Isle of Wight Council

Ventnor to Niton Options Study
Addendum to Geotechnical Options Appraisal - Lowtherville Graben
March 2010

Halcrow Group Limited

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Report No. TH364

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Contents Amendment Record

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Signed
	Draft	Internal review	21/1/10	
01	Draft	For issue	25/1/10	RM
02	Final	For issue	31/3/10	SKT

Contents

1 Introduction

1.1 *Context*

The Isle of Wight Council (IWC) is currently reviewing options to retain a sustainable traffic route between Ventnor and Niton on the south coast of the Isle of Wight. The route along Undercliff Drive has provided a strategic transport link which connects Ventnor with St Lawrence, Niton and the southwest coast of the Isle of Wight, and Bonchurch and Shanklin to the east. The Undercliff Drive has been subjected to ground movement and a number of landslide events in recent times which has resulted in temporary closures and road realignment works.

Halcrow Group Limited (Halcrow) was commissioned by the Isle of Wight Council (IWC) to investigate options for:

- Sustaining and maintaining a viable A-grade route through the western Undercliff which is vulnerable to ground movement and episodic landslide events, and
- Identifying alternative options and required highway improvement works for a traffic route landward of the Undercliff to connect the strategic road network and the A3055 to Ventnor, Niton and Whitwell.

Halcrow has provided a report to IWC giving a geotechnical appraisal of the potential stabilisation and road improvement works, identifying preferred options for Undercliff Drive (Halcrow, 2009). The report identifies preliminary options which may extend the serviceable life of the existing road accounting for the engineering and environmental constraints that have led to the dismissal of previous schemes.

Further to the Undercliff Drive commission described above, Halcrow has been commissioned by IWC to undertake a similar review for the B3327 Newport Road in Upper Ventnor which is subject to severe damage due to ongoing ground movement and subsidence. This report is an addendum to the Undercliff Drive Geotechnical Options Appraisal Report and it provides a similar level of information for the Lowtherville Graben area, i.e. preliminary options which may extend the serviceable life of the existing road and reduce the current extraordinary maintenance requirements.

1.2 *Scope of this study*

The broad scope of works undertaken comprises:

- Review of existing consultant reports and monitoring data held by Halcrow
- Consideration of future options for the road including:
    a. Patch and mend maintenance of the road to maintain its current function
    b. Localised improvements to sustain and extend the serviceable life of the road

The sources of information used in the compilation of this report are described in the text and include consultant reports, maps, documents and data provided to Halcrow by the Council and third parties, and from Halcrow's own records and knowledge of the Lowtherville graben site. It should be noted that, where Halcrow has relied upon information from third parties, Halcrow accepts no responsibility for the accuracy or completeness of that information.

2 Background

2.1 *Site location*

The Undercliff is an extensive area of ancient landslides that extends some 12km from Luccombe to Blackgang on the south coast of the Isle of Wight and includes Bonchurch, Ventnor, St Lawrence and Niton. A distinct feature, known as the Lowtherville graben, has developed in Upper Ventnor since the early to mid-1900s. The graben is located towards the rear of the Undercliff complex, approximately 500m inland. It extends some 500m in length and 20m across, and runs in an east-west direction. The B3327 Newport Road crosses the graben in a NE-SW direction. The site location is shown on Figure 1.

2.2 *Regional geology*

The Undercliff is situated on the southern limb of the Southern Downs of the Isle of Wight and comprises a sequence of interbedded sedimentary rocks which dip seaward by about 1.5° – 2°. The sedimentary rocks were laid down in the Cretaceous period, approximately 80 to 120 million years ago. Parts of the Lower Chalk and Upper Greensand Formations of this geology are exposed in the rear scarp of the Undercliff. A summary of the key geological units is provided in Table 1 (after Moore, Carey and McInnes, in press).

This geological sequence has been heavily disrupted along much of the Undercliff as a result of deep seated and shallow ground instability with some areas of strata being lost as a result of landslides and other key geological units being displaced by large block movements.

The Lowtherville graben is located at the rear of the Ventnor Undercliff, within the Lower Chalk and Upper Greensand.

Formation	Description
Lower Chalk	Comprising the Chalk Marl Member (Grey marly chalk with no flints) underlain by the Glauconitic Marl Member (Calcareous glauconitic sand heavily bioturbated at base)
Upper Greensand	Comprising the Chert Beds (Weak to moderately weak green grey sandstone to grey limestone) underlain by the Malm Rock (Very weak to moderately weak green sandstone to very strong grey limestone) underlain by the Passage Beds (Weak to

Formation	Description
	moderately weak green brown sandstone/ siltstone with glauconitic speckling)
Gault	Very stiff dark grey to brown silty clay
Carstone	Dark grey green brown slightly silty medium to coarse sands and sandstones
Sandrock	Comprising units of both permeable light to dark grey sands and sandy clays impermeable grey sandy clay units
Ferruginous Sands	A number of coarsening-upward units of dark grey sandy clays and silts passing up into fine to medium, grey-green glauconitic sands, with discontinuous cementation

Table 1 - Summary geological description of the Undercliff (Moore, Carey and McInnes, in press)

2.3 *Geomorphology*

Previous studies referenced in Moore, Carey and McInnes (in press) suggest that the current Undercliff landscape was shaped as a result of two main phases of landsliding, which took place after the last Ice Age around 8,000-4,500 and 2,500-1,800 years ago.

The lithological and structural geology of Cretaceous rocks make the Undercliff particularly prone to coastal landsliding. Hard competent rocks such as cherts and sandstones overly overconsolidated clays which are underlain by permeable sandstones. The Gault Formation, comprising overconsolidated clays is of particular significance. The Gault is underlain by the Sandrock below sea level, comprising alternating sand and thin clay layers, both of which control basal sliding and the hydrogeology of the Undercliff landslides.

A landslide model for Ventnor, comprising a retrogressive two-tier landslide system, with distinct upper and lower landslide sections is shown in Figure 2. The Lowtherville graben is located at the rear of the upper tier of this system.

