The Investigation and Monitoring of Coastal Landslides at Barton on Sea, Hampshire, UK

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INTRODUCTION

The majority of the slopes along the Barton frontage have historically been subjected to marine erosion and for many years have undergone phases of investigation, landslide stabilization measures and coast protection. Nevertheless there has been a continuation of slope instability at the site. This paper describes the nature of the landslides that are operating in the undercliff and the significance of certain controlling lithological boundaries within the Eocene Barton Beds on the formation and development of the various landslide systems. This paper also describes the influence of ground water on stability, especially on the deeper seated slips and describes the methods of investigation, monitoring and instrumentation utilized to assess landslide behaviour.

SITE DESCRIPTION, GEOLOGY AND GROUND CONDITIONS

The 1.5km long frontage of Barton on Sea, located on the South coast about 10km east of Bournemouth comprises an undercliff formed from a series of slopes and terraces rising from sea level up to a plateau 100m to 120m inland at an elevation of between 31m and 33m OD. A 5m to 10m high cliff forms the near vertical inland rear scarp of the undercliff landslide system with a talus slope at its toe. Whilst still reflecting aspects of the original geomorphology, most of the undercliff below has been regarded and modified with deep and shallow drainage over many years as part of continued attempts to stabilize the coastal slopes. The toe of the undercliff is protected by rock armour placed along the entire length of the frontage in the early 1990s. A number of short rock armour promontories, referred to as “strongpoints”, extend into the sea at regular intervals along the site, promoting the formation of pocket beaches in front of the rock armour. To the west of the protected coastline the unprotected cliffs of the Naish Farm frontage area a naturally eroding landslip area which is designated a Site of Special Scientific Interest (SSSI) as the type locality of the Bartonian sequence and for its geomorphological character.

The majority of the undercliff is formed from stiff, fissured overconsolidated Barton Clay of the Middle Barton Beds while the upper part of the slope and inland cliff are fromed from the Barton Sands comprising silty fine sands over a sandy clayey silt unit known as the Chama Bed. Approximately 4m to 8m of Pleistocene Plateau Gravels lie uncomformably above the Eocene deposits to form the upper part of the inland cliff. Barton (1973) divided the Barton Clay into a number of zones with boundaries defined by lithological features in preference to palaeontological zones. The ground investigations generally confirmed the stratigraphy proposed Barton, although minor but significant variations were found. Of importance in the development of landslides are the many hard bands of calcareous mudstone and nodule beds, which may induce strain concentration during swelling or shearing. The geological structure of the area is simple with a gentle regional dip of less than 1 degree to the east north east.

This dip results in different lithological units within the Barton Bed sequence outcropping uccessively at sea level along the length of the undercliff which historically have been exposed to wave attack and significant erosion at the toe of the slope. This process has promoted the development and characteristics of the landslides along this coastline (Figure 1).

GROUND INVESTIGATIONS AND MONITORING

As part of the recent phase of landslide investigation, a series of geomorphological and ground behaviour maps fo the site were prepared in 1991, 1992 and 1998. This enabled the ongoing development of the landslides within the undercliff to be determined. The mapping indicated areas of active or marginal movement of the whole undercliff from Naish Farm to the west extending eastwards beyond Hoskins Gap.

Various recent phases of ground investigation were carried out to supplement existing borehole information and instrumentation. This included three boreholes to depths of between 20.0m and 35.5m and 35 static piezocone penetration tests to depths of up to 23.3m and were used to correlate the stratigraphy and landslide systems within the undercliff.

A programme of slope monitoring was initiated, to provide information on the depths and rates of sliding and to give an early warning of worsening conditions. This has included the monitoring of existing and supplementary instrumentation, some of which has now been lost by ongoing landslide activity and comprised:

5 borehole inclinometers to depths of between 17.5m and 25.5m
Slip indicator tubing monitored using brass mandrels to 20m depth in boreholes
Monitoring of over 200no surface ground markers
- On 7 selected section lines
- Points either side of developing cracks on the slope
- Linear measurements between fixed points
- Lines of fixed points along the length of the revetment

Visual inspections – weekly inspections of site
Groundwater monitoring of 6 vibrating wire piezometers, 25 push in standpipe piezometers to depths of between 5.0m and 15.5m and 4 standpipe piezometers in boreholes to depths of between 20m and 34.5m
Manhole Flow Surveys – manual inspection of drainage catch pits and manholes
Rainfall records from local weather station.

