Trade and Mobility on the Rooftop of the World: Gravity Ropeways in Nepal

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Trade and Mobility on the Rooftop of the World: Gravity Ropeways in Nepal

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1. INTRODUCTION

The Global Dimension in Engineering Education (GDEE) is a European Union funded initiative involving the collaboration of development NGOs and universities, with an aim to integrate sustainable human development as a regular part of all technical university courses. Part of the initiative is the development of a set of case studies based on real field experiences of development projects. The case studies cover a broad range of topics directly related those studied in engineering, science and other technology, environment or development-related courses.

This case study looks at a rare and challenging mode of transportation: the gravity ropeway. These are mechanically powered devices that, despite their simplicity, are difficult to implement safely but make a dramatic difference to the movement of goods and people. The case study is based solely on work by Practical Action Nepal (Practical Action Nepal, 2014).

The case study allows students at any level to: analyse a mechanism; consider the challenges of actually building even a simple design; understand the enabling effects of technology; consider the design implications of transferring a technology between contexts; and appreciate the need for individual professionalism in such projects.

Images for this case study can be found in the associated PowerPoint presentation.

1.1. DISCIPLINES COVERED

Mechanical Engineering; Transport; Construction; Economics; Appropriate Technology. Other aspects include: Health & Safety; Development; Social Sciences; Professionalism.

1.2. LEARNING OUTCOMES

1. The contextual considerations of a technology, using the example of a gravity ropeway.
2. That simple technologies are not necessarily easy to engineer.
3. Applying numerical analysis to a real-world situation.
4. The roles of technology and professionalism in promoting human development.

1.3. ACTIVITIES

Class Activity: Individual work and design with numerical analysis – ropeway design and loading.
Homework Activity: Individual work and personal research and essay – alternative contexts and implications for design and socio-economic factors.

2. DESCRIPTION OF THE CONTEXT

The following sections outline the context and impacts of the gravity ropeways used in the Himalayan region of Nepal. The case study touches on a range of issues that are relevant to the activities, including: environmental issues (such as noise); income level; gender; progress on human development indicators; the effect of infrastructure provision in reducing the cost of business; the challenges of construction and maintenance in remote areas.

The case study could be extended to also touch on issues such as: the project cycle; professional ethics; materials science; the effect of climate change on the Himalayan communities; a discussion of the right of access to infrastructure and the extent to which government can and should provide infrastructure to remote communities; the reasons why subsistence farmers and communities remain in difficult environments; the importance of communication and engaging with all stakeholders in an engineering project. Challenges exist with using ropeways to transport water, which could become a design/research project.

2.1. LIVING IN THE HIMALAYAS

The Himalayas are known as the ‘rooftop of the world’. The mountain range contains many of the world’s highest peaks (around one hundred of which are over 7,200 metres) and about 15,000 glaciers – as well as very fertile hillsides and plentiful clean surface water (Wikipedia). The Himalayas are home to many different communities and ethnic groups.

The majestic landscape is quiet, with the only sounds being from the wind, the bells of the Buddhist temples, dogs barking – and an occasional avalanche in the distance.

The country of Nepal is dominated by the Himalayas. The rugged terrain and rapidly changing weather conditions make it very difficult to access the settlements that are scattered in the hills and mountains. In such a harsh mountainous region, transport is very difficult indeed; roads are long, steep and winding, expensive to build and maintain, and are frequently damaged by landslides. Even relatively short journeys (as the crow flies) can take days. Most journeys involve significant stretches on foot, climbing along paths and rope bridges whilst carrying goods and possessions. Getting crops to market can be exhausting and dangerous – it is generally mules, women and children who carry these heavy loads down treacherous, winding dirt tracks.

Nepal is a rapidly developing country and is making impressive progress on most development indicators (Gapminder). However, life is difficult for families living in the remote
mountainous areas of Nepal. One in four people live on $1 a day (World Bank). They survive by growing food to eat and selling what is left over to provide the most basic necessities.

