Trafalgar Court Beach Access

Cliff Assessment and Options Appraisal

Prepared for

North Norfolk District Council

Date

September 2014

CH2MHILL®

62 Hagley Road Edgbaston
Birmingham, B16 8PE
T: +44 121 456 2345
F: +44 121 456 1569

Contents

Cliff Assessment and Options Appraisal

Terms of Reference

In response to North Norfolk District Council's (NNDC) ITT, CH2M HILL issued a proposal on 20 June 2014 to undertake an inspection and assessment of the cliffs and beach access ramp at Trafalgar Court to inform remedial and management options in the short term. NNDC issued an instruction to proceed on 30 June.

The scope of the task is as follows:

- Undertake an assessment of historical cliff recession using a GIS-based review of aerial photographs provided by the client. The results will provide data on the magnitude and frequency of cliff recession events and annual cliff erosion rates. The results will be combined with an analysis of beach profile data to determine the relationship between beach volume and cliff recession.

- The most recent aerial imagery will be used to map the cliff geomorphology, specifically identify the boundaries and type of cliff behaviour units (CBUs) along the study frontage. This data provides a spatial framework for the site inspection and assessment. Defining discrete cliff behaviour units is critically important for understanding the nature and rates of historical and potential cliff instability and erosion across the site, which in turn will inform options for sustainable reinstatement or re-routing of the access path.

- A site visit will be undertaken to refine the geomorphological mapping in order to identify areas of recent activity, geological exposures and any other relevant information. Geomorphological mapping will be undertaken using a recent aerial photo basemap printed at a scale of 1:500, with feature locations being recorded by tape and/or hand-held GPS.

- These new data will be used with existing cliff recession projections in the SMP and the National Coastal Erosion Risk Mapping (NCERM) model to inform a site-specific projection of cliff instability and recession over the next 50 years.

- Assess the options and costs to make repairs to the beach access ramp structure and/or provide alternative provision for pedestrian beach access within the vicinity of the ramp. This task will consider:

    - A range of options for repair and/or upgrade of the access route. These will be conceptual only, with costs estimated to a level appropriate for options appraisal. Only schematic design sketches and plans will be provided and there is no allowance for detailed design drawings.

    - Upgrade options will consider a range of structures and also alternative access routes within the land owned or managed by NNDC that may be considered more stable by the outputs of the task.

- Provide advice as to the longevity of the options when considering the level of coast protection and stability of the cliff, including:

    - The probable life span of the various engineering options will be assessed by considering the 'vulnerability' of each structure to the projected magnitude and frequency of cliff instability and ground movement. This will allow the economic value and expected life of the different options to be assessed over a nominal 50 year period.

- Recommendations for post-construction slope monitoring that can be used as a cost-effective method of appraising the performance of the structure, allowing any problems to be rapidly identified and remedied.

Site Description

Topography

The topography of the north Norfolk coast is dominated by the Cromer Ridge, which is a distinctive area of undulating high ground above 80m OD that runs approximately east-west across north Norfolk (Figure 1). It was formed during a glaciation that occurred in the Middle Pleistocene (c. 500,000 years ago) by a southwards moving ice sheet that deformed and up-thrusted underlying glacial and pre-glacial sediments. Mundesley lies at the eastern margin of the Cromer Ridge, where it intersects the coast to form cliffs 30 to 40 m high formed of weak and deformed glacial sediments. The cliffs at the Trafalgar Court access ramp are c. 40m high. Photographs of the site are provided in Appendix A.