The results of these investigations, coupled with the monitoring programme, have enabled the mechanisms of slope failure to be more clearly identified and stability analyses undertaken.

SLOPE PROCESSES AT BARTON ON SEA

Slope instability has been observed within the undercliff for many years with major slope failures being recorded in 1974 and 1987/88 just east of Hoskins Gap and below the Cliff House Hotel in 1993 and 1998 (See Figure 1). Large scale instability of the undercliff continued to become evident in the winter 1992/93 and became more extensive throughout the remaining 1990s. Localised failures, especially of the lower slopes, have historically been widespread, requiring extensive treatment by ground replacement and shallow drainage.

Prior to the construction of the coast defence in the 1960s, the active slope processes were sustained by continued sea erosion which prevented toe accumulation of slip debris and eventual natural stabilization. However, even with the construction of coast protection measures, slope instability has continued.

The recent geomorphological mapping, ground investigation and monitoring has shown that a number of failure mechanisms are operating within the undercliff. The main mechanisms of instability are illustrated in Figure 2 and are described below:

i) COMPOUND FAILURE SYSTEM involving non rotational failure seated along near horizontal translational shear surfaces at a number of lithological boundaries within the Barton Beds. This type of failure involves the lateral displacement of a block to form an elongated ridge parallel to the cliff and the creation of a graben immediately upslope of the failed block. This also results in the failure of narrow wedges of the upper cliff.

Throughout the Barton undercliff a translational surface exists on the boundary between the Barton Sand and underlying Barton Clay. Deeper seated, lithologically controlled, translational failures correspond to sliding on the Barton Clay F1/F2 lithological interface below and to the west of Hoskins Gap and, at the western end of the site below the Cliff House Hotel, on the Barton Clay C/D lithological interface (Figure 1). The Barton Clay C/D slip surface passes below the rock armour placed in 1991 to outcrop in the seabed and the rock armour has been displaced seaward in this area. It is important to note that the development of these shear surfaces on either the Barton Clay C/D or F1/F2 lithological units occurs where hard bands of calcerous mudstone and nodule beds are present. It is considered that these relatively “stiff” inclusions within the clay lithology may result in the development of strain concentrations during swelling or shearing, hence resulting in the development of preferred slip planes.

ii) SHALLOW TRANSLATIONAL MUDSLIDE FAILURES principally developed within the Barton Clay, but also within the previously failed colluvial material. These are relatively slow moving masses of clay rich debris sliding on translational shear surfaces, often partly along lithological boundaries.

iii) Reactivation of previous slips partially stabilized by replacement of slip debris with limestone quarry run material and rock fill.

HYDROGEOLOGY AND THE ROLE OF GROUND WATER

The Plateau Gravels and the Upper Barton Beds (Barton Sand and Chama Bed) together form a partly confined aquifer. Infiltration from precipitation and other sources is prevented from draining downward due to the presence of the underlying low permeability clay of the Middle Barton Beds. The main component of flow is horizontally towards the face of the cliffs. Here however, flow is partly restrained by the presence of lower permeability colluvium or slip debris, which leads to a build up of pore pressures and locally high water tables.

Within the Middle Barton Beds (Barton Clay), the Highcliffe Sands (zone A3) behaves as a confined aquifer of sufficiently different lithology to be distinguished from the surrounding clay (Figure 1). Piezometric heads in the Highcliffe Sands are typically a few metres above sea level, indicating flow towards the sea, and are much lower than hydrostatic below the phreatic surface in the Plateau Gravel/Upper Barton Beds. This indicates the presence of a perched water table in these upper units and underdrainage of the Barton Clay (zones B to F2) into zone A3. Measured piezometric heads in the Barton Clay suggests that pore pressures in the Barton Clay may not have yet recovered from the depressed levels associated with a rapidly eroding cliff to the levels associated with long term seepage conditions in a stable slope. The implication of incomplete pore pressure recovery is a reduction in factor of safety of the slope with increasing time leading in extreme cases to a delayed failure.

The role of groundwater in causing instability of the cliff and upper bench has long been appreciated. Installation of a sheet piled cut off wall and deep drain formed an essential element of the stabilization scheme devised in the 1960s. The deep cut off drain consisted of a sheet pile wall installed along the upper part of the undercliff, with a deep gravel filled drainage trench on its landward side, with a carrier pipe at or above the Barton Sand/Barton Clay interface and outfalls to sea at regular intervals. Based on observations of piezometric levels and seepage points, it is considered that while these drainage works have been successful in limiting groundwater flow to the lower slopes of the undercliff, they have resulted in only localized drawdown of the phreatic surface upslope. More recently (1998) a series of directional bored sub-horizontal drains have been installed at key locations along the undercliff and their performance is being monitored. Preliminary indications based on drain flow rate measurements are that the method is successfully providing positive drainage to the upper parts of the slope.

