WAVE HEIGHT MEASUREMENTS IN MODEL HARBOURS USING CLOSE RANGE PHOTOGRAMMETRY

L P Adams
J D Pos
University of Cape Town
Republic of South Africa
Commission V

ABSTRACT

This paper describes the experimental procedures adopted by the University of Cape Town to obtain stereophotography of the dynamic water surface in a model harbour in order to extract information regarding wave height distributions and wave directions in the model basin using photogrammetric techniques.

Various methods of measuring the water elevation are discussed and the accuracy of the stereophotogrammetric solution is demonstrated.

A simple example of one of the many uses of stereophotogrammetry in the study of wave forms is illustrated by comparing a theoretical diffracted wave height curve with the actual wave heights.

INTRODUCTION

Model harbours are used by coastal engineers as an aid in the optimization of harbour designs. The models predict wave heights in full scale harbours, the results being used to reduce these wave heights to a minimum in order to prevent damage to moored ships, to the wharf structure and to the mooring systems.

Wave heights in model harbours are commonly measured using parallel wire resistance or capacitance wave probes. A number of these probes are usually mounted on a moveable instrument carriage which can traverse the wave basin to measure the wave heights. The disadvantage of this system is that the wave height at only a limited number of discrete locations can be measured at any one time. The method is time consuming since the instrument carriage has to be moved within the wave basin until the entire water surface has been measured. Excessive spacing of these wave probes may result in points of maximum wave heights being overlooked.

Many of the problems experienced in the use of traditional wave probe equipment to measure the height of a wave can be sensibly overcome by using stereophotography of the water surface as a remote sensing measuring technique. For a number of years coastal engineers in the Department of Civil Engineering at the University of Cape Town have been using stereophotogrammetry to study wave forms in a small laboratory wave basin. Initial work in these studies have already been reported Adams/Pos (1981) and Pos/Kilner (1982) but it would now seem appropriate to report further on the latest developments of the photogrammetric techniques.

STEREOPHOTOGRAPHY OF DYNAMIC WATER SURFACES

The problem of producing stereophotographs of a dynamic water surface is dramatically illustrated by viewing stereoscopically the stereopair of pictures (Fig.1.). The stereopair shows artificially induced waves approaching a breakwater in a model harbour. Large numbers of circular white floats were thrown onto the water surface before photography and simultaneous exposure of the cameras was effected by opening both camera shutters and then illuminating the water surface by means of a high powered electronic flash. It will be apparent from a study of this stereopair that when photographing a dynamic water surface the problems of water penetration, lack of photographic contrast and simultaneous photography must be solved.

