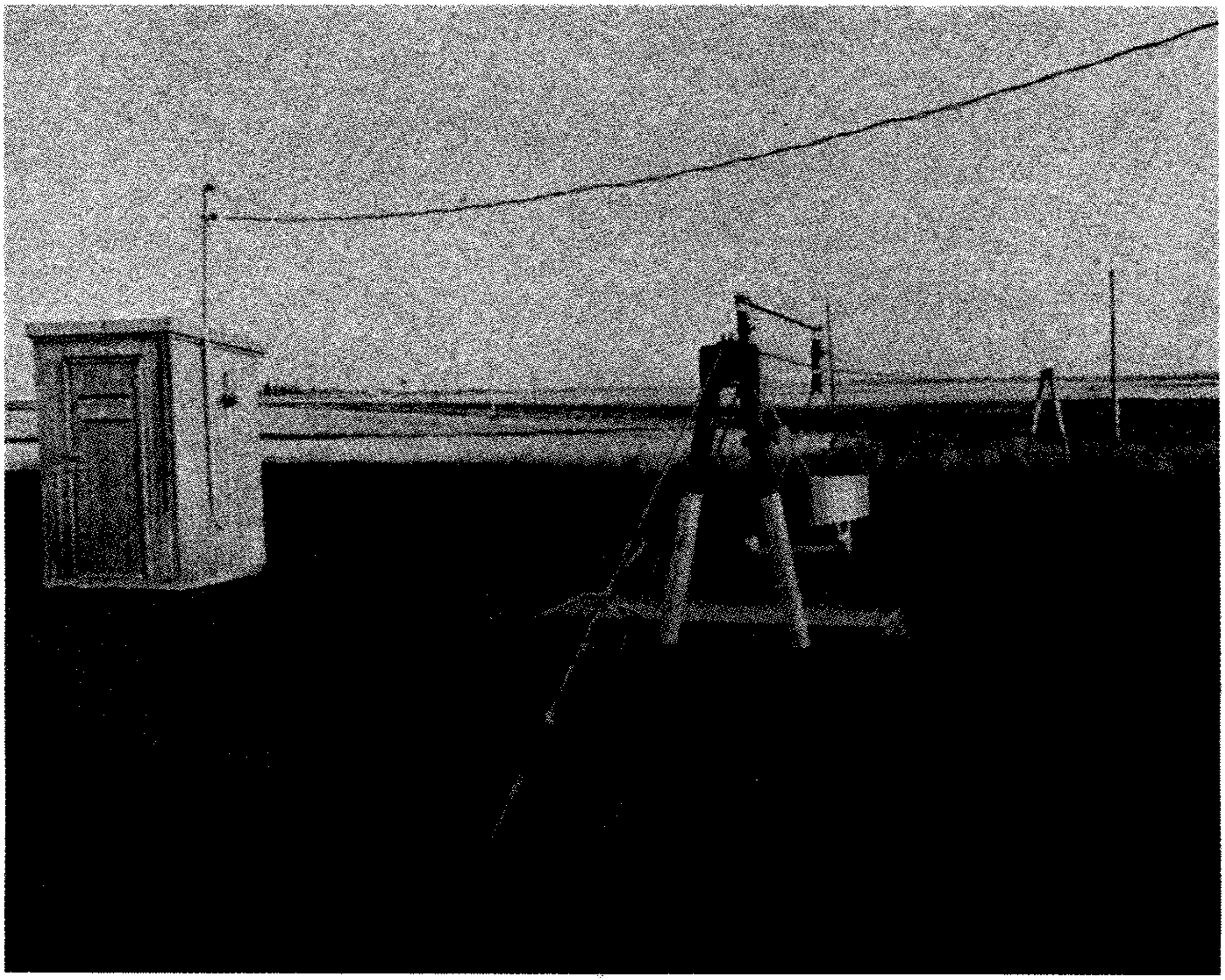
Environment Canada Environnement Canada

Safety Guide—Construction and Operation of Stream-Gauging Cableways

INLAND WATERS DIRECTORATE
WATER RESOURCES BRANCH
OTTAWA, CANADA, 1984

(Disponible en français sur demande)



Typical short-span cableway with sit-down cable car.

Contents

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Abstract

This publication discusses the safety precautions that should be followed in constructing and operating stream-gauging cableways. The main topics covered in the construction section include anchors, footings, main cable supports and the main cable. The operation section discusses inspection procedures and safe measurement procedures. Appendices covering a sample cableway design, main cable sag tables and an inspection guide are also included.

Résumé

La présente publication examine les mesures de sécurité à prendre lors de la construction et de l'exploitation des transporteurs aériens pour le jaugeage des cours d'eau. La partie qui porte sur la construction traite principalement des ancrages, des socles, des supports de câble principal et du câble principal. La deuxième partie, celle de l'exploitation, présente les procédés d'inspection et les méthodes de mesure conformes à la sécurité. En annexe, on trouve un exemple de conception d'un transporteur aérien, des tableaux de flèche du câble principal et un guide d'inspection.

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1. INTRODUCTION

1.1. Cableways are constructed so that field officers of the Water Survey of Canada may obtain measurements of streamflow or sediment discharge and obtain samples at optimum points in a cross section within a given reach. At the same time, use of cableways eliminates the risks to personnel of working from busy highway bridges or from boats. The purpose of this guide is to ensure that cableways are constructed and operated safely and, also, to enable field officers to collect hydrometric data that meet national standards.

1.2. The guide contains minimum standards for the construction and operation of cableways. Design criteria are included, as are inspection requirements. To meet local requirements additional standards may be necessary. These should be developed by Regional Office personnel in consultation with the Regional Safety Officer, Department of Labour.

1.3. Both SI and imperial units are used in the guide. Critical units are exact equivalents; noncritical units are rounded.

1.4. While all persons engaged in construction or operation of cableways have a responsibility to follow safe practices, the responsibility and authority for ensuring that the requirements outlined in this guide are met rests with the Water Survey of Canada's Regional Engineers and the Quebec Division Chief.

1.5. This guide was prepared by personnel in the Hydrometric Methods Section, Water Survey of Canada, and Water Survey of Canada construction personnel. Suggestions for changes are welcome.

2. DEFINITIONS

2.1. *Anchorage*—The anchorages are fixtures to which the main cable and staylines are attached.

2.2. *Cable car*—A carriage suspended from the main cable by two or more sheaves from which the field officer makes discharge measurements, collects samples or performs related tasks. The cable car may be operated manually or by a power system. Cable cars are generally classified as "sit down" or "stand up" depending on the mode of operation.

