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DHV CONSULTANTS &
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# *Guidance on the design of cableways*

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# *Annex - A*

# *Guidance on the Design of cableways*

# 1 Introduction

Cableway systems for stream gauging have been in existence for decades and in many variations. Bank-side operation, where the winch and operator is located on one bank, is the most common system. In India, the USA and Canada there has also been a tradition of using manned cable car systems, in particular for large spans in excess of 200 m. However, these have been phased out in Europe and are being eliminated where possible elsewhere for safety reasons and because of improvements in bank-side equipment.

Manned cable-car systems must also be engineered to a higher specification and be subjected to a more rigorous regime of safety checks producing higher installation and operating costs. Therefore, unless the river is otherwise inaccessible, bank-side operation is the preferred option and the only one considered here.

This guideline covers the design aspects of the cableway cables, support column and foundation. Examples are given of typical designs.

# 2 Bank-side cableway systems

## 2.1 General

Bank-side cableway systems are covered by the international standard ISO 4375 “Cableway systems for stream gauging”. However, the existing standard has been thoroughly revised and is currently in circulation to ISO member bodies as a draft for comment. The design procedures described in this document take account of additional safety recommendations and the clearer definitions of working and ultimate loads for the purpose of selecting cables and calculating forces set out in the draft revision. A sketch of a typical cableway is shown in Figure 2.1.

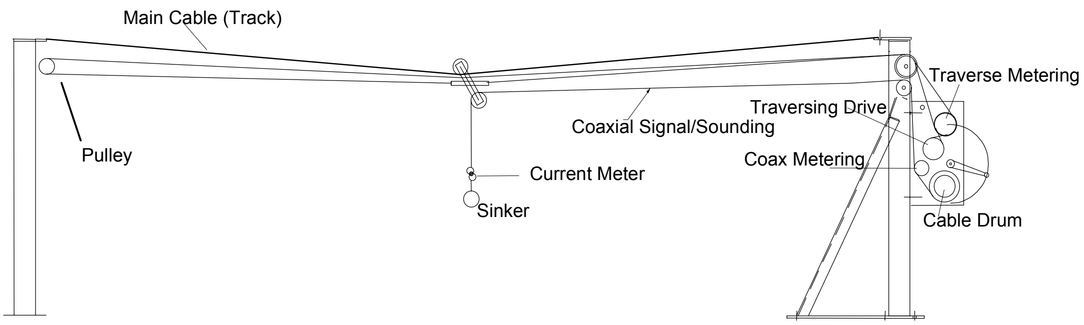



Figure 2.1 Cableway system with loop traverse cable and spooled sounding cable

The main components of a bank-side cableway system are:

- support columns (towers)
- main cable (track cable)
- traversing cable ( tow cable)
- meter suspension cable (sounding cable)
- hydrometric winch

(Alternative names in common use are shown in brackets)

## 2.2 Sinker weight

The design process begins with selecting the appropriate sinker weight as this affects cable selection, support design, foundations and winch. It is important not to over specify the sinker weight. The sinker weights rarely exceed 50 kg. If the river is deep and swift flowing, it may be necessary to specify a heavier sinker. In India practice specifies the mass of a sinker-weight needed in kg as approximately 5 x mean velocity of water in m/sec x depth of water in metres. It is noted that 100 and 150 kg sinker weights have been proposed and these values have been used for sample calculations. However, it is recommended that the sinker weight should not exceed 100 kg.

## 2.3 Selection of cables

### 2.3.1 Selection of meter suspension cable

A FoS (Factor of Safety) of 5 is required by ISO 4375 for the meter suspension cable with respect to the maximum weight of the sinker. A 3.2 mm stainless steel coaxial signal cable has a breaking load 710 kg (6,965 N) and hence would be suitable for suspended loads up to 710/5 = 142 kg (1,393 N). If it is essential to use a 150 kg sinker, then it will be necessary to increase the size of the meter suspension cable, or accept a FoS of 4.7. This may be acceptable, if the winch is fitted with a load limiter (see Sub-section 2.5.4). The **breaking load** of the meter suspension cable is the **design load** for the main cable. It is important that this is not over-specified. For the purposes of providing examples, it has been assumed that sinker weight of 150 kg is being deployed on a 3.2 mm suspension cable and that a FoS of 4.7 is acceptable as the load is limited by a torque limiter.

### 2.3.2 Selection of main cable

Operational loadings on the main cable are a function of:

- the operating sag,
- the weight of the cable, and
- the suspended load.

ISO 4375 recommends an optimum working sag of 2% of the span. The worst case point loading is at mid-span. A main cable is selected so as to provide a factor of safety of 2 with a point loading at mid-span equal to the breaking load of the meter suspension cable. The tension in the cable when suspended between supports of equal height, under static conditions and neglecting wind loading, is given by:

$$T = T_h\sqrt{(1+(4D/S)^2)}, \quad \text{with:} \quad T_h = wS^2/(8D) + PS/(4D) \qquad (2.1)$$

where: $T$ = actual cable tension, in Newton's

$T_h$ = horizontal component of tension T, in Newton's

$w$ = weight per meter run of wire rope or cable, in Newton's

$P$ = the concentrated moving load, in Newton's

$S$ = the horizontal span, in metres

$D$ = cable sag (dip), in metres

From equation (2.1) it is observed that the cable tension is inversely proportional to the cable sag. In the computations of the cable tension for the design and FoS assessment, with respect to the cable sag three cases can be distinguished:

1. initial sag, i.e. the sag due to self-weight of the cable only, to be applied initially to arrive at the required sag of 2% of the span under working conditions with the

suspended load at mid-span; the initial sag is a function of the span, cable diameter and suspended load to be applied
2. working sag of 2% of the span, i.e. the sag due to self-weight of the cable and the suspended load at mid-span, representing the working conditions, and
3. final sag, i.e. the sag due to self-weight of the cable and the breaking load of the suspension cable; consequently, the final sag is considerably larger than the working sag and is typically in the order of about 3.5 to 5% of the span, and is primarily a function of the cable diameter and the breaking load of the suspension cable and varies slightly with span.

From the above it follows, that for the computation of the tension in the main cable one has to apply equation (2.1) with the entries as presented in Table 2.1.

| Cable tension | Sag (D) | Load at mid-span (P) |
|---|---|---|
| Initial | Initial sag | None |
| Working condition | 2% of span | Sinker weight |
| Worst case: failure o suspension cable | Final sag | Breaking load of suspension cable |

Table 2.1 Entries for computation of cable tension

The tension in the main cable for the worst case point loading specified above is the design load for the cableway support columns.

## 2.4 Design of support columns

### 2.4.1 Height of columns

Before columns can be designed to accommodate the loadings applied by the main cable, it is necessary to specify the required height of the columns. This can be calculated as, (see Figure 2.2):

$$H_{col} = D + C - H_{bfl} \qquad (2.2)$$

where: $H_{col}$ = support column height above base

D = ultimate cable sag, which is 2% of cable span S

C = clearance for suspended equipment at highest expected flood level

$H_{bfl}$ = height of column base above highest expected flood level.

