SOFT COPY PHOTOGRAMMETRY TO MEASURE SHORE PLATFORM EROSION ON DECADAL TIME SCALES

UWE DORNBUSCH¹, CHERITH MOSES¹, DAVID A. ROBINSON¹ & RENDEL WILLIAMS¹

¹ University of Sussex, Department of Geography, Chichester Building, BN1 9QJ, UK

Tel. +44 01273 873156; Fax. +44 01273 677196

Email. u.dornbusch@sussex.ac.uk; Internet. www.geog.sussex.ac.uk/BAR/

ABSTRACT: Shore platform erosion is considered a driving mechanism for cliff recession on many rocky coasts and, in the vicinity of sea defence structures, a threat to their stability, yet the spatial pattern of platform erosion, as well as the rate of lowering, is poorly documented. Measurements based on techniques such as the micro-erosion metre or laser scanner, though highly accurate for short time scales and specific locations, are difficult to extrapolate in space and time. They also fail to record meso-scale changes such as block removal. This paper describes a technique to quantify spatial and temporal changes and presents first results.

KEYWORDS: DTM, GPS, CHALK, EROSION, COASTAL PROTECTION

INTRODUCTION

Shore platforms are usually backed by cliffs, many of which are protected by engineering structures including seawalls and groynes. In situations where the cliffs are not protected, shore platform downwearing, in addition to wave attack at the foot of the cliff, is thought to control cliff-line retreat (Trenhaile 1997, 2005). Even when protective structures are in place, the shore platform continues to wear down. This is evidenced by scour marks around the base of, for example, seawalls and groynes. Quantification of platform erosion is important on natural cliffed coastlines, in order to help predict cliff-line retreat and to ascertain its influence on the rate of cliff retreat, and on cliffed coastlines that are protected, in order to help establish the life expectancy of the engineering structures.

This paper reports a new method for measuring rates of shore platform erosion across the whole intertidal platform on engineering time scales. The accuracy of the method is assessed and its ability to detect changes on chalk shore platforms evaluated by presenting results from two test sites.

METHODS FOR MEASURING SHORE PLATFORM EROSION

To date, efforts to measure rates of platform erosion have mostly concentrated solely on small scale spatial and temporal changes. Instruments such as the Micro-Erosion Meter (Robinson, 1976) and the Terrestrial Laser Scanner, (Williams *et al.*, 2000), whilst providing highly accurate micro-scale measures of surface downwearing (millimetres and usually over a maximum of a few years, with the exception of Stephenson & Kirk 1996), have the additional shortcomings of the small number of measurement sites in relation to the area of the shore platform, selectivity of the site locations and thus problems with the

spatial and temporal extrapolation of the results. In addition, the instruments need to be in contact with a reference surface, usually in close (<0.1 m) proximity to the sample point. This makes it impossible to measure processes like block removal as the reference surface is removed as well. Other shortcomings include difficulty in measuring lowering in narrow runnels (gullies).

Conventional surveying techniques such as total station surveys can cover larger areas with a high positional and vertical accuracy, but they are very time consuming and cannot do justice to the relief of shore platforms that can easily reach repeated vertical changes of >1 m over distances of <1 m (dense network of runnels). The extent of the shore platforms also excludes the use of this technique over any large area, especially because surveying close to low water mark is restricted to short periods of time. In addition, historic data based on total station surveys of sufficient spatial density only exist in rare cases.

Developments in softcopy photogrammetry and automatic Digital Elevation Model (DEM) extraction (e.g. Ackermann, 1996) allow for a much more detailed representation of the topography of shore platforms. With the software package used (PCI Geomatics Orthoengine) automatic DEM extraction can be performed at the pixel level of the stereo air photographs thus providing a DEM with a horizontal ground resolution of ~ 0.1 m at a photo scale of 1:5,000. In addition, ground control points for the aerotriangulation can be collected with GPS in sufficient amounts over large areas and with a high accuracy that allows for more stable bundle adjustments. Using air photographs has also the advantage that historic data are in many cases easily available.

The authors are aware of only one previous study (Stephenson 2001) that has attempted to use air photographs to assess changes in shore platform topography. It was unsuccessful in detecting erosion at Kaikoura, New Zealand using air photographs spanning 52 years due to the small scale of the air photographs and lack of ground control points.

SITE SELECTION, DATA AND METHOD

The coast of Southeast England provides an ideal area for the investigation of platform erosion. Observations and previous studies (e.g. Williams *et al.* 2000) indicate that the platform is eroding and the high pixel contrast between the white chalk and the dark flint in the chalk or seaweed cover is ideal for the image correlation and feature matching algorithms employed by the software to extract elevation information from stereo pairs. The coast also includes stretches of platform where sea defences of different ages are present and others where they are absent. In addition, they are located where dense urban development on the clifftop provides numerous, high-quality ground control points (Figure 1). The two test sites presented in this study are located in the area where defences were built in the 1930s (Roedean) and 1970s and 1980s (Peacehaven). Between sites, changes in the coastal orientation are negligible so that wave approach and wave climate can be assumed to be uniform. However, the chalk layers exposed in the platform do differ slightly in age and lithology.

An Annual Beach Monitoring Survey (ABMS) began in 1973 (and is currently carried out by the Environment Agency) with yearly, spring-time, air photograph flights at low tide and at a scale of 1:5,000. The first air photographs were flown in spring 1973, in black and white, with a focal length of 152.05 mm. The flight path in 1973 was displaced up to 300 m landward of the cliff line so that the cliff toe and its proximity are not always visible. The original negatives have been scanned at 14 μm , providing a ground resolution of ~ 7 cm. Calibration information for the camera used is no longer available. To provide the minimum internal orientation parameters it has been assumed that there was no offset in the principal point and no distortion. The fiducial mark coordinates were calculated by measuring the relative distances between the corner fiducial marks on 3 randomly selected photographs. The resulting DEM is referred to in this paper as 1973 DEM.

The second set of photographs used were flown on 5th May 2001, in colour, and at a scale of 1:5,000. These were scanned at 21 μm , providing a ground resolution of ~ 11 cm. A full set of camera calibration parameters was available. The resulting DEM is referred to in this paper as 2001DEM.

Figure 1. The test area, showing schematically the location of seawalls and groynes, and their dates of construction. The black rectangles between Brighton Marina and Roedean, and at Peacehaven, show the location of the two test sites.

Ground control points were collected landward of the shore platform using DGPS referenced to the Environment Agency GPS network that is tied into the Ordnance Survey National Grid. The GPS point accuracy thus achieved was in the order of ± 1 cm in the horizontal and ± 2 cm in the vertical. The ground control points were chosen on the basis that they were clearly visible on both the 1973 and 2001 photographs. Most were corners of roadside drains and rectangular manhole covers aligned parallel to the flight path. The same control points were, as far as possible, used in both sets of photos.

The photogrammetrical analysis was carried out using PCI Geomatics Orthoengine 9.1. For both sets of photographs, approximately 140 ground control points were used and approximately 100 automatic tie points generated for the shore platform. The root mean

square (rms) error for the ground control points and tie points in the bundle adjustment was <0.05 m. Automatic DEM extraction was carried out without interpolating between failed cells. This approach has the advantage that only measured cells are part of the DEM but the disadvantage that the DEM has holes in it. The resulting geocoded DEM was exported in the grid format ArcView. All subsequent analyses (elevation comparison between different data sets) were carried out using ArcView 3.2a.

DATA CONTROL

To determine whether the new photogrammetrical method produces elevation data at the required vertical resolution to measure changes over a 28 year period, the 2001DEM was compared to three different data sets, one photogrammetric survey carried out for the Environment Agency and two ground surveys. Due to a lack of alternative elevation data, the quality of the 1973DEM can be assessed only in relation to the 2001DEM as described in the results section.

The photogrammetric control survey consists of a set of elevation points provided by the Environment Agency, at a stated vertical accuracy of ± 0.2 m that form part of a coarse DEM (EADM) of the entire coast of Southeast England based on the same air photographs of 2001. Points on the shore platform were only collected close to the water edge and at a mid-platform position (Figure 2).

Figure 2. Comparison between the coarse EADM and the 2001DEM at Peacehaven. The circle shows the location of Figure 4 and the square shows the location of Figure 8.

Figure 3. Scatter plot showing the elevation difference between the EADEM and the 2001DEM in relation to the EADEM elevation.

The data comparison is based on 2700 points common to the 2001DEM and EADEM at Peacehaven (Figures 2 and 3), more than half of which (57%) show elevation differences in the order of ± 0.2 m. The average difference between the points is 0.02 m indicating a low systematic error (vertical offset between the two surfaces). Points with significantly higher differences are found either close to the cliff edge or on the cliff (above 25 m OD in Figure 3), where they probably relate to variations in their horizontal position. Small changes in horizontal position close to the cliff edge or close to buildings have significant influence on the elevation; in open areas (e.g. grass areas in Figure 2) and across the shore platform the differences are generally less than ± 0.2 m. Other points with large differences are found at the height of the undercliff promenade (at ~ 5.5 m OD in Figure 3). Here the error introduced by small positional differences either at the edge of the seawall or at the cliff / promenade junction is increased by the fact that the automatic DEM extraction process performs poorly on the featureless concrete surface.

Figure 4. Elevation difference between the total station ground survey of March 2001 and the 2001DEM. The white rectangle shows the inset location. The inset illustrates elevation differences along the margin of a ~1.2 m step between the platform surface and a runnel.

The second and third set of data control points were obtained from independent ground surveys. In March 2001, a conventional total station survey was carried out by Alan Henaff for the ESPED project on the shore platform at Peacehaven (Figure 4) over a period of 3 low tides containing 2262 points covering an area of ~13,000 m² (i.e. 1 point every 5 m²). The main aim of the total station survey was to delimit topographic features, such as steps and runnels, on the platform. This was achieved by recording point pairs in close proximity at the toe and crest of such features (see the inset in Figure 4). The survey was carried out in local coordinates that in 2005 were transformed into the Ordnance Survey National Grid using DGPS surveys of 5 points from the original survey that could be identified in the field. From the survey and the transformation, the rms-error of the survey is assumed to be $\pm 0.02\text{m}$ in the horizontal and vertical.

Figure 5. Scatter plot showing the elevation difference between the total station survey and the 2001DEM in relation to the total station elevation.

Comparison between the survey data and the 2001EDM indicates that 60% of all points have an elevation difference smaller than ± 0.2 m (Figure 4 and 5), although the total station survey points are on average 0.1 m higher than the 2001DEM values. Figure 5 shows that significant elevation differences exist on the concrete undercliff promenade (at ~ 5.5 m in Figure 5) for the reasons described earlier. Large variations between 1 m and 2 m OD relate to problems close to the seawall and groyne (compare Figure 4). Here, the DEM values record the upper surface of the structures whilst the total station point records the elevation of the toe of the structures. Similarly, the increasing negative differences below -2 m OD are associated with deep runnels at the seaward end of the platform. These are captured with the total station as closely spaced point pairs with large elevation difference but not by the DEM with its poorer horizontal resolution. If, for example, the 2001 DEM has one pixel of 0.2×0.2 m in extent with a height of -2 m and the total station survey record 2 points of elevation -2.1 m and -3 m, Figure 5 will show two points, one with an elevation of -2.1 m and a difference of -0.1 m and one with a difference of -0.9 m. The inset in Figure 4 shows these paired points and their elevation difference in more detail.

A second total station survey was carried out in May 2002 by Brighton and Hove Council prior to repair work on the sea defences between Brighton and Rottingdean. Profiles seaward of the seawall were surveyed every ~ 70 m with points recorded at regular intervals of ~ 5 m. The comparison of 591 points common to this survey and the 2001DEM on the chalk platform showed that 90% of the points have an elevation difference smaller than ± 0.2 m.

The comparison of elevations in the 2001DEM with those derived by other photogrammetric methods and conventional ground surveys shows that a DEM of the

chalk shore platform can be produced with a horizontal ground resolution of ~ 0.1 m and an elevation error of $\leq \pm 0.2$ m.

Due to a lack of independent control data on the platform for the 1973DEM the only control has to be based on areas of unchanged topography on the cliff top and the assumption, that differences in elevation between the 2001DEM and 1973DEM on the shore platform are either negligible (± 0.2 m) or negative as the platform can only have been lowered or remained unchanged in elevation.

COMPARISON BETWEEN 1973 AND 2001: ROEDEAN

Elevation differences along the road and the cliff edge (both are assumed not to have changed) are well within the range of ± 0.5 m and predominantly ± 0.2 m (Figure 6). Major changes can be seen on the beaches which have lowered by >1 m (the DEM extraction worked less well on the beaches than on the platform leading to a less continuous DEM) and around some of the groynes that have collapsed, but changes on the shore platform seem to be small at the scale of Figure 6. However, a pattern of changes can be seen, predominantly along lines perpendicular to the coast indicating the development of runnels on the shore platform.

To illustrate the changes to the runnels, elevation changes are shown in one profile that crosses several runnels (Figure 7). Between 1 and 12 m along the 55 m profile an average lowering of 0.35 m can be observed. From 20 m onwards 12 major runnels can be seen that have mainly deepened rather than widened since 1973. Deepening of up to 0.6 m can be seen in some runnels (e.g. at 45 m in Figure 7). In some places (e.g. at 12-18 m, 34-37 m and 46-48 m) the platform seems to have risen by ~ 0.1 m while the topographic pattern of the 1973 surface is well aligned with that of 2001. This suggests a systematic difference between the two DEMs as a rise in the platform by that amount is not possible. Therefore it seems reasonable to adjust the relative profile positions. Adjusting the relative profile position by 0.1 m reduces the areas with 'elevation gain' substantially. The larger scale negative elevation changes relate to the erosion of specific features on the shore platform. For example the band of erosion indicated by the arrow in Figure 6 relates to the erosion of a landward facing step in one particular chalk layer.

From the profile and the overview in Figure 6 it appears that platform erosion at this site is characterised by selective deepening of the runnels and the retreat of steps formed by different chalk layers.

Figure 6. Test site Roedean, 450 to 800 m east of the eastern end of Brighton Marina. The green line shows location of the profile shown in Figure 7. The green arrow indicates the area where a landward facing step has retreated seawards.

Figure 7. Profile shown in Figure 6 from west to east. Lowering of the 2001 surface by 0.1 m (thin black line) removes most of the 'elevation gains' and provides a perfect fit between 34 and 37 m. Elevation change is shown between the 1973 surface and the lowered 2001 surface.

COMPARISON BETWEEN 1973 AND 2001: PEACEHAVEN

Figure 8 shows the changes in platform elevation at Peacehaven. Most of the middle and lower part of the platform together with unchanged areas on the cliff, show elevation differences of the order of ± 0.2 m. Positive differences along the waters edge relate to different levels of water in the lowest runnels during the two surveys. The most significant feature is the band of erosion that reaches a maximum ~ 5 to 15 m seaward of the seawall, where elevation losses well in excess of 1m are recorded. Towards the east, and along the stretches that have been protected more recently (see Figure 8 for installation periods of the sea defences), the erosion does not seem to be significantly less extreme. However, elevations close to the foot of the seawall cannot be compared due to the lack of data from 1973 because of the landward position of the flight path. A more detailed assessment can be made from Figures 9 and 10.

The seawall east of the groyne shown in Figures 9 and 10 was built between 1981 and 1983 whilst the groyne itself and the seawall west of the groyne were built between 1975 and 1977. Both the DEM comparison and Figure 10 show severe erosion close to the groyne and the seawall. Platform erosion has been particularly severe west of the groyne, where both the area and magnitude of erosion are greatest. From standard construction drawings (Stammers 1982), each groyne was originally countersunk into the platform and, on completion, the top of a concrete plinth surrounding the embedded groyne was made level with the chalk platform. Though this standard procedure cannot be confirmed for each individual groyne it appears to have been the case at the tip of the groyne where Figure 9B shows a small area exhibiting no elevation difference, which can be seen from Figure 10 to coincide with the concrete plinth at the tip of the groyne. Based on the assumption that the concrete surface around the groyne represents the chalk surface in 1975-1977, the western side the erosion was measured in the field to range from 0.6 m near the groyne tip to 1.5 m closer to the seawall. These figures compare extremely well with those obtained from the DEM comparison (Figure 9B), which range between 0.55 and 1.6 m.

The orthophoto and the ground photograph show a chalk ridge ~ 5 m long and ~ 0.8 m wide parallel to the groyne (see arrows in Figure 9A and 10). This is also visible in the DEM comparison (see arrow in Figure 9B) and illustrates that even comparatively small features are picked up accurately by the automatic DEM process. However, the apparent elevation increase on the eastern side of the groyne is an artefact of the 2001DEM. These errors, which are often in large shadow areas, or in areas that are more uniform in colour, can easily be detected by visual assessment of the DEMs aided by orthophotos, and comprise only very small areas.

Since the first groynes were built in 1975, annual lowering rates over the chalk platform have ranged between ~ 2 cm and 6 cm per year, depending on location. It should be noted that these are spatial averages, and there may have been significant yearly variations over the 26 years.

Figure 8. Test site Peacehaven. Black square shows location of Figure 9. Green lines on the promenade delimit from west to east three stretches in which the sea defences were built in 1975-77, 1981-83 and 1996-97 respectively

Figure 9. A) Orthophoto of detail of the platform at Peacehaven (for location see Figure 8) showing the topography in 2001 along the red profile line (green line: groyne elevation is 2.2 m above the surrounding platform). B) Elevation differences between 1973 DEM and 2001 DEM.

Figure 10. Western face of the groyne shown in Figure 9 photographed on 19-06-2001. The construction blocks are each 0.33 m in height. Note the platform remnants projecting through the beach shingle.

DISCUSSION

This paper is concerned to evaluate the use of the photogrammetrical method in platform erosion studies. A full analysis of the erosion rates identified will be the subject of a subsequent paper. However, as the figures demonstrate, erosion is greatest on the upper platform and within the runnels. Erosion on the upper platform appears to be particularly fast at Peacehaven. One explanation may be that heavy machinery was used close to the groynes and seawalls to construct them (see photos in Stammers 1982). In contrast at Roedean, when the groynes were built in the 1930s, relatively little disturbance to the shore platform occurred.

CONCLUSION

On shore platforms similar to those discussed and using air photographs with a scale of at least 1:5,000, modern softcopy photogrammetry software combined with GPS ground control point collection allows for the creation of almost continuous digital elevation models with ground resolutions of <0.2 m and vertical accuracies of a similar magnitude. Surface comparisons can be carried out reliably to detect elevation changes in excess of 0.2 m even for isolated objects only a few pixels in size. The high spatial resolution and

continuity of the DEM provides high reliability for the detection of even small-scale elevation changes (<0.2 m) near runnels and edges. The use of air photographs allows access to valuable data sets that go back several decades so that changes in the form and elevation of platform surfaces can be measured over engineering time scales.

REFERENCES

Ackermann, F. (1996). Techniques and strategies for DEM generation in: Greve, C. Ed 1996 Digital Photogrammetry: an addendum to the manual of Photogrammetry. *American Society of Photogrammetry*, 135-141.

Robinson, L.A. (1976). The micro-erosion meter technique in a littoral environment. *Marine Geology* 22, M51-M58.

Stammers, R.L. (1982). Coastal defence engineering in East Sussex – Part II. *Municipal Engineer*, 109, 353-359.

Stephenson W.J. (2001). Shore platform width - a fundamental problem. *Zeitschrift für Geomorphologie*, 45 (4), 511-527.

Stephenson, W.J., and Kirk, R.M. (1996). Measuring erosion rates using the micro-erosion meter: 20 years of data from shore platforms, Kaikoura Peninsula, South Island, New Zealand. *Marine Geology* 131, 209-218.

Trenhaile, A.S. (1997). Coastal dynamics and landforms. Clarendon Press, Oxford.

Trenhaile, A.S. (2005). Modelling the effect of waves, weathering and beach development on shore platform development. *Earth Surface Processes and Landforms*, 30, 5, 613-634.

Williams R.B.G., Swantesson J.O.H., and Robinson D.A. (2000). Measuring rates of surface downwearing and mapping microtopography: The use of micro-erosion meters and laser scanners in rock weathering studies. *Zeitschrift für Geomorphologie*, Supplementband 120, 51-66.

ACKNOWLEDGEMENTS

The authors would like to thank the Environment Agency for access to the air photographs and DEM data used in this study, Brighton and Hove City Council for access to the survey data between Brighton and Rottingdean and the MAST III funded ESPED project for access to the survey data at Peacehaven. This work was funded by the Beaches At Risk INTERREG III project.