GEOTECHNICAL STUDY AREA G9

SANDOWN BAY CLIFFS, ISLE OF WIGHT, UK

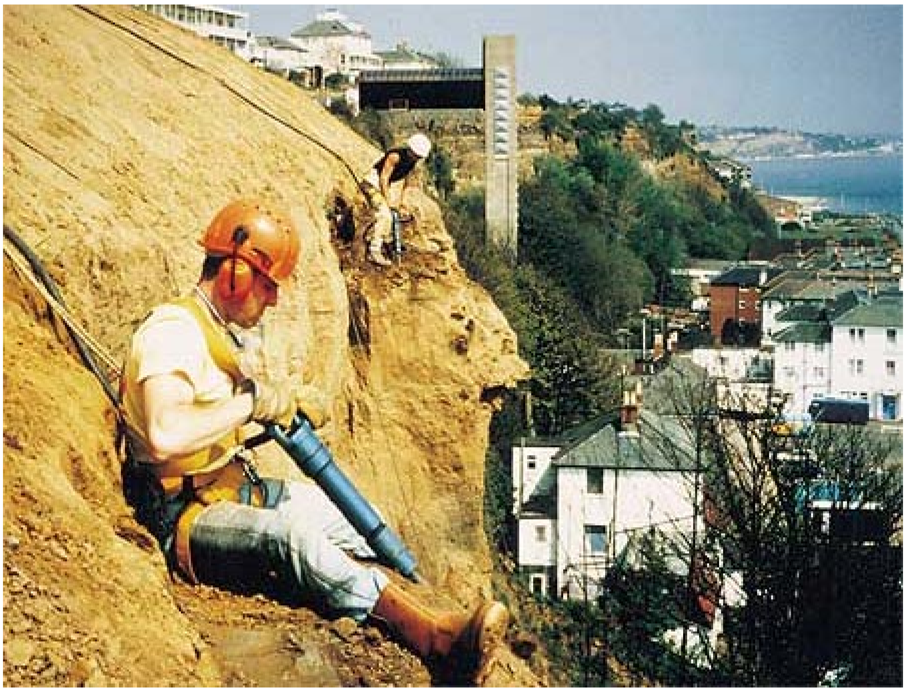

Plate P9 ***Cliff stabilisation works, Sandown Bay, Isle of Wight***

1. BACKGROUND

This study area relates to the management and stabilization of an abandoned Lower Greensand seacliff at Shanklin on the south-east coast of the Isle of Wight (see Figure G9.1). The cliffs, which are vertical and overhanging and up to 40 metres high, are in a major tourism area and have property development, promenades and areas of public access, both above and below the face. The rock material is a weak sandstone subject to minor and mass failure. In recent years and during the lifetime of this particular project, a detailed assessment has been made of the 3.5 km length of cliffs in order to establish the mechanisms of cliff failure, details of the geology, rates of erosion, as well as to provide a hazard and risk assessment. New work undertaken this year and as part of this project is helping to establish a methodology for relative risk assessment and how this has been used in the management of the cliff line in order to prioritise areas for remedial works is described below.

The areas of cliff identified for priority stabilization have been treated (Plate G9). The methods adopted are described and illustrated below and have been undertaken following various investigations, in situ tests and research being carried out, as well as reviews of the details of the design and implementation of the stability measures. Essentially these have consisted of realignment of the cliff top, scaling, rock anchoring and rock bolting, buttressing, drainage and structural support to existing overhanging engineering structures. In addition, experimental application of an impregnating epoxy material to create a weather resistant crust over the cliff face was also commissioned. This element of the geotechnical study of Isle of Wight sites provides an example of a systematic approach to the management of a weak cliff line in an urban area and, both in terms of the text and the illustrations accompanying it, could provide an interesting model for management of weak cliffs in such locations.