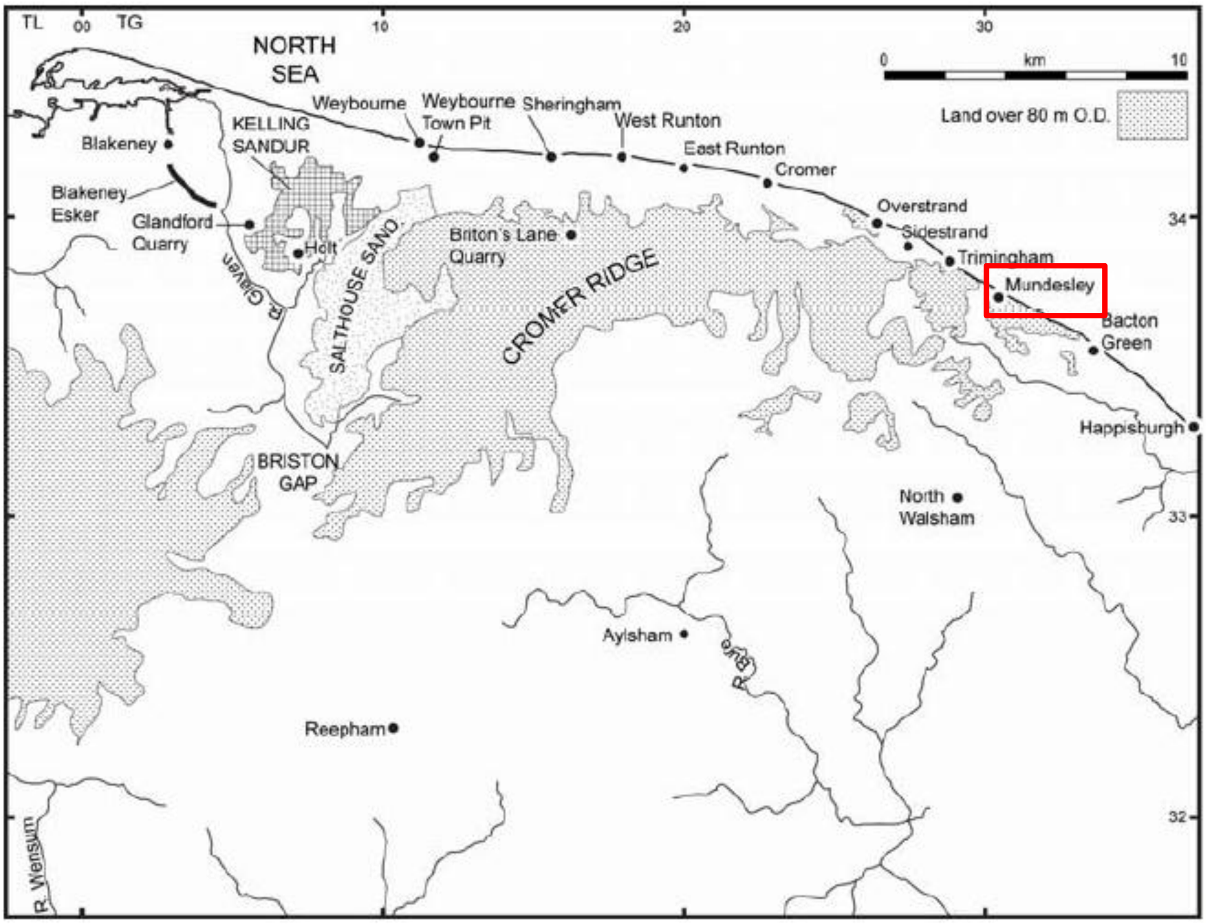


Figure 1. Location map, showing relationship of Mundesley Cliffs to the Cromer Ridge.

Geology

The cliffs are entirely comprised of weak and unconsolidated glacial sediments that were deformed by glaciotectonic processes in the Pleistocene. The stratigraphy of the site comprises, from the base, the Walcott Till Member of the Lowestoft Formation, the Mundesley Sand and Bacton Green Till members of the Sheringham Cliffs Formation and the Britons Lane Sand and Gravel Members of the Britons Lane Formation. The British Geological Survey describe these sedimentary units as follows:

- Briton's Land Sand and Gravel Member (Britons Lane formation): horizontal, massive and low angle planar cross-bedded gravels and cobble gravels with thin seams of horizontal and rippled sand. The lithology has a distinctive high flint content (c.85-89%) of which the majority is of non-chatter marked variety (c.78-85%). The gravels also contain a wide range of far-travelled crystalline erratics including rocks of British and Scandinavian provenance.

- Bacton Green Till Member (Sheringham Cliffs Formation): an extensive diamicton complex that consists of a stratified assemblage of stony diamicton with beds/laminae of sorted material including sand, silt and clay. It has been interpreted as being a subaqueous till deposited by melt-out and gravity flows. The calcium carbonate content of the matrix of the diamicton beds is typically within the region of 10-12%, which is 20% lower than tills from the underlying Lowestoft Formation (such as the Walcott Till).
- Mundesley Sand Member (Sheringham Cliffs Formation): Dull yellow-orange to dull yellowish brown stratified silty sands with a high abundance of detrital chalk in the lower horizons, and opaque heavy minerals. Typical bedding structures include planar cross-bedding, horizontal bedding, massive beds, climbing ripples and convolute bedding. See Appendix A for images of this unit.
- Walcott Till Member (Lowestoft Formation): An olive grey to olive brown silt-rich matrix-supported diamicton that is largely massive in structure. It has a moderate matrix calcium carbonate content of c.36% and contains an abundance of chalk and flint clasts. See Appendix A for images of this unit.

Glacial deformation and landslides make precise identification of the stratigraphy difficult in the field, but the Walcott Till and Mundesley Sand were clearly visible during the site inspection.

Landslides

Sections of the undefended Norfolk coastline that are formed in weak glacial or pre-glacial sediments are among the most rapidly retreating cliffs of the UK, with Happisburgh Cliffs to the southeast of Mundesley widely reported to be retreating at up to 10m/yr, generally through a processes of deep-seated rotation landsliding. Large rotational landslides are also present in the high cliffs at Sidestrand and Overstrand, to the northwest of Mundesley. The weak materials are highly susceptible to toe erosion by wave action, but intense and sustained rainfall also plays an important role in developing landslide shear surfaces at impermeable layers (e.g. at the contact between clay-rich tills and sand units) and triggering mudslides and debris falls from the face of the cliffs.