2.2. INTRODUCTION TO GRAVITY ROPEWAYS

One of the most simple mechanisms is the rope and wheel. They are employed in almost every mode of modern transportation in some way. But as a mode of transport in themselves, their use is rare and restricted to unique – and often challenging – contexts. Using ropeways to transport goods and people across difficult terrain is an efficient and effective solution in place of long and arduous journeys by road or foot, and can greatly help improve the lives of local communities.

In short, a gravity ropeway moves goods up and down a mountainside by hanging trolleys off wheels that roll along support ropes. As one trolley goes up, another trolley goes down. The weight of the descending trolley is what drives the system. The progress of the trolleys is managed by a control cable. The control cable runs through wheels at the stations at the top and bottom, and those wheels are controlled by a manually operated brake.

Ropeways have also been developed to help people cross rivers (where passengers haul themselves along a horizontal ropeway). Aerial ropeways can also be used to carry people and goods, often driven by electric motors powered by micro-hydro (rather than gravity).

Though it is a simple machine, a gravity ropeway must be implemented carefully and safety issues must be addressed. The loading and speed of the trolleys must be adequately controlled to avoid them crashing into the stations and potentially harming the operators. The support wires must be well anchored to ensure against collapse, which could potentially harm people or buildings underneath. The ropes and stations must be protected against corrosion, and the mechanism must be well oiled to prevent damage. The construction of the ropeways – which involves lifting and positioning long and heavy steel cables – is a significant challenge. Steps must be taken to ensure that people are not injured while operating the ropeway. If people (and not just goods) are being carried by a ropeway, then the engineer’s responsibility for the lives of those using it becomes very clear indeed.

When implemented properly, a gravity ropeway can make a significant improvement in the lives of the communities it serves. An initial study showed that the transportation cost of the agro-based products decreases by at least 50% once served by a gravity ropeway system. Such encouraging statistics give the villagers the confidence to supply their products in larger quantities, and to enter competitive city markets. Access to a transportation system and to market linkages improves their socio-economic status in terms of income, health, education and community awareness. Promotion of this technology also helps the local economy by creating employment opportunities and by supporting local manufacturers and
service providers. The economic benefits of gravity ropeways allows for the funding of proper operation and maintenance by the communities that use them. With such support systems in place, gravity ropeways can be in operation for many years at a time.

### 2.3. Practical Action Nepal

Practical Action Nepal (Practical Action Nepal, 2014) is the local office of the international development charity Practical Action (Practical Action, 2014), which is headquartered in the UK. It was founded by the economist E. F. Schumacher who is known for writing ‘Small Is Beautiful’ and who coined the term ‘Intermediate Technologies’ (Schumacher, 1973), which became known as ‘Appropriate Technologies’.

Practical Action Nepal began its transport programme in 1998. It focused on improving and promoting innovative systems that were appropriate to the geographic, environmental and economic context. These included technologies such as cable river crossings and bicycle ambulances and trailers.

The role of Practical Action Nepal is to help communities install ropeways by providing technical assistance and to secure the initial capital costs. A typical process might be that Practical Action Nepal’s Access Project Manager and the community members hold numerous meetings regarding a feasibility study. A feasibility study is then conducted, funded by Practical Action Nepal. Depending on the outcome, a project budget is developed. The study is circulated among the relevant government ministries. If the Finance Ministry approves the budget (which may or may not use international aid donor funding), then an approval letter is sent to Ministry of Local Development who start the project with the cooperation of the agriculture offices, the local co-operatives and the farmers themselves.

The farmers often put in hard work of transporting materials from the nearest road to the uphill station. A lot of manual work is required to transport the cables from the bottom station to the top station and men and women came in great numbers every day to help carry the wires, gravels and necessary tools required for the construction. The construction process is project managed by Practical Action Nepal, who also trains local operators once the gravity ropeway is completed.

### 2.4. Case Study: Janagaon

Janagaon is one of six communities in Nepal who worked together with Practical Action to install a gravity ropeway. It has been in operation since June 2005.

Dharma is 55 years old, with a wife and three children. He grows vegetables on a small plot of land in Janagaon village. He says, “It takes two hours to get down the mountain trail to the
main road, and during the monsoon, accidents are frequent. Now we have the gravity ropeway, the time saved means I can earn three times as much from selling my vegetables. With that extra money I can afford to farm animals, too. But I’m not just glad for me – the whole village is prospering thanks to the ropeway."