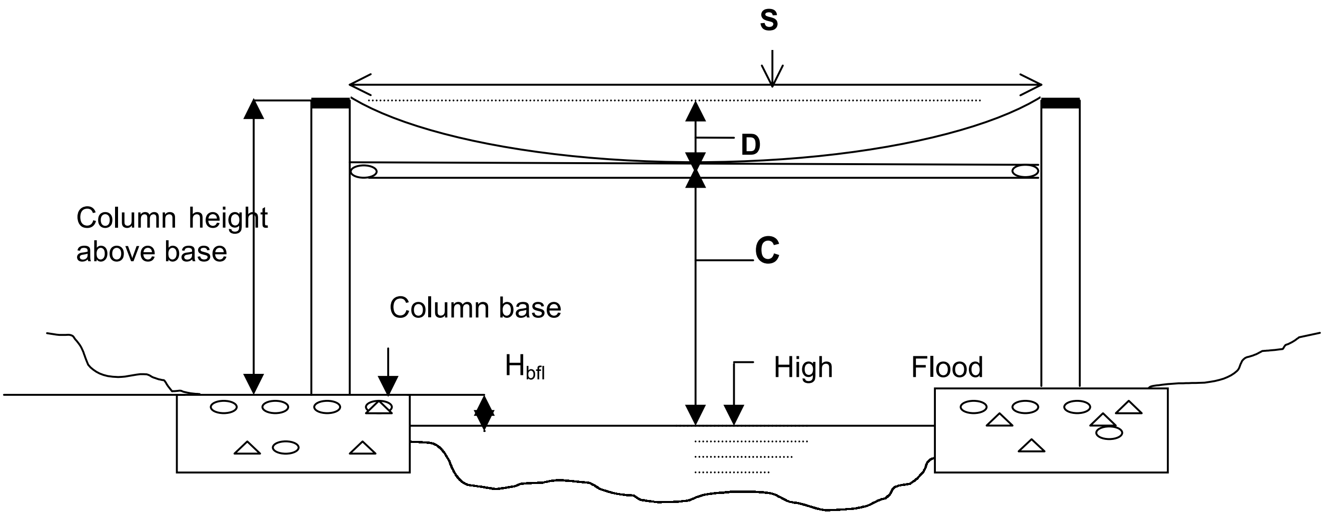



Figure 2.2 Definition sketch design of column height cableway

Ground conditions and availability of space must be taken into account when deciding whether the support may be designed with a backstay or be self supporting. A self-supporting column is preferred on the winch operating side, particularly with columns of up to 3 m, as a backstay intrudes into the working space. Alternatively, a second lighter support may be provided for the winch and traversing cables, located with sufficient clearance in front of a main column.

In the absence of a cross section with information on highest expected flood levels, nominal figures have been use for the examples presented in Chapter 3.

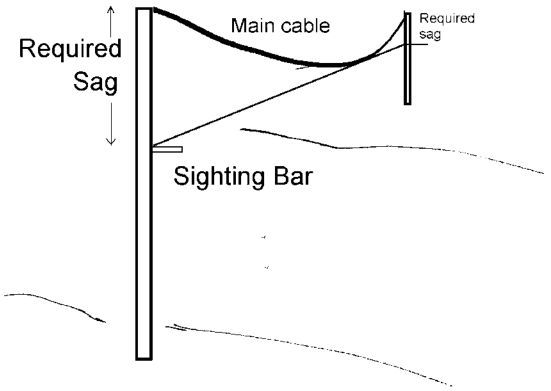
### 2.4.2 Lateral loadings

Allowance should be made for lateral loading in the support columns parallel to the direction of flow, assuming that the worst case loadings would be applied horizontally to the top of the support.

In the examples with this document a drag on the current meter and sinker is used in the case of support without a backline stay.

## 2.5 Tensioning systems

### 2.5.1 Main cable




New wire rope will undergo permanent elongation of up to 0.25%, typically, over a period initially as it is subject to operational loadings. It will also be subject to elastic elongation and expansion and contraction due to temperature changes. It is necessary therefore to have some means of adjusting the tension in the main cable to avoid excessive sag on the one hand and excessive tension on the other. In most cases up to 200 m, a fixed main cable with provision for manual adjustment on the main cable should be adequate. Sighting bars or lines on the supports can be used to check that unloaded and working sags properly reflect the design tensions. For long periods between use, fixed cables may be slackened after use by a few turns of a screw adjuster and re-tensioned before use, using sighting bars to achieve the appropriate initial sag. It is important not to over tension the cable. Operating with a sag of 1% of span, for example, doubles the loading on the system compared with operation at 2%.

It is very convenient to have a system of automatic tensioning using counter weights, steel springs or gas springs, to deal with extreme conditions or in situations where sighting bars cannot be used. However, such systems are more appropriate if the installation will be in regular and continuous use and subject to adequate maintenance of the mechanical parts. Unfortunately, gauging sites are often unused for long periods and the more complex the installation the greater likelihood of malfunction after a period of inactivity. In this case steel springs or counterweights may be more appropriate than gas springs.

### 2.5.2 Traversing cable

A new traversing cable will also stretch during initial use and it may be necessary to shorten the cable at some stage and re-make the termination, depending on the tensioning system chosen. Spring tensioning built into the traveller, spring loaded deflector pulley or manual adjustment may be used to adjust the cable operationally.

### 2.5.3 Traveller

All track wheels, pulley wheels and guide rollers should be close fitting to prevent ropes from coming off the pulley and becoming snagged between pulley cheek and traveller side plates. The main track wheel and sounding cable pulley grooves should have a bottom radius to suit the cable. The track wheel radius should not be too small for the selected main cable diameter. If more than one track wheel is provided, track wheels should be arranged to equally share the load in operation. For example, if two small track wheels are used, the traveller should be articulated.

### 2.5.4 Electrically operated winch

An electrically operated winch must be capable of conversion to manual operation to allow recovery of equipment in the event of power failure. Electrical controls should provide "soft start" to prevent shock loading, "current limit" and "stall detect" to deal with accidental overload. A torque limiter should also be specified for the traverse drive system, so that the traversing cable will slip in a controlled manner should the sinker and current meter assembly become caught up in floating debris. This has the additional advantage of limiting the load on the cableway and causing the traveller and point of suspension to move towards the bank and out of the main current. This is preferable to inserting a shear link or weak link into the cableway system. A shear link parting may introduce a shock recoil loading with unpredictable results. It is important that the winch is able to deal with accidental overload without the intervention of the operator.

### 2.5.5 Manual winch operation

The gearing of the winch should be appropriate to the sinker-weight used. Heavy sinker-weights will require high gearing with correspondingly slow pay-out rates. An automatic load activated brake should be specified to prevent the winding handle from recoiling under the action of the load and the torque limiter should also continue to act in manual mode.

