

**PEDESTRIAN CABLE BRIDGES
FOR
ETHIOPIAN RIVERS**

by

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Abstract

Infrastructure is one of the most essential elements of development for any nation. It is vital for the advancement of economic activities, communication, administration and social interaction of a country. Like most developing nations, Ethiopia needs to expand its infrastructure of which the road sector calls for a special attention

Currently, the Ethiopian government is investing billions of Birr on the improvement of the road sector. This being the case, the amount of money allocated will fall far short of the total sum of money the country needs to bring the road sector development to an acceptable level.

The need for the road sector development is of paramount importance to the rural Ethiopia. These are areas where infrastructure, such as road, bridges, telecommunications, are necessities. For instance, two nearby villages could be separated for almost a season, waiting for the abatement of a small river that howls between them. An attempt to cross this river will result in death of people and their livestock.

To mitigate the problem, the current Ethiopian government, seems to make an effort to construct roads and bridges that connect rural villages, by allocating a huge sum of money. The fact remains, however, such an endeavor demands much more money than the country can afford. Thus, calling for a system which takes cost and efficiency into account to alleviate the problem at hand.

One of the methods that can be applied, and which has been proven to be efficient in other countries of a similar geographic context, is the building of low cost cable bridges, namely, the **suspended cable bridges**. These bridges have been introduced to our nation years back by a certain NGO by the name “**Bridges for Prosperity**” which built four bridges- two in Addis Ababa and two around Dessie.



Figure 1 Suspended cable bridge at Kolfe Keraneyo(9).



Figure 2 Suspended cable bridge at Gambela.



Figure 3 Suspended cable bridge at Gambela.

The importance of these bridges goes far beyond than connecting two separated communities. Their low cost demand and the short time they require to construct makes them the best option for mitigating the problem of communication in such natural problems.

This thesis, therefore, attempts to investigate the possibility of design and construction of pedestrian cable bridges using cable systems. The study has been conducted, taking into account, the use of easily available local and imported materials. Besides, the study attempted to formulate the construction methods.

1.0 Introduction

The improvement of infrastructure in general, the road sector in particular, in a country determines the economic well-being and the overall growth of a nation. The developed world, which has well-built roads, large bridges and overpasses etc. can be cited as an example. While it is comprehensible that the development of such infrastructure is necessary, it, nonetheless, requires a substantial amount of money to put into effect. Such a venture then becomes a hindrance in the sense that the job may only be carried out in a very long time.

This obliges the advent of the development of road infrastructure in a very planned and organized manner that takes into account both the long-term and short-term objectives. The former may include the building of trunk roads and bridges, while the later includes the development of medium to small-scale roads and bridges.

Sadly enough, Ethiopia, being the poorest nation in the horn of Africa, has only 31571 Km of road serving its more than 70 million people. This serves as a reminder of the extent of work ahead in the road sector development to guarantee the economic future and the social integration of the country. Thus, the long-term objective of the country, in terms of developing its road sector, demands a considerable amount of financial back up. In the mean time, however, the country can pursue the objective of building roads and bridges that are time and cost effective; one of these could be the provision of low-cost pedestrian bridges that help connect the peripheral communities to the larger economic and social activities which the major roads and bridges fail to achieve.

On the other hand, with its large, economically and socially diversified population, plus its wide territory, Ethiopia is highly susceptible to both man-made and natural calamities. In such incidents, the existence of well-designed, constructed and efficient modular-bridges is of paramount importance to minimize crises.

This thesis, therefore, attempt to investigate, asses, and recommend options for the provision of efficient modular pedestrian cable- bridges.

1.1 Statement of the problem

In rural Ethiopia where there are no roads and bridges constructed, people of two nearby villages are usually separated and communication with other communities for market and other social purposes is interrupted due to medium and large size rivers howling in between. This is also true for small size rivers flooded during the rainy season.

To construct bridges of medium and large size with concrete or steel requires considerable amount of money, and with the existing economy it is difficult for a country like Ethiopia.

Also due to the topographic nature and the absence of narrow river embankment there are difficulties in constructing bridges with concrete and steel and it is unnecessary to construct with those materials, concrete and steel for pedestrian use only.

Due to factors mentioned above low cost bridge systems need be developed to over come these problems. The intention of this thesis is therefore to prepare standards for low cost bridges, for pedestrian purpose using cable bridges.

1.2 Objectives of the thesis

The objectives of this thesis is to prepare standard design for suspended pedestrian cable bridges for pedestrian purpose only. This includes the analysis and design as well as

formulation of construction methods of suspended pedestrian cable bridges for pedestrian purpose.

1.3 The study design and methodology

The methods employed in this thesis are based on review of available literature, investigation of construction materials, modeling, analysis and design of suspended pedestrian cable bridges of different span and formulation of construction methods.

1.4 Source of data

The source of data has been the reference materials, including Journals related to cable bridges and books about cable bridges

1.5 Application of results

This project is applied in rural areas to provide pedestrian crossing where large and medium size rivers as well as small rivers flooded in rainy seasons cause problems. This benefits the country from allocating considerable sum of money for bridge construction for pedestrian use only. Also benefit people live in rural areas.

1.6 Scope and limitations of the study

The scope of this study is limited to the analysis, design and construction of suspended pedestrian cable bridge.

2.0 Literature Review

Suspended cable bridges has been known and in use in ancient times. The wide use of natural rope bridge by early man led to today's modern suspension cable bridge.

This type of construction is widely used and is indigenous in south East Asia, South America and Equatorial Africa, and was probably in use in these regions long before the earliest known contemporary record, which related to suspension bridge over the Indus River, around 400 A.D (1)

Early Chinese used suspension bridges with main cables of vines or bamboos. The more developed one consists of two ropes hung across the river one hung above the other. A person crossing the river held the upper rope and walked on the lower one.(3)

In South America, suspension bridges were in use in early time. The cables were built of aloe or of twisted osiers, the towers were of natural rock, anchorages were provided by attaching the cables to heavy timber cross beams held fast by rocks. Such bridges had to be over hauled and the cables replaced every few years. (3)

Many suspension bridges of iron chains were built in America and Europe until the end of the Eighteenth century. During this period, the design of Cable bridges was more of an art requiring intuition and out look than a science.(2)

During the first quarter of the nineteenth century, theoretical work on the behavior of a horizontal cable under different loading is understood. Nevertheless in none of the design of this period does there appear any theoretical appreciation of the stiffening function of the light longitudinal girders. The problems were the form and design of the cable members and the fact that the decking was just a beam-like structure hung there from. (1)

The next generations of suspension bridges were designed using theories that deal with cable girder interaction. Rankine published the first theory in 1845 and is called Rankine's approximate theory. Later, in 1880 Levy published what is known as the elastic theory. The fact that the response of a suspension cable under a given loading is non-linear was well understood when the elastic theory was in use but the mathematical expression of this non linearity did not appear in general form until the publication by Melan in 1888.(1)

3.0 History of Cable Bridge.

Probably nature provided the first river crossing bridge, a tree with a branch stretching across to the other side of the stream, accidentally fallen trees connecting the two banks of a stream, the natural arch formed by erosion of soil beneath and many other imaginable provisions.

Primitive suspension bridges are also most likely the first bridge in tropical environments where plants like vines creepers and bamboos were abundant.

The simplest and the most primitive of such bridges are the earliest suspension bridges, which consists of a single cable only. The traveler sits in a loop and pulls him self along.

Creepers of various kinds are used by the native of Equatorial Africa for their suspension bridges, which are often little more than assemblies of ropes between tree tops, though primitive anchorages by stakes in the ground occurred some times.

The development of these primitive suspension bridges of natural ropes is then replaced with iron chains first in China, around 1632 and western people became interested in the introduction of wrought Iron first, as in China, in the form of chains. (1)

In England wrought iron chains were first forged on large scale for use as anchor chains for ships, and suspension bridges using such chains tend to arise near the early shipyards.

It is believed that the first chain bridge in England was erected in 1741(1). It was of primitive nature just 2 ft wide foot-bridges, and it collapsed in 1802 (1). Most of these early chain bridges suffered oscillations in high winds and some collapsed as a result.

The early bridges were said to have one behavior in common, they all swayed and sagged so much that nervous travelers had to be blind folded, tied to a stretcher and carried over.

The gradual development of cable bridge led to the construction of progressively economical and more slender structures. Suspended pedestrian cable bridges are economical and simple in construction, which can be constructed with locally trained workmanship(6).

Due to these advantages suspended pedestrian cable bridges are widely used now a day in developing and under developed countries like Zimbabwe, Cambodia, and Nepal etc. by different local and international NGO's in cooperation with local people.

4.0 Pedestrian cable bridges.

Suspended bridge is a modern version of the traditional Chain bridge. This type of bridge has downward sagging walkway which is suspended below their anchorage cables. The cables are directly anchored to the main anchorage foundation using small pillars for handrail cable support.

A bridge with the main foundation on the same elevation is called a level bridge. The main foundations might not have the same elevation and the bridge is therefore called an inclined bridge.

The hand rail cables are always secured with thimbles and bulldog grips to adjustable anchorages. The main foundations are usually designed as gravity foundations on soil or rock. Anchorage rods may be provided to stabilize the foundation on rock.

The main components of suspended cable bridges are walkway, handrail and main cables, anchorage foundation, as shown in Fig.4 and Fig.5.

The handrail and the main cables are the load bearing elements connected throughout the bridge with hanger rods at constant interval. The hanger rods are fixed at the top to the handrail cable and at the bottom to the cross-beams which are bolted to the main cables. The cross-beams support the walkway deck which is 1.2m in width Chain-link wire mesh netting fences the walkway. It is fixed at the top to the handrail cables and at the bottom to a fixation cable.

The superstructure is completely unstiffened and thus allows some reasonable degree of lateral, vertical and torsional vibration. Therefore stabilizing gauges are required and must be provided by means of wind guy arrangement. Bridge up to 50m spans may be designed without wind guy arrangements.

The suspended bridge is an economical design whenever the required free board can be achieved along with the geological site conditions allowing its construction.

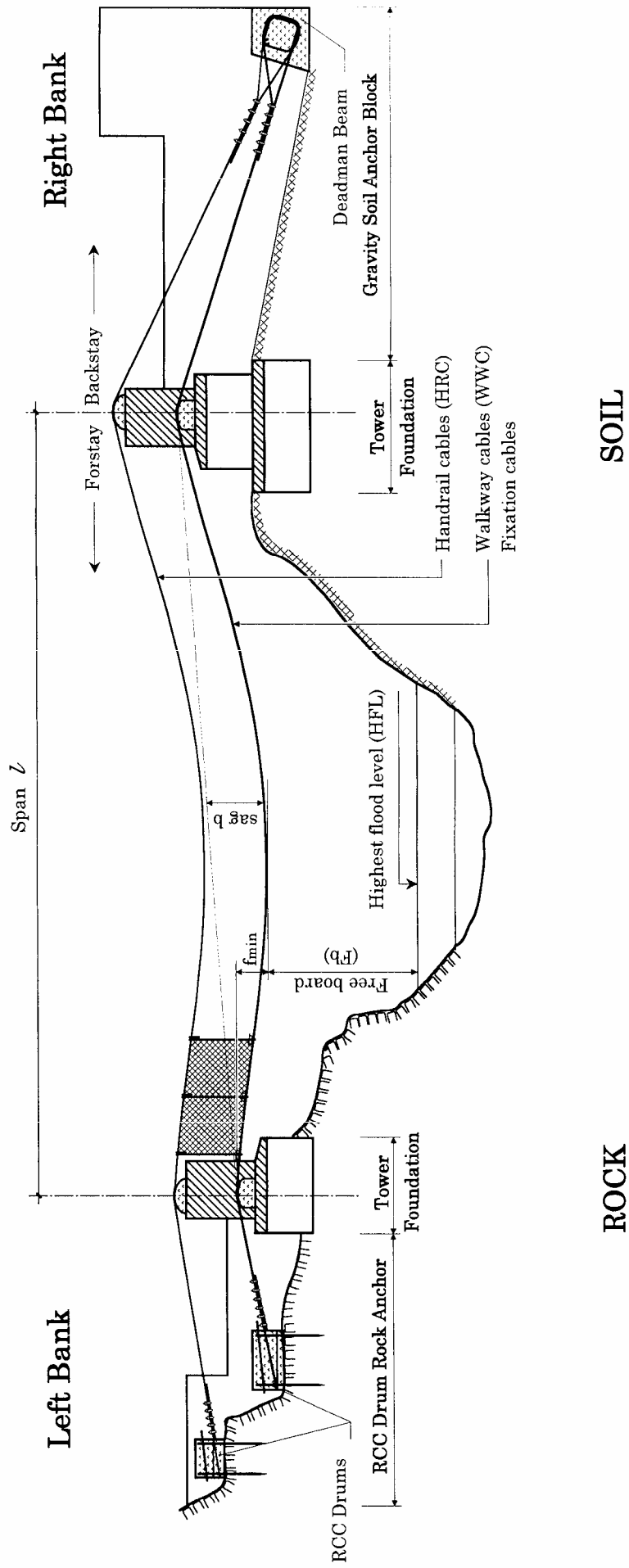


Figure 4 Pedestrian suspended cable bridge typical profile.[9]

