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Introducing a Modified Water Powered Funicular Technology and its Prospective In Nepal

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ABSTRACT

There have been so many alternative technologies introduced for transportation in the hilly regions. Among them, some include electricity-based cable cars while some others include gravity-based like gravity ropeways, funicular transportation etc. In this paper, we would like to discuss the funicular technology proposing a modified version and also suggesting a proper prospective of funicular transportation in Nepal. In this paper, we get into the physics of funicular transportation and generalize it and based on the equation we propose method to optimize the funicular system.

Keywords: *Alternative Technology for Transportation, Gravity Ropeway, Funicular Transportation, Optimize the Funicular*

1. INTRODUCTION

In a hilly country like Nepal, modern transportation techniques like road-ways, air-ways, etc. are difficult to implement. Previously, ropeways were seen as the best option in such areas, including electrical cable-cars, twin technology and gravity ropeways [1],[2]. Currently, Nepal has one cable car for commercial public transport, 21 gravity ropeways, more than 150 wire bridges etc. [3].There have been various case studies about gravity ropeways (also gravity goods ropeways) in Nepal [2] and these ropeways have even been used as means of transport, but funicular railway technology has never been considered in Nepal; although it is geographically suitable for the purpose. In this paper, we would like to introduce the theory of funicular railways and how the proposed modified version could be used in Nepal.

The funicular railway is one of the cable drawn transport systems[4], in which a cable is attached to a pair of block-like vehicles on a rail-track, and the descent of one vehicle causes ascent of another. Funicular has a long history (since 1804)[5].In the paper [5] Hofmann beautifully describes the history as well as various parts of funicular along with some existing funiculars.

The principle of funicular railway operation is that two cars (or, movable parts) are permanently attached to each rail-track exactly opposite to the other (one car stays on the top of other track while the other at the bottom of the track as in figure 2) attached by a cable, which runs through a pulley on the top of the incline. Increasing the load on the car on the top increases the resultant drag force causing acceleration and the car descends along its track and at the same time the same force causes the car at the bottom to ascend along its track since they are attached by the same cable. Nowadays, most funiculars are electricity-driven while there also are a few water-powered funiculars. The electricity-based funicular systems are a result of advancements in the field of funicular railway technology and are also deemed as the most reliable systems. There has been implementation of solar PV technology in funicular railway at Leghorn, Italy [6], while water powered funiculars like Bom Jesus Funicular, Clifton Rock Railways etc.[7] also exist. In the paper [5],Hofmann describes the water powered funicular as water ballast system where funicular railway uses tanks under the floor. The car at the higher elevation is loaded with water so that it descends along the track, causing ascent of the car at lower elevation. The braking is controlled by a brakeman or a driver. Water powered funicular could be an alternative in the places where electricity is not easily available. So in a country like Nepal, where load-shedding is done for more than15 hours a day during winter, water powered funicular system could be a good alternative for transportation.

2. DISCUSSION

Optimized Water Power Funicular (Theoretical)

The new type of funicular railway that we would like to discuss in this paper may not necessarily require electricity, but instead use a new technique of deviation of tracks, which enables the vehicles to gain retardation to finally stop automatically or by use of minimal energy. Also, this system ensures that electricity and other traditional braking systems can be incorporated which optimizes the use of such system. The other features are much similar to the previously used methods. We use simple prototype figures to illustrate the theory. The figures have been created using Google Sketch Up Pro software just for the basic understanding of the physics involved and thus, the actual design of the funicular railway may vary from the ones shown in the figures shown here.

