CLIMATE CHANGE AND SLOPE STABILITY OF THE ACCESS ROAD, LUNDY, BRISTOL CHANNEL

by

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ABSTRACT

The jetty and beach road greatly improved access to Lundy. The latest works carried out from January 2007 to June 2009 strengthened and improved a section of the road up as far as Windy Corner, threatened by instability and marine erosion. The landing beach slipway has also been reconstructed. The new road allows access to the island at all states of tide (tidal range is 9.2 m). The potential for slope instability was evidenced by frequent rock falls and slow monitored movement on the coastal slope across which the access road traverses. Climate change appears to be resulting in increasing local annual rainfall and there is evidence of general sea level rise. Of particular significance is the apparent increase in high intensity rainfall events. Both marine erosion and variation in rainfall have been a trigger for instability.

Current strengthening of the access road where it crosses slopes of marginal stability and where it was threatened by marine erosion has been phased over three years. Phase I works involved the urgent strengthening of the road where it crossed slopes exhibiting down-slope movement.

Due to the location and environmentally sensitive setting, remediation works are complicated in concept, design and construction. Road stabilization works on the coastal slope addressed landslip potential both in the rock mass and in the overlying loose bouldery ground.

Keywords: *Lundy access road, slope stability, climate change, marine erosion*

INTRODUCTION

Maintaining the access road across the coastal slope is essential as it is the only route along which supplies for the island can pass. Lundy is a much valued amenity to the large number of tourists and interest groups who frequently visit the island. Both terrestrial and marine ecology is of scientific importance. If the road were to close due to slope failure or coastal erosion, there would be no easy means of access onto the island. As such, adopting a ‘do nothing’ approach was not viable.

Since 1987, John Grimes Partnership has been involved in the engineering of improved access facilities (Grimes and Hearn, 1999) including the jetty, and the beach road. Financial constraints necessitated a phased approach for the stabilization of the access road from the Landing Beach to Windy Corner and the provision of essential protection against marine erosion, with phases being carried out according to priority. The work has been carried out between January 2007 and June 2009, work ceasing July to early October each year.

Both terrestrial and marine ecology is of great significance on Lundy. In particular and unique to the island, is the Lundy Cabbage, *Coincya wrightii* and its associated fauna, which inhabits the coastal slopes above and below the section of Phase I road stabilized in 2008. Several Environmental Impact Assessments on the jetty project and earlier phases of road repairs engineered by John Grimes Partnership have demonstrated that works have not resulted in adverse environmental impacts.

The access road from the Landing Beach rises steeply (10°) and transverses the coastal slope of marginal stability, as shown in Figure 1. The new slipway and elevated section of road at the Landing Beach completed in the summer of 2009 is also shown in Figure 1.

Along much of the road, both on the seaward and landward sides the road and the coastal slope above are supported by various retaining structures. To the landward side the ground rises between 35° to 60° and typically comprises rough vegetated and boulder strewn slopes.

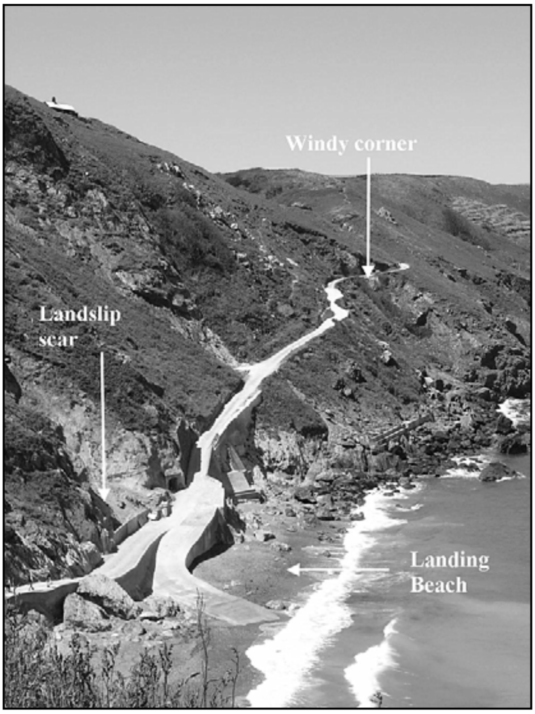

Figure 1: Overview of the Landing Beach and access road along the coastal slope. The landslip scar to the rear of the Landing Beach is the site of retrogressive slipping triggered by marine erosion in the late 1990s