# *3* Examples

## 3.1 Introduction

In this Chapter examples are worked out, including:

- Cable design, (Section 3.2)
- Support design, (Section 3.3) and
- Foundation design (Section 3.4)

In the examples the following design values have been assumed, (see for unit conversion Appendix 1):

- **Temperatures** range from 0 to 60°C (as per maps in Appendix A and B of IS 800 – 1984)
- **Coefficient of expansion for steel** $\alpha_s = 1.25 \times 10^{-5}$ $K^{-1}$ ($^{o}C^{-1}$)
- **Wind load** (p):
  - recommended wind load p = 120 kg/m$^2$ (= 1177 Pa) as per IS:5228 – 1969
  - for cyclone prone areas in Orissa and Kathiawar (Gujarat) the wind load has to be derived from a wind velocity $v_{wind}$ = 150 km/hour as follows (ref. V N Vazirani and M M Ratwani, "Steel Structures", Khanna Publishers, Delhi, 1997, page 337):

    $$p = 0.06 \times v_{wind}^2 \qquad (3.1)$$

    where: p = wind load (Pa)
    $v_{wind}$ = wind velocity (km/hour)

    From this it follows for the cyclone prone areas a design wind load of

    p = 1350 Pa (= 138 kgf/m$^2$), which is 15% higher than the value given above

- **Self weights of track cables** : (as per UK manufacturers )
  - 16 mm cable, self-weight = 0.945 kg/m$^1$ or 9.27 N/m$^1$. (At the time of design values recommended by Indian manufacturers have to be used)
  - 14 mm cable, self-weight = 0.723 kg/m$^1$ or 7.09 N/m$^1$. (At the time of design values recommended by Indian manufacturers have to be used)

## 3.2 Cable sizes

Some examples of the evaluation and selection procedure are given below, using nominal but realistic parameters to illustrate the procedure. Appendix 4 demonstrates the application to two sites for which some data has been made available.

The new (draft) ISO 4375 provides tables to guide the cable selection for various suspension loads, giving an estimate of the initial sag required to produce a working sag of 2% of span. The estimate of the load in the main cable at the breaking point of the suspension cable, takes into account the elongation in the cable and the corresponding increased sag. The ISO tables have been augmented with estimates of loading, sag and factors of safety for working loads of 100 kg (Appendix 2) and150 kg (Appendix 3) over spans ranging from 20 to

200 m for ∅14 mm and ∅16mm wire rope. All calculations are based on the assumption that the cableway has no automatic tensioning device.

The following cases are considered:

a) span = 200 m and sinker weight = 150 kg (1,472 N)
b) span =150 m and sinker weight = 150 kg (1,472 N)
c) span = 100 m and sinker weight = 100 kg (981 N)

## Case a: 200 m span - sinker 150 kg

### Assumed design conditions

Span = 200 m
Working sag 2% of span = 4 m
Sinker weight = 150 kg (1,472 N)
Required factor of safety on main cable = 2
Height of column base above peak water level 2 m
Clearance required for equipment 1 m

### Height of supports $H_{col}$

$H_{col} = D+C-H_{bfl} = 4 + 1 - 2 = 3m$ (see equation 2.2)

### Current meter suspension cable

For a maximum sinker weight of 150 kg (1472 N), a 3.2 mm stainless steel coaxial suspension cable with a break strength 710 kg (6,965 N) will provide a factor of safety of 4.73 (see also Section 2.2).

### Main Cable

Given the design conditions following from the suspension cable, a ∅**16 mm**, galvanised steel, right hand ordinary lay wire rope, minimum break-strength 153,036 N, set up to an initial sag of 0.98% of the span to arrive at a working sag of 2% (see Appendix 3) will produce:

#### Initial tension

Cable tension due to self-weight of ∅16 mm cable
at an initial sag of 0.98% of span, see equation (2.1):
Horizontal Tension $T_h = wS^2/(8D)$ (N)
Actual tension $T = T_h \sqrt{(1+(4D/S)^2)}$ (N)
where:
w = weight of cable ∅16 mm = 9.27 N/m
S = span is 200 m
D = sag at 0.98% of S =0.0098x200=1.96 m
(see also Appendix 3, Table A1.b)
$T_h = 9.27 \times 200^2/(8 \times 1.96) =$ 23,648 N
$T = T_h \sqrt{(1+(4 \times 1.96/200)^2)} = 23{,}648 \times 1.001 =$ 23,666 N

FoS = break-strength/T = 153,036/23,666= 6.47

**Working tension**

Cable tension is due to self-weight ∅16 mm cable and
sinker weight at a working sag of 2% of span, see eq. (2.1)

Horizontal Tension $T_h = wS^2/(8D) + PS/(4D)$ (N)
Actual tension $T = T_h \sqrt{(1+(4D/S)^2)}$ (N)

where:
w = weight of cable ∅16 mm = 9.27 N/m
P = suspended load in N, 150 kg sinker weight = 1,472 N
S = span is 200 m
D = sag at 2% of S =0.002x200=4 m

$T_h$ = 9.27x200$^2$/(8x4)+1472x200/(4x4)= 29,988 N
T = $T_h$ √(1+(4x4/200)$^2$)=29,988x1.003= 30,084 N

These values are also listed in Appendix 3.
(Small deviations with table values are caused by rounding off)

FoS = break-strength/T = 153,036/30,084= 5.09

**Ultimate tension**

Ultimate cable tension is due to self-weight ∅16 mm cable
and a load equal to the breaking-strength of suspension
at an ultimate sag of about 3.7% of span, see eq. (2.1)

Horizontal Tension $T_h = wS^2/(8D) + PS/(4D)$ (N)
Actual tension $T = T_h \sqrt{(1+(4D/S)^2)}$ (N)

where:
w = weight of cable ∅16 mm = 9.27 N/m
P = suspended load = break-strength of susp. cable = 6,965 N
S = span is 200 m
D = ultimate sag is 7.33 m (Appendix 3)

$T_h$ = 9.27x200$^2$/(8x7.33)+6965x200/(4x7.33)= 53,834 N
T = $T_h$ √(1+(4x7.33/200)$^2$)=53,834x1.011= 54,409 N

These values are also listed in Appendix 3.
(Small deviations with table values are caused by rounding off)

**Factor of safety for cable**
FoS = break-strength/ultimate tension = 153,036/54,409 = 2.81

**Permanent extension of rope**

0.25%xS=0.0025 x 200 = 0.50 m

**Thermal expansion of rope**

$\alpha_s x S x \Delta T$ = 0.0000125x200x60 = 0.15 m

where: $\alpha_s = 1.25 \times 10^{-5}$ $^oC^{-1}$, see Section 3.1

$\Delta T$= temperature range = 60 $^o$C, see Section 3.1

**For design of support column:**

- Horizontal component of ultimate tension $T_h$ = 53,834 N
- Moment on base of fixed support
  $H_{col} x T_{h(ultimate\ tension)}$ = 3x53,834 = 161,502 Nm

## Case b: 150 m span – sinker 150 kg

### Assumed design conditions

Span = 150 m
Working sag 2% of span = 3 m
Sinker weight = 150 kg (1,472 N)
Required factor of safety on main cable = 2
Height of column base above peak water level 2 m
Clearance required for equipment 1 m

### Height of supports $H_{col}$

$H_{col} = D+C-H_{bfl}$ = 3 + 1 - 2 = 2 m (see equation 2.2)

### Current meter suspension cable

For a maximum sinker weight of 150 kg (1472 N), a 3.2 mm stainless steel coaxial suspension cable with a break strength 710 kg (6,965 N) will provide a factor of safety of 4.73 (see also Section 2.2).