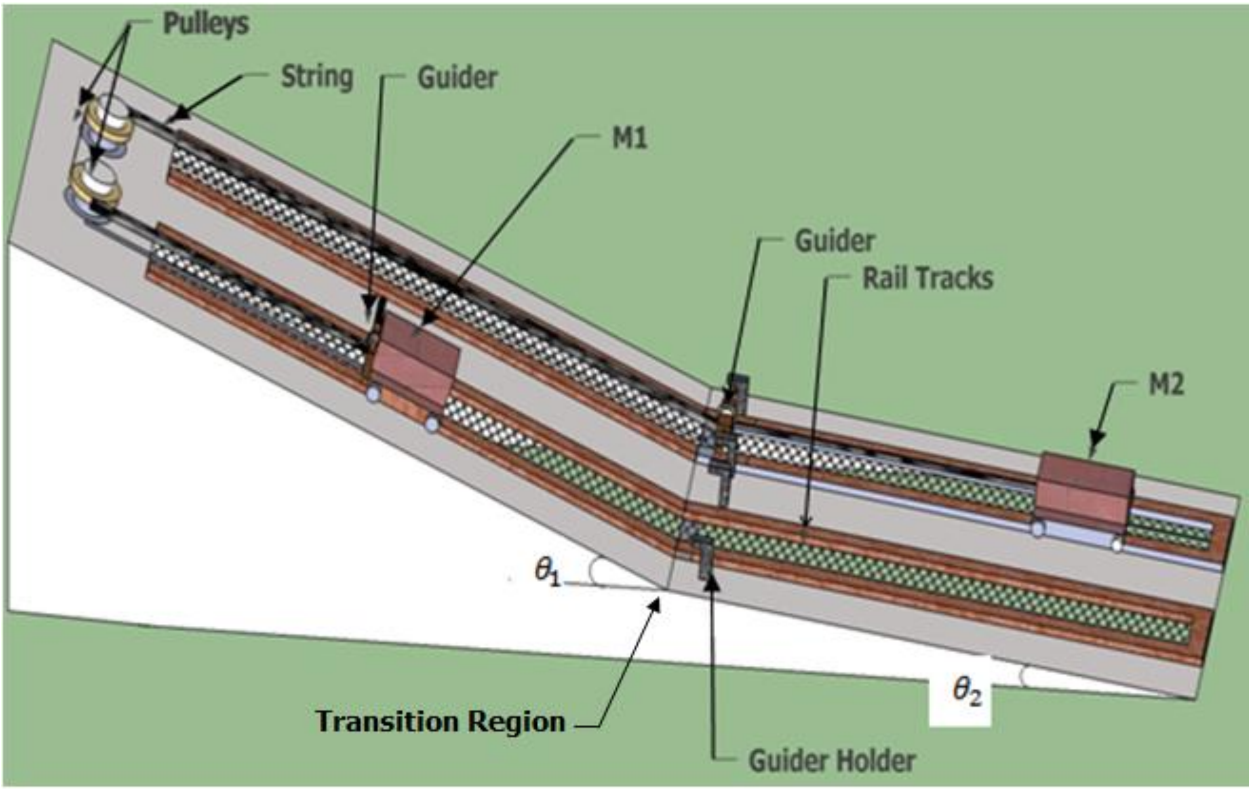

Figure 1: Labeled diagram of modified funicular

Let us consider two sets of rail-track inclined at angles θ_1 and θ_2(Figure 1 and Figure 2) respectively, where $\theta_1 > \theta_2$. Also, let the masses of blocks M1 and M2 be denoted as M and m respectively. Let there be a movable system with an attached pulley having mass Δ called as guider (Figure3). The main function of the guider is, with the help of the pulley and the string, to guide the blocks along their respective tracks by orienting the string parallel to the rail track. The guider moves along with the block until it finds guider-holder as in figures 1, 2, and 3. The guider-holder is placed in such a way that the guider aligns the blocks parallel to the track. This is done to ensure that the tension on the string is always parallel to the motion of the block. At the transition region, the ascending block ascends along the guider at rail track angle $\theta_1$and the descending block loses the guider and descends along the inclination of rail-track angle θ_2. The length of each set of track inclined at an angle is same and it is well ensured that the two blocks lie equidistant from the center at transition region. The mass M+Δ is always greater or equal to the mass m for practical purposes. Let μ be the coefficient of friction between the track and the wheel, g is the acceleration due to gravity and T is the tension on the string. Assuming the tension in the system to remain unchanged during the operation, and there being no loss of energy due to the pulley, we can formulate the equations of motion at equilibrium. If a is the acceleration of the block of mass $M + \Delta$ when it is at rail- track angle of θ_1 and block m at lower rail-track angle θ_2, we have, the resulting force as resolved component of force subtracted from the force opposing the motion by frictional force and tension T as:

$$(M+\Delta)a = (M+\Delta)g\sin\theta_1 - T - \mu(M+\Delta)g\cos\theta_1 \qquad (1)$$