2.4 *Sources of information*

Sources of information used in the preparation of this report include the following:

- Halcrow Group Ltd. Ventnor Coastal Instability Risk: Interpretative Report and Quantitative Risk Analysis. October 2006. Prepared for Isle of Wight Council.

- Insole A, Daley B and Gale A. The Isle of Wight. Geologists' Association Guide No. 60. 1998

- Moore R, Carey J M and McInnes R G, OBE, in press. Landslide behaviour and climate change: predictable consequences for the Ventnor Undercliff, Isle of Wight

3 Site details

3.1 *Site description*

The B3327 Newport Road crosses the E-W trending Lowtherville graben in a NE-SW direction, resulting in an affected length of road of some 50m. The site centre is at National Grid Reference SZ 556 777. The road, already reducing in elevation towards the south, increases in steepness as it crosses the northern edge of the graben feature, just south of the Council Yard, then flattens again within the graben itself. The digital terrain model of the site shows the road to rise slightly as it leaves the graben in the south. The overall change in elevation from the Council Yard to just south of the graben is shown as 7.8m on the land-line model of the site. The site is shown on Figure 3.

The road carriageway has a pavement along both sides. The eastern pavement is separated from the road along part of its length by a low-height concrete retaining wall.

Steephill Down Road connects to Newport road at a T-junction, just on the southern edge of the graben, and provides access to garages of some houses on Gills Cliff Road to the south, as well as to Ventnor Golf Club.

The road and buried services it carries are subject to continuous movement and damage. A large diameter (approx. 1m) brick-built Victorian sewer running down Newport Road has been completely dislocated by movement at the graben and is now redundant.

3.2 *Remedial measures*

Remedial measures to date at Lowtherville graben comprise reactive filling of the graben feature as it settles plus patch-and-mend of the road surface when and where cracks appear. There is evidence of past engineering measures, for example, the construction of a low concrete retaining wall to support the filled road and separate it from the adjacent footpath on the east side of the road. Distress is evident at the site from ground movement, for example, distortion and cracking of adjacent walls, cracking of retaining walls, cracking of the concrete base to the handrail, patched areas in the road and contrasting road gradients throughout the site. Some photographs of the site are shown as Figures 4a, 4b, 4c and 4d.

3.3 *History of movement*

Anecdotal evidence suggests the Lowtherville graben has 'opened up' since the early to mid-1900s, although ground movement in the area was first reported in 1954 by Edmunds and Bisson (Moore, Carey and McInnes, in press). The graben has since subsided vertically by up to 4m (ibid.). Historically there were more houses in the area immediately adjacent to the graben, particularly on the north side of Steephill Down Road. Since the 1980s, more than ten properties have been demolished, including a pair of semi-detached houses located south-west of the Council Yard on Newport Road and The Old Cottage, directly south of the Council Yard.

3.4 *Ground investigation and monitoring*

A ground investigation was carried out in 2002 by Soil Mechanics Limited between 15th May and 16th August 2002 to the instructions of High Point Rendel. The investigation comprised three deep boreholes in central Ventnor and the installation of standpipe piezometers in BH1 and BH3 and an inclinometer in BH2.

An additional ground investigation was carried out in 2005 which comprised the drilling of 3no. boreholes at 2no. locations and associated installations of an inclinometer and double standpipe piezometers at Ventnor Park (BH4, BH4I) and a further piezometer at the base of the Gault Clay in Castle Road (BH5).

A variety of monitoring has been carried out by the IWC and its contractors over the last few years. Details of those monitoring points are shown on Figure 3.

Moore, Carey and McInnes (in press) report that Chandler recorded short-term movement rates of between 53 and 125mm a year at the Lowtherville graben in 1984, compared with the long term average of about 28mm per year over a 20 year period.

Figure 5 shows the monitoring results over a ten-year period from 1995 to 2005 for two settlement cells at the graben, together with groundwater level at the Ventnor Winter Gardens. Settlement Cell 3 has a relatively steady downwards movement, whereas Settlement Cell 4 shows more seasonal variation, within an underlying trend of overall settlement. Analysis of all the monitoring data, including crack extensometers, by Halcrow, reported in Moore, Carey and McInnes (in press), shows a relatively continuous rate of horizontal displacement (6mm per year), with a notable period of accelerated movement in the winter of

2001. Vertical displacement rates (33mm per year) are five times greater than crack extension, which is a characteristic feature of graben development. This data shows that the long-term trend is confirmed by the local authority data recorded since 1995.

Figure 6 shows the settlement cell data with rainfall. These data show a lagged response of three to four months between monthly rainfall and accelerated ground movement. Further discussion of this is given in Moore, Carey and McInnes (in press).

4 Remedial options

4.1 *Aim of remediation*

The aims of remediating the site are twofold:

a). Improvement in the gradient of the road i.e. reduction in steepness, cross-camber and removal/reduction of changes in gradient

b). Reduction in current levels of extraordinary maintenance.

4.2 *Choice of remedial option*

The choice of remedial options for the site falls into three broad categories:

a). Minimal intervention

b). Structural solution

c). Flexible mitigation

Settlement of the graben will continue at the site whatever remedial option is chosen, because the settlement appears to be driven by movement of the landslide block beneath, as shown on the landslide model (Figure 2). Whatever solution is chosen must be able to tolerate the settlement and horizontal movement of the graben anticipated during the design life of the solution.

Any solution chosen needs to accommodate the interface with side roads and provide access to properties. The issue of buried services needs to be addressed at the detailed design stage, to ensure accommodation is made for existing and future services, possibly by provision of service ducts, if the chosen solution prohibits future excavation.

Discussion of each of the above approaches and the recommended choice of a flexible solution as the way forward for the site is presented below.

4.3 *Minimal intervention*

This is the current approach to managing the site and involves reactively responding to the incidence of movement and cracking/distress by means of a range of measures. Such measures include filling cracks in the road pavement, patch repairs to the road pavement and localised filling when the gradients become too extreme, together with construction of ancillary measures such as small retaining walls to support the filled road.

While this approach has successfully kept the road open and useable, the IWC is keen to adopt a relatively low-cost solution which will reduce the need for continued reactive maintenance.