The main components of the ropeway are sourced locally and project staff train local manufacturers to build the parts. Practical Action shows the village group that is taking responsibility for the ropeway how to maintain it. A small charge to each user ensures enough money to keep the ropeway in good repair while also paying for two operators to manage the top and bottom stations safely.

Before the installation of the ropeway in Janagaon, families often went without food or medicine during the winter months. The ropeway means people can get more produce to market from their mountain villages. And because it gets there quicker, it’s fresher and earns them more. They have more time to tend their crops, more money to buy fuel for cooking and heating, and can even pay for education and healthcare.

2.5. CASE STUDY: BISHALTAR

Hira is married with four children and lives high in the hills above the new gravity ropeway station in Bishaltar, constructed in 2007. Hira grows tomatoes on his plot, which is three long hours walk from the roadside where traders come to buy produce. Before the gravity ropeway was constructed, Hira would have to pay a porter to carry his tomatoes down the mountain-side at a cost of 100 rupees per load. Now, a much heavier load can be transported using the ropeway for 15 rupees – seven times cheaper than hiring a porter.

The three hour journey has been cut to just two minutes. The tomatoes arrive fresh and undamaged and fewer porters have to travel down perilous pathways. Hira’s tomatoes didn’t used to command a very high value. He was also limited in the amount he could grow, not by the size of his plot, but because it wasn’t cost effective to transport the goods down the mountainside. Hira was struggling to provide for his family.

Now, Hira and his fellow farmers are producing higher quality and larger quantity of crops, having used some of their profits to buy fertiliser and increase their plot of land. They are earning 5 rupees more per kilogram of goods and are selling to traders from as far as 500kms away. During the farming season, this ropeway transports over 100 cages of produce from the top of the mountain to the bottom every day.

Hira says: “Life is good now. Not just for me but for many other farmers. We couldn’t imagine how much of a difference this simple ropeway would make; I am saving time and money and can finally look forward to a more secure future for my family”.

The whole community is benefiting from the gravity ropeway, being involved in the project right from site selection. Now they have established a committee which represents the villagers using the ropeway, hired two staff members (one for the mountain top station and one for the roadside station) and mobilised over 50,000 rupees in savings (almost £400).
3. **Class Activity**

3.1. **About Gravity Ropeways**

The gravity ropeway operates by gravitational force without the use of external power. It consists of two trolleys which roll along support cables. The trolleys are also attached to a control cable in the middle which moves in a traditional flywheel system. When the loaded trolley at the up-station is pulled downward by the force of gravity, the other trolley at the bottom-station is pulled up by means of the control cable.

The trolleys roll along support cables using a pulley system that guides the cable and provides a cushioning effect. The pulley system consists of a load-bearing pulley on top of the cable and a dummy pulley underneath.

The trolley itself is simply a steel cage made from pipes, and should be as light as possible (say, about 30kg). Its centre of gravity should be well balanced when loaded.

In principle the goods coming down from the up-station must be three times as heavy as the upwards load from the bottom-station. The speed of the trolleys depends on the angle of elevation made by the cables.

A flywheel with bearing and bracket is used as a break to control the landing speed of the trolley at the bottom-station. Brake strips around the wheel are connected to a fixed support at one end and to the brake handle at the other end. Applying force to the handle applies the brakes to the wheel’s rim.

The top and bottom station platforms are civil foundations housing the control pulley, the supporting cables and the braking system. They are used as the loading platforms and must be strong enough to withstand impacts.

Communication between top and bottom stations is done by tapping the wire rope. The operator strikes the wire rope with a stick to send a wave through the wire.