### Main Cable

Given the design conditions following from the suspension cable, a ∅16 mm, galvanised steel, right hand ordinary lay wire rope, minimum break-strength 153,036 N, set up to an initial sag of 0.87% of the span to arrive at a working sag of 2% (see Appendix 3 will produce:

(computational procedure is similar to case a; instead the values have now been taken from Appendix 3 where available)

**Initial tension**

With initial sag of 0.87% of S = 0.0087x150 = 1.31 m

Horizontal Tension $T_h$= 9.27x150$^2$/(8x1.31)= 19,902 N

Actual tension T = 19,902x1.001= 19,914 N

FoS = break-strength/T = 153,036/19,914 = 7.68

**Working tension**

From Appendix 3

Horizontal Tension $T_h$= 27,086 N

Actual tension T = 27,173 N

FoS = break-strength/T = 153,036/27,173 = 5.63

Ultimate tension

From Table

Horizontal Tension $T_h$= 51,710 N

Actual tension T = 52,312 N

Factor of safety for cable

FoS = break-strength/ultimate tension = 153,036/52,312 = 2.93

Permanent extension of rope

0.25%xS=0.0025 x 150 = 0.38 m

Thermal expansion of rope

$\alpha_s$xSx$\Delta$T = 0.0000125x150x60 = 0.11 m

For design of support column:

Horizontal component of ultimate tension $T_h$ = 51,710 N

Moment on base of fixed support

$H_{col}$x$T_{h(ultimate\ tension)}$ = 2x51,710 = 103,420 Nm

*Case c: 100 m span – sinker 100 kg*

Assumed design conditions

Span = 100 m

Working sag 2% of span = 2 m

Sinker weight = 100 kg (981N)

Required factor of safety on main cable = 2

Height of column base above peak water level 2 m

Clearance required for equipment 1 m

Height of supports $H_{col}$

$H_{col}$ = D+C-$H_{bfl}$ = 2 + 1 - 2 = 1 m ( in this case, $H_{col}$ = 2 m would provide some headroom under the cableway)

Current meter suspension cable

For a maximum sinker weight of 100 kg (981 N), a 3.2 mm stainless steel coaxial suspension cable with a break strength 710 kg (6,965 N) will provide a factor of safety of 7.1 (see also Section 2.2).

Main Cable

Given the design conditions following from the suspension cable, a ∅14 mm, galvanised steel, right hand ordinary lay wire rope, minimum break-strength 116,739 N, set up to an initial sag of 0.80% of the span to arrive at a working sag of 2% (see Appendix 2) will produce:

(computational procedure as for case a, instead the values have now been taken from Appendix 2 where available)

Initial tension
With initial sag of 0.80% of S = 0.0080x100 = 0.80 m and
self-weight of ∅14 mm cable of 7.09 N/m

Horizontal Tension $T_h$= $7.09 \times 100^2/(8 \times 0.80)$= 11,078 N
Actual tension T = 11,078x1.001 = 11,084 N

FoS = break-strength/T = 116,739/11,084 = 10.5

Working tension

From Table
Horizontal Tension $T_h$= 16,691 N
Actual tension T = 16,744 N

FoS = break-strength/T = 116,739/16,744 = 6.97

Ultimate tension

From Table
Horizontal Tension $T_h$= 43,349 N
Actual tension T = 44,006 N

Factor of safety for cable
FoS = break-strength/ultimate tension = 116,739/44,006 = 2.65

Permanent extension of rope
0.25%xS=0.0025 x 100 = 0.25 m

Thermal expansion of rope
$\alpha_s \times S \times \Delta T$ = 0.0000125x100x60 = 0.08 m

For design of support column:

Horizontal component of ultimate tension $T_h$ = 43,349 N

Moment on base of fixed support
$H_{col}xT_{h(ultimate\ tension)}$ = 2x43,349 = 86,698 Nm

NOTE: The breaking strengths and other information are typical for galvanised steel right hand lay wire rope of the diameters specified and may be used as a guide. **However, the cable/wire rope manufacturer's actual specifications should be used in the design or checked prior to construction to make sure they comply with the design assumptions.**

It can be seen from the above that a 16 mm diameter wire rope is suitable in examples (a) and (b), and a 14 mm is adequate in the case of example (c). In each case, once the permanent extension has been taken up, adjustment to allow temperature variation is small and could be accommodated by a screw adjuster alone. However, it depends upon being able to sight through between reference bars to determine the correct sag and it is not always possible to do this easily with long spans for many reasons including the support height. A spring or counterweight system would not be so limited and would remove the need to make regular adjustments. It will depend on site conditions whether this is a matter of convenience rather than necessity.

### 3.33.3 Support design

Assuming supports of height 3 m and all other parameters as shown above, the support could be made from a standard universal column, cast directly into the concrete foundation.

The force on the top of the support can be resolved into a horizontal force at right angles to the river and a force acting in the direction of the sag, i.e. with no deflection of the sinker, this component would be vertical, downwards. For the purpose of calculating the lateral loading on the support it is assumed that the suspension/ sounding cable is horizontal at breaking point and the force is applied horizontally, in the direction of flow as the worst case.

***Example:***

***Continuation of case a: 200 m span – sinker 150 kg***

**Perpendicular to river**

Horizontal loading applied by main cable = 53,834 N

Moment on support $M_y$ = 161,502 Nm

Allowable stress for steel $\sigma_s$ = 165 N/mm$^2$

Required section modulus

$Z_y = M_y/\sigma_s = (161{,}502 \times 10^2) / (165 \times 10^2) =$ 979 $cm^3$

**Parallel to river**

Assuming that the main cable is being pulled horizontally in the direction of flow under ultimate loading, a lateral loading of 1/2x6,965 N = 3,483 N (1/2x710 kg = 355 kg) would be applied to the top of the support.

Moment on support $M_x$ = 3483x 3 = 10,448 Nm

Required section modulus

$Z_x = M_x/\sigma_s = (10{,}448 \times 10^2)/(165 \times 10^2) =$ 63 $cm^3$

**Hence suitable is :** Universal Column 254x254 @ 89 kg/m,

with $Z_y$= 1100 and $Z_x$= 378 $cm^3$

If access or handling is difficult, a lighter support could be designed to be bolted together on site. If backstays are permitted a much lighter and simpler support could be used. A simple strutted support is shown in Figure 3.1.

