CLIMATE CHANGE, SLOPE STABILITY AND NECESSARY STABILIZATION OF THE ACCESS ROAD, LUNDY ISLAND, BRISTOL CHANNEL, UK

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Lundy Island is a remote island in the Bristol Channel, situated about 18 km north-north-west of Hartland Point. John Grimes Partnership has had in-depth involvement in the improvement of access facilities to the island since 1998. Prior to construction of the cliff road and new jetty, visitors to Lundy had to disembark using small boats to ferry them from the ship to the south-east end of the island. The access to the top of the island and village was a track that obliquely crossed the steep coastal slopes. The new jetty and road allows access to the island at all weather and states of tide (its tidal range is 9.2 m). Significant movement has been experienced on the coastal slope at the south-east end of the island. The slope exhibits the potential for instability, predominantly sliding and small-scale wedge failure. Climate change is resulting in increasing rainfall and sea level, which may significantly increase both landslip occurrence and marine erosion along this section of coastline.

Strengthening of the access road has been carried out in phases. Due to the location and environmentally sensitive setting, the remediation works are complicated in concept, design and execution. The most recent phase of road stabilization works addressed landslip potential both in the rock mass and in the overlying superficial material. Existing retaining walls were degrading and the road subsiding. The new retaining structure and road was formed by steel reinforced sprayed concrete, which was keyed to the existing road and rock and tied back using piles and anchors.

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INTRODUCTION

Lundy Island (Figure 1) is administered by the Landmark Trust, which leases the island from the National Trust. Most of the island was designated as a SSSI in 1976 and, in 1986 the seas around it were designated Britain's first Marine Nature Reserve. The Landmark Trust commissioned John Grimes Partnership to engineer improved access to Lundy Island in 1998. At the time, access to the island from the passenger ferry was via small shuttle boats to the island and walk along a single lane, stone access track, which had been built between 1830 and 1840. Maintaining the access road across the coastal slope is essential as it is the only route along which supplies for the island can pass. If the road were to close due to slope failure, there would be no means of access for the 20,000 plus visitors who visit the island each year. As such, adopting a "do nothing" coastal management policy is not a viable option. Since 1998, John Grimes Partnership has been involved in the engineering of these new facilities (Grimes and Hearn, 1998) including the new landing jetty in 2001, as well as the design and supervision of the construction of large sections of the cliff access road. Due to financial constraints, the establishment of a phased approach for the stabilization of the access road was required, with phases being carried out according to priority.

Lundy is an environmentally sensitive location both on-land and in the marine environment. The coastal slopes are a habitat for an interesting variety of flora and fauna. In particular and unique to Lundy, is the Lundy Cabbage, which inhabits the coastal slopes above and below the section of stabilized road. Several Environmental Impact Assessments on the jetty project and earlier phases of road repairs have demonstrated that works have not resulted in any adverse environmental effects.

The access road from the old landing beach rises steeply (10°) as shown in Figure 2. In places the seaward side is supported by retaining structures, mainly dry stone walling or gabions. To the landward side the ground rises between 35° to 60° and typically comprises rough vegetated and boulder strewn slopes. There are also several retaining structures, again comprising dry stone walls or gabions, on the uphill side of the road. The section of access road requiring remediation in this current phase of works comprised a 75 m long stretch located some 130 m up track from the old landing beach. The road width varies from 2.7 m to 4.2 m.

GEOLOGY

Lundy is famous for its igneous geology, in particular its Tertiary dyke swarm, which consists of dolerite and trachyte dykes (British Geological Survey, 1980). The Lundy intrusion mainly comprises coarse-grained megacrystic granite (G1), with irregular xenoliths of fine-grained megacrystic granite (G2). Sheets, pods and irregular masses of fine-grained poorly megacrystic granite are also widespread. The southeast of the island, where the road stabilization works are necessary, comprise meta-sedimentary Morte Slates, which consist of grey and greenish grey neritic slates with some thin sandy and calcareous beds. The Lustleigh-Sticklepath fault zone is located to the east of the island.