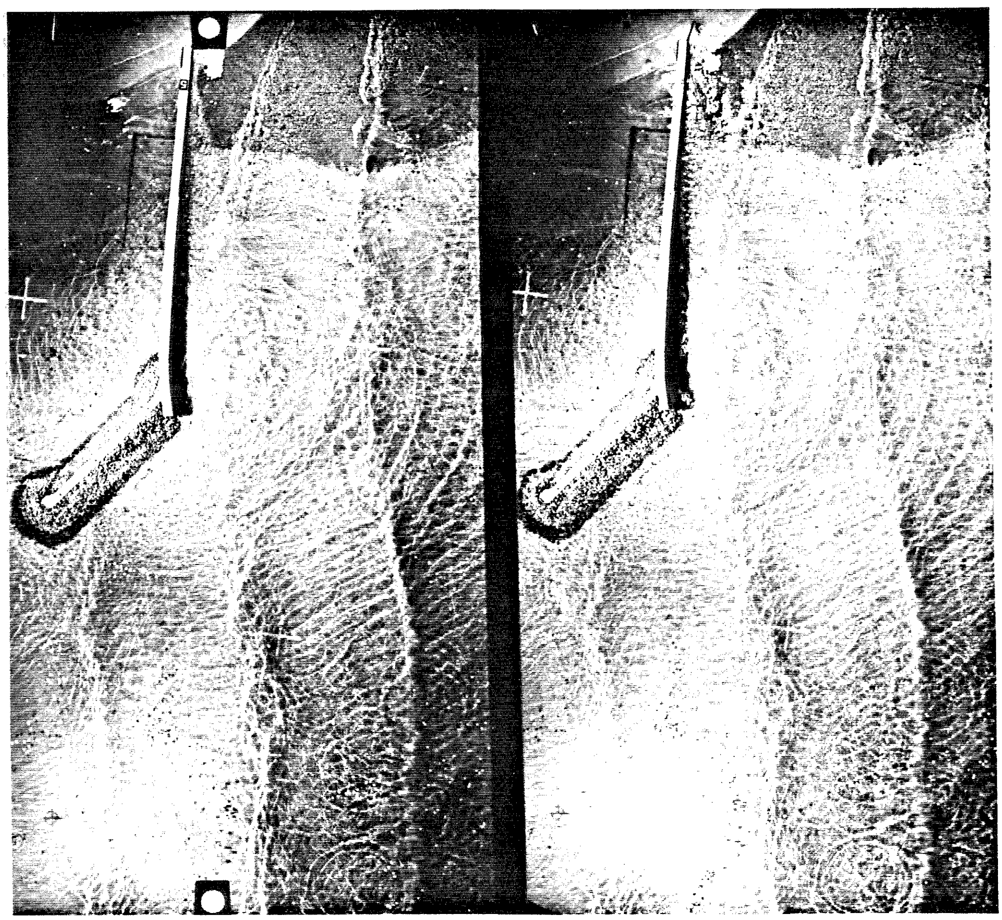

FIG.1. STEREOPAIR ILLUSTRATING WATER PENETRATION PHOTOGRAPHY

Water Penetration

Many methods of photographically defining the water surface have been tried with varying degrees of success. An important consideration is that the substance used to define the surface must not significantly affect the wave process under investigation. It should also be inexpensive and non contaminating with regard to laboratory installations. Surface applications such as aluminium powder and confetti were tried and found inconvenient and various solutions such as P V A settled out too quickly to be satisfactory. Eventually it was decided that a low concentration of cutting oil in water (0.7 per cent) gave a suitably milky fluid sufficient to make the water surface opaque.

Photographic Contrast

The soluble machine cutting oil solves the problem of water penetration but introduces serious lack of photographic contrast since the water surface takes on the appearance of large white projection screen. Photographic contrast was artificially introduced by employing 4 conventional lecture room type overhead projectors placed 4 m above the water surface in the plan positions shown in Fig.2. Transparencies comprising random assemblies of black stars and arrows were projected through the overhead projectors onto the water surface to provide the contrast (Fig.3).

