ROPE ACCESS METHODS IN SLOPE RISK ASSESSMENT AND REMEDIATION

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ABSTRACT

Rope Access Methods provide a safe, cost effective and efficient means of improving the quality of slope risk assessments and inspection of installed remediation measures in areas where access by conventional means is not possible or practical. The method provides a means for observing slope conditions at close quarters thereby enabling hazard identification, trigger mechanisms and detachment probabilities to be assessed with greater confidence. Case studies presented in this paper demonstrate how Rope Access Methods used by experienced geotechnical professionals can be carried out on a site in conjunction with other works. This not only improves the quality of assessments but can reduce project costs and disruption to public infrastructure and public areas.

1 INTRODUCTION

A thorough understanding of slope hazards is a vital part of any slope stability assessment. The ability to view slopes and slope hazards at close quarters is an important part of this process, particularly when assessing hazard sizes, trigger mechanisms and detachment probabilities. Many slopes, both natural and constructed, are difficult, if not practically impossible, to access using conventional forms of access. Therefore assumptions have to be made about the nature of slope hazards and their failure probabilities. These assumptions may result in substantial errors in judgement where assessments are either overly conservative, or where risks are underestimated as hazards, are inadequately assessed or even worse, overlooked entirely. Rope Access Methods (RAM) provide an effective means of addressing these problems. Such methods are commonly employed in the UK and Europe but to date appear to be under utilized in Australia.

Geotechnical investigations involving RAM can be regarded by some project managers and clients as expensive, major undertakings. For example, The Australian GeoGuides for slope management and maintenance (AGS 2007) states that "A thorough inspection of a cliff face is often a major task requiring the use of rope access methods". Our experience has shown that Rope Access Methods provide a relatively simple, rapid and efficient method of slope investigation by experienced geotechnical professionals. This can result in substantial improvements in the quality of slope assessments, cost savings and may lessen the impact on adjacent essential infrastructure such as roads, railways or public areas.

2 CONVENTIONAL METHODS OF ACCESS

Conventional methods of access to very steep slopes traditionally involve the use of ‘cherry-pickers’ (travel towers) or similar hydraulic lifting machines. Use of this equipment requires specialized training and is not very common amongst geotechnical professionals. While larger ‘cherry-pickers’ can reach significant heights in the vertical direction, the side reach and side rotation of observation boxes is often quite poor. The use of these machines to access slopes that are benched, stepped or laid back can therefore be quite limited. A dog-box fitted to a crane may have greater vertical and side reach than a ‘cherry-picker’, however their use is problematic as the operator cannot control the movement from the box. Further restrictions on movement and access are imposed by the safe working distance these machines must adhere to when working near overhead power lines, which can be up to 6m depending on the voltage. While these methods improve observations of surface features, limitations on movement of the boxes often mean no observations can be made behind particular slope hazards. Such observations can be important in inspecting defect conditions and judging detachment probabilities.

Cranes and ‘cherry-pickers’ require good access conditions to the toe of the slope, usually in the form of a road or flat paved area. On roadways this usually involves the closure of more than one lane, if not the whole carriageway, which may create significant logistical problems and disruption to traffic. On railways, the size of the lifting machine may be further limited by overhead wiring structures and the potential for damage to the rail formation. For urban train networks this requires power outages and may require total track possessions resulting in significant inconvenience to the public.

Table 1 provides a summary of the capabilities and limitations of a range of commonly used access equipment and an indication of their hire costs. As indicated on Table 1, this equipment can be very expensive and a lengthy investigation could therefore incur significant costs. Some clients have indicated that if such equipment had to be used they simply could not afford to have the work done.

Binoculars are often used to observe slopes from nearby vantage points, usually from along the toe of the slope. This requires a clear line of sight which is often impeded by slope geometry, vegetation and atmospheric haze. Magnification is also a limiting factor. Due to the viewing angle it is often impossible to fully appreciate the three dimensional nature of slope features, making engineering judgment problematic.

