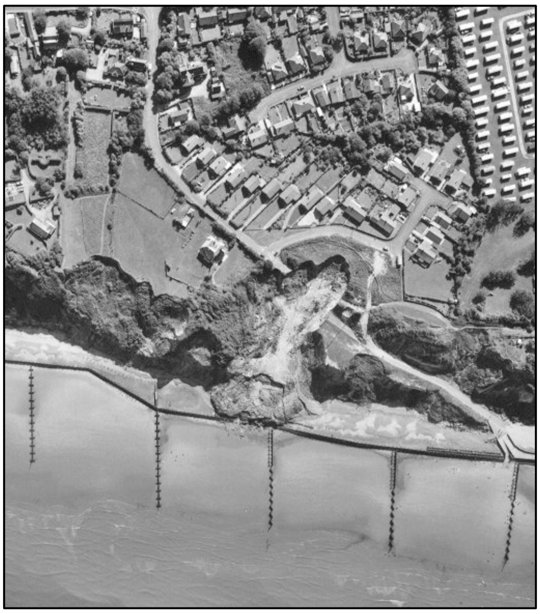
Document 8 – Clifton Way, Overstrand Coast Protection Scheme

The following paper describes the work undertaken to stabilise a cliff failure at Clifton Way, Overstrand, which occurred in the early 1990's. The cost of the work undertaken for this scheme was approximately £1.34 million pounds while the total cost of the works, scheme design and associated expenses was about £1.75 million.

The 3 photographs below are aerial views of the site from 1986, 1992 and 2000. These photos have been reproduced with the kind permission of the Environment Agency, Anglian Region.



The top left photograph is shows Clifton way in 1986 before the major failure occurred. The top right photo is from 1994 and shows the extent of the failure at that time. The photo on the left was taken in 2000, approximately 5 years after the site was stabilised. The rock armour is clearly visable at the toe of the slide and many of the surface drains can also be seen.

GEOTECHNICAL AND OTHER ASPECTS OF THE OVERSTRAND COAST PROTECTION SCHEME

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BACKGROUND

Overstrand is a village of 1100 people situated on 35 metre high cliffs on the North Norfolk coast (**Figures 1 & 2**). There is a long history of cliff failure and coastal erosion, not just at Overstrand, but all along the 34km section of coast for which the Council has responsibility. The need for a coast protection scheme at Clifton Way followed a series of cliff failures. The first occurred in May 1990 and was followed by further failures in November 1992 and January 1994. This last failure severed the 225mm diameter public sewer serving 60 houses and a school. Anglian Water installed a temporary pumping station and main. Approximately 85-90 metres of land was lost as a result of the failures and further failures were expected if no works were implemented. Indeed another 20 metres were lost immediately prior to works starting in March 1995. By this stage the eroding cliff edge was only 5 metres away from the roadway and another failure would have led to the loss of the road and services and the properties they served would have been declared unsuitable for habitation (**Figure 3**)

TOPOGRAPHY AND GEOLOGY

The cliffs generally rise steeply (typically 35-50 degrees) from beach level to approximately 35m OD at a point 60 metre inland . The ground generally rises gently away from the cliff top. The sandy foreshore slopes at around 1 in 50.

The cliffs at Overstrand are underlain by the Upper Chalk at approximately -4m OD, and which here is overlain by a thin bed of flints, grey shelly sand and varied pre-glacial shallow water deposits. These deposits extend into the foot of the cliff, but are not normally visible as they are covered by beach material and cliff debris. The major part of the cliffs are formed of glacial tills, sands, laminated clays and the occasional chalk raft. A strong feature of these cliffs is their rapidly varying nature with the potential for ground water to be present in any part of the cliff mass. The cliffs and foreshore are designated a Site of Special Scientific Interest by virtue of their geological and geomorphological features. The special consent of English Nature is needed to carry out coast protection or drainage works which are otherwise specifically precluded.

COASTAL PROCESSES AND SLOPE FAILURE MECHANISMS

The moderately high glacial till cliffs which dominate this length of coastline are prone to the formation of significant rotational landslides and mudruns. The profile of the coastline south east of Cromer causes longshore currents to become stronger though they are still predominantly offshore. Whereas this stretch of coastline can be exposed to persistent easterly waves, longshore energy is low and the potential for sediment transport is variable; ie. north westerly and south easterly with a net south easterly drift. Beach monitoring shows that the beach is steepening and because of its narrowness the average annual cliff erosion of 1.5 - 2.0 metres is commonplace making this a major source of sediment. The average annual rate of erosion can be misleading when considering a relatively short time frame since cliff top loss tends to occur as discrete failure involving many metres of cliff loss at irregular intervals.

The action of the sea eroding the base of the cliff results in an oversteep slope. In the natural course of events these are continually attempting to degrade to a more stable slope. Generally this means the downward migration of material and a consequent advancement of the toe and regression of the crest to produce ultimately a shallower, more stable slope. In the undefended coastal situation this process is never permitted to be completed as the action of the sea quickly erodes away the debris, thus destabilising the cliff once again, allowing the cycle to be repeated. At the same time, the back scar of the original failure is exposed to weathering and deterioration, leading to a succession of smaller failures, which tends to slow the overall process, but in the end is not sufficient to produce a stable slope. As a result of this cyclical process, failures at any one point tend to be several years apart.

