Vertical Goods Transport System for Sandikhola

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TABLE OF CONTENTS

1. Introduction

Engineers without Boarders (EWB) have been Collaborating with Nepal Water for Health (NEWAH) for several years. EWB held a workshop with representatives of NEWAH in Nepal and came up with seven project areas which were under development or consideration and would be suitable options for the EWB challenge. The projects were aimed at hilltop communities in Nepal's Gorkha district. The village of Sandikhola was used to give context to students taking the challenge but it was essential that the design could be adapted to fit all hilltop communities in the area. The roads in the area are poor and transportation can be difficult and sometimes impossible during the rainy season. This dictated that the project should be conducted in the dry season and preferably would be finished in time for the rain. Funding was said to be available but should be sought after in order to justify the project. It was also noted that many hilltop communities do not have running water, electricity or fossil fuel supply. The project chosen was vertical goods transportation via an aerial ropeway. The systems function would be to transport firewood, crops, animal feed and anything else that the people of the village usually carry up the hill in a bag. The design was continually adapted but this remained the chief objective.

2. Design Criteria

The basis for this design is similar to a zip line. Other inspiration was drawn from winch systems, ski lifts and pedal powered vehicles. The design consists of four fixed towers, two at the top of an incline and two at the bottom. Two tensioned parallel wires shall run up the slope connecting the top and bottom towers together. The towers should be a concrete construction and should have foundations suitable to support the moments and compressive forces exerted on them.

2.1 - Design Criteria

Design criteria, the design development should:

- Be primarily cost driven since it would mostly be funded by grants and was initially expected not to generate a lot of revenue
- Be suitable for the context in terms of powering and materials
    - The mountain communities are assumed to have limited or no access to electricity
    - The concept of an engine powered system was ruled out since fuel would be a constant expense due to purchase and transportation
    - Since the project was designed to be low budget both of these considerations were accounted for and manual power was chosen accordingly
- Should conform to the communities needs
- Should take account of environmental considerations and not cause unnecessary disruption to the communities farmland
- Where possible, materials should be sourced locally, sacrifices should be made to avoid importing expensive components
- Should take advantage of grants and if possible generate a small amount of revenue.

2.2 – Concept Development

At the beginning of the project the group looked at the different concept areas, and decided that the vertical goods transport issue would be the most interesting, and mechanically challenging to develop. Therefore, tasks were divided up between the group members to look at different possibilities that should be considered. In the early stages it was decided that rainwater harvesting in a first flush mechanism should also be looked at as a backup in case it turned out that a vertical goods transport design was unfeasible.

It was originally thought that the vertical goods transport should span all the way down the hillside to a large river at the bottom, a distance of about 5km. This, however, would require multiple stations down the hillside, and a powerful motor in order to be able to pull the basket up all the way from the bottom. It was therefore decided early on in the design process that the ropeway should be designed to only span a distance of 200m in order to allow the system to be man powered. This distance would also mean that only two stations, a top and bottom, would be required.

Originally vertical gravity ropeways were looked at as a means of powering the system as these are already employed in certain areas of Nepal today. Gravity ropeways require the load that is travelling down the slope to be three times larger than the load that is travelling up it, and so the ropeways were deemed to be unsuitable for the people of Sandikhola as their daily routines generally require more goods to be travelling up the slope than down. It was therefore decided that the system should be man powered, due to the absence of a reliable source of fuel for a motor, and the fact that the system should be able to be transferable to any location that is deemed suitable. Having measured up the different options of man powered transport the group decided that bicycles would be the most suitable means of transport, as they are common in the lower areas of Nepal, and allow for a more efficient means of transporting the goods up the slope. Two bikes were chosen to power the system as this would allow for a load of roughly 75kg (including the basket) to travel up the slope.

It was then settled that the system should have two support wires, with a third rope that would actually pull the basket up the slope. The support cables would have to be raised up in order for the basket to not hit the ground while travelling up the slope, and so it was decided that these would be 3m high, as anything above this height would cause too much stress on the supporting towers.

3. Design Overview

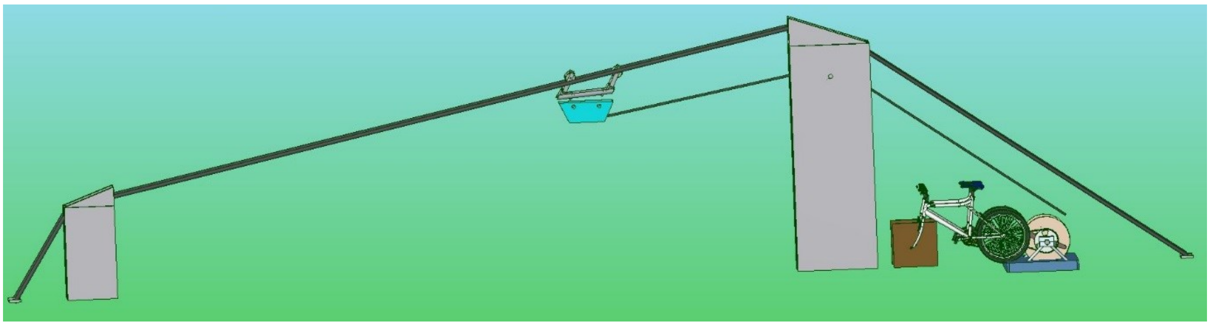


Figure 1 - Side view of Ropeway

3.1 – Design Specifications

The design specifications used to outline the conceptual design were as follows:

- The design should be able to be constructed on a hillside.
- It will carry goods e.g. firewood, crops, animal feed via an aerial ropeway system to alleviate manual labour workload.
- The maximum load expected will be 52.5kg
- There will be a basket drawn up by a winch system powered by a static bicycles.
- Moving parts of the winch system should be sheltered to minimise weather damage and corrosion of parts.

The design concept can be split into several subsystems. These are evaluated for material choice and function in the next section.

Sub system analysis

3.2 - Wires, rope and drum

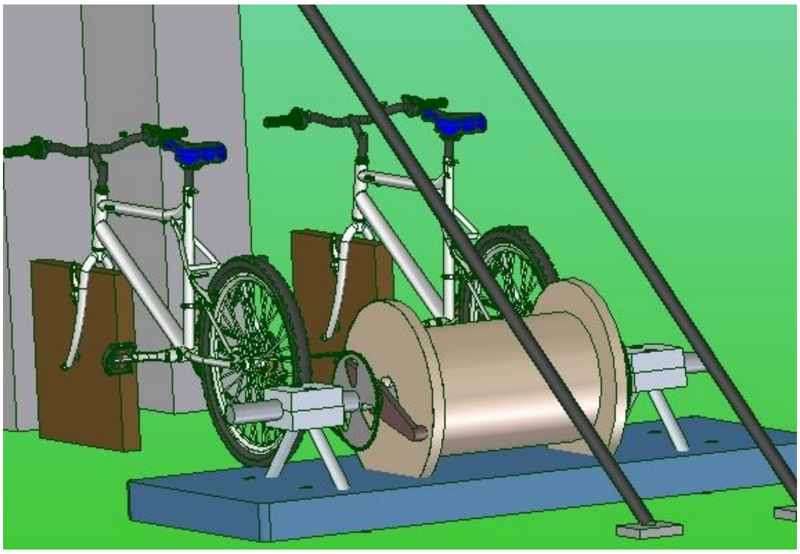


Figure 2 - Drum Barrel System

The drum used for reeling in the driving rope will be the drum that the support cables are supplied on. This will most likely be a wooden drum. It will therefore have an iron sheet wrapped around both flanges so as to provide a smooth, hard surface on which the brakes can act. The use of the drum that is already present cuts significant costs relating to fabricating the drum from scratch, or importing it. They are also much easier to source whether by manufacture or purchase since they are very commonly used. The synthetic rope will be terminated at the drum using a knot. Often a series of clamps would be used for this purpose, however due to limited resources available this simpler but equally effective option was adopted.

The supporting lines shall be made of steel wire of diameter 10mm. Having two supporting wires present it can be shown by calculation that the system will be capable of handling the tension necessary to reduce the sag to only 2.5m. The rope for the driving wire which will be wrapping around the drum will be synthetic climbing rope. This gives the design more flexibility by being easier for the locals to replace considering the climbing industry in Nepal. It will be easier to terminate at the basket and drum due to it being less stiff and more workable than steel. It is also lighter than steel while retaining all the strength properties required to pull the basket up the slope.

3.3 - Braking system and warning bell

A braking system was considered necessary for the ropeway to avoid any damage to the basket if it reached the bottom station too quickly. Braking the basket can be achieved using two methods. The first under normal circumstances is to use the hand crank by controlling the rotation to ensure the line isn't fed out too quickly.

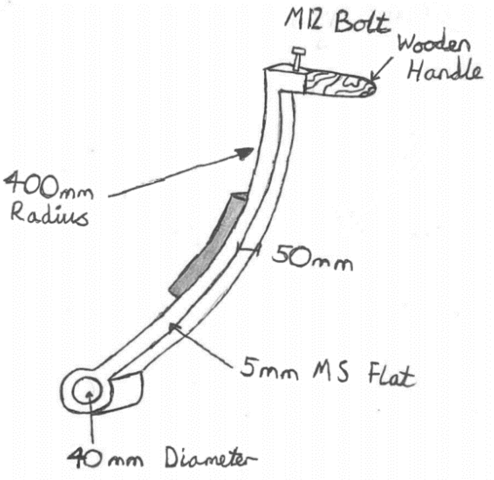


Figure 3 - Brake Arm

The second method is to slow the basket down if it has sped up uncontrollably. This is not considered usual practice but a necessary precaution in case the operator is not using the hand crank brake. The design involved a brake pad on a lever that can be pressed to the round steel surface on the flange.

The brake arm should be made of mild steel as it is widely available and relatively cheap to manufacture. Three different types of material were considered for the brake pads, semi- metallic, sintered and ceramic.

Semi-metallic brakes have a reasonable friction coefficient of around 0.28 – 0.38. They are relatively cheap to manufacture, however they have low durability, which would mean that they would need to be replaced frequently, adding to their overall cost. Ceramic brakes have a long life span, and good thermal resistance, however they are very expensive, an important factor when low cost is one of the designs criteria. It was therefore decided that the brake pads should be sintered, as this would give them a better friction coefficient than semi-metallic brakes as well as having a long life span, and also excelling in wet conditions, which may prove useful in Nepal's rainy season.

It was decided that a warning sounder would be appropriate in order to let the operators know if the basket was getting near the bottom. This would not need to be complicated and a bell on a stand was chosen for this purpose. A small modification to the basket may be required to fit an arm that would strike the bell. Although the design is capable of stopping the basket from its max speed in 10m, the bell should be placed 50m before the bottom station to allow the operator's time to get to the brake and begin the braking procedure.

Once the sounder was heard the operators could lift up the brake, and apply it to the flange of the drum to slow its rotation.

3.4 - Drum stand

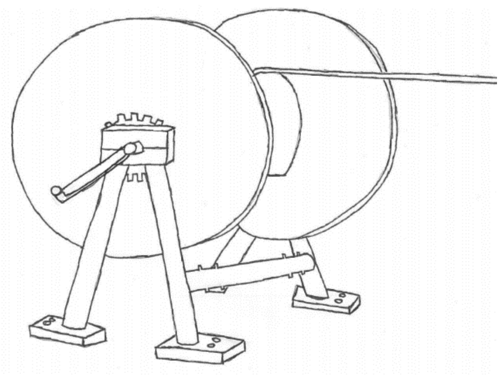


Figure 4 - Drum Stand Isometric View

The winch system is designed to take a drum of dimensions shown in table 1. However due to the design of the system the dimensions of the drum are flexible. The design was intended to be flexible throughout so that it could be repaired and adapted as required by the local people.

The drum stand is composed of two A-frames connected at their peak by a steel axle. The drum is fixed to the axle in such a way that the axle will rotate with drum – see figure 9. This method was adopted since it does not require a fixed size of drum barrel making the design more flexible.

Table 1 – Drum dimensions (mm) [1]

Drum barrel diameter (mm)	400.00
Flange diameter (mm)	770.00
Traverse (mm)	400.00
Wire diameter (mm)	10.00
Wire length (mm)	200000.00
Number of turns on drum	40.00

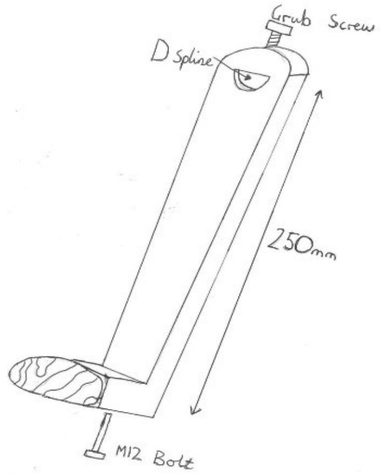


Figure 5 – Crank Handle

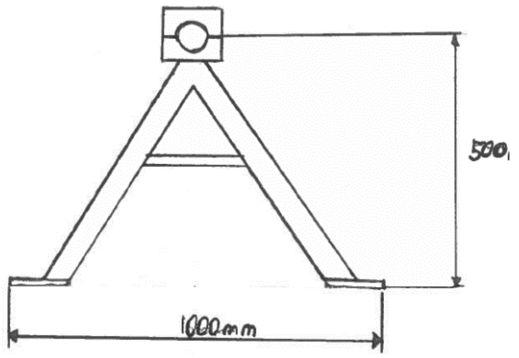


Figure 6 - Side view of Drum Stand

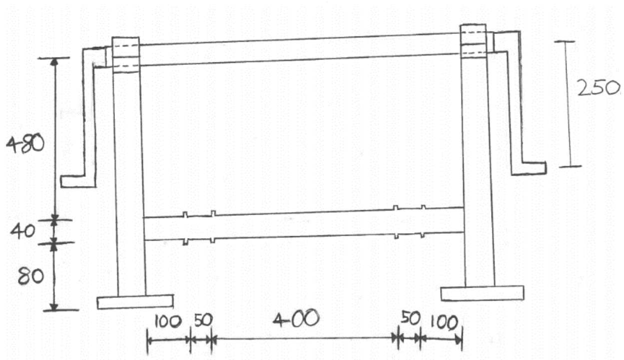


Figure 7 - Front View of Drum Stand

The drum stands will be connected via the main shaft at the top of the stands on which the drum rests, but also by a steel bar of diameter 40mm which will connect the two legs together. This bar will also act as the mount for the brakes which will be fixed in position by welding two small rings on either side of each brake so that they remain aligned with the drum flanges on which they will act. There will also be a crank arm connected to the axle to be used as a back-up for powering the system and also as a brake for the basket on the way down. The crank arm is fitted to the axle using a single D spline to fix rotation and a grub screw to fix lateral movement.