Civil contractors with rope access trained staff are often used to carry out slope remedial works on large cuttings and natural slopes. While these contractors are proficient in their work they do not have formal training in engineering or geology. In many situations where remedial works have been carried out, there are no other access methods available to enable professional assessment of the adequacy of the works. In some circumstances, geotechnical professionals must then rely on contractors to relay observations of ground conditions to professionals stationed on the ground. Clearly, this is not best practice. In contrast, geotechnical professionals consider it important to make a visual assessment of the foundation conditions in footings to ensure they meet design requirements. The need to visually inspect geotechnical hazards and remediation measures installed on steep slopes should be of a similar standard to inspections of other geotechnical features and structures.

Table 1: Summary of Conventional Access Equipment.

Equipment	**Vertical reach (m)**	**Maximum horizontal reach (m)**	**Horizontal reach at maximum height (m)**	**Width in operation (m)**	**Approximate Cost**	**Comments**
Travel Tower 65*	65	22	7.5	6.5	$450 /hr	Stabilisers would close at least 2 traffic lanes.
Travel Tower 40	40	22	5	5.4	$230 /hr	Stabilisers would close at least 1 traffic lane.
Boom Lift 120’	36.6	19	7	4	$650 /day	Would require closure of 2 traffic lanes.
Boom Lift 60’	18.3	15	4	2.4	$300 /day	Would require closure of at least 1 traffic lane.
20 tonne Crane	16.75 (Hook height)	Dependent on load. Typically <18	Dependent on load. Typically <8	6	$180 - $250 /hr	Outriggers would close at least 2 traffic lanes.
55 tonne Crane	40 (Hook height)	Dependent on load. Typically <35	Dependent on load. Typically <8	7	$450 /hr	Outriggers would close at least 2 traffic lanes.
Rope Access	Virtually unlimited	NA	NA	NA	Professional fees + initial outlay for equipment	20 m-70 m common working heights in Australia. Access restrictions at toe of slope are site specific.

Note: Plant equipment data from Sherrin Hire (2007). With the exception of boom lifts, all costs are inclusive of operators on weekly hire. *Largest travel tower in Australia at time of publication.

3 THE ROPE ACCESS METHOD

Rope Access (also referred to as Industrial Rope Access) is a form of work positioning that allows workers to safely access difficult to reach locations. By definition, should full body support be required to access a work site, it is regarded as Rope Access (THS, 2007). It should not be confused with fall arrest systems which are used when there is a possibility of free falls. Rope Access Methods use equipment and techniques originally developed in caving, climbing and mountaineering. However, significant expansion in the use of the method across a range of industries in recent years has seen the development of dedicated and purpose made rope access equipment. Two standards now set out the use of rope access systems in Australia. AS/NZS 4488.1 outlines requirements for materials, hardware and fall protection, while AS/NZS 4488.2 outlines requirements and provides recommendations for the selection, safe use and maintenance of rope access components and assemblies. Issues such as safe work practices, operator training,and competency requirements are outside the scope of the standards.

In Australia, there is no Certificate of Competency for rope access under the National Certification Regulations, nor is there any WorkCover NSW endorsed training courses or certificates (WorkCover, 2000). The Australian Rope Access Association (ARAA) is the dominant industry body for rope access workers and provides training and operates a certification scheme. The ARAA Industry Code sets out safe work practices for the industry. In addition to ARAA, the Industrial Rope Access Trade Association (IRATA) is an international organisation originating in the United Kingdom and is also gaining acceptance in Australia. Accreditation by either organisation is increasingly becoming a requirement to undertake rope access at work sites in Australia. The authors of this paper have been trained in Industrial Rope Access Methods and have been independently certified by ARAA.

ARAA competencies are organised in a three level system, commencing at Level 1 (Basic Operator) through to Level 2 (Basic Supervisor) and Level 3 (Advanced Operator). Level 1 training typically involves an intensive 4 to 5 day course covering practical and technical components as well as occupational health and safety issues. A competency assessment is carried out at the conclusion of the course by an independent assessor by means of a written examination and practical assessment. Certification remains current for a period of three years, after which the ‘operator’ must undergo another competency assessment. Progression to a higher competency level requires a log book record of working hours and further training and assessment.