3.2. **Ropeway Calculation Task**

The following problem is based on the pre-feasibility study of a gravity ropeway by Practical Action in Nongtaw, Nepal.
Span of rope = 763m  
Elevation, y = 358m  
Maximum weight going up: 85 kg  
Maximum weight going down: 155 kg  
Haulage rope used: 6 x 19 fibre core, 9mm diameter (see table to right for mass)  
Minimum sag required (6% of span)  
Horizontal tension components at points a and b are equal and opposite

a) Discuss the nature of loading on the cable (note that for the purpose of this exercise we are excluding wind load)  
b) Calculate g, the vertical distance of the rope from the ground when the point load (carriage) is at halfway point of travel  
c) Estimate the horizontal components of tension using the following moment equations:

\[ \Sigma M_{abt. a} = \Sigma M_{abt. c, RHS} \]

\[ V_b = (\text{span}^2 \cdot d / 2) + H_b \cdot y + x \cdot P / \text{span} \]

\[ x \cdot P + \text{span}^2 \cdot d / 2 + H_b \cdot y + V_a = P + \text{span} \cdot d - V_b = - (y - g) \cdot H_b + d \cdot (\text{span} - x)^2 / 2 \]

d) Estimate the vertical component of tension using the following equations:

e) Discuss how the results above can be used to ensure safety of the gravity ropeway  
f) Discuss the ideal ratio of goods coming down from up-station versus the goods coming up  
g) What are the trade-offs in relation to the favourable slope for the ropeway?  
h) What is the maximum cable length appropriate for gravity ropeways?
3.3. **SOLUTION**

a) Let us examine the loading. The weights would act as point loads:

The maximum weight going down is 155kg = 155*9.81 = 1520.55N
The maximum weight going up is 85kg = 85*9.81 = 833.85N

The self-weight of the rope needs to be estimated.
If the haulage rope used is 6 x 19 fibre core from the table mass can be estimated as 0.292kg/m = 0.292*9.81 = 2.86N/m.

b) The maximum tension in the cable will be observed when the point load (carriage) coming downwards is at mid-span i.e. halfway point of travel.

So x = 381.5m
Minimum sag required is 6% of span which is 45m

g = y – f – sag
= y – (y*(x/span)) – sag
= 179 – 45
= 134m

c) Using the equations provided in the hand-out:

\[(381.5)(1520.55) + (763)^2 (2.86)/2 + Hb (358) = Vb (763)\]
\[(763-381.5)Vb = [(358-134)Hb + (2.86)(381.5)^2] / 2\]

Solving the above equations: \(Hb = -7435.38N, Ha = Hb = -7435.38N\)

d) Using the equations provided in the hand-out:

\[Vb = \left[\left((763^2)(2.86)/2\right) + \left((7435.38*358) + (1520.55)(381.48)\right)/763\right] = 5340.01N\]

and

\[Va = 1520.55 + (763)(2.86) – 5340.01\]

= -1637.28N

e) Using the horizontal component of tensile force it is possible to calculate the maximum rope tension:

\[(T) = \frac{H}{\cos(\beta)}\]

where \(\beta\) is the angle of the rope in relation to the ground from the bottom tower when carriage travelling downwards is at halfway point
This rope tension can be used to assess the volume of mass required at each end to support the cable, thus ensuring safety of the ropeway.

The rope tension should be checked against the allowable tensile strength of the cable material to ensure that a factor of safety of 3 is maintained for the track rope and 3.5 for the haulage rope.

f) The gravity ropeway operates by gravitational force where, to function correctly, the downward load has to be heavier than the load being pulled up. As a rule of thumb, the weight ratio of downward and upward moving load is 3:1. However, the ratio varies according to site condition and accuracy in installation. Actual loading ratio should be carefully evaluated after the operation of the gravity ropeway and should be maintained. If the loading ratio is not properly maintained, the trolley will either approach the station with excessive speed or stop in between. Remember that the cable has self-weight which also needs to be considered when calculating tension in the cable and velocities.

g) The gravity ropeway needs at least 15 degrees slope to operate smoothly as anything less than this would result in high sag in the cable. The maximum slope suitable for gravity ropeways is 40 degrees as steeper the slope the higher the velocity of the trolley. Ideal slope should be between 20-30 degrees.

h) Based on best practice examples from Practical Action the maximum length of experiences of cable should be 1500metres. When the span exceeds over 1500 metres, the tension due to the self-load of the wire rope increases as it is suspended between two points only. In addition, the energy loss due to the friction will be more in longer span ropeways. Therefore, for safety and efficiency, the span of gravity ropeway is recommended to the limit of 1500 metres only. In our example we have excluded friction calculations but in real life frictional forces need to be estimated.
4. HOMEWORK ACTIVITY

4.1. TASK

Students are asked to write an essay of around 2,000 words answering four questions (below). A discussion session in small groups could be held in class about these questions in order to generate and share ideas (since some students may struggle to start getting to groups with the concepts here). Essays should however be submitted as individual work.