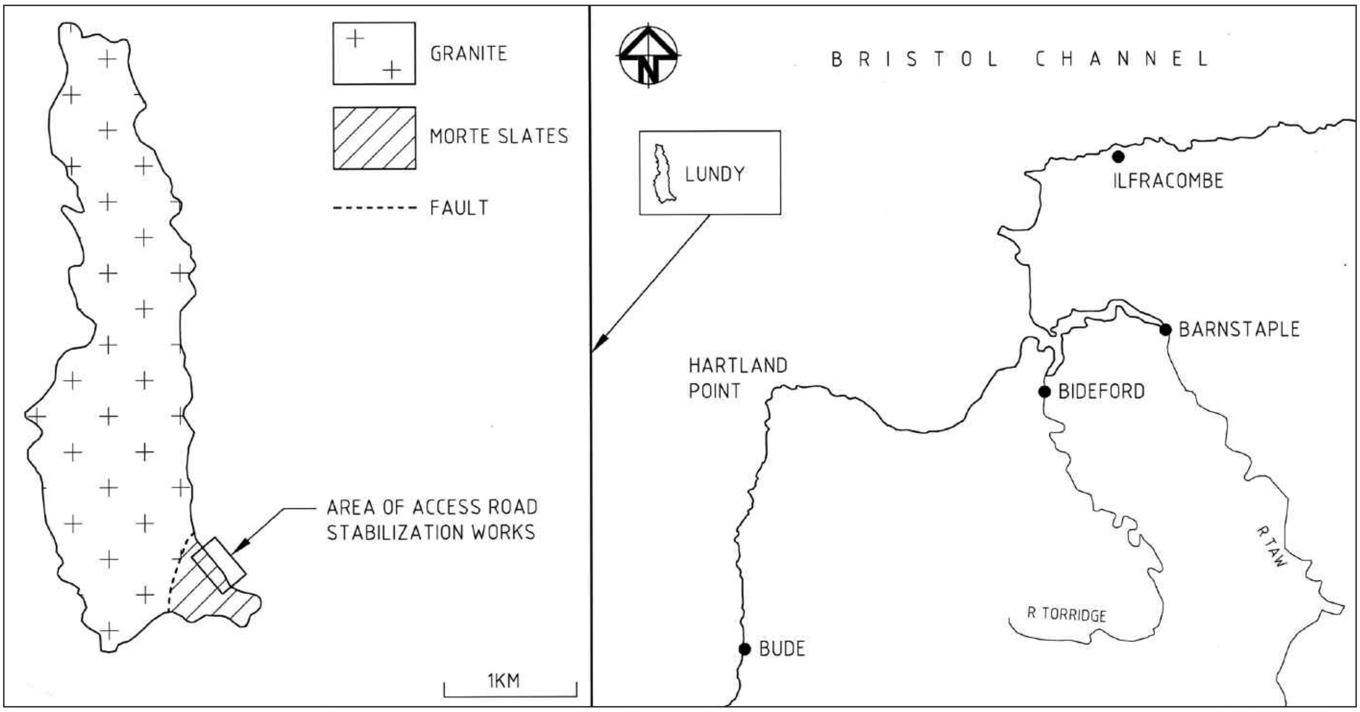

Figure 1. *Sketch-map of Lundy showing location and simplified geological units.*