The drum should be positioned 6m from the support structure. This gives a fleet angle of around 2degrees. The fleet angle is the included angle between a line perpendicular from the drum to the support centre and a line from the support centre to the flange. It is necessary to define this since it is recommended to be between 0.5-2.5 degrees for even spooling. [2]

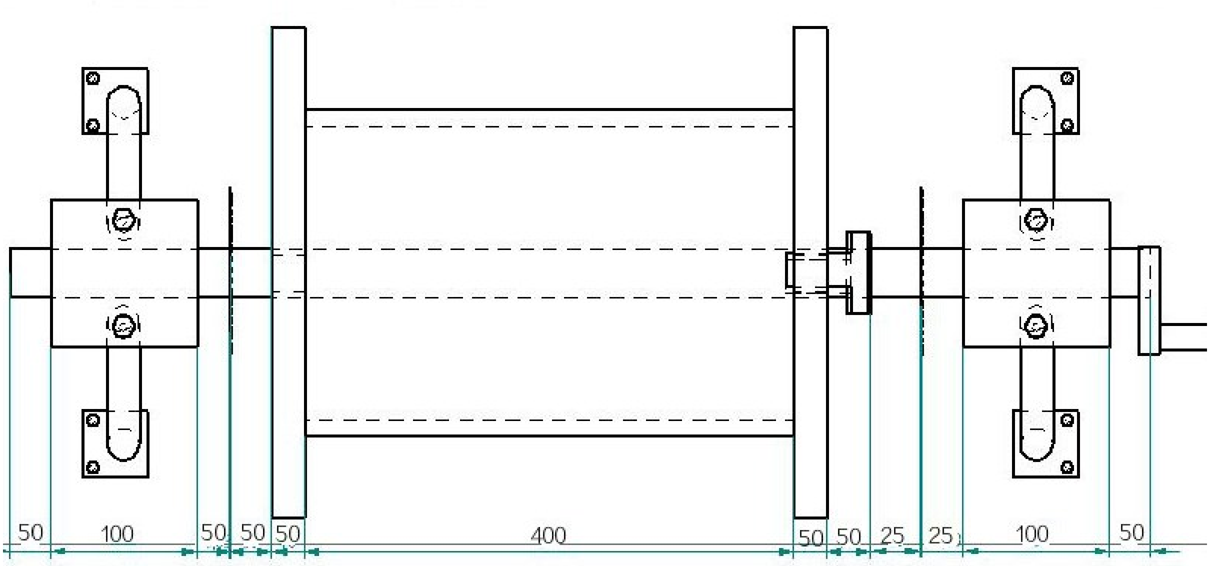
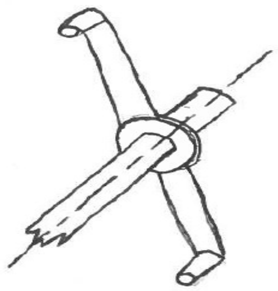


Figure 8 - Top view of Drum Stand, with location of parts

Figure 8 shows the layout for the example drum that is being used, and its dimensions. Where possible the dimensions should be kept roughly similar.



A dual arm will be used to secure the drum to the rotating shaft. The two pins insert into the drum to fix the drum's rotation around the axle. It should be made of mild steel as this material is strong and highly durable, and it is also easily welded when attaching it to the main shaft.

Figure 9 – Isometric sketch of arm

A Stauff clamp should be used to connect the main shaft to the drum stand. The clamp will contain a 40mm ID roller bearing to allow the shaft to rotate freely, and M12 bolts should be used to connect the top half of the clamp to the bottom half.

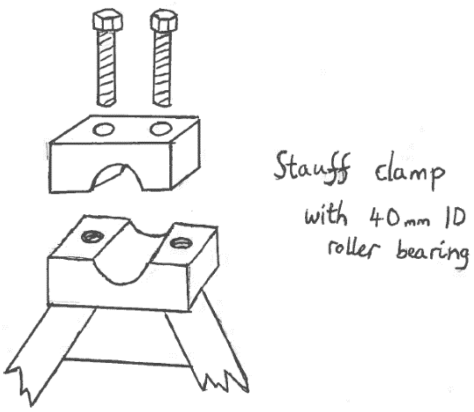


Figure 10 – Sketch of axle clamp/ bearing

3.5 – Supporting Towers

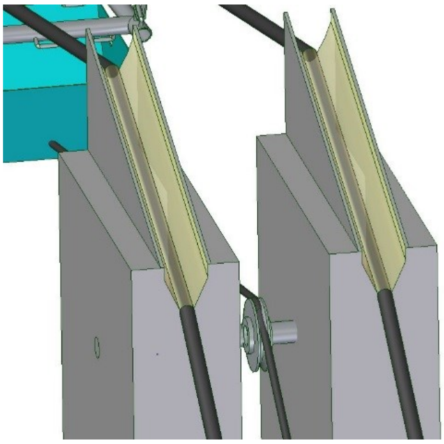


Figure 9 – CAD view of saddles and roller

The proposed material for the towers is concrete. Originally wood and steel structures were also considered for the design, however these two materials were ruled out due to three considerations: simplification of design, cost, and structural strength. Wood was considered to be less strong and more complicated to build, however it would be cheap. Steel was ruled out since it would be more expensive and complicated to create a truss style structure. It would also require skill, knowledge and a level of experience at working with steel.

Concrete was the design chosen since it is strong, easy to source and simple to work with. Another advantage of concrete for the towers is that after some research it was noted that projects run by Practical Action in Nepal had used designs with concrete for aerial river crossings, very similar to this project. The people of Nepal were therefore expected to be more familiar with concrete structures, this also justified the sourcing of materials.

The towers should be 3 meters high, with a base width of 0.5 meters. They should have semi-circular saddles in them that allow the support cables to be held without rubbing on the sides. The tower saddles should be placed 0.75m apart, meaning the support cables will also be 0.75m apart. There will be a steel axle inserted between the towers set into the concrete at a height of 2.5m perpendicular to the support cables. On this axle a small sheave/cable roller should be placed to reduce friction on the rope.

3.6 - Bike

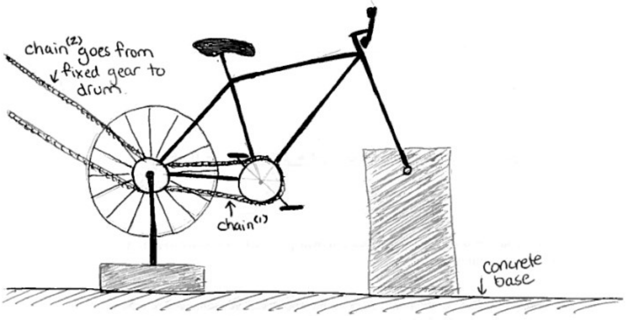


Figure 10 – Sketch of bike

The system adopted uses a bicycle to rotate the drum via a chain drive. This is made more agreeable by the fact that bikes are fairly popular [3]. They should be familiar with how they operate and more likely to have insight should anything need maintenance or repair.

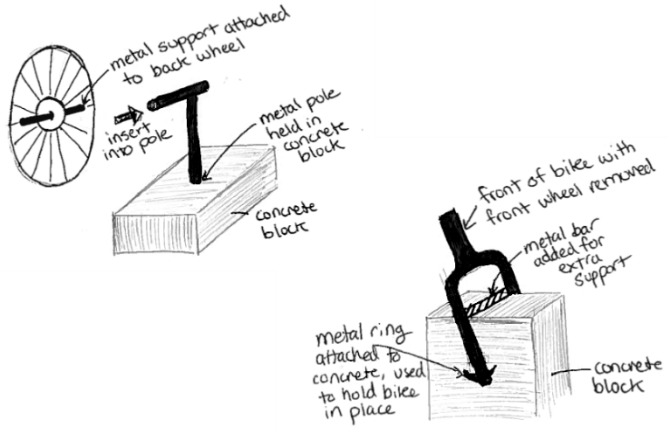
To achieve the required torque for large loads the concept of mechanical advantage can be applied. Using a gearing system the torque required from the peddler can be reduced by using a gear ratio as described by the following equation.

$$\frac{n1}{n2} = \frac{T2}{T1}$$

Where:

- n1 = number of teeth on bicycle gear
- n2 = number of teeth on drum gear
- T1 = Torque on bicycle
- T2 = Torque on drum

This concept allows a very large load to be pulled up a slope using a relatively small torque. The only issue is that the angular velocity ratio varies inversely with the gear ratio. So using a torque ratio of a half will give an angular velocity ratio of 2. This means the cyclist will have to peddle twice as fast to get the same velocity as if no gearing system was used. With that in mind a perceived optimum gear ratio can be decided on to meet desired speed of the system and torque required from the peddler.



The bikes front wheel will be removed and the fork will be mounted directly to a stand. The rear wheel will be mounted on an axle stand. This configuration was adopted for simplicity and cost limitation. The stands can be made from concrete with small metal inserts so that material redundancy is kept.

Figure 11 – Sketches to show front and rear bike supports

The gearing system consists of two parts. A flip flop hub will be used on the bike. This component allows two sprockets to be used simultaneously, one freewheel and one fixed on either side of the hub. The freewheel is connected to the crank and the fixed will be connected to the drum, both via chain. The drum sprocket is fitted to the axle using a single D spline to fix rotation and a grub screw to fix lateral movement.

3.7 - Basket

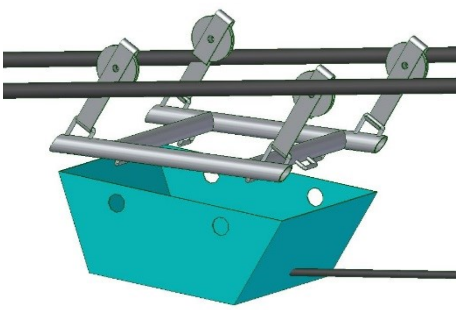


Figure 12 – Sketch of basket

The basket is designed to be interchangeable. To achieve this the basket section can be split into two parts. One part - the mount - designed to be fitted to the cables rolling on small rollers, the other - the basket - is able to detach from the mount using a simple hook. This allows different baskets for different loads to be used. It also allows for easier repair or replacement of the basket. An aluminium basket design is included, with a maximum load of 52.5kg, however this may be left detached to allow the user to attach smaller loads without it if they want to. The mount is designed with hooks on the underside to facilitate this, the user need only secure their basket to the hooks with ropes to secure it to the pulley system.

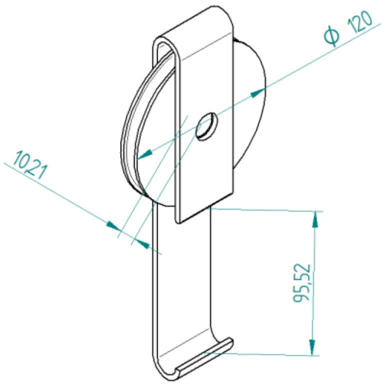


Figure 13 – CAD of roller

The rollers that attach the basket pulley system to the cables should be made of Mild Steel, as this will make them highly durable. The rollers should have a diameter of 120mm to allow for smooth rolling, and the semi-circular part that fits onto the support cables should be 10.21mm so that the roller fits smoothly over the 10mm cables.

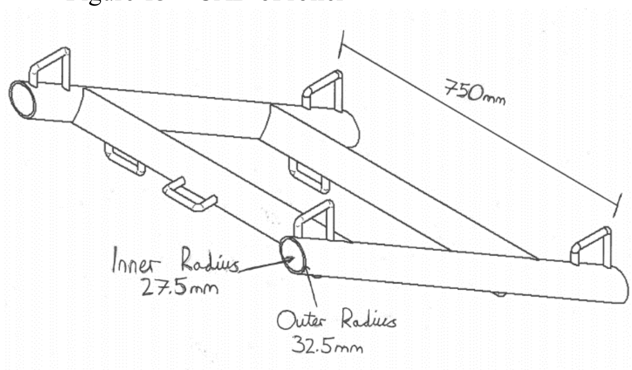


Figure 14 – CAD of Support

The support frame should be composed of 5mm thick steel piping in order to hold the load of the basket. The distance between the two sides of the support frame should be 750mm so that the support rollers are able to fit onto the cables.

