Landslip Remediation for Hilly Road Infrastructure Using a Simple Engineering Solution

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ABSTRACT: The extreme prolonged rainfall and subsequent excessive flooding in late 2010 and early 2011 in Queensland, Australia created numerous landslides in all over the Queensland regions which heavily affected the normal life of public. Considering the safety of road users, both short and long term remediation works were implemented to reduce the potential risks and hazards to an acceptable level and minimise disruptions to public. Risk assessments were also undertaken at every site to evaluate the risk and hazards and risk levels. Taking into account the estimated risk levels, feasible engineering solutions based on both full stabilisation and preventative methods were developed to remediate each landslide site as part of option analysis. Instead of implementing full landslide stabilisation, Shear Key solution, a simple cost effective preventative earthworks solution, has been successfully utilised to remediate one of the sites affected by the landslide considering various aspects including road safety, cost, environmental impacts and public disruptions.

1 INTRODUCTION

Landslide, a type of natural disaster, occurs on a frequent basis all over the world due to various reasons including extreme rainfall and storms. The landslides take a tremendous human and other life and economic toll and enormous disturbances to people in and around the area affected by the landslide.

Queensland was hit by a series of natural disasters the like of which had not been seen for almost 100 years in late 2010 and early 2011. Extreme rainfall, storms and subsequent excessive flooding created many landslides that caused widespread damages across the Queensland and forced the closure of numerous roads and rail networks. Communities were devastated by this event as flooding cut transport lines, with roads blocked or severely damaged. Massive task to reconstruct roads and thereby reconnect the communities were undertaken under the emergency and reconstruction program for more than 3 years.

This paper provides detail regarding one of the affected sites by this natural disaster event. A simple, but appropriate engineering solution was used for the remediation works considering all aspects including safety, cost for remediation, environmental impacts and public disruptions.

2 BACKGROUND INFORMATION

The landslide (as shown in Fig. 1) at the site discussed in this paper was firstly occurred by the natural disaster event in 2011 and road was closed for public considering the safety of road users as the inspection indicated road subsidence, longitudinal cracks and lateral movement. Subsequently short term remediation works were undertaken during the emergent period immediately after the natural disaster event in order to minimise the risk to road users and public and keep the road opened. This short-term remediation works undertaken comprised constructing a 2m high gabion retaining wall near the shoulder of the road.

The heavy rain event in 2013 re-activated the landslip due to the failure of undertaking long-term remediation works. An approximate 35 m long section of this road has been affected by this landslip during the 2013 rain event.

Slope risk assessment based on the New South Wales Road and Maritime Services (RMS) guidelines was carried out to assess the risk and hazards and identify the potential failure mechanisms. Two potential failure mechanisms identified; rotational slip surface failure and existing culvert failure. It was also observed that some gabions constructed during the emergent period were slightly tilting and settling in. This may indicate that the gabions could have been placed on incompetent foundation materials and/or possibly above the existing rotational landslide failure plane. Tension cracks identified along the road (near the centreline of the road as shown in Fig. 2) indicated the starting location of the slip surface on the road embankment surface. Although this was considered as initiation of failure, prolonged delays in dealing with this failure could lead to a catastrophic failure (i.e., formation of deep failure and thus complete road closure) as historically indicated in the past.

Fig. 1 Site failure by 2010-2011rain event

Fig. 2 Landslide re-activated by 2013 rain event

Based on the site inspection and slope risk assessment, the large rotational slip failure mechanism was assessed as medium risk to road embankment infrastructure instability. However, subsequent detailed assessment based on ground conditions revealed higher risk potential for rotational slip failure in future. The rotational failure might continue during the forthcoming wet seasons and lead to a complete failure unless remediation works are completed on time.

3 GROUND MODEL AND DESIGN PARAMETERS

3.1 *Ground Model*

Geotechnical investigations were performed in accordance with Australian Standards (AS1726) to determine ground conditions and develop ground model for the design and analysis. The geotechnical investigation involved fieldworks which comprised the drilling of two boreholes with Standard Penetration Testing (SPT) at regular intervals and ten Dynamic Cone Penetration (DCP) testing across the site. Laboratory testing on the soil and rock samples recovered during drilling the boreholes was also performed to aid with the geotechnical design parameter determination.

Interpreting the geotechnical investigation, a geotechnical (ground) model was developed for the design. The geotechnical model adopted in the design is shown in Fig. 3.