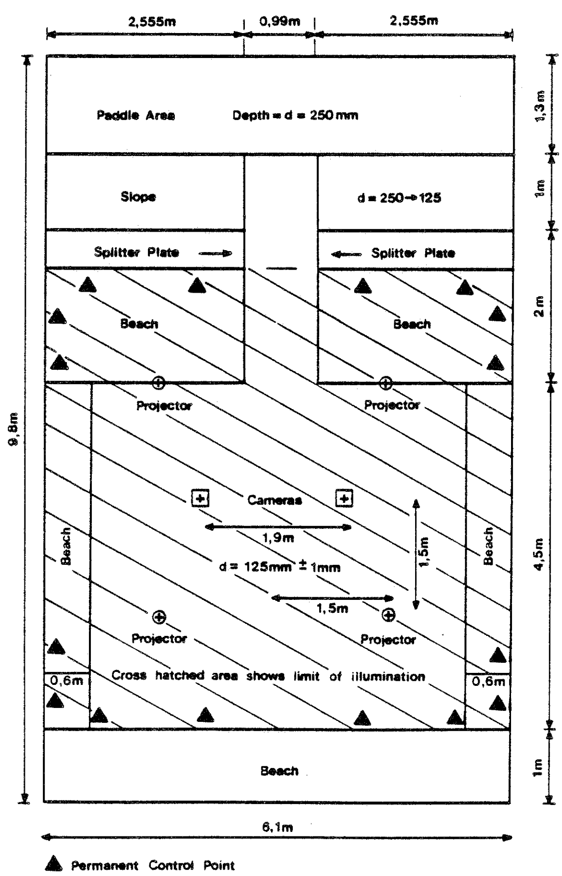

Fig. 2

Typical Harbour Configuration

Illumination, Exposure and Image Movement

Two Zeiss (Jena.) UMK 10/1318 survey cameras were mounted about 5 m above the water surface and 1,9 m apart. A requirement was that two stereoscopic pairs of photographs were to be produced in which the waves in one set were to be 180° out of phase with the waves in the second set. This was solved by placing two microswitches 180° apart on the drive axle of the wave making machinery. The microswitches were connected to the electronic camera firing box which permitted the synchronised firing of the two cameras on command. Since the water was in motion it was necessary that a very short exposure time be employed which introduced the complication of providing sufficiently high powered illumination to capture the image. The illumination problem was overcome by replacing the conventional lamp bulbs in the overhead projectors with powerful flash bulbs placed at the focal points of the focusing lenses and fired by a common capacitance. A shutter speed setting of 1/30 second was used to allow both shutters to be open a sufficient time to encompass the flash duration and to ensure that the individually illuminated control points were adequately exposed. All photography took place at night and due to the very short flash duration the water surface details were effectively 'frozen'. The stereoscopic viewing of the stereopair (Fig.3) illustrates the effectiveness of the stereophotography.