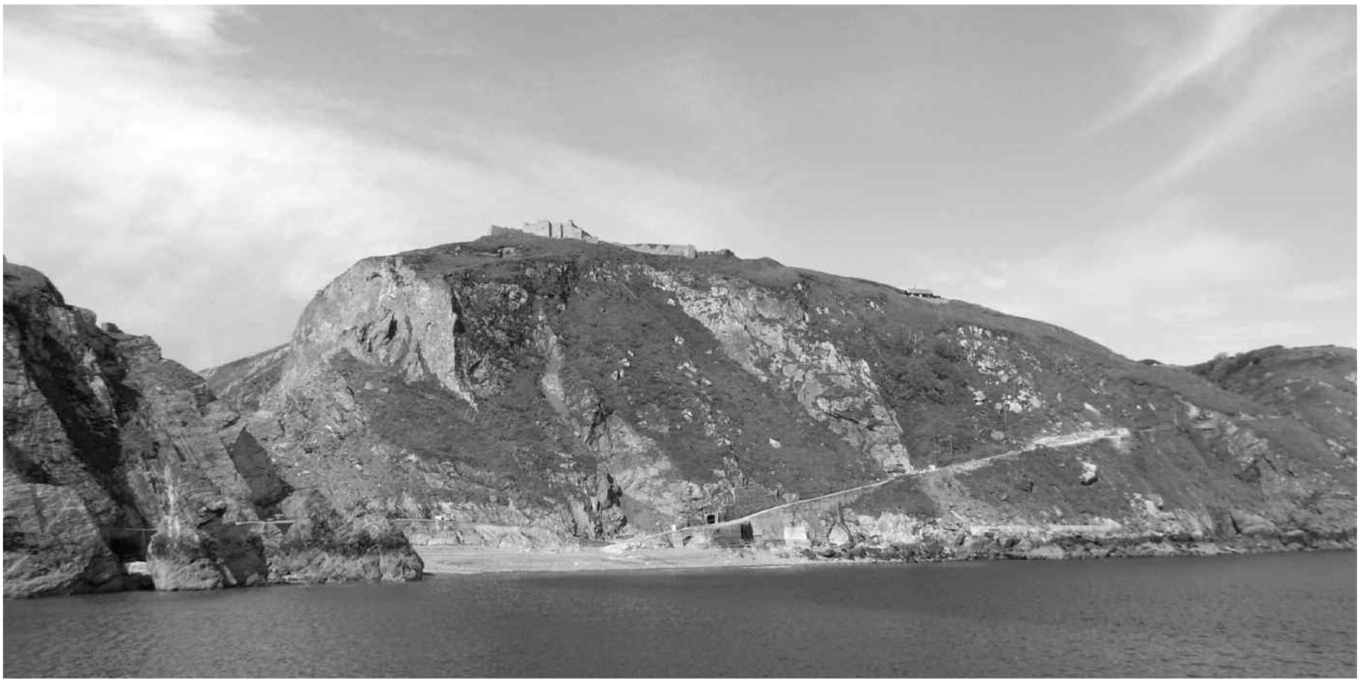

Figure 2. *Photograph of south-east section of Lundy Island, showing the access road from the old landing beach to "Windy Corner". Lundy Castle is situated on the crest.*

The geology along the access road and foreshore has been investigated. Figure 3 shows the simplified geology map of the recent section of stabilization works. Fieldwork has comprised mapping of the geology at accessible locations and by rope access techniques for the steeper slopes and scarps. During the mapping, engineering geological data was collected including recording of lithologies, discontinuity orientations, physical and geomorphological features and inspection of existing retaining and revetment structures.

The meta-sedimentary units observed are predominantly comprised of greenish grey, moderately weathered slates and phyllites. Sampling and analysis of the slates and phyllites indicated that they are generally moderately strong. In addition, several igneous intrusions were recorded. Both basic and trachyte ("lundyite") dykes are present. The dykes tend to be sub-vertical and linear, and in places easily traced over considerable distances (>200 m). The width of the dykes is generally less than 2 m and occasionally less than 1 m. The dykes are typically slightly stronger and less fractured than the metasediments into which they are intruded. However, locally it was observed that the dykes are much less competent and almost decomposed to form a residual soil. The contact between dykes and the metasediments is often faulted and brecciated with some alteration of the rocks.