2.3. *Cable-car puller*—A mechanical device for propelling a cable car along the main cable. The puller may also serve as a brake to keep the car in the required location.

2.4. *Main cable*—The cable on which the cable car travels. The main cable is anchored at each end and is generally supported by A-frames or towers except where bank elevation permits use of sidehill anchorages.

2.5. *Main cable support*—A structure erected on one or both banks, the height of which ensures that the loaded cable car clears the water surface at high stage. The support is typically an A-frame structure, although towers and vertical posts are also used.

2.6. *Messenger cable*—The cable or wire rope used to support aircraft warning markers. This cable may also be used in stringing the main cable.

2.7. *Qualified person*—A person trained in the inspection of cableways and designated by the Regional Engineer or Quebec Division Chief to perform this function.

2.8. *Safety loop*—A loop of wire rope clipped to the main cable on either side of the main cable support so that the top of the support will not slide if the stayline is removed.

2.9. *Shall*—This word is to be understood as mandatory.

2.10. *Should*—This word is to be understood as advisory.

2.11. *Stayline*—A cable attached to the top of the main cable support and connected to the anchorage, used to ensure the stability of the main cable support.

3. METRIC CONVERSION FACTORS

Length

1 inch = 0.025 40 m

1 foot = 0.304 80 m

Area

1 square inch = 645.16 mm^2

1 square foot = 0.092 903 m^2

Volume

1 cubic inch = 16 387 mm^3

1 cubic foot = 0.028 317 m^3

Mass

1 avoirdupois ounce = 28.350 g

1 avoirdupois pound = 0.453 59 kg

Mass/length

1 avoirdupois pound/foot = 1.488 2 kg/m

Mass/volume

1 avoirdupois pound/cubic foot = 16.018 kg/m^3

Force

1 ounce force = 0.278 01 N

1 pound force = 4.448 2 N

Pressure

1 pound force per square inch = 6.894 8 kPa

1 pound force per square foot = 47.880 Pa

Temperature

°C = 5/9 (F + 40) - 40, or 5/9 (F - 32)

°F = 9/5 (C + 40) - 40, or 9/5 (C + 32)

4. CONSTRUCTION

The factors that shall be considered in designing cable-ways (Fig. 1) are described in the following sections. A worked example appears in Appendix A.

4.1. Anchor and Footings

Anchor and footings are designed for a factor of safety of two. Where soil conditions are well defined by tests, this factor of safety may be reduced to 1.5 when designing gravity anchors. On the other hand, in designing footings for small cableways, it may be more economical to use standard overdesigned footings.

Excavation backfill shall be free of organic matter, excessive fine aggregates, boulders greater than 100 mm (4 in.) in diameter or frozen lumps. Where practicable, clean crushed stone or gravel should be used. Backfill should be power-compacted in layers not exceeding 600 mm (2 ft) in thickness. Care should be taken to ensure good drainage around anchors and footings so that erosion will not occur.

The horizontal component of cable tension is used in designing anchors. This value is given by

$$T = \frac{wgS^2}{8D} + \frac{PgS}{4D} = \frac{S(2P + wS)\ g}{8D} \qquad (1)$$

where

T = horizontal component of tension in newtons

w = mass of the wire rope or cable in kilograms/metre

S = horizontal distance between supports in metres

D = vertical deflection of wire rope or cable at mid-span in metres, i.e. the sag

P = mass of single concentrated load in kilograms

g = acceleration of gravity (9.806 65 m/s^2)

If English units are used, remove g from the expression; T will be expressed in pounds (force).

The actual tension, F, in the cable may be expressed as:

$$F = T\sqrt{1 + \frac{16D^2}{S^2}} \qquad (2)$$

4.1.1. Gravity Anchor

4.1.1.1. The following factors shall be considered in design of gravity anchors:

a) Mass of concrete.

b) Mass of earth prism at front of the anchor.

c) Friction between the bottom of the anchor and the earth prism and the earth on which both rest.

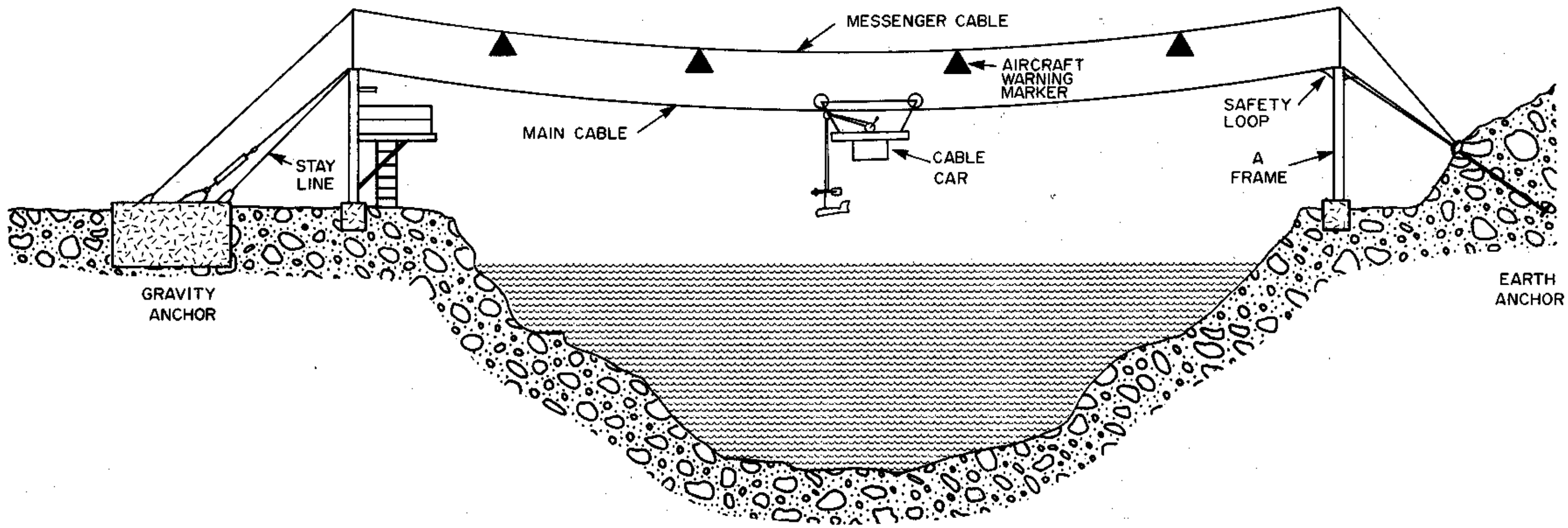

Figure 1. Cableway.

d) Passive pressure of the earth, provided that the front face of the anchorage is placed against undisturbed earth.

e) Shearing resistance of the sides of the anchor and the earth prism.

