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Toolbox

DIGITAL IMAGE TECHNOLOGY AS A MEASUREMENT TOOL IN PHYSICAL MODELS

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Abstract

Advances in digital image technology has allowed us to use accurate, but relatively cost effective technology to measure a number of varied activities in physical models. The capturing and manipulation of high resolution digital images can be used to give useful information on the dynamics of waves, coastal structures and ship motions. The availability of digital cameras, at relatively low cost, has allowed easy transfer of digital images to the computer. This paper discusses recent advances of a number of applications, which have been successfully applied to physical scale modeling carried out at the CSIR.

1. Background

The CSIR has been involved for many years in technology to support the field monitoring of coastal structures and the interpretation of physical models to simulate prototype performance. Digital image technology has made it easier to capture, store, transmit and analyze large amounts of information via the recording and manipulation of digital images. The high resolution of the images and the increased capacity and speed of personal computers has improved our ability to handle the large quantities of data contained in the digital images. Software has been written to interrogate the images (pixel by pixel) to extract the relevant information, which can then be analyzed, stored and used to present the results in animated form. With the large amount of information generated, there is a need to standardize the methods used to interpret the breakwater damage recorded in physical models for different types of armouring.

Besides the tracking of concrete armour movement and damage on breakwaters (Phelp, COPEDEC 1999 and ICCE 2002), digital image technology can be used to determine the profile and size of rock armouring on coastal structures, and has even been used to measure waves and currents, monitor ship motions and track the growth of plumes. Examples of the latest technology used for the latter will be given, but the essence of this paper is to present the methods for interpreting the movement of different concrete units in physical models. These methods will need to be calibrated against the prototype performance of the different units. The CSIR has already done this for Dolos armouring, using annual monitoring data from aerial surveys of the breakwaters at the ports and harbours around the South African coast (Phelp, ICCE 2000).

2. The use of Digital Image Technology for Breakwater Armour Tracking

2.1 Introduction

The relation between model armour unit displacements and prototype damage (displacements plus breakages) is an important factor when modeling breakwater stability. Prototype breakwater monitoring has shown that concrete units can break due to rocking motions without being significantly displaced. Monitoring of damage, in both model and field applications, has been carried out by comparing the before and after images. The damage is then given as a percentage of the total number of armour units on the slope, per area covered by the monitoring survey photograph (station). It is therefore important to track armour movement as accurately and efficiently as possible.

2.2 Damage Definition

Because the model units do not break, it is necessary to estimate the number of units which would have broken, by monitoring the rocking units. The damage definition for a model structure was defined as the number of units which have been displaced more than the height of a unit (H), plus the number of units which have been rocking for more than two thirds of the duration of the test (CSIR, 1989). The rocking was originally monitored by visual observation or by cine camera.

From extensive tests carried out on dolosse, the CSIR found that the percentage of rocking units was roughly equal to the percentage of units displaced over a distance equal to one dolos height (Phelp et al,1994). This implies that prototype damage can be up to 2 or more times the number of units displaced over more than one characteristic length (assuming that rocking units will break). However, this is a complex problem, and is dependant on a number of other variables.

Based on prototype performance of dolos structures it is widely accepted that most large dolosse break when they have moved over a distance of more than H. Interpretation of movements larger than H is therefore uncomplicated. For smaller movements, this is not the case. There is a need to understand the prototype implication of movements smaller than H. Estimates of the relationship between small movements and rocking was made by studying research results of flume tests conducted at the CSIR over a number of years, in which rocking motions were recorded. Digital image technology has made the recording, analysis and understanding of small movements easier and quicker.

The initial shake-down settlement of the model units, which occurs only after the model is filled with water and waves are generated, is normally small, and contributes little to the damage total, but can be easily detected by digital analysis. Although the pre-test condition of the structure is always recorded, for ease of analysis, the base-line image from which the larger movements are recorded (by the digital "flicker technique") is taken after shake-down settlement is complete. In prototype, small shake-down displacements on a newly constructed breakwater can result in high stresses and broken units, which add to the damage total. This was observed in Cape Town (Phelp, ICCE 1994) and in Richards Bay (Pillay, ICCE 1998).

2.3 Flicker Technique

The Flicker Technique is a digital image processing technique which is used to interlace, in real time, the image with a preview of the same breakwater station before the damage occurred. Any changes are then detected as a stroboscopic flashing of just that portion of the screen where the change has taken place.