Another option is to slacken the gradients on the approaches to the graben and fill within the graben area itself, both of which will act to reduce the steepness of the gradients around the graben area. However, without reinforcement within the road structure, movements of the graben beneath will be readily reflected at the surface and require continued maintenance as before.

4.4 *Structural solution*

Structural solutions considered for the site include a variety of options.

A bridging structure could be built at or around existing ground level, with abutments founded in the more stable ground north of the site and the landslide block south of the site. Bearings would be designed to accommodate the anticipated horizontal and tilt displacements caused by movement of the southern landslide block, allowing the graben to subside beneath the bridge. This option could require realignment of the road to minimise the span of the bridge and purchase of land around the existing alignment to facilitate this. The costs of such a solution are expected to be prohibitive and include land costs, costs of the structure itself and detailed ground investigation at the bridge site. Technically, use of such a rigid system in a situation where movements can occur is not advisable as a slight change in the way the graben moves or its position may mean that the design tolerances of the structure are exceeded, resulting in failure.

Transition or approach slabs are used in bridge construction to reduce local settlement behind the bridge abutment and accommodate global 1-dimensional settlement by providing a gradual transition between the bridge deck and the road. Another possible solution for the graben is to use transition slabs to bridge the graben walls, combined with regrading of the road above and below. Again this solution is rigid and requires the graben to continue to behave as it is now. As for the bridge structure, a slight change in the way the graben moves or its position may mean that the design tolerances of the structure are exceeded and it fails.

Another approach would be to provide a slab across the graben with a system which allows it to be jacked up as the graben settles, together with approach slabs each side designed to tolerate anticipated movement over the life of the structure. Design, construction and maintenance costs would be relatively high. As for all the other structural solutions, this approach is rigid and a slight change in the way the graben moves or its position may mean that the design tolerances of the structure are exceeded and it fails.

Essentially the choice of a rigid structural solution is expected to be relatively costly in terms of design, construction, land acquisition and maintenance, and runs the risk of failure should the development of the graben change slightly from that anticipated in the design. This approach is therefore not recommended.

4.5 Flexible solution

A flexible system for the reduction of maintenance costs at the Lowtherville graben would be to construct a soil mattress reinforced with layers of geotextiles overlain by a reinforced road pavement. Granular mattresses or mattresses incorporating other materials, such as tyre bales, are designed to drape over the ground, tolerate movement and reduce the steepness of any distortion suffered by the ground beneath by moving conformably with the ground. Reinforcement of the road pavement will reduce the incidence of reflective cracking and prolong the life of the road.

A mattress may be formed from a variety of materials, including imported granular fill, imported lightweight fill (e.g. lytag made from pfa, tyre shreds, tyre bales), re-use of site arisings. Ideally the solution should be relatively lightweight, to avoid loading the upper part of the landslide system below, however the contribution to slope disturbing forces introduced by any new upfilling will be small.

The steepness of the gradients at the site may be reduced by a combination of trimming and filling. Overfilling of the road level within the graben itself will increase the life of the structure by allowing time for settlement to occur to bring the road back to its current elevation. Trimming the road back to a slacker gradient beyond the graben will mean that as the graben continues to settle, more time is gained before a similar steepness is achieved and/or will reduce the amount of overfilling needed within the graben. Retaining structures may be required either side of the road to facilitate the upfilling.

Use of fill within the graben area will either require a certain amount of filling over adjacent land (this could be landscaped and returned to its owner) or construction of local retaining structures designed to accommodate movement, such as gabions. The extent of such filling or retaining structures would be developed at the detailed design stage.

Following the laying of any geo-gridded reinforcement, it will be important to retain the 'structural' integrity of the geo-grid. This means that new buried services should not be laid subsequently below the geo-grid, unless complex systems of repair to the geo-grid are undertaken. Accordingly, the need for any buried services may be accommodated in such a system by pre-provision of flexible ducting for both existing and future services. Access to side roads may be maintained by construction of ramps with a reinforced road pavement.

This approach to remedial repairs at the Lowtherville graben is the recommended preferred approach. It is relatively low cost compared to the structural solutions. Its flexibility means it should accommodate a certain amount of movement and the use of geotextile reinforcement should reduce both differential movement and the maintenance requirements, by reducing the incidence of reflective cracking at the road surface. Side road access and services may be accommodated within the system. Development of this flexible system is presented below.

4.6 *Design life*

Given the results of settlement monitoring at the Lowtherville graben, settlement rates of up to 40mm per year can be reasonably anticipated at the site. For a design life of 20 years, the structure/solution must be able to tolerate settlement of 800mm without failure (ultimate limit state) while maintaining gradients typically not greater than those currently at the site and preferably shallower (serviceability limit state).

Furthermore, it is much better if at the end of the design life, works can be readily carried out to extend the life of the structure eg by further trimming/filling and raising retaining walls as necessary to accommodate the additional changes in level.

4.7 *Flexible solution options*

4.7.1 *Option 1 – Trimming plus mattress and reinforced pavement construction*

This option comprises:

- Trimming the existing northern graben slope back to a gentler slope.

- Construction of retaining structures to support the land either side.
- Construction of mattress and reinforced road pavement at approximately current levels (i.e. overlying the existing construction).

4.7.2 *Option 2 – Filling plus mattress and reinforced pavement construction*

This option comprises:

- Filling the existing graben area of the road by approx 800mm, to include construction of mattress and pavement – see below.
- Construction of retaining structures around the fill if fill cannot be extended to existing ground either side at a suitable stable slope gradient.
- Construction of suitable gradients with mattress and reinforced pavement into side roads.
- Construction of mattress and reinforced road pavement at higher levels to tie into B3327 north and south.

4.7.3 *Option 3 – Cut/fill plus mattress and reinforced pavement construction*

This option comprises:

- Trimming the existing northern graben slope back to a gentler slope.
- Filling the existing graben area of the road by approximately 800mm, to include construction of mattress and pavement – see below.
- Construction of retaining structures around the fill if fill cannot be extended to existing ground either side at a suitable stable slope gradient.
- Construction of suitable gradients with mattress and reinforced pavement into side roads.
- Construction of mattress and reinforced road pavement at higher levels to tie into B3327 north and south

This potentially allows re-use of arisings from the cut within the fill area and by combining cut with fill lengthens the life of the approach gradients to the graben area. Option 3 is therefore the preferred solution.