The slate typically has a well developed and prominent cleavage tending to be smooth and wavy with kink bands evident in some areas. The phyllites were less perfectly cleaved. Generally there is a second discontinuity set sub-parallel to the

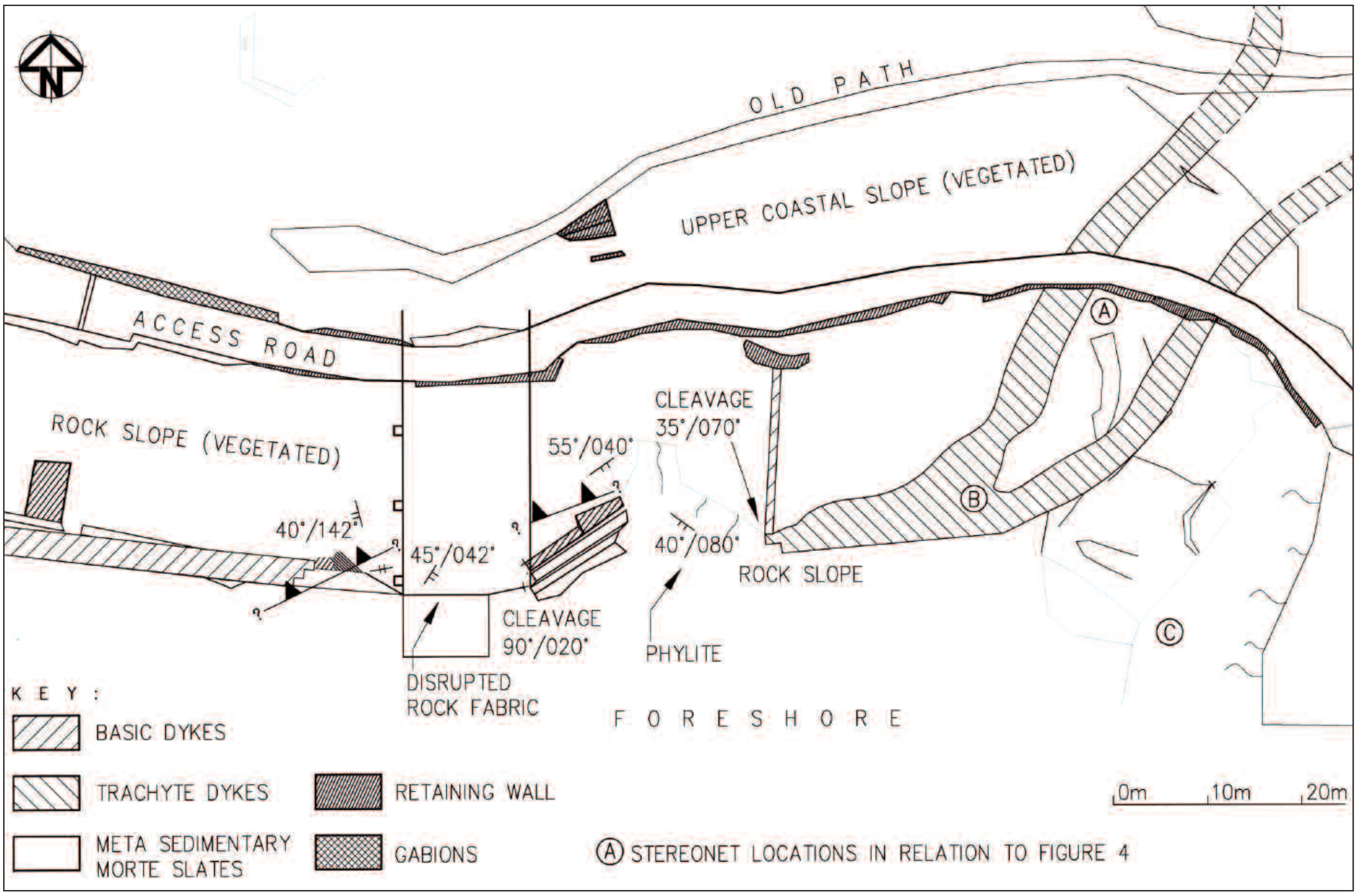

Figure 3. *Simplified section of geological plan in area of access road stabilization works. Locations A, B and C refer to stereographic plots given in Figure 4.*