Similarly, the same acceleration a is gained by the block of mass m lying at rail-track angle $\theta_2$in which tension T pulls upward while the resolved component of force and frictional force opposes the motion, and the equation is as:

$$ma = T - mg\sin\theta_2 - \mu mg\cos\theta_2 \qquad (2)$$

Combining (1), (2) and re-arranging

$$a = \frac{g[(M+\Delta)(\sin\theta_1 - \mu\cos\theta_1) - m(\sin\theta_2 + \mu\cos\theta}{\Delta + M + m} \qquad (3)$$

And on dividing the numerator and denominator of right hand side by m we get,

$$a = \frac{g[\left(\frac{M+\Delta}{m}\right)(\sin\theta_1 - \mu\cos\theta_1) - (\sin\theta_2 + \mu\cos\theta_2)]}{\frac{M+\Delta}{m} + 1} \qquad (4)$$

Let the block of mass $M + \Delta$ reach the transition region (simultaneously, the block of mass m reaches the same region as well) and start to descend with inclination of rail track at $\theta_2$leaving the guider.The block of mass m starts to ascend with an inclination of rail track at θ_1 along with the guider. In such a situation, let us assume that the retardation is gained. Let β be a positive integer. Let W be the tension produced in the string. So, the block of mass M experiences retardation if its resolved component of force is less than the opposing force i.e. frictional force and tension. Hence the equation of retardation will be:

$$M(-\beta) = Mg \sin\theta_2 - \mu Mg \cos\theta_2 - W \qquad (5)$$

Since both the blocks are connected with a cable, the same retardation is experienced by the block of mass m+Δ. Here,Δ mass is added to m because while ascending, the block of mass m incorporates the guider with it. So, to have retardation, the tension W that is pulling the block $m + \Delta$ should be less than the resolved component of the force pulling downwards and the frictional force. So the equation is as:

$$(m+\Delta)(-\beta) = W - (m+\Delta)g\sin\theta_1 - \mu(m+\Delta)g\cos\theta_1 \qquad (6)$$

Combining (5), (6) and re-arranging

$$-\beta = \frac{g[M(\sin\theta_2 - \mu\cos\theta_2) - (m+\Delta)(\sin\theta_1 + \mu\cos\theta}{\Delta + M + m} \qquad (7)$$

Also, on dividing the numerator and denominator of right hand side by M we get

$$-\beta = \frac{g[(\sin\theta_2 - \mu\cos\theta_2) - (\frac{m+\Delta}{M})(\sin\theta_1 + \mu\cos\theta_1)]}{\frac{m+\Delta}{M} + 1} \qquad (8)$$

In equation (3) if $M + \Delta = m$ the equation becomes,

$$a = \frac{gm(sin\theta_1 - \mu cos\theta_1 - sin\theta_2 - \mu cos\theta_2)}{2m} \qquad (9)$$

If$\theta_1 = \theta_2 = \theta$, we get,

$$a = -g\mu cos\theta \qquad (10)$$

The equation (10) implies that if we make rail-track of uniform angle where $\theta_1 = \theta_2 = \theta$ and the total load on downward m block equal to load of M with guider, then retardation is guaranteed. This condition can be considered analogous to the traditional water powered funicular system where the rail tracks have uniform angle. So, in such a case, the system will not accelerate, implying that the system strongly stays at rest if the masses or loads on cars at upper and lower stations stay the same. However, if we intentionally make rail track at different angle (but $\theta_1 > \theta_2$), then satisfying same initial load condition $M + \Delta = m$, by solving equation (3) we obtain the acceleration produced as;

$$a = \frac{g}{2}[(sin\theta_1 - sin\theta_2) - \mu(cos\theta_1 + cos\theta_2)] \qquad (11)$$

$$a = \frac{g}{2}\left[\frac{(sin\theta_1 - sin\theta_2)}{\mu(cos\theta_1 + cos\theta_2)} - 1\right]\{\mu(cos\theta_1 + cos\theta_2)\} \qquad (12)$$

