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Gravity Ropeway Fighting Poverty with Technology

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Abstract—*For the most of the people at one edge who have an access to the modern use of technology life has become lot easier and faster .Whereas as in the other edge there are still people who does not have an access to modern use of technology either due to poverty or remoteness. Gravity Ropeway can be the most suitable technology in remote mountainous part of the world. It is in its earlier stage of development though it has been already in use in countries like Nepal, Bhutan and Uttarakhand state of India. Lots of research and improvement has to be made in terms of safety and reliability.*

Gravity Ropeway is the simplest and cleanest means of transportation most suitable in remote mountainous and impoverished part of the world. It solely works on gravity. Potential energy at higher height is the sole energy that is used to drive the system. As it is relatively lower in costing comparison to building roads and employs a very simple technology, it is both affordable and adaptable. Gravity ropeways neither require any external fuel or power nor are they polluting. The operating costs are the mountain slopes nor spoils nature's beauty and resources. Moreover, it causes no harm to the existing ecology.

Gravity ropeway facilitates the transport of local produces to the road heads and market centers, thus encouraging the communities to engage in commercial farming. Therefore, gravity ropeways should be an integral part as the travel time is less than two minutes to bring down the goods from village to markets downhill. Gravity goods ropeway is not alternative road transportation but it rather add values to the existing road network by complementing it in goods transportation from the remote locations to the road head of the District Transport.

1. INTRODUCTION

One of the simplest mechanisms is the rope and wheel. Using ropeways to transport goods and people across difficult terrain is an efficient and effective solution in place of long and arduous journeys by road or foot, and can greatly help improve the lives of local communities. In short, a gravity ropeway moves goods up and down a mountainside by hanging trolleys off wheels that roll along support ropes. As one trolley goes up, another trolley goes down. The weight of the descending trolley is what drives the system. The progress of the trolleys is managed by a control cable. The control cable runs through wheels at the stations at the top and bottom, and those wheels are controlled by a manually operated brake.

The loading and speed of the trolleys must be adequately controlled to avoid them crashing into the stations and potentially harming the operators. The support wires must be well anchored to ensure against collapse, which could potential harm people or buildings underneath. The ropes and stations must be protected against corrosion, and the mechanism must be well oiled to prevent damage *[1]*.

The construction of the ropeways – which involves lifting and positioning long and heavy steel cables – is a significant challenge. Steps must be taken to ensure that people are not injured while operating the ropeway. When implemented properly, a gravity ropeway can make a significant improvement in the lives of the communities it serves *[2]*.

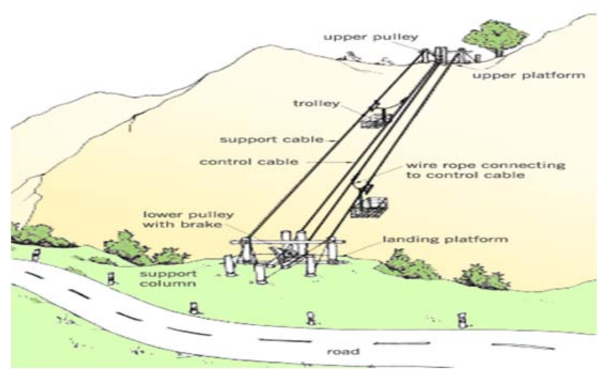

Fig. 1: Gravity Ropeway

2. MATERIAL AND METHODOLOGY

The mechanics of the gravity ropeway works on a very simple pulley system. It consists of two trolleys, rolling over two separate steel wire ropes (track ropes) supported and suspended over two separate towers at the top and bottom ends. The two trolleys that slide on the track rope are connected to a single looped wire rope (hauling rope) of a smaller diameter by means of rope ties. This hauling rope passes around a cast iron sheave at the top and bottom stations. When the loaded trolley rolls down by its own weight along one track rope from the upper station, another trolley with lighter weight at the bottom station hauls up along the next track rope as they are connected to the haulage rope. A simple brake with a rubber/wooden brake shoe is fitted to the sheave at the lower station to regulate the speed of the moving trolleys. Theoretically, the velocity of trolleys at each point along the route corresponding to the given loading ratio can be obtained from the following equations or relations *[3]*.