The following points offer a brief description of the basic techniques of the Rope Access Method:

- Unlike recreational abseiling in which the user is connected to a single rope, Rope Access uses a two rope system with each rope having an independent anchorage point. For this reason it is often referred to as "twin rope". Ropes used must be static kernmantle ropes with ultimate strengths of at least 25kN and a minimum diameter of 10.5mm.
- One rope, the “safety line”, does not support any load with the worker being connected to it at all times by a back-up device designed to arrest movement in the event of a fall. The worker, and a limited quantity of equipment, descends using the second rope, the “working line”.
- Each worker must be able to manually ascend the ropes using the appropriate equipment.
- At least one point of contact must be maintained on each rope in the system at all times.
- Work is always carried out by two or more people, each with the training and ability to rescue each other if required.

In addition to simple ascents and descents a typical slope investigation also requires traverses along benches and gentler slopes and transfers to other ropes while on the rock face. Using a combination of these techniques allows for near-complete coverage of the rock face. Investigations are always carried out using a ‘top down’ approach to ensure workers are not located directly below high risk slope hazards. If such hazards are identified during a descent the worker would typically ascend and move the ropes or in some situations scaling of the hazard(s) may be carried out. The above brief description should not be regarded as a comprehensive description of the use of rope access techniques or equipment, for this the reader is advised to consult the abovementioned standards and industry codes.

4 CASE STUDY 1: USE OF ROPE ACCESS METHODS ON GLENBROOK TO LAPSTONE RAIL CUTTINGS

4.1 BACKGROUND

The Western Rail Line between Glenbrook and Lapstone in the lower Blue Mountains west of Sydney contains a number of large rock cuttings. From track level most rail commuters would be oblivious to the size and extent of the cuts which reach heights in excess of 65m. This section of railway was constructed along the northern side of Glenbrook Gorge between 1911 and 1913. The cuttings are likely to be among the oldest of their size in Australia.

This discussion focuses on the investigation, assessment and remediation of the two largest cuttings located between Lapstone and the Glenbrook Tunnel which have a combined length of approximately 1.1km. The largest of the cuts has been excavated to the full height of the escarpment and is about 67m high. The second cut to the east (see Figure 1) is about 40 m high. Both cuts are constructed at 75º to 85º to the horizontal. The natural clifflines at the site have been trimmed off by blasting, leaving a combination of cut, remnant overhangs, unmodified cliff lines and natural slopes. The site is located in a warping structure known as the South Lapstone Monocline which forms part of the Lapstone Structural Complex (Branagan & Pedram 1990, 1997). The cuts are located entirely in the Triassic Hawkesbury Sandstone Formation which varies in dip across the site from near horizontally bedded in the west, to 10º towards the east at the eastern end.

Figure 1: Engineering Geologist assessing slope hazards on the Eastern Cut.

4.2 INVESTIGATION AND ASSESSMENT

An extensive slope hazard mapping programme was undertaken by two experienced rope access accredited engineering geologists in response to a rock fall which temporarily closed the rail line in 2006. A slope risk assessment was also carried out using a risk assessment system developed by RailCorp whereby each hazard feature is assigned an individual risk rating. The assessments were carried out during periods of emergency track closures, routine weekend track possessions, and during normal rail traffic. As the Western Rail Line is one of the major rail corridors in New South Wales there are usually only four routine weekend track closures scheduled each year, therefore the majority of the assessments were carried out during periods of normal rail traffic. Visual and radio contact was maintained between each abseiler and Rail Protection Officers situated at track level. A speed limit was imposed on trains travelling through the gorge at the time of assessment, with all work stopping well before a train approached. Due to the limited time frame and the complexity of site issues, a Level 3 accredited rope access specialist operator was contracted for the project to install temporary rope anchors in rock and to set up and retrieve rope systems.

A forested reserve, Darks Common, is located above the largest of the cuts. The abundance of large trees in the reserve provided suitable rope anchorage points along the entire length of the cut. However, a housing estate backs onto the second cut to the east, and most of the area at the crest of the cut has been cleared. As a result, a series of temporary rope anchorage points were installed into sandstone outcrops along the crest. A visual assessment of each anchorage site was made by an engineering geologist to ensure the rock was competent and intact. Temporary rope anchorage points comprised 100 mm long Excalibur Screwbolts which were removed following the assessments. In accordance with AS/NZS 4488.2 (Industrial rope access systems - Selection, use and maintenance) each anchor was proof loaded by application of an axial pull-out force of 6kN, using a portable Hilti Pull Tester.