2. THE IMPACT OF INSTABILITY

The 3.5km length of weak sandstone cliffs between Shanklin and Sandown on the south-east coast of the Isle of Wight lies within a major tourism area that has a history of cliff failure and progressive cliff recession. The rate of recession, although relatively slow, has placed at risk some of the cliff top paths and structures in areas of public access and amenity. Furthermore the debris from rockfalls and cliff face erosion presents a significant risk to the safety and development of seafront hotels, businesses and leisure facilities adjacent to the base of the cliff (Plates G9a, G9b, G9c).

The failures became sufficiently problematical by 1988 to merit a general study of cliff stability which was commissioned by the former South Wight Borough Council, in order to provide data on which administrative decisions concerning the management of the cliffs could be based. A procedure has now been developed to evaluate the relative risks to public safety and property posed by different areas of the cliff and a prioritised programme for stabilization works that can be adapted to available budgets, has been prepared. The purpose of this study area example is to detail the methodology, findings and conclusions of the study and report on the design and implementation of the remedial measures undertaken to date in the context of this LIFE project.

In order to assess responsibilities and liabilities for the cliff, it was necessary to define cliff ownership along the sections of the cliff where stabilization works were required. This in itself presented unforeseen difficulties, both due to the antiquity of ownership in some cases and, more importantly, because the title of land ownership may shift as the cliffline retreats due to progressive erosion. For example, when land boundaries were drawn up for ownership plans, often at the end of the last century, the cliffline would have formed the boundary between properties. The vertical line is represented in plan by a single line in which event the ownership and thus responsibility for the cliff is hard to define. However, as the cliff retreats it does so into the property of the cliff top owner. Ownership of the cliff, therefore, passes firmly to the cliff top owners. The land left by cliff recession at the base of the cliff theoretically belongs to the cliff top owners, however, it may be claimed by the cliff bottom owners under ‘squatters rights’ if utilised by them for a period in excess of twelve years.

Irrespective of cliff ownership, it is likely to be the owner of the cliff bottom property who benefits most from stabilization. Cases in law (eg. Leakey -v- the National Trust, anon. 1980) suggests the owners of the land which threatens to cause nuisance to adjoining properties due to natural processes and who are aware that such a hazard exists are likely to prevent such a nuisance or be responsible for the outcome of any such nuisance. This situation may be complicated, however, as the landowners resources may be assessed in terms of the owner of the ‘threatening’ property being able to undertake and pay for remedial measures and the ability of the ‘threatened’ property owner to protect himself from damage.

Further to this, the recent Court case at Scarborough in North Yorkshire following the loss of the Holbeck Hall Hotel initially increased the responsibility of down slope landowners. This was contested by Scarborough Borough Council in the appeal court and was successfully overturned. Nevertheless, landowners must ensure that their land does not cause a nuisance or present safety problems to adjacent owners. Local authorities and others are particularly concerned in relation to the public safety and financial implications.

3. ROLE OF KEY AGENCIES

The key agency involved with Sandown Bay cliff stabilization is the Council, which is the owner of much of the cliff (together with local residents) and which has responsibility for safety and coastal management. There are no other key agencies directly involved in this study area.

4. THE STUDY AREA

The Sandown Bay cliffs range in height from approximately 10 to 35-40m and are inclined at between 60^0 and vertical to overhanging, although their common inclination is $70\text{-}80^0$. It is the combination of this steep cliff morphology, the largely weak and incompetent nature of the rock mass and the presence of discontinuities which lead to the problems of instability. See Figure G9.2.

The cliffs are formed from the gently dipping southern flank of the Sandown pericline. The rock mass of the cliffs is composed entirely of Ferruginous Sands of the Lower Greensand (Cretaceous) Series overlain by weathered sands and superficial deposits (White 1921). The Ferruginous Sands are quite varied in their degree of cementation but are predominantly friable, weakly cemented fine to medium sands. However, within the sequence there are bands of more Ferruginous material which could be described as Sandstone, where the degree of cementation is higher and the resistance to failure and erosion is greater so they often stand proud of the cliff face.