Let us suppose m_1 be the mass of downward moving trolley with load and m_2 be mass of upward moving trolley with load. Here, m_1 is always greater than m_2 .

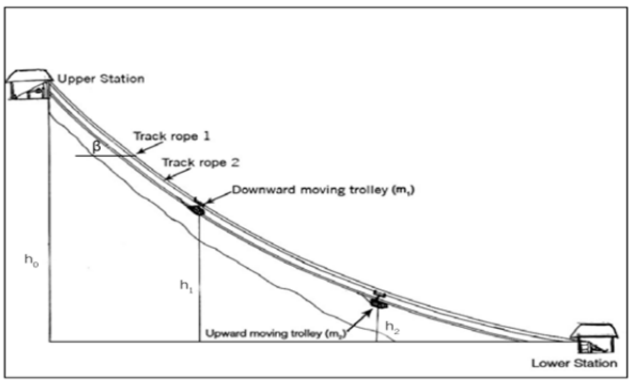

Fig. 2: Design calculation

Here,

I. Initial potential energy of downward moving trolley (PE_0) = m_1 g h_0 , where h_0 is the elevation difference between the upper and lower saddles.

II. Potential energy of downward moving trolley at the point of consideration (PE_1) = m_1 g h_1 where h_1 is the height of the first trolley from lower saddle at the time of consideration.

III. Potential energy of upward moving trolley at the time of consideration (PE_2) = m_2 g h_2 , h_2 is the height of m_2 from lower saddle at the time of consideration.

IV. Combined work done by the masses against the friction (W_1) = 0.25($m_1 + m_2$) cosβS where S is the rope length covered by the trolleys at the time;

V. Combined Rotational Energy of sheaves (W_2) = I ω^2 , where ω= v/r, I = ½ m r^2 where r and m are the radius and mass of the sheave respectively.

Now, as per the principle of conservation of energy, **0.5 (** m_1 + $m_2 + m_h$ **)** v^2 = PE_0 - PE_1 - PE_2 - W_1 - W_2

Here, m_h is the mass of the hauling rope.

From this relationship, the velocity of moving trolleys at specified time and point along the route can be calculated. The actual velocity for a given loading condition is usually less than the velocity obtained from this relationship. As the track rope and hauling rope are not parallel to each other in vertical plane, the hauling rope is pulled towards the track rope while the gravity ropeway is in operation. This leads to the excessive friction between the hauling rope and the sheave which leads to the loss of velocity. Nevertheless, the idea of tentative approaching velocity of the trolley helps to calculate the maximum possible impact load which is very important for the rope design.

3. EXPERIMENTAL PROCEDURE

Wire Rope:

A wire rope is made up of a number of fiber or steel wire strands laid helically around a core. The strands themselves are composed of a number of wires laid in various geometrical configurations. Ropes are manufactured from steel wires which are drawn from steel rods melted in open– hearth or electric furnaces. The wire rope construction, types and other terms used in this guideline are described in the glossary.

Rope Geometry:

The shape of the rope curve is influenced by the weight of the rope, the weight of the trolley that slides upon it, the load in the trolley, wind load, the friction developed on the supports (towers) and the braking friction at rope or at the stations during stoppage and icing (in cold places). In each case, the curve has to be determined for maximum and minimum conditions i.e. for rope only and the line fully loaded. In these conditions, the maximum sag of the rope and the bending angles due to load on the supporting towers at the two ends must be evaluated. Each rope is exposed to tension caused by initial stresses due to tension weight, the rope's own weight and the weight of the loaded trolley at its maximum carrying capacity (120 kg in the case of gravity ropeway). The shape of the curve varies according to the way the rope is fixed, its alignment, angle of inclination and the number of spans (if the gravity ropeway has more than one span).