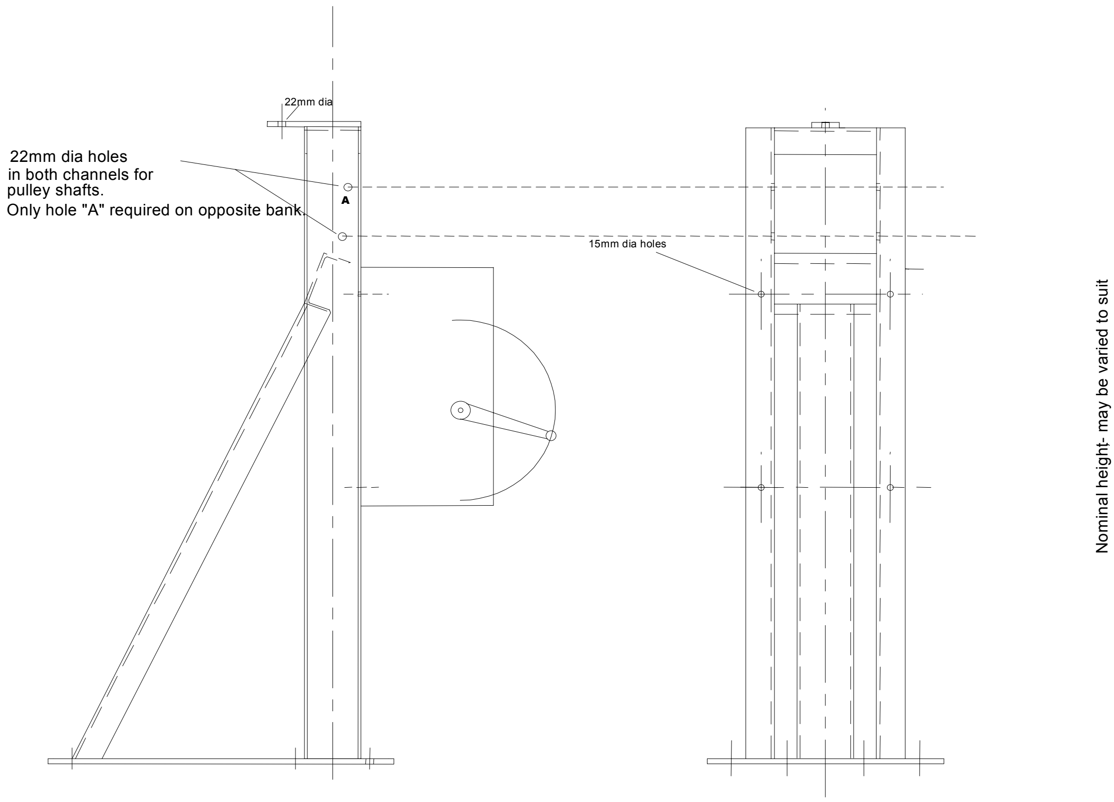



Figure 3.1. Strutted Column and baseplate for bolting on to foundation

## 3.4 *Foundations*

Design of the support foundations is highly dependent on ground conditions and therefore very site specific. However, a case design for 200 m span supports is further illustrated with no back stay. Tower and base are designed to withstand moments. A **254x254 @ 89 kgf/m Universal Column** is adopted, see Section 3.3.

The moment due to ultimate tension on yy-axis $M_{yy}$ = 161.5 kNm
The moment due to hor. force parallel to flow on xx-axis $M_{xx}$ = 10.4 kNm

Adopt foundation block 2 m wide (parallel to flow) x 4 m long x 2.5 m deep

Taking M20 concrete: weight = 2x4x2.5x24 kN/m3 = 480 kN
Load due to cableway = (89x9.81x3+0.5x6,965+ 9.27x100) = (2,619+3483+927) = 7029 N = 7 kN

Vertical component of ultimate tension = 4D/SxT$_h$ =

4x7.33/200x53,834 = 7,892 N = 8 kN

Total vertical load maximum = 480+7+8 495 kN

Average soil load = 495/8 = 62 kPa

$Z_{yy}$ = 1/6x2x4 $^2$ = 5.33 $m^3$, $Z_{xx}$ = 1/6x4x2$^2$ = 2.67 $m^3$

Stress due to Myy is 161.5/5.33 = 30.3 kPa

Stress due to Mxx is 10.4/2.67 = 3.90 kPa

Maximum pressure on base soil = 62 + 30.3 + 3.9 = 96.2 kPa ( 9.8 tf/$m^2$ )

Minimum pressure on base soil = 62 – 30.3 – 3.9 = 27.8 kPa ( 2.8 tf/$m^2$ )

The resultant is within middle third and the block is stable and the bearing loads are as above and acceptable. (Sub-strata bearing capacity needs to match with permissible value of site )

Horizontal forces on the foundation block = 53,834 N = 53.8 kN

Vertical load including block weight (unsubmerged) = 495 kN

Neglect cohesion between base and soil and consider soil friction @ 0.3

Frictional resistance 495x 0.3 = 149 kN or FoS against sliding = 149/53.8 = 2.8

Consider the case when water covers the lower 0.5 metres of foundation block

Reduced weight (495 – 2x4x0.5x9.81) = 451 kN

Frictional resistance 451 x 0.3 = 135 kN or FoS against sliding = 135/53.8 = 2.5

The universal column and an adequately designed base have to be embedded into concrete for transferring moments by shear forces. This has to be designed as part of detailing.

**Due consideration should be given to river training and bank protection.**

# Appendix 1. Units

In this guideline generally the metric or SI unit system is used. This includes:

| Quantity | SI unit |
| --- | --- |
| Mass | kilogram (kg) |
| Force | Newton (N) |
| | kilo-Newton's (kN) |
| Weight | Newton (N) = mass (kg) x 9.81 $m/s^2$ |
| Stress | Pascal (Pa) = Newton/$m^2$ |
| | Mega-pascal (MPa) = $10^6$ Pa |

Besides the metric units for force and stress, the Newton (N) and Pascal (Pa) also the kilogram-force (kgf) and kgf/$m^2$ is used:

| | |
| --- | --- |
| 1 kgf = 9.81 N | 1 N = 0.1019 kgf |
| 1 kgf/$m^2$= 9.81 Pa | 1 Pa = 0.1019 kgf/$m^2$ |
| 1 kgf/$cm^2$= 98,100 Pa | 1 N/$mm^2$ = 1 Mega-pascal (MPa) |
| 1 kgf/$cm^2$= 0.0981 MPa | 1 N/$mm^2$ = 1 MPa = 10.19 kgf/ $cm^2$ |