The degree of jointing of the rock mass varies throughout the study area both in terms of joint frequency and orientation. Of primary importance to the stability of the cliffs are stress release joints orientated sub-parallel to the cliff face.

Well defined seepage lines form a prominent feature along much of the cliffline. The lowest seepage horizon represents the phreatic surface whilst others higher up the cliff are water tables perched above more clay or more cemented, less permeable horizons. The combination of seepage horizons and ferruginous cementation result in the distinctive cliff profile caused be differential erosion. Seepage lines are generally marked by an indentation or bench caused predominantly by seepage erosion and freeze thaw activity, whilst the ferruginous bands frequently overhang.

Talus resulting from cliff face erosion and cliff falls has accumulated at the toe of the cliff and is relatively well developed in the southern portion of the study area between Appley Steps and Hope Road approach. It is characteristically 5-10m high, up to 20m wide and inclined at $30\text{-}40^0$, although shallower and steeper angles have been recorded. This material generally consists of a silty clay and silty, fine-medium sand. Talus also collects on the mid-height benches and in all cases talus can become saturated and is subject to landsliding.

Erosion is taking place along the cliff face through the processes of seepage erosion and mechanical and chemical weathering, including the breakdown of iron oxide bondings, and freeze thaw processes. The undercutting of the cliff above seepage horizons in particular increases the risk of failure. Instability encountered on the cliff face include plane, wedge and toppling failures.

The accumulated talus at the base of the cliff and on the cliff face benches provides protection to the face against sub-aerial denudation. Once the seepage zones are protected by accumulated talus, one of the primary causes of cliff falls is reduced. However, groundwater then seeps directly into the talus, hence encouraging talus instability and a re-exposure of the lower cliff face.

5. CURRENT STATUS AND APPROACH

A detailed survey of the cliff was undertaken early in this project, which formed the basis of the management strategy for the cliffline. The objectives of the cliff stability survey were:

- To collect engineering geological data on the cliffs and to identify the mechanisms of failure for both the cliff and talus slopes.
- To record the engineering geological data on a section by section basis to enable a systematic assessment to be made of the cliff and talus hazard throughout the study area.

- To assign a ranking system for the cliff and talus failure hazard and to differentiate the relative hazard through the study area.
- To assess the risk posed by cliff and talus failures to the various, commercial, residential and amenity developments in the vicinity of the cliffs, thereby to identify, on a rational and objective basis, those areas of highest risk requiring priority stabilization treatment.
- To identify land ownership in the vicinity of the cliffs throughout the study area for consideration of legal responsibility and liability for stabilization work.
- To develop a programme and specification for the appropriate stabilization measures which meet the objectives of reducing risk, within the available local authority budgets.

Data collection was facilitated by the division of the study area into sections. In order that the hazard and risk data could be collected and assessed in a rational manner the sections were delineated on the basis of geology and land use. This method of data acquisition chosen involved the systematic completion of proformas for each section of the cliff and talus and a proforma for each building, cliff top paths, and for each of the six cliff paths that provide access down the cliff.

The cliff proformas contain a sketch of the cliff face and cliff profile and a description of cliff geology. The latter included material composition, stratigraphy, geological structure data, locations, mechanisms and size of cliff failures, the potential for further instability, location of seepage lines, cliff vegetation and any structures such as paths and buildings in the vicinity of the cliff. Some of this information was collected by cliff abseiling techniques. The talus slope, if present, was described in terms of its drainage, stability, vegetation, slope and general dimensions. These data enabled the relative hazard of cliff falls and talus failure to be assessed for each section. Cliff and talus hazard ratings of between 1 and 4 (4 = highest hazard) were assigned to each section of the cliffline on the basis of a qualitative assessment of the potential for failure. See Figure G9.3.