In the above equation, $\{\mu(cos\theta_1 + cos\theta_2)\}$ is positive for our purpose, g is positive. To make the value of acceleration positive, the term $\left[\frac{(sin\theta_1 - sin\theta_2)}{\mu(cos\theta_1 + cos\theta_2)} - 1\right]$ must be greater than zero. So,

$$\frac{(sin\theta_1 - sin\theta_2)}{\mu(cos\theta_1 + cos\theta_2)} - 1 > 0 \qquad (13)$$

$$\frac{(sin\theta_1 - sin\theta_2)}{\mu(cos\theta_1 + cos\theta_2)} > 1 \qquad (14)$$

$$(sin\theta_1 - sin\theta_2) > \mu(cos\theta_1 + cos\theta_2) \qquad (15)$$

$$2\cos\frac{\theta_1 + \theta_2}{2}\sin\frac{\theta_1 - \theta_2}{2} > \mu\, 2\cos\frac{\theta_1 + \theta_2}{2}\cos\frac{\theta_1 - \theta_2}{2} \qquad (16)$$

$$\tan\frac{\theta_1 - \theta_2}{2} > \mu \qquad (17)$$

Equation (17) suggests that in order to achieve acceleration, even when the masses of the blocks at the lower elevation and the upper elevation are the same, the tangent of half the difference of two rail-track angles must always be greater than the coefficient of friction. For our practical purpose, the coefficient of friction is almost constant. So we can choose appropriate track-angles with the lower limit being the coefficient of friction.

The above interpretation is very useful for differentiating the two funicular systems, one having uniform rail-track angle and the other with different rail-track angles. To pull a certain load of mass m at lower elevation, the uniform rail-track angle based system needs larger mass loaded at M to gain certain acceleration whereas the different rail-track angles based funicular system could gain the same acceleration with lesser mass than of the former case.