# Appendix 2 Cable way set up 1

### Cableway set up to achieve a sag of 2% with a working load of 100kg

| | | | | Under normal conditions | | | Failure of suspension cable | | |
|---|---|---|---|---|---|---|---|---|---|
| **Rope Dia** | **Span** | **Initial sag** | **Initial sag** | **Factor of Safety** | **Tension** | **Horizontal Load** | **Factor of Safety** | **Tension** | **Horizontal Load** |
| | metres | % | metres | | N | N | | N | N |
| 14mm | 20 | 0.29 | 0.06 | 8.9 | 13147 | 13105 | 2.8 | 41623 | 40979 |
| 14mm | 30 | 0.40 | 0.12 | 8.6 | 13612 | 13568 | 2.8 | 41929 | 41284 |
| 14mm | 40 | 0.48 | 0.19 | 8.3 | 14063 | 14019 | 2.8 | 42227 | 41580 |
| 14mm | 50 | 0.56 | 0.28 | 8.0 | 14504 | 14457 | 2.7 | 42520 | 41871 |
| 14mm | 60 | 0.62 | 0.37 | 7.8 | 14963 | 14915 | 2.7 | 42820 | 42170 |
| 14mm | 70 | 0.67 | 0.47 | 7.6 | 15414 | 15365 | 2.7 | 43118 | 42467 |
| 14mm | 80 | 0.72 | 0.58 | 7.4 | 15855 | 15804 | 2.7 | 43412 | 42758 |
| 14mm | 90 | 0.76 | 0.69 | 7.2 | 16290 | 16238 | 2.7 | 43705 | 43049 |
| 14mm | 100 | 0.80 | 0.80 | 7.0 | 16744 | 16691 | 2.7 | 44006 | 43349 |
| 14mm | 110 | 0.84 | 0.92 | 6.8 | 17189 | 17134 | 2.6 | 44299 | 43641 |
| 14mm | 120 | 0.87 | 1.05 | 6.6 | 17638 | 17582 | 2.6 | 44600 | 43940 |
| 14mm | 130 | 0.90 | 1.17 | 6.5 | 18080 | 18022 | 2.6 | 44901 | 44239 |
| 14mm | 140 | 0.93 | 1.30 | 6.3 | 18521 | 18462 | 2.6 | 45199 | 44536 |
| 14mm | 150 | 0.96 | 1.43 | 6.2 | 18963 | 18902 | 2.6 | 45500 | 44834 |
| 14mm | 160 | 0.98 | 1.57 | 6.0 | 19412 | 19351 | 2.5 | 45804 | 45137 |
| 14mm | 170 | 1.00 | 1.71 | 5.9 | 19860 | 19797 | 2.5 | 46109 | 45441 |
| 14mm | 180 | 1.02 | 1.84 | 5.7 | 20304 | 20239 | 2.5 | 46412 | 45742 |
| 14mm | 190 | 1.05 | 1.99 | 5.6 | 20750 | 20684 | 2.5 | 46718 | 46046 |
| 14mm | 200 | 1.06 | 2.13 | 5.5 | 21190 | 21122 | 2.5 | 47022 | 46349 |
| 16mm | 20 | 0.50 | 0.10 | 11.4 | 13401 | 13358 | 3.4 | 44605 | 44002 |
| 16mm | 30 | 0.61 | 0.18 | 10.9 | 14008 | 13963 | 3.4 | 45016 | 44411 |
| 16mm | 40 | 0.70 | 0.28 | 10.5 | 14600 | 14554 | 3.4 | 45416 | 44808 |
| 16mm | 50 | 0.77 | 0.38 | 10.1 | 15188 | 15140 | 3.3 | 45813 | 45203 |
| 16mm | 60 | 0.83 | 0.50 | 9.7 | 15773 | 15723 | 3.3 | 46209 | 45596 |
| 16mm | 70 | 0.87 | 0.61 | 9.4 | 16358 | 16305 | 3.3 | 46605 | 45990 |
| 16mm | 80 | 0.92 | 0.73 | 9.0 | 16942 | 16888 | 3.3 | 47002 | 46385 |
| 16mm | 90 | 0.96 | 0.86 | 8.7 | 17523 | 17467 | 3.2 | 47398 | 46779 |
| 16mm | 100 | 0.99 | 0.99 | 8.5 | 18102 | 18044 | 3.2 | 47795 | 47174 |
| 16mm | 110 | 1.02 | 1.12 | 8.2 | 18686 | 18626 | 3.2 | 48195 | 47571 |
| 16mm | 120 | 1.05 | 1.26 | 7.9 | 19271 | 19209 | 3.1 | 48597 | 47971 |
| 16mm | 130 | 1.07 | 1.40 | 7.7 | 19853 | 19789 | 3.1 | 48999 | 48371 |
| 16mm | 140 | 1.10 | 1.54 | 7.5 | 20430 | 20365 | 3.1 | 49400 | 48769 |
| 16mm | 150 | 1.12 | 1.68 | 7.3 | 21008 | 20941 | 3.1 | 49802 | 49169 |
| 16mm | 160 | 1.14 | 1.83 | 7.1 | 21596 | 21528 | 3.0 | 50210 | 49575 |
| 16mm | 170 | 1.16 | 1.98 | 6.9 | 22179 | 22108 | 3.0 | 50617 | 49979 |
| 16mm | 180 | 1.18 | 2.12 | 6.7 | 22762 | 22690 | 3.0 | 51025 | 50386 |
| 16mm | 190 | 1.20 | 2.28 | 6.6 | 23339 | 23264 | 3.0 | 51432 | 50790 |
| 16mm | 200 | 1.21 | 2.43 | 6.4 | 23922 | 23845 | 3.0 | 51844 | 51199 |

# Appendix 3 Cableway set 2

### Cableway set up to achieve a sag of 2% with a working load of 150kg

| | | | | Under normal conditions | | | Failure of suspension cable | | |
|---|---|---|---|---|---|---|---|---|---|
| **Rope Dia** | **Span** | **Initial sag %** | **Initial sag m** | **Factor of Safety** | **Tension** | **Horizontal Load** | **Factor of Safety** | **Tension** | **Horizontal Load** |
| | metres | % | | | N | N | | N | N |
| 16mm | 50 | 0.46 | 0.23 | 7.2 | 21344 | 21276 | 3.2 | 48123 | 47543 |
| 16mm | 60 | 0.52 | 0.31 | 7.0 | 21924 | 21854 | 3.2 | 48538 | 47955 |
| 16mm | 70 | 0.58 | 0.40 | 6.8 | 22512 | 22441 | 3.1 | 48955 | 48370 |
| 16mm | 80 | 0.62 | 0.50 | 6.6 | 23104 | 23031 | 3.1 | 49375 | 48788 |
| 16mm | 90 | 0.67 | 0.60 | 6.5 | 23669 | 23594 | 3.1 | 49785 | 49196 |
| 16mm | 100 | 0.71 | 0.71 | 6.3 | 24251 | 24173 | 3.0 | 50203 | 49611 |
| 16mm | 110 | 0.75 | 0.82 | 6.2 | 24829 | 24750 | 3.0 | 50620 | 50026 |
| 16mm | 120 | 0.78 | 0.93 | 6.0 | 25419 | 25338 | 3.0 | 51042 | 50446 |
| 16mm | 130 | 0.81 | 1.05 | 5.9 | 26003 | 25920 | 3.0 | 51464 | 50866 |
| 16mm | 140 | 0.84 | 1.18 | 5.8 | 26586 | 26502 | 2.9 | 51886 | 51286 |
| 16mm | 150 | 0.87 | 1.30 | 5.6 | 27173 | 27086 | 2.9 | 52312 | 51710 |
| 16mm | 160 | 0.89 | 1.43 | 5.5 | 27744 | 27656 | 2.9 | 52732 | 52128 |
| 16mm | 170 | 0.92 | 1.56 | 5.4 | 28323 | 28232 | 2.9 | 53156 | 52549 |
| 16mm | 180 | 0.94 | 1.69 | 5.3 | 28904 | 28812 | 2.9 | 53583 | 52974 |
| 16mm | 190 | 0.96 | 1.83 | 5.2 | 29492 | 29398 | 2.8 | 54012 | 53402 |
| 16mm | 200 | 0.98 | 1.96 | 5.1 | 30074 | 29978 | 2.8 | 54438 | 53825 |