The sections of access road requiring reconstruction and strengthening as part of these works comprised:

- Phase I: a 75 m long stretch located some 130 m up track from the beach. Strengthening works were substantially completed in 2007. (OS grid ref: SS 14190 43905 to SS 14140 43958)
- Phase I: a small section of retaining wall and unstable rock support immediately to the south of Windy Corner, where the road crosses a trachyte dyke at the head of a steeply sloping valley. Stabilization works were completed in 2007. (OS grid ref: SS 14124 43985)

- Phase II: strengthening of distressed high level retaining wall, completed in January 2008. (OS grid ref: SS 14230 43845 to SS 14210 43875)
- Phase III: the slipway and road adjacent to the Landing Beach. (OS grid ref: SS 14280 43800) The Quay wall and adjacent revetments (OS grid ref: SS 14260 43830 to SS 14230 43870) completed in June 2009.
- Phase III: stabilization of the boat cave portal and adjacent rock face (OS grid ref: SS 14245 43832), completed in June 2009.
- Phase III: construction of wall to sea cave; (OS grid ref: SS 14430 43780), completed in June 2009.
- Phase III: various protection works to highly fractured rock, major discontinuities, caves and gulleys quarried by marine erosion; (OS grid ref: SS 14460 43712, SS 14450 43710, SS 14435 43725, SS 14420 43730, SS 14420 43875), completed in June 2009.

GEOLOGY

Lundy is renowned 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) (British Geological Survey, 1980). Sheets, pods and irregular masses of fine-grained poorly megacrystic granite are also widespread. The southeast of the island, where the road stabilization works were carried out, comprise meta-sedimentary Morte Slates, which consist of grey and greenish grey neritic slates with some thin sandy and calcareous bands.

Figure 2 shows a simplified geology map of part of the recent section of stabilization works prepared for engineering purposes.

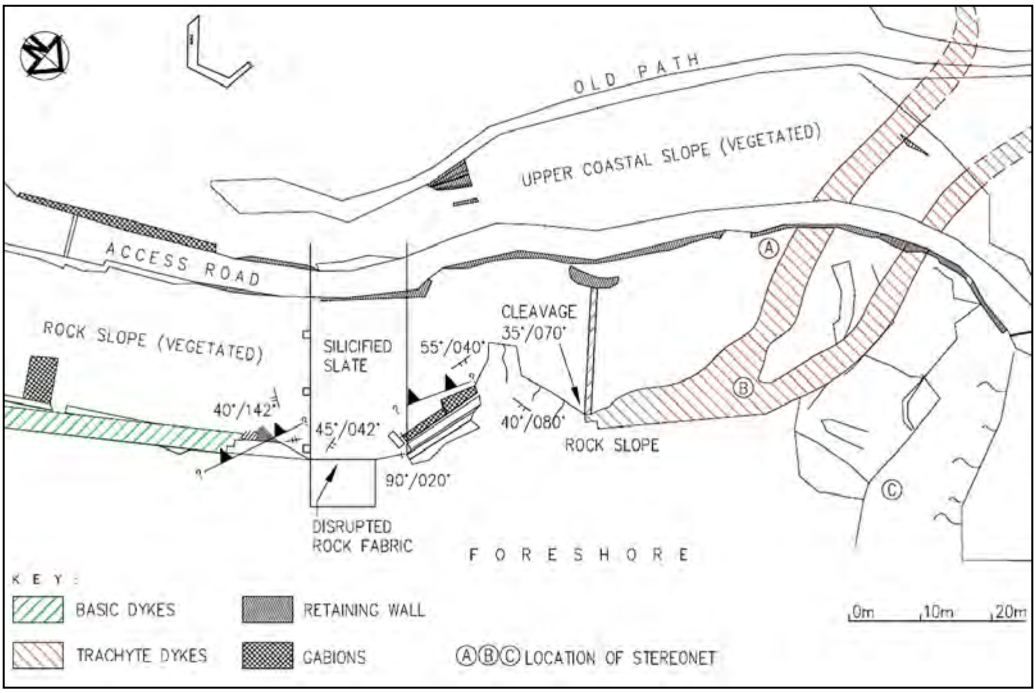

Figure 2: Simplified geology plan of area of Phase I access road stabilization works

