Embankment slope stability issues at iron ore handling projects in Western Australia

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ABSTRACT

Embankment slope stability has been a key issue relating to new iron ore handling projects in Western Australia, the largest iron ore producing state of Australia. This paper describes rigorous embankment slope analyses carried out for a rail bridge embankment, conveyor bridge abutments, conveyor embankments, and a reclaimer berm for two major iron ore handling plant projects in the Pilbara region of Western Australia. The embankment materials used in these projects comprise locally available, controlled, select fill. Cement stabilised fill was recommended for embankments near rail bridge abutments. Methods of investigation and design of select fill are briefly presented. Slope stability analyses were carried out for bridge abutments & embankments under normal, earthquake, flood and rapid draw down conditions using the SlopeW software program. Analyses included large vertical and horizontal forces acting on the embankments. A comparison between the Bishop and Morgenstern-Price methods of analyses are presented in the paper. In general, the rapid draw down condition was assessed as being the most critical case followed by earthquake and normal conditions. Morgenstern-Price analysis method resulted in higher factors of safety than Bishop method.

1 BACKGROUND

Australia is the world's largest iron ore exporter and as a producer, ranks third after China and Brazil (DoIR 2003). In 2005, Australia produced over 258 million tonnes for the domestic and export markets. Although iron ore resources occur in all the Australian States and Territories, almost 90% of identified resources (totalling 31.5 billion tonnes) occur in Western Australia, including about 80% in the Hamersley province, one of the world's major iron ore provinces. The ores from major mines in Western Australia's Hamersley Province of Pilbara region are hauled from working faces to crushing and screening plants using trucks that can carry over 200 tonnes. The ore is then transported for further treatment and blending to port sites.

The Rio Tinto's Yandicoogina (Yandi) mine expansion project and Hope Downs project in the Hamersley region are currently underway. Both developments include the construction of processing, stockpiling and reclaiming facilities at the mine sites. Major facilities include primary crusher, screening facilities, secondary crusher, and stockpile area comprising stacker and reclaimer berms and rail load out facilities. Bridge abutments for railway and conveyors, embankments for conveyors, stacker and reclaimer berms are subject to large static and dynamic loadings. The stability of the slopes for these earth structures is of paramount importance to ensure a safe and cost effective mining operation. This paper presents global slope stability analyses carried out for railway bridge abutments, conveyor bridge abutments and embankments in the Yandi mine, and a reclaimer embankment in the Hope Downs project.

2 SUBSURAFCE CONDITION

Geotechnical investigations for the infrastructure development mainly comprise excavation of test pits, drilling of bore holes, and collection of samples for subsequent laboratory examination and testing. The subsurface conditions for each infrastructure area are discussed below.

2.1 Railway bridge abutment (Yandi)

The new bridge is a duplication of the existing rail loop bridge. The new bridge is of similar design to the existing bridge comprising of a steel framed structure supported on pier and abutment footings. The new bridge is located on the western side of the existing bridge. Footing systems will comprise conventional shallow footings. Photograph of the bridge location is shown in Figure 1.

Figure 1: Photographs of the bridge duplication location

The site has a generalised subsurface profile comprising 1.3-3.7m thick gravelly silty sand/silty sandy gravel layer over conglomerate.

2.2 Conveyor embankment /bridge abutment (Yandi)

The conveyor embankment and bridge abutment locations are underlain by silty gravel up to 10m thick overlying banded iron formation (BIF).

2.3 Reclaimer berm site (Hope Downs)

The subsurface conditions at the proposed reclaimer and stacker sites can be generalised as 7m-10.5m thick sandy clayey gravel layer overlying silicified siltstone.

3 ANALYSIS AND RESULTS

The computer package GeoStudio 2004 version 6.16 (SLOPEW) was used to assess global stability of the proposed slopes under the design loads provided by the project structural/civil engineers. Slip surfaces were analysed using the Morgenstern-Price and Bishop's methods of analyses. In general, the results from Morgenstern-Price method resulted in slightly higher factors of safety (FOS) than Bishop method of analysis.