When sidehill anchors are used, items (b) and (d) above shall be reduced or eliminated, however, the earth surcharge on the anchor should be considered in the computations. When the anchor could be subject to submergence while the cableway is in use, the buoyant force on the anchor shall also be considered.

4.1.1.2. The anchor should be placed in direct line with the main cable so that there is no bending moment on the anchorage connection. The top surface of the anchor should be slightly above ground level so that the U-bar connection may be easily inspected. A benchmark plug may be placed in a horizontal surface of the anchor and referenced to other points for use in future stability checks.

4.1.1.3. The U-bars shall be manufactured in accordance with CSA Standards G40:20-1973 and G40:21-1973 and shall be free of paint and galvanized, preferably only that portion not embedded in concrete. The U-bars for the main cable shall be at least 25 mm (one inch) in diameter.

4.1.1.4. The U-bars shall be embedded in the concrete for at least 30 times their diameter and shall have 150-mm (6-in.) end hooks. The anchor shall have sufficient longitudinal and transverse reinforcement to transmit the load into the anchor.

4.1.2. Rock Anchor

4.1.2.1. Design rock anchors for:

a) Tension

b) Bearing strength of the rock

4.1.2.2. Use drop-forged high-tensile galvanized-steel anchors manufactured in accordance with CSA Standard G40:20-1973 and G40:21-1973 with either wedges or expansion shields or upset ends for grouting. Anchors for the main cable shall be at least 25 mm (one inch) in diameter.

4.1.2.3. Install anchors at least 0.4 m (15.5 in.) in rock with the eye not more than 40 mm (1.5 in.) above the surface. The rod should be in direct line with the main cable. (Anchors installed at an angle to the main cable shall also be designed for bending moment.) Grout the anchor in place using molten zinc, sulphur, Cement Fondu or other commercial grout that expands as it hardens.

4.1.2.4. Where more than one rock anchor is used to support the main cable, the bridle connecting the anchors shall be designed to distribute the load equally.

4.1.3. Other Anchors

4.1.3.1. Anchors of the deadman type, such as pressure-treated logs, I beams or the A.B. Chance anchor, develop their strength by direct compression of the soil in which they are buried. In designing the anchor, the yield strength of the anchor rod itself shall also be checked.

4.1.3.2. Install these anchors with at least 1.5 m (5 ft) vertical cover to ensure that they are below the active frost zone. The rod connecting the anchor to the main cable must be set such that it is in a direct line so that no bending moment will develop in the rod.

4.1.4. Footings

4.1.4.1. Design footings so that the maximum allowable bearing capacity of the soil is not exceeded.

The design load F_v for the footings may be given by:

$$F_v = \frac{F \sin \alpha}{n} \qquad (3)$$

where

α - is the angle of the main cable to the horizontal at the anchorage, generally 30°

n - is the number of footings

F - is the design tension in the main cable from equation (2)

4.1.4.2. Concrete or pipe footings are the most often used. In permafrost areas a timber crib may be required to keep bearing pressures below the maximum allowable. The moss cover over the permafrost should not be disturbed.

4.1.4.3. Footings should be installed so that the top of the footing is about 150 mm (6 in.) above the surface and should extend below the frost line.

4.1.4.4. Anchor bolts shall extend into the footing for a distance of 30 times their diameter and should have 75-mm (3-in.) end hooks.

4.2. Main Cable Supports

Supports shall be sufficiently high that the lowest point of a loaded cable car at mid-span will clear the water surface at maximum probable stage by at least 1 m (3 ft). The clearance should be increased when a stream is likely to carry heavy drift. When cableways are constructed on navigable streams, the clearance of the lowest point of the unloaded main cable shall be sufficient to permit the unimpeded movement of river traffic. The Ministry of Transport provides information on required clearances.

Supports shall be marked in accordance with Ministry of Transport regulations in those cases where the cableway may present a hazard to aircraft.

The tops of the supports at each end of the main cable should be at the same elevation. In the case where the cable car will always be kept on one side of the river, the elevation of the top of the far support can be higher by 0.5% of the span to permit easier return of the cable car. Metal supports should be electrically grounded.

4.2.1. A-Frames

4.2.1.1. The legs of an A-frame shall have a 1:5 slope and the frame itself when installed shall be plumb. The A-frame shall have a horizontal tie at the base and diagonal bracing as required. The A-frame members shall be designed as columns to withstand the vertical force given in equation (3). Use an l/r ratio of 120 for the A-frame legs and 200 for bracing.

4.2.1.2. Steel pipe, steel sections, or pressure-treated timber may be used in construction of A-frames. Steel should be galvanized or painted and timber should be painted to prevent deterioration. (Steel sections, if galvanized, shall be free from dirt and rust before painting.) Steel pipe A-frames shall have drain holes to prevent moisture buildup.

4.2.1.3. The top of the A-frame shall be equipped with a steel saddle or sheave of the appropriate size on which the main cable rides.

4.2.2. Towers

4.2.2.1. The legs of a tower shall have a 1:5 side slope to eliminate the need for side guys. The tower legs shall have horizontal ties at the base and diagonal bracing as required. The tower members shall be designed as columns (l/r ratio of 120 for main members, 200 for bracing) to withstand the vertical force given in equation (3). In addition, towers shall be designed for forces caused by wind loads when the uniform load exceeds the concentrated load.

4.2.2.2. Steel sections shall be used in construction of towers. The materials shall be galvanized or painted.

4.2.2.3. The top of the tower shall be equipped with a steel or equivalent (e.g. Australian iron bark wood) saddle of the appropriate size on which the main cable rides.

4.2.3. Other Supports

4.2.3.1. Other supports such as guyed or cantilevered posts may be used for short span cableways. The design and construction requirement of these supports is similar to 4.2.1. and 4.2.2. except that the lateral stability of guyed posts must be considered and side guys designed. Cantilevered posts shall be designed for bending and for passive resistance and shearing of soil.

4.2.4. Platforms, Ladders and Stairs

4.2.4.1. Platforms shall be as long as the cable car and wide enough to permit easy access to the car; platforms may be split or offset as required. Where necessary, fixtures should be provided to enable rope tackle to be used in raising or lowering equipment to and from the platform.

4.2.4.2. Platforms higher than 1.2 m (4 ft) above ground level shall be equipped with a handrail 1.1 m (42 in.) high with intermediate rail on both sides and with a toeboard at least 90 mm (3.5 in.) in height. The platform shall have a non-skid, well-drained, open-construction surface.