Groundwater has an equally if not more important influence on the stability of the lower slopes, especially in relation to deep-seated slips such as the compound failure systems (mechanism i) described above. Historically coastal retreat occurred at a relatively fast rate of just under 1m per year. The associated unloading resulted in a zone of depressed pore pressures in the thick Barton Clay sequence which temporarily prevented deep-seated instability of the oversteep undercliff. Other mechanisms of slope degradation intervened before deep-seated failure of the whole cliff or of a major part of the undercliff could occur. However, since coastal retreat has been slowed down significantly by the coast protection and stabilization measures implemented in the late 1960s, pore pressures are slowly recovering, making deep-seated large scale failures, such as that currently observed below the Cliff House Hotel increasingly likely. Delayed failure of cutting slopes in clay, as described above is well documented, for example by Vaughan and Walbancke (1973). The significance of this mechanism to protected coastal slopes, however, is less widely appreciated.

Results from monitoring of instrumentation described above show clear relationships of ground movement with the onset of the wet winter period (Figure 3). A comparison of monthly rainfall with ground movement has been made for those monitoring points that show significant seasonal trends in movement. Monthly rainfall records and antecedent rainfall for between 1994 and 1999 are presented in Figure 4 which also shows the start and end of significant ground movement for selected locations derived from borehole inclinometer data and topographic surveys. Ground movement for the winters 1994/95 to 1998/99 generally start to accelerate during October/November. The rapid response between the onset of winter rainfall and ground movement is probably a reflection of the relatively high soil permeability of the ground.

Accelerating ground movements in October/November generally appear to commence when monthly rainfall for the average current and preceding months (antecedent 2 month average) is in excess of about 80mm/month. The onset of ground movement in

October/November 1996 however appears to have initiated at a lower average rainfall threshold of about 55mm/month. Once high rates of movement have commenced during the winter period, monthly rainfall has to reduce to relatively low levels for rates of ground movement to reduce back to summer levels with average monthly rainfall typically being about 40mm to 50mm.

CONCLUSIONS

By the use of detailed geomorphological mapping, coupled with ground investigation and the ongoing extensive slope monitoring being undertaken by New Forest District Council, it has been possible to determine the nature and geometry of the complex landslide systems occurring within the Barton undercliff. Instability at the cliffs at Barton on Sea is shown to be the result of complex and interrelated mechanisms controlled by both lithology and groundwater. Ground investigation information suggests that, although coastal erosion has been largely arrested by the construction of coastal defences, pore water pressures are now recovering which, unless remedial action is taken, will result in the progressive reduction of the factors of safety of deep seated failure mechanisms possibly resulting in further failures in the future.

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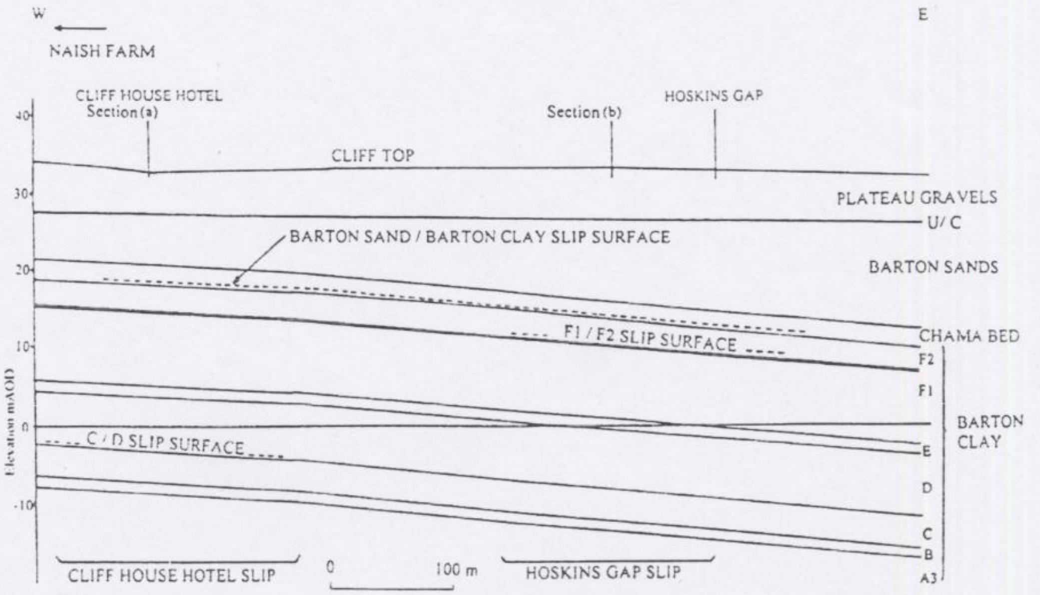