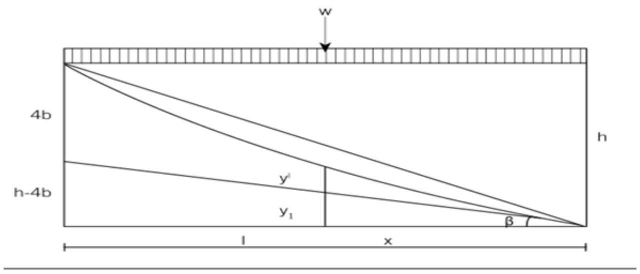

Fig. 3: Dynamic calculation (i)

In the above diagram,

$$y = y_1 + y'$$

Where,

$$y_1 = \frac{4bx^2}{l^2} \text{ and } y' = \frac{(h-4b)x}{l}$$

Hence

$$y = \frac{4bx^2}{l^2} + \frac{(h-4b)x}{l} \qquad \text{(i)}$$

This is equivalent to the parabolic equation,

$$y = ax^2 + bx \qquad \text{(ii)}$$

Hence from this relation, y for each corresponding x is obtained and the rope curve can be plotted

Integrating the equation (ii),

$$\frac{dy}{dx} = \text{Tan}(\beta) = 2ax + b \qquad \text{(iii)}$$

This relation gives the slope of the curve at the point of consideration. Hence, we can obtain the tension in the rope anywhere from the following relation.

$$T = H/\cos(\beta)$$

The curve of the rope can be obtained from the following relation too.

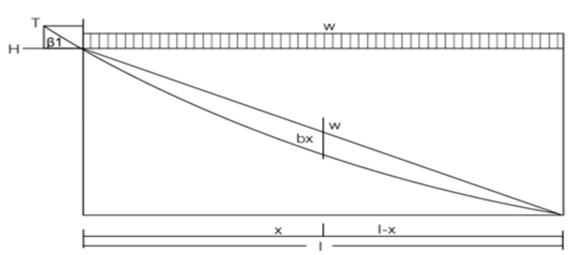

Fig. 4: Dynamic calculation (ii)

When the chord is horizontal, we know that,

$$b = \frac{w(l-x)x}{2H} \qquad \text{(a)}$$

And the rope sag is maximum at x = l/2

$$\text{So}, b_{\max} = \frac{wl^2}{8H} \qquad \text{(b)}$$

Now, dividing equation (a) by (b), we obtain the ratio.

$$b : b_{\max} = \frac{4.x}{l}.\frac{(l-x)}{l}$$

As the maximum sag is known, the rope curve can be plotted from this relation. The curve shape calculation using the catenary's equation is elaborative and arduous. The errors arising from the approximation when replacing the catenary by parabola do not exceed 2.6 per cent. Therefore, in almost all the cases, it can be assumed with sufficient accuracy that the rope curve is parabolic *[4]*. For small span and sag, the error due to the assumption amounts to fraction of one per cent. The error varies proportionately with the ratio of b/l. With uniformly distributed load over the rope span in the plan view, the error amounts to:

b/l < 1/20	error < 0.3%
b/l = 1/10	error = 1.3%
b/l =1/5	error = 5%

Some codes for aerial ropeway suggest that the profile of the rope may be considered parabolic if the sag is less than 10 per cent of the span.

Rope length:

For a rope, the horizontal projection length (on base) is = l, maximum sag = b max and the difference in level between supports = h, the rope length can be calculated from the basic equation of the element of arc as follows:

$$dl = \sqrt{dx^2 + dy^2}$$

Various authors have derived slightly different formula for the rope length, which are as follows:

$$L = l + \frac{h^2}{2l} + \frac{8b^2_{\max}}{3l} \qquad \text{Chltary}$$

$$L = l + \frac{h^2}{2l} + \frac{w^2 l^3}{24T^2 \cos^2 \beta} \qquad \text{Gullsashvill}$$

Stress in rope:

The rope in the gravity ropeway is subjected to tensile stress due to its own weight and the bending stress caused by the live load.

The maximum stress on the rope,

$$\sigma_{\max} = \sigma_t + \sigma_b ,$$

$\sigma_t > \sigma_b$ must be maintained to avoid the loosening of wire rope.

