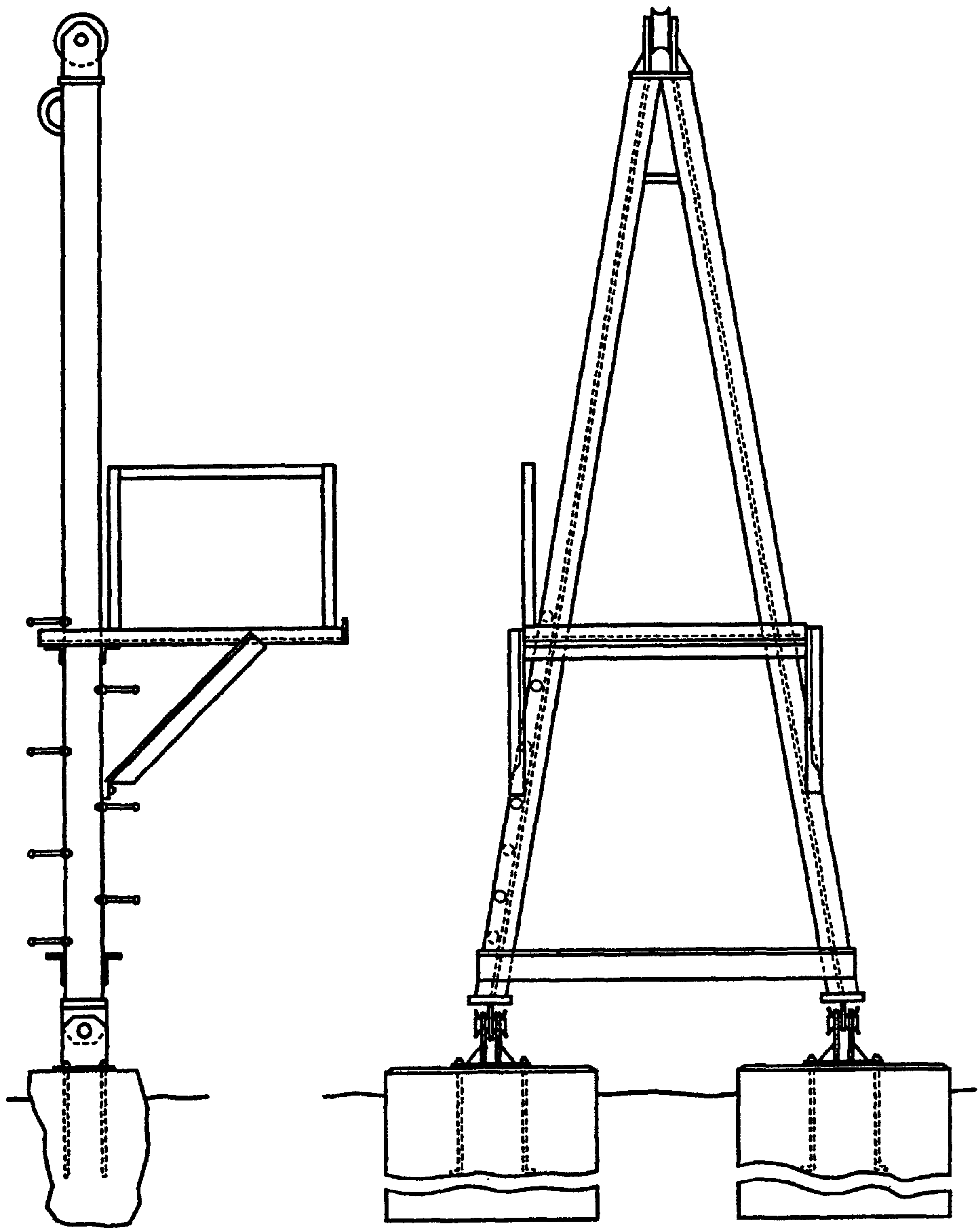


Figure 22. Steel A-frame.