cleavage, which denotes bedding. The cleavage/bedding orientations are variable at different locations, indicative of folding, though no fold axes were observed during the fieldwork. Faults and major joint discontinuity sets were identified, generally orthogonal to the cleavage/bedding planes. Some of the discontinuities are very persistent and planar. The geomorphology is determined to a large extent by these planes. Stereographic plots are shown in Figure 4.

The upper steep scarp slopes are generally formed along the principal discontinuities and many of the shallow valley and spurs visible on the coastal slopes are formed along intersections of two principal discontinuity sets. Between the spurs and within the valley features are accumulations of talus and ancient slip debris.

During glacial periods the Irish Sea ice sheet extended into the Bristol Channel and pushed up onto the Lundy shore (British Geological Survey, 1980). The extremely disrupted and dilated rock mass fabric evident on the coastal slopes and foreshore, as well as during the drilling of piles, is indicative of the action of ice; i.e. an ice wedged open fabric. This open texture and juxtaposition of many of the boulders on the steep rock slope is more indicative of a basal till than landslip.

Stability assessment

For several years prior to reconstruction, movement had been recognized along the section of road being examined, with localised collapses of dry stone walls, development of tension cracks and subsidence of the road and small magnitude (<1 tonne) landslips above the road. The road use had been subject to a risk assessment, which prohibited its use in wet weather.

Much of the original track along this section was retained on the seaward side by dry stone walling, which was in places dilapidated and showing signs of bulging, failures and areas of re-building. Some of the bulging areas had been supported by metal angles driven into the ground. Although the rockhead is relatively shallow, the dry stone walls have largely been constructed on talus or ancient slip debris above the rock. The dry stone walling would not meet current design criteria for retaining structures and considering the signs of distress, its condition was deemed critical in places with a high risk of sudden collapse under loading, particularly during wet weather.

Land-slipping of soil and rock debris had been identified as being active in this area and is greatly influenced by rainfall run off. Discontinuity controlled sliding is active. The potential for wedge failure has also been recognized; however, the geometry of the rock is such that there is only a slight risk of small unstable wedges forming in the coastal slope.

Climate change

Figure 5 shows the moving 5-year annual average rainfall for the island (rainfall data provided by Landmark Trust). This indicates an increase of nearly 10% in average annual rainfall over a 35-year period. With road use prohibited during wet weather, any further increase in rainfall would result in unacceptable traffic restrictions across the island. Also, with an increase in rainfall, an increase in slope instability can reasonably be expected. The effect of surface water run-off has already been evidenced during fieldwork. Over the past five years, the road from the old landing beach to Windy Corner has increasingly exhibited distress. In latter years monitoring has shown stick-slip movement triggered by prolonged intense rainfall.

An increase in marine erosion is also likely due to the predicted increases in sea level rise of 640 mm over the next 75 years (Posford Haskoning Ltd, 2003). The marine environment