The entire frontage of Mundesley is defended, with a concrete toe apron at the Maritime Museum access, boulder-filled gabion baskets held in place by sheet piling as far northwest as the Trafalgar Court access and a detached wooden palisade fence beyond that (see Appendix A). Past repairs to the Trafalgar Court access ramp have included sand-filled bags placed at the toe of the cliff, behind the boulder-filled gabion baskets. The beach is held in place by wooden groynes. The condition of structures fronting Trafalgar Court was assessed in by Mott MacDonald in October 2012 as part of the Cromer to Winterton Ness Study and the detached wooden palisades were consider to be in good condition, with up to 25yrs residual life, and the timber groynes were considered to be in a good/fair condition, with a residual life of up to 15 years.

These structures act to protect the cliff toe from erosion by typical waves and have significantly constrained the cliff recession rate. However, they are less effective against higher waves, such as those experienced during the December 2013 storm surge and in 2008, which caused toe erosion and widespread cliff instability. There are no slope stabilisation or drainage measures in place on the cliffs or at the cliff top.

While the coastline shows a generally uniform steep, slightly embayed (c. 40 degrees) cliff morphology there is local variation and evidence for localised episodic instability through shallow mudsliding and block falls. These variations have formed a series of cliff behaviour units, characterised by similar materials and recession potential, to be defined. Large landslides, such as those seen to the northeast at Sidestrand and Overstrand, are absent from this stretch of coastline.

Beach Behaviour

The health of beaches in the study area in assessed using a series of 2D beach profiles. The Environment Agency’s comprehensive monitoring of the East Anglian coast includes two profiles, N067 and N068, in the study frontage that have been monitored since 1991. Data collected between 1991 and 2011 were assessed by the Environment Agency (2013) who concluded:

- N067, near Trafalgar Steps. Small erosion of MHW (i.e. beach lowering) at an average rate of 0.2m/yr but no change in MLW gives a shallower beach profile. No change in the cliff top.
- N068, near Maritime Museum beach access. Small erosion of MHW (i.e. beach lowering) at an average rate of 0.4m/yr but no change in MLW gives a shallower beach profile. No change in the cliff top.

In addition to this monitoring, the EA undertake additional monitoring of different profiles, with data from 2011 to 2014.

- MH023 c. 50m northeast of the Trafalgar Court access ramp. Fluctuation in beach level at MWH by c. 1m, with no clear trend. More limited change at MLW. The beach level prior to the surge was relatively high.
- MH028 c. 50m southeast of the Trafalgar Court access ramp. Fluctuation in beach level at MWH by c. 2m and up to 3m change at MLW with no clear trend at either location. The beach level prior to the surge was relatively high.

The data suggest that while overall beach erosion was low, particularly in the context of the whole East Anglian dataset, the progressive reduction in beach profile allows waves to break higher up the beach, meaning a greater amount of wave energy reaches the back of the beach and toe protection measures. This suggests that erosion of the cliff toe is likely to have progressively increased over the monitoring period. The data from the toe of the Trafalgar Court access indicates that limited fluctuation in beach levels has occurred since 2011, and that levels in 2013, prior to the surge, were towards the top of the 2011-2014 envelope.

Cliff Behaviour

Cliff behaviour units (CBUs) were mapped using 2012 aerial imagery with boundaries refined during the site inspection and field mapping. Aerial imagery dating from 1946 to 2012 was used to qualitatively assess past cliff activity combined with observations and mapping from the site inspection to characterise the current position. The assessment assumed that total cover of vegetation indicates an inactive cliff, and a total absence of vegetation or clear evidence of recent landsliding was an active cliff. CBUs with some evidence of exposed geology and landslides were classed as marginally active. The results are summarised in Table 1.

The position of the cliff top was also mapped for the earliest reliable image (1988) and most recent image (2012) to calculate recession rates. When errors in the georeferencing of the aerial imagery are taken into account, this analysis showed that no recession could be detected at the CBUs in the study area between 1988 and 2012 (24 years). The 1946 imagery was of sufficient quality to show that no large landslides were present in the CBUs further highlighting the long-term stability of the cliff top in this location.

NNDC records highlight that a large landslide occurred on the cliffs fronting Seaview Road in 2001. Review of the aerial photographs suggests this event occurred immediately northwest of CBU A and involved collapse of a cliff top promontory in a large rotational mudslide event. Such events occur when adjacent mudslides create embayments with an intervening promontory that progressively fails due to loss of support.

Overall, the cliff instability data highlight that while the cliff top in the study area has not retreated by an appreciable amount, there has been episodic and widespread activity on the cliff face. This reflects the composite nature of the cliffs, with the resistant upper till unit able to stand at a near vertical angle while the weaker, slightly lower angle underlying sand unit fails through episodic block falls and mudslides due to undercutting at the toe. The periods and locations of activity occur randomly in space and time, suggesting that factors other than storms are responsible for triggering cliff failures and that CBUs operate independently.