PEDESTRAIN SUSPENDED BRIDGE
Typical Plan

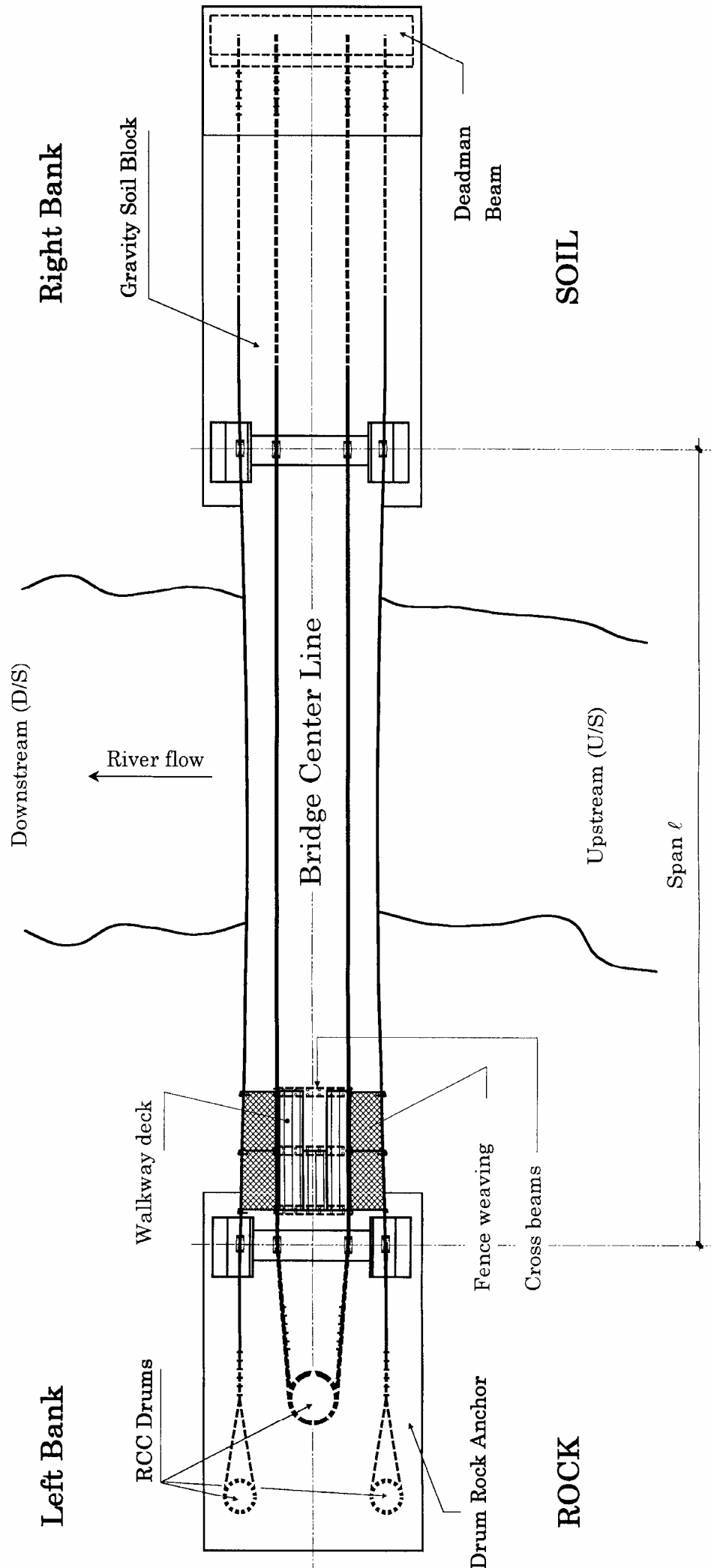


Figure 5 Pedestrian suspended cable bridge typical plan.[9]

4.1 Cables system

Cables are main structural component which are used as walk way support and hand rail. Cables are made flexible and strong structural members that carry axial loads in tension. They do not carry compression. The hand rail and walk way supporting cables are connected by vertical cable hangers of the same height at equal interval. The voids between successive hangers are filled by wire mesh. Meshing between hangers is made to protect people from falling sidewise.

4.2 Walk way system

The walk way system of the pedestrian suspended cable bridge is a service giving part of the bridge in which people walk on it and cross the river. The component of the walkway may be timber or steel fixed to the lower chord.

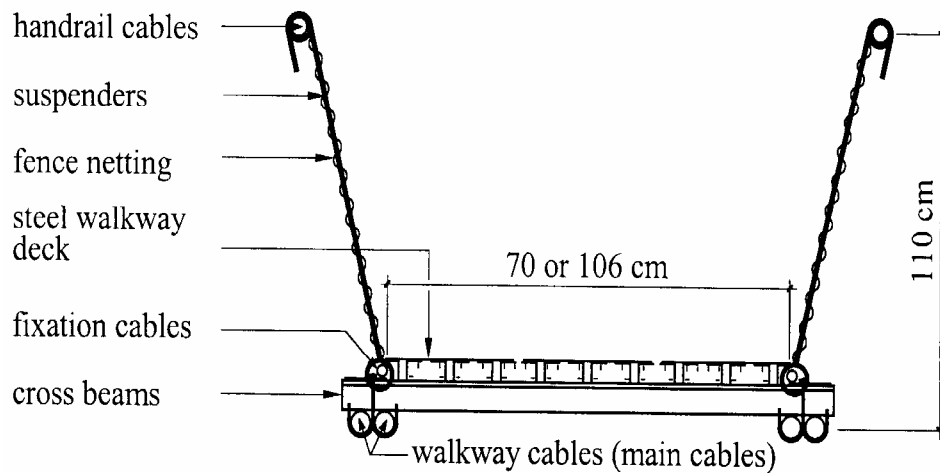


Figure 6 Walk way system.[9]

4.3 Foundation and anchorage

Anchor block is a structural component of suspended bridge that anchors the cable outwards and downwards at the end of the bridge. Beside the configuration of the cables, cable bridge can also be distinguished by the manner the cable system is anchored at the ends.

There are two types of anchoring cables.

- Gravity block anchor for different soil/rock conditions with variable block height. (refer to Fig. 7)

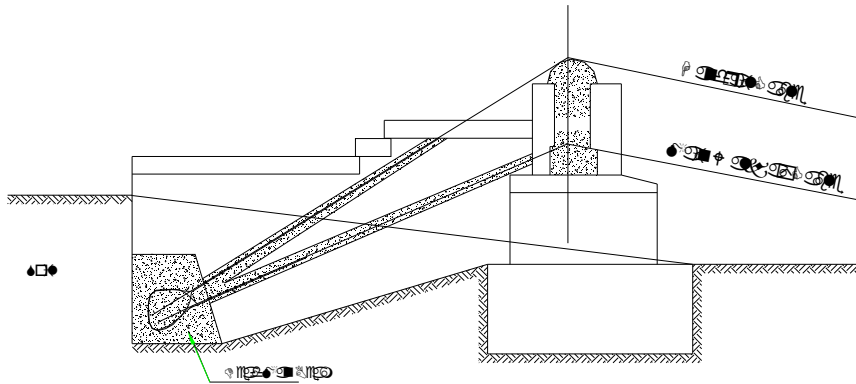


Figure 7 Gravity block anchor.

- Drum rock anchors for fractured or soft rock or for hard rock. (Fig. 8)

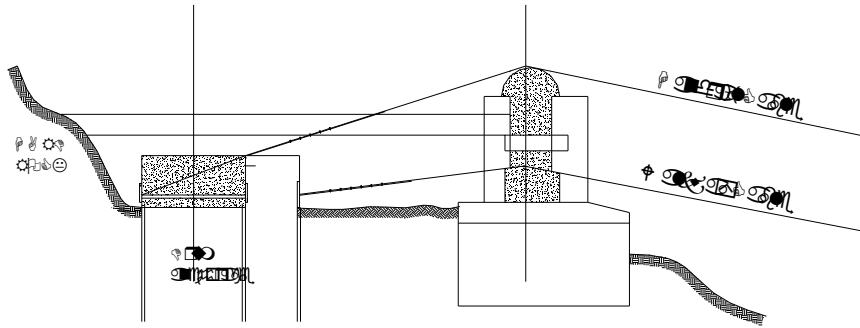


Figure 8 Drum rock anchor.

Bridge foundation transfers all loads from the bridge superstructure to the foundation soil safely.

During foundation design a number of failure mode are analyzed by different models. Because subsoil conditions vary in a great deal it is necessary to determine the local subsoil parameters by means of geotechnical investigation. Such as, pits, laboratory investigation of samples etc. before foundation design is carried out.

In addition to the above mentioned use anchorage rod can be provided to prevent the foundation from sliding or toppling or both combined. The anchorage rod should be placed at the back of the foundation to make sure that they are embedded in sound rock.

During sliding the shear resistance, and during over - toppling the tensile resistance of the anchorage rod will be mobilized.

5.0 Construction Materials

The choice of materials to be used for suspended pedestrian cable bridge affects the final project cost and construction methodology. The choice of material is governed by local availability, the cost and ease of the transportation to the site, the degree of workmanship to be employed, the degree of supervision, quality control availability, durability and maintenance of cable bridges.

The strengths and properties of every cable type depend on the properties of the individual wires comprising the rope as well as the rope construction.

The cable type used in these type of cable bridges is the helical (spiral strand) type which will be discussed in Section 6 and the nominal size of to be used are 13mm, 26mm, and 48mm for different span range.

The wire rope is a flexible, multi-wired, stranded precision product. It is composed of wires, strands and core. In general, any numbers of multi wired strands are helically arranged around the core.

A predetermined number of wires of proper size are helically laid together in a uniform geometrical pattern with a definite pitch or lay. By this process a strands is then closed together around the core with a definite length of lay, forming a wire rope of the required diameter.

The construction materials used for the standard pedestrian cable bridges besides the above mentioned wire rope (cables) are concrete, stone masonry wire mesh nettings, steel fixtures and fasteners such as bulldog grips, nuts, bolts etc.

6.0 Cable mechanics

6.1 Types of cable

Cables are long, slender, flexible structural members that are designed to carry axial loads in tension.

Cables to be used in cable supported bridge made up of the steel wire characterized by considerably large tensile strength than that of ordinary structural steel. The steel wire is of cylindrical shape with diameter of 3 to 7mm. The steel material for the wire is manufactured with a chemical composition characterized by a higher carbon content than allowed for structural steel(4).

In the chemical composition, the high carbon content of cable steel, about four times that of structural steel, is of special significance. This high content of carbon makes the cable steel unsuited for welding(4).

Although the single wire forms the basic element for cables, several wires are often shop assembled to form prefabricated strands.

There are several types of cable, to be used in the construction of cable bridges, such as helical strands (spiral strand), parallel -wire strands. The different cable types are shown in Fig. 9 and Fig. 10 below.

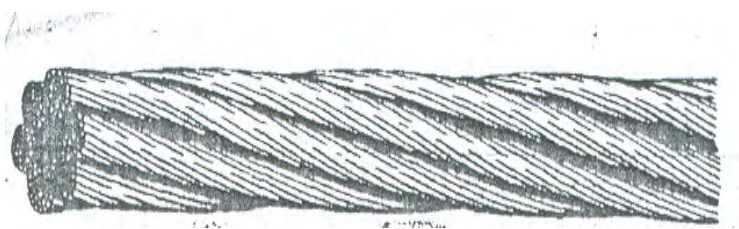


Figure 9 Spiral strand

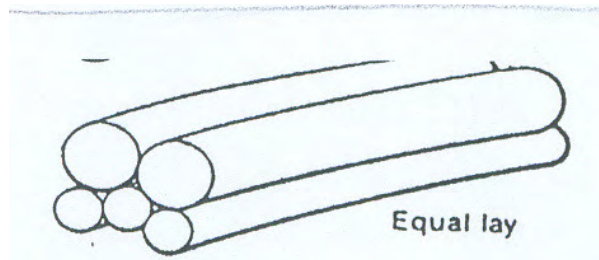


Figure 10 Parallel - wire strand

Of these two different types of cable, spiral strand is commonly used in suspended pedestrian cable bridge since the flexibility of this spiral may ease the anchorage and the bending of the cable at the anchorage block.

6.2 Mechanical properties of cable

The mechanical properties of cable include static strength, relaxation, fatigue strength, hysteresis etc.

The modulus of elasticity is slightly lower than for ordinary structural steel. Thus for design purpose a value of $E = 110 \text{ GPa}$ is generally used.

For the wires most commonly used for cables the minimum tensile strength will be 1570 MPa and the yield stress is 1180 MPa. For the design the limit of proportionality is of significance as this stress indicates an absolute upper limit for the stresses in the service condition due to the fact that it is unacceptable to get permanent (irreversible) elongation of the wire for loads that will occur with a large number of repetitions through out the life time of the bridge.

The most important parameters for design are indicated in Table 1 below.