Unusually, at the Overstrand site, there were three separate failures in three and a half years with an overall recession of the cliff top of about 90m. While the first in May 1992 only led to the temporary loss of a maintenance access road, the third, in January 1994, posed a serious threat to domestic property on the cliff top. The failures appeared to have been initiated by a combination of localised high groundwater and the presence of large irregular blocks of laminated clay in a silty clayey sand matrix and led to the slipped material flowing out over the beach. The autumn and winter of 1993/4 had been characterised periods of heavy rain with considerable flooding. By mid 1994 a small section of the access road from the cliff top had moved over 100m and been deposited on the beach having been first displaced in a failure in November 1992. The failure exhibited many features strikingly similar to the Holbeck landslide at Scarborough in 1993. Further substantial failures were predicted if no action was taken (**Figure 4**).

INITIAL RESPONSES

1 Social

The seemingly endless cycle of slope failures had an immediate effect on the local community. The market value of property throughout the village slumped, and many householders found themselves unable to obtain buildings or contents insurance. Although not able to assist directly, North Norfolk District Council offered advice and assistance where possible. The Council met with those householders directly affected and also made contingency arrangements for the emergency evacuation of the sixteen properties directly at risk.

2 Engineering

While visual inspection of the remaining cliff face suggested nothing out of the ordinary, the behaviour of the cliffs with its succession of failures indicated this was far from being the case. The Council appointed the specialist consultants Rendel Geotechnics in January 1994 to advise on the immediate steps that should be taken and to carry out a feasibility study on possible long term options. It was thought likely that ground water was a major contributory factor. Several years previously the

Council's consultant at the time had carried out a survey using divining rods and had identified a number of underground "streams" in the vicinity. If they existed then they may well have been a factor.

Shortly before the January 1994 failure the Council had started a programme of deep bored wells in the vicinity of the slip. It was hoped to intercept any underground water and drain it into the underlying chalk. These wells identified that the ground surrounding the slip area consisted almost solely of a soft grey silty clay with occasional sand lenses. In an attempt to improve the efficiency of the wells a vacuum pumping system was installed. However, only a maximum of 20% vacuum was achievable due to leakage, probably arising from a partially saturated gravel bed at about 30 metres depth. The system was eventually abandoned and the wells were allowed to operate as gravity wells draining in to the chalk. The purpose of these boreholes was extended and they provided Rendels with valuable geotechnical data. Piezometers were installed in a number of the bore holes and where these have survived the works are still being used for monitoring.

As referred to previously much of the slipped material was very soft; it was also highly variable in nature with much standing water and open fissures. This combination exacerbated the problems by ensuring the material remained in its saturated state. Rendels advised that as soon as practicable the surface should be temporarily graded and the surface sealed to prevent further ingress of water and assist surface run-off. The aim was to attempt to interrupt and delay the continuing cycle of failure / slip / erosion / failure while a permanent solution was being sought and implemented.

The state of the material and safety considerations prevented implementation of this work, but a site investigation contract was let which included two sampled bore holes, twelve piezocone penetration tests and the installation of eight push-in and the two bore hole piezometers referred to above. A ground movement early warning system comprising electrolytic tiltmeters and a datalogger connected to a computer and paging system was installed. This system was an integral part and potential trigger for any emergency evacuation of property. After teething problems the system worked well and provided additional reassurance to householders most at risk.

Eventually, ground conditions improved sufficiently to attempt works on the actual slip. A preliminary earthworks contract was let in March 1994 under the supervision of Rendels. As referred to previously the maintenance access road had been lost and a new track had to be created from the cliff top. Other works were:-

- the construction of a ramp up from beach level on to the toe of the slip;
- localised reprofiling of the landslide to seal the surface and improve run-off of surface water;
- excavation of trial pits for the preliminary investigation of the slip mass;
- excavation of drainage sumps within which electric pumps were installed to aid drainage of the slip mass;
- installation of preliminary drainage measures to the eastern side of the landslide to inhibit the development of mudslides.

Over the 12 months between this work and commencement of the permanent works further similar work was necessary. It was generally successful in slowing movement during most of that time, although during March 1995 a further small failure occurred. The work was not successful in preventing the mudslides on the eastern side and these continued right up to the time of the permanent works.

RESULTS OF SITE INVESTIGATIONS

The results of site investigation well borings, boreholes, piezometers, cone penetration tests and trial pits confirmed the complex structure of the materials forming the cliffs and the ground water regime. Whereas the intact materials outside of the landslide may be interpreted and simplified, the slipped materials and the slip plane geometry are less easily understood. The principal materials encountered and their assigned design parameters, based on laboratory results were as follows:

MATERIAL TYPE	OCCURRENCE (RL)	BULK DENSITY	PHI	C
		Mg/m3	DEGREES	kN/m2
SLIP DEBRIS		1.8	25	0
BROWN CLAY	+36 TO +32	2	29	0
LAMINATED CLAY	+32 TO +5	2	20	0
SAND/SAND GRAVEL	+5 TO -5	2	35	0
CHALK	-5 TO -	-	-	-

At the cliff top ground water was modelled as being 1.5 metres below ground level and hydrostatic down to +8m AOD, with under drainage in the sand/gravel reducing the hydrostatic pressure to +1m at datum It was appreciated that this simplistic model would have to be treated with extreme caution when identifying and detailing the most appropriate slope stabilisation measures.