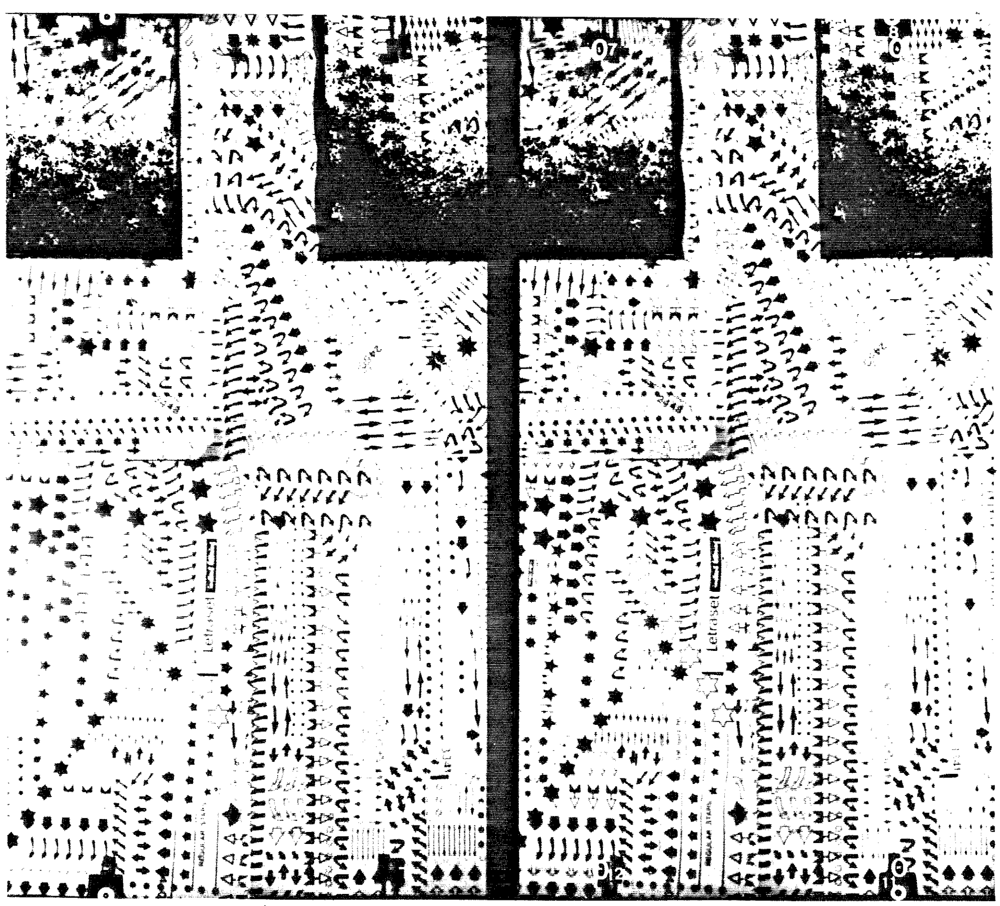

FIG.3. STEREOPAIR ILLUSTRATING WAVE FORMS IN MODEL HARBOUR

GROUND CONTROL

Since many harbour configurations were to be modelled under varying wave conditions it was decided to establish a permanent and generous ground control system to give more than sufficient ground data to provide for the analytical and analogue analysis of wave heights and patterns using any of the well known stereophotogrammetric methods. In the event 16 control points were located around the edges of the wave basin (Fig.2) and in three planes; one plane below the water surface where points were located in open cannisters and two planes above the water surface. Control points were co-ordinated by a combination of trilateration and spirit levelling to an accuracy of better than 1 mm. All control point targets were individually illuminated.

ANALYSIS

The scope of this particular project was confined to the determination of water surface elevations and for this purpose many well known stereophotogrammetric techniques are available to the coastal engineer varying from the use of the simple mirror stereoscope and parallax bar to the more sophisticated analogue stereoplotter or analytical stereocomparator.

An organisation concerned with the design of harbours would normally be a national engineering or maritime laboratory and it would be logical to assume that the use of sophisticated, and hence costly, camera and stereophotogrammetric equipment would be natural since the purchase of such equipment would be only a comparatively small item in the budget of such an organisation. There is no doubt that the use of large format wide angle metric cameras and a precision stereocomparator say on-line to a computer is the sensible solution, however experience has shown that large organisations do not necessarily follow the sensible approach. Management in cases where new methods of measurement are proposed tend to suggest the use of less costly equipment. In the employment of stereophotogrammetry as a measuring tool in model harbour studies this would involve the use of non metric cameras and simple image measuring equipment.

In anticipation of the penny pinching attitude of the maritime management engineer a number of accuracy tests have been undertaken on stereopairs of wave photography using measuring equipment of varying degrees of sophistication and cost. As an illustration the heights of well defined crest and trough image points down the line of waves entering the harbour entrance and moving towards the opposite beach (Fig.3) have been measured using

1. Parallax bar and mirror stereoscope
2. Zeiss (Jena) Topocart stereoplotter
3. Zeiss (Jena) Steko 1818 stereocomparator

Parallax bar and mirror stereoscope

Contact scale and two time enlargement prints of Fig.3 were made and parallax bar measurements taken of all control points and 16 well defined wave crest and trough points.

Heights of image points were calculated using the well known (Thompson 1954) 5 parameter adjustment of crude height formula

$$dh = ao + a_1x + a_2y + a_3xy + a_4 x^2$$

The calculations were repeated using a further term (a_5z) and an iterative calculation process to take account of the comparatively large variation in the height of control points.

Stereoplotter

The original negatives were mounted in the stereoplotter and the normal orientations carried out. Variations between machine and ground heights of control points were evenly distributed. The machine heights of the crest and trough points were then recorded.

Stereocomparator

Again the orientation and recording of control and image point coordinates were as normal. Experience has shown that provided sufficient non-planar control points are available then the use of projective transformation calculations rather than traditional relative orientation methods to determine space coordinates of common image points gives a more satisfactory result. This method of calculation has the added advantage that the inner orientation elements of the cameras are not required so that non metric cameras could replace the metric cameras which were used in this case.

Results

Tabulated below are the heights of the 16 water surface points as determined by the various methods. On the premise that the average of tabulated results 2-6 were the best height values the standard deviations of single height determinations were calculated as indicated in the table below. The high precision obtained by the lowly parallax bar was an interesting feature of this exercise despite the tedium of the observing procedures. When the use of stereophotogrammetry as a means of measuring water surface elevations was first suggested for this project it was postulated that an accuracy of better than 2 mm was possible. Results illustrated here and obtained elsewhere continue to support that postulate.