The derivation of the rating for the hazard posed by cliff fall or talus failure to each of the elements has been discussed above. An estimated value was assigned to each element and categorised into a rating based on a qualitative assessment of commercial value, cost of reinstatement and the potential for injury or fatality if large scale failure occurred.

The vulnerability of the land use elements was assessed by considering first the distance of the element of the hazard and second the vulnerability to damage as a function of construction type. In the case of buildings at the base of the cliff the construction type and distance from the toe of the cliff or talus were recorded on the building proformas and the rating system as shown in Table 1 below, together with the damage susceptibility was built into the assessment of risk.

DISTANCE FROM BUILDING TO TOE OF CLIFF / TALUS (M)	RATING
1	6
1-2	5
3-5	4
6-10	3
11-20	2
20	1

Table 1 Rating system for buildings at base of cliff

5.1 Cliff stabilization works

In recent years a total of approximately £1,500,000 has been spent on cliff stabilization works; this has followed a prioritised works programme as described above (see Figure G9.2). The main elements of the current approach have involved re-profiling of the cliff top where sufficient space is available for the cliff top to be de-vegetated and battered back. Re-profiling was concentrated at the southern end of the Bay and allowed the removal of superficial deposits, which as a result of cliff recession were overhanging, plus some of the overhanging sandstone. More importantly, however, re-profiling removed a number of large buttresses left by the failure of adjacent material along joints perpendicular to the face and tension fractures on the upper cliff face.

The angle of the battered slope was determined by a number of factors. It was necessary to remove as much of the existing unstable upper face as possible if more expensive stabilization measures were not to be employed; land take, however, had to be minimal. Observation of existing slopes showed that an angle of 60^0 should be stable and consultation indicated that this would be the maximum able to support the controlled growth of vegetation. The ability to grow and maintain vegetation on the slope was important as this would prevent excessive infiltration into the cliff top close to the face. The second technique used was face scaling. This work involved the removal of loose materials using hand held pneumatic drills with operatives working using abseiling techniques.

For some areas of cliff different methods of rock anchorage were appropriate. Anchors, bolts and dowels were incorporated into the completed cliff works. Rock anchors were installed to provide support for the cliff beneath cliff top structures and overhanging footpaths where cliff top space was insufficient to allow relocation of the paths. Rock bolts and dowels were installed in natural rock buttress areas where the volume of rock within the buttress was too large to remove and / or the buttress was deemed to provide a restraining effect on the cliff behind. Standard single cable anchors of up to 9m in length were designed to accommodate a 5 tonne load, with double corrosion protection (as detailed in British Standard 8081) being used.

Lightly loaded rock bolts with high bolt density were considered desirable for several reasons. First, a greater bolt frequency provides a better area coverage in fractured rock. Also the long term effectiveness of a highly tensioned bolt in weak sandstone is questionable irrespective of the initial capacity of the fixed anchorage. With a greater frequency the effect of loss of tension due to loss of face plate integrity in a single bolt will be less critical. Allowance for a degree of bolt failure was made in the design, and long term monitoring of the bolts will provide empirical data from which a prediction of actual bolt performance can be more accurately made.

In addition to these measures, meshing comprising tensioned maccaferi mesh was installed over the entire rock face in certain locations to provide support for the face where confinement of unstable portions of the face was deemed preferable to scaling. This particular technique was also appropriate adjacent to flights of steps where there was a risk to pedestrians from occasional rock falls or slides.

Much of the instability within the cliff was the result of undercutting be erosion and weathering along seepage lines. In addition, during the drilling for the test bolts, it was discovered that a significant amount of water collected in open fractures behind the cliff face. To minimise these effects drainage holes were installed in the cliff face. This took the form of a 50mm diameter slotted tube installed into the face at key locations such that seepage horizons were drained and, where encountered, waterfilled tension fractures behind the cliff were also drained. The drainage holes proved to have a profound effect on reducing the consequence of freeze thaw action during the freezing winter conditions.