4.2.4.3. Ladders shall be installed at a slope of 1:5 so that there is toe clearance of 180 mm (7 in.) measured from the centreline of the rungs. The ladder shall be at least 400 mm (15 in.) in width. The ladder shall extend at least three rungs above the platform surface, or secure and convenient hand grabs shall be provided. Where ladders are more than 6 m (20 ft) in length, the ladder shall be caged, and in addition, a resting platform shall be provided when lengths of climb are greater than 9 m (30 ft). Alternatively, fall arresters may be provided instead.

4.2.4.4. Stairs shall be at least 0.6 m (24 in.) in width and have a secure handrail when total height exceeds 1.2 m (4 ft). The stair treads shall have a non-skid, open-construction surface.

4.2.4.5. All metallic components used in platforms, ladders and stairs shall be non-corrodible or painted; all wooden components shall be treated with preservative and painted.

4.2.5. Cable Car Retainer

4.2.5.1. Each cable support having a platform shall also be equipped with a cable car retainer that engages the cable car as it approaches the platform.

4.2.5.2. A secure means of locking the car shall be provided.

4.2.6. Sag Targets

4.2.6.1. Where feasible, sag targets showing the correct unloaded sag should be attached to the cable supports. Alternatively, a record of elevation of the low point of the cable at the correct unloaded sag should be maintained for the station.

4.3. Main Cable

4.3.1. The main cable shall be designed using the value of F from equation (2). A factor of safety of 5 shall be used when the main cable is wire rope and a factor of safety of 4 for bridge strand. Note that thimble and clip connections develop a maximum of 80% of the ultimate strength of the cable when installed according to manufacturer's specifications.

4.3.2. The design loads for the main cable comprise the following:

a) Uniform load based on mass of main cable

b) Concentrated load at mid-span

   i) Breaking strength of sounding cable, 4450 N (1000 lb) for 2.5 mm (0.1 in.) cable and 7100 N (1600 lb) for 3.2 mm (0.125 in.) cable.

   ii) Mass of cable car and equipment.

   iii) Mass of operator.

c) Wind and ice load (where the uniform load exceeds the concentrated load).

The main cable should be designed so that the unloaded sag is not greater than 2% of the span. Sag tables are given in Appendix B.

4.3.3. In no case shall a wire rope or cable less than 20 mm (0.75 in.) be used as a main cable. Also, the main cable shall be galvanized and prestretched to a tension equal to 50% of the nominal ultimate strength. The recommended wire rope for relatively short span cableways is 110/120 improved plow, 6 x 19, IWRC; for long cableways or ones carrying larger than normal loads (such as in sediment surveys operations), bridge strand is recommended.

4.3.4. The use of cable safety loops clipped to the main cable on each side of the saddle or sheave is recommended, particularly in areas subject to vandalism.

4.4. Staylines

4.4.1. Back stays shall be designed for a load equal to F (1 - cos α) with a factor of safety of 5. The value of the load given by this expression is conservative.

4.4.2. Side guys, when used, shall be designed for wind loading.

4.4.3. In no case shall staylines smaller than 10 mm (0.375 in.) be used; 15-mm (0.5-in.) staylines may be required on longer cableways. The recommended stayline is 1 x 7 galvanized guy strand.

4.4.4. Back stays should be installed so that they are in direct line with the main cable. All staylines shall be taut at the time of installation. Where feasible, staylines should not connect to the same U-bars as the main cable.

4.5. Wire Rope Fittings

4.5.1. All fittings such as turnbuckles shall be drop-forged rather than cast and shall be galvanized. In addition, all turnbuckles should have safety rivets or bolts and nuts with ends peened to prevent complete unturning by vandals.

4.5.2. Fittings such as cable clips, fist grips, guy grips, and so forth shall be used in accordance with manufacturer's instructions.

4.6. Aircraft Warning Markers

4.6.1. When required by the Ministry of Transport, aircraft warning markers shall be suspended immediately above the main cable from a messenger cable.

4.6.2. The design of the markers, and their spacing shall conform to Ministry of Transport regulations.

4.7. Cable Cars

4.7.1. General

4.7.1.1. Cable cars shall be designed to sustain the load used in 4.3.2.(b) with a safety factor of two.

4.7.1.2. All metallic structural members shall be free of welds and protected against corrosion. All wooden parts of the car shall be treated with preservative and painted.

4.7.1.3. Cable car sheaves shall be at least 200 mm (8 in.) in diameter and have pre-lubricated sealed bearings or self-lubricating bronze bushings. Forged steel sheaves are recommended. The sheaves shall be designed and installed so that the main cable cannot wedge between the sheave and the cable car hangers.

4.7.1.4. Cable cars shall have finger guards adjacent to the inward side of the sheaves.

4.7.1.5. Cable cars should be equipped with a reel support at a convenient location for use from either end of the car. The support shall be oriented so that the deflection of the suspension cable over the reel's guide sheave is less than 90°. Other guide sheaves should adhere to minimum winding diameters specified by manufacturers of the suspension cable used.

4.7.1.6. The cable car shall be provided with a means of securing it at any position on the main cable.

4.7.1.7. The cable car shall be provided with a container for small articles. The container shall have a drain hole.

4.7.2. Sit-down Cable Car

4.7.2.1. Sit-down cars are generally used on short span cableways or on cableways for which it is seldom necessary to use sounding weights having a mass of 45 kg (100 lb) or greater. A typical car is shown in Figure 2.

4.7.2.2. In addition to the requirements given in 4.7.1., sit-down cars shall have a seat at each end of the car and shall have a foot rest. The clearance between the seat and the main cable shall be at least 0.9 m (36 in.).

4.7.2.3. Where the height of the sides of the sit-down car is inadequate to contain the operator, say, 200-250 mm (or 8-10 in.), additional guardrails should be provided.

4.7.3. Stand-up Cable Car

4.7.3.1. Stand-up cars are generally used on long span cableways where sounding weights having a mass of 45 kg (100 lb) or greater are frequently used. Stand-up cars are also used at all sites where sediment survey programs are in effect. A typical car is shown in Figure 2.