# Appendix 4 Sample Calculations

Sample calculations have been carried out using data contained on cross sections supplied by Maharashtra State Surface Water Department. Column heights have been calculated in relation to ground level, making no allowance for working platforms or other building works. The minimum support height relates to the higher of the two supports.

Maximum sinker weight has been estimated using mass (kg) = 5 x mean velocity (m/s) x depth (m), although this is a little artificial for the River Shivan as no slope information was provided to allow a proper estimate of velocity.

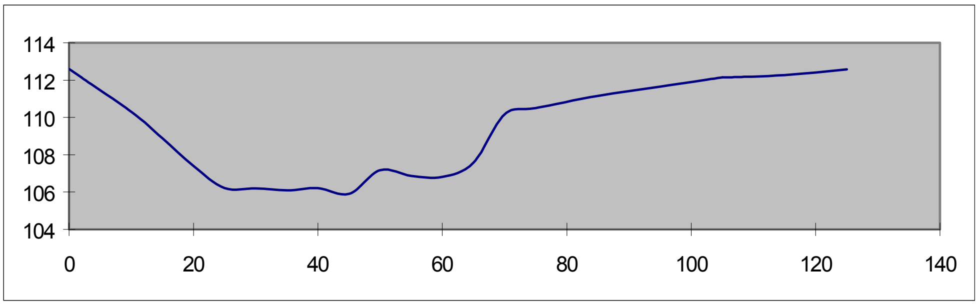
Steel sections have been selected from a table of British Standard sections, assuming a permissible stress of 165 $N/mm^2$ in compression and tension.

The support height may be affected by other factors not considered here, such as the site of the winch installation.

In the absence of detailed information, assumptions have been made to allow the sample calculations to proceed.

# River Telenadu at Parsewada

Estimates of discharge and velocity using slope-area method




Cross section up to max flood level

| Chainage | Elevation | delta x | delta y | Depth | Sigma a calc A | Sigma pw calc P |
|---|---|---|---|---|---|---|
| 0 | 112.6 | | | | | |
| 2 | 112.15 | 0 | 0 | 0 | | |
| 10 | 110.3 | 8 | 1.85 | 1.85 | 7.44 | 8.25 |
| 15 | 108.88 | 5 | 1.42 | 3.27 | 12.80 | 5.20 |
| 20 | 107.4 | 5 | 1.48 | 4.75 | 20.05 | 5.21 |
| 25 | 106.21 | 5 | 1.19 | 5.94 | 26.73 | 5.14 |
| 30 | 106.19 | 5 | 0.02 | 5.96 | 29.75 | 5.00 |
| 35 | 106.1 | 5 | 0.09 | 6.05 | 30.03 | 5.00 |
| 40 | 106.22 | 5 | -0.12 | 5.93 | 29.95 | 5.00 |
| 45 | 105.91 | 5 | 0.31 | 6.24 | 30.43 | 5.01 |
| 50 | 107.17 | 5 | -1.26 | 4.98 | 28.05 | 5.16 |
| 55 | 106.87 | 5 | 0.3 | 5.28 | 25.65 | 5.01 |
| 60 | 106.81 | 5 | 0.06 | 5.34 | 26.55 | 5.00 |
| 65 | 107.56 | 5 | -0.75 | 4.59 | 24.83 | 5.06 |
| 70 | 110.15 | 5 | -2.59 | 2 | 16.48 | 5.63 |
| 75 | 110.5 | 5 | -0.35 | 1.65 | 9.13 | 5.01 |
| 85 | 111.15 | 10 | -0.65 | 1 | 13.25 | 10.02 |
| 95 | 111.65 | 10 | -0.5 | 0.5 | 7.50 | 10.01 |
| 105 | 112.14 | 10 | -0.49 | 0.01 | 2.55 | 10.01 |
| 105.8 | 112.15 | 0.8 | -0.01 | 0 | 0.00 | 0.77 |
| 115 | 112.27 | | | | | |
| 125 | 112.57 | | | | | |
| | | 103.81271 | | Area | 341.14 | 105.50 |
| | | | | R | 3.23 | |
| | | | | n | 0.035 | assumed |
| | | | | s | 0.00204 | |
| | | | | Q | 963 | cumecs |
| | | | | velocity | 2.8 | m/s |

| | |
|---|---|
| Estimated peak discharge | 963 cumecs |
| Estimated mean velocity, peak discharge | 2.8 m/s |
| Estimated Maximum sinker weight | 88 kg (5 x mean velocity x depth) |

## River Telenadu at Parsewada

| | | | |
|---|---|---|---|
| Span | 150 | m | |
| Max Sinker Weight | 100 | kg | |

From Appendix 2 for 100kg sinker, a 14mm rope would provide a factor of safety of 2.6

| | | | |
|---|---|---|---|
| Peak water level | 112.15 | m | |
| Assuming Winch installed on right bank | | | |
| Level of support base (right bank) | 112.57 | m | |
| Level of support base (left bank) | 115.27 | m | |
| Height of right bank Base above peak water leve | 0.42 | m | |
| Clearance for equipment | 1 | m | |
| Working sag @ 2% | 3 | m | |
| Minimum height of RB support | 3.58 | m | working sag + clearance - height of base above peak level |
| Level of cableway | 116.15 | m | |
| height of support (left bank) | 0.88 | m | |

For Right Bank Support:

| | | | |
|---|---|---|---|
| Maximum horizontal loading (from Table 1) | 44834 | N | |
| Moment on RB support | 160506 | Nm | height of support * max horizontal loading |
| Required section modulus Zx | 973 | $cm^3$ | Moment / allowable stress (165N/mm2) |
| Horizontal force in the direction of Flow | 3482 | | |
| Moment on support parallel to flow | 12466 | | |
| Required section modulus Zy | 76 | $cm^3$ | |

Universal Column

254x254 x 89kg/m with Zx= 1099 $cm^3$ and Zy= 379 $cm^3$ would be suitable.

OR

Universal Beam

406x178 x 60kg/m with Zx= 1059 $cm^3$ and Zy= 125 $cm^3$ would be suitable.