ENGINEERING DESIGN

1 Earthworks

Several possible stabilisation measures were identified as being technically viable, although the structural solutions such as retaining walls were considered unacceptable from environmental criteria. The need to maintain the cliff top alignment and minimise encroachment across the beach were severe restrictions on the choice of stabilisation options. Because of the highly variable materials within the slipped mass the favoured design had to allow for complete flexibility with regard to modifications during construction. It was considered an adequate improvement in slope stability could be achieved through reprofiling, draining and strengthening the slipped mass. The design philosophy adopted was to excavate the upper part of the slipped mass to form a stepped surface below the shear plane. This was to be done in restricted areas so as to reduce the risk of failure of temporary slopes due to heavy rain. Dedicated drains were to be installed for all significant seepages and a suitable drainage blanket laid over the entire excavated surface prior to backfilling with suitable material o be compacted in layers to form stable slopes. In the lower part of the slope, where multiple shear planes were likely to be deeper, a no-fines concrete or reinforced concrete shear key configuration was designed with suitable drainage in order to stabilise the lower slopes. The advantage with this technique was rapid construction and the provision of stable temporary cutting s for the contractor to build the coast protection works. The flexibility of the design also allowed for complete excavation of the slipped material and replacement, subject to the contractor's construction programme. Surface drains were designed to intercept run-off; however previous experience suggested that interception drains are best constructed after the construction has been completed and after a full wet season by which time nature will have determined where concentrations of run-off will take place. There was a requirement not to use imported topsoil on the site and there was concern that grass would take several years to establish itself in which case there could be an ongoing surface erosion problem. Surface drains were designed with a sacrificial filter fabric which could be removed at the appropriate time so as to minimise clogging of the drainage stone (**Figure 5**).

2 Toe Protection

Protection of the toe was necessary to prevent further erosion of the cliffs at the site of the landslip and break the constant cycle of failure. The previous timber revetment defence had been breached by the slip and could not offer sufficient protection if it were to be replaced. Beach levels at the site fluctuate between a normal level of around +1.8mOD to a lowest observed level of -0.3mOD. The wave climate at the site is dependent on high tides and storm surges as the cliff toe lies above mean high water. The chosen method of toe protection, a rock armour revetment, was considered the most suitable for this particular site. Road access to the cliff top was limited and access to the beach further restricted. The site therefore lent itself to sea borne delivery of bulk materials.

The design parameters used were:-

Still water level with 1 in 55 year surge	+4.3mOD
Offshore wave height of 1 in0.13 year return	4.1 m
Joint probability	1 in 100 years
Inshore wave height (after Goda)	H_S 2.84m
	$H_{1/10}$ 3.63m
Rock density	2.65 tonne/m^3
Damage criteria	0-5 %
Overtopping criteria	1.0 l/s/m

The straight forward design yielded a revetment with a 1 in 2 slope requiring the use of 7-14 tonne primary armour on 700-1300kg bedding stone. A total of 20,000 tonnes of rock were necessary (**Figure 6**).

CONSTRUCTION

Toe Protection Works

A 26 week contract was let in March 1995 to May Gurney (Construction) Limited. As described above there were two main elements of the works, the earthworks (including under drainage) and coast protection. Co-ordination of these two was vital if a further failure was to be avoided. Delays in obtaining suitable barge transport for the rock armour meant that a significant construction work was not undertaken until the summer. Before the rock arrived works were limited to preparing haul roads and improving the access from the cliff top to the beach.

The rock was delivered in the middle of the holiday season in July 1995 and all 20,000 tonnes unloaded in seven days using a 2000 tonne lighter barge operating in near perfect conditions. The rock was stockpiled on the beach as close to the site as possible and the beach returned to the tourists.

Removal of the slip debris was carried out in stages. The surplus material was placed along the cliff toe to east and west of the site. Excavation was extended downwards through the slip material and the underlying beach in to the stable beach material about 1.5 metre below beach level. As each panel of material was removed it was replaced with the rock armour. This incremental approach meant that the normally routine activity of placing the armour took 3 months to complete.

Drainage and Earthworks
Within the main body of the slip, excavation of the debris to below the level of the slip plane commenced at the same time as the toe works. The general sequence adopted by the Contractor was to excavate material working down from the top of the slope, cutting benches into the intact soil below the level of the slip plane as the excavation proceeded down the slope. Upon completing the excavation in a given area a drainage blanket was placed and filling operations commenced. Where potentially more permeable horizons were exposed in the formation, i.e. sand layers, unpiped french drains were installed beneath the drainage blanket to provide additional flow capacity. The earthworks operations progressed in sections across the site from east to west.

The excavation and filling operations were carefully controlled. Excavation was permitted only over a narrow frontage and the method or extent of working varied when movement of the soil mass was detected. At one stage while working the near the toe cracking was detected which necessitated considerable additional excavation. Likewise the filling operation was carefully controlled. Moisture content was specified to be between the optimum p% and (p+3.5)%. The level of compaction required at the specified moisture content was 98% of the dry density. These requirements were rigorously enforced.

