

THE USE OF THE STEREO-PHOTOGRAMMETRY METHOD
IN GEOTECHNICAL ENGINEERING WORK

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ABSTRACT:

The stereo-photogrammetric technique is a powerful method for obtaining incremental displacements for any point of a plane object subjected to a transformation. In this paper the principle and the method giving the associated displacement fields are described. As an example the method has been applied to geotechnical model tests to study the behaviour of a shallow plate anchor embedded in a dry sand and subjected to an uplift force. Several interesting observations are made about the mode of failure and the sand deformations.

KEY WORDS: Anchor, Geotechnique, Model Tests, Pseudo Stereo-Photogrammetry, Sand, Stecometer.

1- INTRODUCTION

Engineering testing often involves the measurements and analysis of displacements or deformation in materials under various types of loading conditions. For many problems in soil mechanics it is by no means trivial to establish the shape of the displaced field. It is especially important to know the characteristics of the displacement field in order to relate it to the relevant soil mechanics parameters.

In the literature several successful methods have been described for performing such measurements, e.g. optographic trace recording (Feesser, 1984), X-ray technique (Bourdeau & Recordon, 1988), speckle interferometry (Pater & Niewenhuis, 1987), tomodensimetry (Desrues et al, 1991).

In the present investigation, pseudo stereo-photogrammetry, a technique by which geometrical information is derived from a pair of negatives or photographs, has been used. Although its best known application is in topography mapping, it is being applied to an increasing extent to a variety of scientific and engineering measurements, such as concrete deformations (Torrenti et al, 1989), expertise work (Adamou et al, 1991). In this paper, the utilisation of this technique to monitor the zone of sand displaced by a plate anchor subjected to an uplift load is presented and the results are discussed.

2- PSEUDO STEREO PHOTOGRAMMETRY

This method is based on the fundamental principles of conventional stereo-photogrammetry. Close range photography techniques yield global information, on both components of displacement, throughout cross sectional areas; i.e. the number of possible measurements is limited

only by the resolution of the photographs. High density displacement information allows the comprehensive analysis of strains. Also since the photographs represent a permanent record of the event, information may be obtained from them at any time following their exposure. Typically, a test material is housed in a rectangular container and is visible, in cross section, through transparent glass which constitute one side of the container. Successive photographs of the model are taken by a fixed camera as the test progress. When two photographs, including a relative displacement of the soil particles with respect to a fixed object, are viewed together as a stereoscopic pair, a three dimensional image with distinct topography will be perceived. The test material may or may not contain targets for measurements at discrete points. If targets are not present, it becomes necessary for the materials to have sufficient texture to form a discernable surface for photogrammetric measurement. This method has a number of inherent features which can be advantageous when considering the technique for specific applications. Andrawes (1976) and Welsh (1986) listed the following advantages:

- Remote, non contacting measurement can be made.
- No embedded markers are used.
- The photographs provide a permanent record which can be remeasured at a later date.
- Measurement can be made with the object in-situ.
- Conventional standard equipment available for stereo photogrammetry can be used directly.
- Efficiency of measuring the displacements in the areas of large discontinuities or high displacement gradients since every particle can be individually traced.

3-RECORDING THE DISPLACEMENT FIELD

An accurate and complete photographic record of the displacement field should fulfill the following conditions:

-A set of static reference marks should be recorded in the photographs. This is necessary to determine the datum level for height measurement in the stereo image. In the present investigation an orthogonal grid was scored for this purpose on the inside face of the glass side of the box. This grid was formed of equal squares 25mm X 25 mm.

-The camera used should have a good quality lens capable of producing sharp negatives so that the objects in the pair of photos are easily fused when viewed stereoscopically. In displacement field work the overlap is 100% and the movement of particles between photos will be recorded through the same part of the lens. Any distortion by the lens will produce similar errors in successive photos and the measurement of the parallaxes between points will not be significantly in error. For a high degree of accuracy a plate camera capable of taking glass plates or large size negatives is preferable. In the present study a Hasselbad 500 LM camera fitted with an 80mm lens, capable of producing a 55mm by 55mm negative, was used. A clear relief image is enhanced if the photos contain contrasts between adjacent objects. Careful illumination of the model can improve the texture of the surface and the quality of the photos. Two floodlights were positioned at an angle of 45° with respect to the camera sand bed axis. The camera had a black screen (with only the lens protruding) to minimize unwanted reflections in the glass window. The camera position was approximately 0.5m from the edge of the model.

-The camera should be fixed in position relative to the stationary parts of the model so that the optical axis is perpendicular to the plane of displacements. If the camera moves between photos this will become apparent, when a pair of photos is viewed stereoscopically, by differences in parallax between points in the model which are known not to have moved. Andrawes (1976) stated that the error introduced by a tilt of the camera of 2° from the perpendicular will introduce an average error of about ±1% in the value of the contours. In this study the camera has been mounted on a rigid pedestal and the pictures were taken with the help of a remote control device so that the camera was not touched during the test.