TABLE OF WAVE ELEVATIONS (MMS)

WAVE POINT	PARALLAX BAR: CONTACT SCALE, PARAMETERS 5	PARALLAX BAR: CONTACT SCALE, PARAMETERS 6	PARALLAX BAR: 2X ENLARGEMENT, PARAMETERS 5	PARALLAX BAR: 2X ENLARGEMENT, PARAMETERS 6	TOPO-CART	STERO	AVERAGE
	1	2	3	4	5	6	2 - 6
1	80,6	82,3	84,8	85,0	84	83,6	83,9
2	23,3	26,0	34,8	35,1	33	32,1	32,2
3	76,4	78,2	78,5	78,8	78	76,6	78,0
4	29,9	32,5	32,2	32,6	31	28,9	31,4
5	82,5	84,3	85,0	85,2	88	84,4	85,4
6	33,0	35,7	33,2	33,6	33	35,7	34,2
7	71,4	73,5	70,7	71,0	74	71,1	72,1
8	34,5	37,2	33,0	33,4	36	34,0	34,7
9	65,2	67,5	68,1	68,4	71	69,3	68,9
10	34,1	36,9	33,7	34,1	37	34,9	35,3
11	60,5	62,9	61,7	62,0	64	62,8	62,7
12	39,4	42,2	40,7	41,1	37	37,9	39,8
13	63,4	65,8	68,6	68,8	68	67,2	67,7
14	41,2	44,0	41,0	41,4	39	39,3	40,9
15	60,5	63,0	63,1	63,4	61	61,3	62,4
16	45,5	48,3	46,4	46,7	42	43,8	45,4
STD.DEVIATION	± 3,14	± 2,40	± 1,21	± 1,24	± 1,80	± 1,16	