4. Finite Element Analysis of the Support Frame

In order to ensure that the support frame would be capable of supporting the proposed load of itself, the basket and the goods, a finite element analysis was carried out on the support frame. A simplified version of the model was used due to the difficulty that small features such as round corners etc. can pose to FEA in Solid Edge, with simplified geometry to make analysis possible. In the analysis, a load of 1500N total was placed on the support frame, across the two centre supports. As the maximum combined load of the support frame, basket and load was rated at 75kg, this therefore represents double the load that could be expected when the system is working at its intended capacity in order to allow for a safety factor in the support.

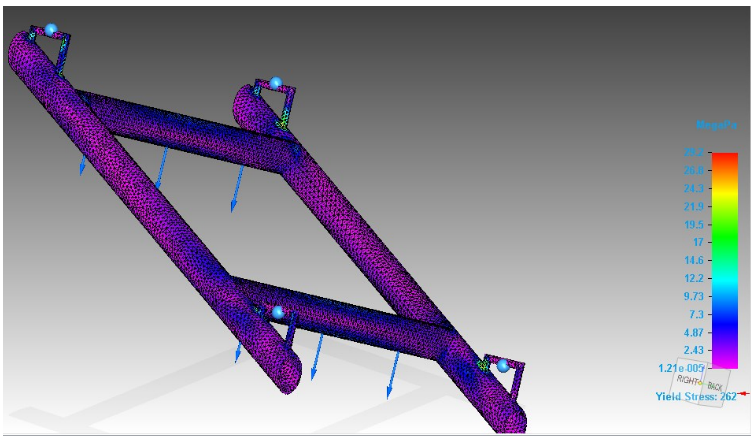


Figure 15 – FEA of support frame

As can be seen in Figure 15 (left), the maximum expected stress expected within the frame resulting from the 1500N load occurs at the intersection of the support hooks with the frame. As the upper support hooks must also hold most of the weight of the frame, they have the highest concentration of stress.

As can be seen in Figure 16 (right), the peak stress occurs in a small area at the base of the support hook. At 29.2 MPa, this maximum stress is well below the yield stress of the steel it is constructed from, which is 262MPa.

As can be seen in Figure 17 (below) the maximum deflection will occur in the bottom support, however the small deflection of 0.06mm would be expected to have little impact.

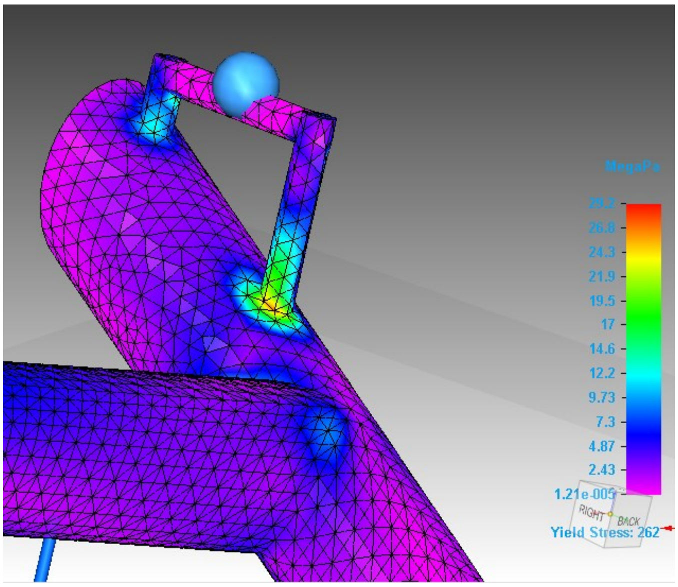


Figure 16 – FEA of support frame, peak stress

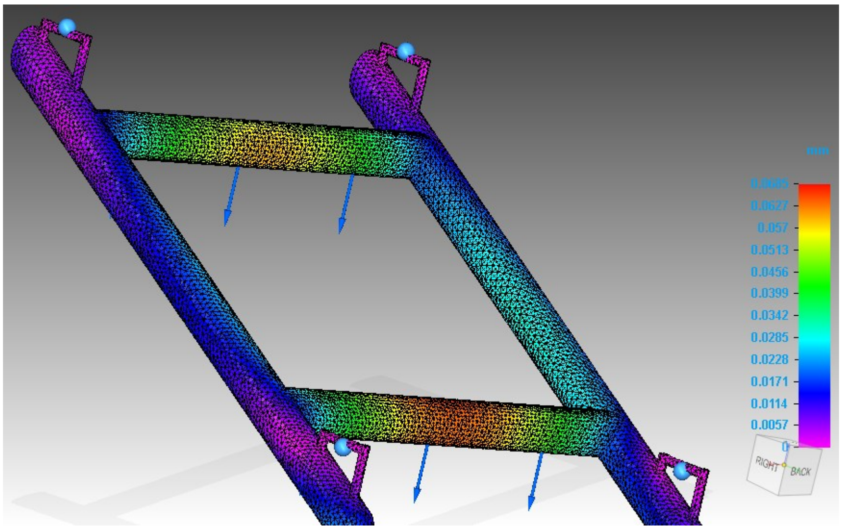


Figure 17 – FEA of support frame, max deflection

Thus, even at double the maximum expected load, the support frame will be more than capable of holding all the weight required of it.

5. Instruction Manual

- Concrete foundations put in place, approximate volume (6x2x0.25m)
- Before concrete has set place threaded inserts ferrules for winch drum and steel hook for cable anchoring, preferable to give options for different offsets from support tower
- Begin building supporting tower structure using concrete
  - Make cylindrical outer casing using wood and rope to tie together
  - Fill casing with premixed concrete
  - Insert top cable run
- Manufacture drum stand
  - Weld steel sections to form A-frames
  - MIG weld bearing block onto A-frame peak
  - Insert axle
  - Bolt on bearing block top
  - Attach feet to line up with threaded inserts in foundation

- Bolt drum structure to foundation inserts at 6m offset (optimum)
- Attach cable to the steel hook insert at top station anchor using cable grips
- Bring cable down to bottom station and ensure cable is running over top of towers at both stations
- **Begin tensioning process [4]**
  1. Secure tensioning tool to central U anchor
  2. Secure turnbuckle assembly to U anchor
  3. Feed out around 3m from the tensioning tool reel
  4. Feed the live end of the cable through the tensioning tool cable grab with approximately 0.5m to spare
  5. Terminate the live end using 3 cable locks
  6. Begin cranking the lever arm to start putting tension on the wire
  7. When at appropriate tension connect the turnbuckle assembly and the terminated end of the live wire
  8. Begin releasing the reel so that it feeds out until the tensioning tool is slack
  9. Remove tensioning tool and adjust turnbuckle if more tension if required

- Repeat for other supporting wire in the same fashion
- Fit basket at bottom station
- Tie synthetic rope to basket and bring to top end
- **Tie rope to drum**
  1. Feed end of the rope through the hole in the side of the drum
  2. Using simple half-moon clamps to fix to the side of the drum going round in a square centred at the axle
  3. Connect bike and drum via the chain drive
  4. Reel in the rope by pulling the basket up the hill so that the rope is spooled onto the drum with the basket weight acting as back tension
- Attach 50m warning bell
- Connect braking system to drum
- Test system

6. Financing the system

There are three main possible sources of funding, grants, loans and charging for usage. One option is to fund the entire system through grants, and have the system operated by two volunteers from the community. It may be difficult to find people with sufficient spare time to dedicate to running the system full time, and so it may be necessary to only run it for a few hours per day. For example, to have a collection area at each end where people can drop goods off throughout the day, to be transported up during the period when operators are available, with the intention of having all goods at the top in time for the end of the day.

Alternatively, the system could be funded through both grants and loans, and a charge for usage introduced to repay loans and hopefully make a profit eventually. If the system was in regular use, it would be possible to hire permanent operators for a full shift each day, allowing immediate transport without building up a backlog. Otherwise, as a hybrid solution, operators could be hired part time, on a similar short schedule to the volunteering described above. This would be a few hours paid work, and would supplement the income of the operators, but would be cheaper to run than the full time option.

The cost that must be charged is dependent on the amount of money that must be paid back, and so may be reduced if the costs are lower than predicted, or grants secured to partially fund the project. Alternatively, the fee may stay the same, with profit reinvested into a maintenance fund for the system.

One option for grant based funding may be to apply for assistance from the Nepalese government's Poverty Alleviation Fund [5], which is expanding into Gorkha District as of 2014. PAF distributes development funding from the World Bank's International Development Agency, the International Fund for Agriculture Development and the Government of Nepal to local projects, led by a community organisation, supported by a partner organisation, typically an NGO. The community is expected to make a contribution to the cost of the program. For income generating projects, PAF will cover 78% of the cost with 6% to come from the local government and other partners. The other 16% is split into 7% as cash and 9% as goods in kind from the community [6]. This remaining 16% of funding could be accounted for with a loan, to be repaid from profits of the system. Total PAF expenditure for projects in 2013 was Rs (Nepalese rupees) 13.122 billion (just under £80,000,000). In the financial year 2013/14, over 3000 projects were expected to be funded. If PAF funding could be secured, the remainder of the cost could be covered easily by fees for usage.

Sandikhola has an adult population of approx. 300, of which about 95% live in households with an assessed income of Rs 500-800 per day [7]. NMW is 8,000 Rs per month. Over 30 days, this will cost 267 Rs per day. Sandikhola has 60 households. Assuming an uptake rate of 2/3 houses, 7 Rs per household per day is required to pay the full time wage for a single operator, so 14 Rs for the entire system. Charging 25 Rs per day would prevent heavy usage from impacting finances of users too heavily, while allowing the system to make a profit. A lower rate could be introduced, charging 15 Rs for a single load, for people who only need a specific item transported. The higher rate would be for unlimited usage, but in practice, given that the major goods (crops/wood) are gathered or harvested the time saved is unlikely to add up to more than one extra trips worth of goods, resulting in a rate of 2-3 trips per day. Assuming 10 households at a 15 Rs tier therefore, and 30 at a 25 Rs charge, we can expect a turnover of 900 Rs per day, with a profit of 345 Rs per day. This is equivalent to £3.20 per day (at 2/11/14 exchange rates).

If PAF funding is granted, then assuming initial set up costs of £5,000 (estimated costs & contingency), the community will be expected to contribute £1,100 to the construction, with the rest provided by the PAF. Assuming the prices outlined above, and with the system operating full time, the system will recover its costs to the community within 345 days of operation assuming all profit is used for repayment. If money is also set aside for a maintenance fund at the same time, the time to recover costs will naturally be higher. This proposal can of course be modified to suit their needs, for example if the community is willing to pay higher prices, the operators may be paid above NMW, or extra operators could be taken on. To lower prices, the community could use one of the hybrid schemes described above, paying operators to work part time for a few hours a day, at the cost of instant transportation.

It is crucial the community is consulted and they are given the opportunity to decide how financing will work for themselves. For example, instead of a payment per day, they may wish for a local council to administer the financing, paying for access on a monthly basis or as part of a small community charge from all households. This is something best chosen by the community to suit their own needs, but we have proven the system is commercially viable in some form or another.

7. Similar Projects

Other similar projects have been constructed by the charity Practical Action across Nepal [8]. Practical Action has funded gravity based ropeways, intended primarily to send goods downhill in several communities across the country, including Benighat and Kalleri. These gravity ropeways take advantage of the fact that most of their goods are travelling downhill to reduce the effort required to lift goods. By placing a significantly larger load in a basket going downhill, a lighter load (⅓ the weight or less) can be pulled up at the same time. As our design is intended primarily for uphill use this gravity solution would not be as helpful to us, however the principles of supporting the basket are the same, and so this is a good example of a project similar in scale to ours which has been executed successfully in Nepal already.

Practical Action has also been involved in the development and construction of wire bridges called tuin throughout Nepal. Tuins' are a form of ropeway design for crossing a river, and are widely in use in Nepal, where they are often found in place of bridges. A tuin typically serves a community of about 300 people, and they are a proven system. The tuin represents a similar system to ours, and has been implemented previously successfully.

PAF has previously funded many forms of infrastructure, including short distance ropeways. For example, they funded an agricultural ropeway in Chandibhanjyang, with an estimated final project cost of Rs. 4.6 million (almost £30,000), significantly more than the cost of our proposed system [9]. This ropeway was intended to provide better market access for farmers in hilly areas. By making it faster to transport goods, our system is attempting to similarly improve access for farmers and so is clearly the kind of project that may be eligible for funding by the PAF.

8. Vertical Goods Suitability to Sandikhola

8.1 – Social Considerations

The people of Sandikhola, as well as many of the other villages in and around the Gorkha District of Nepal, spend much of their day walking to collect firewood and grass. The walk is roughly a 3 hour round trip, with the villagers carrying heavy loads on their return journey. This trip sometimes has to be carried out 2-3 times per day, so it is clear that a system that transports their goods up the steep hills in the area would be very beneficial to their lives. [10]

There is a well-documented link between doing heavy manual labour or lifting, and the occurrence of back pain. This is why there is a large number of cases of back pain documented in farmers. In Nepal it is estimated that around 71% of the population have suffered from lower back pain, [11] which if compared with America, where only 31% of the population are reported to have suffered from back pain in the last year, is significantly greater[12]. A vertical good transportation system could be used to reduce the time and distance that the villagers have to carry the goods, and thereby reduce the strain that is placed on their backs, hopefully contributing to a reduction in the reported number of cases of back pain.