This provides a practical cost effective method using off-the-shelf hardware, such as a digital camera or other optical device fixed at a position perpendicular to the face of the armoured slope and set up to be controlled remotely. Remote control allows successive images to be taken without touching the camera. This allows perfect overlap. Figure 1 below shows the set up of the camera, linked directly to a Laptop PC, above the wave flume.

Figure 1. Remote controlled digital video camera or on-line Laptop PC for data capture.

Pictures are taken before and after a test condition and prepared for analysis. Two images are analyzed using flicker software to assess the displacement that has occurred during the wave condition. Movements are indicated by different colours for different displacements.

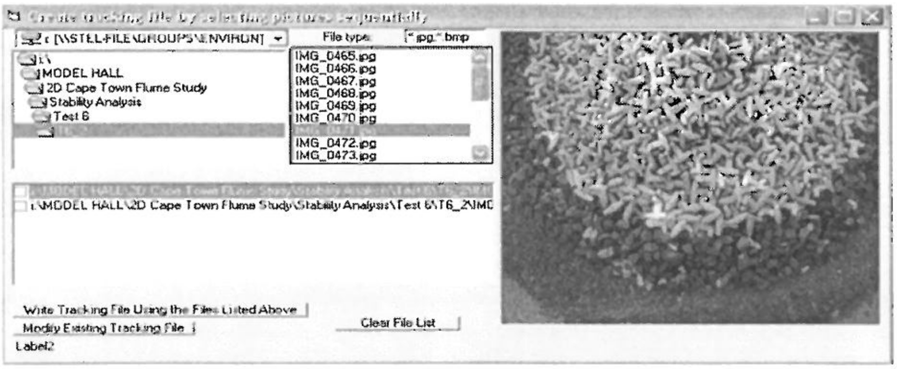
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Figure 2. Image capture and file naming, ready for analysis using the Flicker Technique.

2.4 Damage Calibration

The user calibrates the images by capturing a reference shape of a know dimension as illustrated in Figure 3 below. This process needs to be done only once per test setup. By inserting the referenced image into the armour track program one can determine the factor for converting pixels to metres by drawing a line using a mouse on the screen. This line is given a co-ordinate on the screen relative to the reference shape. These co-ordinates are used to determine the length of the line in pixels. The pixel to known scaled dimensional factor is used to convert armour unit displacements from pixels to real dimensions.

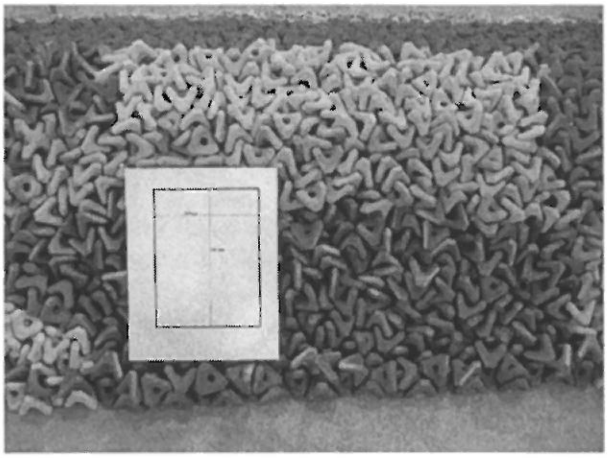

Figure 3. Calibration of Image using a known reference shape.

Once the lines are drawn on the image they are imported into a spreadsheet and converted from pixels to prototype units, thereafter these displacements are substituted into the damage formulae. The armour unit displacements are then scaled to a prototype measurement and converted to a damage percentage (Phelp and Zwamborn 2000). Thereafter the results are tabulated in a spreadsheet, represented graphically (Figure 4) and the movements are viewed in a Power-point presentation format.

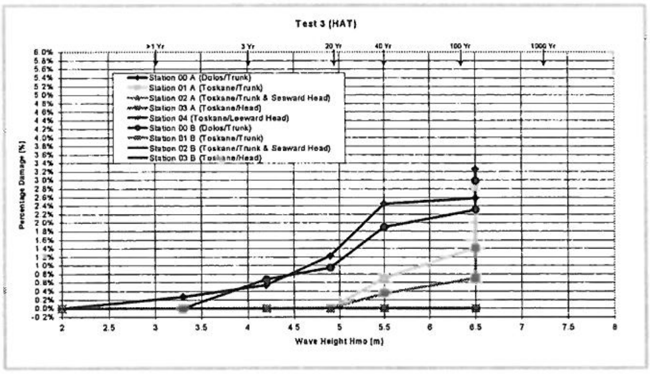

Figure 4. Results plot of wave condition vs cumulative damage.