3.1 Railway bridge abutment location (Yandi)

The evaluation of the design loads and material strengths was undertaken in accordance with the Australian Standard for Bridge Design, AS5100 2004. Factor of safety was verified using Limit State method. A surcharge of 100 kPa (including dynamic load allowance and load factor as per AS5100.2 2004) was applied on the surface at the back of the abutment. The engineering parameters selected for stability analyses of the rail bridge embankment is shown in Figure 2.

Based on AS1170.4-1993, AS5100.2-2004 and Research by Gaull et al (1987), factored horizontal ground acceleration due to earthquake loading of 0.06g was considered applicable for seismic events. This included a reduction factor of 0.5 to allow for inertia effects.

The embankment and foundation cross sections modelled for the stability analyses were derived from the general arrangement drawing provided by the project structural/civil engineer and from the results of subsurface investigations at the bridge site. Results of the rail bridge embankment stability analyses for normal conditions and during a seismic event are summarised in Table 1.

Table 1: Factors of safety against global slip failure

Load Case	Bishop Method(FOS)	Morgenstern-Price(FOS)
Normal Case	2.3	2.6
Seismic Event	2.1	2.3

Typical output of the slope stability analysis for normal case is presented in Figure 2.

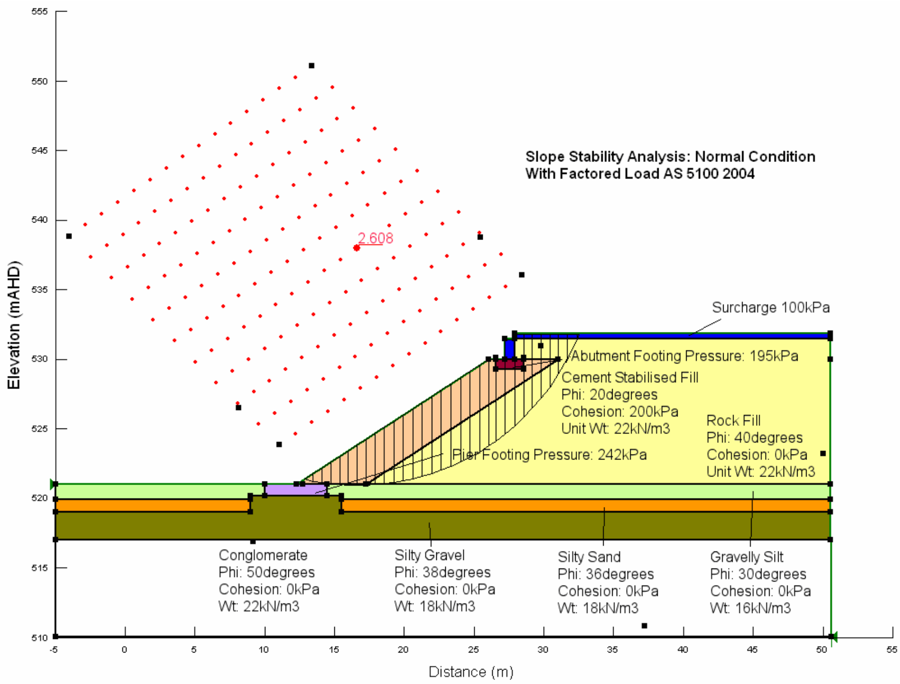


Figure 2: Typical slope stability analysis for normal case Railway Bridge Abutment (Yandi)

3.2 Conveyor embankment /bridge abutment (Yandi)

The conveyor embankment and bridge abutments comprise of select fill and lateritic (ironstone) rip rap over in situ silty gravel. Figure 3 shows the conveyor embankment and bridge abutment cross sections. The geotechnical parameters adopted for slope stability analysis are presented in Figure 3.

The following minimum factors of safety (FOS) were considered appropriate when assessing the potential for global slip failure of abutment and embankments:

Case 1 Normal Condition (frequent event): Minimum FOS of 1.5;
Case 2 Flood Event (infrequent event): Minimum factor of safety of 1.35;
Case 3 Rapid Drawdown (infrequent event): Minimum factor of safety of 1.35;
Case 4 Earthquake Loading (rare event): Minimum factor of safety of 1.2.