A horizontal rope spacing of about 8 m to 10 m was found to be optimum for achieving coverage of the cut faces, however, in some locations the spacing was reduced where the cut morphology was particularly irregular and obscuring. Due to the abrasiveness of the Hawkesbury Sandstone and the presence of numerous sharp edges on crests and ledges, a number of rope protectors (cylindrical sheaths of heavy weight material) were placed over the ropes during each abseil descent. All portable equipment such as cameras, range-finders, paint and writing material were secured by lanyards to each abseiler to prevent interference with the railway below. Similarly, ropes were contained in bags which also prevented entanglements in vegetation. The rope access assessments were made to a height of about 10 m to 15 m above track level, a safe working distance above the railway overhead wiring structures. The height of each hazard feature relative to track level was measured using laser range-finders and the chainages of each feature were recorded relative to the Railcorp chainage system. Following completion of each abseil, ascending rope access methods were then used to physically climb back up the ropes to the crest of the cuts.

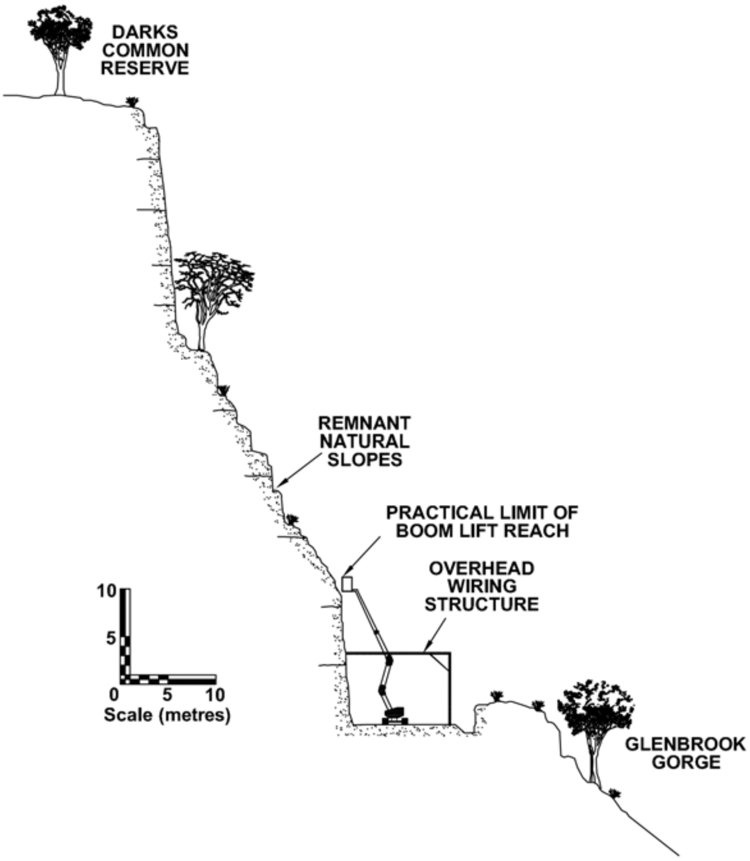

Figure 2: Typical section through the Western Cut

During the investigation two rock falls occurred, triggered by root jacking near the crest of the cuts during periods of light rain. The authors were witness to one of these rock falls which struck the railway overhead wiring structures. Using rope access methods, the source area was able to be investigated and assessed for stability soon after the fall occurring, with advice provided enabling rapid remediation of the site.

To assess the lower 10 m to 15 m of the cuts during periods of total track possessions and power outages, Manitou Boom Lifts were used. Figure 2 presents a section through the largest cut highlighting a number of access conditions and constraints to conventional methods of access.

4.3 REMEDIATION

The majority of rock fall hazards identified were surficial and had formed as a result of adverse jointing and/or bedding orientations and weathering. Prolonged weathering and growth of vegetation on the cuts appear to be mainly responsible for increasing the incidence of rock falls.

Due to the cut heights and slope geometry it is not possible to see large portions of the cuts from the narrow railway corridor below. A system was therefore needed to present the locations of hazards in order to plan and coordinate remediation work. Consequently, a helicopter was used to obtain a continuous series of overlapping, high resolution digital photographs of the cuts. These were digitally merged to create large scale hazard location plans. Height markings were painted at intervals down the cuts at various locations prior to the photography to assist with locating hazards.