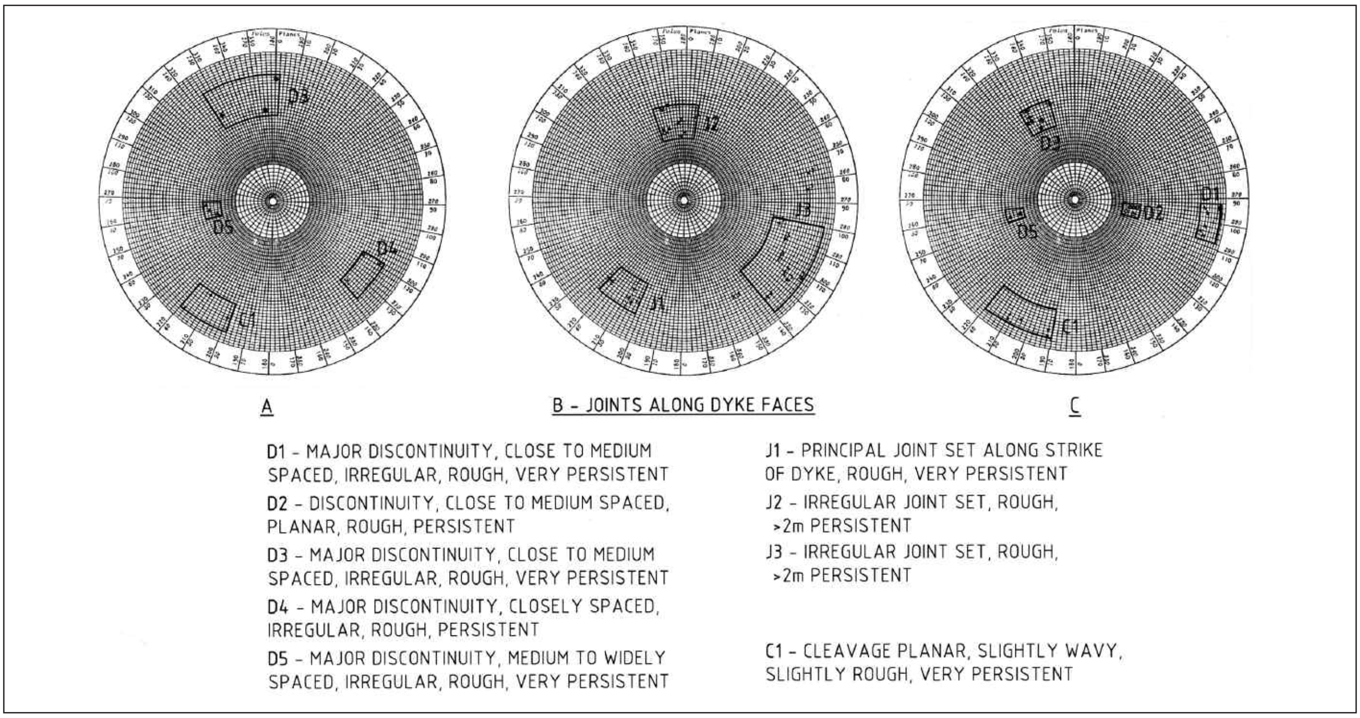

Figure 4. *Example stereographic plots of significant discontinuities (locations shown in Figure 3).*

