Blasting-induced rock slope instability in Senai, Johor – a preliminary post-construction assessment

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Abstract: A new railway line was constructed recently in the state of Johor, Malaysia to link the Senai Airport and the newly built Tanjung Pelepas Port. Its alignment transverses some hilly terrain and thus resulted in the formation of a number of major cut slopes. One of them is a 35m high slope near Senai, Johor, which is cut in bedrock of the Late Cretaceous-Early Tertiary Pulai Granite. A preliminary post-construction geological assessments carried out on the rock slope indicate that most of the unstable elements are mainly due to excessive and poor blasting practice. Overblasting has resulted in widening of major joints, excessive overbreaks, unstable and loose overhanging blocks. Results of kinematic stability analysis on the discontinuities indicate that the rock slope has the potential to undergo planar, wedge and toppling failures. Rock falls could also take place by over toppling. Excessive overbreaks and fragmentation of the rock mass could be minimised if a proper geological appraisal on the bedrock was carried out beforehand, and suitable blasting practice adopted during the excavation works. Based on the results of this study, it was recommended that remedial measures should be undertaken in two different phases. Phase 1 is to scale off all the loose, potentially unstable blocks. This should be followed by phase 2 if necessary, *i.e.* fixing of wire netting, rock fall protection system or rock dowels.

Keyword: blasting-induced instability; overblasting, discontinuity, remedial measures.

INTRODUCTION

A preliminary post-construction study of the rock cut near Senai, Johor was undertaken. The site is located along the newly constructed rail link from the existing main line between Senai and Kempas Baru to Port of Tanjung Pelepas. The surrounding site area is extensively cultivated with oil palm trees. The site specific details, especially the actual location are not included in this paper in view of contractual requirement.

SITE GEOLOGY AND GEOMORPHOLOGY

The study area is underlain by the Pulai Granite which is of Late Cretaceous to Early Tertiary age (Burton, 1973). The granite is largely grey in color and medium to coarse grained with porphyritic textures. Some of the granite is lighter in color due to the presence of more acidic minerals such as quartz, feldspar and plagioclase.

In the exposed rock cut, the weathering grade of the granite ranges from slightly weathered to fresh i.e. Grades II to I. The bedrock is overlain by soil derived from in-situ weathering of the bedrock. The soil mainly consists of silty SAND to sandy SILT and is reddish to yellowish brown in color. This soil material can be classified as residual soil to completely weathered rock i.e. Grades V to VI. The depth and thickness of soil and weathered material changes to fresh rock is extremely variable as can be seen in the slope exposures (Plate 1).

The rock cut is through a hill which was excavated to the current formation level. The top of the hill is gentle and cultivated with oil palm trees.

Plate 1: View of rock slope in study area

At the cut, erosion channels are found mainly at the boundary area between soil and rock. There erosion channels basically formed by surface run-off along weak zones such as cracks and joints as well as the soil and rock interface. Further development of these features may lead to water seeping through discontinuities in the rock slope. No sign of water seepage out of the discontinuities and slope face was, however, seen.

METHODS OF STUDY

A brief physiographic study of the area was first made to understand the existing drainage condition, vegetation and slope changes. The geological study of the exposed rock slope was made using the walk-over method where observations as well as discontinuity surveys were carried out. However, due to time constraints, no laboratory testing was carried out.

Discontinuities (joints, tension cracks and fault planes) were measured using a geological compass. Signs of newly-developed cracks that could contribute to potential failures or release planes or slope instability was also identified. The discontinuity data was analyzed using the Geo-orient program which is a stereographic plot technique to identify the number of discontinuity sets and their orientation.

The study area was divided into two slope sections namely Right Hand Side (RHS) and Left Hand Side (LHS), the left and right hand sides being named while facing toward increasing chainage i.e. toward Port of Tanjung Pelepas. Overall views of the RHS and LHS slope faces were shown in Plate 2 and 3 respectively.

rock slope; their orientations adversely affecting slope stability. Joints may occur in distinguishable sets of discontinuity or randomly oriented.

For better understanding of the inference of the discontinuities or the stability of rock slope, the discontinuity data were analysed separately i.e. LHS Slope and RHS Slope. For detailed assessments, the RHS slope was further divided into three different zones namely RHS Zone I, RHS Zone II and RHS Zone III.