Table 1 Design parameters and chemical composition of cables.

Parameter	Unit	Cable	Values
Yield strength	MPa		1180
Tensile strength	MPa		1570
Modulus of elasticity	GPa		110
Chemical composition			
C	%		0.8
S	%		0.2
Mn	%		0.6
Cu	%		0.05
Ni	%		0.05
Cr	%		0.05
P	%		0.03
Sn	%		0.02

6.3 Corrosion protection

The susceptibility to corrosion of cables is a major problem at the very beginning of modern cable bridge construction, which concentrate the attention of structural engineers on the importance of an efficient surface protection and still today much effort is put to develop improved corrosion protective system(7).

With the large number of wire each having a small diameter, the cable becomes extremely vulnerable to surface corrosion. In addition most of the wires will be inaccessible for direct inspection and maintenance in the completed cable, that cavities often are present between wires, and that the steel material in the wires is sensitive to corrosion.

Galvanized wires are today generally used in suspended pedestrian cable bridges. To further increase the corrosion protection, after formation to a circular shape, the completed cable will be treated with zinc dust paste before being wrapped by a soft-annealed galvanized, and if executed with the necessary care, very good protection will result.

For parallel-wire strand the corrosion protection was generally made by placing the wire inside a tube. The tube was made of either stainless steel or polyethylene (PE). Stainless steel offered the advantage of a well known and long lasting protection, but it gave rise to complications during erection as the thin walled tubes had to be kept straight or very modestly curved during installation due to the material's high modulus of elasticity.

Lubrication also keeps rope free from corrosion since it contains water repellent and rust preventive additives. In the ropes for cable bridge, non drying type and non bituminous lubricant is used.

6.5 Behavior of cable under loading

The main advantage of using a cable as a load carrying element lies in the most efficient load transfer by pure tension.

A cable carrying transverse load, the geometrical configuration is decisive due to the fact that the axial force which is horizontal force at mid span is inversely proportional to the sag. From this it follows that a straight cable is unable to carry any transverse load as zero sag will imply an infinitely large cable force.

Cable that is transversely loaded will have to be supported vertically and horizontally.

The large horizontal reactions required at the supporting point of the main cables will make it impossible to support them on vertical columns only. It will be necessary to continue the main cables as back stays to anchor blocks positioned in some distance from the masonry support.

7.0 Analysis and Design of cable bridges

7.1 Modeling and analysis

A single flexible cable suspended between two fixed points is the simplest possible kind of suspension bridge. The initial problem in such a case is to determine the form taken by the cable when loaded solely by its own weight, and to find the tension in the cable at any point along its length.

7.1.1 Catenary curve of cable

The curve in which a frictionless uniform cable or a perfectly flexible uniform cable hangs when freely suspended between two fixed points is called catenary. By perfectly flexible it is meant that the cable offers no resistance to bending at any points. In such cases the resultant action across any section of the cable consists of a single force whose line of action is along the tangent to the curve formed by the cable.

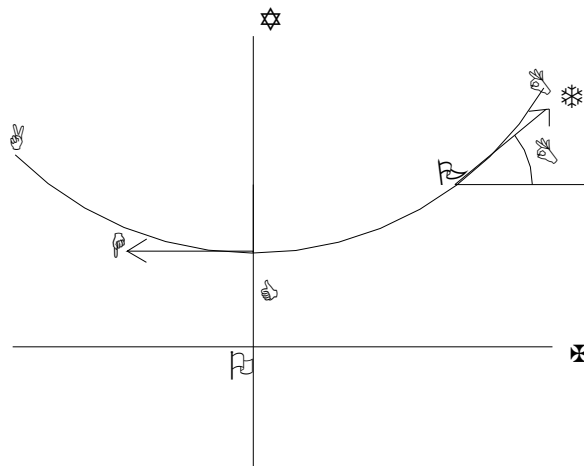


Figure 11 Cable hang between two points.

Let us consider the cable suspended between A and B as shown in Fig.11 above and let C be its lowest point. Let O be the origin for the coordinates X and Y , be vertically below C ,

and let S be the length of the arc measured from C to any point P along the cable. Let the tension in the cable be H at C and T at P , where its inclination is β .

Assume that the cable is an inextensible, the weight of the cable per unit length is w , and the weight of portion CP will be wS . Consider the portion OP is in equilibrium. This section is subjected to the horizontal tension H at C , the tension T at P and its weight wS .

The three forces are lying in one plane; the line of action of the weight must pass through the point where the lines of action of H and T meet. Resolving the forces horizontally and vertically, we have the equilibrium equations

$$\begin{aligned} \sum F_x = 0 & \quad T \cos \beta - H = 0 \\ & \quad T \cos \beta = H \end{aligned} \tag{7(a)}$$

$$\begin{aligned} \sum F_y = 0 & \quad T \sin \beta - wS = 0 \\ & \quad T \sin \beta = wS \end{aligned} \tag{7(b)}$$

Dividing Eq. 7(b) by 7(a) will give us.

$$\tan \beta = \frac{wS}{H} \tag{7(c)}$$

Since w is constant, the ratio H/w is a constant for a given cable and it is convenient to write.

$$c = \frac{H}{w} \tag{7(d)}$$

Where

$C =$ is constant

$H =$ Horizontal force

$w =$ Weight per unit length

There fore: from Eqs. 7(d) and 7(c)

$$S = C \tan \beta$$

This is the intrinsic equation of the catenary and the constant C is known as the parameter of the catenary.

Rewriting the above equations.

$$\frac{dy}{dx} = \tan \beta = \frac{S}{C}$$

$$S = C \frac{dy}{dx}$$

And differentiating to obtain

$$C \frac{dy^2}{dx^2} = \frac{ds}{dx} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2}$$

Let $y' = \frac{dy}{dx}$ and $y'' = \frac{d^2y}{dx^2}$

$$Cy'' = \sqrt{1 + (y')^2}$$

This gives on integration.

$$C \sinh^{-1} y' = x + A$$

Where A is a constant of integration.

Since the origin is vertically below the lowest point C , we note

That at $X = 0$, $\frac{dy}{dx} = 0$ gives;

$$\frac{dy}{dx} = \sinh \frac{x}{C} \tag{7(e)}$$

Integrating Eq.7(e) is obtained.

$$y = C \cosh \frac{x}{C} + B$$

Where B is another constant of integration.

If we take the origin at a depth C below the lowest point O . If the catenary, we have;

$$y = C \cosh \frac{x}{C} \tag{7(f)}$$

Eq.7(f) is the general equation of curve that a cable forms when it is subjected to w , its own weight per unit length.

The length of any arc of the cable is;

From equation

$$ds = (\sqrt{1+(y')^2})dx$$

If the ends of the cable are at the points (x_0, y_0) and (x_1, y_1) , the length is

$$L = \int_{x_0}^{x_1} \sqrt{1+(y')^2} dx$$

Substituting $y' = \sinh \frac{x}{C}$ and using identity for hyperbolic functions,

$$(1 + \sinh^2 \beta)^{\frac{1}{2}} = \cosh \beta$$

Obtain
$$S = C \sinh \frac{x}{C}$$

7(g)

From Eqs. 7(a) and 7(b) squaring and add two terms.

$$T^2 = H^2 + (wS)^2$$

We express the tension T as a function of x :

$$T = H \sqrt{1 + \sinh^2 \frac{wx}{H}}$$

$$T = H \cosh \frac{wx}{H} \tag{7(h)}$$

From Eq. 7(f)

$$\cosh \frac{x}{C} = \frac{y}{C}$$

Therefore Eq. 7(h)

$$T = H \frac{y}{C}$$

$$T = wy$$

Hence the tension varies as the height above the directrix.

- The horizontal component H of T is constant and equal to wc .

- The vertical component of T at any point P is equal to ws
- The resultant tension T at any point P is equal to wy . Where y is measured from the directrix through O .

All the above results depend up on parameter C . For a cable hanging symmetrically between two fixed points at the same levels the value of C can be determined directly from Eq. 7(f) or 7(g), provided the central dip of the cable or its total length are known.

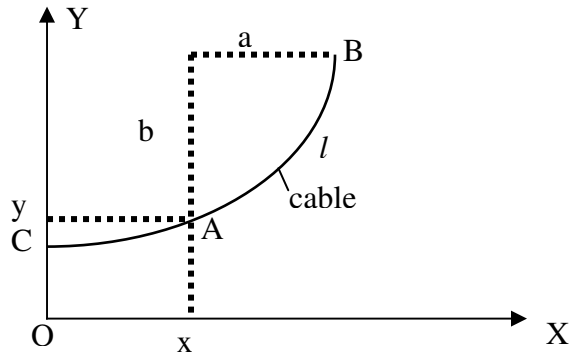


Figure. 12 Schematic diagram for portion of cable.

Here we will concentrate with a cable of given length l hanging. Let the co-ordinate of A be (x, y) , and that of B be $(x+a, y+b)$, all measured from an origin O below the lowest point C as the previous analysis.

Then at A ,

$$y = C \cosh \frac{x}{C}$$

and

$$s = C \sinh \frac{x}{c}$$

and

at B ,

$$y + b = C \cos \frac{x+a}{C}$$

$$s + l = C \sinh \frac{x+a}{C}$$

Subtraction

$$b = C \left(\cosh \frac{x+a}{C} - \cosh \frac{x}{C} \right)$$

$$l = C \left(\sinh \frac{x+a}{C} - \sinh \frac{x}{C} \right)$$

By squaring these two equations and taking their difference, we have

$$2C \sinh a = (l^2 - b^2)^{\frac{1}{2}}$$

This gives C in terms of the known dimensions a , b and l , but it can not be solved explicitly; numerical solution in any particular case is straight forward, using a table of hyperbolic functions.

7.1.2 Parabolic cable

In many practical cases, the total dead weight of the suspended bridge may be approximated to a parabola if subjected to uniformly distributed load on plan since the analysis of cable geometry in parabolic shape is simple and of more practical importance than the common catenary.

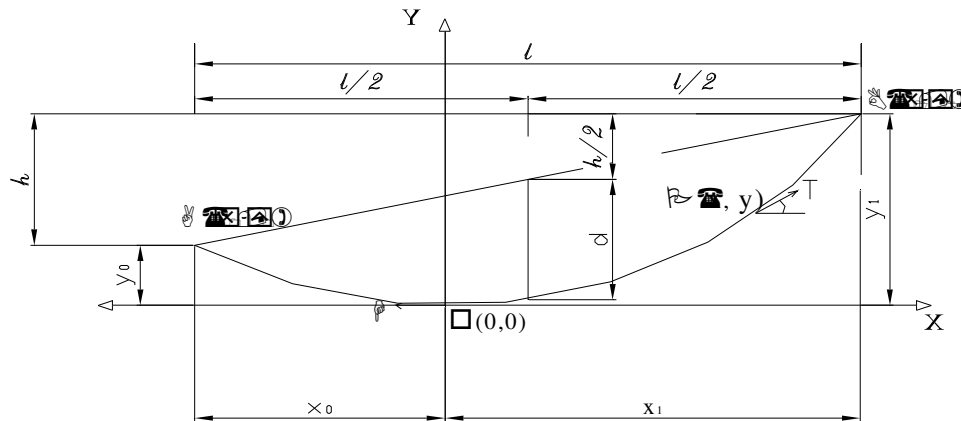


Figure 13 Schematic diagram for parabolic cable at different level.

We will consider a cable as before to be perfectly flexible and inextensible. The cable is hanged between two fixed points A and B as shown in Fig.10. Let O be lowest point of the cable and be taken as origin of the coordinates. The load w is constant and is uniformly distributed per unit of span length l and let H be the tension in the cable at O and T is tension at any point P . Let the coordinates of point A be (x_0, y_0) and the coordinates of point B be (x_1, y_1)

The vertical load on the length of cable OP will be $w x$ and from the equilibrium of this portion of cable.

$$\sum F_x = 0 \quad T \cos \beta - H = 0$$

$$T \cos \beta = H \quad 7(i)$$

$$\sum F_y = 0 \quad T \sin \beta - wx = 0$$

$$T \sin \beta = wx \quad 7(j)$$

Where β is the slope of the cable at P . Dividing Eq. 7(j) by Eq. 7(i) will give

$$\tan \beta = \frac{dy}{dx} = \frac{wx}{H} \quad 7(k)$$

By integration

$$y = \frac{1}{2} \frac{wx^2}{H} + A$$

Where A is a constant of integration, but at $X=0$, $Y=0$, so that $A=0$ thus,

$$y = \frac{1}{2} \frac{wx^2}{H} \quad 7(l)$$

Equation 7(l) is the equation of the cable form, which is a parabola with its vertex at O .

Then by squaring Eqs. 7(i) and 7(j) and adding them

$$T^2 (\sin^2 \beta + \cos^2 \beta) = H^2 + (wx)^2$$

$$T = H \sqrt{1 + \left(\frac{wx}{h}\right)^2}$$

Where T - is the tension at any point P .

We see from the above equation that the minimum tension in the cable occurs at $X = 0$ and is equal to H .