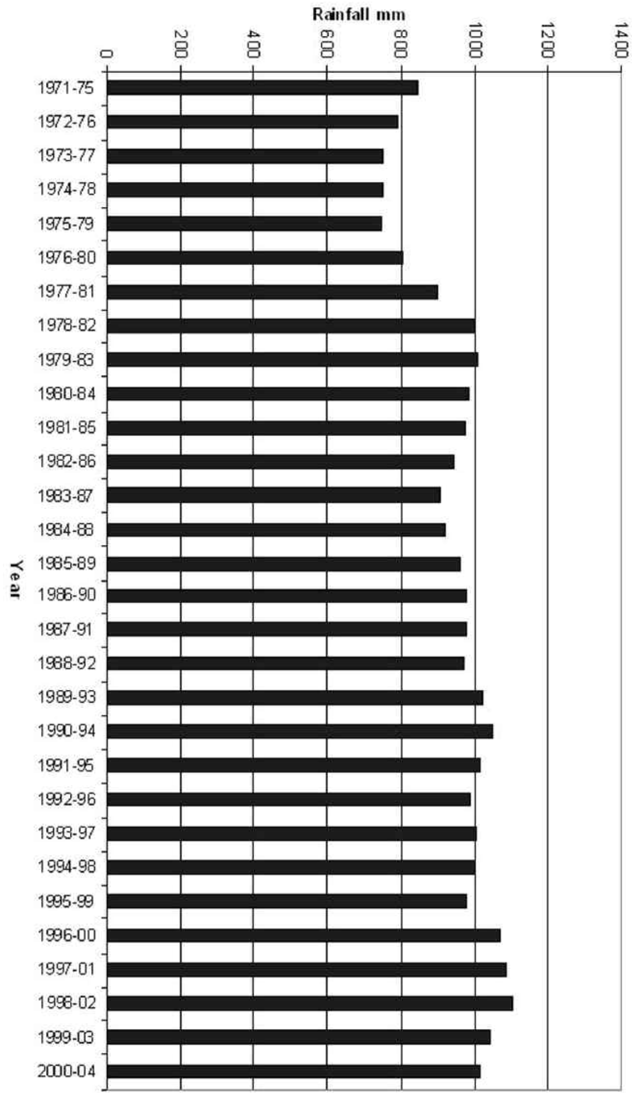

Figure 5. *Five-year moving average rainfall data (source Landmark Trust) which indicates a steady increase in rainfall.*

is a high energy one and the significant non-shoaling wave height has been predicted to be some 10 m (Posford Haskoning Ltd, 2003). The major mechanism of erosion is the exploitation of major discontinuities by storm waves. Sea level rise is anticipated to make little difference to the current level of erosion of the hard rock lithologies exposed on the cliff line. However, a rise in sea level will result in increased erosion of the undernourished beaches. These beaches are typically recharged by land slip material and strewn with boulders. In the winter of 2006, storms removed the majority of the beach material. What sediment was left was readily entrained within storm waves amouring them and facilitating erosion. Any long-term erosion of these energy absorbing beaches will result in the sea cliffs and backshore structures being exposed to a greater ferocity of marine attack. Sediment transport studies have indicated that although sediments move on and offshore in response to storm and more tranquil sea states; there is an overall loss of sediments to the south due to strong currents that occur off Rat Island (the south eastern tip of Lundy).

Retaining and strengthening works

Due to the location and environmentally sensitive setting, the remediation works are complicated in concept, design and execution. They are brought together in an optimum way for remote island working. Each phase of works to the access road started with the conceptual design (Figure 6) from which evolved the final structural design, which provides an engineering solution to the perceived situation, physical and geotechnical conditions for each phase.

It was recognized that in this section of access road there was a landslip potential both in the rock mass and in the superficial material overlying the rock mass. Existing retaining walls were degrading and the track subsiding. As such, it was recommended to construct a new retaining structure formed by steel reinforcement and sprayed concrete. The structure was keyed to the existing road and rock and tied back using piles and anchors. These piles and anchors were designed to stabilize identified areas of rock instability. Piles were socketed into rock at sufficient depth to militate against wedge failure.

Physically it is considered that the impact is minimal. Little excavation works were carried out. The only foundation