The kinematic stability analysis of the rock slope was carried out based on Hoek & Bray (1981). Results of this study are summarized in Table 1.

RHS Zone I

There are seven discontinuity sets for this zone. However, three sets i.e. set J1 with dip and dip direction of 79/183, J2 (60/306) and J3 (68/044) can be considered major while others i.e. J4 (37/080), J5 (40/127), J6 (18/180) and J7 (19/237) are minor. Intersection of the discontinuity planes produced a potential for wedge failures, while the J2 and J6 planes will also act as the main release planes. The stereoplot presented in Figure 1.

Plate 2: Overall view of the right hand side cut rock slope
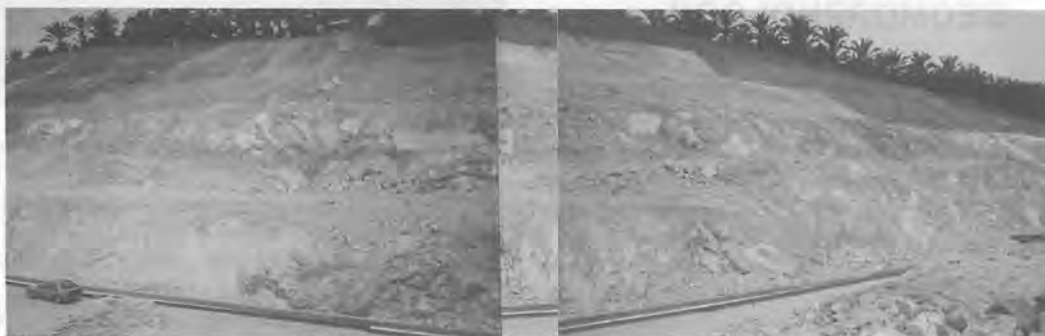

Plate 3: Overall view of the left hand side cut rock slope

RESULTS OF STUDY

Discontinuities in rock mass can be found in form of joints, faults, shear planes and tension or stress relief crack. Joints form the main discontinuity planes in the granite

RHS Zone II

There are six discontinuity sets in Zone II. Only 2 sets can be considered as major i.e. J1 (85/179) and J2 (67/336) while the minor discontinuity planes are J3 (54/312), J4 (15/227), J5 (52/110) and J6 (51/079).

Intersection of J5 and J6 plane can produce potential wedge failures while J5 plane itself can produce potential planar failure plane. The J4 plane has a potential to produce toppling failure plane and can also react as a release plane to the wedge failure plane intersected between J5 and J6. The stereoplot is presented in Figure 2.

(63/107), J4 (67/075) and J5 (70/059) while the minor sets are J6 (64/004) And J7 (26/327). Potential wedge failures can be produced by intersection of J1 and J3, J4, J5 or J6. The J2 and J3 planes can produce potential planar failure planes. The J7 plane can act as release plane for all potential wedge failure planes. Stereoplot is presented in Figure 3
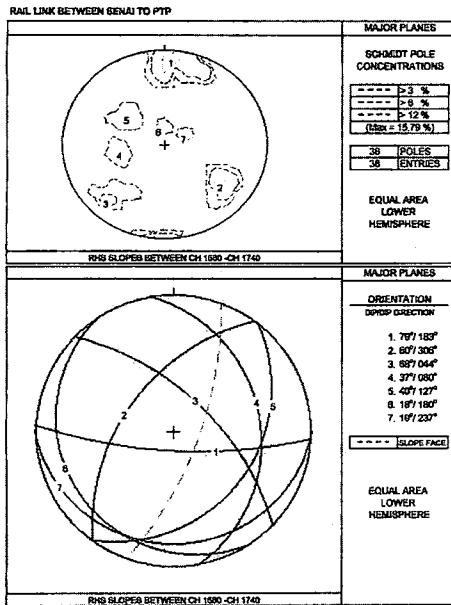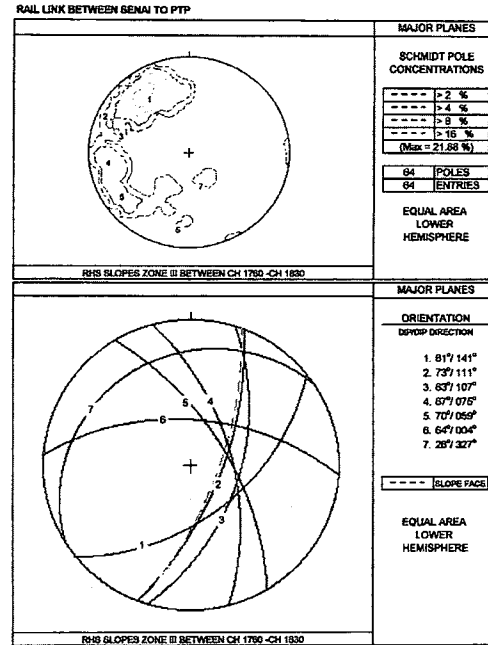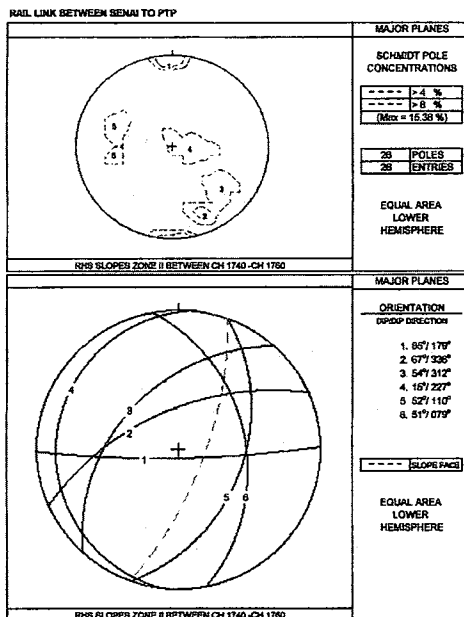

