# 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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[4]This 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.

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# 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 tothe 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

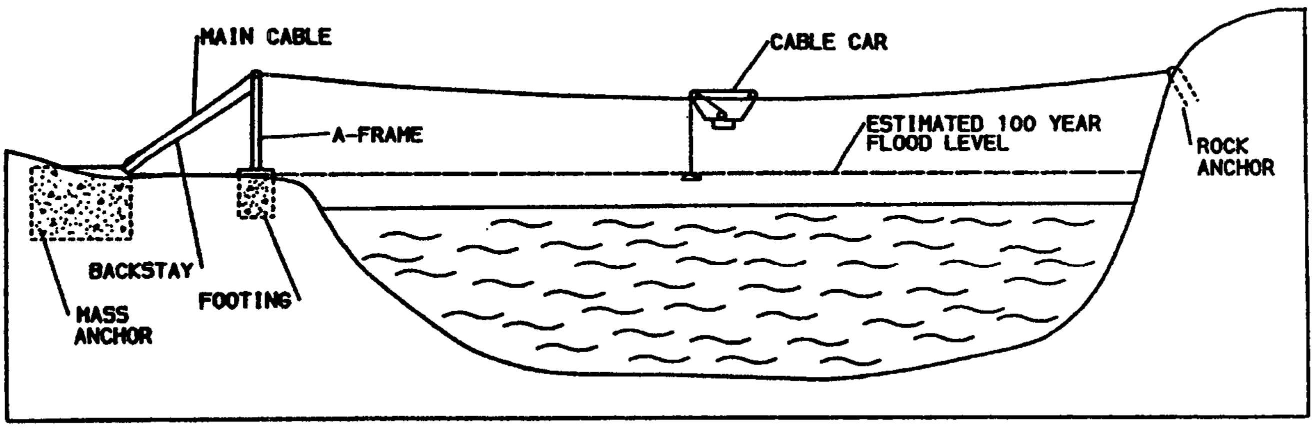


**Figure 1.** Typical cableway.

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 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 ($\phi$) $\geq$ 30°
Friction angle of concrete on soil ($\delta$) = 20°
Unconfined compressive strength ($q_u$) $\geq$ 0.5 ton/ft$^2$
Moist unit weight ($\gamma$) = 100 lb/ft$^3$
Submerged unit weight ($\gamma'$) = 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° $\leq$ ($\phi$) < 30°
Friction angle of concrete on soil ($\delta$) = 14°
Unconfined compressive strength 0.25 ton/ft$^2$ $\leq$ ($q_u$) < 0.5 ton/ft$^2$
Moist unit weight ($\gamma$) = 100 lb/ft$^3$
Submerged unit weight ($\gamma'$)= 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).