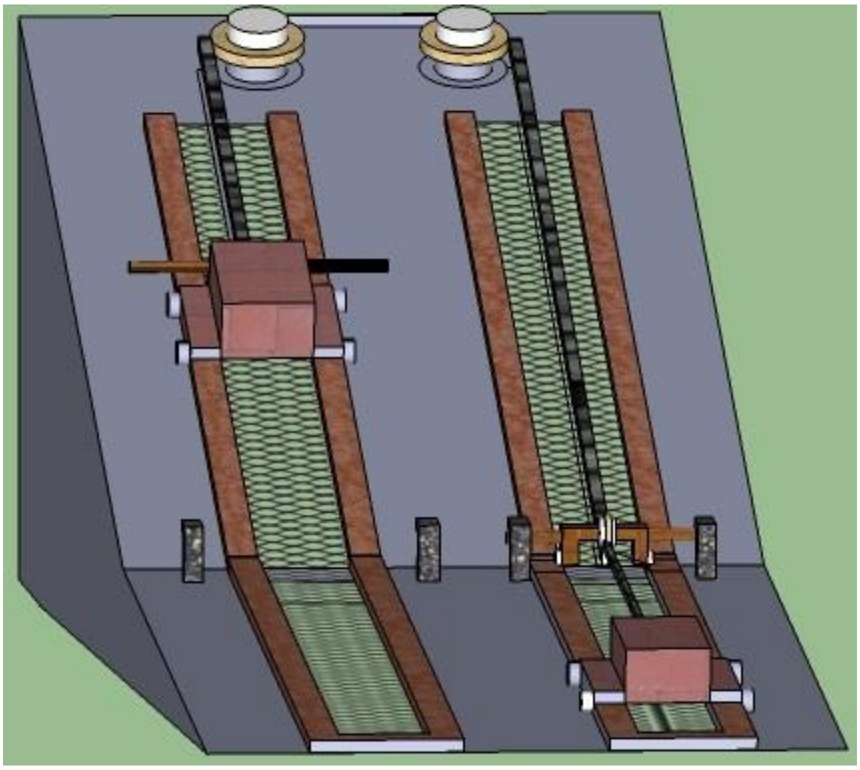

Figure 2 Front view of figure 1

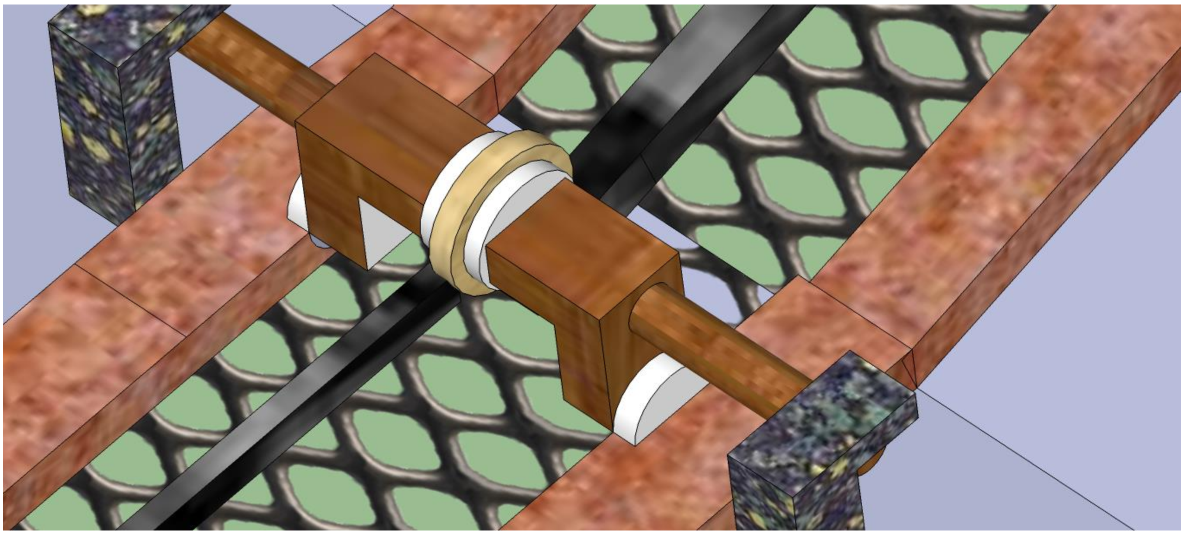

Figure 3: Guider with guider-holder

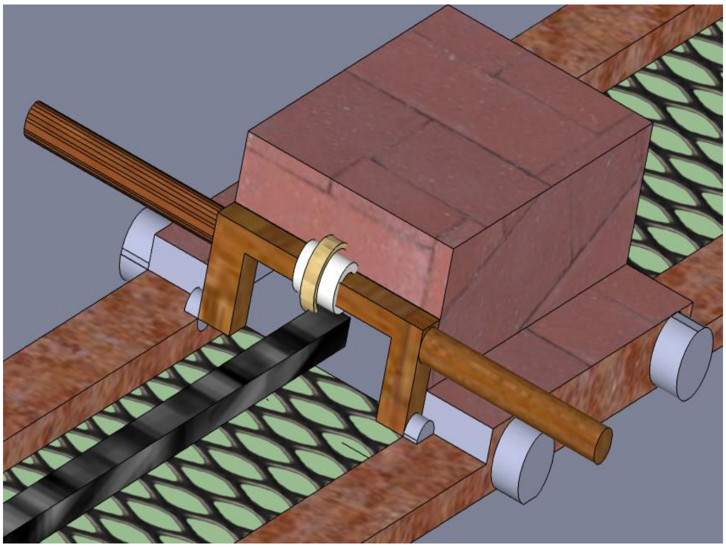

Figure 4: Guider in motion along with block 'M'