Water pressures behind and in front of the abutment/embankment face were assumed to be as follows:

Case 1 (Normal): water level at 510.4mAHD upstream and 511.4mAHD within the select fill;

Case 2 (Flood): water level at 513.9mAHD upstream, and 514.9mAHD within the select fill;

Case 3 (Rapid Drawdown): water level at 510.4mAHD upstream, and 512.2mAHD within the select fill;

Case 4 (Earthquake): water level 510.4mAHD upstream, and 511.4mAHD within the select fill.

Based on AS1170.4-1993, horizontal ground acceleration due to earthquake loading of 0.1g was considered applicable for load case 4. No reduction was applied to the acceleration coefficient for inertia effects within soil and rock. A nominal live load of 10kPa (road and conveyor) is considered for the trafficked area near conveyor tracks. A line load of 20kN/m is considered as the conveyor loading.

3.2.1 Bridge abutments

A summary of the results of slope stability analysis is presented in Table 2. Typical output of the slope stability analysis for normal event is presented in Figure 3 (b).

Table 2: Factors of safety against abutment global slip failure

Load Case	Design Minimum FOS	Calculated FOS
Case 1 (Normal)	1.5	1.60
Case 2 (Flood)	1.35	1.86
Case 3 (Rapid Drawdown)	1.35	1.52
Case 4 (Earthquake)	1.2	1.26

Based on the results presented in Table 2, the factors of safety exceed the minimum design requirements for all 4 cases. As such, the abutment arrangement provided an adequate FOS against global failure.

3.2.2 Conveyor embankment

Analyses were undertaken for the following four cases.

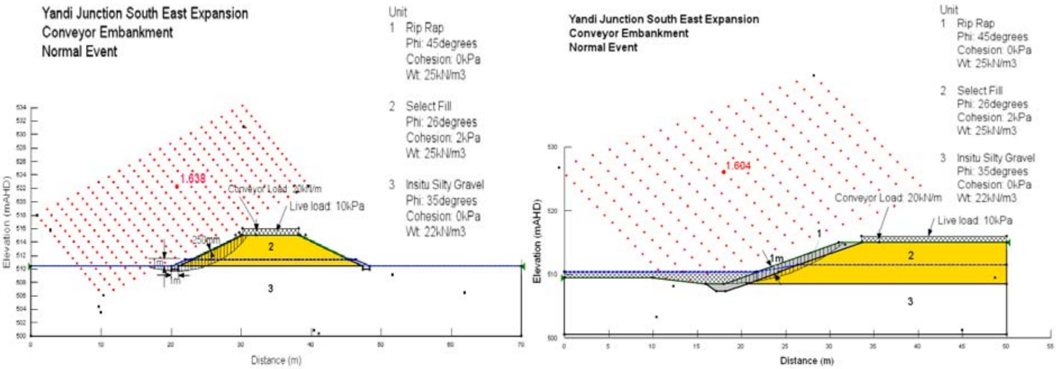
Arrangement A: Conveyor embankment arrangement without any erosion protection
Arrangement B: Conveyor embankment arrangement with 1m thick riprap erosion protection but without toe protection
Arrangement C: Conveyor embankment arrangement with 1m thick riprap erosion protection and toe protection
Arrangement D: Conveyor embankment arrangement with 0.25m thick riprap erosion protection and 1m thick toe protection.

The results of the analyses are presented in Table 3. Typical output of the slope stability analysis for normal event for Arrangement D is presented in Figure 3 (a).

Table 3: FOS against embankment global slip failure

Load Case	Design Minimum FOS	Calculated FOS
Arrangement A		
Case 1 (Normal)	1.5	1.35
Arrangement B		
Case 1 (Normal)	1.5	1.29
Arrangement C		
Case 1 (Normal)	1.5	1.63
Case 2 (Flood)	1.35	1.64
Case 3 (Rapid Drawdown)	1.35	1.41
Case 4 (Earthquake)	1.2	1.31
Arrangement D		
Case 1 (Normal)	1.5	1.60
Case 2 (Flood)	1.35	1.86
Case 3 (Rapid Drawdown)	1.35	1.52
Case 4 (Earthquake)	1.2	1.26

Based on the results of the analyses, it appears that the FOS against global slope failure for conveyor embankments without erosion protection arrangement (Arrangement A) or erosion protection arrangement without toe protection arrangement (Arrangement B) was not adequate. The conveyor embankment arrangement with riprap erosion protection and toe protection arrangements (C and D) appear to provide adequate FOS against global slope failure. The thickness of the rip rap layer might be reduced to nominally 0.25m at 1m above the base of embankment to provide erosion protection during ultimate flood event.