Since $y = y_0$ at $x = x_0$ and $y = y_1$ at $x = x_1$ Eq. 7(l) yields

$$H = \frac{wx_0^2}{2y_0} = \frac{wx_1^2}{2y_1}$$

$$y_1 = \frac{wx_1^2}{2H}$$

$$y_0 = \frac{wx_0^2}{2H}$$

$$y_1 - y_0 = h$$

$$x_0 + x_1 = l$$

and

$$h = \frac{w}{2H} (x_1^2 - x_0^2)$$

$$h = \frac{w}{2H} l(2x_1 - l)$$

$$x_1 = \frac{l}{2} + \frac{Hh}{wl}$$

From $y = \frac{1}{2} \frac{wx^2}{H}$ substitute for H gives,

$$x_1 = \frac{l}{2} \left(\frac{4d+l}{4d} \right)$$

and therefore

$$x_0 = l - x_1$$

$$x_0 = l \left(\frac{4d-l}{8} \right)$$

From Eq. 7(l)

$$y_1 = \frac{wx_1^2}{2H} = \frac{(4d+h)^2}{16H}$$

and

$$y_0 = \frac{wx_0^2}{2H} = \frac{(4d-h)^2}{16H}$$

The angle at any point $p(x,y)$ is,

$$\tan \beta = \frac{dy}{dx} = \frac{wx}{H}$$

Substitute for H from Eq. 7(l) above

$$\tan \beta_x = \frac{2y}{x} \tag{7(m)}$$

From the above equation, the angle at point A and B are,

$$\tan \beta_1 = \frac{2y_1}{x_1} = \frac{4d+h}{l}$$

$$\beta_1 = \tan^{-1} \frac{4d+h}{l} \tag{7(n)}$$

$$\tan \beta_0 = \frac{2y_0}{x_0} = \frac{4d-h}{l}$$

$$\beta_0 = \tan^{-1} \frac{4d-h}{l} \quad 7(o)$$

Tension

$$T = w \sqrt{x^2 + \frac{x_0^4}{4y_0^4}} = w \sqrt{x^2 + \frac{x_1^2}{4y_1^2}}$$

If $|x_1| > |x_0|$ the maximum tension occurs at support B , and its magnitude is given by

$$T_{\max} = wx_1 \sqrt{1 + \frac{x_1^4}{4y_1^2}}$$

$$T_{\max} = \frac{wl^2}{8d} \sqrt{1 + \left(\frac{4d+h}{l}\right)^2} \quad 7(p)$$

7.1.3 Supports on the same level

If the supports are on the same level, $y = y_0 = d$ where d is the sag of the mid point C of the cable. Also, $x_1 = x_0 = l/2$, where l is the span. Then the minimum tension in the cable is

$$H = \frac{wl^2}{8d} \quad 7(q)$$

and

The tension T in the cable at X is

$$T = w \sqrt{x^2 + \frac{l^4}{64d^2}}$$

Hence, for supports on the same level, with $X = l/2$, yields the maximum tension in the cable.

$$T_{\max} = \frac{wl}{2} \sqrt{1 + \left(\frac{l}{4d}\right)^2} \quad 7(r)$$

7.1.4 Length of a cable

To determine the length L of a cable, consider infinitesimal element ds , of the cable at any point P Fig.14. By geometry, $ds/dx = \sec \beta$. Since $\sec \beta = [1 + \tan^2 \beta]^{1/2}$,

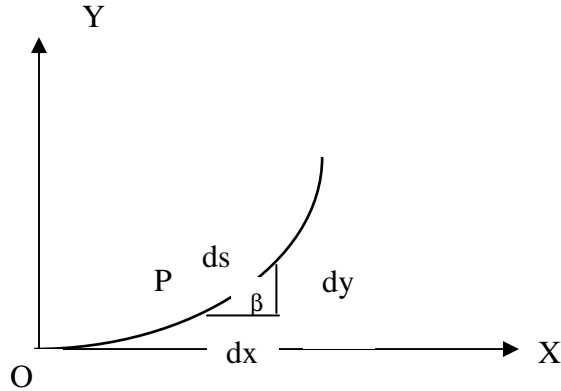


Figure 14 Element ds of cable.

$$ds = \sqrt{1 + \frac{64d^2 x^2}{l^4}} dx$$

Hence, the total length L is given by

$$L = \int ds = 2 \int_0^{\frac{l}{2}} \left(\sqrt{1 + \frac{64d^2 x^2}{l^4}} \right) dx \quad 7(s)$$

For small ratios of sag d to span l , a convenient approximation of the length L can be obtained by expanding the integrand of Eqn. 7(s) by the binomial series and retaining only the first few terms(8):

$$L = l \left(1 + \frac{1}{2} \left(\frac{h}{l} \right)^2 + \frac{8}{3} \left(\frac{b}{l} \right)^2 \right) \quad 7(t)$$

If a cable is stretched rather tightly, so that it is approximately straight, the weight of segment over an interval x is approximately $w \square x$, where w is a constant. Consequently the theory of the parabolic cable that has been developed in this section may be applied as an approximation to a cable that is loaded by its own weight, provided that the sag is small compared with the span length of the cable. If the ratio of sag to span is 0.15 or smaller, the error in this approximation is less than 5%.

7.1.5 Sag calculation

In a suspended bridge, all the load bearing cables are suspended with the same sag. The sag in the dead load condition is defined in consideration of the entrance angle at the higher saddle. The entrance angle at the higher saddle is not to be large, since the movement at the entrance angle is high.

Basic formula for finding hoisting and full load sags, d_h and d_f

The difference of horizontal tension H can be calculated as follow(8),

$$\Delta H^* = H^* - H_d = \frac{w^* l^2}{8d^*} - \frac{w_d l^2}{8d_d} \quad 7(u)$$

or

$$\Delta \sigma^* = \frac{\Delta H^*}{A} = \Delta L^* \frac{E}{L_d}$$

$$\Delta H^* = \Delta L^* \frac{EA}{L_d} \quad 7(v)$$

From Eqs. (7u) and (7v)

$$w^* = \frac{8d^* \Delta L^* EA}{l^2 L_d} + \frac{d^*}{d_d} w_d \quad 7(w)$$

Then,

$$\Delta L^* = L^* - L_d = \frac{8}{3l} (d^{*2} - d_d^2)$$

and

$$w^* = \frac{64EA}{3l^3 L_d} d^* (d^{*2} - d_d^2) + \frac{d^*}{d_d} w_d$$

and

$$C = \frac{64EA}{3l^3 L_d}$$

7.2 Design of cable Bridge

7.2.1 Loading

A cable supported bridge is designed with a detail structural analysis of its main components in Section 7.2.5.

For designing a bridge structure, a number of different loadings, such as live load, dead load, wind load, and seismic loads etc. may be relevant

Live load:

The proper evaluation of characteristic live load for suspended bridge is very difficult. The nature of the trail, the traffic volume, the importance of surrounding places and many other factors determine the value of live load. A live load of 4 kN/m² has been used(5).

Dead load:

The dead load includes the weight of all permanent components of the bridge structure. It is the weights of all cables connected to the walk way structure, walk way beams, walkway decks, hangers.

Table 2 Dead load values of walk way

Walk way width	120 cm.
Dead load (Excluding cables loads)	0.634 kN/m ²

Hoisting Load

For achieving design cable geometry in dead load geometry in hoisting case has to be known. The hoisting load means the weight of cable alone.

Table 3 Hoisting load of cables

Cable diameter	13	26	32	36	40
Unit weight (KN/m)	0.0064	0.0251	0.038	0.048	0.0594

Wind Load

The design wind load is, given as a uniformly acting linear load or uniformly distributed load. Although wind loading on suspended bridges may have a horizontal as well as a vertical load component the effect of the latter is considered irrelevant to the design and is therefore, neglected in the standard design.

Snow load

Snow doesn't appear in large quantity in Ethiopia. Because of the high live load and the low probability of a full live load occurring on a bridge loaded by snow, at high altitude, it is taken for granted that the snow load is already covered satisfactorily by the live load.

Temperature Effects

A difference in temperature causes a change in the cable length. A change in the cable length causes a variation in the bridge sag. This variation in sag will be reflected in the cable force. This effect is however insignificant and is not counted in the design of cables. But the changing in sag is relevant to take into consideration during the hoisting of cable.

Seismic load

Earthquake load shall be taken to be horizontal force determined on basic of the elastic response coefficient, C_{sm} . And the weight of the superstructure (5).

The elastic seismic response coefficient, C_{sm} for the m th mode of vibration shall be taken as,

$$C_{sm} \frac{1.2AS}{T_m^{2/3}} \leq 2.5A$$

Where

T_m period of vibration of m^{th} mode.

A acceleration coefficient.

S site coefficient.

Since the coefficient S and t_m are different for different site condition and span of bridge, the maximum values of $C_{sm}=2.5A$ is taken for this standard design.

Table 4 Acceleration coefficient and maximum elastic coefficient of different seismic zone.

Zone	Acceleration coefficient, A	Maximum elastic coefficient, C_{sm}
1	$A \leq 0.03$	0.075
2	$0.03 < A \leq 0.05$	0.125
3	$0.05 < A \leq 0.07$	0.175
4	$0.07 < A \leq 0.1$	0.25

7.2.2 Bridge site selection

The bridge site should fulfill the following selection criteria.

- For minor river, detour from the traditional crossing point is not acceptable.
- For major river, detour up to 500m u/s and d/s from the traditional crossing point is acceptable.
- The freeboard between the lowest point of the bridge and the highest flood level.

should not be less than 5m.

7.2.3 Selection of Lay out

The lay outs will be selected based on the following data and explanation

- The bridge is a pedestrian bridge and all loading will confirm to this.
- Span range is from 50m to 120m
- The deck is made up of steel
- The cable which will be used is a wire cable with stress capacity of $F_{yk} = 1180\text{MPa}$ and $E = 110\text{ GPa}$
- The width of the bridge can be limited to 1.2m.

7.2.4 Limits and Recommendations

As mentioned in Section 7.1.5, the maximum inclination at higher foundation saddle at dead load case should be

$$\beta_{1,d(\max)} \leq 12^\circ$$
$$d_d \approx \frac{l}{19} - \frac{h}{4}$$

To obtain better stability of the bridge,

$$\beta_{1,d(\text{rec})} \approx 10^\circ$$

and

$$d_d \approx \frac{l}{23} - \frac{h}{4} \quad \text{is recommended.}$$

The lowest point of the parabola of an inclined bridge must remain inside the span for all loading cases.

Recommendations for dead load case,

$$x_{1,d(\text{rec})} \leq \frac{3}{4}l$$

and

$$h = \frac{l}{14}$$

7.2.5 Basic design calculation principle

As the structure at dead load is the initial loading, the sag, d_f , of the full load case and the sag d_h of the hoisting load case have to be calculated. The maximum full load tension has to be less than the cable capacity.

For finding hoisting and full load sags, d_h and d_f corresponding to the hoisting and full unit load w_h and w_f respectively.

The following procedure of iteration is carried out to find the sag, d_h and d_f .

Step 1. Calculate $l = \text{nominal span (m)} + 2 \times 0.25\text{m}$
where 0.25 is distance from front to saddle.

Step 2. Assume value of h and d_d in range of recommendation

Step 3. Calculate

$$L_d = l \left(1 + \frac{1}{2} \left(\frac{h}{l} \right)^2 + \frac{8}{3} \left(\frac{b}{l} \right)^2 \right)$$

Step 4. Assume size and number of cables.

Step 5. Calculate w_h and w_f

Step 6. Calculate constant factor, C.

$$C = \frac{64EA}{3l^3 L_d}$$

Step 7. Assume $d^* = 1.22 d_d$ for full load sag.

$$d^* = 0.93 d_d \text{ for hoisting load}$$

Iteration is started with the primary value of d^* .

Step 8. Calculate

$$w^* = C d^* (d^{*2} - d_d^2) + \frac{d^*}{d_d} w_d$$

Step 9. Calculate and test the condition

$$\Delta w = |w_i - w^*| \leq 0.01$$

- if greater repeat calculation from Step 11 and then to step 9 with d^* new .

- if yes proceed to step 12.

Step 10. Calculate new d^* .

$$d^* = d_d + (d_{old}^* - d_d) \frac{w_i - w_d}{w_{old}^* - w_d}$$

Index i means load case I, either full load or hoisting load.

Step 11. Calculation of the maximum tension at full load case is performed.

$$T_{\max} = \frac{wl^2}{8d} \sqrt{1 + \left(\frac{4d+h}{l} \right)^2}$$

Step 12. Check the capacity of the cable. If the maximum tension at full load case is greater than the capacity of the cable selected, then the assumption of cable size or number of cable should be revised, step 4.

In Table 4 the cable combinations is made on the bases of the above design calculation procedure.

The design example of main and handrail cable for 100m span of pedestrian cable bridge is done in Appendix A.