There are already several vertical goods transportation systems in place in Nepal thanks to the work of Practical Action, however these are all gravity ropeways which require the load that is being sent down to the bottom station to be at least 3 times greater than the load travelling up the other side. This is fine for areas where the goods are being transported to nearby markets etc. but in areas such as Sandikhola the needs of the community are different, with there being a greater requirement to send goods up the ropeway than down again.

Due to the inaccessible nature of the community, and the fact that petrol is an unreliable and even unobtainable fuel source for the village, it seems clear that a motor powered transportation system would also not be suitable for the area.

A human powered transportation system would therefore be the best alternative to suit Sandikhola's needs. As bicycles are already a popular means of transport in Nepal, and they are able to provide a more efficient means of transport than other methods it was decided that these would be the easiest and most efficient way of powering the system. They produce more than enough torque to reel in the rope attached to the basket, and allow the villagers to reel in the baskets without tiring themselves out too much.
In Sandikhola it seems to be typically the women of the village that do most of the collecting of firewood and leaves etc. and it would therefore be them that benefit most from the introduction of the vertical goods transportation system.

The idea would be to employ two villagers to operate the system as explained in the financing section. This would leave the women free to collect several loads of materials and have them transported up the slope, saving them many hours of work, and allowing them to spend the saved time focusing on other parts of their daily lives.

8.2 – Environmental Considerations

With regard to the environmental impact of the ropeway on the local environment, we would expect the largest environmental impact to come during the construction phase. The path of the ropeway must be cleared of obstacles that may interfere with the basket, which may necessitate the removal of trees from the path. Given that there are local farms, this can be mitigated by passing over farmland instead of trees if possible. In addition, the basket is not particularly wide, so not many trees would need to be removed to make a safe route. There would also be a temporary increase in traffic, as trucks bring goods to the construction sites. This may lead to a slight increase in air pollution, however as it is estimated only five trips would be required this is unlikely to be a long term effect. The excessive leakage of lubrication oil from the ropeway could result in water pollution. This can be mitigated by careful monitoring to ensure the cables are not excessively lubricated.

The usage of a bike powered system instead of an engine means that the ropeway will be very quiet to operate. Similarly, the ropeway will provide a way to transport goods that are not dependent on fossil fuels. For deliveries where it is possible to split the load, usage of the ropeway can provide a way to reduce reliance on vehicles for the climb uphill.

9. Timeframe of project

The construction of a typical aerial ropeway system shall take a maximum of 3 months including all necessary preparatory activities. Major milestones of this ropeway design are categorized into three standard stages for projects of this kind:

a) Planning Stage: Community kick off meeting (outline of project objectives and community involvement). Identification of start and end points, surveying of wire path (scoping out trees and rock faces), identifying the most ideal location to make the system most useful, purchasing and transportation of materials to site.
b) Construction Stage: On the job training with community for construction, constant community evaluation and input would be beneficial, final inspection and testing of design, official handover of system to community to allocate any responsibilities (formation of public ropeway committee).
c) Monitoring and supervision: evaluation from project management, community evaluation and feedback, planning for next project.

Figure 18. Flowchart indicating project stages

10. Cost

The project can be split into three dominant cost centres: materials, transportation of materials and the construction/labour cost. The materials cost is covered in the Bill of Materials (BOM), the transportation and labour costs are taken from the datasheet provided from EWB.

10.1 - Cost of materials
The Bill of Materials, (Appendix 1) is composed of six sections which are as follows:
1. Name - The term best used to describe the part of the system in question
2. Comment - It's purpose or placement in the system
3. The quantity required in appropriate units
4. The cost per unit
5. Total cost of item
6. Source or Supplier

The table was created so that it could be used as or be the basis of an order sheet. This means it can stand alone when the items need to be ordered. The aim was to source all of the materials locally, in many cases they could be taken from EWB's datasheet. For more specific items related to cables and ropeways external sources had to be explored. This task was initially made difficult by the limited information on what could be bought or manufactured in the area. With that in mind it would be sensible to air freight a load of specific items to Kathmandu and assume the rest could be sourced from within Gorkha District. The complete materials cost was estimated to be **£2764.86**

10.2 - Cost of transporting materials

The cost of transporting the materials was dependant on where the materials could be sourced. For the materials on the EWB spreadsheet this was defined and split into two rates, one from Kathmandu and one from Chitwan. Given that 1 truck could carry 200 50kg bags of cement or $5m^3$ of material and 1 minitruck can carry 40 bags of cement $2m^3$. It is estimated that this project will require 75 bags of cement and 6m3 of material from Chitwan. This approximates to 2 trips by truck from Chitwan to Gorkha and 5 trips by minitruck to Sandikhola. This gave an estimated cost of **£405**. All other materials were assumed to come from Kathmandu as per the NEWAH datasheet. This was approximated to 2 trips by truck to Gorkha and 5 trips by minitruck to Sandikhola. This gave an estimated cost of **£417**. Water is also an essential commodity for this project due to the amount of concrete that is used. Given that water supply in Sandikhola is an issue and the project may require around 2500 litres all told we assumed that it should be transported to site. From Maps supplied on Google Earth it was found that the nearest river is on the route from Sandikhola to Kathmandu. The river is an equivalent distance from Sandikhola as Gorkha so the trip rate to the river was estimated to be the same as the one to Gorkha. We need 2500l which is $2.5m^3$ therefore it will require 3 trips by minitruck costing **£135**.
This combined give a total transportation cost of **£957.**

10.3 - Cost of labour

The labour cost for the project is divided into two parts: skilled labour cost and unskilled labour cost. Given that the cost of skilled labour per day is **£3.84** and **£2.56** for unskilled labour per day. We estimated that the days of installing skilled components such as cement, air valves and pipes are almost 2 months due to the complicated geographical conditions. Assuming a maximum of 3 skilled labourers were working at any given time this gave an estimated cost of **£690**. We assumed that 1 month would be sufficient for unskilled labour. Assuming a maximum of five people working at any given time the estimated cost was **£385**. In conclusion, the total cost of labour is approximately **£1075.**

The total cost for materials, transport and labour was **£4796.86**

11. Calculations

11.1 - Nomenclature

Table 2 - Nomenclature

m_1	mass of flange	h	height of tower
m_2	mass of axle	w	width of tower
m_3	mass of drum barrel	τ_{AC}	torque about center of tower A
r_1	radius of flange	τ_{BC}	torque about center of tower B
r_2	radius of axle	θ	angle between tower A and drum
r_3	inner radius of drum barrel	β	angle between tower B and basket
r_4	outer radius of drum barrel	σ_C	compressive stress
τ	torque	σ_B	bending stress
F_A	applied force	P	load

T	tension	A	area
r	radius (0.2m)	M	moment about neutral axis
m_b	mass of basket	y	perpendicular distance to neutral axis
m_r	mass of rope	P_{cr}	critical load
w	mass of rope per unit length	E	young's modulus of elasticity
I	moment of area about neutral axis	L	length
a	acceleration	F_x	horizontal forces
v_f	final velocity	F_y	vertical forces
v_i	initial velocity	R_A	horizontal reaction force at tower A
Δx	distance traveled	R_B	horizontal reaction force at tower B
g	acceleration due to gravity	N_A	vertical reaction force at tower A
d	sag	N_B	vertical reaction force at tower B
R	radius where F_A acts		

11.2 - Calculating the Tension in the Supporting Wires

The following formula [13] was used to calculate the tension:

$$T = \frac{wL^2}{8d}$$

Although this formula is for a horizontal wire, it still helps to give a reasonable estimate as to about how much the wire will have to be tensioned for a given amount of sag. The following chart shows the ranges of tension needed for a given amount of sag.

Table 3 – Deflection against tension

Deflection (m)	Tension [N]	Tension [kN]
1	19620.00	19.62
2	9810.00	9.81
3	6540.00	6.54
4	4905.00	4.91
5	3924.00	3.92
6	3270.00	3.27
7	2802.86	2.80

The weight per unit length of the wire was estimated to be about 0.4kg/m*(9.81m/s^2) for a 10mm wire. [14]

If a sag of 2.5 meters is chosen, the wires will need to be tensioned to 7.848kN. The safe load for a 9.5mm wire is 10.9kN which is significantly larger than the tension. It is important to note that the safe load for a 10mm wire will be even greater than 10.9kN.

It was concluded that the tension in the support wire could range between 3.92kN and 7.85kN. However, this is the absolute minimum and maximum tension that is recommended. It is preferred that the tensioned be aimed towards 4kN.

As a check, the extension of the wire from the load in the basket was calculated using the formula [15]:

$$Elastic\ Extension = \frac{PL}{EA}$$

The young's modulus used for the wire in the calculation was 4000 kg/mm^2 [16]. This is most likely not the proper value for the young's modulus of the wire used, however it is less than the actual value. The actual young's modulus would result in an even smaller stretch of the wire. In other words, this value is being used as a safety precaution to find the very largest extension possible.

Using a load having a mass of 75kg, the elastic extension of the wire would be 0.0477m. This is a very small number when compared to the 5m deflection.

Although there are two supporting wires carrying the 75 kg mass, the mass was not halved during the calculations. If the wind were to knock the basket around, it would displace the load on the wire from the basket, and possibly increase the load on each wire. Assuming the worst case scenario (a mass of 75 kg on each wire), the stretch is still quite small.

The purpose of this calculation was to determine whether or not the load from the basket would have a large effect on the deflection of the supporting wires. As the extension is very small, it is fair to say that the effect on the supporting wires is very small and can be neglected for most other calculations.

11.3 - Calculating the Force Required to Stop the Basket and Load

It is important to know how much force is required to stop the basket from moving, or to hold it in place.

Case 1

The first case that will be analysed is when the basket is stationary.

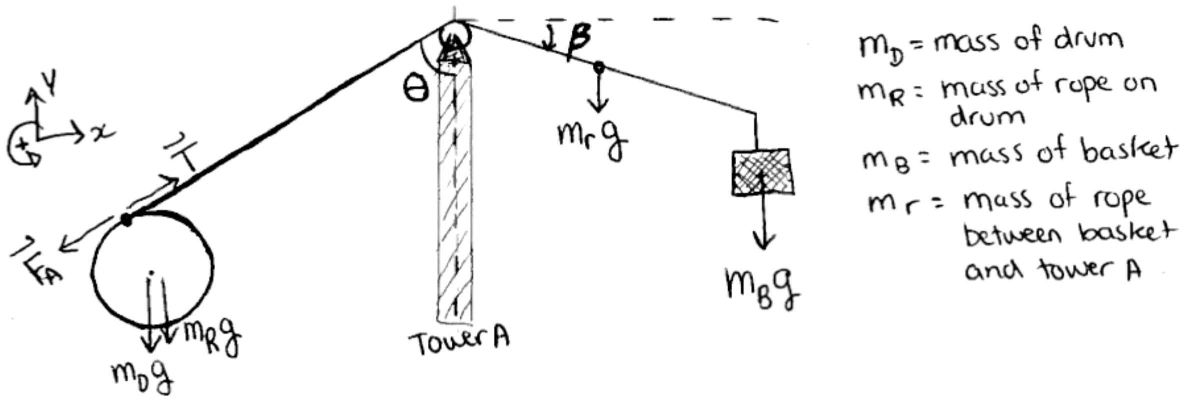
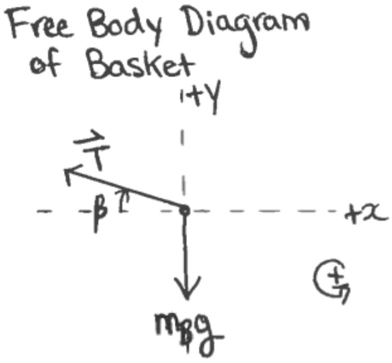


Figure 19. Tension FBD

The most force required to hold the basket in place will be when the mass from the rope is the greatest, which will be when the basket is at the very bottom.



$\sum \tau = (F_A + T)r = 0$ Because the system is not moving

$$F_A = -T$$

$$T = (m_B + m_r) * g * sin(\beta)$$

Where β = 30 degrees, m_B = 75kg, and m_r = 0.065kg/m*200m.

Figure 20 – FBD of basket (1)

It is important to note for these calculations that the mass of the rope between the spool and the first tower was neglected. This mass is very small when compared to the mass of the rope on the spool and the mass of the rope between the first tower and the basket.

The maximum force required to keep the basket stationary is 431.64N. However, this is neglecting other factors such as wind.

If it is assumed that the maximum wind is 20 mph, the total force would be no larger than 20N. [17]

So, the maximum force required to keep the basket stationary is 451.6N.

Case 2

The second case that will be analysed is when the basket is in motion and moving down the slope. The two situations that will be analysed in this scenario are when the basket is near the top of the incline (i.e. close to the first tower) and when the basket is near the bottom of the incline (i.e. close to the second tower).

2.a. Near the top

The inertia from the rope around the drum will be different depending on where the basket is along the slope. Calculating the inertia for the rope:

$$I_{rope\ around\ drum} = \frac{1}{2}(w * L)({r_4}^2 + {r_3}^2)$$

$$I_{drum} = 2I_{flange} + I_{axle} + I_{drum\ barrel}$$

$$I_{drum} = 2\left(\frac{m_1 {r_1}^2}{2}\right) + \frac{m_2 {r_2}^2}{2} + \frac{1}{3} * m_3({r_4}^2 + {r_3}^2)$$

Where w = (0.065kg/m), L = 200m, r_4 = 0.215m and r_3 = 0.2m.

