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Environmental Evaluation Of Landslide Remediation Options

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ABSTRACT

A major landslide occurred over a 200m section of a local road in the Sunshine Coast Hinterland following a period of heavy and prolonged rainfall in the summer of 2010/2011. Various technically feasible remediation options were proposed for deliberation and evaluation with the relevant authority. The traditional options approach judges the environmental impacts subjectively with quantification of direct construction costs only. This approach quantified the environmental costs so that direct comparison of the options could be made against each of the client's key drivers and their relative perceived importance. Quantifying the costs of the environmental impact include evaluating the embodied energy, greenhouse gas (GHG) emission cost, and the cost of pavement repair for the external roads. The latter would occur due to the accelerated rate of degradation, as a result of using heavy goods vehicle (HGV) to transport materials to and from the site across local roads. GHG calculations included emissions from diesel fuel consumption and embodied emissions associated with transportation of materials, construction material use and construction methodology.

Keywords: landslide repair, environmental impact, greenhouse gas emissions, embodied energy

1 INTRODUCTION

For any particular landslide, there is normally more than one feasible remediation solution. Different transportation agencies would use different approaches to evaluate the remediation options and select the preferred solution. Regardless of the approach used, it is imperative that the remediation solution adopted should have considered all factors, some of which may not be tangible and their relative costs are not easily estimated especially those related to environment aspect. The weighting assigned to each factor would depend on the situation current at the time of evaluation which may require consideration of society/political pressure, maintenance budget, past experience, etc. The environmental impact should be assigned an appropriate weighting, but traditionally this has been non quantitative rather than a calculated environmental "cost".

This paper presents the environmental and construction costs associated with a large landslide that occurred in Maleny, the Sunshine Coast Hinterland. The discussion covers remediation options considered and the approach used to evaluate five technically feasible remediation options by comparing their total internalised costs which comprise their construction costs, embodied energy and environmental costs.

2 BRIEF DESCRIPTION OF THE SITE CONDITIONS AND GEOLOGY

Look and Thorley (2011) discuss the application of landslide risk management to various case studies in south east Queensland. A local road where multiple landslides occurred in the Sunshine Coast was shown to have an annual probability of failure of 0.4%, but this was biased towards the high summer 2010/ 2011 rainfall for the Maleny area, which was 232% above the 796mm average. The landslide discussed in this paper occurred over a 200m section of that local road. The local road is a narrow 2-lane single carriageway roadway and was of asphaltic construction. The landslide occurred where this section of road embankment traverses a relic in-filled drainage line close to the toe of a steep escarpment.

This section of road overlies colluvial soils of variable type and consistency, being up to 6m in thickness. The colluvial materials comprise a matrix of high plasticity silty clay with occasional gravel beds and mixtures of cobbles and boulders. The colluvium overlies residual soils grading to extremely weathered igneous rocks of the North Arm Volcanics Formation. A hydrological study of the site showed that water from further up the slope was being preferentially concentrated in this natural low point beneath this section of road. The presence of large boulders also presented interesting challenges where installing piles or ground anchors might be required. A cross-section of the ground model is shown in Figure 1 with the steep escarpment above the road not shown for figure clarity.