Operation and Design

We are mostly interested in water powered funicular system and hence we will focus on its base. The operation of the proposed funicular is similar to that of the traditional water powered funicular system. There have to be two stations for loading and unloading of water and that of goods, and people. Also, the stations should guarantee the storage and the supply of water. There are various alternatives for storing the water. The stations can be chosen near the water source in the hilly areas or special arrangement can be made to collect waste water from the village. The Funicular of Fribourg was one such water powered funicular to use waste water from cities [8]

The design of the system varies from place to place. The length of the system, rail-track angle, etc. varies from location to location. Accordingly, we can work with the equation (3) and (7) so as to make appropriate acceleration and deceleration. The equations (3) and (7) have a large number of solutions for various angles, mass ratio, coefficients of friction. The engineers and designers can choose the appropriate parameters of those equations

3. RESULTS

For the computation of data, we did a simple programming with the help of the software called MATLAB. In the program, there are several input parameters to be taken into consideration, so as to get acceleration and retardation. The program can generate many values of acceleration and retardation on various parameters such as different values of θ_1,θ_2,μ etc.

The equations (4) and (8) show the dependence of mass ratio on acceleration and retardation. This is important because we can choose any combination of masses; for example,$M + \Delta$ equal to 100 kg and m equal to 50 kg would give same acceleration as $M + \Delta$ equal to 1000kg and m equal to 500 kg (taking all other parameters fixed) because the mass ratio is 2. Similar is the case for retardation. So, in the programming we took various mass ratios and θ_1,θ_2. A large data set of acceleration and retardation was obtained and was plotted in a graph with the help of software called Origin Pro 8. In the actual MATLAB program, we have fixed the coefficient of friction as 0.12 just for simplicity. There is no specific purpose behind selecting the value of coefficient of friction. It is just a random number chosen and can be varied. In the figures below, we will show the nature of acceleration and retardation on various mass ratios and various θ_1,θ_2 while fixing the value of the coefficient of friction as 0.12. The variation of coefficient of friction too generates a different solution and requires many graphs. We avoided it in order to decrease the number of graphs.

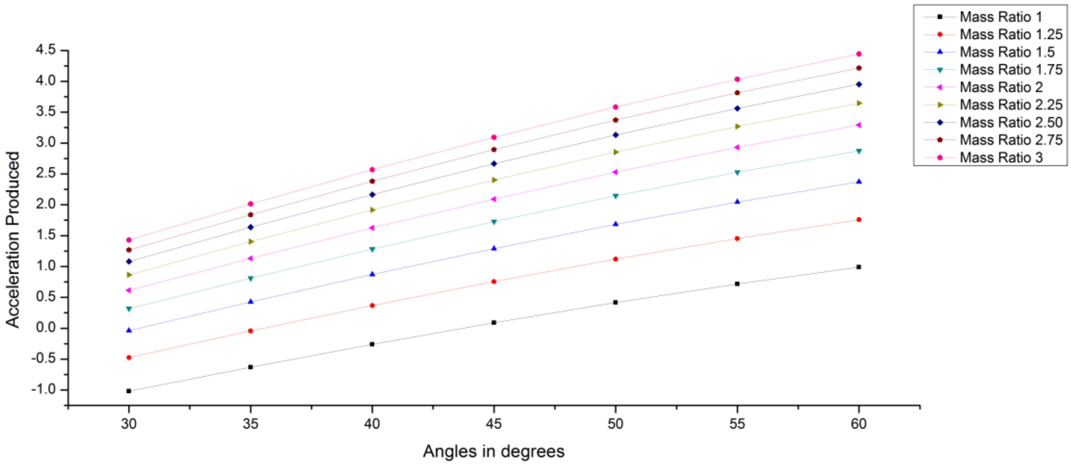

Figure 5: Acceleration produced when rail track inclination of ascending block (M2 in figure 1)is kept constant at 30 degrees, for different values of rail track angle of inclination of descending block (M1 in figure 1) and different mass ratios up to transition region