4.8 *Construction details*

Final construction details, especially in terms of road construction, will be determined when ground investigation and topographical survey results are available as the investigation will include tests to determine subgrade surface modulus/CBR. Figure 7 shows a diagrammatic representation of the proposed construction.

It is anticipated that the typical fill/road construction will comprise 200mm to 300mm of bound courses (surface course, binder and base course), incorporating an anti-reflective cracking geotextile. This will overly 500mm to 600mm of subbase/capping, which will incorporate geotextile reinforcing layers, to create a mattress which will conform to settlement of the ground beneath and "drape" over the ground, masking some of the movement within a smoother profile. The technical properties of the geotextile will be chosen to be compatible with the strain caused by settlement of the graben with time and the modulus of the infill material, as appropriate. The potential re-use of arisings from cut areas will be investigated, as well as the use of imported fills, lightweight fills or recycled aggregates, provided the chosen materials meet the technical specification for the fill in terms of shear strength, modulus etc. Locally, deeper areas of fill may be required.

Positive drainage from the new road surface and new areas of fill will need to be provided into existing drainage systems, to avoid uncontrolled run-off into the graben beneath.

Flexible solutions for retaining walls should be used, such as gabion construction. Gabions may be hand-packed with a local stone facing in keeping with nearby walls, but their flexibility means that the significant cracking which characterises so many of the existing walls will be mostly avoided. In the future, as the system settles, it will be straightforward to add another layer or two of gabions to increase the wall height to that required, provided the original design/sizing permits this. The initial wall will be designed, if required by IWC, to allow for such future construction.

4.9 *Future works needed*

Various future works will be required in order to make the Option 3 solution possible. These include:

- Topographic survey of the road, footways, adjacent roads, including identification of cracks, street furniture, manhole covers, drains etc

- Detailed mapping on the ground of cracking and distress

- Ground investigation – to investigate potential voids beneath site, cross-hole geophysics plus targeted boreholes to investigate anomalies (to be grouted as necessary); investigation of proposed works area, road subgrade, soil parameters for retaining wall design

- Services – liaise with service providers regarding existing and potential services through the site, including the provision of service ducts in the design

- Detailed design – geotechnical, pavement and road design

- Design check in terms of suitability of vertical road alignment, cambers, gradients, drainage etc

- Waste Management Licensing Exemption/WRAP protocol submission if appropriate for recycled aggregate/materials proposed in construction

5 Cost estimate

5.1 *Construction works*

The cost estimate for the construction works for the flexible solution described above, including for 100m road construction, 50m gabion walling either side of the road and provision of settlement monitoring equipment, together with an allowance for the non-standard nature of the works is of the order of £0.7m. Table 2 below summarises the main work items. It should be noted that the cost estimate is based on broad approximations of quantities and that no detailed design has yet been undertaken.

Item	Cost
Road construction (B3327 and side road links)	£167,500
Additional excavation and filling	£17,100
Geotextiles	£21,250
Footpath	£5,850
Gabion walls	£90,500
Monitoring	£100,000
Service ducts	£25,850
Preliminaries	£85,600
Contingency	£205,500
Service diversions	£30,000
TOTAL	£749,150

Table 2 – Construction works cost estimate

An allowance should be made for the additional costs of the items identified in Section 4.9 above.