Material excavated from the slip was again placed at the toe of the cliff to east and west of the site. In its excavated state this material was not considered suitable for use as fill. Most of the fill material used was derived from a small head land to the west of the site. As the excavated material dried some was re-used as fill towards the end of the earthworks operation. The surplus remaining in the deposition areas at the cliff toe was graded and left in situ as sacrificial material.

As well as the under drainage the scheme also incorporated a comprehensive system of surface drainage. The clay final surface had been deliberately graded and compacted so as to minimise water penetration into the site. However, this left it prone to surface erosion. A network of piped and unpiped french drains was installed to control surface run-off. After completion of the earthworks the site was planted and seeded in accordance with English Nature's requirements. The works were completed in December 1995.

POST CONSTRUCTION
Importance is attached to post contract monitoring. Survey markers were fixed to several of the armour stones to enable any movement to be detected. Similarly, the slope and beach are monitored. The tiltmeters installed to monitor the cliff top before work commenced were retrieved and re-installed around the top of the slope.

Currently they provide a three hourly record of movement of the ground. So far the only changes detected have been those associated with daily and seasonal temperature fluctuations. Failure of the grass seed to germinate on the exposed north facing slope has led to some gullying of the slope. Where this has occurred additional drains have been installed locally.

In a separate Contract, Anglian Water diverted the sewer and constructed a pumping station to ensure continuance of the sewerage facility. After some delay the new arrangement was commissioned in February 1997. The coast protection contract was completed within the tender price and the scheme appears to be performing well.

CONCLUSIONS

In terms of depth of land lost, this slip was one of the largest known on the North Norfolk coast. It also confirmed one of the most apparent features of these cliffs, that of their totally unpredictable nature. The scale of the slip resulted from a localised, but large, pocket of saturated soft silty clay. Only the highly engineered geotechnical solution prevented further encroachment and loss of land; traditional methods that just protected the toe from erosion would not have achieved the same result.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of their colleagues both to the project and to this paper and, in particular to Noel Delahaye, now with Mott MacDonald for his efforts during both design and construction. Acknowledgement must also made of the MAFF engineers in Cambridge for their help and assistance.