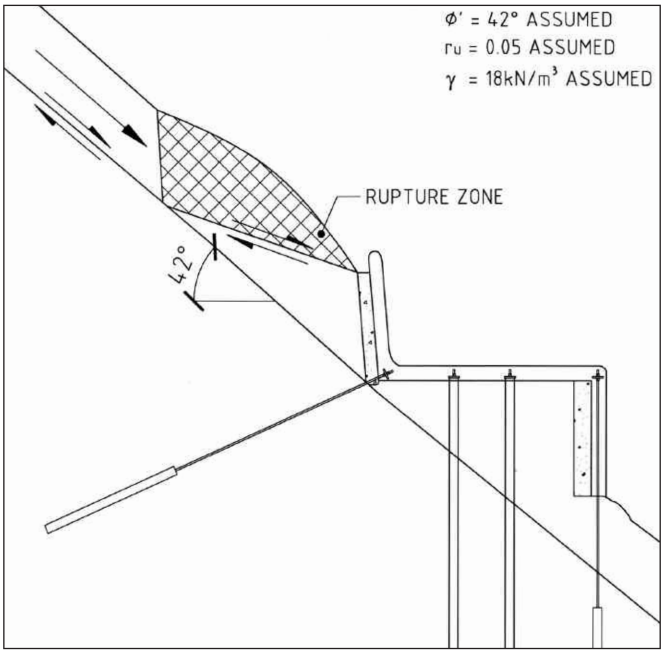

Figure 6. *Conceptual design for retaining and stabilization works. New road and retaining walls are formed over existing structures and tied back using piles and anchors.*

requirement is to build the structure off reasonably competent rock. The structural engineering principle is to utilise the compressive strength in the rock mass, improve the shear strength of the rock mass by anchoring and providing a tensile capacity by the provision of reinforced sprayed concrete facing elements. Using this method, traditionally dug foundations are not necessary.

An assessment of the environmental impact of dust generated during the drilling of piles and anchors was made. It was concluded that the dust would be non-toxic and although it would drift over the local vegetation, given the wind and rainfall typically experienced on Lundy, that there would be negligible long-term impact. It was also considered that movement of the soil above rockhead is likely to continue and that there was still landslip potential if the intrinsic shear strength of the superficial material was exceeded. Although this would not significantly affect the stability of the track, it is important to safeguard future users of the access road. As such, a rock trap was incorporated into the design to prevent over topping.

The use of sprayed concrete

In contemporary engineering, sprayed concrete is more likely to be used as protection against erosion, temporary support or as a structural repair medium, rather than as a material to achieve difficult to form reinforced concrete structures. Sprayed concrete is an excellent medium to form difficult to access structures and is ideally suited to remote island working. Properly managed (using suitable plant and experienced operators), it can be used to produce highly durable and economic engineering solutions. The main advantage of using sprayed concrete in marine environments is that, if placed properly, it produces a consistent concrete structure with high strength and very low permeability, which is vital when using embedded steel reinforcement. The texture and profiling of the sprayed concrete can be readily contoured with the surrounding topography. On Lundy Island, the sprayed concrete was placed by skilled operatives. The cement gun sprayed concrete apparatus is key to achieving the high strength, low permeability concrete necessary for such a scheme. A frame supporting strong mesh netting is erected to the rear of the spraying platform to catch the majority of the rebound material. It has been estimated that less than 0.1% of the sprayed concrete will penetrate the netting. Inspection of the completed road found that drift was maintained within a distance of only 20 cm, minimizing the impact on flora and fauna. Figure 7 shows Lundy Cabbage thriving adjacent to the finished access road. The colour of the sprayed concrete is similar to much of the rock and once weathered combines well within the landscape. The fragility of the slopes and coastline means that any considered visual impact caused by the proposed works is greatly outweighed by any impact caused by doing nothing and providing no coastal protection.

Figure 7. *Photograph of access road almost one year after works showing Lundy Cabbage in the foreground re-established immediately adjacent to sprayed concrete wall.*

Summary

The deteriorating access road along the coastal slope is a vital link to the island and its maintenance is essential. Predicted climate change and increases in sea level have the potential to increase rates of erosion of the coastal slope and foreshore. The piecemeal remediation works and on-going monitoring of the existing road and revetments is necessary to ensure future access to the island. These regular inspections and protection of weak lithologies and master discontinuities will limit preferential erosion and is consistent with a managed retreat philosophy.

All of the projects conducted on Lundy have been complicated in concept, design and execution due to the islands remote location and environmentally sensitive setting. The use of sprayed concrete is considered to be the most cost-effective and least damaging technique for stabilizing the road and retaining walls on Lundy Island. It has allowed work to be done relatively quickly, which minimized any disturbance to flora and fauna.

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