Remedial works were programmed to ensure that hazards with high risk ratings were treated as a priority. These works involved an intensive programme of rock scaling, rock bolting, tree removal and shotcreting. The majority of the work was carried out by rope qualified contractors, with boom lifts used to treat lower areas of the cuts when possible. In some situations working platforms were lowered down the cuts using compact, portable cranes that were anchored at the crest to assist with rock bolting.

The majority of the rock bolt and scaling locations were marked by paint on the cuts prior to the work commencing to aid efficiency with remedial requirements and direction provided on site to contractors during the work. Where the work was not directly observed by engineering geologists each hazard was later revisited to check that the work was completed in accordance with the recommendations provided.

5 CASE STUDY 2: LAWRENCE HARGRAVE DRIVE

5.1 BACKGROUND

Lawrence Hargrave Drive (LHD) is situated in the northern suburbs of Wollongong in NSW (see Figure 3). In the area between Clifton and Coalcliff, LHD was constructed some 20 m to 45 m above sea level along a coastal escarpment comprising of steep cliffs some 300 m high.

This section of LHD has a history of severe embankment instability, rock fall, debris slide and debris flow problems with the site rated by the Roads and Traffic Authority of NSW (RTA) as the highest for slope instability risk to roads in NSW (Hendrickx *et al.*, 2005). In August 2003, the NSW government closed the road for safety reasons and the LHD Link Alliance was formed between the RTA, Barclay Mowlem, Coffey Geosciences and Maunsell to develop an engineering solution to reduce the risk to ‘acceptable’ levels. The road was closed for 2 years while remediation works were completed. Remediation consisted of major bridgeworks over the ocean bypassing the areas of highest rock fall risk and supplementary geotechnical works to remediate adjoining slopes. Rope Access Methods were utilised to implement geotechnical remediation works as conventional methods would have severely restricted construction access through the narrow site and significantly lengthened the construction time.

The geological sequence of the southern Sydney Basin comprises an essentially flat-lying sequence of interlayered sandstone, mudstone and coal of the Illawarra Coal Measures, overlain by interbedded sandstones and mudstones/claystones of the Narrabeen Group and the upper Hawkesbury Sandstone (Bowman 1974). The site was subdivided into five geotechnical domains based on geomorphology (Hendrickx *et al.*, 2005). The main cliff forming units between Coalcliff and Clifton are the Hawkesbury Sandstone at the top of the escarpment, Bulgo Sandstone forming cliffs up to 80 m high in the central portion of the slope, and cliffs in Scarborough Sandstone up to 30 m high immediately above the roadway.