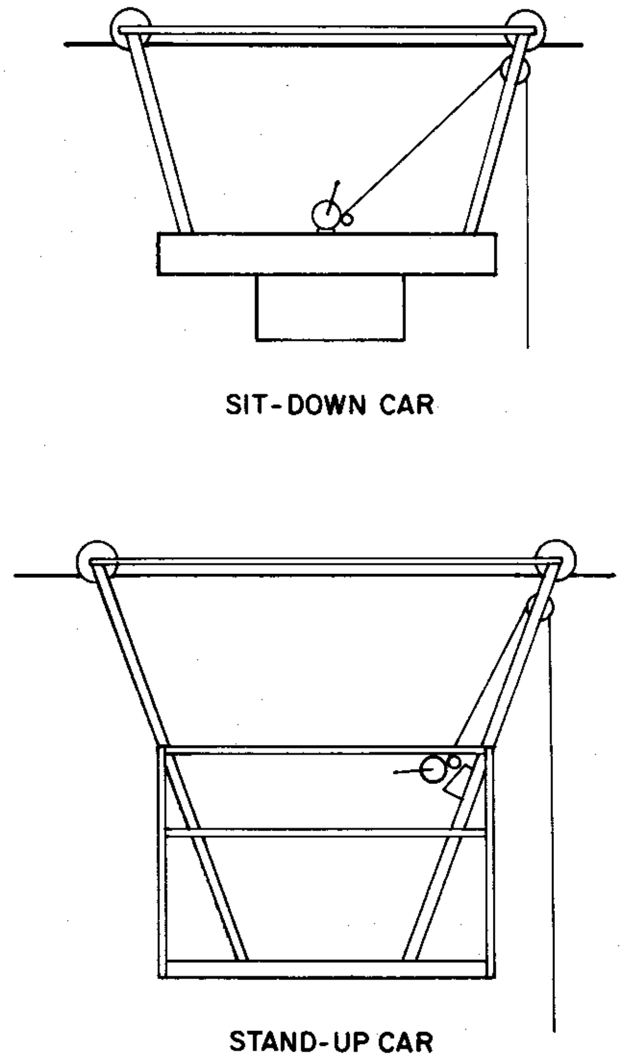

Figure 2. Sit-down and stand-up cable cars.

4.7.3.2. In addition to the requirements given in 4.7.1., stand-up cars shall have a clearance between the floor and the main cable of at least 1.8 m (6 ft) and shall have a protective railing on all sides at a height of at least 1.1 m (42 in.) above the floor with an intermediate railing. The floor shall have a toeboard at least 90 mm (3.5 in.) in height around its perimeter.

4.7.4. Cable Car Accessories

4.7.4.1. Each cable car or cable car operator shall be equipped with a cable car puller and a cable car retriever. The unmanned rather than the breeches-buoy type of retriever is preferred.

5. OPERATION

5.1. Inspection

Once yearly, and more frequently for newly installed cableways, the following items should be checked where applicable by a qualified person and an inspection report such as the one shown in Appendix C completed and submitted to the appropriate personnel in the Region. In cases where the safety of the cableway is in doubt, the structure shall be checked with a dynamometer to twice the design tension.

5.1.1. Anchors and Footings

a) General condition of concrete and connections.

b) General condition of rock and other anchors.

c) Connections free of soil and debris.

d) No movement of footings; anchor's surface should be visible. Check that the distance from a point on the anchor (such as a benchmark) to a point on each footing (such as an anchor bolt) is unchanged.

e) Check for subsidence, heaving or sloughing of the earth in the vicinity of the anchor. Check rock for new fractures.

5.1.2. Main Cable Supports

a) A-frames, towers, etc., should be plumb and true.

b) All timber should be sound and repainted if necessary. Check that bolts are secure.

c) All metal parts should be free of corrosion. Check that bolts are secure.

d) Check points of wood-to-metal contact for wear, rot or corrosion.

e) All ladders, stairs, platforms, etc., should be securely fastened and free of corrosion.

f) Check that all metal supports are properly grounded, if required.

5.1.3. Main Cable

a) General condition of wire rope or bridge strand. Note excessive rust penetration, broken or frayed strands. Pay particular attention to portions at or near anchorages. Ensure cable is not in contact with soil.

b) Verify that unloaded sag is correct or adjust as required.

c) Check condition of markings on cable and paint if necessary.

5.1.4. Staylines and Aircraft Warning Markers

a) General condition of wire rope as in 5.1.3.(a).

b) Check that staylines are taut.

c) Replace missing or faded aircraft warning markers.

d) Check that connection of aircraft warning markers to their cable is secure.

5.1.5. Wire Rope Fittings

a) Check for slippage at connectors and clips and check nuts for tightness.

b) Replace any missing or defective clips. Saddles of wire rope clips shall be on the live wire.

c) Check safety loops.

5.1.6. Cable Cars

a) General condition, including sheaves. Sheaves should be free running (grease if applicable) and free from wear.

b) Wooden and metal parts should be free from rot or corrosion. Paint or replace, as required.

c) Check that bolts are tight and replace any missing ones.

d) Check that braking system is workable.

e) Check that reel mounts and fasteners for restraining devices are secure.

5.1.7. Other

a) All potential hazards, such as trees, power lines, utility poles, should be noted.

b) Unstable soil or bank conditions and danger of falling rock should be noted.

c) Encroachment of construction, excavation, or roadway activity on the cableway area should be noted.

5.2. Measurement Procedure

5.2.1. Inspection

A brief inspection of the items discussed in 5.1. should be made before measurements are begun. This is especially important at sites subject to vandalism or after a period of high water when anchors may have been submerged.

Hazards, such as running ice or drift, that may be prevalent at the time of measurement should be assessed. Measurements shall not be made during lightning storms.

5.2.2. Operation

The following safety considerations apply:

a) Keep both hands free when climbing ladders. When necessary, use a backpack, rope or hoist to raise equipment to the platform.

b) Follow safe procedures when handling large sounding weights or sediment samplers.

c) Wear an approved life jacket while in the cable car.

d) Use a restraining device while in the cable car where local conditions make this necessary.

e) Do not release the cable car from a support and allow it to run out of control—use a brake or a rope attached to the A-frame or cable support. Be especially cautious during high water—remember that loaded sag will be significantly greater than an unloaded sag.

f) Wear eye protection (glasses, goggles) while the car is moving to avoid eye damage from particles falling from main cable.

g) Do not attempt to put a cable car puller on the main cable while the car is moving. Have a back-up method of getting to shore in the event of loss or damage to the puller.

h) Watch for drift, boat traffic, aircraft or other hazards.

i) Keep hands off the main cable.

j) Always carry a good pair of side-cutters.

k) Lock the car securely when finished. Where vandalism is a severe problem and the car would not present a hazard, the car may be left in the centre of the span and a retriever used each time.

5.2.3. Emergency Procedures

5.2.3.1. Sounding Line Caught by Debris

If the sounding equipment becomes caught in drift or ice, the sounding cable will break before the integrity of the cableway is endangered. (The sounding cable will usually cut through ice.) Nevertheless, it is preferable to cut the cable to avoid the possibility of injury from the broken cable. Cut the cable as close to the reel as possible, keep legs clear, and hold on to the cable car because it will rebound when the tension is released.