TABLE 1

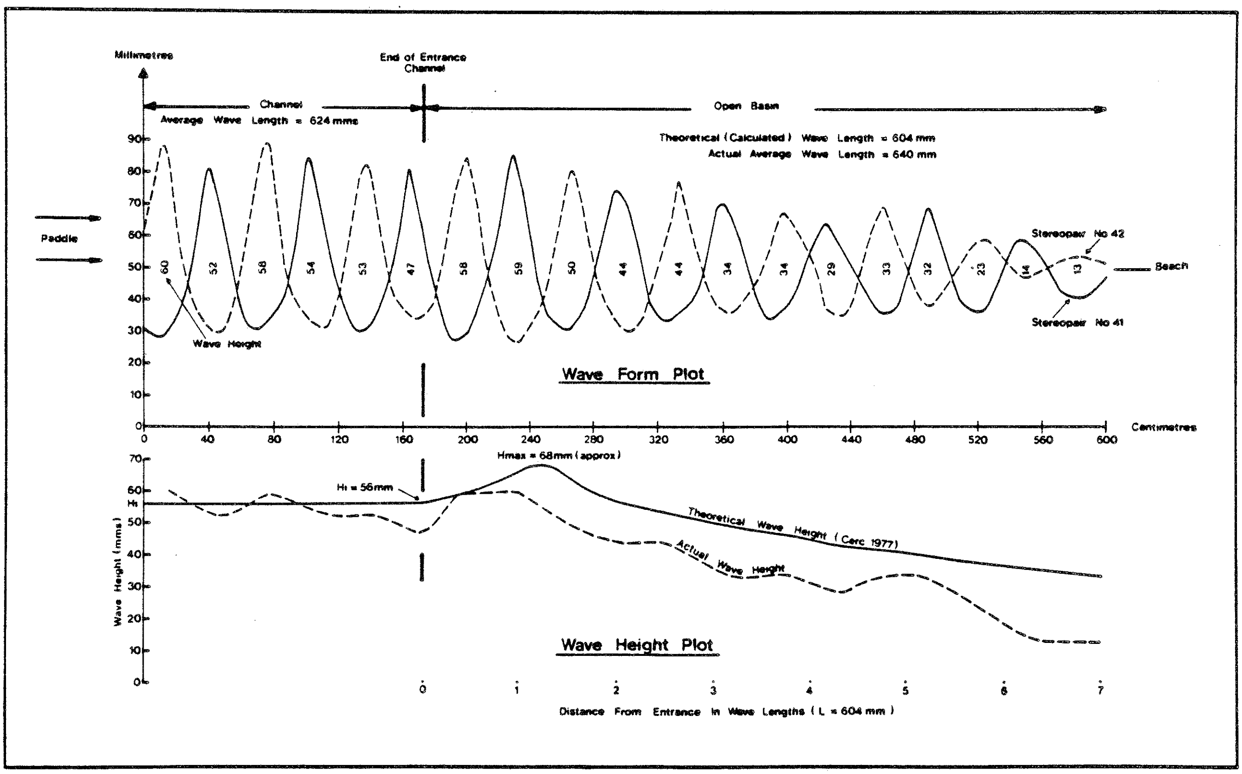

FIG.4 PLOT OF WAVE PROFILE AND COMPARISON DIAGRAM

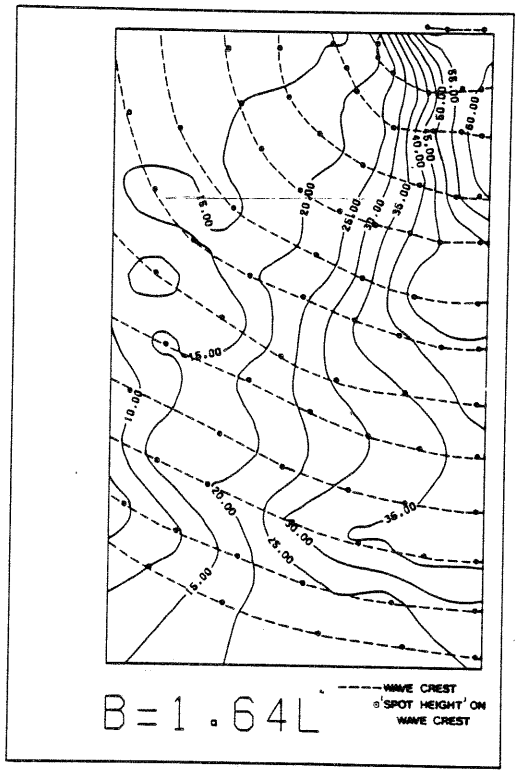

FIG.5 CONTOUR PLOT OF LEFT HAND SIDE OF BASIN

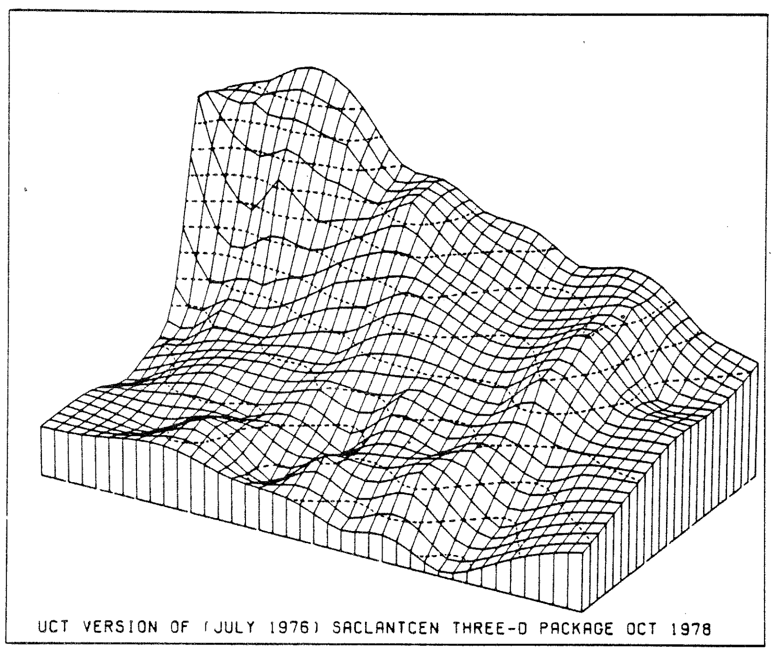

FIG.6 COMPUTER GENERATED 'THREE DIMENSIONAL'
VIEW OF LEFT HAND SIDE OF BASIN

PRACTICAL EXAMPLE

An exercise was undertaken using the stereopair No 41 (Fig.3) and a second stereopair, No 42, which imaged waves 180° out of phase with the first set. The stereopairs were oriented in the Topocart stereo-plotter and the water elevations of the wave form running down the centre of the harbour entrance channel, through the open basin to the beach were recorded every 5 cm along the profile. The resulting wave form plots are shown in Fig.4. The height of each individual wave is given by scaling the vertical distance between the trough of one set with the corresponding crest of the second set as indicated on the plot.