In critical areas beneath footpath overhangs where further deterioration of the cliff face could not be allowed, their complete protection was installed in the form of permanent timber shuttering. Pressure impregnated, stress graded timber planking was held close to the face by rock bolts. High density fill material comprising a load bearing polystyrene fill was cut to the appropriate size and shape and installed behind the timbers. This acted as a lightweight fill against which the timbers could be tightened on the bolts, thus achieving both a complete weather proof protection and active force on the cliff face.

As part of an assessment of stabilization techniques an experimental section of cliff was treated chemically by means of injection and spraying of materials. Those substances requiring injection into the rock were not pursued as it was felt that any induced pressure behind the cliff face could create an adverse effect. The use of sprayed substance was, therefore, investigated further. A large scale trial was undertaken using a very low viscosity impregnation epoxy resin applied as a fine spray to the rock surface. The cliff face was first repaired by removing loose blocks and blowing the cliff face with compressed air to remove any loose weathered outer surface material. The epoxy spray was then applied at rates of 0.5 litres per m^2 to the face. On setting, a crust of some 2-5cm in thickness was formed over the treated area. It was evidence that whilst this was highly beneficial, on its own the epoxy is not the solution to overall stability. Consequently tensioned mesh was also installed over the cliff face to ensure overall cliff face integrity was maintained.

In order to go some way towards quantifying the effects of the epoxy spray a crude durability test was performed to compare an untreated and treated sample of the bonded sand material. The epoxy impregnation prevented the immediate breakdown of weak bonds on the outer surface of the sample area. Also water was prevented from soaking into the body of the sample. Disintegration did eventually occur due to infiltration through insipient fractures which had not been totally sealed by the epoxy.

It is too early to ascertain fully the effectiveness of the epoxy resin impregnation, however, early results suggest that lithological variations within the rock mass will render some areas unsuitable for treatment. In one area where the rock material was especially weak the hard skin created by the epoxy impregnation began to peel away from the cliff face almost immediately. Elsewhere, however, results are promising and it is hoped that with other supporting systems this will significantly reduce face recession.

With respect to the talus slope at the base of the cliff, on-going instability has the effect of re-exposing the lower cliff face at a number of locations along the cliff line. In addition to removing lateral support of particular importance where seepage horizons discharge directly into the talus, this also allows the resumption of sub-aerial denudation of the face. A range of drainage works were undertaken to improve the situation by improving stability.

6. EXPERIENCES, SUCCESSES AND PROBLEMS WITH CURRENT APPROACH, AND LESSONS LEARNT

The description above has outlined the basis for assessment of the hazard and risk along the Sandown Bay cliff line and has outlined some of the remedial techniques that are being adopted to address specific prioritised problem areas. This location, therefore, identifies a procedure that has been tried and tested whereby the condition of a weak cliffline may be assessed and remedial works designed as part of an on-going management programme. The hazard rating system employed provides a rationale by which prioritised stabilization works to fit budgetary constraints can be designed and implemented. It is believed that this approach may prove valuable to others wishing to adopt a phased programme to addressing hazards in weak rock locations such as this.