5.2.3.2. Cableway Failure

If a cableway is well constructed and maintained, the chance of a failure is remote. Should a failure occur, the action that must be taken will depend on the extent of the failure, and on the river conditions at the time of failure. Generally, if possible, it is preferable to work along the cable to shore rather than trying to swim to shore.

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APPENDIX A

SAMPLE CABLEWAY DESIGN

Given:

A cableway that will be used for a typical hydrometric program (i.e. no sediment work) will have a span of 160 m. The maximum water level in the past 30 years has been about 15 m; height of the left bank to station datum is 20.5 m and the right bank, 18.0 m. The right bank is readily accessible; the left is not. Both banks of the stream are composed of Class 4 soils.

Computations:

For a span of 160 m, the unloaded sag should not exceed 160 (0.02) = 3.2 m. From the sag tables, it appears that 22-mm (0.875-in.) IWRC or 25-mm (1.0-in.) fibre core wire rope would be satisfactory. Assume the use of 22-mm IWRC wire rope having a mass of 2.01 kg/m and a breaking strength of 306 kN. The erection sag would be 3.04 m and the loaded sag, 5.53 m.

Anchors and Footings

The horizontal component of cable tension would be

$$T = \frac{S(2P + wS)\ g}{8D}$$

$$= \frac{160\ [2(700) + 2.01(160)]\ 9.81}{8(5.53)}$$

$$= 61.1 \text{ kN}$$

and the maximum tension in the cable would be

$$F = \sqrt{1 + \frac{16D^2}{S^2}} = 61.7 \text{ kN}$$

$$\text{Factor of safety} = \frac{306}{61.7} = 4.96 < 5$$

Try 25-mm IWRC having a mass of 2.62 kg/m, breaking strength 398 kN, with erection sag 2.12 m and loaded sag of 4.48 m.

T then is 76.2 kN and F, 76.7 kN and the factor of safety becomes 5.19 > 5.

As the right bank is accessible, a gravity anchor can be used. Assume an anchor measuring 1.4 x 1.4 x 1.2 m high.

The mass of concrete would be 2.35 (2400) = 5640 kg (density of concrete is about 2400 kg/m^3).

The mass of the earth prism, assuming that, ϕ, the angle of internal friction of the earth, is 20°, then becomes

$$\frac{(1.4)(1.2)^2 \tan(45 + 10)}{2}\ 1600 = 2300 \text{ kg}$$

(density of soil is about 1600 kg/m^3).

The gravitational force on the concrete anchor and earth prism is then 9.81 (5640 + 2300) = 78.0 kN.

Resolving this force parallel and perpendicular to the main cable at the anchor gives:

parallel 78.0 sin 30° = 39.0 kN

perpendicular 78.5 cos 30° = 67.4 kN

The friction force can then be obtained from the perpendicular force, assuming a friction coefficient of 0.4.

friction force = 0.4 (67.4) = 27.0 kN

The passive pressure of the earth, P_p, is given by the equation

$$P_p = \frac{\rho g h^2}{2} K_p \text{ per metre of width}$$

where

ρ is soil density

g is acceleration of gravity

h is height of the anchor

K_p is coefficient of passive resistance $\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right)$

Therefore,

$$P_p = \frac{1600(9.81)(1.2)^2}{2}\left(\frac{1 + \sin 20}{1 - \sin 20}\right)(1.4)$$

= 32.3 kN for 1.4 m wide anchor

The shearing resistance along the sides of the anchor and of the earth prism is

$$\left[2(1.2)(1.4) + 2\left(\frac{1.2^2 \tan 55}{2}\right)\right]\ (14.5)$$

$$= 78.5 \text{ kN}$$

(assuming shear strength of soil is 14.5 kPa).

The total resistance to movement of the anchor is then:

Gravity force	39.0 kN
Friction force	27.0 kN
Passive pressure force	32.3 kN
Shearing resistance	78.5 kN
Total	176.8 kN

Maximum tension in the cable is 76.7 kN, therefore, the factor of safety is 2.31 > 2.

As the left bank is not readily accessible, a Chance anchor could be used. A Chance EHS anchor number 12645 correctly installed in a vertical hole in Class 4 soil has a holding strength of 22 kN. This would provide a factor of safety of 2.87. The 32-mm (1.25-in.) anchor rod supplied with the anchor has a yield strength greater than 220 kN.

The force applied to the A-frame footings will be

$$F_v = \frac{F \sin \alpha}{h} = \frac{76.7 \sin 30^\circ}{2} = 19.2 \text{ kN}$$

Assume footings are 0.6 m in diameter and 1.0 m in length.

The force exerted on the soil due to the weight of the footings would be

$$\frac{\pi(.6)^2}{4} \times 1 \times 2400 \times 9.81 = 6.7 \text{ kN}$$

The total force exerted by each footing is then 25.9 kN and the pressure is 25.9/.29 = 89.3 kPa.

The allowable pressure on Class 4 soil is in the order of 575 kPa, therefore, the factor of safety is more than adequate. In fact, the diameter of the footings could be reduced to 0.4 m.

On the left bank, where pouring concrete is difficult, the smaller diameter concrete footings could be used, or alternatively, the A-frame ends could be fitted with 0.3 m square bearing plates.

A-frames

Allowing for clearance above the water surface, the height of the A-frame saddles must be at least 15 + 1 + 2 + 4.5 = 22.5. As the elevation of the left bank is 20.5 m, assume that a 3-m A-frame would provide adequate clearance for a sit-down cable car. A 5 m high A-frame on the right bank gives a saddle elevation of 23.0 m. The slope between the saddles will be 0.3%.

Both the 3-m and 5-m A-frames can be manufactured to standard drawings using 100-mm (4-in.) steel pipe. The 5-m A-frame should be made from heavy wall pipe so as not to exceed l/r requirements.

Platform and Ladder

The platform and ladder on the right bank can also be made to standard drawings, since there are no unusual requirements.

Main Cable

The design of the main cable was essentially complete when the anchorages were designed. The only remaining computation is that of the total length of cable. On a short span cableway the length between A-frames will be almost identical with the span, while the length of backlines will be equal to twice the A-frame height (assuming backlines are at 30° to the earth's surface). The length of cable that will be turned back from each thimble is about equal to the length of each turnbuckle.

For this example a main cable 176 m in length would be correct.