Figure 1 Geological cross section showing areas of failure and controlling lithology

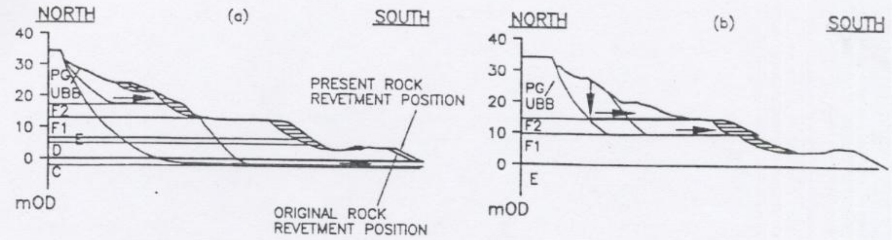

Figure 2 Mechanisms of slope failure; a) below Cliff House Hotel and b) west of Hoskins Gap

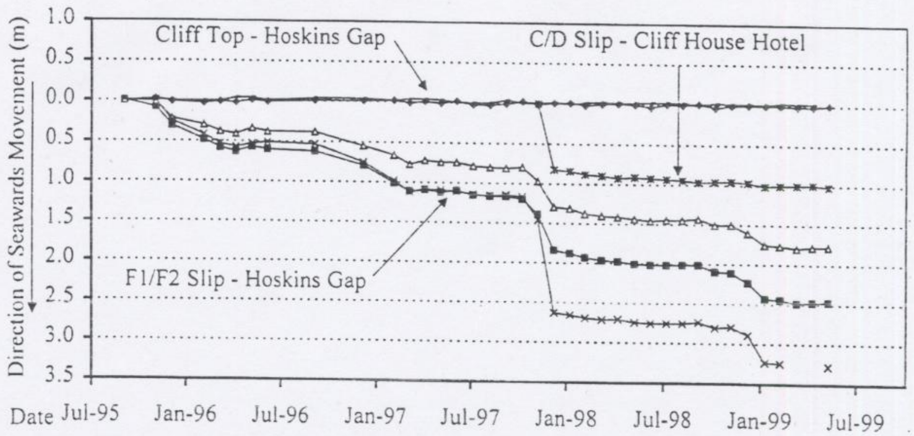

Figure 3 Typical surface ground movement monitoring results

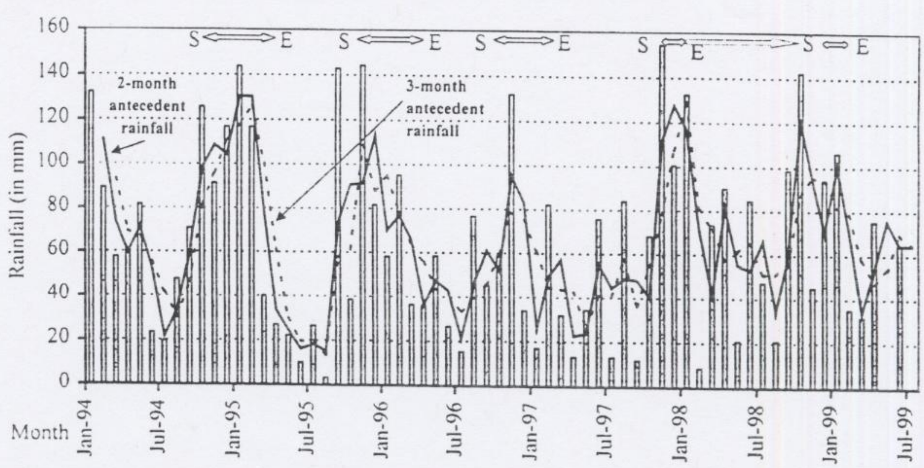

Figure 4 Relationship of start (S) and end (E) of ground movement with rainfall