(a) Conveyor embankment (b) Bridge abutment

Figure 3: Typical slope stability analyses for normal case

3.3 Reclaimer berm site (Hope Downs)

The reclaimer berm is about 4m high and 22m wide at the crest. The following embankment profile as illustrated in Figure 4 was considered in the slope stability analysis.

- A select rock fill layer is to be placed on one side of the embankment so that a stable slope batter of 1V : 1.2H, and hence a 5.65m wide space between the reclaimer machine rail track and the slope crest for crane and light vehicle access, can be achieved. The 4m thick rock fill layer is the recommended thickness of the rock fill layer based on the results of the stability analysis.
- The rest of the berm will comprise of select clayey gravel structural fill.
- On the other side of the embankment a slope batter of 1V:2.5H was analysed as required.

For the analysis of embankment stability using computer software SLOPEW, the geotechnical parameters used are presented in Figure 4. The tracks for the reclaimer machine are located about 5.65m from the embankment crest at the rock fill side of the embankment and at the other side, 2.5m from the embankment crest. As provided by the project structural engineer, the reclaimer machine line loadings of 375kN per metre (vertical) and 52kN per metre (horizontal) were considered in the analysis. At the rock fill side of the embankment a live load of 10kPa (for crane and other light vehicle loadings) between the reclaimer machine track and embankment crest was also considered in the analysis. For the analysis of embankment stability, 2 embankment conditions were considered, which are as follows:

- Normal loading condition; and
- Earthquake event. An acceleration coefficient (a) of 0.1 was adopted, based on Figure 2.3(d) of AS1170.4-1993, which is equivalent to an earthquake event annual exceedance probability of about 1:500 years.

Engineering design for embankment structures require minimum global stability Factors of Safety of 1.5 for normal condition and 1.2 for the earthquake event. A typical result of stability analysis for the reclaimer berm at the rock fill side of the berm for normal case is presented in Figure 4. The calculated FOS for the slip circle just underneath the reclaimer machine foundation was higher than the desired factor of safety. Due to restriction in the size of this paper the results of the analyses are not discussed in detail.

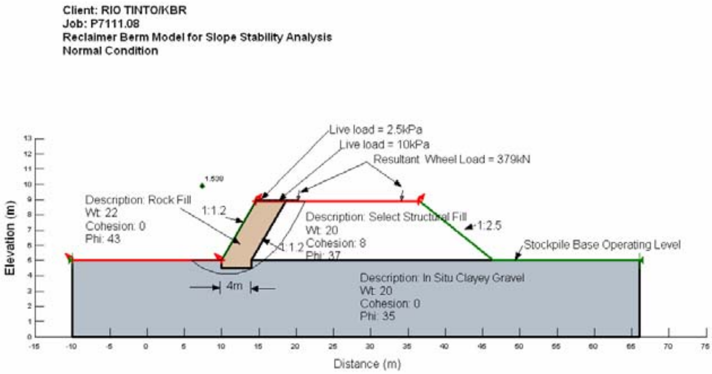


Figure 4: Typical slope stability analyses for normal case Reclaimer Berm (Hope Downs)

The results of stability analysis for the other side of the reclaimer berm (comprising of select structural fill at a slope batter of 1V: 2.5H) are:

- Minimum FOS of 1.49 under normal condition, and;
- Minimum FOS of 1.44 under earthquake loading condition, which are both considered adequate.

4 SUMMARY AND CONCLUSIONS

The results of global stability analysis undertaken for rail bridge abutments and conveyor bridge embankment and abutments for the Yandi mine, and reclaimer and stacker berms for the Hope Downs project of Rio Tinto in the Hamersley region of Western Australia, are presented. The embankment materials used are locally available, controlled select fill. A number stability conditions were analysed such normal condition, earthquake event, flood event, and rapid drawdown. In general, rapid drawdown condition appeared to be the most critical case, followed by earthquake and normal conditions. Flood condition appeared to be most stable case. For the Yandi railway bridge abutment, the Morgenstern-Price analysis method resulted in higher factors of safety than Bishop method.

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