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

In respect of the slate, this typically had a well-developed and prominent cleavage tending to be both smooth and wavy with kink bands evident in some areas. The phyllites were less perfectly cleaved. Generally there was a second discontinuity set sub-parallel to the cleavage, which denoted bedding. The cleavage/bedding orientations were variable at different locations, indicative of folding, though no folds axes were observed during the fieldwork. Faults and major joint discontinuity sets were identified, often steeply inclined and orthogonal to the cleavage/bedding planes. Thrust faults sub-parallel to the cleavage were also observed. Some of the discontinuities are highly persistent and planar. The geomorphology is determined to a large extent by these planes. Lower hemisphere equal area stereographic plots recording rock mass discontinuity geometry are recorded in Figure 3.

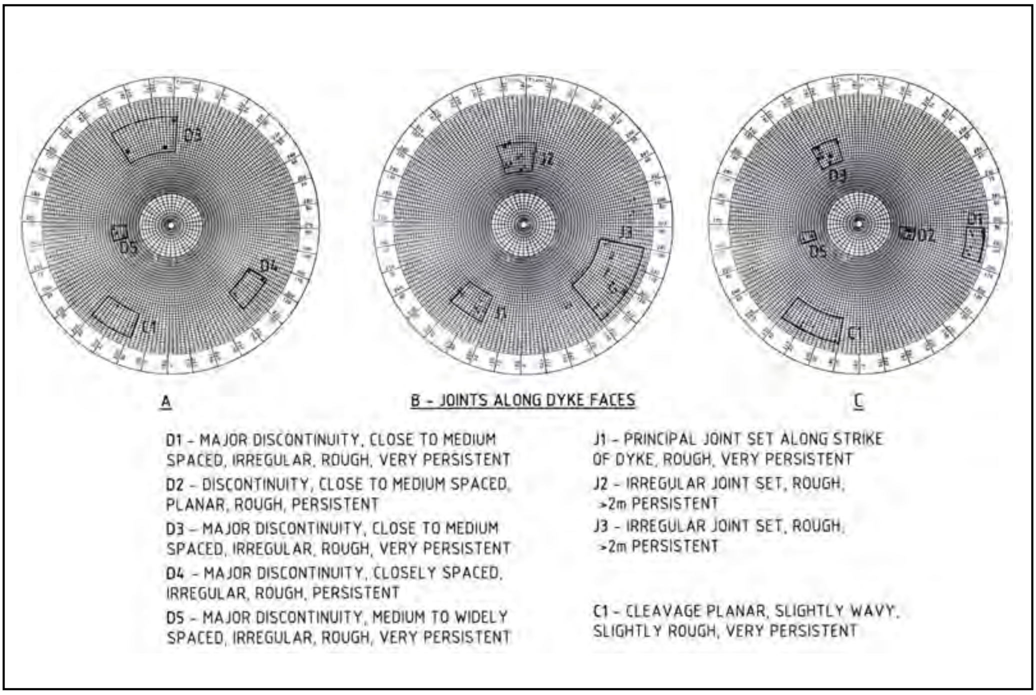

Figure 3: Example stereographic plots of significant discontinuities (locations shown in Figure 2)

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 and along the trace of weathered dykes. Between the spurs and within the valley features are accumulations of talus and ancient slip debris.

GLACIATION

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 ice sheet advanced from the west - north-west of Lundy, with only the land above approximately 110m OD projecting through the glacier. The west and north-western coastline shows some evidence of glaciations ice-moulding, polishing and Quaternary gravel deposits (Mitchell 1968). Whereas the coastal slope on the eastern and southern coastlines displays a rough rock fabric indicative of ice-plucking. The ground above 110 m OD was subject to permafrost conditions.

During site investigations and piling works along the access road, the extremely disrupted and dilated rock mass fabric was evident on the coastal slopes and foreshore. These features are indicative of ice plucking; 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 tilt than landslip (Figure 4).