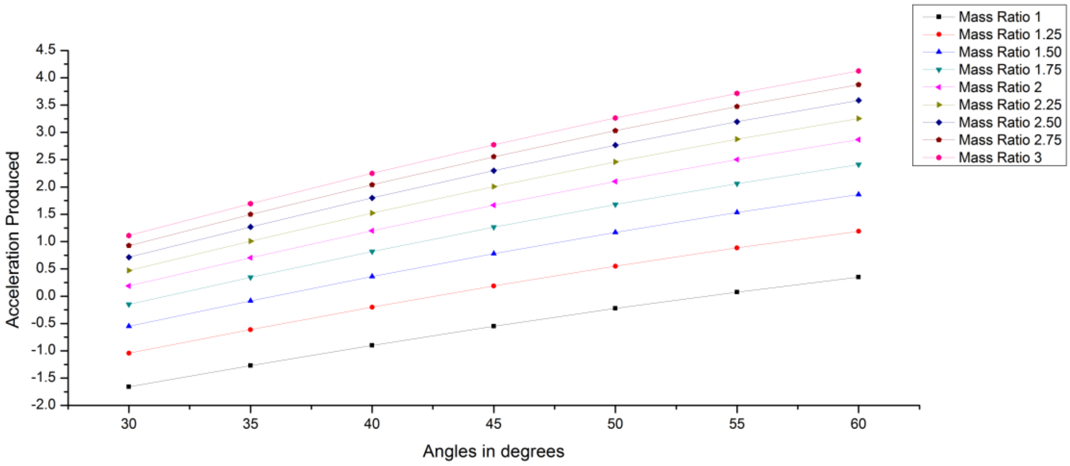

Figure 6: Acceleration produced when rail track inclination of ascending block (M2 in figure 1) is kept constant at 40 degrees, for different values of rail track angle of inclination of descending block(M1 in figure 1) and different mass ratios up to transition region

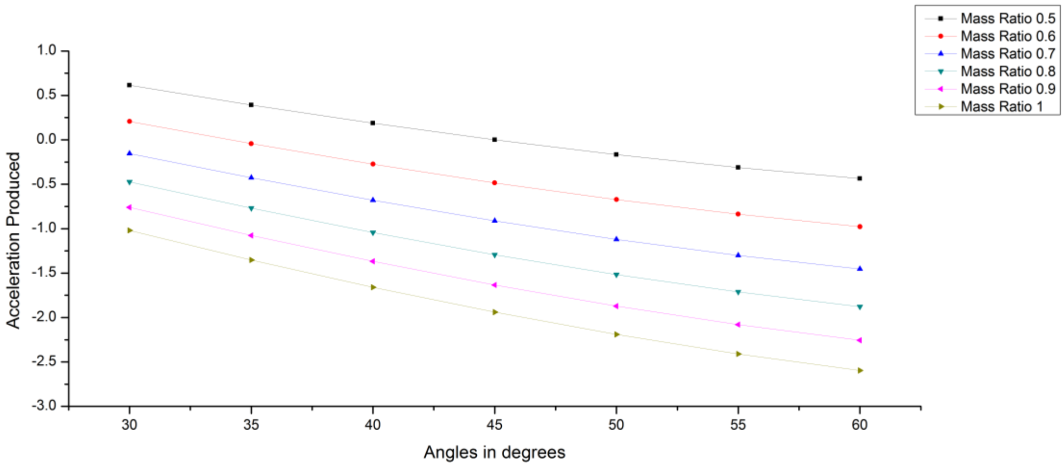

Figure 7: Acceleration produced when rail track inclination of ascending block (M2 in figure 1) is kept constant at 30 degrees, for different values of rail track angle of inclination of descending block (M1 in figure 1) and different mass ratios up to transition region