3.2 *Design Parameters*

Geotechnical design parameters were derived based on the results of the geotechnical investigation, relevant references and authors' previous experience on similar ground conditions. The geotechnical design parameters adopted for the design are summarised in Table 1.

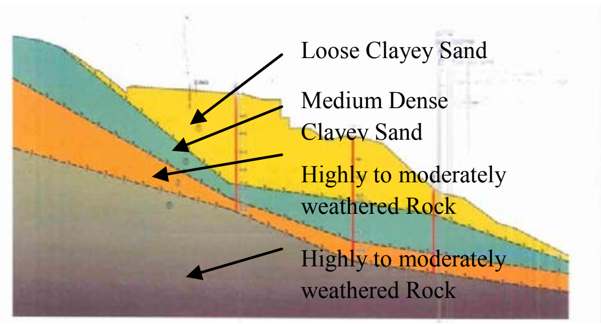

Fig. 3 Ground Model

Table 1. Geotechnical Design Parameters

Material Description	γ (kN/m3)	c' (kPa)	φ' (°)
Loose clayey sand	18	3	27
Medium dense clayey sand	20	3	32
Extremely to highly weathered rock	21	30	30
Highly to moderately weathered rock	24	60	35
Rock Fill	19	0	40

<u>Note:</u> γ - Unit weight, c'- Effective cohesion, φ'- Effective friction angle, Bedrock type is interbedded mudstone, sandstone and conglomerate.

4 CONCEPT DESIGN

As part of the concept design, design option analyses were carried to evaluate the design option alternatives and present the relative merits of each option considered on the basis relative cost, technical robustness, and constructability. Five different design option alternatives were considered during the concept design stage (Table 2). The above design option alternatives proposed in the concept design stage comprised both complete remediation and preventative solutions.

The aim of the complete remediation solution was to enhance road embankment stability to meet standard minimum design requirements and minimise the maintenance needs in the future. Whilst the preventative solution was aimed to prevent any further instability of the road infrastructure and thereby ensure safety of road embankment.

Table 3 provides comparisons of the aspects considered to compare each design alternatives during option analysis phase.

Table 2. Design Options considered

Design Option	Description
A	Remove the failed materials and replace them with granular/rock fill material
B	Install sheetpile wall to enhance upslope stability and prevent any further movement
C	Utilise micropile to enhance slope stability and thus embankment performance
D	Use shear key to enhance slope stability, increase drainage conditions and embankment performance
E	Use light weight fill to enhance slope stability by reducing active loads for slope instability

Table 3. Aspects considered in the design options analyses

Aspects considered	Maximum Score	Design Options considered (as per Table 2)				
		A	B	C	D	E
1. Performance	30	30	15	15	25	5
2. Cost	20	5	15	10	20	15
3. Traffic impact	20	5	5	10	20	10
4. Environmental	10	5	10	10	5	5
5. Construction issue	10	5	10	10	5	5
6. Future Maintenance	10	10	10	10	5	10
Total	**100**	**60**	**65**	**65**	**80**	**60**

Notes:

1. Acceptable embankment stability over 100 years design life (including potential downslope stability and drainage improvements).
2. Remediation cost including land resumption.
3. Public disruptions during construction including likely road closure.
4. Environment impacts including removal vegetation due to the proposed remediation measure.
5. Issues during construction (including removal and disposal of materials).
6. Future maintenance requirements.

As noted in Table 3 above, remediation by the preventive methods was found to be cost effective and aimed to enhance road embankment instability with very minimal disturbances to public. It should be noted that the preventative methods would not control potential of cracks development at the middle of the road as the failed materials wouldn't be removed by these methods. Therefore maintenance by relevant authority on a regular basis (particularly after a heavy rain event) may be required to seal the crack (if any) and keep the road operational all times.

Based on a discussion with the relevant authority (client), the preferred remediation design was 'Shear key solution' as this was simple and would provide huge economic and social benefits without compromising the safety of road embankment and thereby road users and public.

5 ANALYSIS AND RESULTS

The adopted cost effective and simple shear key solution comprised a shear key using rockfill at the downslope. Temporary soil nails were used to support the excavations during construction stage. Horizontal drains were also installed to dissipate water from the road embankment. The shear key was designed with minimum 1.0m embedment depth into competent soil and/or weathered rock.