Figure 4: Example of open texture of exposed rock and juxtaposition of boulders

CLIMATE CHANGE

Figure 5 *(overleaf)* shows the moving 5-year annual average rainfall for the island (rainfall data provided by Landmark Trust), which suggests an increase of nearly 10% in average annual rainfall over a 35-year period. A subjective observation in respect of rainfall patterns is that it tends to include one or several high intensity, but relatively short duration episodes rather than prolonged low intensity rainfall. These high intensity events are particularly likely to trigger instability.

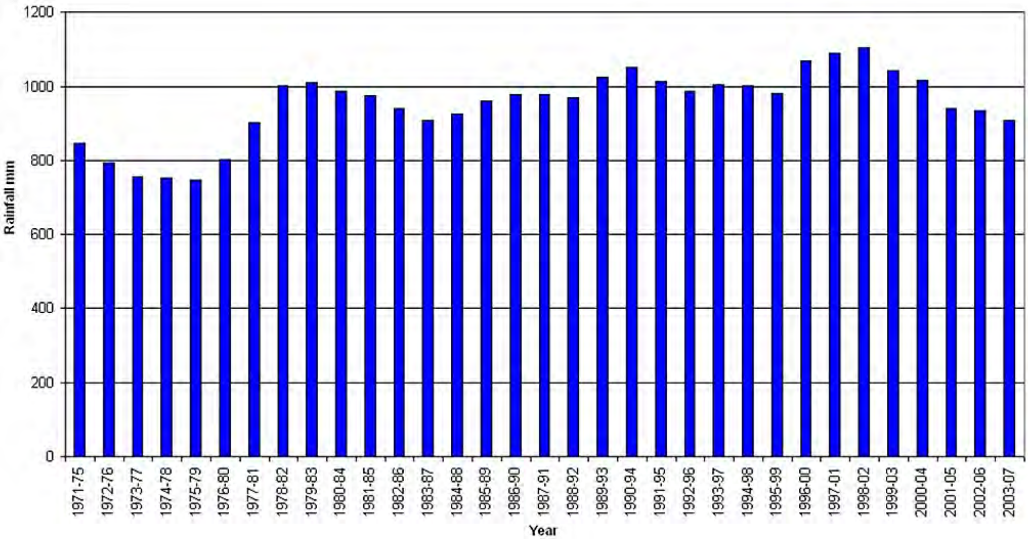

Figure 5: Five-year moving average rainfall data (source Landmark Trust) which indicates a steady increase in rainfall

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 had increasingly exhibited distress. Monitoring showed intermittent or 'stick-slip' movement triggered by prolonged intense rainfall.

An increase in marine erosion is also likely due to the predicted increases in sea level of 640 mm over the next 75 years (Posford Haskoning Ltd, 2003). The marine environment is a high energy one and the significant non-shoaling wave height on the east side of the island was predicted to be some 10 m (Grimes,1990). The main mechanism of erosion is the exploitation of major discontinuities by impinging storm waves. Breaking storm waves 'slamming' into the cliff pressurize trapped air in surface irregularities and fissures in the rock surface. The pressure generated can be substantially greater than hydraulic pressures, in fact up to one hundred times greater. Pressures generated by these slamming waves 'quarry' rock from the sides, rear and roof of actively eroding gulleys and caves. This type of erosion is storm related and can be very rapid.

Sea level rise will result in increased erosion of undernourished beaches. Beaches are typically recharged by land slip material. In the winter of 2006, storms removed the majority of the beach material. What sediment was left was readily entrained within storm waves armouring them and facilitating abrasion of both structures and natural rock. Long-term erosion of energy absorbing beaches will result in the sea cliffs and backshore structures being exposed to a greater ferocity of storm waves. Sediment transport studies conducted by Hydraulics Research Wallingford (1988) 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).

STABILITY ASSESSMENT OF THE COASTAL SLOPE

For several years prior to reconstruction, movement had been recognized along the section of road ascending the coastal slope. Much of the original track along this section was retained by dry stone walling. Although the rockhead is relatively shallow, the dry stone walls were constructed on talus or ancient slip debris above the rock. The walls were also inadequate and increasingly showing distress; they were becoming dilapidated, bulging and slipping down slope. There have been localised collapses of the walls, tension cracks along the road and above retaining walls opened and progressive subsidences were evident (see Figure 6). Small magnitude (< 1 tonne) landslips from above the road were a common occurrence. In places, angled sectional steel had been driven into the ground to provide additional support to the retaining wall on the downslope side of the road. Walls were in a very poor condition with a high risk of sudden collapse under loading, particularly during wet weather. They were also inadequate to proffer any restraint against landslip and to mitigate such an occurrence.