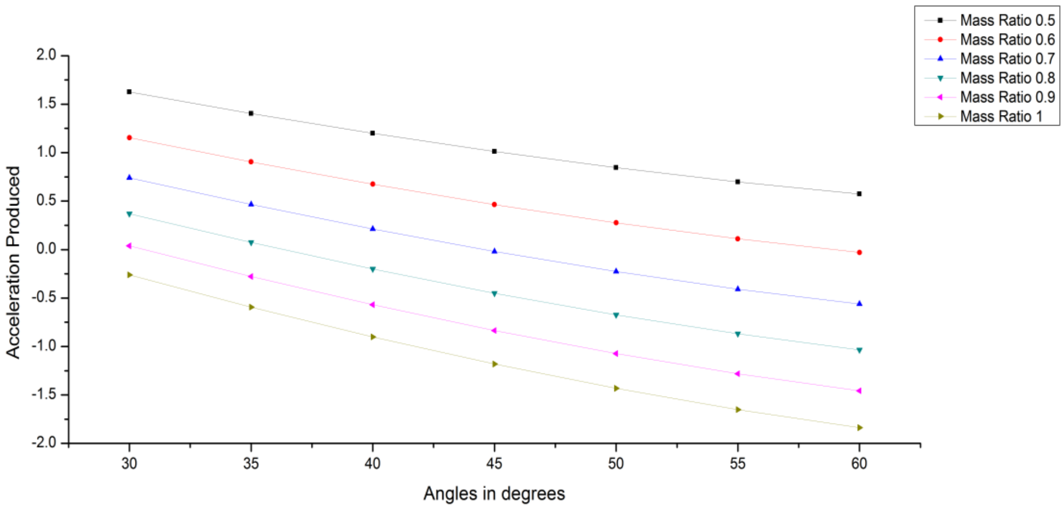

Figure 8 Acceleration produced when rail track inclination of ascending block (M2 in figure 1)is kept constant at 40 degrees, for different values of rail track angle of inclination of descending block(M1 in figure 1) and different mass ratios up to transition region

The above figures (figures 5 and figure 6) represent the values of acceleration produced (represented by the Y-axis) in the system during motion. The angle of inclination of rail track of the ascending car (M2 in figure 1) is kept constant and the angle of inclination of rail track of the descending car (M1 in figure 1) is varied from 30 degrees to 60 degrees. The values of acceleration or retardation produced have been calculated for different mass-ratios (see legend). Figures 5 and 6 represent the values when the cars are in the first half of their respective tracks (motion represented by Equation (3) and figures (7) and (8) represent the values when the cars are in the second half of their respective tracks (motion represented by Equation (7)). It is also clear from the figures that for higher mass-ratios the acceleration produced in the system is greater for the fixed values of rail- track angles for the first half of the tracks, and consequently the retardation (negative acceleration) is also greater for the second half of the respective tracks.

4. CONCLUSION

We would like to conclude by emphasizing the water powered funicular system in Nepal. Nepal is a hilly country where 77% of landmass is covered by hills and mountains [9]. Funicular transportation has never been introduced in Nepal. The proposed modified funicular system seems optimal for two important reasons. The first is that due to the deviation of tracks midway, there is increase in velocities of both the cars in first half of their respective tracks, while in the next half of their respective tracks, there will be decrease in velocities. Finally, when the cars approach the respective stations, the brakeman can easily stop the system because the velocity has been greatly reduced. Another important factor of optimization is the mass ratio between M1 and M2 (as in Figure:1). It is seen that if (17) is satisfied then in comparison to uniform inclination of rail track, the rail-track separated into two equal parts with different angles can operate smoothly in lower mass ratio. So, even by loading less mass on the upper station, desired acceleration can be achieved. Furthermore, there are many parameters to consider like angle of rail track, block mass, guider mass and many other choices to design that help to optimize the traditional water powered funiculars. So, choosing the best location, we can have an environment-friendly funicular transportation to be run even without electricity. So, water powered funiculars has a good prospective in Nepal and the optimized version makes it even more beautiful to implement.

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