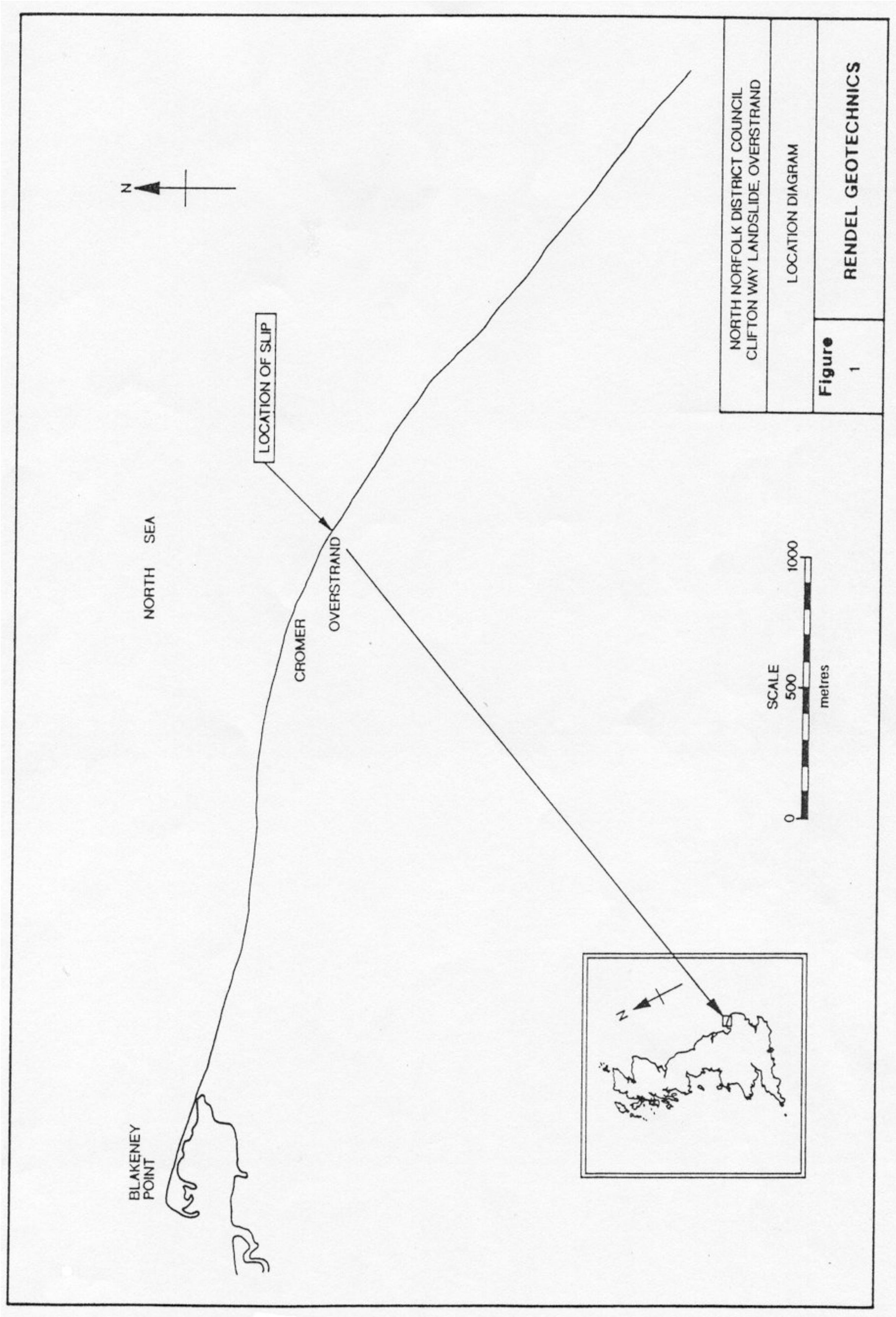

Figure 1 - Location Plan

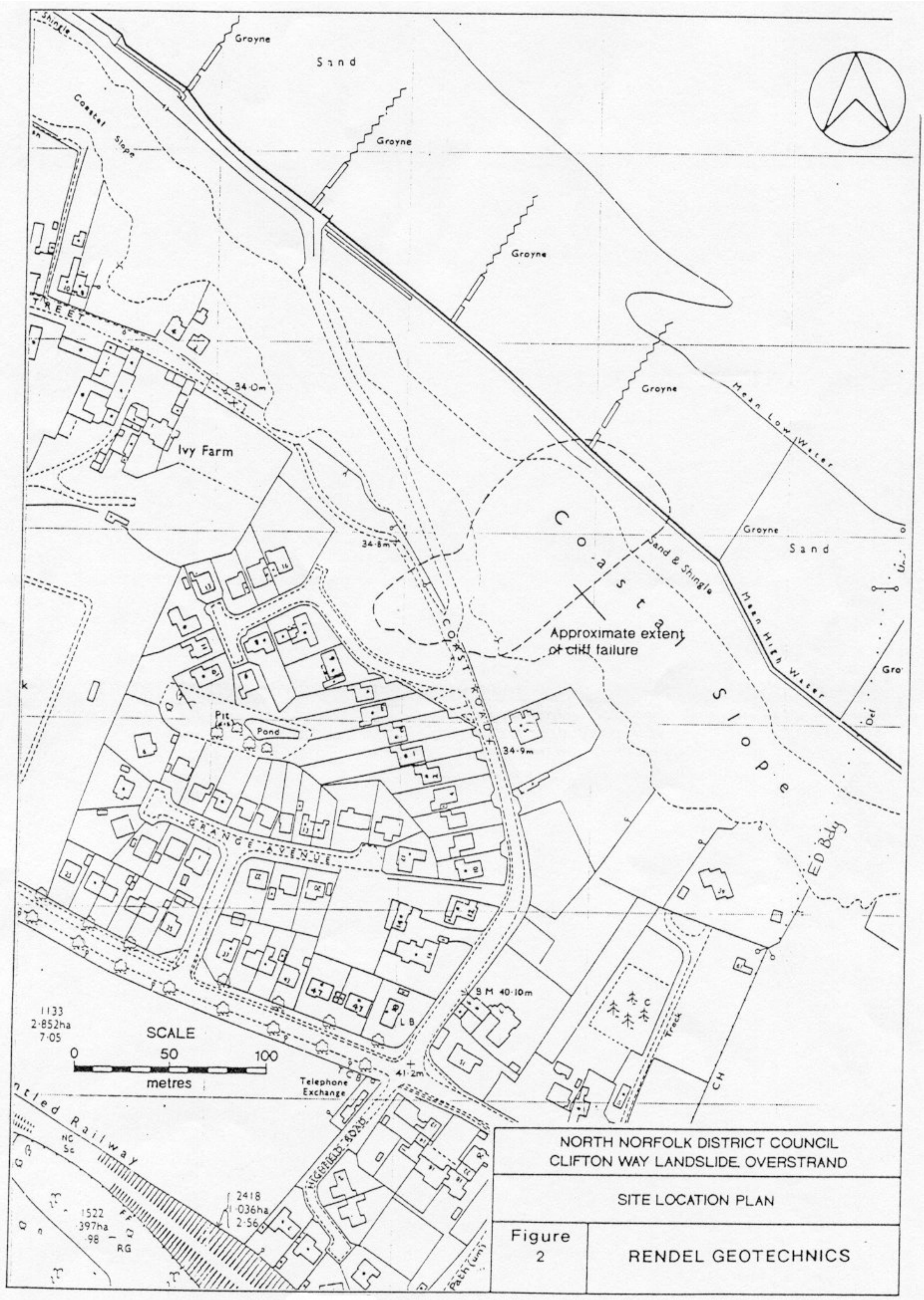

Figure 2 - Site Plan

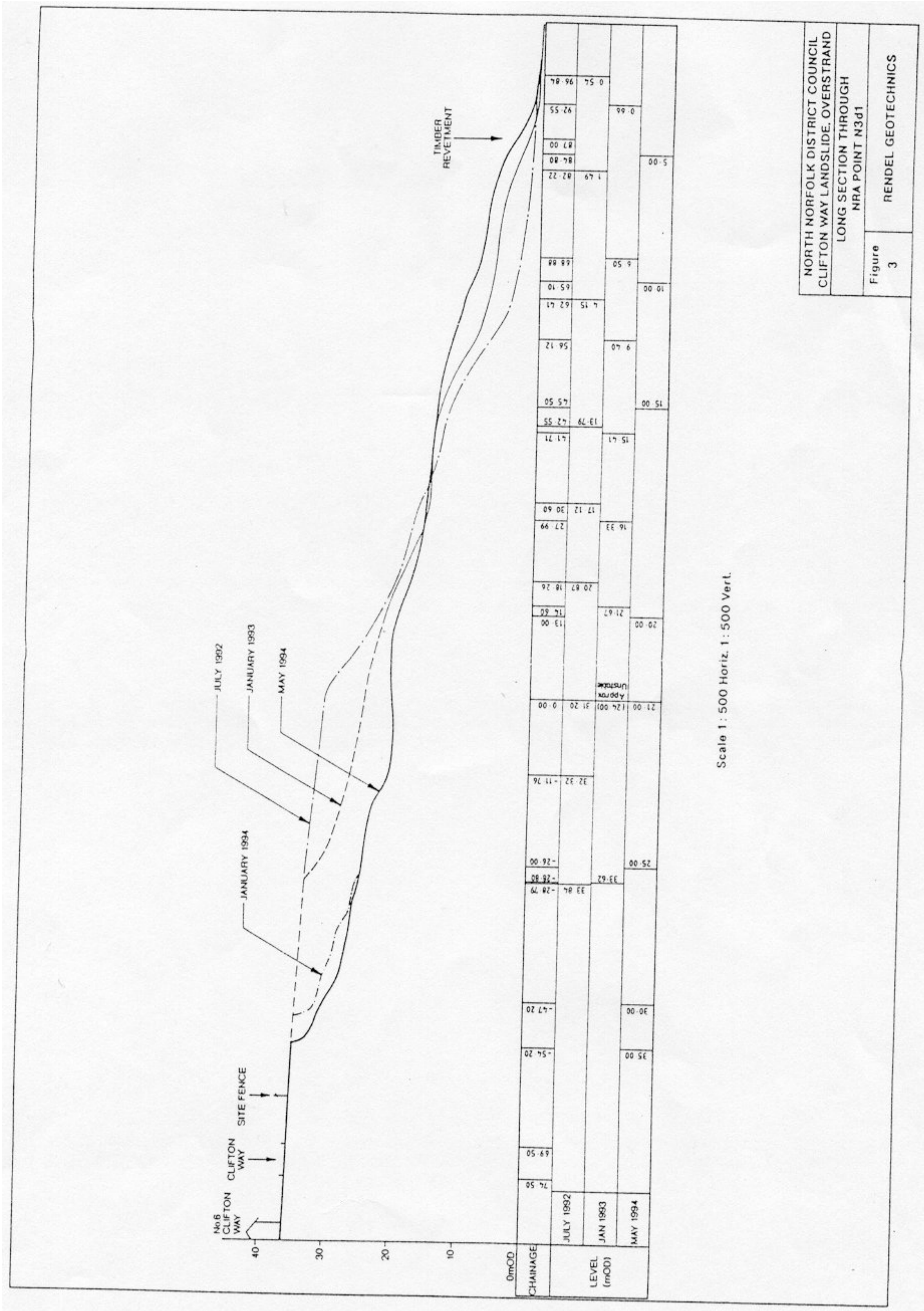