7. REFERENCES

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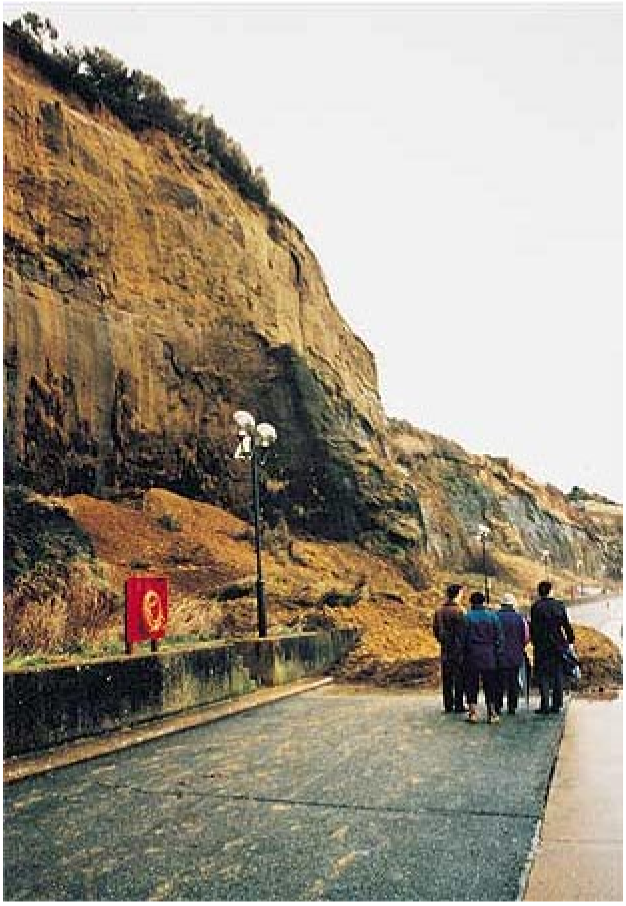