Staylines

The tension in the staylines will be 76.7 (1 - cos 30°) = 10.3 kN. Wire rope 13 mm (0.5 in.) in diameter having a breaking strength of 54.5 kN (6 x 7, IWRC, improved plow) would provide sufficient factor of safety.

Aircraft Warning Markers

Aircraft warning markers would probably be required on a 160-m cableway regardless of location. Three markers suspended from a 13-mm (0.5 in.) cable should suffice.

Cable Car

A standard sit-down cable car should be supplied.

APPENDIX B

MAIN CABLE SAG TABLES

Table B-1. 6 x 19, IWRC, improved plow, pre-stressed, design load is 700 kg

Cable span in metres	Loaded sag at T °C	No load sag at T °C	No load sag at T + 50°
(a) 19 mm (0.75 in.)			
40.00	1.58	0.80	1.12
60.00	2.42	1.31	1.69
80.00	3.29	1.88	2.32
100.00	4.19	2.49	2.99
120.00	5.13	3.16	3.71
140.00	6.09	3.87	4.47
160.00	7.09	4.63	5.27
180.00	8.13	5.42	6.11
200.00	9.19	6.26	6.99
(b) 22 mm (0.875 in.)			
40.00	1.19	0.26	0.62
60.00	1.83	0.56	1.02
80.00	2.50	0.94	1.48
100.00	3.21	1.39	2.00
120.00	3.95	1.89	2.56
140.00	4.72	2.44	3.17
160.00	5.53	3.04	3.82
180.00	6.36	3.68	4.51
200.00	7.23	4.37	5.24
220.00	8.14	5.10	6.01
240.00	9.07	5.87	6.82
260.00	10.04	6.67	7.67
280.00	11.05	7.52	8.55
300.00	12.08	8.40	9.47
(c) 25 mm (1.0 in.)			
40.00	0.92	0.12	0.25
60.00	1.44	0.29	0.54
80.00	1.98	0.53	0.91
100.00	2.56	0.83	1.34
120.00	3.16	1.21	1.81
140.00	3.81	1.64	2.33
160.00	4.48	2.12	2.89
180.00	5.19	2.66	3.50
200.00	5.92	3.24	4.14
220.00	6.70	3.86	4.82
240.00	7.50	4.53	5.54
260.00	8.34	5.24	6.29
280.00	9.21	5.98	7.08
300.00	10.11	6.77	7.91
320.00	11.05	7.59	8.77
340.00	12.02	8.45	9.67
360.00	13.02	9.34	10.60
380.00	14.06	10.27	11.56
400.00	15.13	11.24	12.56

Table B-1 (cont'd)

Cable span in metres	Loaded sag at T °C	No load sag at T °C	No load sag at T + 50°
(d) 29 mm (1.125 in.)			
40.00	0.74	0.09	0.15
60.00	1.16	0.21	0.35
80.00	1.61	0.39	0.63
100.00	2.10	0.63	0.97
120.00	2.61	0.92	1.37
140.00	3.16	1.26	1.83
160.00	3.74	1.66	2.32
180.00	4.36	2.11	2.86
200.00	5.00	2.61	3.44
220.00	5.68	3.15	4.06
240.00	6.39	3.74	4.71
260.00	7.13	4.37	5.40
280.00	7.91	5.03	6.13
300.00	8.72	5.74	6.89
320.00	9.56	6.49	7.69
340.00	10.44	7.27	8.52
360.00	11.34	8.09	9.38
380.00	12.29	8.95	10.28
400.00	13.26	9.84	11.21
420.00	14.27	10.77	12.17
440.00	15.31	11.73	13.17
460.00	16.38	12.73	14.20
480.00	17.49	13.76	15.27

Table B-2. 6 x 19, fibre core, improved plow, pre-stressed, design load is 700 kg

Cable span in metres	Loaded sag at T °C	No load sag at T °C	No load sag at T + 50°
(a) 19 mm (0.75 in.)			
40.00	1.69	0.93	1.22
60.00	2.58	1.49	1.84
80.00	3.50	2.10	2.51
100.00	4.45	2.76	3.23
120.00	5.44	3.46	3.98
140.00	6.46	4.21	4.78
160.00	7.51	5.00	5.62
180.00	8.59	5.83	6.49
200.00	9.70	6.71	7.41
(b) 22 mm (0.875 in.)			
40.00	1.27	0.34	0.73
60.00	1.95	0.68	1.16
80.00	2.67	1.10	1.64
100.00	3.41	1.57	2.18
120.00	4.19	2.10	2.77
140.00	5.00	2.68	3.40
160.00	5.84	3.31	4.07
180.00	6.72	3.98	4.78
200.00	7.62	4.69	5.54
220.00	8.56	5.44	6.33
240.00	9.53	6.23	7.16
260.00	10.54	7.06	8.03
280.00	11.57	7.92	8.93
300.00	12.64	8.83	9.87
(c) 25 mm (1.0 in.)			
40.00	0.99	0.13	0.29
60.00	1.53	0.32	0.61
80.00	2.10	0.57	1.00
100.00	2.71	0.90	1.44
120.00	3.34	1.30	1.93
140.00	4.01	1.75	2.46
160.00	4.71	2.25	3.04
180.00	5.44	2.80	3.65
200.00	6.21	3.40	4.31
220.00	7.00	4.04	5.00
240.00	7.83	4.72	5.73
260.00	8.69	5.44	6.49
280.00	9.59	6.20	7.29
300.00	10.51	6.99	8.13
320.00	11.47	7.83	9.00
340.00	12.46	8.70	9.91
360.00	13.48	9.60	10.85
380.00	14.53	10.54	11.82
400.00	15.62	11.51	12.83

Table B-2 (cont'd)

Cable span in metres	Loaded sag at T °C	No load sag at T °C	No load sag at T + 50°
(d) 29 mm (1.125 in.)			
40.00	0.79	0.10	0.16
60.00	1.23	0.22	0.37
80.00	1.71	0.40	0.66
100.00	2.21	0.65	1.01
120.00	2.75	0.94	1.42
140.00	3.32	1.30	1.88
160.00	3.92	1.71	2.39
180.00	4.55	2.17	2.94
200.00	5.21	2.68	3.52
220.00	5.91	3.23	4.15
240.00	6.64	3.82	4.81
260.00	7.40	4.46	5.50
280.00	8.19	5.14	6.24
300.00	9.01	5.85	7.00
320.00	9.87	6.60	7.80
340.00	10.76	7.39	8.64
360.00	11.68	8.22	9.51
380.00	12.63	9.08	10.41
400.00	13.61	9.98	11.34
420.00	14.63	10.91	12.31
440.00	15.68	11.87	13.31
460.00	16.76	12.87	14.34
480.00	17.88	13.90	15.40
500.00	19.02	14.97	16.50