As the system is designed to have the basket moving at relatively slow speeds, the basket should not ever exceed 6m/s. The only way the basket would come close to 6m/s is if it started falling on its own without resistance from the break. However, assuming the worst case scenario, it is reasonable to say that the person operating the system should be able to reapply the break before the basket exceeds 6m/s (v_i). It was also decided that the system should be able to stop within a distance of 10m (Δx). A warning system will be placed 10-15m before the end of the line to warn the operator to apply the break. Using the following equation, the maximum acceleration needed to stop the basket in the worst case scenario is -1.8m/s^2 (a).

$$a = \frac{v_f^2 - v_i^2}{2 * \Delta x}$$

Where v_f = 0. This acceleration will be used for both scenarios as it is not dependent on where the basket is along the incline.

Using conservation of torque, the applied force required to stop the basket in 10m from the very top of the incline is 527.59N.

$$\sum \tau : I\frac{a}{r} = F_A * r - T * r$$

$$\frac{I * a}{r^2} + T = F_A$$

Where the tension was calculated by:

$$T = (m_b) * g * \cos(60^o) + a(m_b)$$

It is important to note that $\frac{I*a}{r}$ and T are in the same direction, as both the accelerations are negative (a and g are in the same direction). However, the applied force was taken to be positive because the only important factor is the value, as the break will be applied perpendicular to the drum. The friction will take over in whatever direction will slow the drum down. It is also assumed that the force is applied at a radius of 0.2m. If this is not the case, the new applied force can be calculated using the formula:

$$\frac{I * a}{r * R} + \frac{T * r}{R} = F_A$$

Where r = 0.2m. However, it is likely that R will be equal to or greater than 0.2m, in which case the applied force would be the same or less than the previously calculated value. In other words, increasing R would decrease the applied force.

Case 2.b. Near the bottom (10m from bottom)

This scenario is the more likely case. In the *case 2.a* the basket is unlikely to reach 6m/s that quickly at the very top of the incline. It is more likely that the basket would break away somewhere down the incline and start to gather speed. However, the way the break system is designed, it is unlikely that the basket would start to free fall down the incline, but it is important to calculate the maximum force it would take to stop the system in the case of a failure.

For this case, the position of the basket is 10m from the second tower (along the incline). The inertia of the rope around the drum will be different from the last case, as there is less rope around the drum.

$$I_{rope\ around\ drum} = \frac{1}{2}(w * L)({r_4}^2 + {r_3}^2)$$

Where *L* now equals 10m. All other values are the same. The acceleration calculated in the previous case is used for this case as well (a = -1.8m/s^2). Again using conservation of torque, the applied force to stop the system when the basket is 10m away from the second tower is 521.12N.

$$\frac{I * a}{r * R} + \frac{T * r}{R} = F_A$$

Where the tension is given by:

$$T = (m_b + m_r) * g * \cos(60^o) + (m_b + m_r) * a$$

And where $m_r = 0.065kg/m * 190m$.

The force required to stop the basket when it is moving at 6m/s is greater at the top, however, it is less likely to reach such a high speed.

It is also important to take into account the possibility of a strong wind. As used in the stationary case, if a wind of 20mph is acting on the system, an extra 20N would have to be added to the tension, increasing the required applied force.

$$T = m_b * g * \cos(60^o) + m_r * g * \cos(60^o) + 20N$$

Note that if $R = r$, 20N can just be added to F_A, however, if not, the 20N must be added into the tension equation.

Another important factor to take into account is sag. However, the sag will not be very large, and may actually decrease the required applied force.

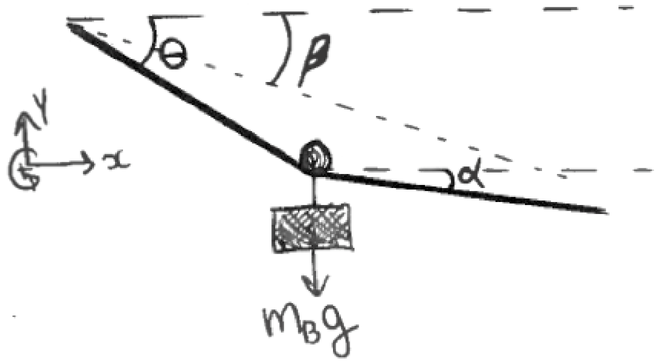


Figure 21 – FBD of basket (2)

The original angle that the basket was on, was 30 degrees clockwise for the positive x-axis. Looking at the diagram, theta is greater than 30 degrees, and alpha is less than 30 degrees. However, the basket is resting on the part of the wire that is at angle theta, so the tension will be less than originally estimated. Therefore, sag actually decreases the force required to stop the basket. However, given that this would be a very small difference, it is safer to just neglect the effect of sag and keep the value the same for the maximum applied force.

To summarize, when the basket is stationary, the maximum force required to hold the basket in place would be 451.6N and the maximum force required to stop the basket when it is moving is 527.59N.

11.4 - Calculating the Forces, Torques, and Stresses Acting on the Supporting Towers

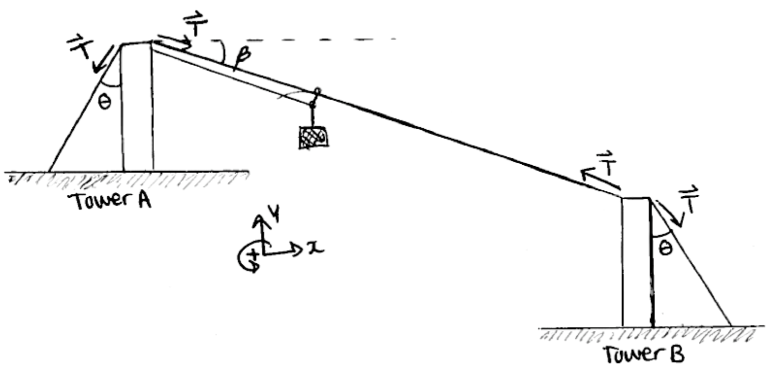


Figure 22. FBD of support towers

This is the setup for the following equations. The tension includes the weight from the basket and the rope, and will be taken to be 7.848kN for the purpose of calculating the absolute maximum elements acting on the supporting towers. First the forces and torques for both towers will be found so the maximum of them can be used to find the stresses.

Tower A: Top Tower

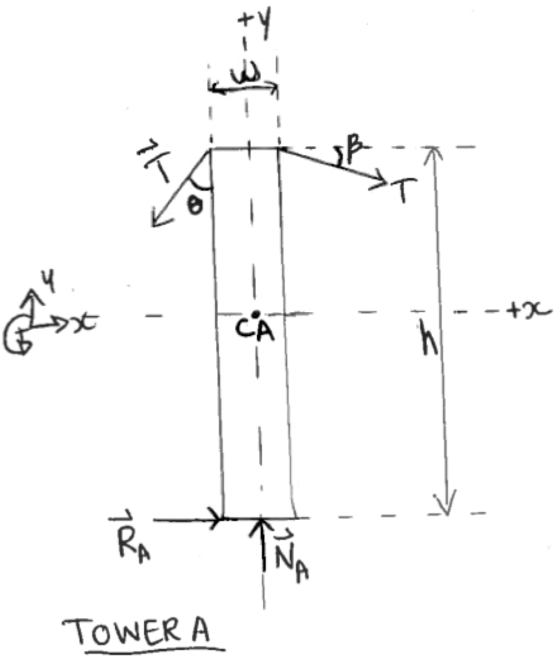


Figure 23 – FBD of top support tower

The free-body diagram shows the tensions acting on the top of the tower and the reaction forces acting at the bottom of the tower.

First, the sum of the forces in the horizontal and vertical direction, as well as the torque about the centre of the tower, were found.

$$\sum F_x:\ T*\cos(\beta) - T*\sin(\theta) + R_A = 0$$

$$\sum F_y:\ N_A - T*\cos(\theta) - T*\sin(\beta) = 0$$

$$\sum \tau_{CA}:\ \frac{h}{2}R_A + \frac{h}{2}T*\sin(\theta) + \frac{w}{2}T*\cos(\theta) - \frac{h}{2}T*\cos(\beta) - \frac{w}{2}T*\sin(\beta) = \tau_{CA}$$

It is assumed that θ = 25 degrees, h= 3m, w = 0.5m, and as said before T = 7.848kN. Solving these equations with these values would give, N_A = 11.04kN, R_A = -3.48kN or 3.48kN to the left, and τ_{CA}= -9.829kNm or 9.829kNm clockwise.

Tower B: Bottom Tower

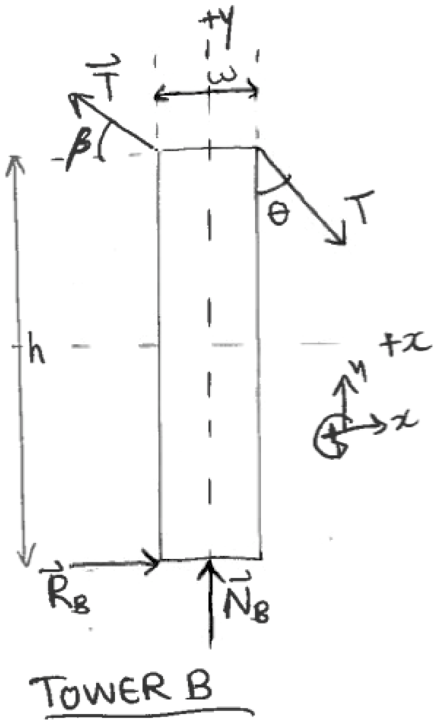


Figure 24 – FBD of bottom support tower

The same process used to find the forces and torque for Tower A was used for Tower B as well. The sum of the forces and torque was given by the following equations:

$$\sum F_x:\ -T*\cos(\beta) + T*\sin(\theta) + R_B = 0$$

$$\sum F_y:\ N_B - T*\cos(\theta) + T*\sin(\beta) = 0$$

$$\sum \tau_{CB}:\ \frac{h}{2}R_B + \frac{h}{2}T*\cos(\beta) - \frac{w}{2}T*\sin(\beta) - \frac{h}{2}T*\sin(\theta) - \frac{w}{2}T*\cos(\theta) = \tau_{CB}$$

The same assumptions were made: θ = 25 degrees, h= 3m, w = 0.5m, and T = 7.848kN. Solving these equations with these values gave: N_B = 3.19kN, R_B = 3.48kN, and τ_{CB} = 7.829kNm.

Since all the values found for Tower B were either equal to or less than the values found for Tower A, it is proper to assume that the stresses will either be the same or less than those in Tower A. Therefore, since the maximum stresses must be calculated, Tower A values will be used to calculate the stresses.

Calculating the Stresses (Using Forces and Torques for Tower A)

There are two kinds of stresses acting on the beam: compressive stress and bending stress. They are given by the following formulas:

$$\sigma_c = \frac{P}{A}$$

$$\sigma_B = \frac{My}{I}$$

The bending stress was calculated using $M = \tau_{CA}$, y = 1.5m, and I = 1/12*(0.5m)^4.

There were compressive stresses in the vertical and the horizontal direction. The total compressive stress can be found by adding these two terms. The vertical compressive stress used $P = N_A$ and A = (0.5m)^2. The horizontal compressive stress used $P = R_A$ and A = (0.5m*3m).

The overall stress was obtained by adding all of the stresses together. According to these calculations, the absolute maximum stress that would act on the towers is about 2.8 MPa.

It should be noted that the exact value for the maximum bending stress of concrete is not known. However, several sources have suggested ultimate stresses or strengths for concrete that are well within the range of safety for this structure. The book "Mechanics of Materials" by James M. Gere and Barry J. Goodno (8th Edition) says that concrete in compression has an ultimate stress range of 10-70MPa and a modulus of elasticity range of 17-31GPa [18]. However, most sources agree that the maximum compressive stress for concrete is much larger than the maximum bending stress for concrete. Two other source [19] and [20] suggest that the ultimate strength for concrete is 3 MPa, assuming density of 27g/cm^3. So, taking 3 MPa to be the maximum allowable stress for the towers, the towers are still well within the safe limit.

Taking the smallest modulus of elasticity from the previous text book source (E = 17GPa) and using the equation:

$$P_{cr} = \frac{\pi^2 EI}{4L^2}$$

The critical load of the concrete tower can be found to be about 2.43 *10^{7}N. P_{cr} is much larger than any tension force that would act on the tower. This shows that the limiting factor in the design of the towers (and in determining how large of a tension the towers can hold) will be the maximum stress. However, assuming that the support towers are made out of concrete with the specified dimensions (3m tall with a square cross section of 0.5m), the structure is well within the safety limits.

11.5 Torque Required from Bikes

The maximum torque that the bikes must exert on the drum is given by the formula:

$$\tau = (m_b + m_r) * g * \sin(\beta) * r$$

This formula gives the maximum torque as 86.33Nm which is less than the maximum torque that can be generated by two bikers (135.60Nm). [21]

12. Design Adaptability

The design can be varied for 2 different things depending on the needs of the community:
-The length could be increased to 275m as long as the sag was allowed to increase to 5m.
-The angle of elevation could be increased to 45° if the sag was 5m.

Anything above these and the support towers would have to be reinforced with steel bars to hold the load.

Table 4 – Maximum parameters

Adapted Focus	Support wire tension (N)	Support Wire extension (m)	Maximum Stationary Braking Force (N)	Maximum Braking Force in Motion (N)	Overall Maximum Stress In Towers (N/m^2)	Torque required to move basket (Nm)
sag	7848	0.0477	451.64	527.59	2788159.87	86.33
length	7418.81	0.0657	475.55	530.14	2788159.87	91.11
elevation	3924	0.0477	630.43	679.97	1125958.05	122.09

As no exact specifications were given for designing this vertical transportation system, it was important for the variables of the design to be manipulated to fit into the desired location of the villagers.