The data highlight that CBU E (Figure 1), which includes the beach access ramp and steps, was marginally active in 1988 but shows inactivity in other time periods. The activity in 2008 that damaged the lower section of the path is not indicated in the closest subsequent imagery from 2010. In contrast, CBU D has consistently shown activity. CBU F does not show any activity in the period 1988 to 2012, but the site visit highlighted widespread evidence for instability (Figure 1 and Table 1).

The data from the 2001 Seaview Road landslide indicates that large cliff top recession events do occur, but a rare along this frontage (in terms of spatial location and a time period since the 1940s) and tend to relate to failure of unstable cliff top promontories formed between mudslide embayments.

Table 1. Qualitative assessment of cliff activity. Trafalgar Steps are in CBU E.

CBU	Description	1946	1988	1999	2007	2010	2012	2014
A[1]	Composite cliff, sand over till	Imagery unclear	Inactive	Marginally active	Inactive	Inactive	Marginally active	Marginally active
B	Composite cliff, sand over till. Active cliff falls	Imagery unclear	Inactive	Active	Inactive	Marginally active	Marginally active	Active
C	Composite cliff, sand over till. Active cliff falls	Imagery unclear	Inactive	Active	Marginally active	Active	Active	Active
D	Composite cliff, sand over till. Active cliff falls	Imagery unclear	Marginally active	Active	Marginally active	Marginally active	Marginally active	Marginally active
E	Composite cliff, till over sand. Active mudslides	Imagery unclear	Marginally active	Inactive	Inactive	Inactive	Inactive	Marginally active
F	Composite cliff, till over sand. Active mudslides	Imagery unclear	Inactive	Inactive	Inactive	Inactive	Inactive	Marginally active
G	Composite cliff, till over sand. Active mudslides	Imagery unclear	Inactive	Inactive	Inactive	Inactive	Inactive	Marginally active

Note: [1] The Seaview Road failure occurred immediately northwest of CBU A.

Cliff Geomorphology

A site visit to map the cliff geomorphology was undertaken on 31 July 2014. The slope characteristics were measured with a tape and clinometer and were recorded on a 1:500 basemap. The results are shown in Figure 1.

The cliffs northeast of the access ramp, including CBUs A, B, C and D comprise three stratigraphical units with corresponding slope morphology and instability features. The base of the slope is formed of a near-vertical cliff up to 5m high formed of a matrix-supported dark grey sandy clay diamicton containing gravel of flint, chalk and crystalline minerals that is interpreted as Walcott Till. This cliff is failing through debris fall processes and blocks of fallen material are evident on the beach. The main body of the cliff is formed of a yellowish orange sand that is laminated near its basal contact. This is interpreted as Mundesley Sand. It forms slopes up to 40 degrees and is subject to widespread failure through sand falls with well-developed talus cones that extend across the back of the beach and obscure the lower cliff. The upper part of the slope comprises a near-vertical cliff that is c. 2m high and formed in sand and gravel that is susceptible to localised failure by falls and topples. This upper unit was not clearly exposed due to vegetation and instability, and may be either the Bacton Green Till or the Briton's Lane Sand and Gravel.

Legend

Slope morphology
- Cliff (>40 degrees)
- Sharp break of slope
- Smooth break of slope
- Sharp convex break of slope
- Sharp concave of break of slope
- Smooth concave break ofslope
- Gully

Slope direction and angle
- Smooth slope
- Uneven slope

Coastal structures
- Rock-filled bags
- Rock-filled baskets
- Wooden groyne
- Wooden palisade fence
- CBUs

Mund_geomorpg

Geomorphology
- Cliff (Walcott Till)
- Cliff (Mundesley Sand)
- Cliff (Bacton Green Till?)
- Plateau (Bacton Green Till?)
- Gully (Bacton Green Till)
- Active mudslide
- Active cliff fall
- Relict mudslide
- Upper beach and talus
- Beach

Client: North Norfolk District Council

Project: Trafalgar Court Beach Access Ramp

Figure 1 Slope geomorphology

CH2MHILL®
Halcrow
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE

Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com

The cliffs of the Trafalgar Court access ramp (CBU E) comprise two stratigraphical units with corresponding slope morphology. The Walcott Till was not observed here and is assumed to be below beach level and/or obscured by talus. The majority of CBU E is formed in Mundesley Sand that forms steep slopes of 35 to 40 degrees. The lower half of Mundesley Sand slope is affected by debris falls that are typically 20m wide, up to 30m long but rarely more than 1m deep. These features are likely to have been triggered by toe erosion during the storm surge and have undermined the lowest section of the footpath and threaten other parts of the path. The upper part of the slope is well-vegetated, but shows evidence for former mudslide activity in the form of linear tracks and relict mudslide embayments. The upper slope unit is cut in sands and gravels (Britons Lane Sand and Gravel or Bacton Green Till).

Where this slope appears below the footpath, it lies at an angle of less than 25 degrees and is indented by a series of gully heads that were dry during the visit. One of the gullies that lies at the apex of the path is up to 1m deep and cuts to the top of the cliff. Above the footpath the slope is very smooth with an angle of over 40 degrees. This section is likely to be a cut slope dating from path construction after World War 2.

The cliffs to the southeast, comprising CBUs F and G, comprise c. 60 m wide mudslide embayments that have 35 to 40 degree slopes, and a c. 45 degree upper cliff up to 2m high. The mudslides have formed in till and sand and the cliff shows widespread evidence of instability including active and relict mudslide and recent toe erosion to form near-vertical cliffs fronted by recent debris accumulations.

Summary of Cliff Instability

The active instability features observed on site affect the cliff faces of all CBUs observed, with the basal till unit failing though blocky debris falls and the overlying sands failing through debris falls and debris slides. In both cases, the depth of failure is shallow and no headscarp recession was observed. However, this shallow cliff face instability has damaged the lowest part of footpath, and ongoing cliff instability threatens other parts of the path.

The cliff instability that damaged the footpath during the December 2013 surge was caused by toe erosion during the storm surge, which overtopped the existing defences. However, not all instability features observed on site, including those that have the potential to affect the remaining section of the path, are a result of toe erosion and the impact of elevated groundwater and surface water flow must be taken into account. These processes play an important role in the development of mudslides that are seen in CBUs D, E, F and G. The importance of surface water flows and groundwater is indicated by the localised gully erosion at the slope top, and the indented upper slope marking the heads of a series of groundwater-triggered mudslides.

The site is covered by policy unit 6.08 of the Kelling Hard to Lowestoft Ness Shoreline Management Plan (SMP2). This indicates a hold the line policy for the short and medium term and then progressive adoption of policies that allow along-shore sediment transfer to nourish the beach to provide natural coast protection, with localised erosion management at high risk certain sites. This means the existing toe protection measures at Trafalgar Court cliffs, which are largely effective, will be in place for at least 50 years. Over this the next 50 years, the amount of headscarp recession is likely to continue the pattern of limited change observed over the previous 50 years. This assumes that in addition to the coast protection measures remaining in place, beach levels will continue to fluctuate about historical levels.

Path Condition

The condition of the footpath was visually assessed during the site visit. The path is a c 2.5m wide ramp formed from concrete slabs with a tarmac surface. It descends to beach level along an angled route, with an upper section c. 100m long dropping at 10 to 12 degrees towards the southeast and a lower section c. 70m long that originally dropped towards the northwest to the beach. The lowest c. 30m of the path has been lost to lower cliff collapse and erosion, and the path currently ends mid-slope. The damaged section of path has been broken into a series of large blocks of concrete that lie at the slope toe.

The upper section of path is in a good state of repair. It shows some evidence for settlement, but cracks are minor and easily repairable. The adjacent slopes are steep, but show no evidence of instability. With minor maintenance to the pavement, this section of path is considered to have a life of at least 20 years.

The remaining part of the lower section of path is in a similarly reasonable state of repair, with some evidence for settlement and localised damage to the handrail that extends along the down-slope edge. However, recent instability on the slope below the path threatens to undermine the structure at two locations and consequently, with no intervention to stabilise the slope, it is unlikely that it will last much more than five years, and will perhaps fail soon if there are repeat winter storms and further toe erosion in 2014/15.

Options for Remediation of the Path

Based on the geomorphological mapping and footpath condition assessment, a series of options are presented for reinstatement of a permanent access route from Trafalgar Court to the beach. In all cases, it is assumed that a pathway at least 1.5m wide is required but that disabled access will not be needed. All costs are expressed as a credible range to cover uncertainties such as cost of local materials and access for construction.

The options are presented on Figure 2 and comprise the following:

- Option 1 – remediate existing lower section of path
- Option 2 – remediate part of the existing lower section of path with a short stair to the beach
- Option 3 – abandon the lower section of path and construct a long stair to the beach

In all three options, work is limited to the lower section of path because the upper section is considered to be stable in the short-term. However, if no work is undertaken to stabilise the lower section of slope, it is likely that the upper slope will be progressively undermined and ultimately headscarp recession will occur. Furthermore, the design life of all proposed options is conditional on maintenance of the existing coast protection measures that will afford the primary method of toe protection to the slope.

Other options, which might involve design and construction of a new footpath across adjacent lengths of cliff, are not considered feasible given the steeper and more active slopes observed in CBUs C and F.

The upper section of the existing path, labelled 1 on Figure 2, is considered to be sound, and is likely to have a lifespan of at least 20 years with minor maintenance and with repair of the lower slope. It is therefore recommended that this 110m long section be retained. The remaining 38m long section of the lower path that has not been lost to erosion (labelled 2) is at risk due to loss of support from the underlying slope and therefore its lifespan cannot be guaranteed in the short-term. However, this section of path can be stabilised by reinstating the lower slope and need not be abandoned.

The proposed engineering, estimated costs and estimated design life of the three options are provided in Table 2.

Option 1 comprises construction of a gravity structure to support a replacement section of footpath to beach level (1a) and reinforcement of the existing section of path that is affected by undermining (1b). The gravity structure may comprise a gabion basket wall, or a crib-lock wall that comprises a timber lattice with stone infill similar to that shown in the photograph. Depending on the precise design requirements, the structure could be founded on a concrete foundation to accommodate any projected beach lowering. The structure would enable the reconstruction of the footpath along the same the alignment and also provide additional erosion protection. It is presumed that the structure will need to support the new backfill and footpath but not the cliff, which does not include deep-seated instability features, and therefore its construction should be relatively slender. Reinforcing the existing, undermined section of path could involve use of short soil nails with localised hard facing and granular fill, or additional gabion baskets. Both options would include soil netting and seeding to limit erosion by surface water runoff. While the principal method of toe erosion protection would be the existing gabions, but both gravity structure options would afford some protection against storm surges, particularly if soil netting was used and vegetation became well-established.

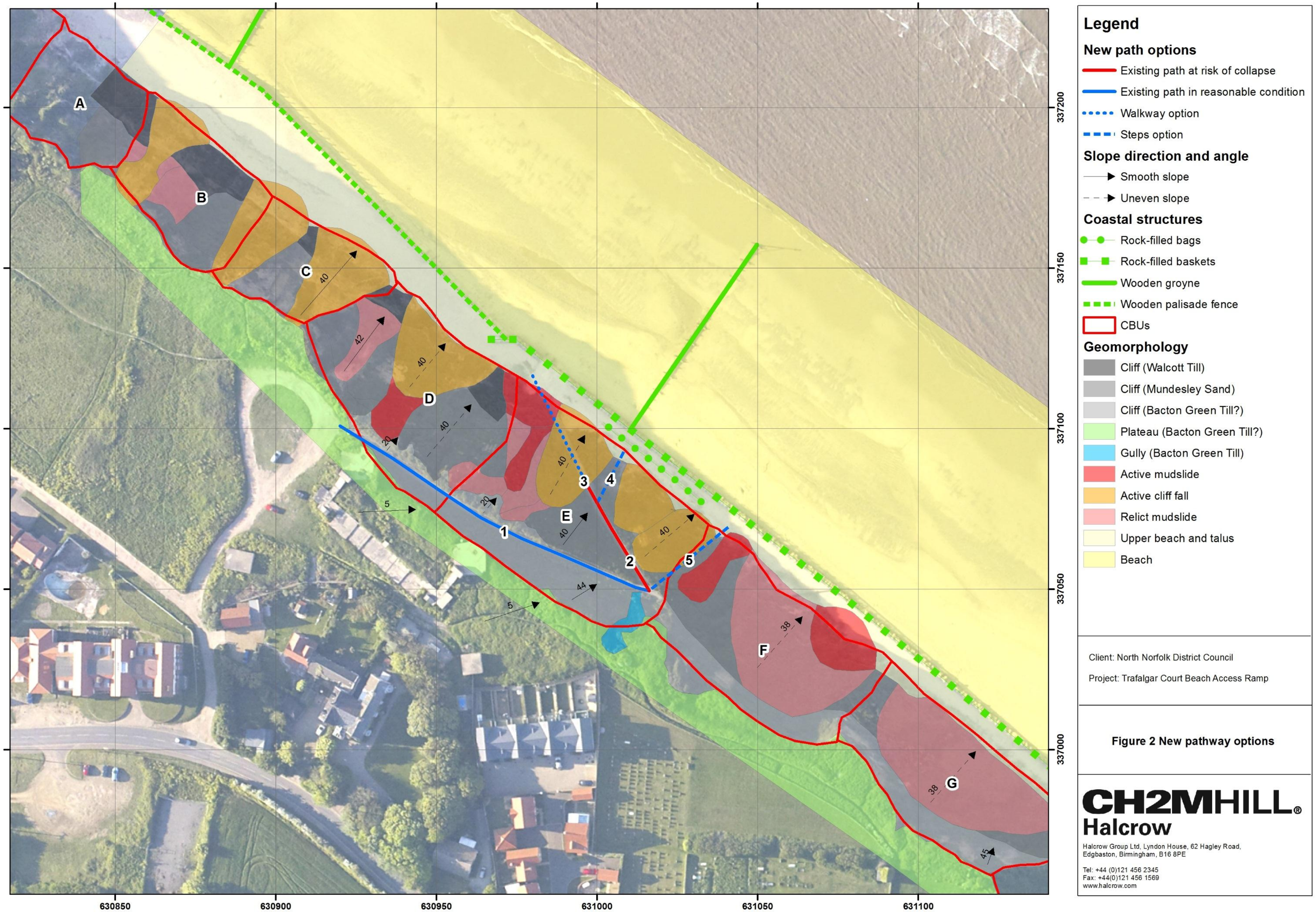

Legend
New path options
Existing path at risk of collapse
Existing path in reasonable condition
Walkway option
Steps option
Slope direction and angle
Smooth slope
Uneven slope
Coastal structures
Rock-filled bags
Rock-filled baskets
Wooden groyne
Wooden palisade fence
CBUs
Geomorphology
Cliff (Walcott Till)
Cliff (Mundesley Sand)
Cliff (Bacton Green Till?)
Plateau (Bacton Green Till?)
Gully (Bacton Green Till)
Active mudslide
Active cliff fall
Relict mudslide
Upper beach and talus
Beach
Client: North Norfolk District Council
Project: Trafalgar Court Beach Access Ramp
Figure 2 New pathway options
CH2MHILL
Halcrow
Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Edgbaston, Birmingham, B16 8PE
Tel: +44 (0)121 456 2345
Fax: +44(0)121 456 1569
www.halcrow.com
630850
630900
630950
631000
631050
631100
337200
337150
337100
337050
337000
A
B
C
D
E
F
G
1
2
3
4
5

Table 1. Estimated costs for the footpath options

Option	Description of proposed works	Design Life (years)	Costs	Whole Life Cost (/yr)
1a – Remediate existing path: Gravity Structure	• From beach level the lower-most 35m of 2m wide ramped path and associated hand rail has been lost. In order to stabilise the slope using an earthwork solution a gravity structure such as a gabion wall (stone filled baskets) or crib lock wall (timber lattice with stone infill) with mesh face protection. The structure would enable the reconstruction of the footpath along the same the alignment and also provide erosion protection. It is presumed that the structure will need to support the new backfill and footpath but not the cliff, and therefore its construction should therefore be relatively slender. • Volume of fill required (assuming failure is approximately 1m deep throughout and an additional 2m of fill is required to provide the facing system) is about 1500 m^3. 7m^2 of new path needs construction (current design is cast concrete slabs with tarmac capping – see note 1). Area of slope that may requiring netting/seeding c. 500 m^2. • If gabions or crib lock walls are adopted then additional erosion toe protection should not be required along this section, which already benefits from boulder-filled gabions.	>60 (see note 2)	£100k to £150k	Annual inspection (see note 4): £200
1b - Additional works:	• The remaining 37m of the lower section of path is also at risk, with c. 10m already being under-mined by shallow failures. The solution would be provide either short soil nails and a localised hard face solution to strength the slope immediately below the footpath or construct a row of gabions to support the edge of the footpath, and re-instate footpath as required. • Volume of fill required (assuming failure is 0.5m deep throughout) is c. 325 m^3 with 40m of 1m high gabion baskets constructed in front. Volume of stone 40m^3. • An area of current instability measuring c 650 m^2 requires netting/seeding.		Additional £30k to £45k (see note 6)	
2 – part-remediate path, with short stair to beach	• Treated timber stairs founded on posts embedded into the slope. The vertical height of the steps is c. 15m, and based on a 40 degree gradient the length of the steps are 24m. • The remaining 37m of the lower section of path is at risk, with c 10m already being under-mined; for this section solution 1b outlined above should be applied. • An area of current instability measuring c 650 m^2 requires netting/seeding.	15 to 20 (see notes 1 and 2) 15 to 20	£70k to £100k (plus £30k to £45k for gabion edge support described in 1b)	Annual inspection (see note 4): £200 Maintenance (see Note 5): £500 per visit
3 – long stair to beach and abandon lower path	• Treated timber stairs founded on posts embedded into the slopes (slope angle is about 40 degrees, vertical drop is c. 25m, steps therefore pass over approximately 40m of slope) • Netting/seeding required to limit erosion of the adjacent slopes.	15 to 20 (see notes 1 and 2) 15 to 20	£120k to £180	Maintenance (see Note 5): £1000 per visit

Notes:

1. Upper section of intact footpath requires new layer of tarmac. 110m long x 2m wide = 220 m^2; this has not been included in the above estimates. Other options may include stone surfacing or the use of concrete slabs.

2. The design life of the solution relies upon the ongoing maintenance of the toe erosion protection measures to ensure serviceability

3. The design life of the solution relies upon the maintenance of the slope erosion protection measures (netting and vegetation)

4. Annual inspection prior to holiday season and after a tidal surge or significant storm event.

5. For example replace broken boards and/or refit loose boards. Erosion protection repairs not included.

6. Modular construction using gabion baskets filled with suitable stone to provide a free draining solution. The gabions would form a supporting wall and with the use of geotextile separators this should prevent the washing of fines from the slope.

The structure is unlikely to suffer outflanking over its design life because of the projected stability of the headscarp in the area and maintenance of existing toe protection measures under the hold the line policy. However, beyond 50 to 60 years, the shoreline management policy changes to no active intervention and the structure has reached its design life so significant changes to the cliffs, including loss of the access and cliff-top properties, are expected.

This option is estimated to cost £130k to £195k, but would have a design life of at least 60 years. Annual maintenance of £200 to cover site inspections are required, but the cost of any post-storm repairs are excluded from these costs.

Example of a crib-lock wall

Example of a wooden stair with passing places

Option 2 comprises reinforcement of the existing section of path that is affected by undermining (1b) but abandonment of the lower-most section of path, with access to the beach by a short stairway, similar to that in the photograph above. The stair will be of lightweight timber construction that is founded on posts embedded in the slope. Such a structure could accommodate a small amount of ground movement or toe erosion without being damaged. The estimated total cost of the remediated lower path and short stair is estimated to be £100k to £145k, but is unlikely to have a design life of over 20 years. The annual maintenance costs are estimated to be £700 to cover annual inspections and replacement of damaged timbers.

Option 3 comprises the abandonment of the entire lower section of footpath and replacement with a long stairway. As in option 2, this structure is envisaged to be of lightweight timber construction that can accommodate a small amount of toe erosion and slope instability without being damaged. The estimated total cost of this option is £120k to £180k but is unlikely to have a design life of over 20 years. The annual maintenance costs are estimated to be £1,000 to cover annual inspections and replacement of damaged timbers.

Conclusion and Recommendations

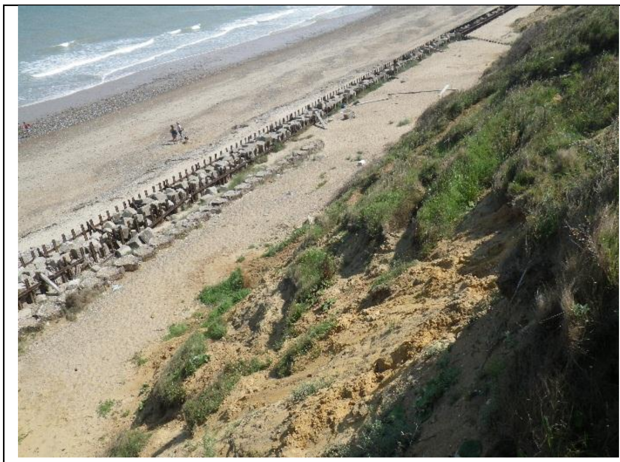
Geomorphological mapping indicates that the cliffs in the area of the Trafalgar Court access steps experience periodic toe erosion that triggers localised and shallow instability in the lower part of the slope. No deep-seated instability features are present in the upper part of the slope, although it is evident that erosion from surface water drainage and development of small gullies and mudslides periodically occurs. Assessment of historical aerial imagery indicates that despite these erosion processes, the cliff line is stable and that very limited headscarp recession has occurred since the 1940s. Adjacent stretches of cliff also show very limited headscarp recession, but they include active mudslides on their lower slopes and steeper upper slopes.

It is therefore recommended that options to restore access to the beach maintain the general position of the current pathway. Three options are proposed:

- Option 1 – remediate and replace the entire lower section of path using gabion baskets or crib lock wall. This option is the most robust and is likely to last for 60 years. The initial cost is estimated to be £130k to £195k with limited annual maintenance requirements.
- Option 2 – remediate the existing part of the lower section of path and construct a short stair to the beach. This option is less robust and is unlikely to last for more than 20 years. The cost is estimated to be £100k to £145k with some annual maintenance to cover repairs to the stairway. However, in the event that the structure is significantly damaged by a storm surge and/or shallow instability it is likely that it can be repaired for significantly less than the original cost of construction.
- Option 3 – abandon the entire lower section of path and construct a long stair to the beach. As with option 2, this is a less robust solution that is unlikely to last for more than 20 years and the cost is estimated to be £120k to £180k with some annual maintenance to cover repairs to the stairway. However, in the event that the structure is significantly damaged by a storm surge and/or shallow instability it is likely that it can be repaired for significantly less than the original cost of construction.

Option 1 is the most robust design, and despite having the greatest cost of construction, it is considered to provide the best value over a 60 year time period. The stairway options are both cheaper to construct, but their more limited design life, and increased requirements for annual maintenance mean their total cost over 60 years is likely to be significantly greater.

Appendix A – Photographic record



Boulder-fill baskets protecting the cliff toe at Trafalgar Court access

Details of the lowermost section of footpath lost in the December 2013 storm surge. Note the geology here is Mundesley Sand

Overview of the lowermost section of path showing undermining of remaining section and toe defences of gravel-filled bags

Overview of the northern section of the site showing transition from boulder-filled gabions to detached palisade fence

Shallow instability features triggered by toe eroson that are undermining of the lower path.

Detail of the lost section fo path caused by toe erosion of Mundesley Sand

	
CBU north of the access ramp showing steep cliff and debris falls.	Overview of the upper section of path showing stable slope and footpath in good condition.
	
Detail of relict mudslide embayment between the upper and lower sections of path.	CBU south of the access ramp showing steep slope and localised reactivation of mudslide debris
	
Walcott Till below the Mundesley Sand where the path formerly reached beach level. This unit crops out below beach level in the vicinity of the path	Mudslide embayment that led to loss of the lower-most section of footpath