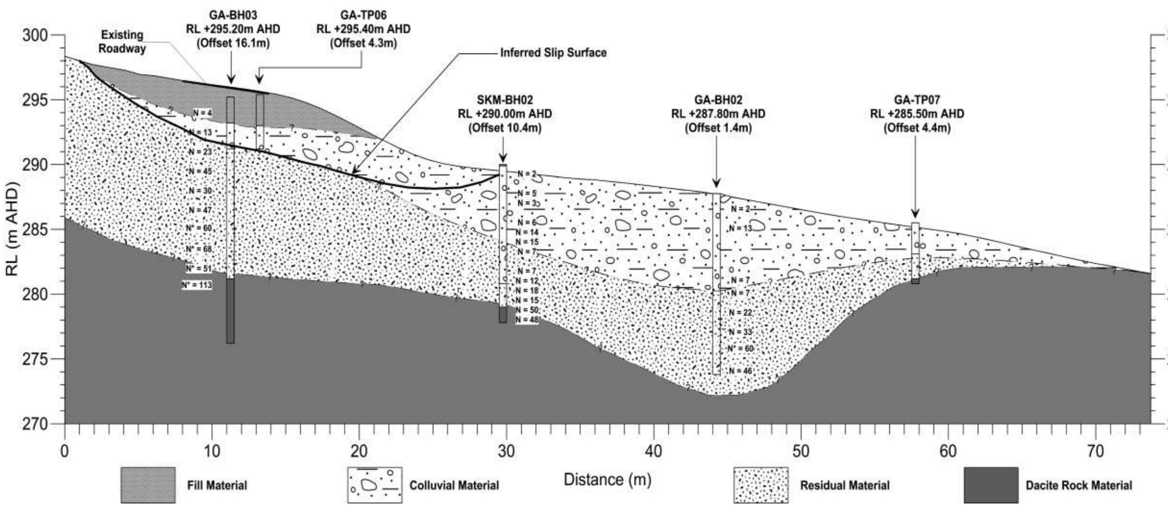

Figure 1. Typical cross section through landslide

3 PROPOSED REMEDIATION OPTIONS

Technically feasible remedial options were developed on the basis of the ground and groundwater models formulated from a synthesis of the information obtained from the several stages of ground investigation work including geological, hydrological and geomorphological mapping of the site. The advantages and disadvantages of each option are presented in the following subsections.

3.1 Cast in Place Pile Wall Restrained with Ground Anchors

This remediation option involves the construction of a row of cast-in-place piles and installation of permanent ground anchors.

Advantages; (i) minimal site clearing is required; (ii) no local soils are required to be disposed of site; (iii) heavy vehicle movements are required only for transportation of concrete, steel reinforcement and steel tendons; and (iv) construction is less weather dependent.

Disadvantages; (i) trenching up to a depth of 6m below ground along the alignment of the cast-in-place piles is required for removal of cobbles and boulder prior to the installation of the cast-in-place piles (ii) mobilisation of specialist equipment for installing the piles and the ground anchors; and (iii) permanent ground anchors would require long term maintenance.

3.2 Rockfill Buttress

This remediation option involves removal of all failed materials and constructing a rockfill buttress with a side slope of 1(V): 1.5(H).

Advantages; (i) construction of the rockfill buttress is less weather dependent compared to general earthwork; and (ii) construction requires only general earthwork equipment.

Disadvantages; (i) a large quantity of failed materials needs to be transported out for disposal and a large volume of rock needs to be imported for constructing the rockfill buttress; (ii) temporary works are required for stabilising the excavated slope and dewatering during removal of failed materials; (iii) part of the slope of the rockfill buttress is located beyond the right-of-way and therefore land resumption is required; and (iv) the estimated construction cost is the highest.

3.3 Reinforced Fill Slope backfilled with Lime Treated Local Soils

This remediation option involves removal and re-use of all colluvial soils in a reinforced fill slope formed at a relatively forgiving 50 degree from the horizontal. It was assumed that these local soils would need to be treated with lime prior to being re-used as backfill materials.

Advantages; (i) minimum movement of materials to and from the site; (ii) the estimated construction cost is the lowest; and (iii) construction is less weather dependent with limed material.

Disadvantages; (i) temporary works are required for stabilising the excavated slope and dewatering during removal of the failed materials; (ii) stringent quality control during construction; (iii) an elaborate subsurface drainage system is required; (iv) approval to use non standard "quality" material; (v) availability of lime and (vi) technical viability has to be established by laboratory testing.

3.4 Reinforced Fill Slope backfilled with Imported Granular Materials

This remediation option involves removal of all failed materials and constructing a reinforced fill slope with its front face inclined to a more economical 60 to 70 degree from the horizontal. Granular materials for backfilling need to be imported from a quarry located about 15 km from the site.

Advantages; (i) less weather dependent compared to backfilling with lime treated local soils; (ii) a subsurface drainage system is not required.

Disadvantages; (i) large quantities of failed material needs to be transported out for disposal and large volume of granular material needs to be imported for backfilling; (ii) temporary works are required for stabilising the excavated slope and dewatering during removal of failed materials.

3.5 Earthfill Embankment with a Rock Toe

This remediation option involves removal of all failed materials and constructing a rock toe and an earth fill embankment. It was intended to use site won colluvial soils for constructing the embankment.