Every armour unit has its own damage formula. This damage formula is based on prototype damage information and known characteristics of the armour unit (examples are given in Figures 5 to 10 below). There is currently an informal working group attempting to standardize the formulae for various units - suggested formulae are listed below.

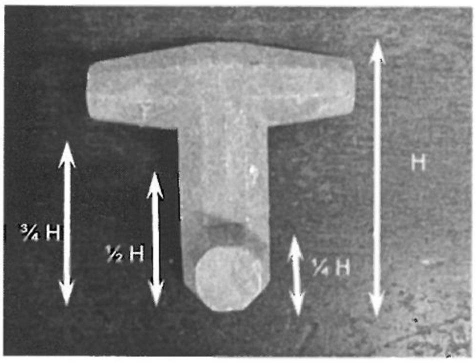

Figure 5. Dolos damage = 0,5(½H<displacements<H) + >H.

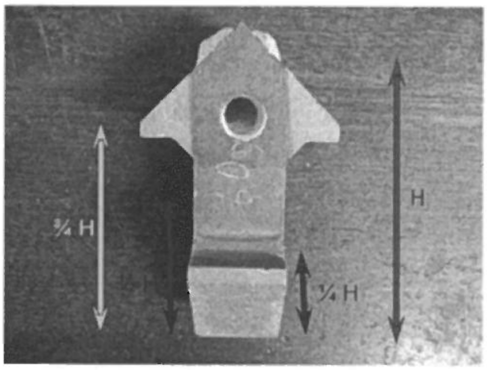

Figure 6. Toskane damage = only displacements >H.