Prior to the works, the road use had been subject to a risk assessment prohibiting its use in wet weather and necessitating measurement across zones of known displacement to ascertain any incremental down-slope movement. Measurements were necessary prior to cargo trafficking and following severe and prolonged wet weather. Zones where movement was evident also required observation during cargo movements.

Figure 6: Tension cracks along edge of road prior to stabilization works (OS Grid Ref: SS 14150 43950)

Land-slipping of generally smallish quantities of soil and rock debris had been identified as being active. This was seen to be generally triggered by intense rainfall. Discontinuity controlled sliding is also active particularly in the cliffs and steep rock faces above the road. The potential for wedge failure in the lower slopes was also recognized. Below the road, discontinuity shear strength is generally such that such instability is infrequent.

RETAINING AND STRENGTHENING WORKS

Due to both the environmentally sensitive setting and difficulty in ensuring consistent quality of work and economic construction on a remote island, the remediation works were complicated in concept, design and execution. Optimisation was achieved using a sprayed concrete technique known as Guniting. The dry process was used (Grimes & Hearn, 1999). Cement and a well-graded sand (finer than 10mm) was mixed and sprayed to form structures. Water is added at the nozzle. The skill of operatives facilitated a consistent, strong and durable concrete.

The new retaining structure (OS grid ref: SS 14190 43905 to SS 14140 43958) was formed by steel reinforcement sprayed concrete, constructed over the existing road.

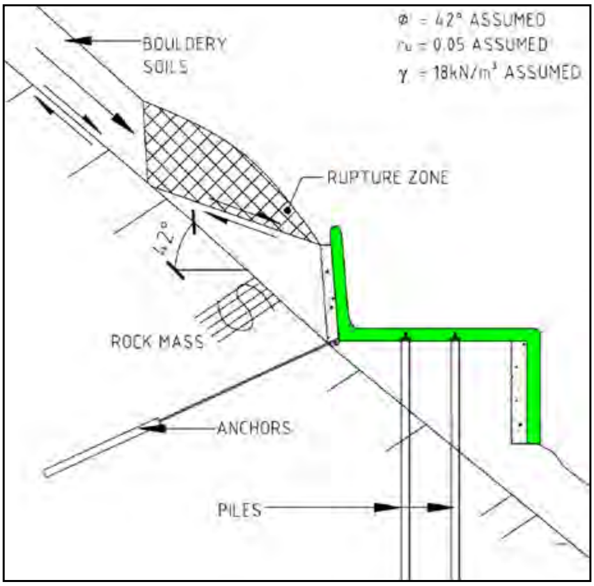

Figure 7: The conceptual model for stabilization of the access road across the coastal slope (Grid Ref. SS 14190 43905 to SS 14140 43958)

Piles were extended into the ground to provide an adequate rock socket below the level that rock joints were found to be dilated and below which the ground could be adversely affected by sliding in the lower slope. The up-slope section was designed to resist any pressure generated by down-slope sliding. Grade 316 stainless steel anchors were extended between 6m to 12m into the rock depending on its quality to resist down slope movement. The reinforced sprayed concrete arrangement is a continuous stiff structure. Should part of the structure be heavily impacted by landslip, the load will be effectively shared by adjacent structures.

It was also considered that movement of the superficial ground 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 far as possible, up-slope walls were constructed to a level that projected above the upper ground surface and filled behind with appropriate 'soft' material to act as a land slip mitigation structure; i.e. reducing down slope velocity of slipping ground and, to some extent, catching debris.

The toe of the down slope wall could not be extended into rock due to site constraints. In the event of slippage from below this wall, the arrangement remains adequately supported and restrained by the configuration of piles and anchors. Galvanized

'Kwikastrip', made by Halfen, was built into the base of the lower wall to facilitate the provision of structural continuity with any underpinning should this ever prove necessary.