For Left Bank Support:

| | | | |
|---|---|---|---|
| Maximum horizontal loading (from Table 1) | 44834 | N | |
| Height of left bank support | 0.88 | m | |
| Moment on LB support | 39454 | Nm | height of support * max horizontal loading |
| Required section modulus Zx | 239 | $cm^3$ | Moment / allowable stress (165N/mm2) |
| Horizontal force in the direction of Flow | 3482 | | |
| Moment on support parallel to flow | 3064 | | |
| Required section modulus Zy | 19 | $cm^3$ | |

Universal Beam

203x133 x 30kg/m with Zx= 278 $cm^3$ and Zy= 52 $cm^3$ would be suitable.

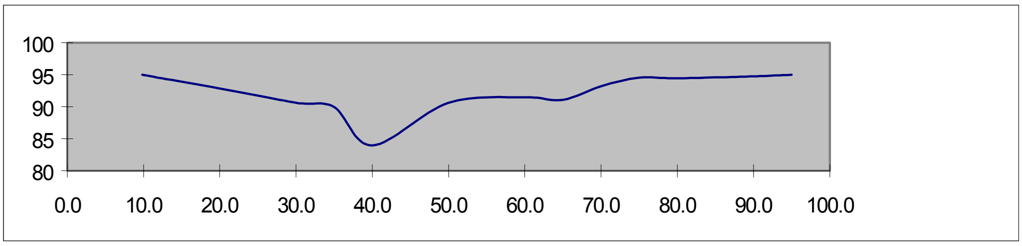
Range of Tensioning Device

| | | | |
|---|---|---|---|
| Temperature Range - 0 to 60 deg C | 60 | | Temperature range |
| Permanent extension of rope | 0.375 | m | 0.0025 x Span |
| Thermal expansion of rope | 0.1125 | m | 0.0000125 x span x temperature range |

Rigging screw would be adequate

## River Shivan near Khamgaon

Estimates of discharge and velocity using slope-area method




Cross section up to max flood level.

| Chainage | Elevation | delta x | delta y | Depth | Sigma a | Sigma pw |
|---|---|---|---|---|---|---|
| 0 | 97.85 | | | | calc A | calc Pw |
| 9.8 | 95 | 0 | 0 | 0 | | |
| 10 | 94.95 | 0.2 | 0.05 | 0.05 | 0.00 | 0.18 |
| 20 | 92.895 | 10 | 2.055 | 2.105 | 10.78 | 10.21 |
| 30 | 90.66 | 10 | 2.235 | 4.34 | 32.23 | 10.25 |
| 35 | 89.94 | 5 | 0.72 | 5.06 | 23.50 | 5.05 |
| 40 | 83.94 | 5 | 6 | 11.06 | 40.30 | 7.81 |
| 50 | 90.62 | 10 | -6.68 | 4.38 | 77.20 | 12.03 |
| 60 | 91.49 | 10 | -0.87 | 3.51 | 39.45 | 10.04 |
| 65 | 91.07 | 5 | 0.42 | 3.93 | 18.60 | 5.02 |
| 70 | 93.23 | 5 | -2.16 | 1.77 | 14.25 | 5.45 |
| 75 | 94.55 | 5 | -1.32 | 0.45 | 5.55 | 5.17 |
| 80 | 94.45 | 5 | 0.1 | 0.55 | 2.50 | 5.00 |
| 90 | 94.75 | 10 | -0.3 | 0.25 | 4.00 | 10.00 |
| 95 | 95 | 5 | -0.25 | 0 | 0.63 | 5.01 |
| 100 | 95.25 | | | Area | 268.98 | 91.21 |
| 110 | 95.86 | | | R | 2.95 | |
| 120 | 97.66 | | | n | 0.035 | |
| 130 | 98.35 | | | s | 0.00204 | |
| 140 | 98.45 | | | Q | 714 cumecs | |
| | | | | velocity | 2.7 m/s | |

**NOTE:**
No slope information was provided for this site. The slope for the Telenadu was used to complete the calculations and give a general indication of peak values.

| | |
|---|---|
| Estimated peak discharge | 714 cumecs |
| Estimated mean velocity, peak discharge | 2.7 m/s |
| Estimated Maximum sinker weight | 147 kg (5 x mean velocity x depth) |

## ~~River Shivan at Khamgaon~~

| | | | |
|---|---|---|---|
| Span | 140 | m | |
| Max Sinker Weight | 150 | kg | |
| From Appendix 3 for 150kg sinker, a 16mm rope would provide a factor of safety of 2.9 | | | |
| Peak water level | 95 | m | |
| Assuming Winch installed on left bank | | | |
| Level of support base (left bank) | 97.85 | m | |
| Level of support base (right bank) | 98.45 | m | |
| Height of left bank Base above peak water lev | 2.85 | m | |
| Clearance for equipment | 1 | m | |
| Working sag @ 2% | 2.8 | m | |
| Minimum height of LB support | 0.95 | m | working sag + clearance - height of base above peak lev |
| **To provide headroom under cable, use** | 1.8 | m | |
| Level of cableway | 99.65 | | |
| height of support (right bank) | 1.2 | m | |
| For Left Bank Support: | | | |
| Maximum horizontal loading (from Table 2) | 51286 | N | |
| Moment on LB support | 92315 | Nm | height of support * max horizontal loading |
| Required section modulus Zx | 559 | $cm^3$ | Moment / allowable stress (165N/mm2) |
| Horizontal force in the direction of Flow | 3482 | | |
| Moment on support parallel to flow | 6268 | | |
| Required section modulus Zy | 38 | $cm^3$ | |

Universal Column.

203x203 x 60kg/m with Zx= 581 $cm^3$ and Zy= 199 $cm^3$ would be suitable.

OR

Universal Beam

305x165 x 40kg/m with Zx= 559 $cm^3$ and Zy= 83 $cm^3$ would be suitable.

| | | | |
|---|---|---|---|
| For Right Bank Support: | | | |
| Maximum horizontal loading (from Table 2) | 51286 | N | |
| Height of right bank support | 1.2 | m | |
| Moment on RB support | 61543 | Nm | height of support * max horizontal loading |
| Required section modulus Zx | 373 | $cm^3$ | Moment / allowable stress (165N/mm2) |
| Horizontal force in the direction of Flow | 3482 | | |
| Moment on support parallel to flow | 4178 | | |
| Required section modulus Zy | 25 | $cm^3$ | |

Universal Column.

203x203 x 46kg/m with Zx= 449 $cm^3$ and Zy= 151 $cm^3$ would be suitable.

OR

Universal Beam

254x146 x 37kg/m with Zx= 433 $cm^3$ and Zy= 72 $cm^3$ would be suitable.

Range of Tensioning Device

| | | | |
|---|---|---|---|
| Temperature Range - 0 to 60 deg C | 60 | | Temperature range |
| Permanent extension of rope | 0.35 | m | 0.0025 x Span |
| Thermal expansion of rope | 0.105 | m | 0.0000125 x span x temperature range |

Rigging screw would be adequate