13. Future Improvements

Transporting People

Our current design may not be suitable for transporting people due to safety reasons. This system was designed to be transporting goods. Theoretically, if the person weighed less than the maximum load, the system should operate fine. However, it is not advisable to transport people in the system as is. If the people of Sandikhola wish to improve the system so that it is able to safely transport people, a new basket would most likely have to be used (as the one used now would barely be able to fit a person in it) and reinforcements might have to be placed along the bearings for the basket/cables/pulleys/etc. It is difficult to say how the system would have to be modified without seeing it in operation.

More Efficient Power System

It would be ideal to implement high-precision gears and sprockets to increase efficiency. However, this would cost a considerable amount of money, which is the reason why it was not used for this design.

If there was enough money and access to fuel for an engine, that would make it easier to operate the system. This would also increase the allowable load for the system. However, the support towers would have to be reinforced with steel if the load is increased.

Another idea for powering the system would be from solar energy, and establishing solar panels on or next to the towers.

Steel Structure

Compared to concrete, steel is stronger and lasts longer. A steel frame structure would greatly improve the system and would allow for much larger loads to be transported. Although a steel frame might be more complicated to set up (might require welding and structure overall more complicated), parts could be more easily replaced or modified than in a concrete tower.

Movable Towers

Seeing as there is not much money for Sandikhola to implement a large number of these vertical transportation systems, it would be convenient to be able to move the system from place to place. Looking at the design of the current system, it would impractical to attempt to move the whole thing around. However, if the system was scaled down to a smaller size, it would be easier to move it around.

Combined With Other Systems (Multifunction)

The transport system has a shelter for the rain, which could modified to act as a rainwater-collection and purification system. This could be built into the tower and would act as another structure that collects rainwater. It would also increase traffic towards the towers. The system should be regularly visited by the people and placed in a popular area so that it is used and regulated on a daily basis.

Increasing the Length of the System

In consideration of the budget, the traveling distance of the basket was limited to 200m. If money was not a limiting factor, the system could be established over a much larger distance, with multiple supporting towers along the path. This would also allow for the path of travel to manoeuvre around obstacles. As mentioned previously, adjusting different variables (i.e. tension and deflection) would allow for a longer traveling distance also.

Illuminating system

The current system would only be operable during the day. However, if lighting was installed along the path of travel, it would allow for the system to operate after dark. It would also make the system safer during the day, as the path would be more visible for people walking along the hills. However, due to the current distribution of electricity in Sandikhola, this idea would not be practical unless the lighting was generated from solar energy.

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Appendix 1

1. Bill of Materials

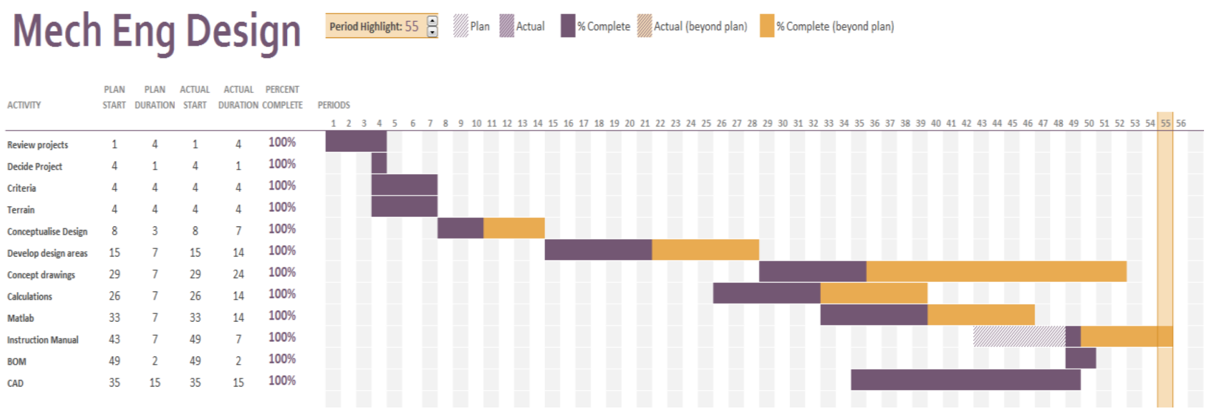
Bill Of Materials					
NAME	**DETAILS**	**QUANTITY**	**UNIT**	**COST**	**Proffered supplier**
	Purpose	No. of Units	Cost per Unit	GBP	
Concrete					
Cement	Component of concrete	15 bags	4.13	61.95	Datasheet
Sand	Component of concrete	$1.0m^3$	15.36	15.36	Datasheet
Aggregate	Component of concrete	$1.0m^3$	4.80	4.80	Datasheet
Water	Component of concrete	Approx. 500 litres			Sourced Locally
Threaded ferrule insert	For bolting down stand	10	0.50	5.00	Karunamaya Hardware, Kathmandu
U hook ferrule insert	Anchor for fixed cables	4	0.50	2.00	Karunamaya Hardware, Kathmandu
Tools For Concrete					
Casting	To hold shape while setting, wood planks	1	10.00	10.00	Sourced Locally
Mixer	Necessary for large quantities	1		200.00	Rental
Spade	Move and mix concrete	3	3.51	10.53	Datasheet
Drum Stand					
Steel tubing	For the frame structure	6m	5.46	43.68	Datasheet
Steel foot plates	To allow bolting down	4		10.00	Hulas Steel, Kathmandu
Metal axle/machined bar	To mount the drum	1		10.00	Hulas Steel, Kathmandu
Split pillow block bearing	Allows the axle to rotate	2	50.00	100.00	Bearingboys
M12 Bolts	For fixing frame to concrete	8	1.50	12.00	Karunamaya Hardware, Kathmandu

Brake Spacers	Hold brake in place	4	1.00	4.00	Hulas Steel, Kathmandu
Bike					
Bike (the actual bike)	Used to power system	2	50.00	100.00	Sourced locally
Supporting metal bars	To stabilise the bike during use	1m		10.00	Hulas Steel, Kathmandu
Additional Chain	attaching bike drive to drum axle	1		7.00	Wiggle
Flip-flop hub	One side fixed one side freewheel	1		35.00	Wiggle
Sprocket	Fixed to drum axle	2			Hulas Steel, Kathmandu
Rope and Terminations					
Synthetic rope	Used to pull basket	300m		500.00	Amazon
Wire rope	Used to support basket	600m	1.79	1074.00	Datasheet
Bulldog grips	Used to create swage loop	18	1.11	19.98	Datasheet
Wire rope thimble	to shape rope loop	6	1.11	6.66	Datasheet
Tensioning tool	aka 'come along' initial tensioning	1	35.00	35.00	Amazon
Turnbuckle	Used to tension cable once set up	4	10.00	40.00	Amazon
Carabiner	Attaches synth. rope to basket	5	2.50	12.50	Karunamaya Hardware, Kathmandu
Supporting Towers					
Cement	Component of concrete	50 bags	4.13	206.50	Datasheet
Sand	Component of concrete	2.0m^3	15.36	30.72	Datasheet
Aggregate	Component of concrete	2.0m^3	4.80	9.60	Datasheet
Water	Component of concrete	2000l			
Suspension saddle	For looping wires over supports	4	3.25	13.00	Datasheet
Cable roller	For moving rope at support	1	20.00	20.00	Alibaba
Basket assembly					
Pipe	Used in support frame (2.5m x 48.26OD)	2.5m	2.44	6.1	Datasheet
Steel Bar	To shape into hooks for frame	10kg	0.58	5.8	Hulas Steel, Kathmandu

Pulley	Support frame on cable	4	10	40	Sourced Locally
Aluminium	For Basket (3x1250x1250mm)	1	107.68	107.68	Hulas Steel, Kathmandu
Brake assembly					
Steel Bar	Curved to form brake part	2			Hulas Steel, Kathmandu
Brake Pad	Fixed to steel bar	2			
M12 Bolt	Fixes wooden handle to steel bar	2	1.5	3	Karunamaya Hardware, Kathmandu
Wooden Handle	For applying brake	2			Local Carpenter
			Total cost	**2768.86**	

Appendix 2

1. Gantt chart



Appendix 3

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Calculations for a 200m transportation system with a sag in the wire of 2.5m

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Support Cables


The Tension in the wire was calculated to be 7848.00 N for a sag of 2.5m
This value is well bellow the allowed safety value of 10.9kN for a 9.5mm wire.


The elastic extension of the wire on its own was calculated as 0.0477 m
The load from the basket was neglected as it is much smaller than the tension in the wire.


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Braking Force for Stationary Basket


The force required to hold the basket and rope in position in a worst case scenario was found to be 431.64 N.
If a wind of 20mph is factored into the calculations then the maximum force to keep the basket stationary would be 450N


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Braking Forces for basket in motion


If the basket was in motion travelling down the slope then the inertia of the barrel and rope when the basket is at the top of
the slope would be 2.03 kg/m^2

If the basket was travelling down the slope at 6m/s and the operators decided that they wanted to stop it in 10m then the baskets
deceleration would need to be 1.80 ms^-2

Using this deceleration, and the Inertia of the basket at the top of the slope the force required to stop the basket can be
calculated as 527.59 N

If the basket was in motion travelling down the slope then the inertia of the barrel and rope when the basket is at the bottom of
the slope would be 1.50 kg/m^2

Using the same deceleration, and the Inertia of the basket at the top of the slope the force required to stop the basket can be
calculated as 521.12 N
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Calculating the Forces, Torques, and Stresses acting on the supporting towers

The torque applied to the top tower by the support cables was calculated as 9829.16 Nm

The torque applied to the bottom tower by the support cables was calculated as 7829.16 Nm

The overall stress in the towers can be calculated using the maximum torque value that was found, in the top tower, in order to get an overall stress of 2788159.87 N/m^2

When this is compared with the critical load of the tower, calculated as 24274200.64 N it is clear that the towers will be more than capable of bearing the load

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The torque required at the barrel to move the basket up the slope is 86.33 Nm.

This is still bellow the torque which could be produced by 2 bikes cycling together at full power,
which is quoted as 135.60 Nm.

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If the vertical goods transportation system was to be adapted to allow for a sag of 5m then its length could be extended to 275m without issue.

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Support Cables

The Tension in the wire was calculated to be 7418.81 N for a sag of 2.5m
This value is well bellow the allowed safety value of 10.9kN for a 9.5mm wire.

The elastic extension of the wire on its own was calculated as 0.0657 m
The load from the basket was neglected as it is much smaller than the tension in the wire.

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Braking Force for Stationary Basket

The force required to hold the basket and rope in position in a worst case scenario was found to be 455.55 N.
If a wind of 20mph is factored into the calculations then the maximum force to keep the basket stationary would be 450N

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Braking Forces for basket in motion

If the basket was in motion travelling down the slope then the inertia of the barrel and rope when the basket is at the top of the slope would be 2.25 kg/m^2

If the basket was travelling down the slope at 6m/s and the operators decided that they wanted to stop it in 10m then the baskets deceleration would need to be 1.80 ms^-2

Using this deceleration, and the Inertia of the basket at the top of the slope the force required to stop the basket can be calculated as 530.14 N

If the basket was in motion travelling down the slope then the inertia of the barrel and rope when the basket is at the bottom of the slope would be 1.50 kg/m^2

Using the same deceleration, and the Inertia of the basket at the top of the slope the force required to stop the basket can be calculated as 521.12 N

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Calculating the Forces, Torques, and Stresses acting on the supporting towers

The torque applied to the top tower by the support cables was calculated as 9829.16 Nm

The torque applied to the bottom tower by the support cables was calculated as 7829.16 Nm

The overall stress in the towers can be calculated using the maximum torque value that was found, in the top tower, in order to get an overall stress of 2788159.87 N/m^2

When this is compared with the critical load of the tower, calculated as 24274200.64 N it is clear that the towers will be more than capable of bearing the load

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The torque required at the barrel to move the basket up the slope is 91.11 Nm.

This is still bellow the torque which could be produced by 2 bikes cycling together at full power,
which is quoted as 135.60 Nm.

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Also if the vertical goods transportation system was to be adapted to allow for a sag of 5m its angle of incline could be extended to 45° without issue.

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Support Cables

The Tension in the wire was calculated to be 3924.00 N for a sag of 2.5m
This value is well bellow the allowed safety value of 10.9kN for a 9.5mm wire.

The elastic extension of the wire on its own was calculated as 0.0477 m
The load from the basket was neglected as it is much smaller than the tension in the wire.

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Braking Force for Stationary Basket

The force required to hold the basket and rope in position in a worst case scenario was found to be 610.43 N.
If a wind of 20mph is factored into the calculations then the maximum force to keep the basket stationary would be 450N

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Braking Forces for basket in motion

If the basket was in motion travelling down the slope then the inertia of the barrel and rope when the basket is at the top of the slope would be 2.03 kg/m^2

If the basket was travelling down the slope at 6m/s and the operators decided that they wanted to stop it in 10m then the baskets deceleration would need to be 1.80 ms^-2

Using this deceleration, and the Inertia of the basket at the top of the slope the force required to stop the basket can be calculated as 679.97 N

If the basket was in motion travelling down the slope then the inertia of the barrel and rope when the basket is at the bottom of the slope would be 1.50 kg/m^2

Using the same deceleration, and the Inertia of the basket at the top of the slope the force required to stop the basket can be calculated as 673.50 N

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Calculating the Forces, Torques, and Stresses acting on the supporting towers

The torque applied to the top tower by the support cables was calculated as 4018.33 Nm

The torque applied to the bottom tower by the support cables was calculated as 2250.56 Nm

The overall stress in the towers can be calculated using the maximum torque value that was found, in the top tower, in order to get an overall stress of 1125958.05 N/m^2

When this is compared with the critical load of the tower, calculated as 24274200.64 N it is clear that the towers will be more than capable of bearing the load

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The torque required at the barrel to move the basket up the slope is 122.09 Nm.