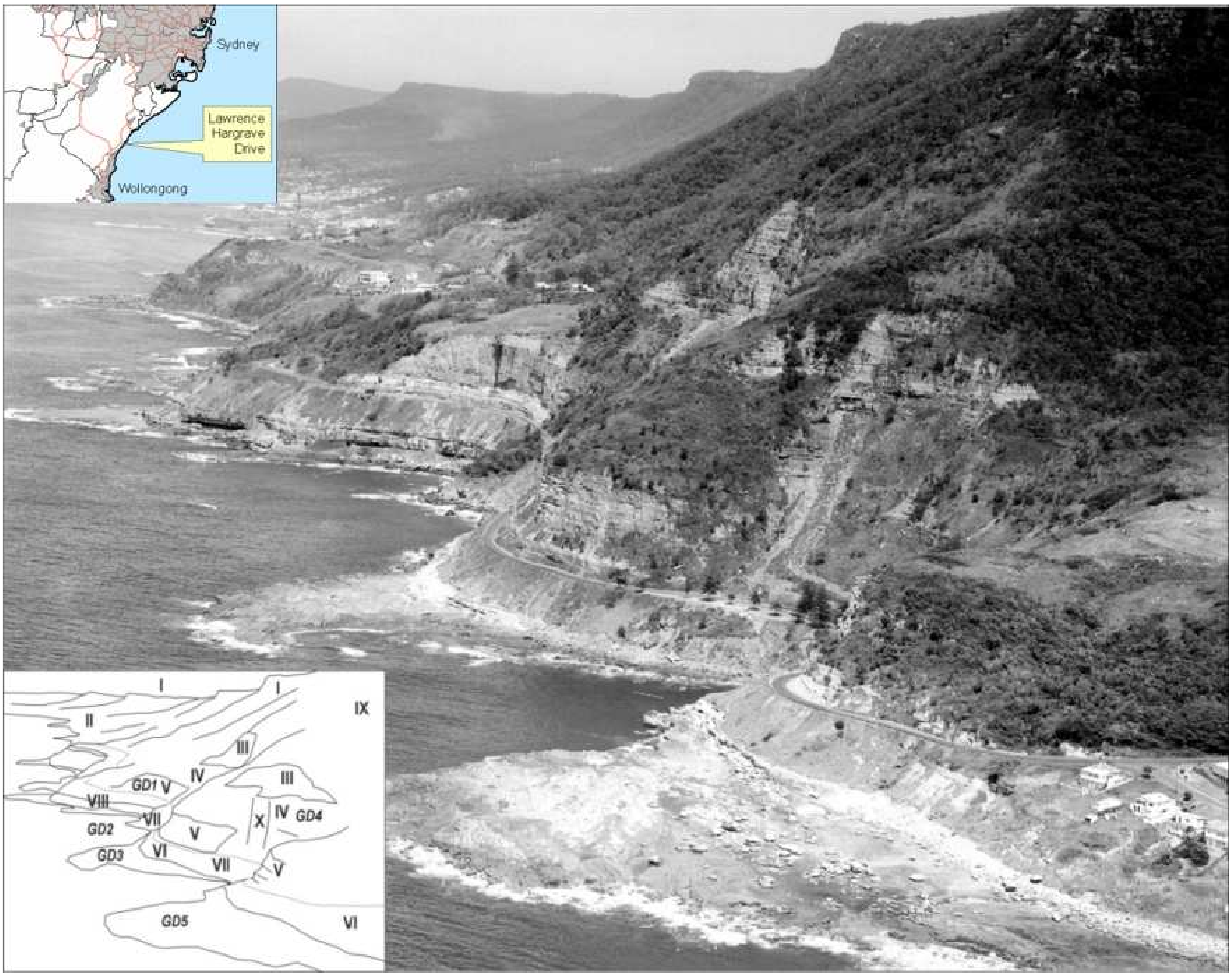

Figure 3: Aerial photograph looking south taken in November 1967, modified from Figure 1 in Hendrickx *et al*., 2005. Main features include: I. Escarpment marked by top of Hawkesbury Sandstone cliffs; II Typical coastal plain and profiles developed south of site - note gradual truncation of coastal plain towards front of photo; III Bulgo Sandstone cliffs; IV Stanwell Park Claystone slopes; V Scarborough Sandstone cliffs; VI Wombarra Claystone slope below road; VII Colluvial fans; VIII Coalcliff Sandstone cliffs and old coal loading platform-Bulli Coal seam marked by dark band; IX large Hawkesbury Sandstone boulders on upper Bulgo slope; X Talus accumulation on Stanwell Park Claystone. Note wave cut platforms. Geotechnical domains GD1-5 are also shown.

5.2 WORK UNDERTAKEN

Geotechnical remediation works were focused in Geotechnical Domains GD4 and GD5, and parts of GD1. The major hazards in GD1, GD2 and GD3 were bypassed by bridges that now support the road over the ocean.

Access through the site during construction was via LHD and temporary construction tracks. Use of conventional construction and inspection methods for the geotechnical program (such as boom lifts and cranes) would have resulted in closure of construction access through the site for lengthy periods posing a major challenge to the project. Construction using RAM however allowed for virtually unimpeded access through the site and was a major factor in the selection of specialized subcontractors to undertake the geotechnical works program.

Geotechnical works included presplit blasting, installation of several hundred rock anchors up 8 m long up to 30 m above road level; installation of pinned rock fall mesh over cliffs up to 30 m high, installation of shotcrete to protect weak shale layers up to 25 m above road level and providing cable support to boulders in colluvium above GD4.

The remainder of this section focuses on use of RAM used by professional engineering geologists to assist geotechnical works in GD5.

GD5 comprises near vertical cliffs up to 30 m high in Scarborough and Otford Sandstone separated by a thin interval of Wombarra Claystone that overlie a headland developed in Coalcliff Sandstone (Figure 4). Both sandstone cliffs are a source of rockfalls to LHD below. The slope above the cliffs is relatively flat with good 4WD vehicle access via the adjoining coke works in Coalcliff.