Plate Gba ***Cliff fall at Littlestairs, Shanklin***

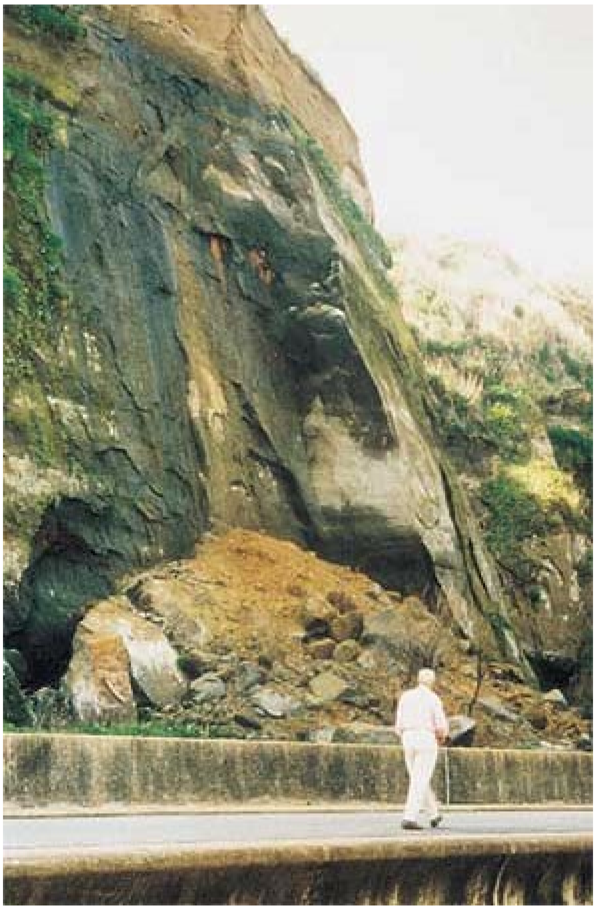

Plate G9b ***Cliff fall at Littlestairs, Shanklin***

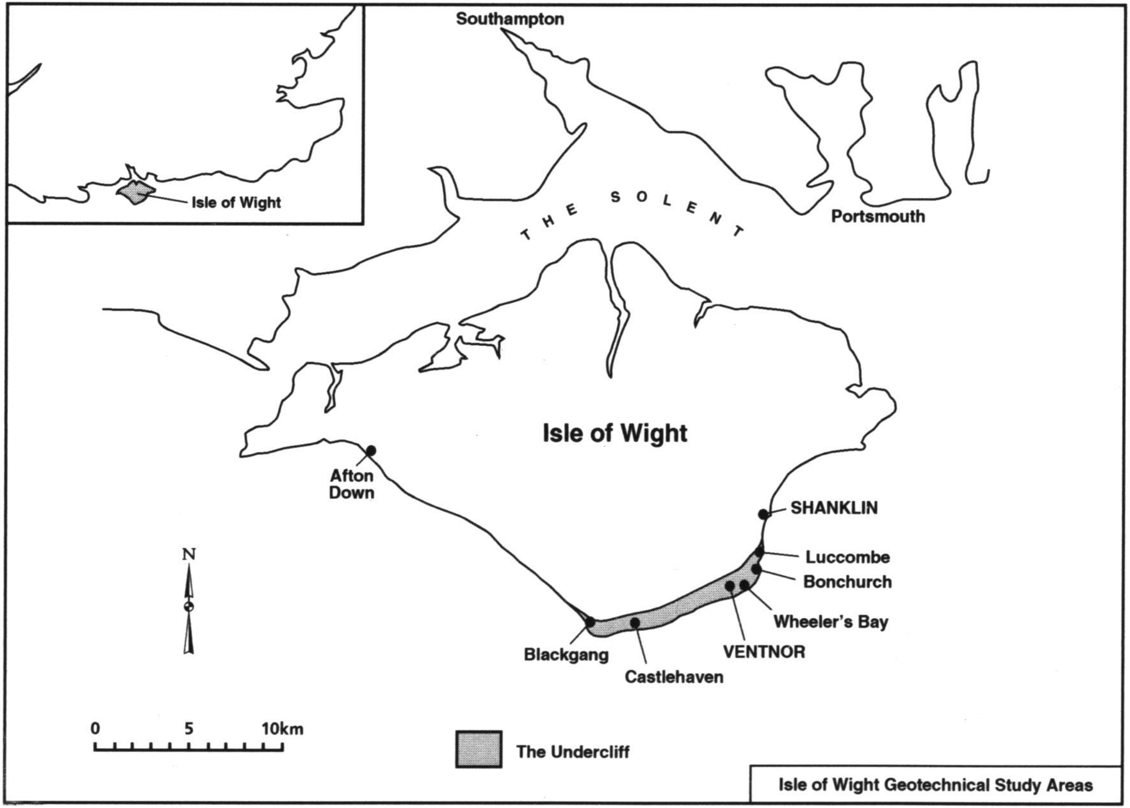

Figure G9.1 Sandown Bay location map.