This is still bellow the torque which could be produced by 2 bikes cycling together at full power,
which is quoted as 135.60 Nm.

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2014 EWB Challenge Report

Vertical Goods Transport System

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Daniel Rose

Yuzhe Zhou

Executive Summary

Engineers without Boarders (EWB) have been Collaborating with Nepal Water for Health (NEWAH) for several years. EWB held a workshop with representatives of NEWAH in Nepal and came up with seven project areas which were under development or consideration and would be suitable options for the EWB challenge. The Projects were aimed at hilltop communities in Nepal's Gorkha district. The village of Sandikhola was used to give context to students taking the challenge but it was essential that the design could be adapted to fit all hilltop communities in the area. The roads in the area are poor and transportation can be difficult and sometimes impossible during the rainy season. This dictated that the project should be conducted in the dry season and preferably would be finished in time for the rain. Funding was said to be available but should be sought after in order to justify the project. It was also noted that many hilltop communities don't have running water, electricity or fossil fuel supply.

Other objectives that were kept in mind throughout the project were:

- Ensuring the design could be integrated to the community without, social, environmental and financial difficulty
- Ensuring the design was kept simple enough so that it was reliable and easy to use
- Making an effort to source materials locally

The project chosen was Vertical goods transportation via an aerial ropeway. The systems function would be to transport firewood, crops, animal feed and anything else that the people of the village usually have to carry up the hill in a bag. The design was continually adapted but this remained the chief objective. It was noted that villagers had to spend much of their day travelling up and down the hill carrying things in bags strapped to their heads. This would be exhausting work which also puts tremendous strain on the neck. The design of the vertical goods ropeway would alleviate the intensity of this task. The ropeway should also bring the community together by having a construction project to tackle and a final design which requires teamwork to use. It was quoted in the design brief that many ropeway systems are available for transportation are available for river crossings but no design for vertical goods transport vertically. It was assumed that if such a design was created there would be widespread uptake from communities similar to Sandikhola.

The basis for this design is similar to a zip line. Other inspiration was drawn from winch systems, ski lifts and pedal powered vehicles. The design consists of four fixed towers, two at the top of an incline and two at the bottom. Two tensioned parallel wires shall run up the slope connecting the top and bottom towers together. The towers should be a concrete construction and should have foundations suitable to support the moments and compressive forces exerted on them. A basket hangs from the two wires. This is pulled up and down the system using two bicycles mechanically connected to a cable drum.

Concept Development

Group looked at an analysed each of the design areas for their suitability for the strengths of our members and for how much they would benefit the community. It was decided that the vertical goods transportation system looked most appropriate for mechanical engineers to develop while being a topic that would provide a wealth of benefits to hilltop communities. Rain water harvesting and first flush systems were also investigated further as a back-up in case the vertical goods transport was found to be unfeasible.

It was originally thought that the vertical goods transport should span all the way down the hillside to the big river at the bottom, a distance of about 5km. This, however, would require multiple stations down the hillside, and a powerful motor in order to be able to pull the basket up all the way from the bottom. It was therefore decided early on in the design process that the ropeway should be designed to only span a distance of 200m in order to allow the system to be man powered. This would reduce the cost of running compared to using a motor and also reduce emissions and environmental impact. This distance would also mean that only two stations, a top and bottom, would be required. The cost and construction impact were also seriously decreased by shortening the system. The group came to the conclusion that a longer more expensive system would have been difficult to justify and implement.

Originally vertical gravity ropeways were looked at as a means of powering the system as these are already employed in certain areas of Nepal today. Gravity ropeways require the load that is travelling down the slope to be three times larger than the load that is travelling up it. These were deemed to be unsuitable for the people of Sandikhola as their daily routines require more goods to be travelling up the slope than down. It was therefore decided that the system should be man powered, due to the absence of a reliable source of fuel for a motor, and the fact that the system should be able to be transferable to any location that is deemed suitable. Having measured up the different options of man powered transport the group decided that bicycles would be the most suitable means of driving the system. They are common in the lower areas of Nepal, and allow for a more efficient means of transporting the goods up the slope than other options such as hand cranks or treadmills. Two bikes were chosen to power the system as this would allow for a load of roughly 75kg (including the basket) to travel up the slope.

Final Design Specifications

The design specifications used to outline the conceptual design were as follows:

- The design should be able to be constructed on a hillside.
- It will carry goods e.g. firewood, crops, animal feed via an aerial ropeway system to alleviate manual labour workload.
- The maximum load expected will be 52.5kg
- There will be a basket drawn up by a winch system powered by a static bicycles.
- Moving parts of the winch system should be sheltered to minimise weather damage and corrosion of parts.

The final design concept can be clearly split into subsystems, although linked it was considered most appropriate to evaluate these individually.

Wires, rope and drum

The drum used for reeling in the driving rope will be the drum that the support cables are supplied on. This will most likely be a wooden drum, and so it will have a steel sheet wrapped around both flanges so as to provide a smooth, circular surface on which the brakes can act. The use of the drum that is already present cuts significant costs relating to fabricating the drum from scratch, or importing it. They are also much easier to source whether by manufacture or purchase since are very commonly used. The synthetic rope will be terminated at the drum using a knot. Often a series of clamps would be used for this purpose, however due to limited resources available a simpler but equally effective option was adopted.

The supporting lines shall be made of steel wire of diameter 10mm. Having two supporting wires present it can be shown by calculation that the system will be capable of handling the tension necessary to reduce the sag to only 2.5m. The rope for the driving wire which will be wrapping around the drum will be synthetic climbing rope. This gives the design more flexibility by being easier for the locals to replace considering the climbing industry in Nepal. It will be easier to terminate at the basket and drum due to it being less stiff and more workable than steel. It is also lighter than steel while retaining all the strength properties required to pull the drum up the slope.

Braking system and warning bell

A braking system was considered necessary for the ropeway to avoid any damage to the basket if it reached the bottom station too quickly. Braking the basket can be achieved using two methods. The first under normal circumstances is to use the hand crank by controlling the rotation to ensure the line isn't fed out too quickly.

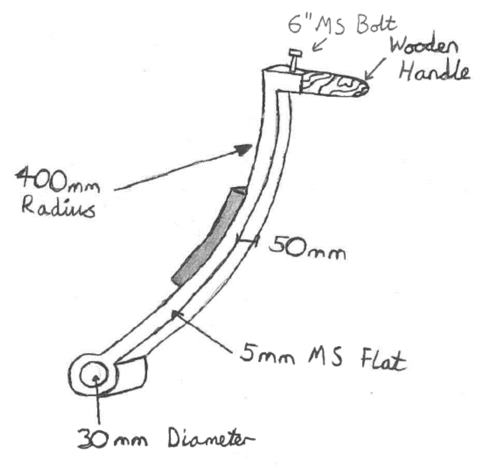

Figure 1 - Brake Arm

The second method is to slow the basket down if it has sped up uncontrollably and is not considered usual practice but a necessary precaution in case the operator is not using the hand crank brake. The design involved a brake pad on a lever that can be pressed to the round surface of the flange.

The brake arm should be made of mild steel as it is widely common and relatively cheap to manufacture. Three different types of material were considered for the brake pads, semi- metallic, sintered and ceramic.

Semi-metallic brakes have a reasonable friction coefficient of around 0.28 – 0.38. They are relatively cheap to manufacture, however they have low durability, which would mean that they would need to be replaced frequently, adding to their overall cost. Ceramic brakes have a long life span, and good thermal resistance, however they are very expensive, an important factor when low cost is one of the designs criteria. It was therefore decided that the brake pads should be sintered, as this would give them a better friction coefficient than semi-metallic brakes as well as having a long life span, and also excelling in wet conditions, which may prove useful in Nepal's rainy season.

It was decided that a warning sounder would be appropriate in order to let the operators know if the basket was getting near the bottom. This would not need to be complicated and a bell on a stand was chosen for purpose. A small modification to the basket may be required to fit an arm that would strike the bell. Although the design is capable of stopping the basket from max speed in 10m, the bell should be placed 50m before the bottom station to allow the operators to get to the brake and begin the braking procedure.

Once the sounder was heard the operators could lift up the brake, and apply it to the flange of the drum to slow its rotation.

Drum Stand

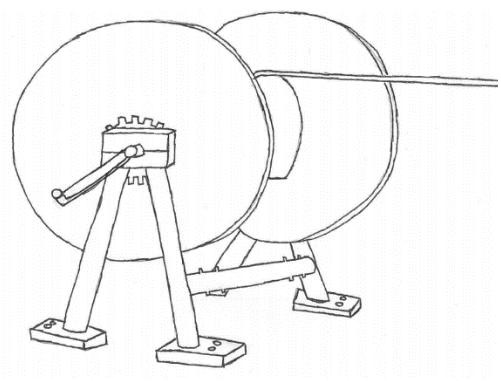

Figure 2 - Drum Stand Isometric View

The winch system is designed to take a drum of dimensions shown in table 1. However due to the design of the system the dimensions of the drum are flexible. The design was intended to be flexible throughout so that it could be repaired and adapted as required by the local people.
The drum stand is composed of two A-frames connected at their peak by a steel axle. The drum is fixed to the axle in such a way that the axle will rotate with drum. This method was adopted since it does not require a fixed size of drum barrel making the design more flexible.

Supporting Towers

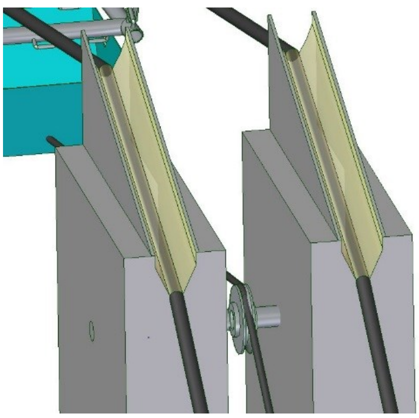

Figure 3 - CAD view of saddles and roller

The proposed material for the towers is concrete. Originally wood and steel structures were also considered for the design, however these two materials were ruled out due to three considerations: simplification of design, cost and structural strength. Wood was considered to be less strong and more complicated to build, however it would be cheap. Steel was ruled out since it would be more expensive and complicated to create a truss style structure. It would also require skill, knowledge and a level of experience at working with steel. It would however have been stronger and could be a future option if the ropeway is to be improved in the future. Concrete was the design chosen since it is strong, easy to source and simple to work with. Another advantage of concrete for the towers is that after some research it was noted that projects run by Practical Action in Nepal had used designs with concrete for aerial river crossings, very similar to this project. The people of Nepal were therefore expected to be more familiar with concrete structures, this also justified the sourcing of materials.

Bike and basket

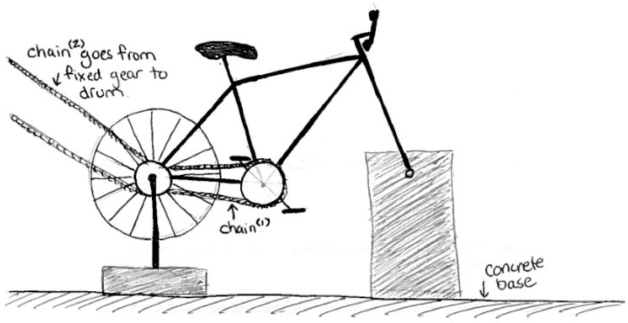

Figure 4 - Sketch of bike

The system adopted uses a bicycle to rotate the drum via a chain drive. This is made more agreeable by the fact that bikes are fairly popular [1]. They should be familiar with how they operate and more likely to have insight should anything need maintenance or repair.

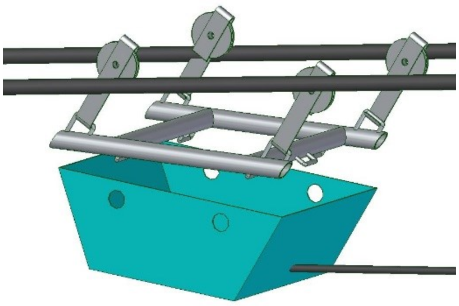
Figure 5 - Sketch of basket

The basket is designed to be interchangeable. To achieve this the basket section can be split into two parts. One part - the mount - designed to be fitted to the cables rolling on small rollers, the other - the basket - is able to detach from the mount using a simple hook. This allows different baskets for different loads to be used. It also allows for easier repair or replacement of the basket. An aluminium basket design is included, with a maximum load of 52.5kg, however this may be left detached to allow the user to attach smaller loads without it if they want to. The mount is designed with hooks on the underside to facilitate this, the user need only secure their basket to the hooks with ropes to secure it to the pulley system.