4-MEASUREMENT OF DISPLACEMENT

The major movements in the anchor model occur parallel to the vertical axis and therefore the negatives were set up in the instrument so that the vertical axis shown in the negatives was parallel to the x axis of the instrument. This dramatized the apparent relief when the pair was viewed stereoscopically. In the negatives

the grid appears as a distinct white colour "datum" surface from where the measuring mark can be driven towards the elevated sand particles. The measurements were made point by point along steep slopes, peaks, depression and breaks in the relief. If the whole displacement field is to be reproduced there must be an interpolation between the measured points. It was found that measurements at 500 points gave good reproduction of the images viewed.

5-COMPUTER PROCESSING OF DATA

The author has developed a computer program which processed all the data given by the stereocomparator and plotted all the required diagrams using the UNIRAS package. The measurements made in the stecometer are from points which are randomly spaced throughout the field. These measurements are used by the program to calculate the values of the vertical and horizontal displacements which occur in the field at the position of the nodes of a regular grid which covers the whole field. The fields of the vertical and horizontal displacement components are then plotted. The displacement component values are combined to give the resultant displacements at the nodes of the grid and they are also used to derive the strains throughout the field.

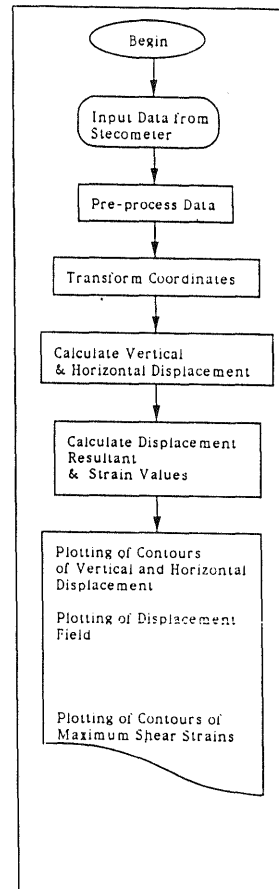


Fig. 1 Flow Chart

6- STRAINS COMPUTATION

The strains are calculated from the values of the vertical and horizontal displacement at the nodes of the grid. Each element of the grid is considered to be a square element (12.5mm X 12.5mm). The vertical and horizontal strains are calculated through the centre of the element. The following assumptions (James, 1972) apply:

- 1- displacements vary linearly across each element which in turn assumes that the sand in every element strains uniformly.
- 2- changes in the geometry of the system during testing have a negligible effect on the calculated strains.
- 3- compressive strains are assumed to be positive.

The shear strain is defined as the angular distortion at the centre of the element taken from the top right hand quarter of the element and is calculated from the appropriate vertical and horizontal displacements of the four corners of the element. All the strain values are assigned to the centres of the elements and the coordinates of the nodes of the grid containing the strains are redefined to these positions. The nodal points of each element are numbered proceeding in a counterclockwise direction around the element in the order 1,2,3 and 4 (fig. 2).

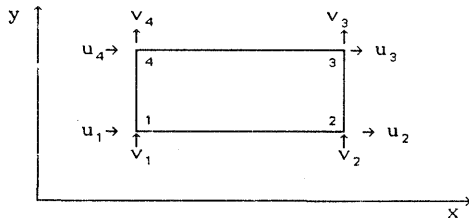


Fig.2 Numbering convention for the nodal points.

The following equations were derived :

$$\epsilon_x = \frac{(u_1 + u_4) - (u_2 + u_3)}{2x}$$

$$\epsilon_y = \frac{(v_1 + v_2) - (v_3 + v_4)}{2y}$$

$$\gamma_{xy} = [((v_2 - v_1) + (v_3 - v_4))/2x] + [((u_4 - u_1) + (u_3 - u_2))/2y]$$

Where, ϵ_x , ϵ_y and γ_{xy} are the axial strains and shear strain respectively. u and v represent the horizontal and vertical displacement.

7- TESTING PROCEDURE

The apparatus consisted of a wooden box, 600 cm by 300 cm in plan and 400 cm depth. The front viewing face of the box was designated to allow a 6 mm thick glass to slide in and out. Sufficiently stiff bracing for this glass face was obtained on the bottom and sides of the tank by the use of thin U metal plates. It was restrained against the frame by bolts screwed through tapped holes in the front of the box. A semi circular brass bush with 5 mm inside diameter was fixed in the base at the centre of the box immediately behind the glass face. A semi circular brass disc 50 mm diameter and 13 mm thick was welded to the upper end of 5 mm diameter shaft to make the anchor unit. The shaft was 400 mm long, its diameter having been reduced to 5 mm from the middle to the upper end in order to be pushed through the bush. The bottom end of the shaft was fixed to a load cell which in turn was fixed to the base plate of a 1 ton Whykeham Farrance multispeed machine. A Sangamo transducer was also fixed to the base plate to record the displacement of the plate anchor. The load cell and the LVDT were connected to a data logger and a plotter in order to monitor the different stages of the test. The sand was placed in layers of 30 mm thickness until the required depth was reached, a rectangular hopper, 650 mm by 300 mm in plan and 300 mm in depth, being used to produce a rain of sand grains and therefore achieve the required densities. Details of the technique have already been given in Bouazza (1990) and Bouazza & Finlay (1990).