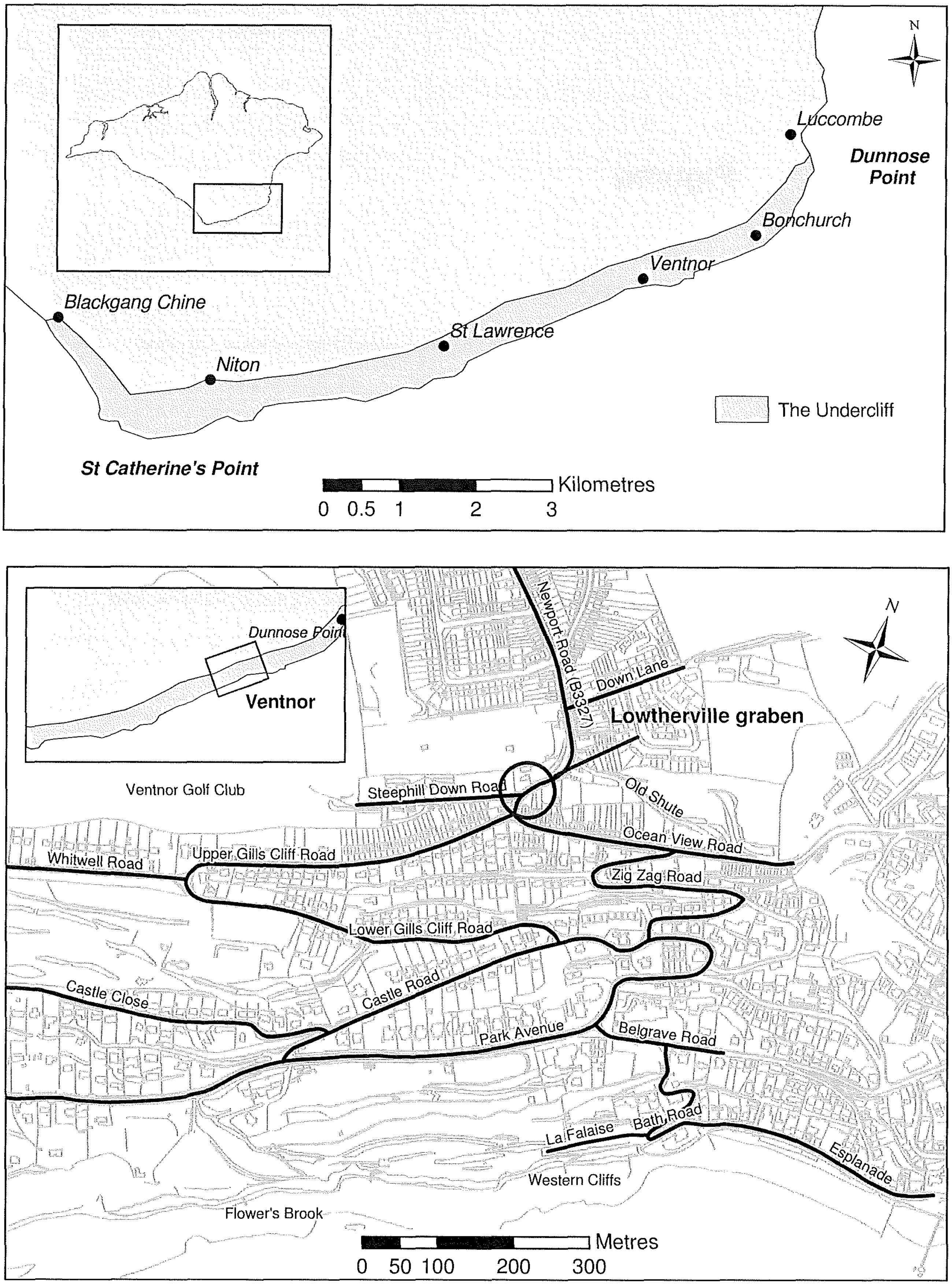
6 References

Halcrow Group Ltd, 2009. *Ventnor to Niton Options Study, Undercliff Drive Geotechnical Options Appraisal.* Report No. TH361 Issue No. Draft.

Moore R, Carey J M and McInnes R G, OBE, in press. *Landslide behaviour and climate change: predictable consequences for the Ventnor Undercliff, Isle of Wight*

Figures

Figure 1 Site location



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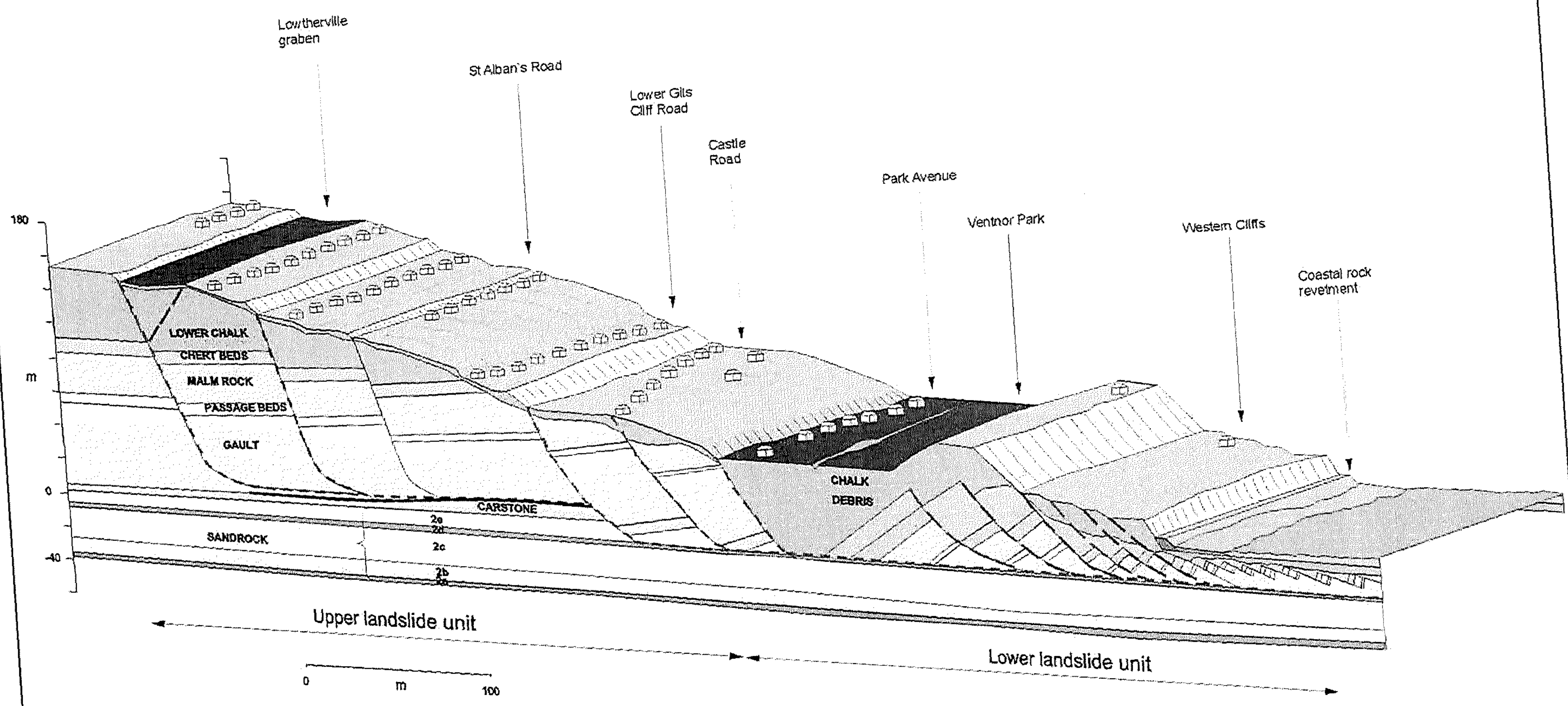

Figure 2. Landslide model of Ventnor Undercliff (after Moore, Carey and McInnes, *in press*)