Stability of the road embankment in short term (during construction) and longterm (during operation) was assessed during the detailed design as discussed in the following sections.

5.1 *Slope stability*

Slope stability analysis has been undertaken on a critical section of the affected road embankment. The slope stability computer program SlopeW with Morgenstern and Price method was used to assess the stability of the slope in each construction stage. The ground water level was assumed at 2 m below ground surface.

The results of the slope stability analyses are given in Table 4 and the graphical representation for the long terms condition is given in Fig. 4.

Table 4. Results of Slope Stability Analysis

Stages	Factor of Safety
Short Term - during excavation (with the use of temporary soil nail support)	1.1 to 1.35
Long Term (with no nails)	1.45
Long Term (with nails)	1.7

The factors of safety (FoS) calculated for the long term condition with no temporary soil nails is 1.45. The above results show that the calculated

FoS is slightly below the minimum design criteria (i.e. FoS = 1.5). However, such a FOS value was considered acceptable to protect the road embankment slope from any further (future) instability. In addition, it should be noted that the presence of temporary soils nails installed and left behind the shear key mass improve the overall factor of safety to 1.7.

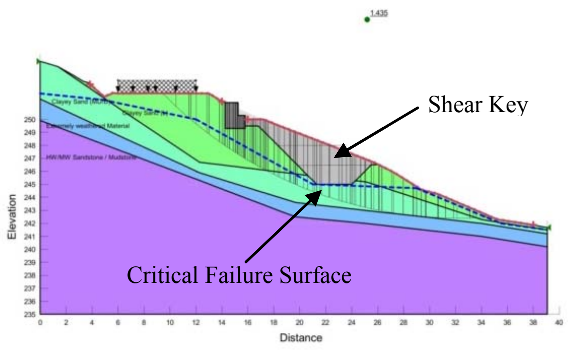

Fig. 4 Slope stability analysis results (without soil nails)

5.2 *Plaxis Modelling*

Finite element analysis using Plaxis 2D has also been undertaken to complement the results of slope stability analysis and assess the performance of road embankment with shear key.

The results of the analysis indicate that the performance of shear key option is considered sound and appropriate. The predicted deformation is relatively low (less than 6mm) at long term worst case scenario (flooded condition) as shown in Fig 5. The calculated Factors of Safety (FoS) obtained from the Plaxis safety analysis are 1.6 and 1.3 at normal and flooded conditions respectively.

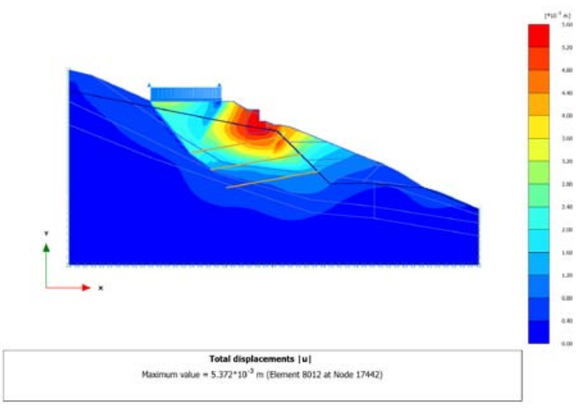

Fig. 5 Total displacement contours at flooded condition (Plaxis Modelling)

6 CONCLUSIONS AND RECOMMENDATIONS

Based on the successful completion of the project, the following conclusions and recommendations are drawn:

- Landslip remediation of the road embankment has been completed using a simple shear key solution
- Capital cost to remediate the landslide has been significantly reduced through adopting appropriate solution and effective planning in comparison to undertaking full scale landslide stabilisation or remediation measures.
- Disturbances to public and road users have been kept very minimal during construction and the construction was completed on time
- Preventative methods with maintenance should be utilised for landslide remediation wherever possible and when the cost of maintenance is found to be cost effective and easy
- Undertaking remediation will be very useful and will have potential saving prior to a complete failure by a landslide

REFERENCES

Australian Standards AS1726 – Geotechnical Investigations
NSW Slope Risk Assessment Guidelines Version 4.1
Plaxis Finite Element Program Version 2012
Stability Modelling with SLOPE/W Version 2012
Transport Network Reconstruction Program Design Guidelines Version 2 (May 2013), Department of Transport and Main Roads, Queensland.