Also appearing on Fig.4 is an interesting comparison between the theoretical diffracted wave heights and the actual wave heights. For this particular exercise the incident wave train has the following characteristics: wave period 0,67 secs, wave height approx 56 mms and wave length (calculated using Airy wave theory) 604 mm. The gap to wavelength ratio (B/L ratio) is 1,64. The water depth is 125 mm $\pm$ 1 mm.

The theoretical diffracted wave height curve shown on Fig.4 was constructed according to a CERC (1977) diffraction diagram for B = 1,64L breakwater gap configuration. The CERC diffraction diagram used was based on the Penney and Price (1952) solution for the diffraction of water waves passing through a breakwater gap.

In addition to the wave train profile produced by observing the two stereo-pairs in the analogue TOPOCART plotter the same harbour configuration was analysed analytically using the STEKO 1818 stereocomparator which is interfaced via an analogue to digital converter and a data communication interface with a TEKTRONIX 4051 microcomputer. The Tektronix 4051 is in turn linked to a mainframe computer (UNIVAC 1100/81). Since the harbour configuration is symmetrical about the centre line only the left hand side of the basin was analysed in this exercise. The resulting wave height contour plot is shown in Fig.5 and a graphical computer generated three dimensional view in Fig.6. Both these plots were based on corresponding crest and trough elevations and interpolated using a computer graphics package available at the University of Cape Town.

The interpretation of these diagrams is beyond the scope of this paper and within the province of the coastal engineer but the diagrams do give a simple illustration of the usefulness, efficiency and accuracy of the use of stereophotogrammetry in model harbour studies. No other method hitherto employed in these type of studies can match the mass of visual and metrical information provided by the stereophotograph.

CONCLUSIONS

The major problems of obtaining accurate measurement of wave heights in model harbours using conventional techniques as contemplated in the introduction to this paper have been successfully solved using stereo-photogrammetry. Stereopairs of photographs can be taken in a very much shorter period of time than is required for a scan using wave probes with the added advantage that the information contained on the photographic plates is infinite, permanent, synoptic and detailed. Furthermore using this remote sensing technique there is no interference in the wave processes. The ability to make photographic exposures on command allows for photography to be undertaken very shortly after the wave making machinery is activated and before the wave field is contaminated by the distorting effects of wave reflections from internal walls. This "infinite basin" technique allows the researcher to accurately model the situation of a continuous wave train entering a basin of infinite extent which is an important consideration if one wishes to compare the experimental results with existing theoretical solutions.

Three areas of utilisation for the photogrammetric wave height and pattern recording technique appears possible. The first is the routine use in applied investigations where refraction and diffraction effects are important as for example in the analysis of model harbour configurations. The second is to make use of the procedures as a check on the validity of various existing wave theories and thirdly the application of the technique in close conjunction with mathematical modelling (such as finite element modelling) in order to calibrate the models and thus to improve their predictions. For example, experimental wave diffraction diagrams, determined photogrammetrically, have been compared with theoretical predictions using finite element analysis. (Pos 1983).

REFERENCES

Adams, L.P. and Pos, J.D. 1981 Model harbour wave form studies by short range photogrammetry. Photogrammetric Record, 10(58) : 457-470.

CERC 1977 Shore protection manual, Vol.1 U.S. Army Coastal Engineering Research Center, Third Edition.

Penney, W.G. and Price, A.T., 1952 The diffraction theory of sea waves and the shelter afforded by breakwaters Philosophical Transactions of the Royal Society of London, Vol. A224 : 236-253. March 1952.

Pos, J.D. and Kilner, F.A., 1982 Laboratory photogrammetric wave height measurement. Proceedings of the 18th International Conference on Coastal Engineering, Cape Town. 15 pages.

Pos, J.D., 1983 Wave diffraction using finite and infinite elements. Proceedings of the Finite Element Methods in South Africa, 1983 Symposium. Cape Town 11-12 January. Also to be published in Computer Methods in Applied Mechanics and Engineering.

Thompson, E.H., 1954 Heights from parallax measurements. Photogrammetric Record 1(4) : 38-49