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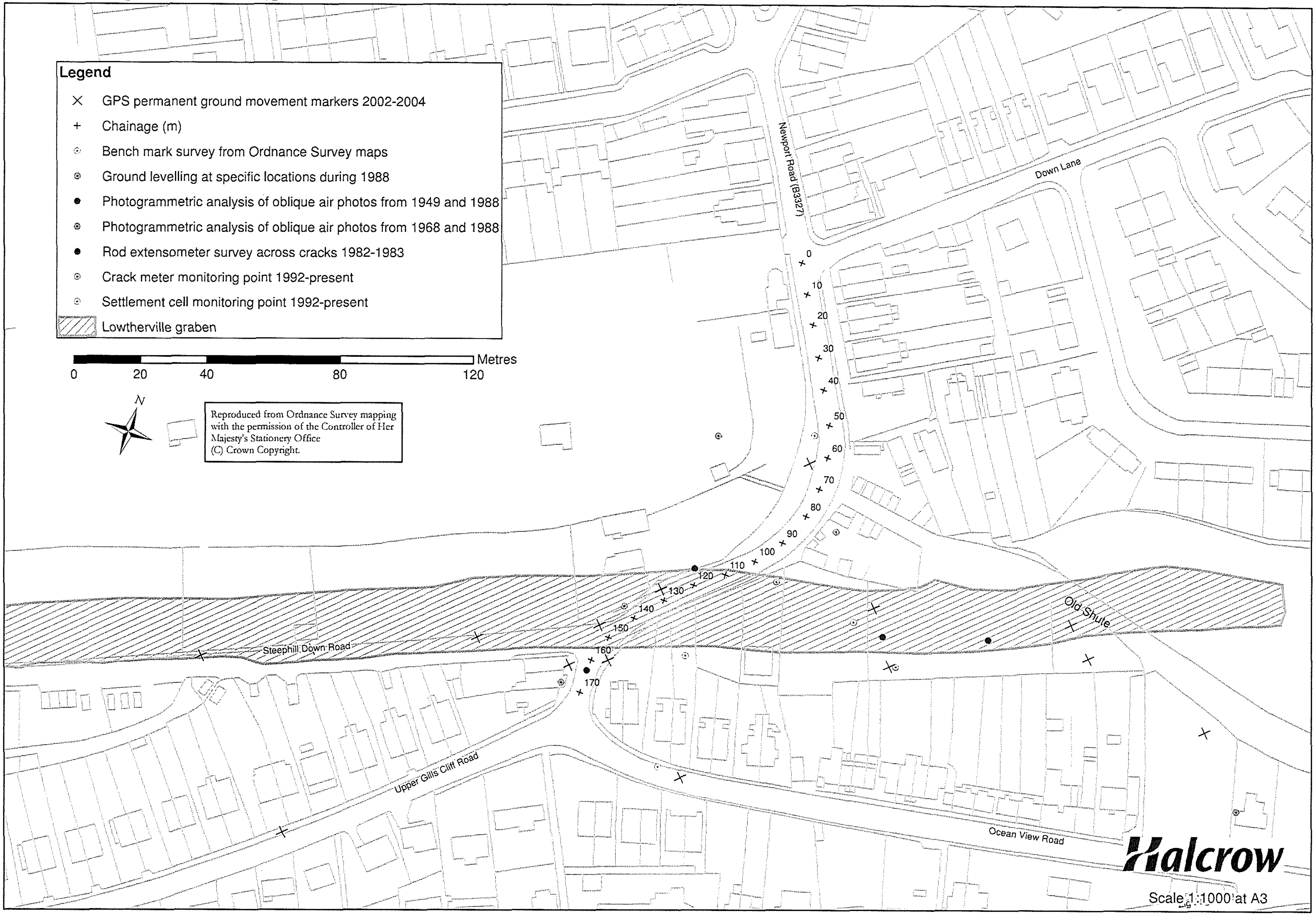
Figure 3. Site plan and monitoring point locations



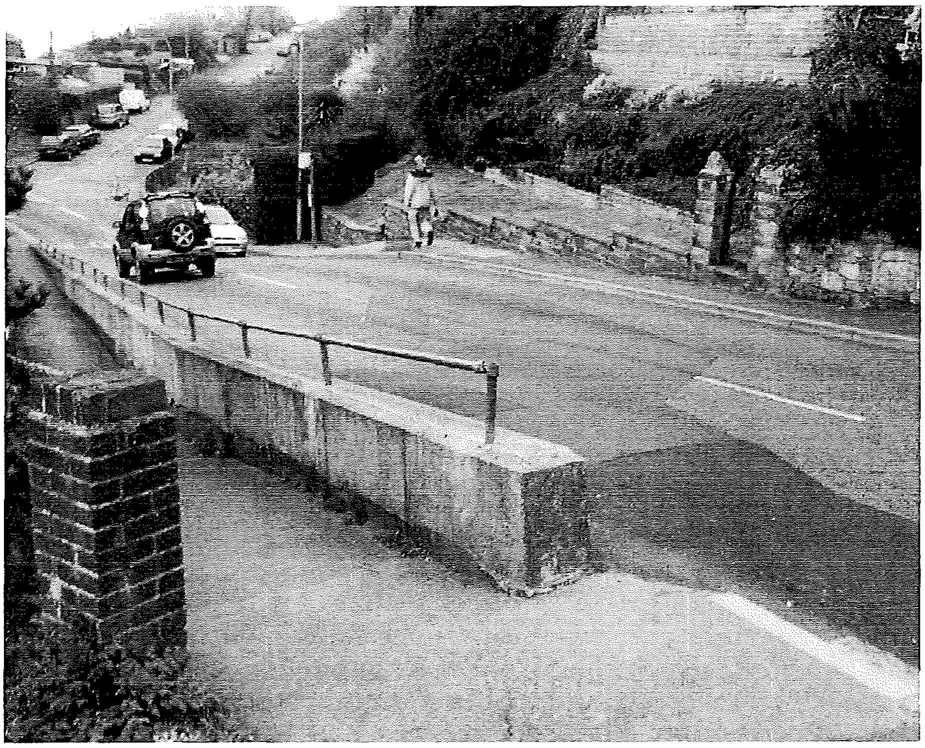


Figure 4a, Looking south down B3327 to Steephill Down Road, north side of graben

Figure 4b, Movement and cracking of wall at south side of graben opposite Upper Gills Cliff Road