Table 4 Cable Combination for different span and their maximum cable tension

Span <i>S</i> (mm)	<i>L_d</i> (m)	Cable size (mm)			Area of cable				<i>W_h</i> (KN/M)	<i>W</i> (KN)
		Main cable	Handrail cable	Windguy cable	<i>A_M</i> (mm ²)	<i>A_H</i> (mm ²)	<i>A_T</i> (mm ²)	<i>A_W</i> (mm ²)		
50	50.7172	2Ø ₂₆	2Ø ₂₆	2Ø ₂₆	584	584	1168	584	0.131	1.14
55	55.7387				584	584	1168	584	0.131	1.14
60	60.7602				584	584	1168	584	0.131	1.14
65	65.7818				584	584	1168	584	0.131	1.14
70	70.8033	2Ø ₃₂	2Ø ₂₆	2Ø ₂₆	884	584	1468	584	0.164	1.18
75	75.8248				884	584	1468	584	0.164	1.18
80	80.8463				884	584	1468	584	0.164	1.18
85	85.8678				884	584	1468	584	0.164	1.18
90	90.8893	4Ø ₂₆	2Ø ₂₆	2Ø ₂₆	1168	584	1752	584	0.196	1.21
95	95.9108				1168	584	1752	584	0.196	1.21
100	100.926				1168	584	1752	584	0.196	1.21
105	105.954	2Ø ₃₂ + 2Ø ₂₆	2Ø ₂₆	2Ø ₂₆	1468	584	2052	584	0.229	1.24
110	110.975				1468	584	2052	584	0.229	1.24
115	115.997				1468	584	2052	584	0.229	1.24
120	121.018				1468	584	2052	584	0.229	1.24

8.0 Wind-guy and wind tie cables.

In order to achieve sufficient lateral stability of a bridge under wind load and earthquake load, wind-guy arrangements are required. The simplest method is to use wire rope in a parabolic arrangement for our case.

In fact, the parabolic wind-guy arrangement is a three dimensional structural system. It takes a parabolic shape both in plan and in vertical plane with in the port of the bridge span, as shown in Fig. 15 .

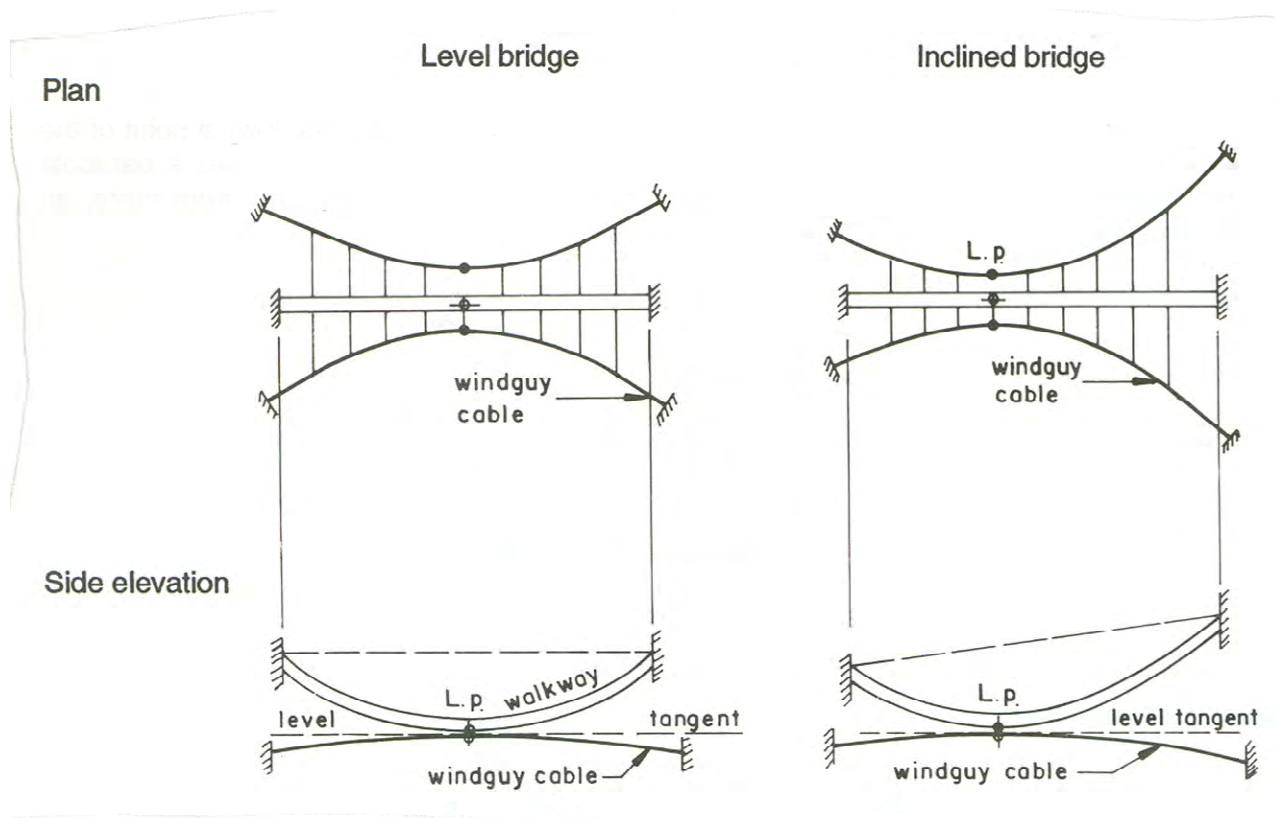


Figure 15 Windguy arrangement in plan and elevation.[8]

Wind guy arrangements are generally designed in such a way that all four ends of the wind gey cables are anchored to separate wind gey cable anchorage foundations, and the wind gey cable is below the whole bridge. It gives the bridge additional stiffness to the walk way and also it supports the bridge to over come wind load and earthquake load.

The connection between the wind gey cable and the walkway of the bridge is made by wind ties.

Generally in plan the vertex of the wind-gey cable, should be placed near to the lowest point of the bridge parabola. But if the location of the wind gey foundation position is not

suitable as per desired layout, the vertex of the windguy cable can be shifted to either side.

8.1 Design of windguy cable structure

Design of windguy cable structure includes the determination of number, diameter, and lay out in the plan of the windguy cables. The number and diameter are calculated by assuming a theoretical parabola within the bridge span. Further the lay out in the plan view can be determined based on the sag at mid span. It is assumed that the full wind load on the walkway can be borne by this system only. The necessary free board has to be maintained for any cable alignment at dead load case.

8.2 Basic calculation procedure

For calculating the cable tension a simplified procedure on the safe side is applied.

The following assumption is considered in the design

- The effect of the wind load on the bridge is totally taken by the windguy system
- The increase in sag of the windguy cable due to wind load is neglected in calculating tension
- The inclined position of the wind guy cable is neglected. The calculation of tension in wind guy cable is done for wind load directed perpendicular to the bridge axis and for its layout in plan
- The vertical load of the wind guy cable and the windtie are omitted

Geometry of theoretical parabola.

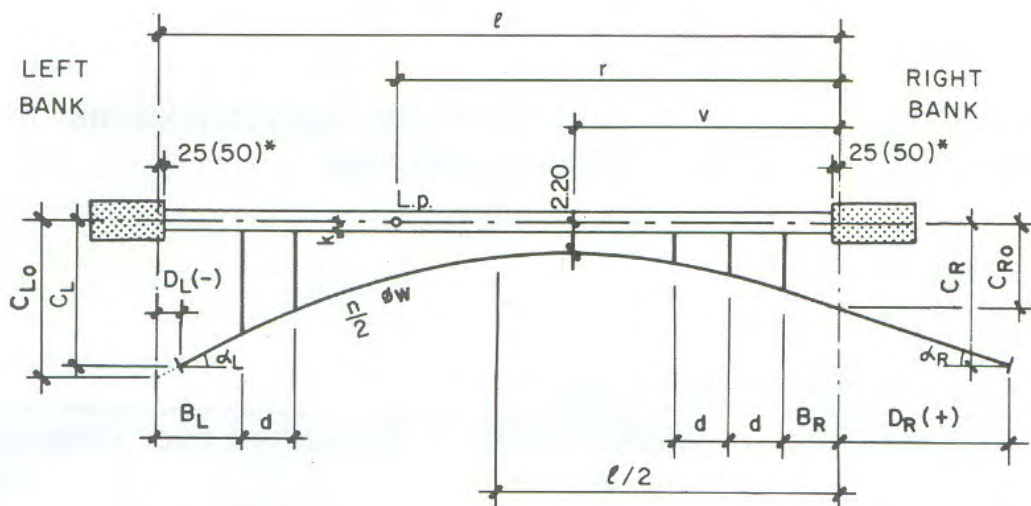


Figure 16 Layout of suspended cable bridge in plan.

From layout of suspended bridge with wind guy in plan, Fig.16.

- The X - axis is identical with the bridge axis
- The Y - axis is through the vertex of the wind guy cable
- Distance h_w ,

$$h_w = f_w \left[\left(\frac{l-v}{v} \right)^2 - 1 \right] \quad 8(a)$$

$$h_w < 0 \quad \text{if} \quad v > \frac{l}{2}$$

$$h_w = 0 \quad \text{if} \quad v = \frac{l}{2}$$

- Sag at midspan

$$d_w = \frac{hw^2v^2}{16f_w \left(\frac{l}{2} - v \right)^2} \quad 8(b)$$

- Windguy cable tension,

$$H_w = \frac{wl^2}{8d_w} \quad 8(c)$$

$$T_R = H_w \sqrt{1 + \left(\frac{2f_w}{v} \right)^2} \quad 8(d)$$

$$T_L = H_w \sqrt{1 + \left(\frac{2f_w(l-v)}{v^2} \right)^2} \quad 8(e)$$

Inclination between the windguy cable and the bridge axis of the windguy cable at anchorage foundation in the plan remain the same up to the first wind tie.

$$\alpha_R = \arctan \frac{2f_w}{v^2} (v - B_R) \quad 8(f)$$

$$\alpha_L = \arctan \frac{2f_w}{v^2} (l - v - B_L) \quad 8(g)$$

Distance from the windguy cable to the bridge axis measured on the saddle or the tower axis

$$C_{RO} = \frac{f_w}{v^2} (v - B_R)^2 + \tan \alpha_R \cdot B_R + 2.2m \quad 8(h)$$

$$C_{LO} = \frac{f_w}{v^2} (l - v - B_L)^2 + \tan \alpha_L \cdot B_L + 2.2m \quad 8(i)$$

Assuming the coordinate of the vertex of the wind guy cables are at $x=0$ and $y=2.2m$. (any arbitrary value can be taken).

Distance from the front of the windguy cable foundation to the bridge axis.

$$C_R = \frac{f_w}{v^2} (v - B_R)^2 + \tan \alpha_R \cdot (B_R + D_R) + 2.2m \quad 8(j)$$

$$C_L = \frac{f_w}{v^2} (l - v - B_L)^2 + \tan \alpha_L \cdot (B_L + D_L) + 2.2m \quad 8(k)$$

8.3 Limits and Recommendations.

The sag at mid span in plan of the windguy cable is recommended from

$$d_w = \frac{l}{8} \text{ to } d_w = \frac{l}{10} \text{ m.}$$

At the vertex of the windguy cable a connection must be provided to the walkway cross beam of the bridge. Fix the vertex distance near to a cross-beam.

As V must be located to a cross beam, the first possible distance from the saddle of the main foundation or tower axis to the windtie be calculated as follows.

$$v = (d_t \cdot i_R) + B_R \geq B_R \quad : \quad B_R = V - (d_t \cdot i_R) > \frac{d_t}{2}$$

$$(l - V) = (d_t \cdot i_L) + B_L \geq B_L \quad : \quad B_L = l - v - (d_t \cdot i_L) > \frac{d_t}{2}$$

Distance between wind ties $d= 6.0m$

9.0 Suspended cable bridge foundation.

Design and analysis of bridge foundations must guarantee that all loads acting from the bridge superstructure on to the foundations are safely transferred to the sub soil. Because sub soil conditions vary in a great deal, it is necessary to determine the local subsoil parameters by means of geotechnical investigation. Unlike in the analysis of the superstructure, it is not usual during foundation analysis to compute the stress pattern within the soil mass to test the required safety level. During foundation design, a number of failure modes are analyzed by use of different models and for each one a factor of safety is computed. These safety factors are compared with the required values which may differ according to the different models analyzed

The bridge foundations are main cable anchorages, wind-guy cable anchorages. The other accessory structures are retaining wall, drainage and other protective structures, where necessary.

Following the basic failure models, the relevant models used for the analysis and design of foundations are:

9.1 Sliding Failure.

The major load leading to the failure of cable anchorage foundations is the horizontal component of the cable tension, which drives the foundation to slide forward. As the driving load increases, it results in a shear load which exceeds the shear resistance in the foundation base, a flat foundation being loaded by a more or less horizontal load will start sliding on the sub soil. The shear resistance develops basically due to frictional resistance, interlocking and adhesion between different particles. In our case, the shear force is the product of the normal force acting in the foundation base and the friction angle between foundation base and sub soil as shown in Fig.18, below. Generally a safety factor of $F_{SL} \geq 1.5$ is used.