Load consideration:

The gravity ropeway is subjected to the following loads while in operation:

a) Wind load

b) Dead load

c) Live load

d) Temperature stress

e) Impact load

f) Seismic load

g) Dynamic load

The seismic load is not considered in the design whereas dynamic load is partially considered.

Wind load:

The maximum wind load is considered as 1.3 KN/m^2 in lateral direction corresponding to 160 km/hr wind speed

$$w = 1.05 \frac{v^2}{16} (\frac{kg}{m^2})$$

where V is in meter per second.

For calculating the tension in the rope, the wind load is considered to act at an inclination of 20 degrees to horizontal direction.

Dead load:

Weight of the rope, which is considered uniformly distributed Live load: It consists of weight of the trolley, weight of the goods and half the weight of the haulage rope. It is considered as point load in calculation.

Impact load:

Upon sudden application of brake, impact load is produced in the ropeway system. The impact load is mainly carried by the haulage rope so a certain percentage of impact load is to be considered in the haulage rope design. As it is difficult to ascertain the amount of impact load transferred to haulage rope, it is considered to be 50 per cent of the maximum possible impact load. During the movement, the trolley moves back and forth in the track rope so the minimal impact load is imparted to the track rope. It is considered to be 10 per cent of the total impact load *[5]*.

Maximum possible loads:

Maximum possible load in track rope = wt. of track rope + wt. of trolley + wt. of downward moving goods + 50 per cent of weight of haulage rope + 1/3rd of maximum wind load + 10 percent of impact load Maximum load in haulage rope = wt. of the

haulage rope + maximum wind load + 50 percent of impact load. The rope factor of safety should be checked for the following two loading conditions:

Dead load + maximum wind load

Full load + 1/3rd of maximum wind load

Impact load

As the gravity ropeways operate in the hilly terrains, consideration of wind load is very crucial. The operation of the ropeway during heavy storms should be strictly prohibited.

Rope tension calculation

For rope tension calculation, first of all the rope sag at dead load is assumed and the rope tension is calculated for the corresponding sag *[6]*. The full load sag is then obtained from iterative methods but more conveniently from computer analysis like SAP. Tension in the wire rope is calculated from the following relation.

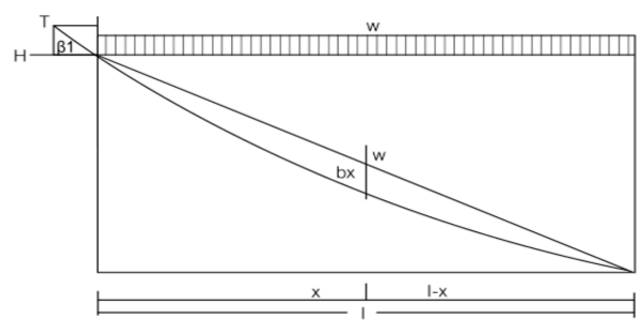

Fig. 5: Dynamic stress calculation

For uniformly distributed load (w)

Horizontal reaction at point x (H_x) $= \dfrac{w_x(1-x)}{2b_x}$,

H_x is maximum at b_x =b.

Maximum horizontal reaction (H) $= \dfrac{wl^2}{8b}$

where w is weight per meter and b is the maximum sag.

For point load (w)

When the point load is at x,

Horizontal reaction x (H_x) $= \frac{W_x(1-x)}{2b_x}$

The reaction is maximum when the point load is at the Centre.

Hence,

$$H_{\max} = \frac{Wl}{4b}$$

where w is point load and b is the maximum sag.

Point and live load in combination

At x,

$$H_x = \frac{w_x(l-x)}{2b_x} + \frac{W_x(l-x)}{b_x}$$

When b_x = b

$$H_{\max} = \frac{wl^2}{8b} + \frac{Wl}{4b}$$

4. RESULT & DISCUSSION

Calculation:

Gravity rope way works on the simple principle of conservation of energy. The Potential energy gained by the loaded pulley at the top station is used as the source of energy to operate this system. This potential energy is sacrificed to overcome wind resistance, frictional force and the remaining energy is converted into Kinetic energy of trolleys and the sheave.