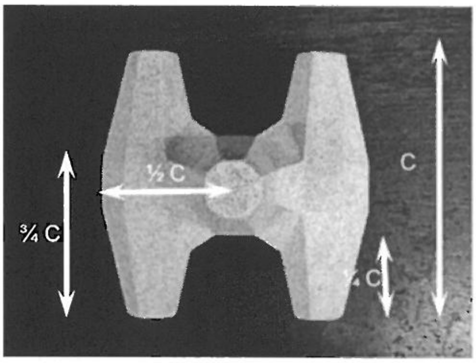

Figure 7. Core-loc damage = 0,4 (½C<displacements<C) + >C

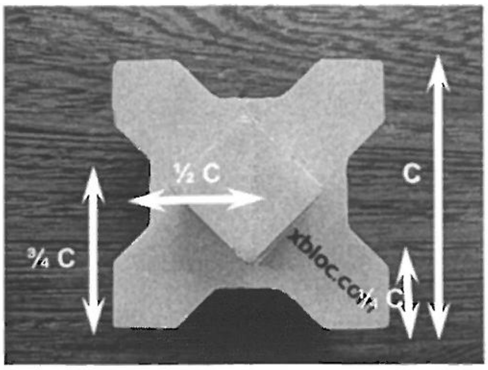

Figure 8. X-Block damage = 0,5 (½C<displacements<C) + >C

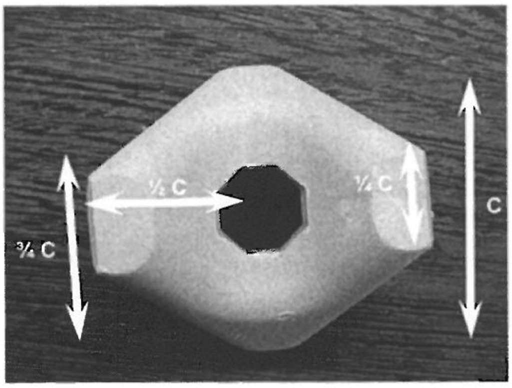

Figure 9. Stabit damage = 0,5 (½C<displacements<C) + >C

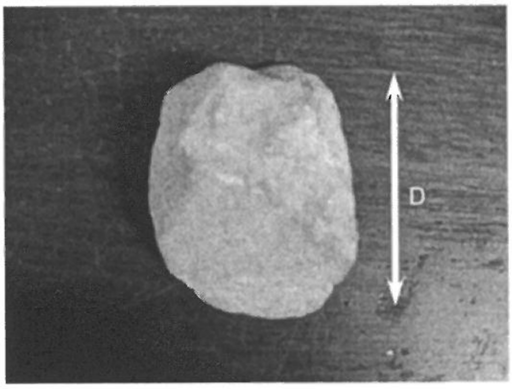

Figure 10. Rock damage = only displacements >D

3. Other uses of Digital Image Technology in Physical Models

3.1 Introduction

Much of the information, which is used for decision making, in the modeling of ship motions and coastal and port structures, is based on visual data. The most useful form of visual data is the highlighting of changes from one image to another. Visual data is most effectively captured as digital images, which can later be analysed to record particular movements or rates of change of part of the image highlighted by sampling lines. This motion detection or difference analysis has a wide range of application from monitoring changes to the interface between the sea and shore / structure, and even tracking the movement of water to the motion of moored vessels. Many of the applications of digital image technology used in physical models have similar uses in prototype monitoring (Phelp et al, ICCE, 2002). Examples of the model applications are grouped as follows:

Modeling of sea and shore / structure interface, including breakwater damage (Armour Tracking has already been described above), changes to coastal structures, surface profiles and texture (rock size), and sediment erosion / accretion.

Measurement of water movements, including the recording of waves (buoy tracking), turbulence, overtopping and run-up, currents (drogue tracking), and plumes (dye circulation).

Tracking of vessel motion, including the measurement of moored ship motions (roll, pitch, yaw, sway, surge and heave) and free motions.

3.2 Surface Profiles using Laser Scanning

High Definition Surveying (HDS) scanning techniques with very accurate laser beam digital scanners are now being used to measure 3D model surfaces, such as rock armour slopes and movement of sediment on sea beds (Figure 11). From a single set-up, the whole model, or parts thereof, can be scanned and measured. Digital terrain maps or profiles can then be extracted and plotted. Difference charts can also be used to calculate volume changes (erosion or accretion) and armour damage. Accuracies of 2mm have been achieved at a scanning distance of 50m. Co-ordinated calibration points are needed at regular intervals in the model.

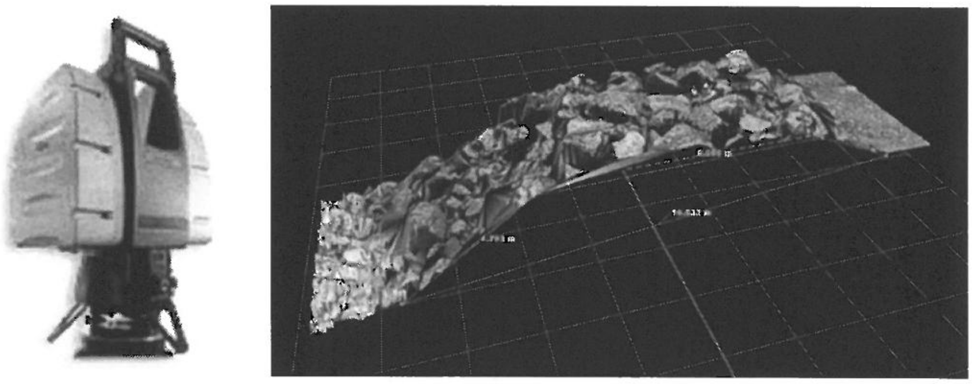

Figure 11. High definition laser scanner and digital terrain map for taking surface profiles.

3.3 Rock Size Analysis using Digital Images

A useful application of digital image technology, for both model and prototype, is the automated analysis of rock sizes taken from scaled images of the rock slopes. In a similar method used for armour tracking, described above, the image scale is calibrated by known (pre-surveyed) dimensions visible in the image. Edge detection software (by Envirovision Solutions) is then used to mark the boundaries of individual rocks (Figure 12), which can be isolated, measured and binned according to size. From this information grading curves can be drawn for a representative sample of the armour rocks on the surface of the rock slope.