The briefing to students is as follows (reproduced in ‘Activity 2 handout for students’):

“The case study has focused on the use of gravity ropeways for transporting goods in the Himalayan region of Nepal. Practical Action has also developed ropeways to help people cross rivers (where passengers haul themselves along a horizontal ropeway) and aerial ropeways that are powered by electric motors (rather than gravity).

Write a short essay covering each of the following:

1. Analyse and list around ten attributes of the context in this case study (the Himalayan region of Nepal) that make ropeways a good solution here. Briefly explain why you think each attribute is important. Consider technological aspects, application aspects and non-technological aspects (such as geography, economics, need, environment, etc). Estimated word limit: 300 words.

2. Describe at least three alternative contexts in which a simple ropeway like this would be a good solution to move goods or people, referring to the attributes you have listed. These could be in a different country or region of the world, and they might have different socio-economic, geographical and climatic conditions. Estimated word limit: 300 words.

3. Choose one of these alternative contexts and describe changes to the design that would need to be considered for this solution to be made more appropriate to that context. Again, consider technological, application and non-technological aspects (for example: if the context is near the sea then perhaps salt corrosion may be an issue?; does the context call for assistance from external experts or would the community be able to mobilise such expertise themselves?; how might the design and economics change if the ropeway is to appeal to the particular client group?). Estimated word limit: 700 words.

4. There are significant risks surrounding ropeways, whether they transport goods or people. Imagine you are the project engineer for Practical Action Nepal. What is the role of the engineer in each stage of the ropeway’s life cycle in minimising these risks? Estimated word limit: 700 words.”
4.2. EVALUATION CRITERIA

This task calls for imaginative and abstract thinking about the contexts in which a particular technology can be used. It requires the student to apply analytical skills to non-technological information. It attempts to push students to overcome any assumptions that they may make about a context, and challenges the idea that even simple technologies can be successfully transferred from one place to another. The question on professionalism and the role of the engineer should make them consider their own capabilities and duties, and hopefully what they can and cannot take responsibility for. The best essays will be written when the student imagines themselves as the person experiencing the technology in the context, without making too many assumptions and not taking any factor for granted.

Suggested evaluation criteria:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Task Completion (30%)</th>
<th>Argument &amp; Content (30%)</th>
<th>Topic Knowledge (30%)</th>
<th>Presentation &amp; Writing Style (10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> (80%+)</td>
<td>Exceeds most expectations for the assignment.</td>
<td>Highly original argument, high level of engagement with content presented in the resource or supplementary resources.</td>
<td>Broad and accurate knowledge of the topics covered, consistent use of topical vocabulary.</td>
<td>Excellent.</td>
</tr>
<tr>
<td><strong>B</strong> (70% - 79%)</td>
<td>Meets all or exceeds some of the expectations for the assignment.</td>
<td>Strong argument, moderately high level of engagement with content presented in the resource or supplementary resources.</td>
<td>Familiarity with most of the topics covered in the course, some use of topical vocabulary.</td>
<td>Excellent.</td>
</tr>
<tr>
<td><strong>C</strong> (60% - 69%)</td>
<td>Meets most of the basic expectations of the assignment.</td>
<td>Solid argument, limited engagement with resources or supplementary resources.</td>
<td>Gaps in content and vocabulary, but can express some issues with authority and/or background.</td>
<td>Good.</td>
</tr>
<tr>
<td><strong>D</strong> (50% - 59%)</td>
<td>Meets a few basic expectations.</td>
<td>Weak argument, little to no engagement with resources supplementary resources.</td>
<td>Confusion of facts, inconsistent or incorrect assertions, skirting of subject, digressions.</td>
<td>Poor.</td>
</tr>
<tr>
<td><strong>F</strong> (&lt;50%)</td>
<td>Fails to meet any generic or specific expectations.</td>
<td>No argument, no engagement with resources or supplementary resources.</td>
<td>Failure to engage topic entirely or substantively, little or no demonstration of topical knowledge.</td>
<td>Awful.</td>
</tr>
</tbody>
</table>
4.3. **Example Answers**