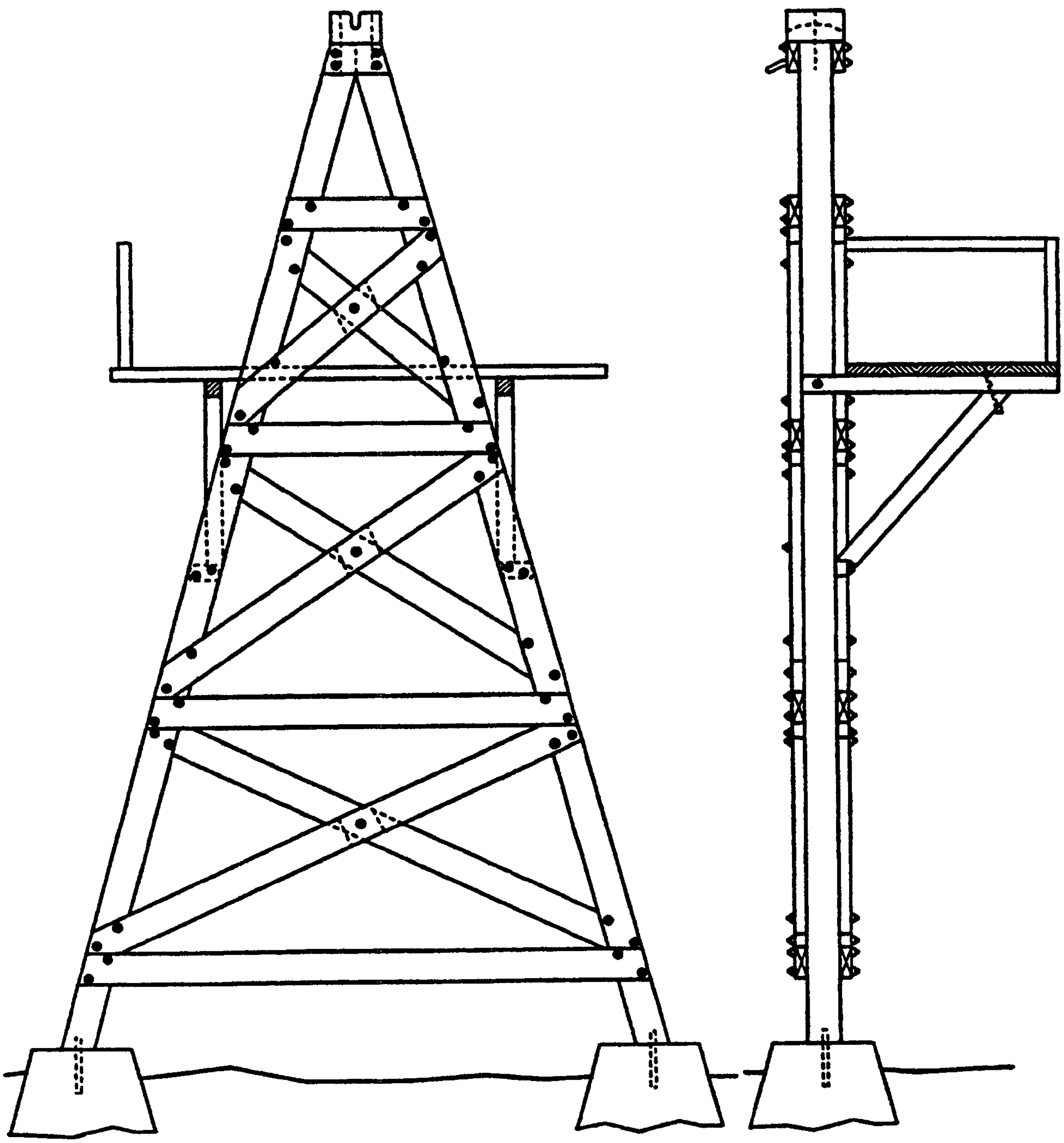


Figure 23. Wooden A-frame.

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/ft^3 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

Anchorages 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/in^2. Reinforcing steel must have a minimum yield strength of 40,000 lb/in^2.

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-