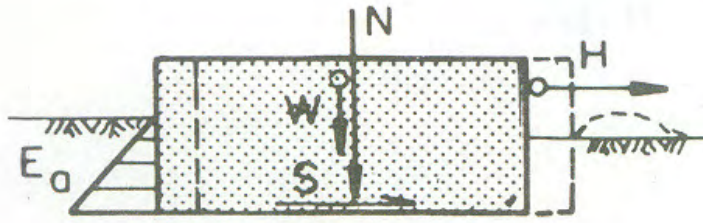


Figure 18 Forces in foundation in sliding mode of failure in foundation.[8]

$$F_{sl} = \frac{\text{Retaining Forces}}{\text{Driving Forces}}$$

$$F_{sl} = \frac{N \cdot \tan \phi}{S} \geq 1.5 \quad 9(a)$$

9.2 Dead-man foundation.

The failure of the deadman anchorage foundation is similar to the sliding failure, as shown in Fig.19, below. The deadman foundation mobilizes the weight of the earth mass in front of the foundation, thus producing a resistive force of passive earth pressure to the foundation. But to attain the pick resistance, relatively large deformation is required. Hence, a high safety factor of $F_{SL} > 3.5$ is necessary to reduce this large deformation.

$$F_{sl} = \frac{E_{ph} - E_{ah} + (w - T_v) \cdot \tan \phi}{T_h} \geq 3.5 \quad 9(b)$$

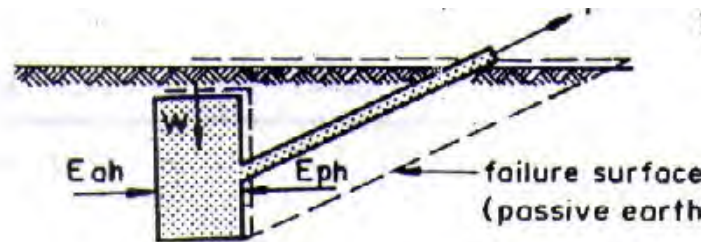


Figure 19 Deadman foundation sliding mode of failure.[8]

9.3 Over turning

There is no tension forces transferred from the foundation to the subsoil or with in subsoil it self. Foundation with its resultant out side the foundation base or close to the border will start to topple. The cause is the misbalance of retaining moment against driving moment around the point usually, as shown in Fig.20, A safety factor of $F_t \geq 1.5$ is used.

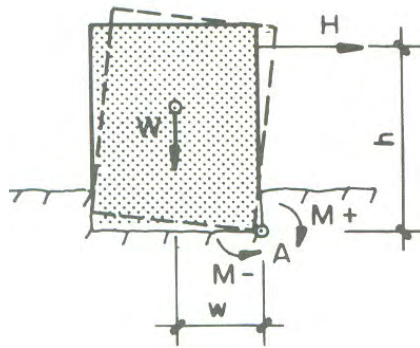


Figure 20 Over turning mode of failure in foundation.[8]

This failure is controlled by setting the limits to the eccentricity of the resultant force in relation to the center point of the foundation base area. As long as the resultant force lies within the core of the foundation base, the whole contact area foundation-soil is subjected to compression so that no gap will develop

$$F_t = \frac{\text{Retaining Moment}}{\text{Driving Moment}} \geq 1.5$$

$$F_t = \frac{M^-}{M^+} \geq 1.5 \quad 9(c)$$

9.4 Loss of bearing capacity

Vertical loads are transmitted to the soil by means of foundation structures. The relation between the load and the settlement depends of the soil characteristics.

A foundation under increasing vertical load, first show a more or less linear increase in the settlement. When the increasing load reached certain limit the observed settlement will increase rapidly. At this point the bearing capacity of the subsoil is exceeded and the foundation fails. The surface of movement for this failure mode is located within the soil mass, as shown in Fig.21, below.

Generally, this problem is analyzed by using the bearing capacity developed by Terzaghi and extended by different authors.

The pressure developed by the rigid foundation can be calculated

$$\sigma = \frac{R_v}{B L} \left[1 \pm \frac{6e_x}{B} \pm \frac{6e_y}{L} \right] \quad 9d$$

When the resulting force in the foundation, R is located within the core of the foundation,

the whole base will be under pressure, $\left[\frac{e_x}{B} + \frac{e_y}{L} \right] < \frac{1}{6}$; $\sigma > 0$

No negative pressure will occur which cannot be transmitted to the soil.

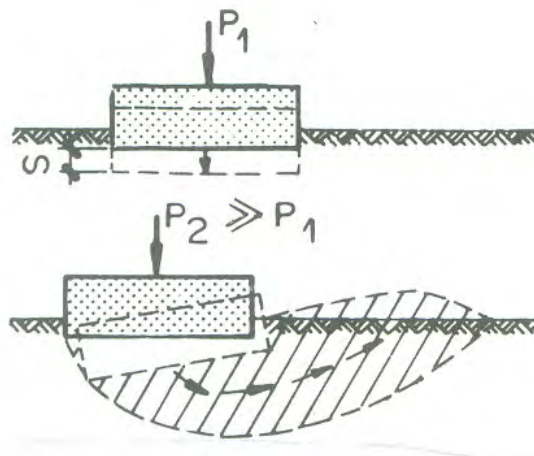


Figure 21 Bearing capacity failure mode. [8]

The foundation placed at the top of an inclined slope will fail under a lesser load than the same foundation in flat terrain and care must take in placing of foundation near slope terrain.

10.0 Formulation of construction methods

The construction of bridge starts from construction of substructure, which includes foundations, abutments and wing walls and then the superstructure. For suspended cable bridge, the substructure can be constructed similar to the conventional concrete bridge substructures.

Suspended Cable Bridge are assumed to be constructed at deep gorge site which do not need abutments and wing walls, there fore it is focused only on the construction methods and detailing of the superstructure as related to the materials selected in the design.

10.1 Layout and foundation excavation

The construction of suspended cable bridge needs care in layout the bridge geometry, since the static analysis is based on the geometry of the bridge which is measured from topography of the bridge site.

Foundation should be excavated with slopes to provide stability of the cut slope.

In rock excavation, the excavation should be done manually with out blasting. Excavation in rock is done by first drilling holes to weaken the rock and then using the crowbars to break up and dig out the rock.

10.2 Transportation and storage of the material

Wire rope should be handled and transported carefully to avoid any defects like kinks, splices and broken stands. Pulling or dragging the cable along the road for transportation is not permitted. One of the cable defects is shown in Fig.22, below.

The Steel parts should be loaded and unloaded carefully to avoid damages. There is a great chance of damage of steel part during loading unloading and transportation. The most common damages are the deformation of cross beams, steel decks, Suspenders, and reinforcement bars due to mishandling during loading and unloading.

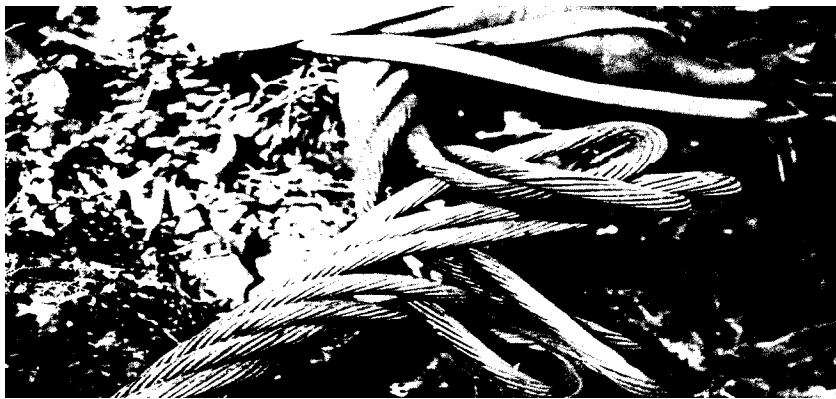


Figure 22 Cable defect in transportation or storage.[9]

To avoid any damages in loading, transportation and storing of steel parts

- Do not allow steel parts to fall from a height
- Galvanized and non-galvanized steel parts must always be stored under a roof with adequate protection from rain and should not be in contact with the ground.
- Galvanized steel parts should not be transported and stored together with salt and acid
- Steel parts, particularly suspenders and reinforcement bars, should not be permitted to bend during transportation and storage.

Before cable cutting, the cable ends should be tightened by a binding-wire to avoid lessening of the cable wires, as shown in Fig.23, below.

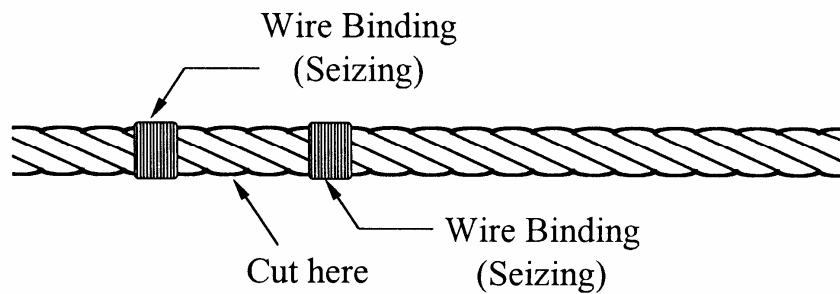


Figure 23 Wire binding before cutting.[9]

Care should be given for transportation and storing of the cement. The prime importance is the proper packing of the cement before transportation to make it watertight.

Cement must always be stored under a roof with adequate protection from rain. A raised plank floor is necessary to prevent cement from damp storage must be arranged in such a way that the oldest cement can be used first.

After the construction of foundation or masonry blocks, the saddles for the walkway cables are to be placed in between the towers, as shown in Fig.24, below. The positions of the saddles has to be checked thoroughly and the levels can be controlled by water level instrument or transparent plastic pipe filled with water.

The tower or Limb walls support the handrail cables. The limb walls are made of stone masonry with concrete core. The handrail cable saddles are to be placed on top of the concrete core of the limb wall. Make sure that the position and shape at the top of

concrete core of the limb wall. Make sure that the position and shape at the top of concrete is curved so that the handrail cable touches the saddle plate only.

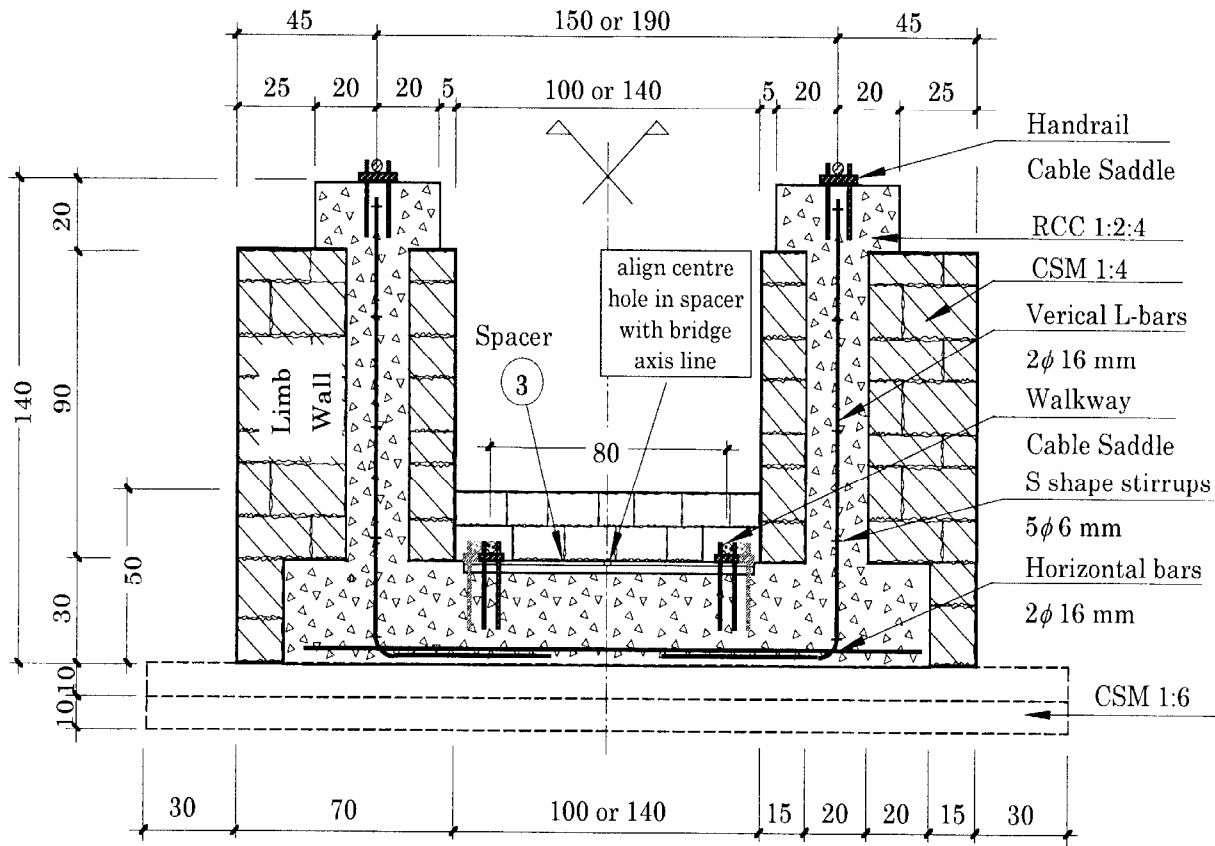


Figure 24 Saddle points for hand rail and walkway cables.[9]

10.3 Construction of Dead man Beam.

Dead man beam is a cast in situ reinforced concrete beam that lies buried under the gravity structure, in soil foundation, as shown in Fig.25, below.