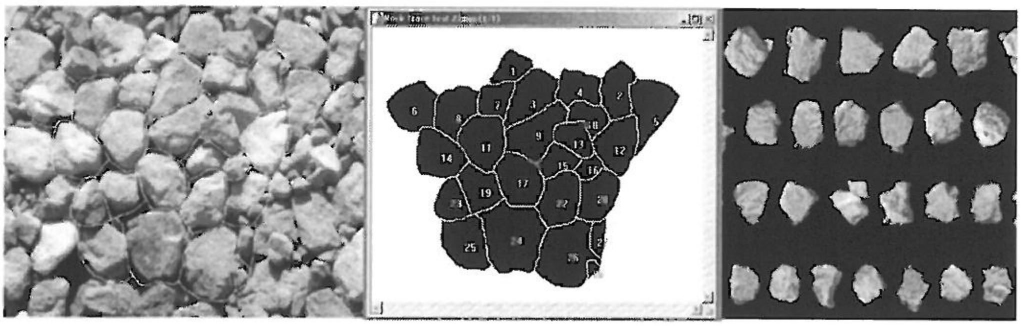

Figure 12. Rock Sizing using Edge Detection, Identification and Binning of Individual Rocks.

3.4 Water Movement and Buoy Tracking

A successful application of digital video imaging has been the measurement of waves, both in prototype and in physical models. Wave measurements are achieved by aiming a digital video camera onto a tethered buoy / float in the area of interest. The calibration procedure sets up a digital terrain model to map the pixels with real-world coordinates. This allows any sampling line to resolve true height, length and direction. The higher the observation point, the better it is for measuring large waves, as this reduces the moments when the float is hidden behind high wave crests. A keogram or time stack, is formed by plotting the sampled lines (stacking a time series of pixel movement profiles) along side each other. Each movement along the sampling line is recorded as a contrast feature trace or wave signal (Figure 13).

The main advantage of the above system is that it is relatively inexpensive and the most vulnerable part (the float in the water), is easily replaceable. A number of floats can also be deployed in different locations to record site-specific wave conditions and water levels. By using a combination of three buoys tethered in a specific way, the current velocity and direction can also be measured by the relative distance apart, and orientation of the buoys. This system has been successfully tested by CSIR, in both model and prototype applications.

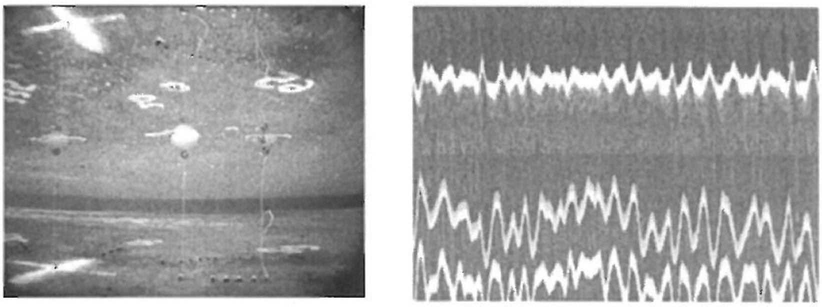

Figure 13. Tethered Floats viewed below water to produce time history Keograms.

3.5 Moored Ship Motion

A remote digital video camera is positioned, almost horizontally, portside onto the ship, with the video image covering the central two-thirds of the ship (Figure 14). Video images of the moored ship are recorded at a standard TV frequency of 25Hz. Accurately dimensioned white strips (contrast strips) are fixed onto the top and either side of the ship, to provide contrast lines for identification of the ship motions. Two mirrors placed at 45° above the bow and stern give a vertical view of the ships deck in the same plane as the video image, thereby capturing all six degrees of freedom of ship motion.

Each video image (768 x 576 pixels) is scanned by a number of fixed sample lines of a single pixel width, which cut the contrast strips (one vertical line at the bow, one at the stern and one horizontal line at bow or stern). These sample lines are scanned simultaneously and are projected as a single vertical line. By stacking these lines side by side (at 25Hz) to form a time stack or keogram (Figure 14), a record of all 6 degrees of freedom can be measured by tracing the dynamics of the appropriate contrast strips. The ship motion traces can then be easily and efficiently stored as a BitMap file for each test.