Figure 1: Stereoplot for RHS Zone I

Figure 3: Stereoplot for RHS Zone III

LHS Slope

This slope face has 8 discontinuity sets. All of the discontinuity sets can be considered as major sets based on their density, though, not all of them contribute to potential instability. Potential wedge failures can be produced by the intersection of J5 and J8, J4 and J8, J6 and J8, J1 and J6 and J1 and J5. J3 plane can produce potential planar failure plane while J7 can act as release plane for all potential wedge failure planes.

Figure 2: Stereoplot for RHS Zone II

RHS Zone III

The distribution of discontinuity sets mainly concentrated within 20meters of the slope face while another 50 meters the slope face is massive without many discontinuity sets. There are seven discontinuity sets in this zone. The major sets are J1 (61/141), J2 (73/111), J3
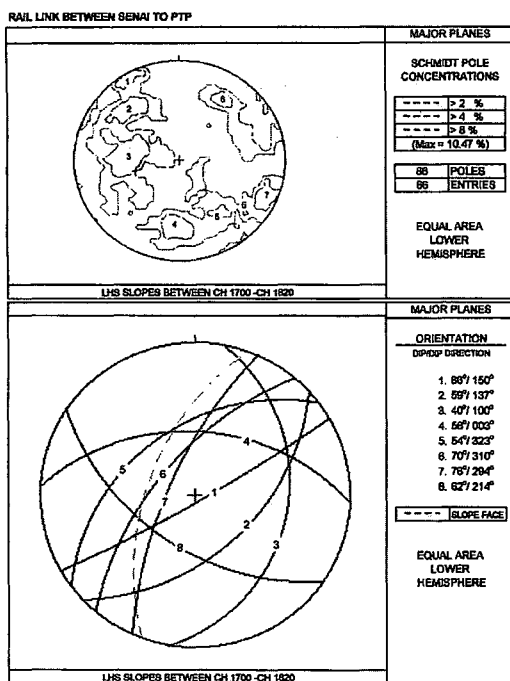
RAIL LINK BETWEEN SENAI TO PTP

Figure 4: Stereoplot for LHS Slope

POTENTIAL HAZARDS

There are some potentially unstable blocks or loose blocks that may have been left after blasting works and can also be seen resting on the berms as well as on the top of rock cut. Rock blocks varying in size up to 2.0m³ can be seen scattered at the toe of the slope.

The exposed discontinuities on cut rock slope can be weakened by weathering. Failure may take place by sliding when the resistance offered by the discontinuities is not sufficient to support the destabilizing component of force from the weight of the rock block. Rock falls could also take place by over toppling. In this case, the slabs or columns of rock, with height considerably greater than their thickness may overturn unfavourable condition.