Advantages; (i) less importing of material compared to the options in Subsections 3.2 and 3.4.

Disadvantages; (i) construction is weather dependent; (ii) temporary works are required for stabilising the excavated slope and dewatering during removal of the failed materials; and (iii) an elaborate subsurface drainage system is required.

4 COST COMPARISON

The approach used to evaluate the remediation options is to compare their total internalised costs. This approach quantifies the environmental impacts in monetary term which is added to the construction cost to obtain the total internalised cost. The environmental cost comprises the greenhouse gas emissions cost and the pavement repair cost which were estimated separately.

4.1 Construction Costs

The construction costs were estimated from the conceptual design of the remediation options and the rates from Rawlinson (2011). The estimated construction costs for the options are given in Table 1.

Table 1: Estimated comparative construction costs of the remediation options

Option	Description	Construction Cost Estimate (AUD)
1	Cast-in-place pile wall restrained with ground anchors	$3,300,000
2	Rockfill Buttress	$3,800,000
3	Reinforced Fill Slope backfilled with Lime Treated Local Soils	$2,400,000
4	Reinforced Fill Slope backfilled with Imported Granular Materials	$2,000,000
5	Earthfill Embankment with a Rock Toe	$3,200,000

Note: The estimated construction costs exclude common cost items such as pavement, road furniture, surface drainage system, project management, etc. and are based on concept design only with Rawlinson's (2011) rates. Actual tendered rates for the preferred option with detailed design did vary.

The remediation options with the lowest estimated construction costs were Options 3 and 4 which were estimated to be $2.4 million and $2 million respectively.

Having submitted these options to the client, there was much discussion on the effects on the local residents, existing pavement damage, constructability, etc. Yet much of this discussion was qualitative and not quantified. An attempt was therefore made to quantify these, as well as environmental costs which are not direct cost to the project, but has a wider community "cost".

4.2 Environmental Cost

4.2.1 Greenhouse Gas Emissions Costs

Embodied energy of a material is the sum total of all the energy required to produce that material. Chau et al. (2006) compare the embodied energy for retaining walls. Similarly, Misra and Basu (2011) use a sustainability index comparison to show driven piles are more sustainable than drilled shafts for the loads and cases considered. The impact of process associated emissions has been studied previously.

Greenhouse gas (GHG) calculations included emissions from diesel fuel consumption and embodied emissions associated with transportation of materials, construction material use and construction methodology. The emission factors for diesel fuel and embodied emissions are defined in Table 2.

Table 2: GHG emission factors for diesel fuel and construction materials

Material	GHG Emission Factors (t CO_2-e/t)	Reference	Comments
Diesel	2.95 kg CO_2-e/L	DCC NGA Factors Nov 2008	Includes scope 3 (production) emission
Asphalt	0.01	Vic Roads Sustainability Tool v1	5% bitumen content
Road base/Rock fill (crushed rock)	0.008	Vic Roads Sustainability Tool v1	
Concrete	0.258	Vic Roads Sustainability Tool v1	Conventional cement
Steel	2.65	Vic Roads Sustainability Tool v1	
Plastic	2.32	Vic Roads Sustainability Tool v1	Adopt value for PVC

Table 3: Estimated Costs associated with GHG emissions ($ values rounded to nearest 1000)

Option	Description	Total GHG Emission (t CO_2-e)	GHG Emission Cost (AUD)
1	Cast-in-place pile wall restrained with ground anchors	2477	$57,000
2	Rockfill Buttress	781	$18,000
3	Reinforced Fill Slope backfilled with Lime Treated Local Soils	323	$8,000
4	Reinforced Fill Slope backfilled with Imported Granular Materials	521	$12,000
5	Earthfill Embankment with a Rock Toe	580	$14,000

GHG emission costs were calculated based upon a carbon price of $23 per t CO_2-e, as defined within the Climate Change Plan (Commonwealth of Australia, 2011).

The costs associated with GHG emissions for each option are presented as Table 3 and show similar results with the exception of Option 1 which has considerably higher cost. Option 3 has the lowest GHG emissions cost.