1. Attributes that students take from the case study will hopefully range from the obvious to the subtle. Examples attributes might include:
   - **Technological**: Strong foundations. The rocky terrain allows for strong foundations for the top and bottom stations of the ropeway.
   - **Technological**: Sourcing materials. The materials required to build the ropeway are relatively easy to transport compared to, say, the materials needed to build a bridge.
   - **Application**: Unmet need. There is a serious need in this context because there are roads cannot service the communities.
   - **Application**: Small loads. The goods are from subsistence farmers and the quantities involved were small enough for human porters to carry, so the loads being placed on the ropeway are quite small and manageable.
   - **Non-technological**: Low noise. The case study mentions the tranquillity of the environment so the ropeway is a good solution because it is low noise.
   - **Non-technological**: Affordability. The community is already paying for porters to transport goods, so funds are therefore available to pay for the ropeway instead.

2. This question begins to look at the concept of technology transfer and the importance of considering the context in which a technology will be used. Students should be able to explain why the contexts they have chosen would suit a ropeway. Hopefully the introduction to the task will have prompted some students to consider ropeways for moving people too. Example alternative contexts might include:
   - Crossing a seasonal river bed (wadi) in a desert region
   - Getting goods to and from an off-shore lighthouse
   - Carrying small numbers of backpacker tourists to a lookout point on the edge of an escarpment
   - Filming tracking shots inside caves for a television wildlife documentary
   - Carrying goods across a narrow canyon
   - Unloading a supply ship at a small sea port in a developing country

3. Students will have an understanding of the technical design from the earlier activity. This question looks into how the technology needs to be adapted to make it appropriate to their new context, and so gives the student the opportunity to express some ideas on engineering design. The depth of consideration given to the context is key here. Taking the context of crossing a seasonal river bed (wadi) in a desert region, example design changes might include:
   - **Technological**: Changes to the foundation structures of the stations at each end of the ropeway to take into account that they may have to be in sand.
• Technological: The possibility of altering the length of the ropeway since the width of seasonal rivers changes from one year to the next.
• Technological: Methods for cleaning sand out of the mechanisms.
• Application: Since this ropeway will be horizontal it cannot use gravity, so a method of hauling the trolley across will be required.
• Application: If the ropeway is to carry people, a more extensive maintenance, testing and safety regime will be required.
• Non-technological: Will the ropeway be manned and operated for a fee or left for users to operate themselves (and if so, how will its upkeep be paid for)?
• Non-technological: Will introducing the ropeway completely displace the work of boatmen who currently row goods across the river, and perhaps give rise to social tensions within the community?

4. This question begins to address professionalism and the role of the engineer. Since these matters are not really discussed in the case study, the point of this question is to develop the awareness of the student of their own role in any project. Answers should correspond to stages of the project cycle and might include:
  • Needs assessment: ensuring all stakeholders are consulted.
  • Planning: ensuring the route taken by the ropeway takes into account engineering and community perspectives.
  • Design stage: getting the calculations right.
  • Construction: ensuring no corrupt practices.
  • Testing: not cutting corners to meet the project timetable.
  • Training: ensuring safety and equal access for all.
  • Operation: providing advice on whether the ropeway should be closed in a storm.
  • Maintenance: checklists to help ensure the correct procedures are followed.
  • Decommissioning: the ropeway is dismantled to leave the site safe.
BIBLIOGRAPHY


FURTHER/SUGGESTED MATERIAL

- Video: Ropes of Hope www.youtube.com/watch?v=Lc6JRVuYqZU
- Video: Gravity Goods Ropeway www.youtube.com/watch?v=LaHS8eHzYqg
- Video: Gravity Ropeways in Nepal www.youtube.com/watch?v=nvbGTBWMtkI