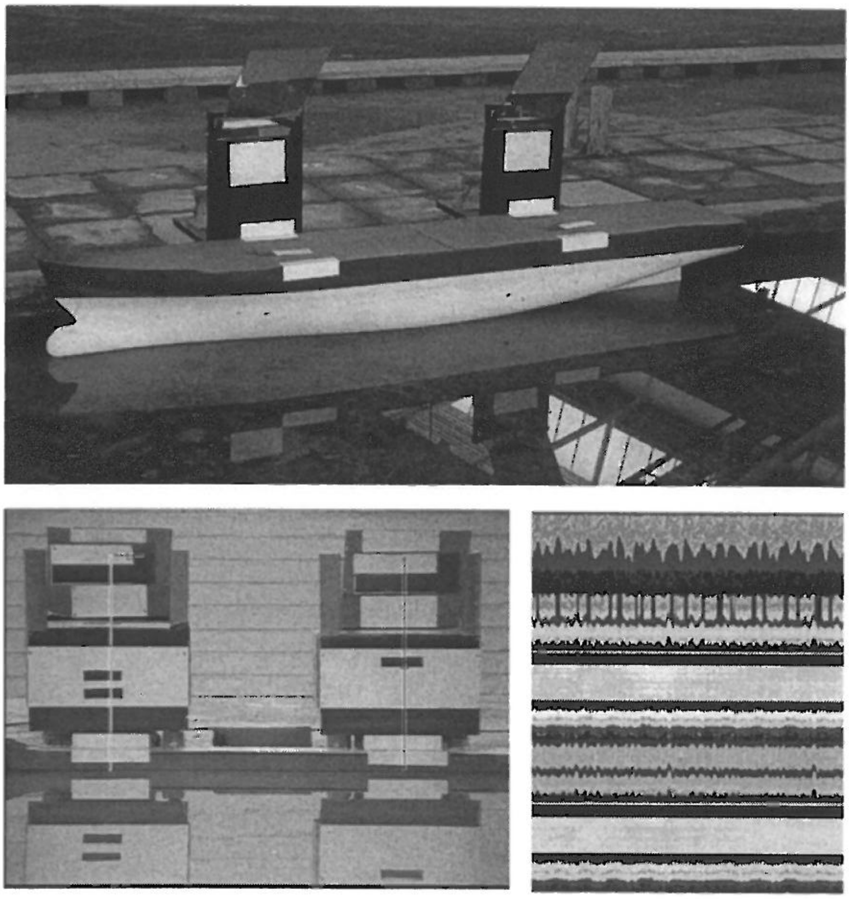

Figure 14. Sample lines drawn on digital image to produce Keogram of Ship Motion

4. Conclusions

Digital Image Technology has many useful applications in physical modeling where accurate monitoring and data capture is required. Similar applications can be found in prototype measurements. It is however essential that model damage should be calibrated by the monitoring of prototype breakwaters, and that the collective data be analyzed to give guidelines for the interpretation of model damage. This is especially important because of the detailed displacement data, which is now easily produced by digital imaging techniques. It is also very important that strict quality control be applied to both model and prototype, to further reduce the variations between design and prototype performance. There is a need to share and standardize measurement techniques and damage interpretation: for example, the different damage definitions which are applicable to different breakwater armour units. Future closer collaboration between CoastLabs is recommended.

Acknowledgments

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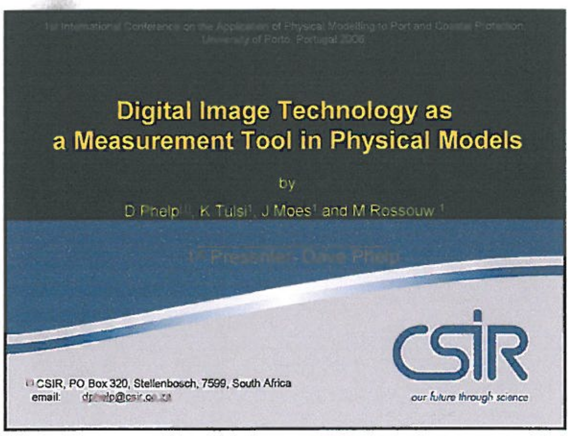

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Digital Image Technology as a Measurement Tool in Physical Models

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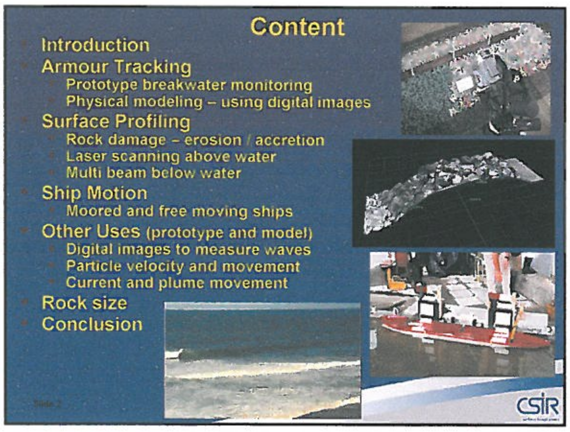