Plate G9c ***Cliff fall at Littlestairs, Shanklin***

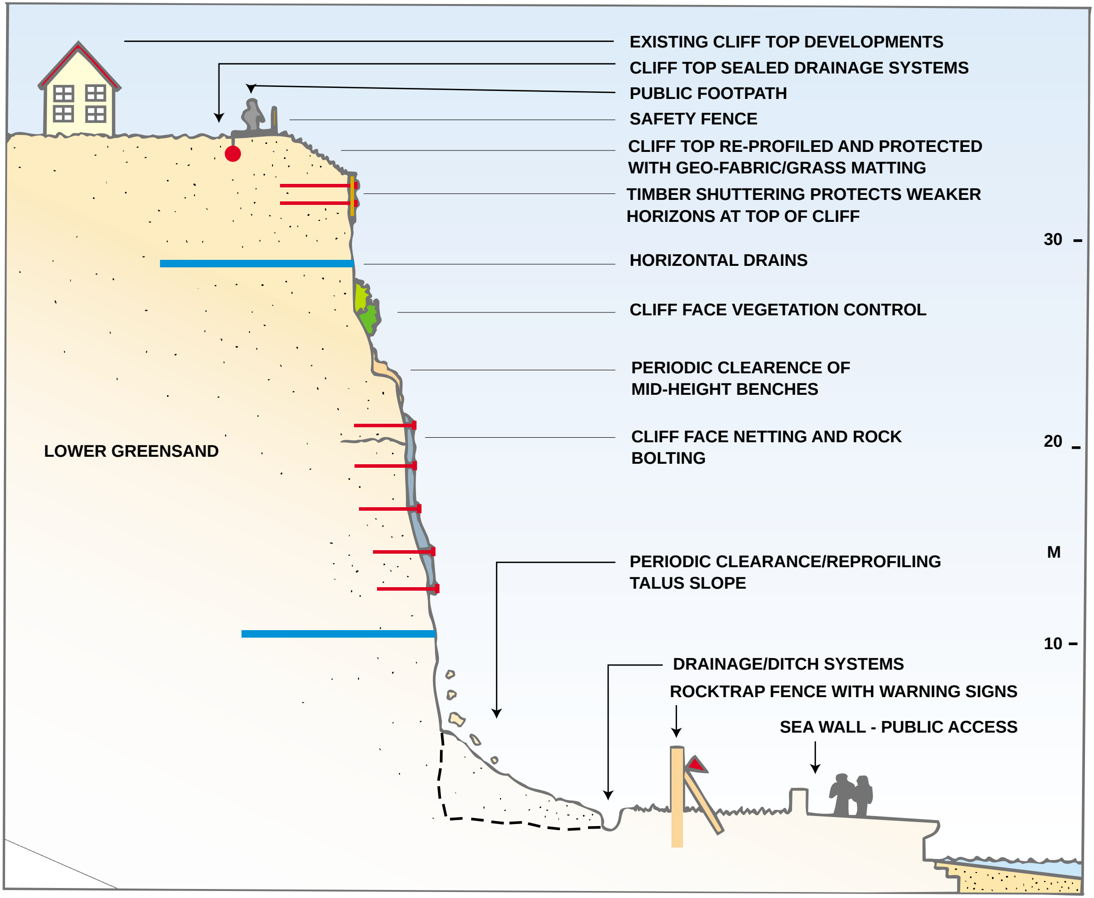

Figure G9.2 Cross section illustrating stabilization measures, Sandown Bay.

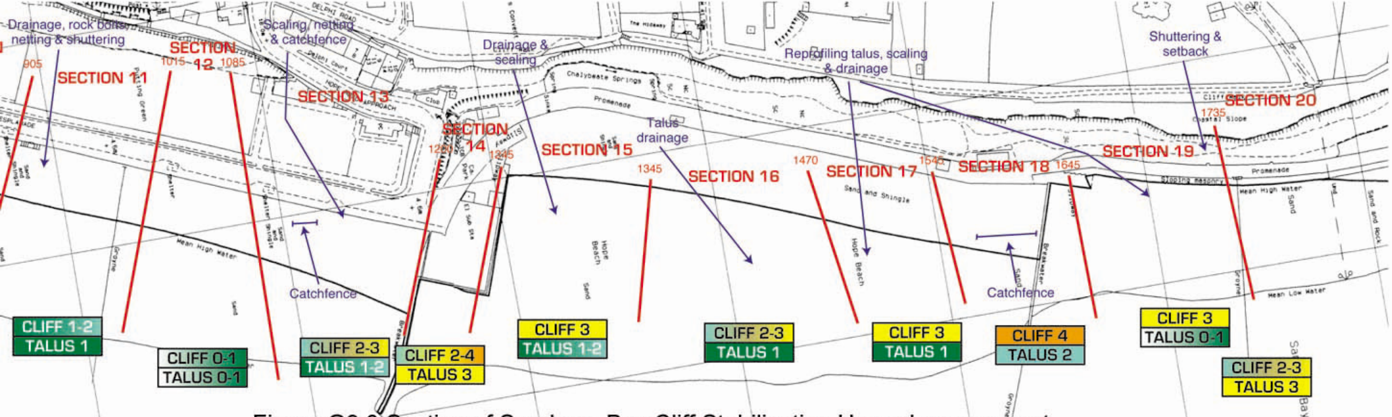

Figure G9.3 Section of Sandown Bay Cliff Stabilisation Hazard assessment
(please contact the project partners (see 'Home' page) for details of the complete plan.)