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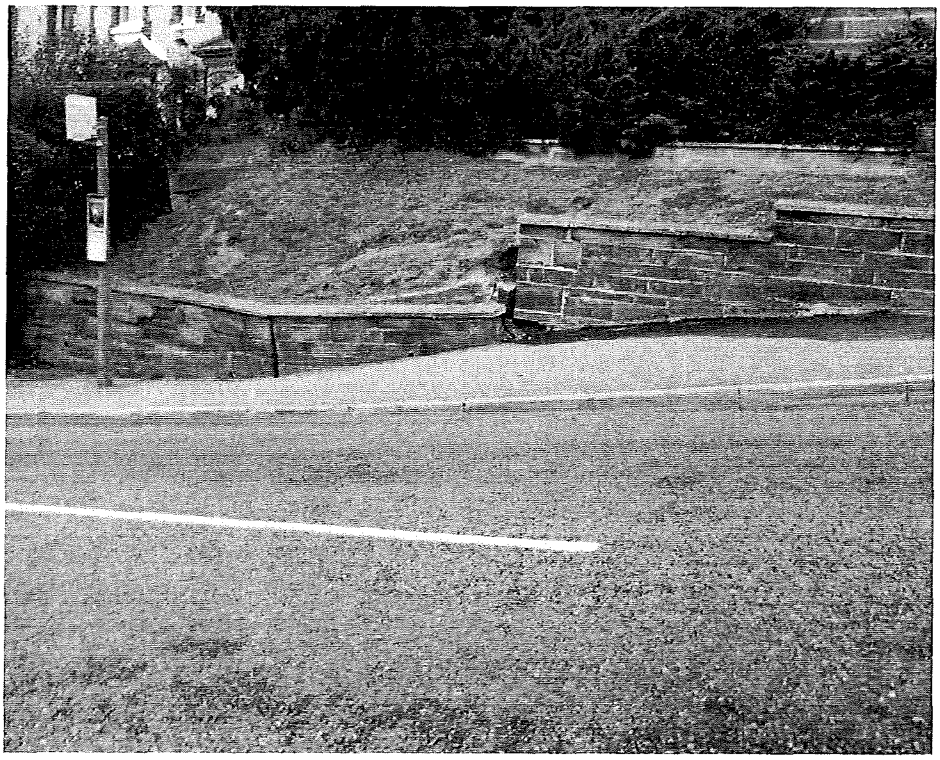
Figure 4c, Distress to retaining walls, north of graben


Figure 4d, Cracking of rigid handrail base, north side of graben

Figure 5 - Relationship between settlement at the Lowtherville graben and daily rainfall (10/1995-05/2005)

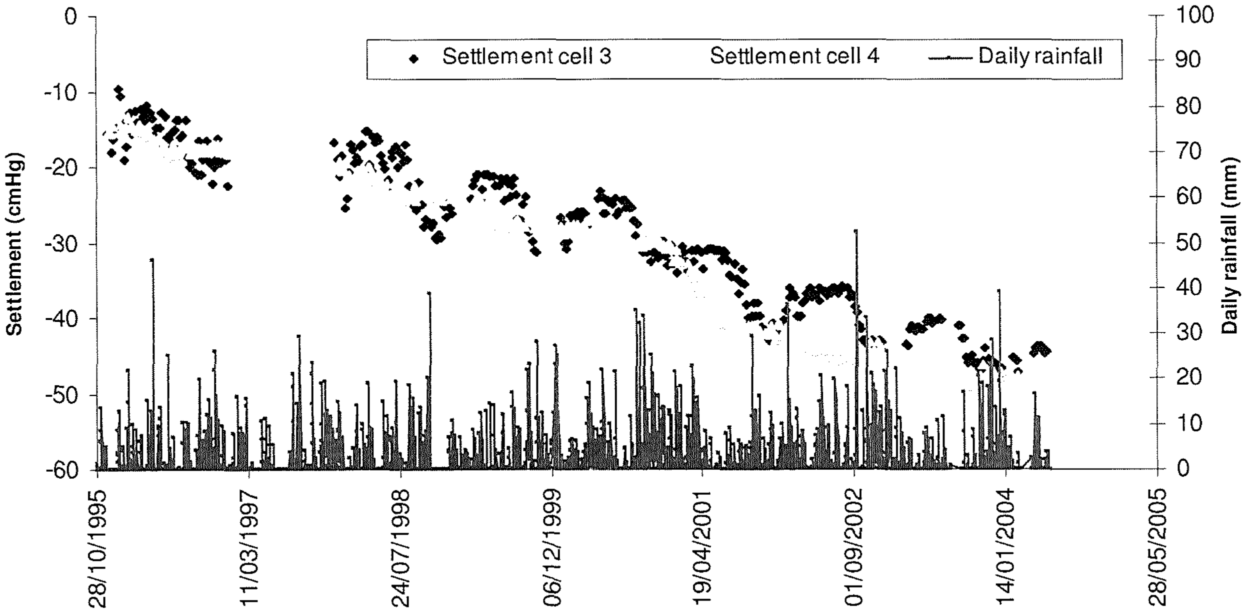

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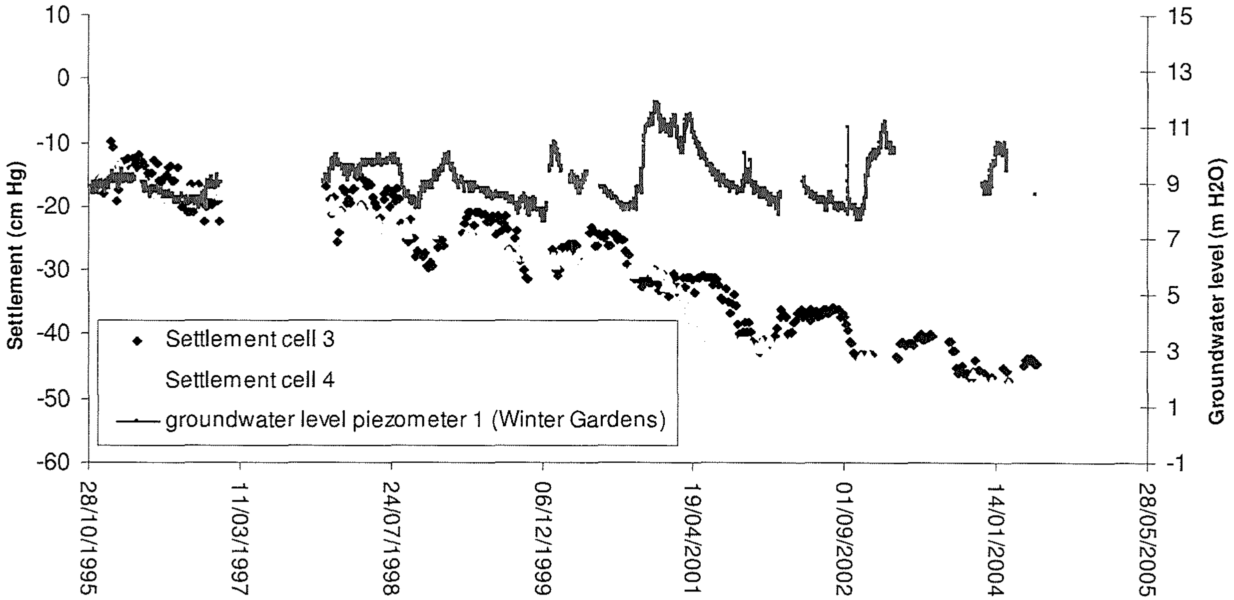
Figure 6 - Relationship between settlement at the Lowtherville graben and groundwater level at Winter Gardens (10/1995-05/2005)