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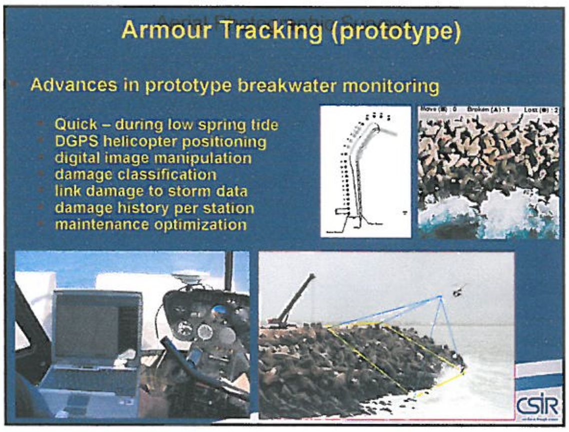
  - Digital images to measure waves
  - Particle velocity and movement
  - Current and plume movement
- Rock size
- Conclusion

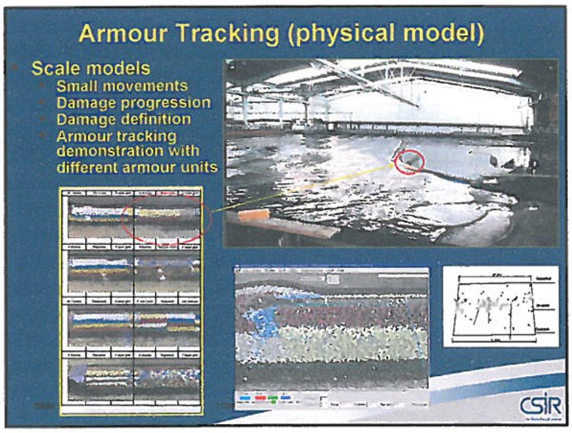
Introduction

- Digital imaging is inexpensive
- Ability to manipulate / store data
- Flicker technique to detect change
- Visualize / present accurate results
- Applicable to both prototype / model
- Need to standardize measurement methods and damage interpretation



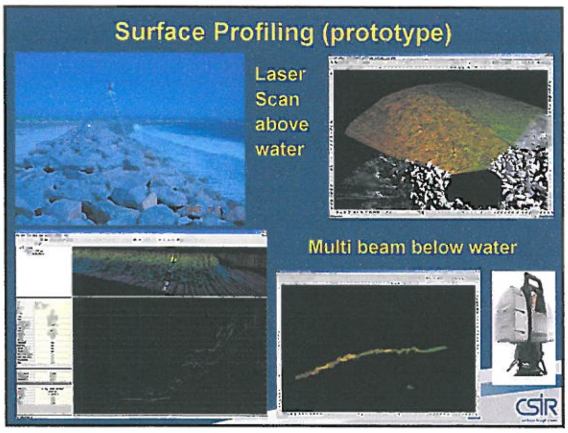
Armour Tracking (prototype)

- Advances in prototype breakwater monitoring
  - Quick – during low spring tide
  - DGPS helicopter positioning
  - digital image manipulation
  - damage classification
  - link damage to storm data
  - damage history per station
  - maintenance optimization



Armour Tracking (physical model)

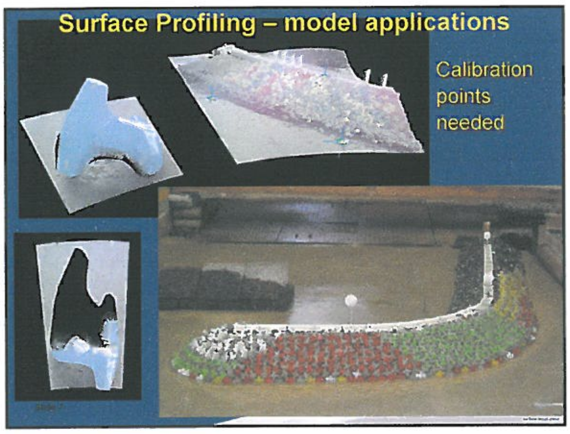
- Scale models
  - Small movements
  - Damage progression
  - Damage definition
  - Armour tracking demonstration with different armour units