The handrail and walkway cables are placed around the reinforcement bars before casting the concrete beam.

At one bank the cables are inserted in to a polyethylene (PE) pipe, so that the cables can still be moved while sag setting. Tensioning cable must tighten with the bridge of bulldog grip.

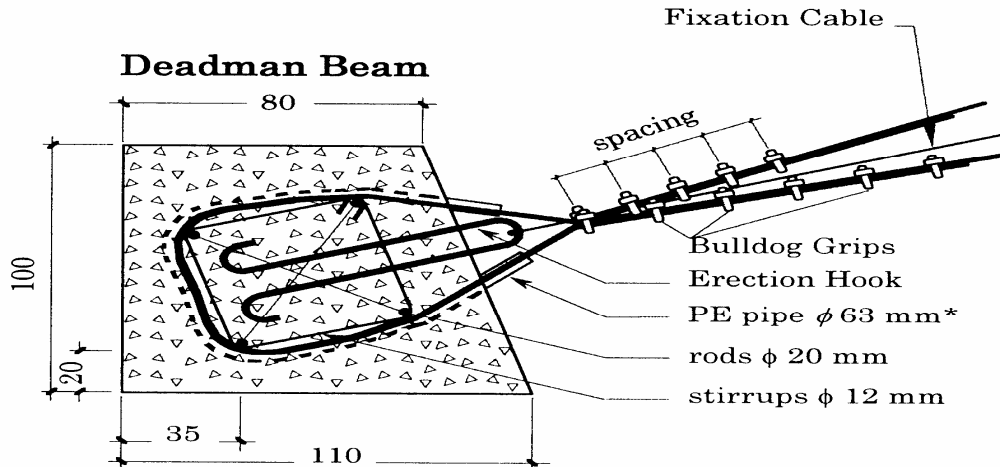


Figure 25 Deadman beam construction..[9]

10.4 Construction of Drum Anchorage in Rock

There are two types of drum anchorage in rock.

Drilling holes in to rock makes drum anchorage in hard rock. Fill the hole with cement mortar before the anchor-rod is inserted. The form work for the drum is made by plain galvanized iron sheet inside lined with a plastic sheet or bamboo mat and use binding wire around the bamboo mat to prevent the bamboo mat bulging during casting of concrete, as shown in Fig.26, below.

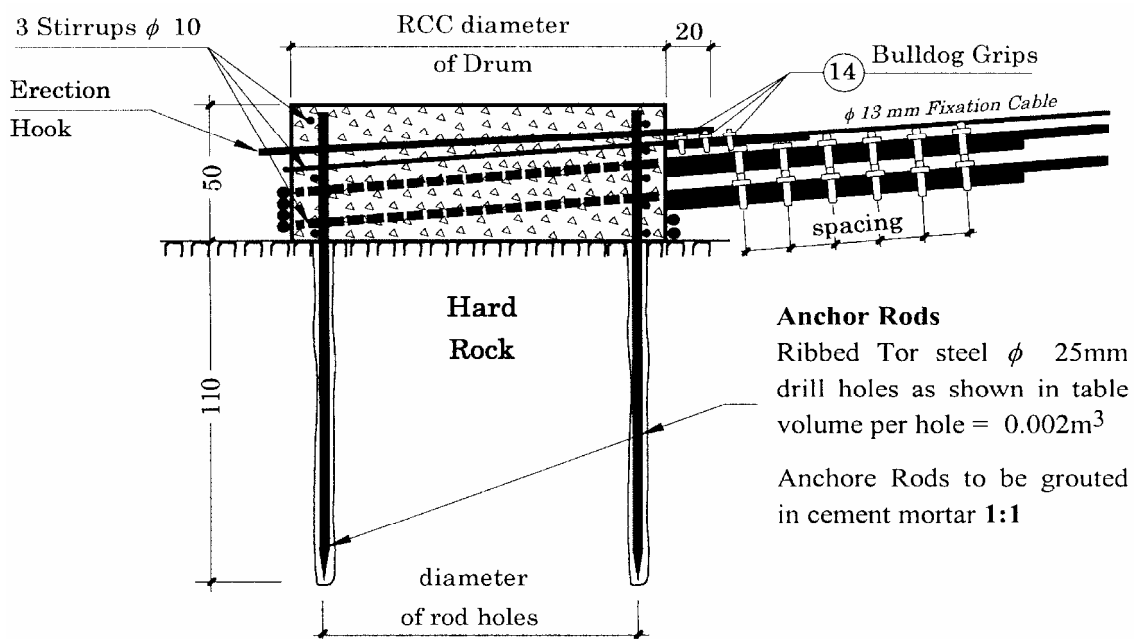


Figure 26 Drum anchorages in hard rock.[9]

Drum anchorage in soft or fractured rock are not done by drilling holes but by excavating a round pit instead. The anchor reinforcement has to be placed in the pit and is fixed with stirrups. The excavated pit is then filled with concrete and well compacted or vibrated up to ground level. At this stage the anchor rods should protrude above ground level. The formwork for the drum is made by plain iron sheet inside lined with a plastic sheet bound together with binding wire or bamboo mat as of anchorage in hard rock, as shown in Fig.27, below.

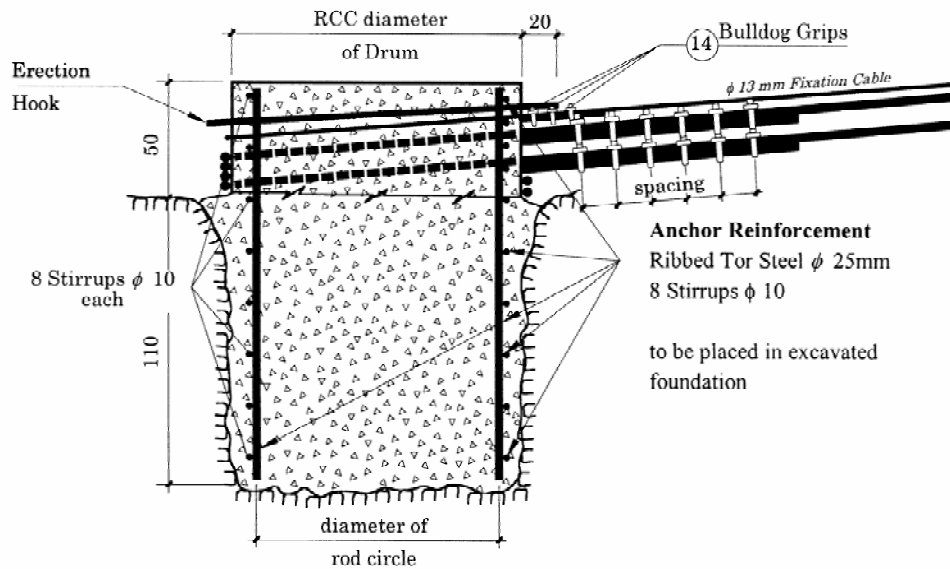


Figure 27 Drum anchorage in soft and fractured rock[9]

10.5 Cable Hoisting and sag setting

After the dead man beam in soil foundation or the drum anchor in rock foundation casted, the cables are hoisted and the prescribed sag set.

Cables are pulled by hand and for final setting with the help of the cable-pulling machine. Pull the cable until it reaches a level higher than the calculated elevation. Each cable should be left in this over pulled position for a day. This over pulling is done to prevent any later relaxation of the cable, which may lead to a tilted walk way. Then slowly release some force carefully moving the lever of the cable-pulling machine until the

desired pre- calculated elevation has been reached. Then immediately retighten the bulldog grips, then completely released the tension applied by the machine and check also that parallel cables have equal hoisting sag.

After the cables have been pulled and the hoisting sag is firmly set the cable anchorage has to be fully completed before any fitting works for the walkway start.

The gravity structure on top of the dead man beam or drum anchor is constructed. The exposed side of gravity structure is jointed with cement sand mortar stone masonry work.

10.6 Walk way fitting

After the gravity structures of the cables anchorage have been completed, the fitting work for the walkway must only started

It is better to start fitting from one bank first. Fit crossbeam, steel panel or wooden planks as close as possible to the bridge entrance. Maintain equal vertical distance between hand rail and walkway cable. If wood is used for the bridge deck use washer below bolt heads.

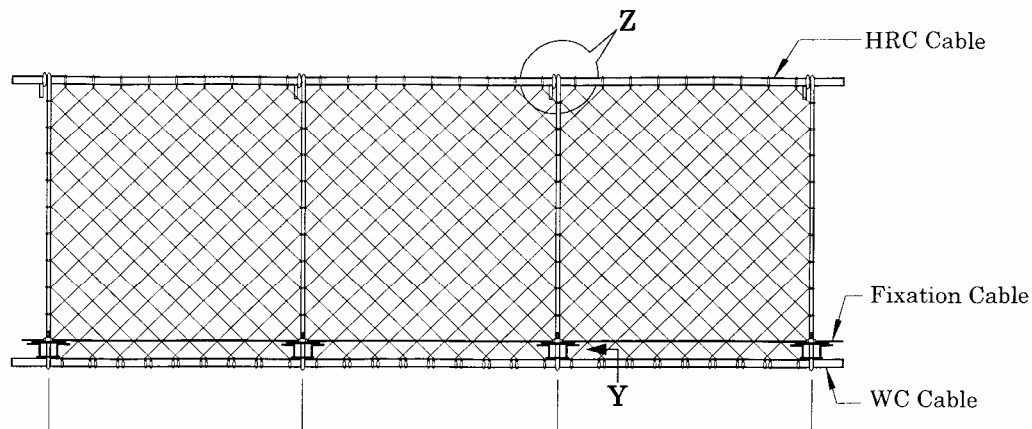


Figure 28 Mesh netting for walk way [9]

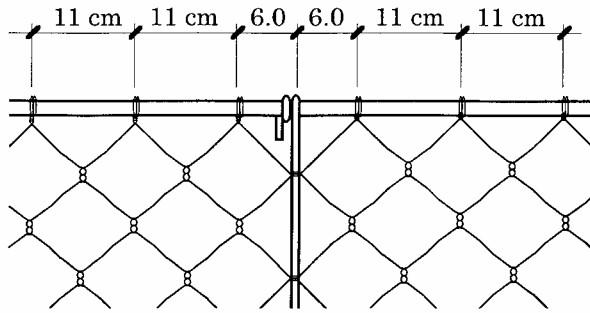


Figure 29 Detail Z[9]

Mesh netting is woven on the sport with gabion wire between the handrail cable and the fixation cable. First fix the fixation cable by pulling it through the bottom eye of the suspender along either side of the walkway, and then join it with short piece at the other end of the bridge.

10.7 Finishing work and water management

The life expectancy of the bridge largely depends on proper water management. Any water seepage encountered during excavation should be intercepted as close as possible to its origin and channeled safely to a near by water course, specially vulnerable area is the place behind the deadman beam. Provide a drain behind the dead man beam with side out let. Divert surface water and provide drainage channels as necessary and divert water as far away from bridge foundation as possible for managing surface water, also fill the gap around completed anchor block well above the existing surface.

Finally provide finishing structure like retaining walls, steps or staircases, small improvements

10.8 Maintenance

Maintenance of suspended bridge is necessary in keeping the pack animals and peoples walking with out a problem through out bridge life span. It is extremely essential to guarantee their permanent and safe use maintain them in usable condition, and to preserve the investment made in these bridges. In order to determine the required maintenance, regular inspection of the bridge should be made after completion of the construction work.

Bridge maintenance work consists of the following two categories.

Routine maintenance

Routine maintenance is a preventive type of maintenance and should be done regularly. It is important to protect the bridge from getting big and irreparable damages and assures long-term use by keeping them in serviceable condition.

After completion of the bridge construction, routine maintenance should be carried out on regular basis. In general, the works under routine maintenance are simple in nature.

These includes, cleaning and removing all sorts of debris, dirt, plants and bushes in and around the drainage channels, the cable anchorage terminals, the tower base, the area around foundations the area below the bridge entrance and the bridge access trails.

Fixing and re-tightening of walkway wire mesh, nuts and bolts, bulldogs grips, I- bolts etc. which are loose.

Inspection and checking of the slope and river bank protection structures and execution of minor repair work.

Major maintenance

Major maintenance work includes all works which need proper planning, surveying, design. Certain level of knowledge and skill is required to execute the major maintenance of the bridges.

The major maintenance work includes the following tasks, replacing of rotten wooden planks and galvanized steel decks, repairing of wind guy arrangements and systems adjustment or replacement of suspenders. Repainting of all non galvanized steel parts, redesigning of all loose cables and adjusting bridge alignment, river bank and slope protection works etc.