Figure 3 - Cross Section Through Slip

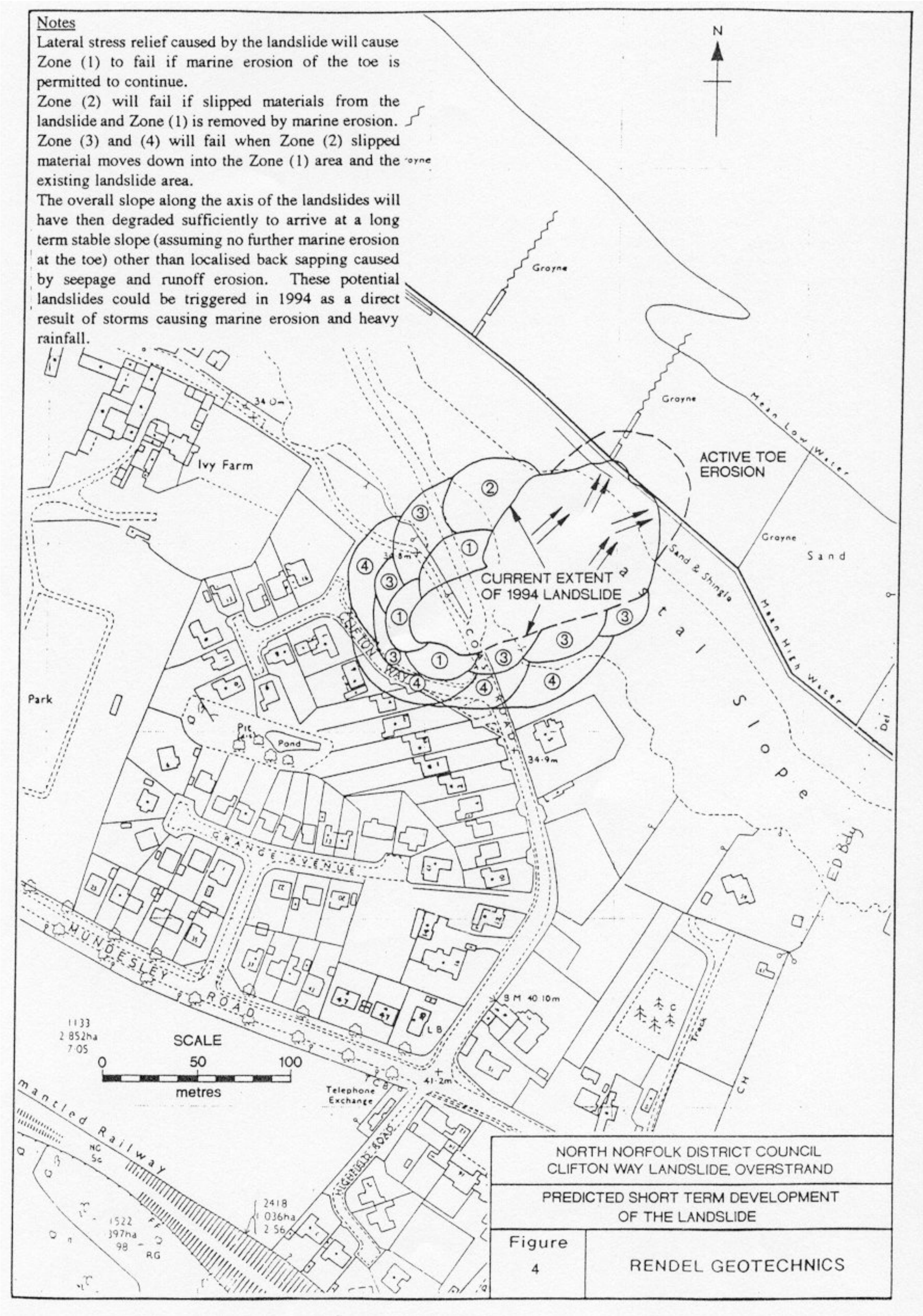

Figure 4 - Projected Development of Landslide

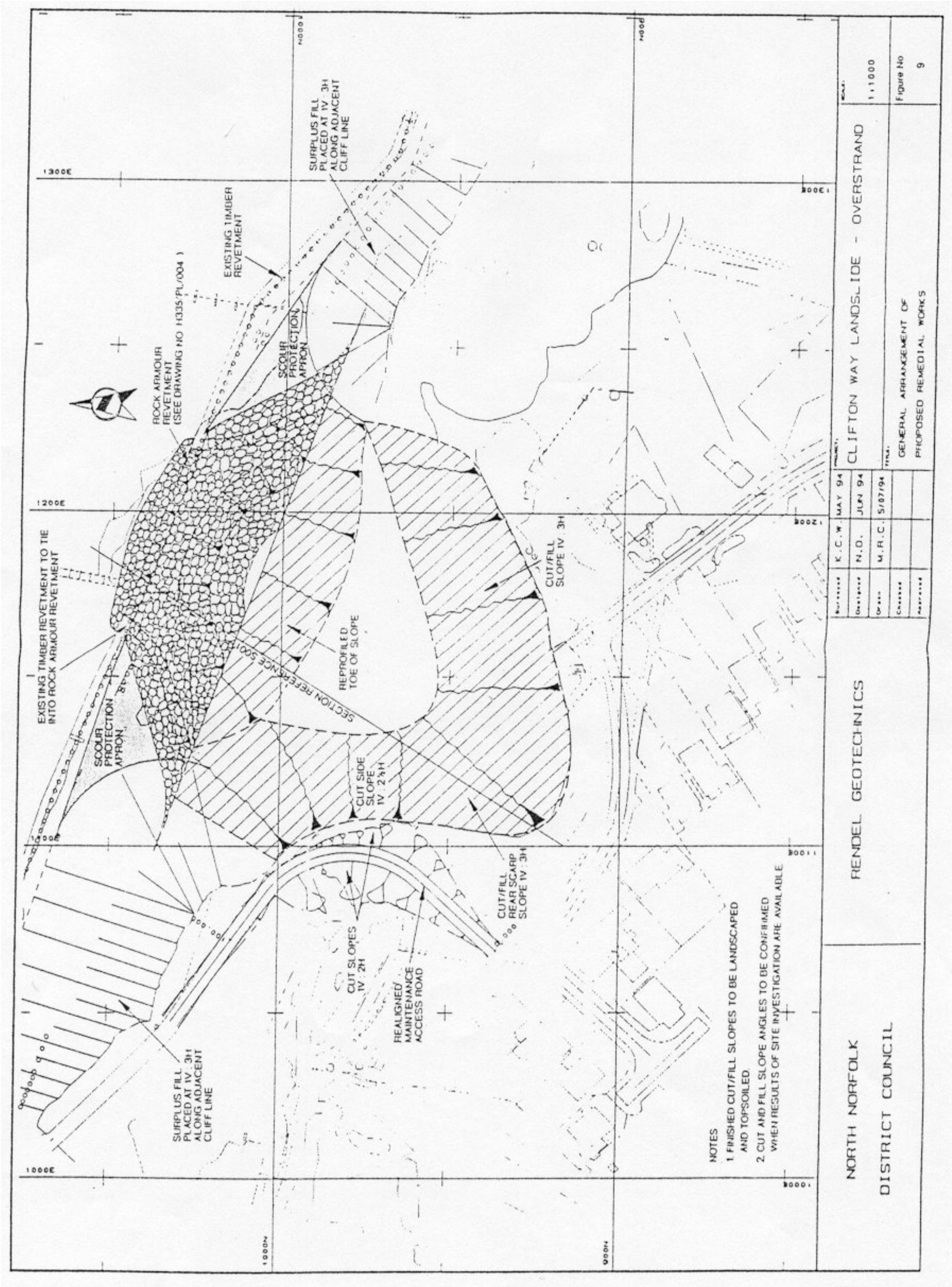

Figure 5 - General Arrangement of Works

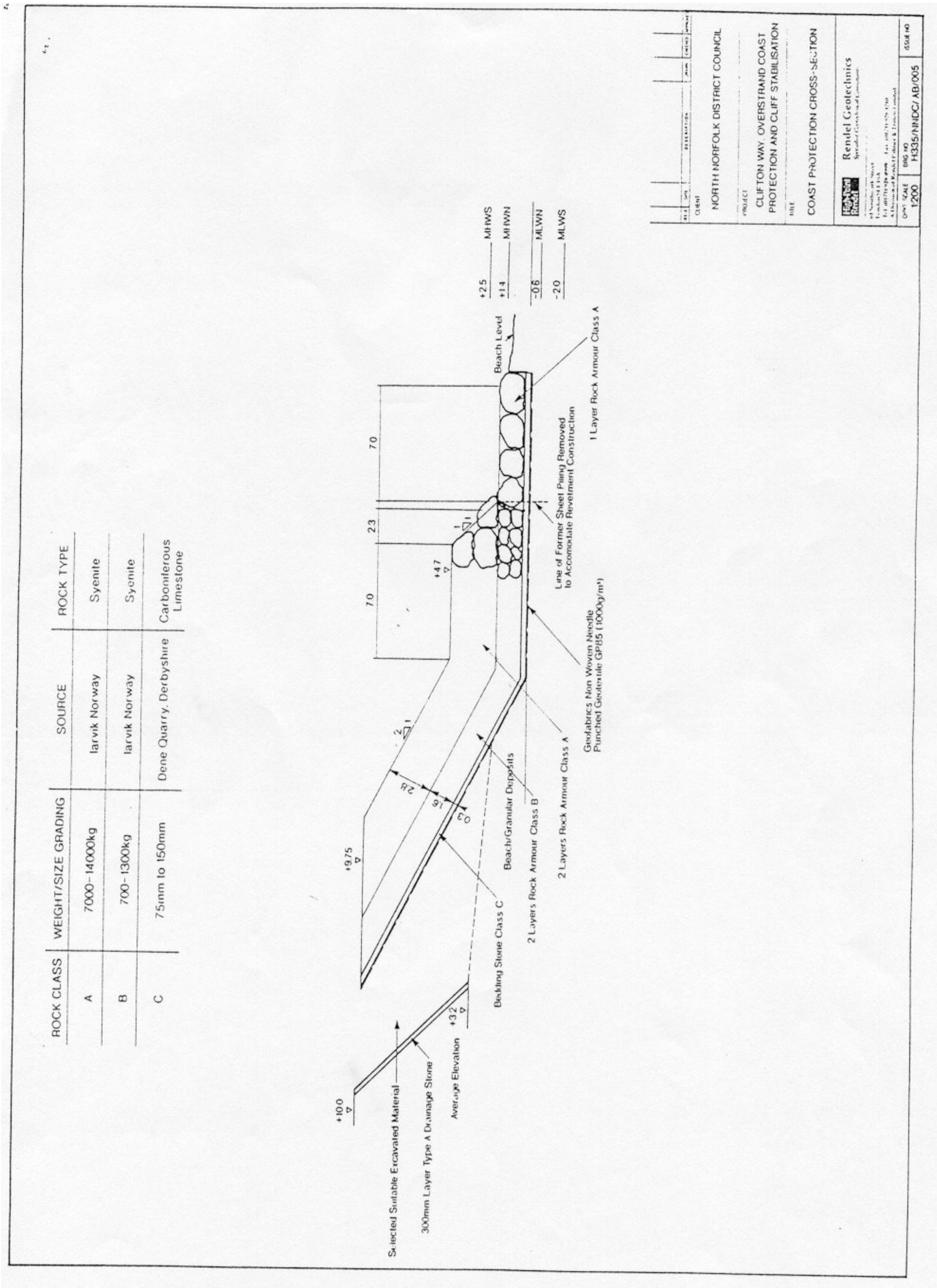

Figure 6 - Section Through Rock Armour Coast Protection

Figure 7 - The Old Coast Road Before Works Commenced

Figure 8 - Benching of Earthworks and Installation of Under Drainage

Figure 9 - Earthworks Nearing Completion

Figure 10 - Rock Armour Toe Protection Works