Mechanical Justification and Engineers Role

It was settled that the system should have two support wires, with a third rope that would actually pull the basket up the slope. The support cables would have to be raised off the ground and tensioned to prevent the cables from sagging causing the basket from being dragged along the ground during operation. The torque required from the two bicycles needs to be at least as great as the load of the basket on the system. To ensure this was the case a mechanical advantage was gained by using a gear ratio in the drive train. The mechanical concepts developed were seen to be practical given the context but it should be noted that the engineer's role in the project does not stop there. The final concept described in this report would be presented to the community and the sponsors outlined in the finance section. Any feedback must be taken into account and any design changes made. The timeline and each of the project stakeholders input at each stage is outlined below.

The construction of a typical aerial ropeway system shall take a maximum of 3 months including all necessary preparatory activities. Major milestones of this ropeway design are categorized into three standard stages for projects of this kind:

a) Planning Stage: Community kick off meeting with investor representatives present (outline of project objectives and community involvement). Identification of systems start and end

points, surveying of wire path (scoping out trees and rock faces), identifying the most ideal location to make the system most useful.
b) Construction Stage: Purchasing and transportation of materials to site, on the job training with community for construction, constant community evaluation and input would be beneficial, final inspection and testing of design, official handover of system to community to allocate any responsibilities (formation of public ropeway committee).
c) Monitoring and supervision: evaluation from project management, community evaluation and feedback, planning and development for next project.

Social and Environmental Considerations

The people of Sandikhola, as well as many of the other villages in and around the Gorkha District of Nepal, spend much of their day walking to collect firewood and grass. The walk is roughly a 3 hour round trip, with the villagers carrying heavy loads on their return journey. This trip sometimes has to be carried out 2-3 times per day, so it is clear that a system that transports their goods up the steep hills in the area would be very beneficial to their lives.

There is a well-documented link between doing heavy manual labour or lifting, and the occurrence of back pain. This is why there is a large number of cases of back pain documented in farmers. In Nepal it is estimated that around 71% of the population have suffered from lower back pain, which if compared with America, where only 31% of the population are reported to have suffered from back pain in the last year, is significantly greater. A vertical good transportation system could be used to reduce the time and distance that the villagers have to carry the goods, and thereby reduce the strain that is placed on their backs, hopefully contributing to a reduction in the reported number of cases of back pain.

There are already several vertical goods transportation systems in place in Nepal thanks to the work of Practical Action, however these are all gravity ropeways were found not to be suitable for Sandikhola. A human powered transportation system would therefore be the best alternative to suit Sandikhola's needs. As bicycles are already a popular means of transport in Nepal, and they are able to provide a more efficient means of transport than other methods.

In Sandikhola it seems to be typically the women of the village that do most of the collecting of firewood and leaves etc. and it would therefore be them that benefit most from the introduction of the vertical goods transportation system. The idea would be to employ two villagers to operate the system as explained in the financing section. This would leave the women free to collect several loads of materials and have them transported up the slope, saving them many hours of work, and allowing them to spend the saved time focusing on other parts of their daily lives.

It is also hoped that a project like this would provide an opportunity to strengthen the communities bond by working as a team to build and operate a system with many positive benefits for the community.

With regard to the environmental impact of the ropeway on the local environment, we would expect the largest environmental impact to come during the construction phase. The path of the ropeway must be cleared of obstacles that may interfere with the basket, which may necessitate the removal of trees from the path. Given that there are local farms, this can be mitigated by passing over farmland instead of trees if possible. In addition, the basket is not particularly

wide, so not many trees would need to be removed to make a safe route. There would also be a temporary increase in traffic, as trucks bring good to the construction sites. This may lead to a slight increase in air pollution, however as it is estimated only five trips would be required so this is unlikely to carry a long term effect. Water for the large amount of cement required was initially a concern especially considering Sandikhola's difficulty in accessing it. With that in mind extra trips to collect water were included in the budget.
The usage of a bike powered system instead of an engine means that the ropeway will be very quiet to operate. Similarly, the ropeway will provide a way to transport goods that is not dependent on fossil fuels.

Cost

The project can be split into three dominant cost centres: materials, transportation of materials and the construction/labour cost. The materials cost is covered in the Bill of Materials (BOM), the transportation and labour costs are taken from the datasheet provided from EWB.

The aim was to source all of the materials locally, in many cases they could be taken from EWB's datasheet. For more specific items related to cables and ropeways external sources had to be explored. This task was initially made difficult by the limited information on what could be bought or manufactured in the area. With that in mind it would be sensible to air freight a load of specific items to Kathmandu and assume the rest could be sourced from within Gorkha District. The complete materials cost was estimated to be **£2764.86**

The cost of transporting the materials was dependant on where the materials could be sourced. For the materials on the EWB spreadsheet this was defined and split into two rates, one from Kathmandu and one from Chitwan. It is estimated that this project will require 75 bags of cement and 6m^3 of material from Chitwan. This approximates to 2 trips by truck from Chitwan to Gorkha and 5 trips by minitruck to Sandikhola. This gave an estimated cost of **£405**. All other materials were assumed to come from Kathmandu as per the NEWAH datasheet. This was approximated to 2 trips by truck to Gorkha and 5 trips by minitruck to Sandikhola. This gave an estimated cost of **£417**. Water is also an essential commodity for this project due to the amount of concrete that is used.
From Maps supplied on Google Earth it was found that the nearest river is on the route from Sandikhola to Kathmandu. The river is an equivalent distance from Sandikhola as Gorkha so the trip rate to the river was estimated to be the same as the one to Gorkha. We need 2500l which is 2.5m^3 therefore it will require 3 trips by minitruck costing **£135**.
This combined give a total transportation cost of **£957.**

The labour cost for the project is divided into two parts: skilled labour cost and unskilled labour cost. Given that the cost of skilled labour per day is **£3.84** and **£2.56** for unskilled labour per day. We estimated that the days of installing skilled components such as cement, air valves and pipes are almost 2 months due to the complicated geographical conditions. Assuming a maximum of 3 skilled labourers were working at any given time this gave an estimated cost of **£690**. We assumed that 1 month would be sufficient for unskilled labour. Assuming a maximum of five people working at any given time the estimated cost was **£385**. In conclusion, the total cost of labour is approximately **£1075.**

The total cost for materials, transport and labour was **£4796.86.**

Financing Options

There are three main possible sources of funding, grants, loans and charging for usage. One option is to fund the entire system through grants, and have the system operated by two volunteers from the community. It may be difficult to find people with sufficient spare time to dedicate to running the system full time, and so it may be necessary to only run it for a few hours per day.

Alternatively, the system could be funded through both grants and loans, and a charge for usage introduced to repay loans and hopefully make a profit eventually. If the system was in regular use, it would be possible to hire permanent operators for a full shift each day, allowing immediate transport without building up a backlog. Otherwise, as a hybrid solution, operators could be hired part time, on a similar short schedule to the volunteering described above. This would be a few hours paid work, and would supplement the income of the operators, but would be cheaper to run than the full time option.

The cost that must be charged is dependent on the amount of money that must be paid back, and so may be reduced if the costs are lower than predicted, or grants secured to partially fund the project. Alternatively, the fee may stay the same, with profit reinvested into a maintenance fund for the system.

One option for grant based funding may be to apply for assistance from the Nepalese government's Poverty Alleviation Fund [2], which is expanding into Gorkha District as of 2014. PAF distributes development funding from the World Bank's International Development Agency, the International Fund for Agriculture Development and the Government of Nepal to local projects, led by a community organisation, supported by a partner organisation, typically an NGO. The community is expected to make a contribution to the cost of the program. For income generating projects, PAF will cover 78% of the cost with 6% to come from the local government and other partners. The other 16% is split into 7% as cash and 9% as goods in kind from the community [3]. This remaining 16% of funding could be accounted for with a loan, to be repaid from profits of the system. Total PAF expenditure for projects in 2013 was Rs (Nepalese rupees) 13.122 billion (just under £80,000,000). In the financial year 2013/14, over 3000 projects were expected to be funded. If PAF funding could be secured, the remainder of the cost could be covered easily by fees for usage.

Sandikhola has an adult population of approx. 300, of which about 95% live in households with an assessed income of Rs 500-800 per day [4]. NMW is 8,000 Rs per month. Over 30 days, this will cost 267 Rs per day. Sandikhola has 60 households. Assuming an uptake rate of 2/3 houses, 7 Rs per household per day is required to pay the full time wage for a single operator, so 14 Rs for the entire system. Charging 25 Rs per day would prevent heavy usage from impacting finances of users too heavily, while allowing the system to make a profit. A lower rate could be introduced, charging 15 Rs for a single load, for people who only need a specific item transported. The higher rate would be for unlimited usage, but in practice, given that the major goods (crops/wood) are gathered or harvested the time saved is unlikely to add up to more than one extra trips worth of goods, resulting in a rate of 2-3 trips per day. Assuming 10 households at a 15 Rs tier therefore, and 30 at a 25 Rs charge, we can expect a turnover of 900 Rs per day, with a profit of 345 Rs per day. This is equivalent to £3.20 per day (at 2/11/14 exchange rates).

If PAF funding is granted, then assuming initial set up costs of £5,000 (estimated costs & contingency), the community will be expected to contribute £1,100 to the construction, with the rest provided by the PAF. Assuming the prices outlined above, and with the system operating full time, the system will recover its costs to the community within 345 days of operation assuming all profit is used for repayment. If money is also set aside for a maintenance fund at the same time, the time to recover costs will naturally be higher. This proposal can of course be modified to suit their needs, for example if the community is willing to pay higher prices, the operators may be paid above NMW, or extra operators could be taken on. To lower prices, the community could use one of the hybrid schemes described above, paying operators to work part time for a few hours a day, at the cost of instant transportation.

It is crucial the community is consulted and they are given the opportunity to decide how financing will work for themselves. For example, instead of a payment per day, they may wish for a local council to administer the financing, paying for access on a monthly basis or as part of a small community charge from all households. This is something best chosen by the community to suit their own needs, but we have proven the system is commercially viable in some form or another.

Communication and Handover to Community

Assuming the village of Sandikhola do not speak English there are likely to be language barriers between the design team and the community. This would be alleviated by NEWAH's group based in Bharatpur and the EWB team. The design was aimed to be fully supported by pictures and an instruction procedure for the construction and assembly was created to be as clear as possible.

Reflection of Team Roles

The team first began meeting twice a week in order to come up with a concept suitable for development. These meetings were continued throughout the semester despite all members having busy schedules. The frequent meetings helped to break any tension in the team while also ensuring the project was not left by the wayside. The meetings minutes the delegation of tasks were documented and posted to a social networking group created for communication and file sharing purposes. The team had two extended meetings to work through the calculations side of the project as soon as a final concept was reached to ensure the design was feasible. There were a couple of extra extended meetings towards the end in order to piece the report together. As a group the team work well together without any detrimental conflict. Each individual team member pulled their weight and any member would look for work and to help out others with the task load. Over the team was positive and well organised.

Sarah Conley

Focussed on calculations and full explanation and justification of the systems mechanical and structural integrity. Developed bike powered concept into final design.

Zuoning Liu

Initially aided design of supporting structures. Investigated and analysed the environmental considerations. Assisted with estimating and calculating the costing of the project.

Ross McDonald

Designed the basket for the system, produced full CAD model of the basket and carried out an FEA study of the component. Researched and justified the financial plan for the project.

Ruaridh Richardson

Wrote the MATLAB code for the calculations and researched the social and community benefits of this system in Sandikhola. Produced the design for the braking system and aided in the calculations for the gears.

Daniel Rose

Produced the design for the winch system, Explanation of how the system fits together in the design overview complete with instruction manual for construction and assembly. Produced Bill of Materials. Assisted with costing calculations

Yuzhe Zhou

Initially aided design of supporting structures. Produced full CAD model of the design and produced rendered views to best describe the layout of the system.

Appendix A

Instruction Manual

- Concrete foundations put in place, approximate volume (6x2x0.25m)
- Before cement has set place threaded inserts for winch drum and steel hook for cable anchoring, preferable to give options for different offsets from support tower
- Begin building supporting tower structure using concrete
    - Make cylindrical outer casing using wood and rope to tie together
    - Fill casing with premixed concrete
    - Insert top cable run
- Manufacture drum stand
    - Weld steel sections to form A-frames
    - MIG weld bearing block onto A-frame peak
    - Insert axle
    - Bolt on bearing block top
    - Attach feet to line up with threaded inserts in foundation
- Bolt drum structure to foundation inserts at 6m offset (optimum)
- Attach cable to the steel hook insert at top station anchor using cable grips
- Bring cable down to bottom station and ensure cable is running over top of towers at both stations
- **Begin tensioning process**

2. Secure tensioning tool to central U anchor
3. Secure turnbuckle assembly to U anchor
4. Feed out around 3m from the tensioning tool reel

5. Feed the live end of the cable through the tensioning tool cable grab with approximately 0.5m to spare
6. Terminate the live end using 3 cable locks
7. Begin cranking the lever arm to start putting tension on the wire
8. When at appropriate tension connect the turnbuckle assembly and the terminated end of the live wire
9. Begin releasing the reel so that it feeds out until the tensioning tool is slack
10. Remove tensioning tool and adjust turnbuckle if more tension if required

11. Repeat for other supporting wire in the same fashion
12. Fit basket at bottom station
13. Tie synthetic rope to basket and bring to top end
14. **Tie rope to drum**
    5. Feed end of the rope through the hole in the side of the drum
    6. Using simple half-moon clamps to fix to the side of the drum going round in a square centred at the axle
    7. Connect bike and drum via the chain drive
    8. Reel in the rope by pulling the basket up the hill so that the rope is spooled onto the drum with the basket weight acting as back tension

- Attach 20m warning bell
- Connect braking system to drum
- Test system