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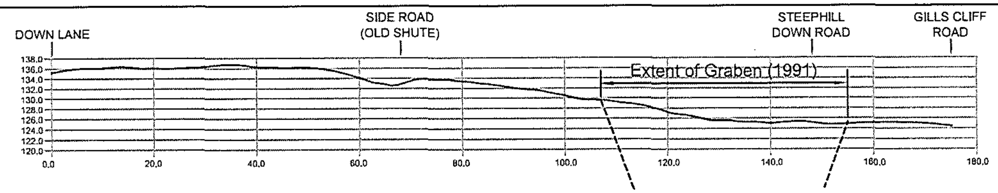
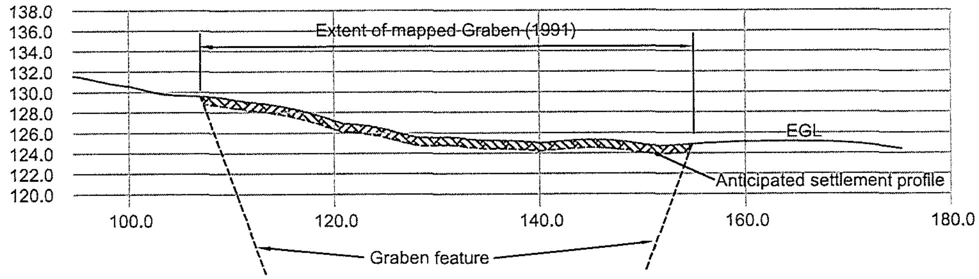
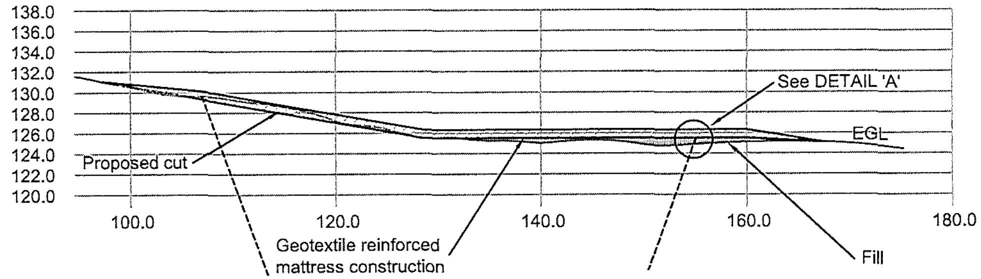


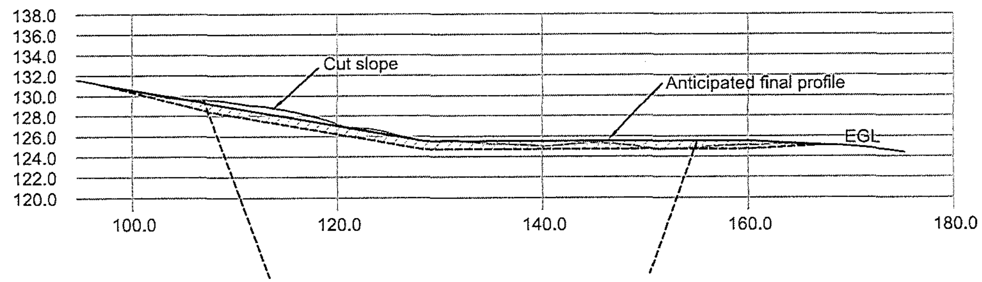
Lowtherville graben - Long section
1:1000 scale



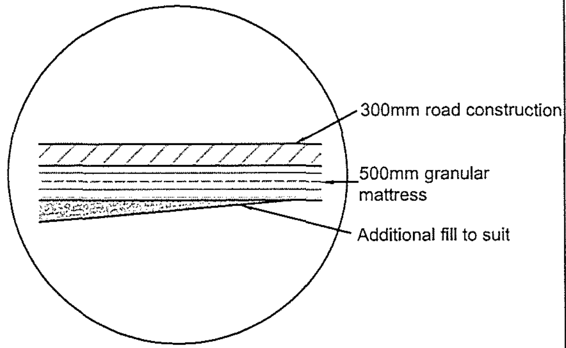
Existing with anticipated settlement profile
1:500 scale



Proposed cut and fill mattress construction
1:500 scale



Anticipated final construction
1:500 scale



DETAIL 'A'

PRELIMINARY

Notes:

Revision	By	Chk'd	Auth'd	Date	Description

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Project

VENTNOR TO NITON OPTIONS STUDY

Drawing

LOWTHERVILLE GRABEN REMEDIAL OPTION

Drawn by	NR	Date:	21.01.10
Checked by	ST	Date:	21.01.10
Authorised by		Date:	

Drawing No. FIGURE 7

Revision –

Drawing Scale at A3: AS SHOWN

CAD Filename: