APPLICATION OF PHOTOGRAMMETRY IN MONITORING OF MARINE RUBBLE STRUCTURES

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Abstract

Photogrammetry provides a new perspective to monitoring work in the way that photographs are rich of information and can be analyzed at any time with high repeatability. This method has the advantage of depicting the entire ground surface whereas the conventional monitoring techniques can only handle discrete point measurements. In the Hei Ling Chau typhoon shelter monitoring project, the survey division of Civil Engineering Department, Hong Kong Special Administrative Region has employed photogrammetric techniques to detect surface deformation of the rubble mound breakwater.

This project forms part of the study results in exploring the practical monitoring methods for the total 120 km long seawalls and breakwaters in the territory of Hong Kong. In view of the fact that walkover visual inspection and conventional surveying techniques are dangerous and ineffective in detecting settlement on the rugged armour surface over a large area, photogrammetry provides a quantitative solution to capture and detect surface deformation by low altitude photography.

1. Introduction

Armours with an average weight of two tons each have been widely used in the construction of the exterior-most layer of seawalls and breakwaters (Plate 1). However, the armour layer is inevitably subject to deterioration, mainly due to the dynamic wave actions and settlement of the filling materials. If left unattended, the loss of this armour layer will result in the exposure of the underlying core material and eventually leading to complete failure of the whole structure.

The primary objective of this study is to devise an effective means to monitor the rubble mound structure and identify the quantity and magnitude of the undermining. The monitoring results so derived would be used to trigger remedial repair action should the damage exceeds the maintenance criteria.

Experience in the Cleveland Harbour [Pope, et al, 1993] monitoring project revealed that majority of the breakwater movement was characterized by the armour settlement along the waterline of the active wave zone. The methodologies recommended in this study and the results so generated should therefore be sensitive to both the horizontal displacement as well as the vertical settlement. To this end, many other conventional survey methods have been studied to address the issues. For instance, using level to monitor the settlement of some selected points; total station to establish profile lines along the length of the breakwaters at fixed intervals; and GPS to measure three-dimensional coordinates of some chosen points. No doubt these methods give straightforward and accurate results, their applications are however restricted to discrete point measurement and sometimes impractical in the rugged ground condition.

Plate 1: Hei Ling Chau breakwater (South)

2. Accuracy Requirement

During the first few years after completion of the rubble mound structure, consolidation settlement of the armour to seek interlocking equilibrium is very common. By experience, the settlement magnitude varies from a few centimeters to decimeters depending on the armour size [CED, 1996] and its location on the breakwater. The consolidation settlement with a small magnitude is considered normal and should be differentiated from the armour loss caused by the dynamic wave action. In this study, only the latter armour movement above the water level that might possibly cause breakwater failure will be catered for. Hence, a method that provides a positional accuracy up to ±0.3m will serve the monitoring purpose.

3. Terrestrial Photography vs Aerial Photography

The other concerns in choosing the appropriate methodology for the task include the availability and the ease of equipment mobilization. Evaluation has been carried out to study the application of using hand-held Rolliflex 6008 metric camera to take photographs from a boat moving in parallel to both sides of the breakwaters (Plate 2). Due to the inherited weakness of the small format (6cm x 6cm) photography [Warner, W.S. et al, 1996], numerous photographs and vast number of ground controls are required for creating sufficient stereoscopic overlaps to cover the 1km long breakwater. Moreover, the major drawback is that the crest portion on the breakwater can, by no means be captured at such a low angle from the sea level. All these rendered the terrestrial photography little advantage over the conventional survey in terms of field effort involvement.

Plate 2: Terrestrial photography from a moving boat

The another option is to take low altitude aerial photography from a Wild RC10 aerial camera side-mounted on a Sikosky S76C helicopter (Plate 3). In order to achieve a reasonably large photo scale while at the same time to maximize the ground coverage, the photographs were taken from as low as 700ft with a 152mm lens. In the Hei Ling Chau study case, the 1km long breakwater could be fully covered by about 20 photographs with 80% forward overlap. From these photographs, the whole breakwater, even the inaccessible area that falls within the active wave zone can be assessed with no risk.

Plate 3: Side-mounted Wild RC10 camera on helicopter

4. Mission Planning

The accuracy of aerial photography is dependent upon the photo scale and photo quality. The former is simply the ratio of lens focal length versus the flying height whereas the latter is a matrix of ground control accuracy, film scanning resolution, and weather conditions. To ensure a smooth aerial photography operation, it is important that the following factors affecting the photo quality have been seriously considered and well planned before take-off:

- camera platform
- lens type
- flight route
- flying height
- forward/lateral overlap
- required number of photos coverage
- exposure interval
- film/shutter speed
- exposure value
- ground control details

In this study, the flight line was set to follow the longitudinal direction of the Hei Ling Chau breakwater. This would not only minimize the number of turns between lines but also, the breakwater itself served as a good reference for orientation to the pilot.

In low altitude photography, the sun's altitude as well as its azimuth position should be carefully considered at the planning stage. A variation of these factors between two epochs will produce different image shadow of the armour. This would inevitably affect the reliability of the subsequent image overlay analysis. To maintain a homogenous set of photographs at maximum exposed surface above sea level, the photographs should be taken between 10a.m. to 2p.m. during the low tide and around the same time of the year.

5. Ground Control

It requires about twenty photographs to cover the 1km long Hei Ling Chau breakwater. Photo control is the important link to bring the photographs in proper orientation with the real world. As the rubbles are irregular and all look similar from above, it is very difficult to find sufficient geometrically well defined natural features on the rubble structure to serve as the control points for aerotriangulation. To achieve a reasonably accurate result, aerial photographs have to be taken from as low as 700ft high. At this ground cover, one will find nothing except the breakwater and the sea on the face of the photograph. To overcome the problem, 22 circular photo controls were painted on both sides of the breakwater as shown at Figure 1.

The minimum size (S) of the target pattern is related to the stereo-plotter resolution (σ) and the photo scale. For instance, the minimum diameter of a target composed of concentric circles for a wide-angle photography taken at 700ft high will be:

$$
\begin{aligned}
S &= 5 \times \sigma \times \text{photo scale} \\
&= 5 \times 12.5\mu\text{m} \times 700 \times 0.3048 / 0.152\text{m} \\
&= 0.09\text{m, or } 0.10\text{m (say)}
\end{aligned}
$$

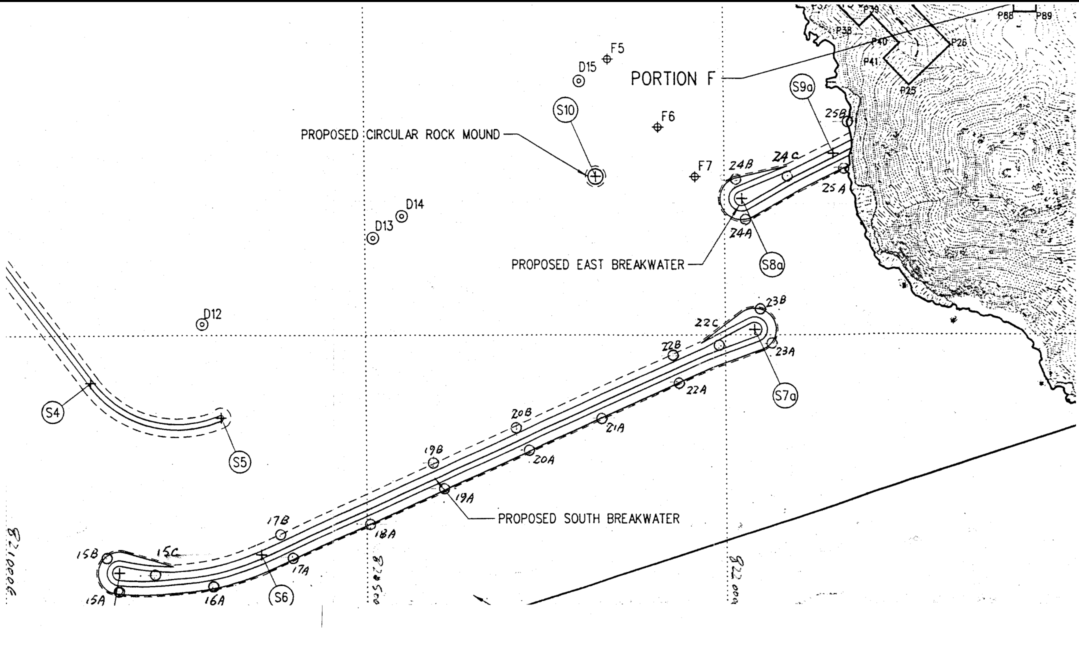

Figure 1: <u>Distribution of photo controls</u>

The co-ordinates and levels of these ground controls were picked up by GPS in real time kinematic mode from a known station in the vicinity, at a relative planimetric and vertical accuracy of ±3cm. The initial values of these markers were then used in the photogrammetric process to correlate the breakwater with respect to the reference datum. As the whole length of the breakwater is vulnerable to settlement, the reliability of these pre-marked controls on the rubble surface is sometimes questionable. For this reason, the "Free network adjustment" approach was adopted in the subsequent adjustment process to determine the respective rotation parameters of every epochs.

6. Detection of movement

Orthophotos at 1:500 scale and digital terrain models (DTM) with 2m grid intervals were formed based on the photographs taken at different epochs. As advised by the Photogrammetric and Air Survey Unit of Lands Department, the planimetric accuracy of the orthophotos and vertical accuracy of the DTMs are both ±0.2m at 90% confidence level.

Horizontal displacement of the rubble, if any, could be discovered from overlaying two commonly registered orthophotos (Plate 4) formed at different epochs. With the aid of some simple visual magnifying tool, any horizontal movement greater than ±0.3m could be identified. This method is simple and perhaps a bit primitive, but it is perfectly sound in most cases without the need of sophisticated computing facilities. However, owing to the relative low flying height, shift in nadir point, different in sun attitude, azimuth and etc, the ortho image of rubble might not be truly rectified. Hence, bias arising from the image shift might occur.

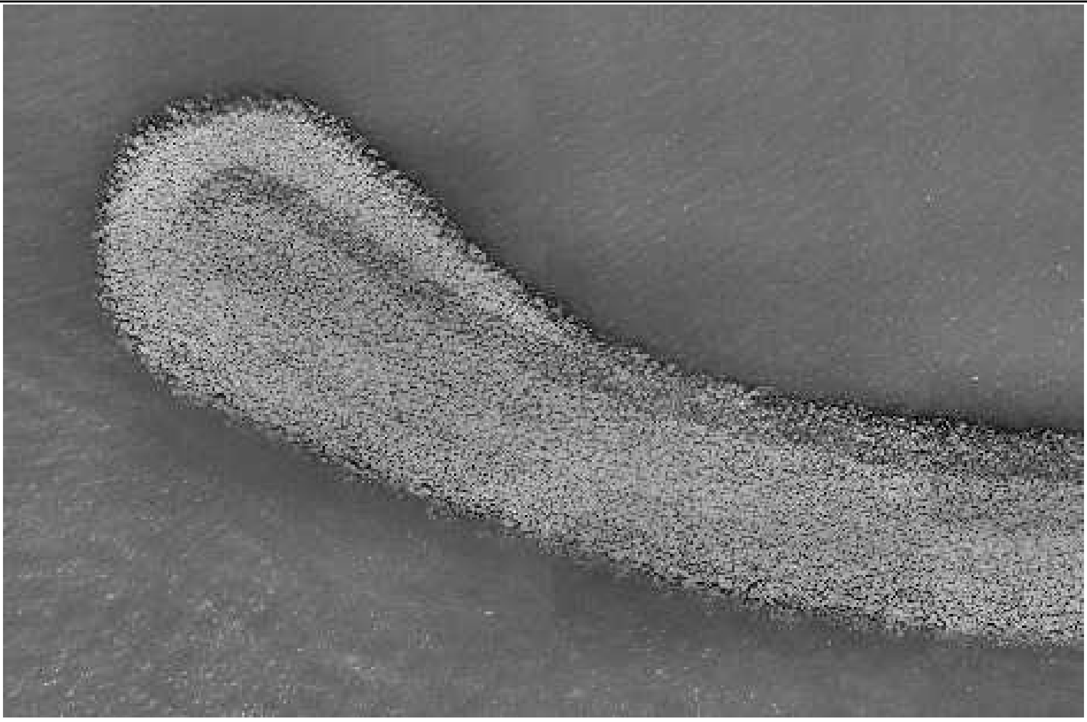

Plate 4: Orthophoto

In regards the vertical movement, the breakwater surface is represented by a DTM based on the Z values of the ground points so happened to fall on the 2m grid lattice. The vertical separation between two DTMs (Figure 2) obtained at different epochs is regarded as the vertical settlement. However, this method does not involve any interpretation of a particular feature on the breakwater. Due to the irregularity of the rubble surface, a slight shifting of the local grid might give rises a big height difference in particular when the grid intersection falls on the armour edge.