Surface Profiling (prototype)

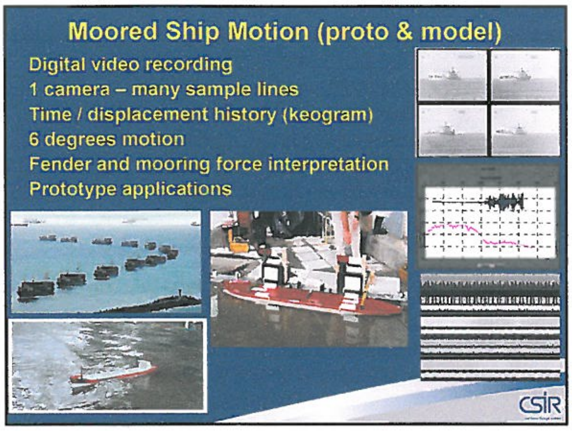
Laser Scan above water

Multi beam below water



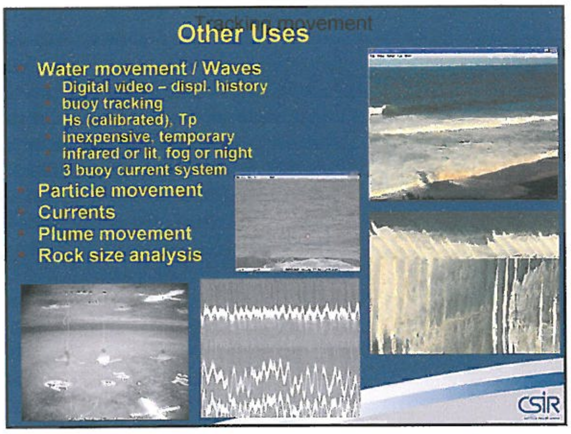
Surface Profiling – model applications

Calibration points needed



Moored Ship Motion (proto & model)

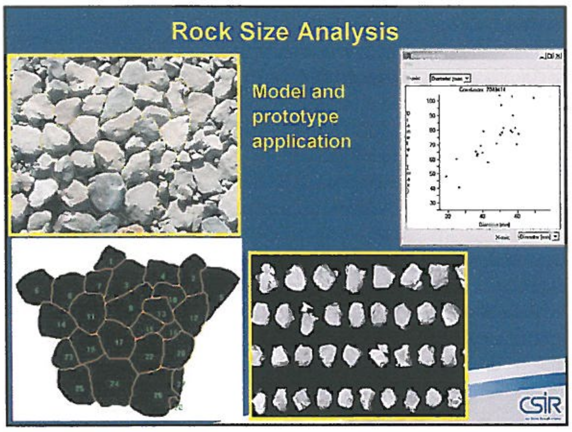
- Digital video recording
- 1 camera – many sample lines
- Time / displacement history (keogram)
- 6 degrees motion
- Fender and mooring force interpretation
- Prototype applications



Other Uses

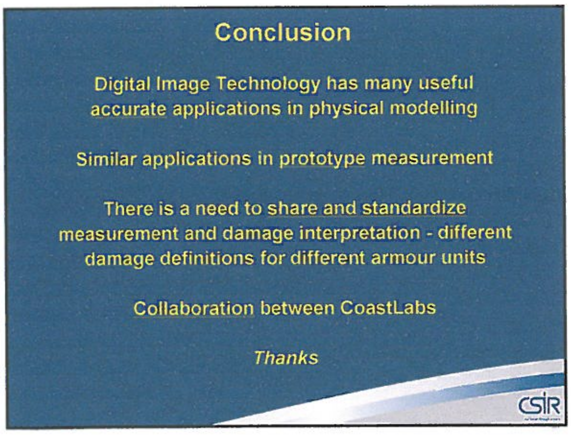
Tracking movement

- Water movement / Waves
  - Digital video – displ. history
  - buoy tracking
  - Hs (calibrated), Tp
  - inexpensive, temporary
  - infrared or lit, fog or night
  - 3 buoy current system
- Particle movement
- Currents
- Plume movement
- Rock size analysis



Rock Size Analysis

Model and prototype application



Conclusion

Digital Image Technology has many useful accurate applications in physical modelling

Similar applications in prototype measurement

There is a need to share and standardize measurement and damage interpretation - different damage definitions for different armour units

Collaboration between CoastLabs

Thanks