Loose blocks situated or resting on the cut slope or overhanging on the cut slope in which may have been produced by poor blasting practice, can be remedied by scaling.

The space between the toe of slope and concrete drains for rock trap ditch is very narrow. However, should the rock slope failure occur as identified in this study, the effect will be localised. The failure at the lower elevation may only cause damage to the concrete drain at the toe of the slope and injuries to people standing or walking close to the slope while the rock falls from the higher slope elevation, the damage may happens to the rail track, the train and injuries to people working in the middle of the rail track.

RECOMMENDATIONS

Adequate drainage system should be provided on the slope face. The proposed measures for cut rock slopes at the study area shall be as follow:

First Phase

For the first phase work, scaling works has to be carried out. The scaling will involve removing of loose blocks or scree from exposed rock faces. Potentially unstable blocks shall be removed carefully, without blasting, to prevent further loosening of the face.

Joint inspection shall be made prior to the scaling works to identify the scope and extent of the works. Further assessment to the rock slope need to be carried out upon completion of the scaling works to confirm whether the second phase mitigation measure need to be carried out.

Second Phase

Further mitigation measures proposed must be not to ameliorate the dangers that may arise from rock falls by method that are cost effective and durable. Detail design for this second phase measure if necessary shall be carried out by qualified Geotechnical Engineer. The proposed measures shall be as follow:

Fixing of Wire Mesh to Rock Surface

For rock slope with combination of highly jointed rock and potential single block failure can be fixed with wire mesh anchored to the rock slope face. This measure suitable for area at RHS slope and for the lower slope face area at LHS slope. The estimated area required for this measure is approximately 1800m².

Rock Fall Protection System

Rock fall protection system shall be constructed at the second berm of the LHS slope. This system is also designed to act as barrier to prevent debris or felling rock from slope failure to roll down and reach the bottom of the slope or the track area. The estimated length of the area required this measure is approximately 50m.

Rock Dowels

Rock dowels should also be considered as one of the mitigation measures. This measure can be applied through out the slope face either RHS or LHS slope. The estimated numbers of rock dowels to be installed shall be approximately 80.

CONCLUSIONS

This paper has presented the results of a preliminary study carried out at the new rail link in Senai, Johor. Various potential failure modes have been highlighted. Potential hazards pertaining to the potential failure modes were also highlighted. Some recommendations were suggested for remediation of the unstable rock slope face. It is to be noted that good and suitable blasting practice shall be adopted to enhance the performance of rock slope in term of stability. Advise from the relevant expert such as geologist is needed prior to construction works in rock

Slope Zone	RHS Slope Zone I	RHS Slope Zone II	RHS Slope Zone III	LHS Slope
Slope face (D/DD)	75°/110°	75°/110°	75°/110°	65°/290°
Major discontinuity plane (D/DD)	J1: 79°/183° J2: 60°/127° J3: 68°/044°	J1: 85°/179° J2: 67°/336°	J1: 61°/141° J2: 73°/111° J3: 63°/107° J4: 67°/075° J5: 70°/059°	J1: 86°/150° J2: 59°/137° J3: 40°/100° J4: 56°/003° J5: 54°/323° J6: 70°/310° J7: 76°/294° J8: 62°/214°
Minor discontinuity plane (D/DD)	J4:37°/080° J5: 40°/127° J6: 18°/180° J7: 19°/237°	J3: 54°/312° J4: 15°/227° J5: 52°/110° J6: 51°/079°	J6: 64°/004° J7: 26°/327°	Nil
Potential failure mode	Wedge: J1/J3, J1/J4, J1/J5, J4/J5, J3/J7, J4/J6, J4/J7	Wedge: J5/J6 Planar: J5 Toppling: J4	Wedge: J1/J3, J1/J4, J1/J5, J1/J6 Planar: J2, J3 Toppling: Nil	Wedge: J5/J8, J4/J8, J6/J8, J1/J6, J1/J5 Planar: J3
Proposed mitigation measure	Scaling Wire mesh Dowels	Scaling Wire mesh Dowels	Scaling Wire mesh Dowels	Scaling Wire mesh Rock-fall system Dowels

Table 1: Summary of rock slope condition

material to ensure proper construction method adopted for certain geological condition.

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Manuscript received 28 March 2005