4.2.2 Pavement Repair Cost for External Roads

Execution of the remediation options requires movement of materials to and from the site. Materials that are produced during the construction process which cannot be incorporated into the permanent works will need to be transported out for disposal while some of the construction materials will require to be imported from external sources. Each option requires transportation of different quantities and types of materials to and from the site. This increase in movement of HGV on the external roads will accelerate the rate of degradation of their pavement structures. The additional pavement repair cost for the external roads due to this increase in HGV movement was estimated for each remediation option and are shown in Table 4 below. This is based on the anticipated quantities of materials to be transported and the number of HGV movements between the site and the external material sources.

Table 4: Estimated pavement repair cost for external road due to increase in HGV movements (values are rounded to nearest 1000)

Option	Description	Volume of Material (m^3)	HGV Movements (both ways)	Proportionate Pavement Repair Cost (AUD)
1	Cast-in-place pile wall restrained with ground anchors	812	162	$10,000
2	Rockfill buttress	42,597	8,519	$610,000
3	Reinforced Fill slope backfilled with lime treated local soils	18,597	3,719	$270,000
4	Reinforced Fill slope backfilled with imported Granular materials	30,447	6,089	$440,000
5	Earthfill embankment with a rock toe	29,597	5,919	$430,000

In contrast to GHG emissions, Option 1 requires the least movement of HGV on external roads and therefore has the lowest estimated pavement repair cost. Option 2, 4 and 5 incur an estimated pavement repair cost of greater than $400,000. This is principally due to the requirement to import a large quantity of material to the site.

Approximately 60% of materials required for Option 3 are obtained on site and as a result, require significantly less movements of HGV. The anticipated pavement repair cost for the local roads (external to the project site) is about $270,000 as these roads were not designed for heavy truck loading. This excludes the inconvenience time for the repair and upgrading of these local roads.

4.3 Total Internalised Cost

The total internalised cost of a remediation option is obtained by summing all the direct and indirect costs. This allows a comparison to be made not solely on the direct cost (related to construction) but also other indirect costs (related on environmental impacts, inconvenience to the community etc.). A summary of the total internalised costs for the five remediation options is shown in Table 5.

Construction costs greatly influenced the outcome of the total internalised cost across all remediation options. Construction costs generally accounted for 89% of the total internalised costs.

Despite having relatively minor emission and pavement repair costs, Option 1 has the second highest total internalised cost due to its high construction cost which contributes about 98% to its total internalised cost. Option 2 has the highest total internalised cost as both its construction cost and environmental cost are the highest amongst the five remediation options.

Options 3 and 4 have the lowest total internalised costs amongst the five options. Both have relatively low construction costs and generated fewer GHG emissions when compared with other options. As the total internalised costs of these two options are comparable, these were the two options shortlisted for further consideration. Option 3 was eventually chosen as the preferred solution to advance to detail design, as the authority required the least movement of HGV during execution of the remediation work. Technical feasibility was also confirmed by liming tests including both standard size and large size shear box testing

Table 5: Total internalised cost (values are rounded to nearest 1000) – see Table 1 notes

Option	Description	Construction Cost Estimate (AUD)	Total Environmental Cost Estimate (AUD)	Total Internalised Cost Estimate (AUD)
1	Cast-in-place pile wall restrained with ground anchors	$3,300,000	$67,000	$3,367,000
2	Rockfill buttress	$3,800,000	$628,000	$4,428,000
3	Reinforced Fill slope backfilled with lime treated local soils	$2,400,000	$278,000	$2,678,000
4	Reinforced Fill slope backfilled with imported granular materials	$2,000,000	$452,000	$2,452,000
5	Earthfill Embankment with a rock toe	$3,200,000	$444,000	$3,644,000

5 CONCLUSION

An environmental approach was used to evaluate the remediation options for a large landslide. Besides the direct cost (related to construction), the costs of environmental impacts (indirect costs) were quantified so that a consistent comparison can be made of the total internalised costs of the remediation options. This approach requires the environmental costs to be assessed and quantified whereas the traditional approach only judges the environmental impacts subjectively with quantification of direct construction costs only. At this site the environmental costs represented 2% to 23% of the construction costs for the various options.

This case study highlights that the use of traditional high quality imported materials has a significantly higher environmental costs which may not form part of the project but affects the wider community. While this site showed a significant environmental cost, at other smaller landslide sites the environmental cost associated with remediation were not as significant. This approach is of most use where tangible environmental impacts are apparent but need to be quantified and compared against other technically viable alternatives.

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