Keynote Paper III
Stability of slope cuts in metamorphic bedrock areas of Peninsular Malaysia

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Low to medium grade regionally metamorphosed rocks of the greenschist facies are the predominant metamorphic bedrock of Peninsular Malaysia and include almost all its' Lower and Upper Palaeozoic rocks. Lower Palaeozoic strata mostly occur as medium grade regionally metamorphosed rocks and consist of mica and quartz-mica schists, marbles, graphitic schists, quartzites and amphibole schists. Upper Palaeozoic strata constitute low grade regionally metamorphosed rocks and mainly occur as quartzites and phyllites interbedded with argillites, slates, meta-siltstones and meta-volcanics. Although a variety of metamorphic rocks is found, only three groups are of importance in discussions on slope stability due to their wide-spread occurrence, i.e. Mica Schists, Interbedded Quartzites and Phyllites, and Marbles.

In areas of mica schists (including quartz-mica and graphitic schists), weathering profiles show variable morphological features that are influenced by not only their topographic settings, but also by the structural planes, textural, chemical, and mineralogical variations, inherent in the bedrock mass. Two broad morphological zones can be differentiated; an upper Zone I of completely weathered bedrock, and a lower Zone II of in situ, moderately to highly weathered bedrock. In some rare cases, a bottom Zone III of slightly weathered to unweathered bedrock can also be seen. Zone I is up to about 5 m thick and consists of soft to very stiff, silty to sandy clays, often containing lateritic concretions. Zone II is up to 30 m and more thick and consists of alternating bands of variously coloured, stiff to hard, silts and sandy silts that show distinct relict bedrock textures and structures.

In low-lying to undulating terrain over mica schists, low cuts (< 5 m high) expose morphological Zone I materials and are usually stable, though steep ones (> 60° overall cut angle) can be affected by earth falls and shallow slips. These small failures occur during rainfall, long after the end of construction, and are preceded by the development of tension, and desiccation, cracks. High cuts (> 5 m high) expose materials of morphological Zones I and II and are usually stable, though at steep cuts (> 50° overall cut angles), the Zone I materials can be affected by small earth falls and shallow slips, and the Zone II materials by wedge failures, slab and block slides. In low-lying to undulating terrain, when groundwater tables are intersected by the slope cuts, slumps and compound slides can occur under undrained and drained conditions.

In hilly to mountainous terrain over mica schists, low cuts (< 5 m high) expose morphological Zone I materials and are usually stable, though steep ones (> 60° overall cut angle) can be affected by earth falls and shallow slips. High cuts (> 5 m high) expose materials of morphological Zones I and II and are also usually stable, though at steep cuts (> 50° overall cut angle), the Zone I materials can be affected by small earth falls and shallow slips, and the Zone II materials by wedge failures, slab and block slides. The small failures involving Zone II materials occur during periods of rainfall and result from sliding along favorably orientated, relict structural discontinuity planes, particularly foliation. Large compound slides can also sometimes affect the high cuts, particularly during or following, periods of continuous rainfall when a rise in groundwater tables can lead to sliding that is controlled in part by relict foliation. 'Softening' of Zone II materials with time and exposure can also gradually lead to disaggregation (air slaking) of slope materials and result in small debris falls. In areas where the slightly weathered to unweathered bedrock of Zone III is exposed at steep cuts (> 60° bench face angles), small to large, block and slab slides, as well as wedge failures can occur, often during rainfall, as a result of sliding along day-lighting, structural discontinuity planes, particularly foliation.

In areas of interbedded quartzites and phyllites, weathering profiles show extremely variable morphological features that are influenced by not only their topographic settings, but also by the structural planes, textural and mineralogical variations, inherent in the heterogenous bedrock mass. Two broad morphological zones can

Warta Geologi (Newsletter of the Geological Society of Malaysia), Vol. 25, No. 3, May-June 1999

be differentiated; an upper Zone I of completely weathered bedrock, and a lower Zone II of in situ, moderately to highly weathered bedrock. In some rare cases, a bottom Zone III of slightly weathered to unweathered bedrock can also be seen. Zone I is up to about 5 m thick and consists of soft to very stiff, silty to sandy clays, and dense clayey sands, often containing lateritic concretions. Zone II is up to 30 m and more thick and consists of alternating bands of variously coloured, stiff to hard, clays, silts and sandy silts, and dense to very dense, sands and silty sands, that show distinct relict bedrock textures and structures.

In low-lying to undulating terrain over interbedded quartzites and phyllites, low cuts (< 5 m high) expose morphological Zone I materials and are normally stable, though steep ones (> 60° overall cut angle) can be affected by earth falls and shallow slips. These small failures occur during rainfall, long after the end of construction, and are preceded by development of tension, and desiccation, cracks. Higher cuts (> 5 m high) expose materials of morphological Zones I and II and are usually stable, though at steep cuts (> 60° overall cut angle), the Zone I materials can be affected by small earth falls and shallow slips, and the Zone II materials by wedge failures, slab and block slides. In low-lying to undulating terrain, where groundwater tables are intersected by cuts, slumps are likely to occur under undrained and drained conditions.

In hilly to mountainous terrain over interbedded quartzites and phyllites, low cuts (< 5 m high) only expose morphological Zone I materials and are usually stable, though steep cuts (> 60° overall cut angle) can be affected by earth falls and shallow slips. Higher cuts (> 5 m high) expose materials of morphological Zones I and II and are often stable, though at steep ones (> 50° overall cut angles), the Zone I materials can be affected by small earth falls and shallow slips, and the Zone II materials by wedge failures, slab and block slides. The small failures involving Zone II materials occur during periods of rainfall and result from sliding along favorably orientated, relict structural discontinuity planes, particularly bedding. Large compound slides can also sometimes affect the higher cuts, particularly during or following, periods of continuous rainfall when a rise in groundwater tables leads to sliding that is controlled in part by relict bedding planes. 'Softening' of the Zone II materials with time and exposure can also gradually lead to their disaggregation (air slaking) of slope materials and result in small debris falls. In areas where the slightly weathered to unweathered bedrock of Zone III is exposed at steep cuts (> 60° bench face angles), small to large, block and slab slides, as well as wedge failures can occur, often during rainfall, as a result of sliding along day-lighting, structural discontinuity planes.

In areas of marble bedrock, weathering profiles are extremely thin and often absent, due to the removal by solution of almost all the weathering products. Bedrock outcrops are found both at the surface in the form of steep-sided, isolated hills and at depth in the form of a subsurface karst covered by a thick layer of alluvium. These bedrock outcrops show very variable, external and internal features, including the development of pitted, rilled and scalloped surfaces, as well as the development of solution hollows, notches, caves and tunnels of variable sizes. Slope cuts of any height in marble bedrock are primarily dependent upon the orientations, and surficial features, of its' inherent structural discontinuity planes, particularly joint and fault planes. At cuts of moderate to steep angles (> 50° overall cut angle), day-lighting discontinuity planes can result in small to large, block and slab slides, as well as wedge failures.

It is concluded that the stability of slope cuts in metamorphic bedrock areas of Peninsular Malaysia is dependent upon several factors; the most important one being the structural discontinuity planes inherent in unweathered bedrock, and indistinctly to distinctly, preserved as relict structures in their weathering profiles. The overall, and individual bench, angles of slope cuts is also important in influencing their stability, whilst the topographic setting determines the influence of groundwater tables. Climatic conditions, as rainfall duration and intensity, also influence the stability of the cuts.