Let us consider, at any time t, the trolley is at the height h_1 =50cm from the ground, the velocity acquired by the trolley at this point is calculated as

Table 1: Energy Calculation

Energy	Symbol used	Formula	Value(J)
Max Potential Energy	PE_0	$m_1 g h_0$	31.2375
Potential energy of loaded trolley at h_1	PE_1	$m_1 g h_1$	20.825
Potential energy of lighter trolley at that time (h_2)	PE_2	$m_2 g h_2$	0.6125
Loss due to friction	W_1	$\mu(m_1 + m_2)\cos\beta.S$	1.4614
KE of trolley 1	KE_1	$\frac{1}{2} m_1 v^2$	?
KE of trolley 2	KE_2	$\frac{1}{2} m_2 v^2$	?
Rotational Energy of Sheave	W_2	$\frac{1}{2} I\omega^2$	?

From the law of Conservation of energy;

$$PE_0 - PE_1 = PE_2 + \frac{1}{2} m_1 v^2 + \frac{1}{2} m_2 v^2 + W_1 + \frac{1}{2} I\omega^2$$

Where, $I = \frac{1}{2} mr^2$ and $\omega = \frac{v}{r}$

Hence $W_2 = \frac{1}{2} I\omega^2 = \frac{1}{2} mv^2$

$$\Rightarrow PE_0 - PE_1 = PE_2 + \frac{1}{2}(m_1 + m_2 + m)v^2 + W_1$$

$$\Rightarrow PE_0 - PE_1 - PE_2 - W_1 = \frac{1}{2}(m_1 + m_2 + m)v^2$$

$$\Rightarrow v = \sqrt{\frac{2(PE_0 - PE_1 - PE_2 - W_1)}{(m_1 + m_2 + m)}}$$

$$\Rightarrow v = \sqrt{\frac{2(31.2375 - 20.82 - 0.6125 - 1.4614)}{(4.25 + 0.25 + 0.05)}}$$

$$\Rightarrow v = 1.90 m / s$$

Results: The velocity of the trolleys at the height h_1 =0.50 m is 1.90 m/s .Now,

Table 2: Velocity Calculation

Energy	Symbol	Formula	Value(J)
KE of loaded trolley	KE_1	$\frac{1}{2}m_1v^2$	7.67
KE of lighter Trolley	KE_2	$\frac{1}{2}m_2v^2$	0.45125
KE of Sheave	W_1	$\frac{1}{2}I\omega^2$	0.09

5. CONCLUSION

An initial study showed that the transportation cost of agro-based products decreases by at least 50% once served by a gravity ropeway system. Such encouraging statistics have villagers the confidence to supply their products in larger amounts, and to enter competitive city markets. Access to a transportation system and to market linkages improves their socioeconomic status in terms of income, health, education and community awareness. Promotion of this technology also helps the local economy by creating employment opportunities and by supporting local manufacturers and service providers.

Due to this fact, the rural communities from ages are facing rather exhausting, time consuming and often dangerous journeys to access basic services like administrative, health and education facilities, and access to markets to sell their produces. Each year substantial quantities of surplus agricultural produces perish due to lack of adequate infrastructures and facilities to transport them to the markets in time. As such, rural communities survive with subsistence agriculture despite the huge economic and market potentials. Gravity ropeway facilitates the transport of local produces to the road heads and market centers, thus encouraging the communities to engage in commercial farming. As the travel time is less than two minutes to bring down the goods from village to markets downhill, perishable goods can be transported to the markets in no time which considerably prevents them from getting rotten. Gravity ropeway can be an economical solution to transport goods to the hills and valleys and vice-versa. Export of greater quantity of local produces from the village and import of lesser quantity of outside materials to the village will be an ideal condition to install a gravity ropeway which will ultimately promote local produces and help boost the local economy. Gravity goods ropeway is not an alternative to road transportation but it rather add values to the existing road network by complementing it in goods transportation from the remote locations to the road head. Therefore, gravity ropeways should be an integral part of the Local Transport Master Plan for the mountainous and hilly districts.

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