Work by rope access trained engineering geologists involved inspection of hazards, mark-up of rock anchor locations, supervision and planning of PCF® low energy explosive works, and general oversight of slope stabilisation works (Figure 5). The area above the cliffs was cordoned off with barrier fencing to restrict access to the cliff edge. Set up of ropes utilised large trees set back about 10 m from the cliff edge as anchor points. These were later supplemented with steel rock anchors that were to be used to hang steel rock fall mesh. Scaling and rock removal work was initially carried out from the top down to remove fractured rock masses resulting from blasting. Radio contact was maintained between team members and a lookout on the road below, who would halt rope access work to allow for the safe passage of construction vehicles. Rope protectors were used to prevent damage to ropes at the sharp cliff edge and locally on the cliff face where sharp sandstone protrusions outcropped. Bags and lanyards were used to secure equipment such as crow bars, cameras, range finders, paint and writing material to prevent them falling below. As there was no quick access to the crest of the cliffs from below, all down traverses required a climb back up the cliffs.

Figure 4: View of GD5 showing cliffs in Scarborough Sandstone following blasting undertaken as part of the geotechnical remediation. The cliffs were subsequently scaled and additional support provided by rock anchors and rock fall mesh. All work, including drilling for rock anchors, was carried out using rope access methods.

6 OTHER EXAMPLES

The authors have also used RAM to access cliffs in remote areas. One example involved inspection of a large fractured rock mass 30m above a dam access road. Access to the top of the cliffs was via a bushwalk in steep terrain adjacent to the cliffs. The authors then used Rope Access Methods to inspect the upper portion of the cliffs and to conduct a close up inspection of the fractured rock mass. This rock mass was subsequently stabilised using high strength rockfall mesh anchored to competent rock. Boom lifts on site not only blocked access along the narrow road below they did not have sufficient vertical or horizontal reach to provide an adequate inspection.

In another example, the authors were called upon to conduct an inspection of cliffs above a major water supply pipeline. An earlier attempt to inspect the cliffs using a boom lift was of limited success, as the equipment lacked the horizontal reach to allow for an adequate inspection of the cliffs. The authors were able to gain access quickly to the top of the cliffs using RAM where a large, loose rock wedge not previously observed was identified.

Another project involved accessing parts of a sandstone escarpment over 150 m high, where a directionally drilled bore was to be drilled beneath the escarpment from the plateau above, down to a river below. In some locations the depth of rock cover above the proposed bore was very shallow (<5 m), and there was a concern of borehole blowout and subsequent leakage of drilling fluids into an ecologically sensitive environment. The only access to the area was by bushwalking through dense forest. Mapping of rock mass defects and the slope profile was undertaken along the bore alignment using RAM with prisms and conventional surveying techniques. This enabled zones of the escarpment with a high risk of borehole blowout to be monitored and appropriate environmental controls established.

Figure 5: Engineering Geologists supervising scaling works in GD5. Note rope and equipment set up and Lawrence Hargrave Drive about 40 m below.

7 DISCUSSION

Physical fitness and contraindications for personnel working at heights are perhaps the only limitations to the use of RAM on natural and constructed slopes. While the use of RAM becomes easier with experience and improved technique, ascension of the ropes is a strenuous activity requiring a reasonable level of fitness and is a core competency.

While not strictly a limitation, it is our experience that in most cases RAM may be less cost effective for assessing slopes below about 10m to 15m in height where there is reasonable access to the toe of the slope and the view is not obscured by vegetation, slope geometry or other features.

RAM has the capacity to greatly improve the quality of both slope inspections and slope remedial works on rock slopes. It provides an unparalleled means of assessing slope conditions (often in remote inaccessible areas) and, more often than not, such conditions are quite different to what deduced from observation from below or even from a cherry picker. In addition to improved data collection and slope observations, RAM can also improve the monitoring of steep slopes. Changes in slope conditions can be assessed visually with greater confidence and quantitative systems such as crack monitors and reflective survey points can be readily installed on the rock face. The case studies discussed in this paper demonstrate that rope access work can be carried out simultaneously with other works on a site and during road or rail traffic, providing appropriate controls are in place. This not only reduces project costs but also reduces disruption to public infrastructure and public areas.

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