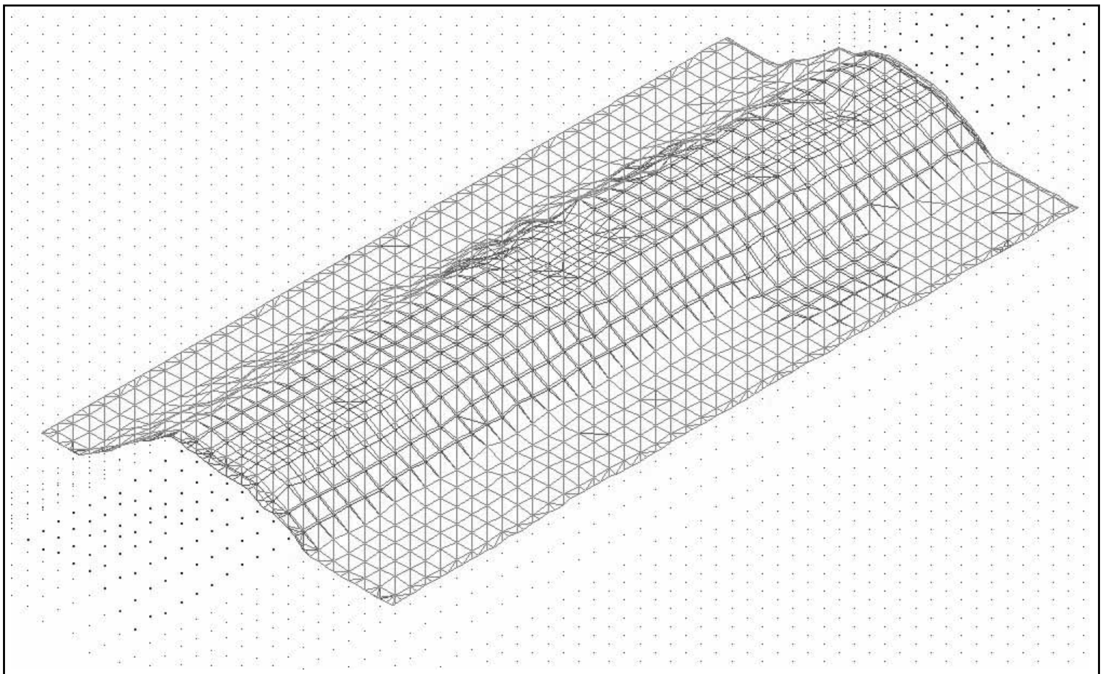

Figure 2: DTM overlays

In view of the above limitations, the detection of movement would be conducted in several stages. Firstly, the Isopach (Figure 3), which is a surface of point data representing the difference between two models of different epochs, was formed to identify the problematic area at a quick glance. And then the portion of the identified problematic area would be closely examined by overlaying pairs of orthophotos for planimetric displacement. Lastly, cross sections (Figure 4) over that particular area were drawn for detailed study of the vertical settlement. If there was an indication of possible movement, new DTMs of the problematic area would be formed, but this time, at a smaller grid interval, say 0.5m and the above process repeated once again until satisfactory result was obtained.

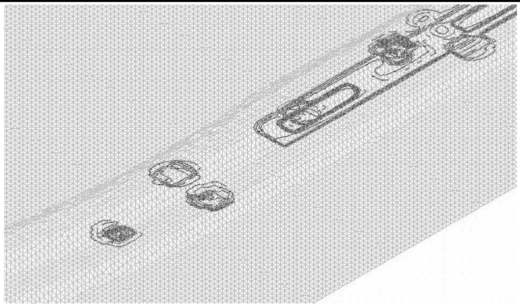

Figure 3: Isopach

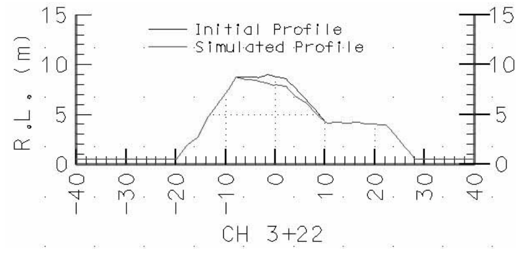

Figure 4: Cross-section

7. Conclusions

Low altitude photography provides valuable information for the analysis of the breakwater condition above the sea surface. From this study, the detection of movement by means of DTM and orthophoto overlays is proven to be safe and effective as compared with other conventional monitoring techniques. The reliability of this method is dependent upon the photo-scale, quality of photo controls, surface texture of the photographs and the density of the DTM grid intervals.

Nowadays, the advancement in digital photogrammetry technique has fully automated the feature correlation process. Yet manual interaction is still required when the surface texture is irregular. The setting of an appropriate grid interval is a matter of balance between effort and quality. In this case, the initial 2m grid DTM represents the breakwater surface very well for quick detection of the major settlement. Once the problematic area is identified, a smaller grid, say 0.5m interval should be used to generate a more reliable DTM for quantitative measurement.

Helicopter provides a versatile platform for low altitude photography. The flying height may vary from less than a hundred feet to over a thousand feet subject to the site conditions and other flight restrictions. Experience in this exercise found that coordination between the pilot and the photographer is vital to the success of photo taking on the helicopter. However, a much stringent schedule than that of the fixed-wing aircraft was experienced. The logistic support must be taken into account if the remaining sites of the whole territory are monitored by this method in the future. In this respect, perhaps the forthcoming 300mm camera lens of the Lands Department provides an alternative that can produce a similar result but at doubled the flying height from a fixed-wing aircraft.

Acknowledgements

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