It is considered that the impact on the environment is minimal. An assessment of the environmental impact of dust generated during the drilling of piles and anchors was made. It 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, it would have a negligible long-term impact.

THE FORESHORE

The landing beach is a wave cut platform covered with slatey shingle. The beach has always tended to be undernourished and highly mobile. The sediments that accreted in the summer months were typically rapidly deflated in winter. The beach had been systematically deflating over the past 20 years. In 1989-1990 it was substantial recharged with sediments derived from the blasted excavation of the road across the promontory. Prior to the recent slipway reconstruction works, the beach was deflated to the extent that large areas of bare rock were exposed (Figure 8).

During and since the winter of 2008-2009, when the slipway was under reconstruction it was apparent that the beach had continued to accrete. Although some future deflation is likely during winter months, the new slipway appears to be encouraging the beach to inflate and stabilize. In May 2009 the shingle mass was greater that we had observed for perhaps five years. Shingle beaches provide good protection against marine erosion effectively absorbing wave energy.

Figure 8: Deflated beach during winter months. Base of quay wall undermined and rock exposed on beach

Marine erosion has always exploited both weak lithologies and structural geologic weaknesses in the hard rock sea cliffs (Figure 9). The slates are also faulted and distorted, with faulting frequently parallel to the cleavage. Intra-cleavage fault zones of loose brecciated material are easily eroded. An example is evident to the rear of the sentinals. Such faulting along which rapid erosion has occurred is evident in the protected sea cliff extending out to form the promontory (SS14375 43728).

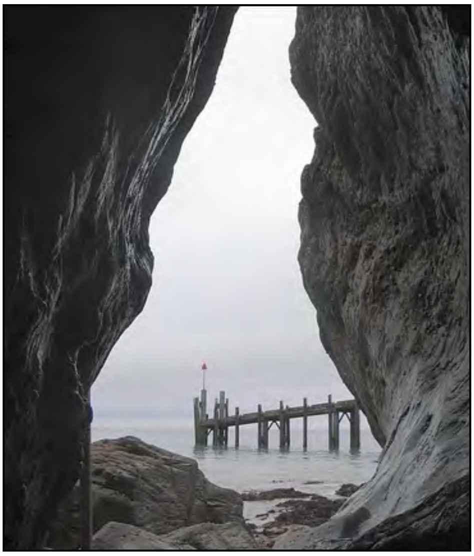

Figure 9: A large sea cave which undermined the beach road (OS grid ref: SS 14430 43780). A protective facing was constructed across it as part of the necessary works

WORKS TO MAINTAIN VEHICULAR ACCESS ALONG THE BEACH ROAD

These works involved localised reinforced gunite protection of the major geologic weaknesses in the sea cliffs where these were being significantly eroded by storm wave action, to the potential detriment of the road. The landing beach slipway had deteriorated to an unusable condition as a result of marine erosion. To the south east of the boat cave, marine erosion was also the initial trigger for the retrogressive sliding in the cliff/steep slope to the rear of the road. Elevating the road afforded necessary protection to the cliffs but also improved access (Figure 10).

Figure 10: Overview of the Landing Beach during works

The road level was increased to 7m AOD, which is 2m higher than the highest astronomic tide level (5.0m AOD). This allows use of the road at all states of the tide, with some restriction on access during storms. The slipway profile required adjustment to allow for the increase in road level. The harsh marine environment necessitated the use of an anchored solid reinforced concrete slipway arrangement to achieve an acceptable level of structural durability.

Structure of the road consisted of an anchored reinforced gunite retaining wall backfilled with fragmented slate derived from scaling The Saddle (Figure 11). Reinforcement was grouted into competent rock at regular centres to form vertical cantilevered beams. Such an arrangement is referred to as 'soldiers'. The soldiers were restrained against outward movement by anchors extending into the cliff. A reinforced gunite wall was formed by spanning reinforced concrete horizontally between the 'soldiers'.

Figure 11: Spraying of gunite to rear of slipway

The existing revetments forming the Quay (SS14255 43830) and cliff protection to the north east were also in a poor state of repair (Figure 8). Severe basal abrasion and extensive undermining was evident. A high level masonry retaining wall (Figure 12) had cracked and exhibited recent movement and was considered to be in danger of sudden and catastrophic collapse. Engineered works included the construction of anchored reinforced gunite strengthening to the existing revetments (Figure 13), gunite infill of erosion features and the construction of anchored reinforced gunite protective aprons (Figure 14). The aprons reduced the risk of quarrying type erosion.