Table B-3. Bridge strand, pre-stressed, design load is 1100 kg

Cable span in metres	Loaded sag at T °C	No load sag at T °C	No load sag at T + 50°
(a) 22 mm (0.875 in.)			
40.00	1.10	0.16	0.50
60.00	1.68	0.37	0.85
80.00	2.29	0.64	1.24
100.00	2.92	0.98	1.66
120.00	3.58	1.37	2.13
140.00	4.26	1.80	2.64
160.00	4.96	2.27	3.17
180.00	5.68	2.78	3.74
200.00	6.43	3.32	4.35
220.00	7.20	3.90	4.98
240.00	7.99	4.51	5.64
260.00	8.81	5.15	6.33
280.00	9.65	5.82	7.05
300.00	10.51	6.52	7.79
320.00	11.40	7.25	8.56
340.00	12.31	8.01	9.36
360.00	13.25	8.79	10.19
380.00	14.21	9.61	11.04
400.00	15.19	10.44	11.91
(b) 25 mm (1.0 in.)			
40.00	0.84	0.07	0.14
60.00	1.29	0.17	0.33
80.00	1.76	0.31	0.58
100.00	2.26	0.50	0.89
120.00	2.77	0.73	1.25
140.00	3.31	1.00	1.64
160.00	3.87	1.32	2.07
180.00	4.45	1.68	2.53
200.00	5.05	2.08	3.02
220.00	5.68	2.51	3.54
240.00	6.32	2.98	4.09
260.00	6.99	3.48	4.67
280.00	7.68	4.02	5.27
300.00	8.39	4.58	5.90
320.00	9.13	5.18	6.56
340.00	9.88	5.80	7.24
360.00	10.66	6.45	7.94
380.00	11.46	7.12	8.67
400.00	12.28	7.83	9.42
420.00	13.12	8.56	10.20
440.00	13.99	9.31	11.00
460.00	14.87	10.09	11.82
480.00	15.78	10.90	12.66
500.00	16.71	11.72	13.53

Table B-3 (cont'd)

Cable span in metres	Loaded sag at T °C	No load sag at T °C	No load sag at T + 50°
(c) 29 mm (1.125 in.)			
40.00	0.66	0.06	0.09
60.00	1.03	0.13	0.22
80.00	1.42	0.24	0.39
100.00	1.83	0.39	0.62
120.00	2.26	0.57	0.89
140.00	2.71	0.78	1.20
160.00	3.19	1.03	1.56
180.00	3.69	1.32	1.95
200.00	4.21	1.65	2.38
220.00	4.75	2.01	2.84
240.00	5.31	2.40	3.33
260.00	5.90	2.83	3.85
280.00	6.51	3.29	4.40
300.00	7.14	3.78	4.97
320.00	7.79	4.31	5.57
340.00	8.47	4.86	6.20
360.00	9.16	5.44	6.85
380.00	9.88	6.06	7.53
400.00	10.63	6.69	8.23
420.00	11.39	7.36	8.95
440.00	12.18	8.05	9.70
460.00	12.99	8.77	10.47
480.00	13.82	9.52	11.26
500.00	14.67	10.29	12.08
(d) 32 mm (1.25 in.)			
40.00	0.55	0.05	0.08
60.00	0.86	0.12	0.18
80.00	1.19	0.22	0.33
100.00	1.54	0.35	0.53
120.00	1.91	0.50	0.76
140.00	2.31	0.70	1.04
160.00	2.72	0.92	1.35
180.00	3.16	1.17	1.70
200.00	3.63	1.46	2.09
220.00	4.11	1.78	2.51
240.00	4.62	2.14	2.96
260.00	5.14	2.52	3.44
280.00	5.69	2.94	3.94
300.00	6.27	3.38	4.48
320.00	6.86	3.86	5.04
340.00	7.48	4.37	5.62
360.00	8.12	4.90	6.24
380.00	8.78	5.47	6.87
400.00	9.47	6.06	7.53
420.00	10.17	6.68	8.22
440.00	10.90	7.32	8.93
460.00	11.65	7.99	9.66
480.00	12.43	8.69	10.41
500.00	13.22	9.41	11.19

APPENDIX C

CABLEWAY INSPECTION GUIDE

CABLEWAY INSPECTION REPORT

Location:

Span: m, ft.	Dia: mm, in.	Erec. Sag: m, ft.	Design Load: kg, lb.

Item	Comments
1) Main cable	
2) All wire rope fittings	
3) Anchorages and footings	
4) A-frames, other supports, ladders, step bolts, loading platforms	
5) Back stays and/or other stay supports A/C warning cable	
6) Cable car	
7) Other	

I certify that the cableway located at the above-described stream-gauging station was inspected by me in accordance with the attached Cableway Inspection Guide on ...., 19 . . . Deficiencies requiring early correction are as follows:

....

Signature

CABLEWAY INSPECTION GUIDE

Item	Guide
1) Main cable	General condition of the wire cable. Excessive rust penetration, broken or frayed strands must be noted – pay particular attention to portions at or near anchorages. Ensure portions of cable do not contact soil or debris and note action taken. Make visual inspection of sag and adjust if necessary. Check condition of markings on cable and paint if necessary.
2) All wire rope fittings	Note any missing or defective fittings and replace. Saddles of wire rope clips must be on the live wire. Note any slippage at connectors and clips and, if necessary, snug all clip nuts using a suitable wrench.
3) Anchorages and footings	Check general condition of concrete and connections. Connections should be free of soil and debris and contacting concrete should be sound. Signs of movement of footings, deadman and sidehill anchors should be noted. Check for subsidence, heaving or sloughing of surrounding ground and note; this is necessarily required for installations in permafrost.
4) A-frames, other supports, ladders, step bolts, loading platforms	A-frames should be plumb and true. Timber should be sound and painted or treated with preservative. Points of wood-to-metal contact should be closely examined for wear, rot or corrosion. Ladders, platforms, etc., are to be securely fastened.
5) Back stays and/or other stay supports A/C warning cable	Give general condition of wire rope. Pay particular attention to portions at or near anchorages. Ensure cable does not contact soil or debris. Replace missing or faded aircraft warning markers.
6) Cable car	General condition, including sheaves (grease if applicable). Reef mounts and fasteners to restraining devices to be secure. Braking and/or drive systems (if applicable) to be functioning.
7) Other	All hazards such as trees, power lines, utility poles should be described. Unstable bank conditions and danger from falling rock to be noted. Encroachment of construction, excavation, or roadway activity on the cableway area should also be noted.