11.0 Conclusions and recommendations

Based on the analysis and design made for different span of suspended pedestrian cable bridge as well as the method of construction formulated, it is simple to judge that this system is viable with minimum cost and time, and able to contribute towards an alternative communication means for the country.

The suspended cable bridge is relatively simple to construct. There fore, the requirement of skilled personnel and equipments than concrete and steel bridges for pedestrian use. Since, the suspended pedestrian cable bridge is a viable solution based on this study. Academic institutions and road construction sector towards the wide use of suspended pedestrian cable bridge in Ethiopia.

The road construction sectors needs to be made aware of this alternative.

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Appendix A

Design example of main and handrail cable structures for nominal span of 100m suspended cable bridge.

$$F_{yd} = 1.180/1.15 \text{ KN/mm}^2 = 1.026 \text{ KN/mm}^2$$
$$E=110 \text{ KN/mm}^2$$

Step 1 calculate, l .

$$l = \text{nominal span} + 2 \times 0.25 \text{ m}$$

$$l = 100.5 \text{ m}$$

Step 2 calculate h from topography

Elevation difference of right and Left bank

$$h = \text{Elev. (B)} - \text{Elev. (A)}$$

Assume $h=7\text{m}$, for illustration purpose.

Check $h < l/14$

$$h < 100.5/14$$

$$7 < 7.18 \text{ ok!}$$

That is the lowest point remains inside the bridge span.

Assume Value for

$$\beta_{1,d(rec)} \approx 10^\circ$$

$$d_d \approx \frac{l}{23} - \frac{h}{4}$$

$$d_d = 100.5/23 - 7/4 \text{ m}$$

$$d_d = 2.62 \text{ m}$$

Use $d_d = 2.62 \text{ m}$

Step 3 Calculate L_d

$$L_d = l \left(1 + \frac{1}{2} \left(\frac{h}{l} \right)^2 + \frac{8}{3} \left(\frac{b}{l} \right)^2 \right)$$

$$L_d = 100.5 \left(1 + \frac{1}{2} \left(\frac{7}{100.5} \right)^2 + \frac{8}{3} \left(\frac{2.62}{100.5} \right)^2 \right)$$

$$L_d = 100.9259 \text{ m}$$

Step 4 Select number and size of cables

$$\text{Main cable } 4\phi 26 \quad A_m = 1168 \text{ mm}^2$$

$$\text{Handrail cable } 2 \phi 26 \quad A_H = 584 \text{ mm}^2$$

$$A_T = 1752 \text{ mm}^2$$

$$\text{Windguy cable } 2 \phi 26 \quad A_w = 584 \text{ mm}^2$$

Step 5 Calculate w_h and w_f

Hosting load case, w_h :

Main and handrail cable weight	0.151 KN/m
Walk way deck	0.414 KN/m
Walkway support with hanger	0.22 KN/m
Fixation cable	0.01 KN/m
Wire mesh netting	0.06 KN/m
Wind guy cables	0.05 KN/m
Wind tie (average)	0.03 KN/m
	0.935 KN/m

$$\text{Factored dead load, } w_d \quad 1.3 \times 0.935 = 1.216 \text{ KN/m}$$

Full load case w_f

$$\text{Factored Live load} \quad 1.6 \times 4 = 6.4 \text{ KN/m}$$

$$\text{Factored dead load} \quad = 1.216 \text{ KN/m}$$

$$w_h = 0.196 \text{ KN/m}$$

$$w_f = 7.616 \text{ KN/m}$$

Sag calculation

Step 6 Calculate constant

$$C = \frac{64EA}{3l^3 L_d}$$

$$C = \frac{64 \cdot 110 \cdot 1752}{3 \cdot 100.5^3 \cdot 100.9258}$$

$$C = 0.04013$$

Case 1 Hoisting load sag

step 7 Assume

$$\begin{aligned} d^* &= 0.93d_d \\ &= 0.93 \times 2.62 \text{ m} \\ &= 2.4366 \text{ m} \end{aligned}$$

Step 8 Calculate, w^* .

$$\begin{aligned} w^* &= Cd^*(d^{*2} - d_d^2) + \frac{d^*}{d_d} w_d \\ &= 0.04013 \times 2.4366 \times (2.4366^2 - 2.62^2) + \frac{2.4366 \times 1.216}{2.62} \\ &= 0.78076 \text{ KN/m} \end{aligned}$$

Step 9 Check $\Delta w = |w_i - w^*| \leq 0.01$

$$|\Delta w| = |0.196 - 0.78076| > 0.01$$

After several iteration

Step 10 Calculate new $d^* = 0.9 \text{ m}$

step 9 Calculate w_{new}^* ,

$$w^* = 0.199 \text{ KN/m}$$

Step 10 $|\Delta w| = 0.003 < 0.1 \text{ ok!}$

Hoisting sag $d_h = 0.9\text{m}$

Case 2 Full load sag d_f .

Step 7 Assume $d^* = 1.22 \times 2.62\text{m}$

$$d^* = 3.196\text{m}$$

Step 8 Calculate, w^*

$$w^* = 0.04013 \times 3.196 (3.196^2 - 2.62^2) + \frac{3.196 \times 1.216}{2.62}$$

$$w^* = 1.913 \text{ KN/m}$$

Step 9 $\Delta w = 7.65 - 1.913$
 $= 5.703 > 0.01$

After several iteration

Step 10 $d_f^* = 5.475\text{m}$
 $w^* = 7.619\text{KN}$
 $\Delta w = 0.003 < 0.01$ ok!

Step 11 Maximum tension at full load

$$T_{\max} = \frac{wl^2}{8d} \sqrt{1 + \left(\frac{4d+h}{l}\right)^2}$$
$$T_{\max} = \frac{7.616 \cdot 100.5^2}{8 \cdot 5.475} \sqrt{1 + \left(\frac{4 \cdot 5.475 + 7}{100.5}\right)^2}$$

Step 12 $T_{\max} = 1827.4 \text{ KN} < 2004.14 \text{ KN}$ ok!

Appendix B

Design example of windguy cable structure for nominal span of 100m.

Assume that the rights as well as the left bank up stream and down stream have no problems for placement of foundations. The upstream windguy parabola shall be arranged symmetrically to the down stream windguy parabola

Assume bridge site is seismic zone 4.

From the topography of the bridge site selected.

(for illustration purpose)

$$C_L = 11.0\text{m}$$

$$D_L = 10.0\text{m}$$

Assume

$$d = 6.0$$

$$k = 0.65$$

$$l = 100.5$$

The first cross beam is fixed at 0.1m from saddle on right side, the vertex of the windguy is fixed at 40th cross beam.

There fore

$$v = 0.1 + 39 \times 1.2 \text{ m}$$

$$v = 46.9 \text{ m}$$

Calculate, f_w .

$$j = 0$$

$$y_0^1 = C_L = 11.0$$

$$\begin{aligned} x_0 &= l - v - D_L \\ &= 100.5 - 46.9 - 10 \\ &= 43.6\text{m} \end{aligned}$$

$$f_w = \frac{v^2}{x_0^2} (y'_0 - 2.2m)$$

$$f = \frac{46.9^2}{43.6^2} (11.0 - 2.2)$$

$$f = 10.18m$$

Calculate h_w .

$$h_w = f_w \left[\left(\frac{l-v}{v} \right)^2 - 1 \right]$$

$$h_w = 10.18 \left[\left(\frac{110.18 - 46.9}{46.9} \right)^2 - 1 \right]$$

$$= 3.12m$$

Calculate, d_w .

$$d_w = \frac{h_w^2 v^2}{16 f_w \left(\frac{l}{2} - v \right)^2}$$

$$d_w = \frac{3.12^2 46.9^2}{16 \cdot 10.18 \left(\frac{100.5}{2} - 46.9 \right)^2}$$

$$d_w = 11.72m$$

Check d_w in between 1/8 and 1/10 ok!

Since the bridge site is seismic zone 4, $C_{sm}=0.25$

$$Eq = C_{sm} \times w_e$$

$$= 0.25 \times 0.96 \text{ KN/m}$$

$$= 0.24 \text{ KN/m}$$

where w_e is the weight of the bridge

Eq is earth quake load.

Since the weight of the bridge is very small wind load govern the design of windguy cable.

Calculate cable tension, H_w , T_R , T_L

$$H_w = \frac{w_{lat} l^2}{8d_w}$$

$$H_w = \frac{1.0 \cdot 100.5^2}{8 \cdot 11.72}$$

$$H_w = 107.2 \text{ KN}$$

$$T_R = 107.2 \sqrt{1 + \left(\frac{2 \cdot 10.18}{46.9} \right)^2}$$

$$T_R = 116.9 \text{ KN}$$

$$T_L = 107.2 \sqrt{1 + \left(\frac{2 \cdot 10.18(100.5 - 46.9)}{46.9^2} \right)^2}$$

$$T_L = 121.1 \text{ KN} < 299.6 \text{ KN}$$

Use 2 Φ 26

Appendix c

Design of deck

Data

span = 1.2m

deck beam spacing is 1.2m.

Loading

self weight and walkway load = $1.3 \times 0.634 \text{KN/m}^2 \times 1.2\text{m}$
= 0.989KN/m

live load = $1.6 \times 4 \text{KN/m}^2 \times 1.2\text{m}$
= 7.68KN/m

design load = 8.67KN/m

$$M = \frac{wl^2}{8}$$

$$M = 1.5606 \text{KN-m}$$

$$\text{section modulus, } \frac{M}{\sigma} = \frac{1.5606}{300,000} = 0.000005202$$

Select the section from tables.

Notations

A	Sectional area	mm ²
E	Modulus of elasticity	KN/mm ²
F	Safety factor	-
H	Horizontal component of cable tension	KN
$\square \sigma^*$	Change in stress in cable due to assumed sag.	KN/mm ²
$\square H^*$	Change in horizontal tension in cable due to assumed sag	KN
$\square L^*$	Change in length in cable due to assumed sag	m
L	Cable length between saddles	m
T	cable tension	KN
T_{max}	Total cable tension at higher foundation (all cables)	KN
d^*	Assumed sag.	
d	Sag, measured in the middle of the bridge from the chord	m
x_l	Horizontal distance from the cable saddle at the higher foundation saddle to the lowest point of the parabola	m
y_l	Maximum sag, vertical distance from the cable saddle at the higher foundation saddle to the lowest point of the parabola	m
w	Load	KN/m
w^*	Load corresponding to an assumed sag d^*	KN/m
h	Difference in elevation between the cable saddles at the higher and lower foundation saddles	m
l	Design span, distance between the saddles	m
n	Number	
P	Live load	KN/m
s	Nominal span, distance between the front of main foundations	m
β	Cable inclination at saddle	deg
Δ	Increase (+) or decrease (-) of sag or cable length, due to changing load	
B_L, B_R	Distance of the first windtie from the saddle of the main foundation or tower axis	

C_L, C_R	Distance from the front of the windguy cable foundation to the bridge axis	m
C_{Lo}, C_{Ro}	Distance from the windguy cable to the bridge axis measured on the - Saddle axis for suspended bridges - tower axis for suspension bridges	m m
D_L, D_R	Distance from the front of the windguy cable foundation to the saddle of the main foundation or tower axis. Sign: - inside of span (-) - Outside of span (+)	
T_L, T_R	Windguy cable tension at the windguy cable anchorage foundation	KN
T_{max}	Maximum windguy cable tension	KN
e_d	Horizontal distance from the saddle of the higher foundation to the Vertex of the walkway (refer to 7)	m
d_w	Distance between the windties in the plan	m
F_w	Sag of winguy cable at the distance, V , in the plan	m
h_w	Value for the theoretical windguy cable parabola within the bridge span (refer to sketches)	m
k	Distance from the bridge axis to the center of the windtie-connecting bolt at the cross-beam	m
r	Horizontal distance from the saddle of the main foundation or tower axis to the vertex of the windguy cable in the plan measured from the right side	m
v	Horizontal distance from the saddle of the main foundation or tower Axis to the vertex of the windguy cable in the plan, measured from the right side	m
w_{lat}	Lateral load	KN
x, y	Sheaf of coordinate axis for the windguy cable in the plan	-
$x;$	Value for the theoretical windguy cable parabola within the bridge span (refer to sketches)	m
\varnothing_w	Diameter of windguy cables	mm
α_L, α_R	Angle between the windguy cable and the bridge axis at the windguy cable anchorage foundation in the plan	deg
Indices:	R Right side	

<i>L</i>	Left side
<i>W</i>	Windguy cable
<i>h</i>	Hoisting load case
<i>d</i>	dead load case
<i>f</i>	full load case
<i>i</i>	load case (either full or hoisting)
<i>M</i>	Main cables
<i>H</i>	Handrail cables
<i>W</i>	Windguy cables
<i>l</i>	Higher foundation
<i>0</i>	Lower foundation

Declaration

This thesis is my original work and has not been presented for a degree in any other university and that all sources of material used for the thesis have been dually acknowledged

Candidate

Advisor

Name_____

Signature_____