The high level wall (Figures 12 and 13) was strengthened as part of Phase II works. The rock slope below the road (Figure 12) was susceptible to landslip, which could be triggered by storm wave activity. The rock was underpinned and secured.

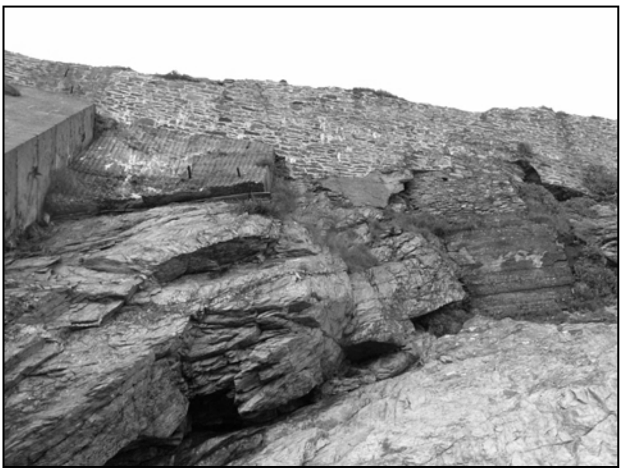

Figure12: High-level wall retaining access road which displayed cracking and was considered to be in danger of collapse


Figure13 (left): Completed works to the quay and revetments. **Figure 14** (right): Gunite facing to the sea cave (Figure 9)

Adjacent to the boat cave (Figure 10) retrogressive sliding has occurred since the mid 1990s. In 2005 it was observed in the cave that there was displacement of rock above a discontinuity plane, which dipped into the north-east side of the boat cave portal. Masonry in the boat cave had also loosened and displaced in response to this movement. Evidence indicated that continuing discontinuity controlled landslips might regress back into the hillside and could eventually adversely affect the castle. With the prospect of further landslip induced increased incision into the slope, the risk of larger more frequent slides would increase. Measures to halt basal sliding were considered imperative. Works were designed to stabilize the slopes in an attempt to halt this retrogressive slippage. Stabilization works included low level, localised dentition, comprising a reinforced gunite surface layer to act as an essentially rigid tension skin across the discontinuous rock anchored by bolts extending to depths of up to 4m. Within the boat cave a reinforced sprayed concrete lining dowelled into the rock floor, and sprayed against an irregular rock surface, provided the necessary tensile restraint to the rock mass exhibiting movement. A new gunite wall to the rear of the road, which retains soft ground acts as a land slip mitigation structure. The impact on the road from falling rock will to some extent be alleviated by this arrangement.

THE USE OF GUNITE

In contemporary engineering, gunite is much more likely to be used as protection against erosion, temporary support or as a structural repair medium, than as a material to achieve difficult to form reinforced concrete structures.

It 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 to protect it against corrosion. The texture and profiling of the sprayed concrete can be readily contoured with the surrounding topography. It can be used just above lowest tide levels using Sika 4a to achieve rapid set.

On Lundy, the gunite was placed by skilled operatives, Martin O'Connor, Russell Yelland, and Paul Clark, with Gareth Chapman of Saxtons (a Cornish Drilling Company) being responsible for drilling and anchoring. Martin, Russell and Paul had previously worked on the construction of the beach road, jetty approach structure and shore building foundations, all constructed using rock anchored reinforced gunite. The cement gun sprayed concrete apparatus is key to achieving the high strength, low permeability concrete necessary for the scheme. A frame supporting strong woven flexible fine meshed netting was 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 minimal, and key to reducing the impact on flora and fauna. Figure 15 shows Lundy Cabbage thriving adjacent to the finished Phase I strengthened road.

The sprayed concrete colour 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 15: Photograph of access road almost one year after works showing Lundy Cabbage in the foreground re-established immediately adjacent to sprayed concrete wall

CONCLUSION

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 island's 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. It has allowed work to be done relatively quickly, which minimized any disturbance to flora and fauna.

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