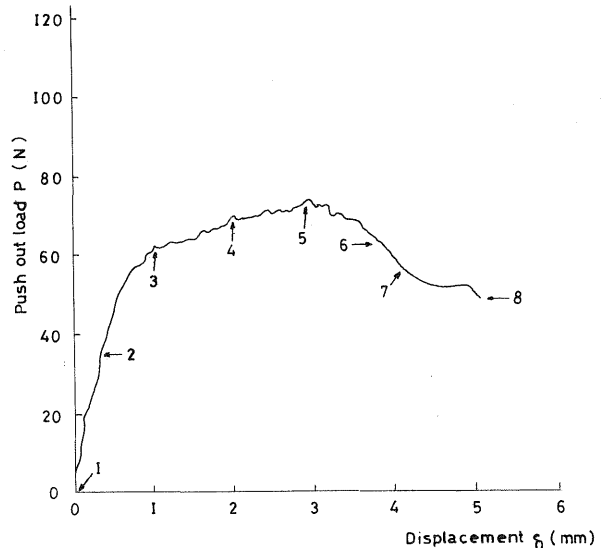


FIG.3: TYPICAL LOAD VS DISPLACEMENT CURVE.

During each test a sequence of eight photographs was taken, the first prior to pushing, the remainder at approximately 1.0 mm upward displacement interval. A typical load versus displacement curve is given in figure 3. It shows a smooth peak followed by a softening stage, the numbers on the curve are the serial numbers of the photographs. The stereocomparator used in this study was a Zeiss Jena Stecometer type C.

8-DISCUSSION & CONCLUSION

In this study, the sand used was a uniform subrounded sand from Leighton Buzzard. Tests were performed at a relative density (I/D) of 75% and a depth/diameter (D/B) ratio of 4. When the anchor is subjected to loading the load is transmitted to the sand surrounding it. The deformations occurring in the sand were observed and recorded. Figures 4 to 7 show the displacements and strains for one increment of the applied load. They show the zones of the bed that responded to the applied load. It should be noted that displacement contours are given in mms and maximum strain contours in percentages.

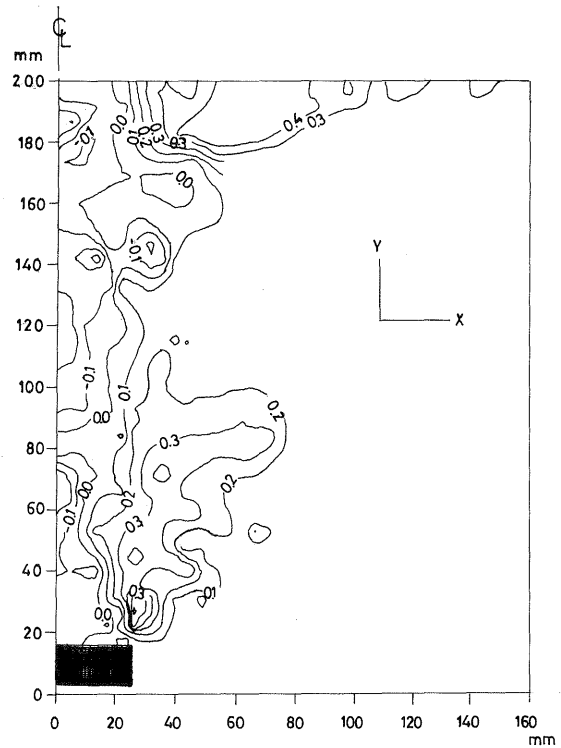
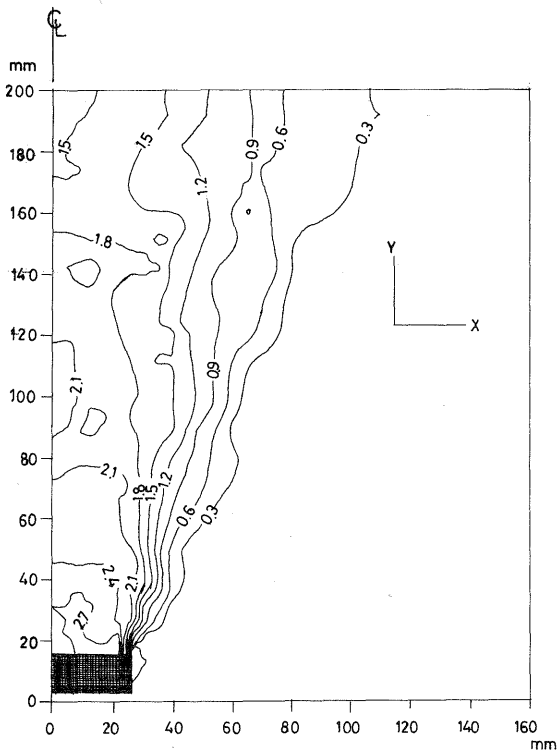


FIG. 5: CONTOURS OF HORIZONTAL DISPLACEMENTS IN LEIGHTON BUZZARD SAND, $D/B = 4$, $ID = 75\%$, $\delta = 2.7$ mm.

For a vertical displacement of 2.7 mm, it can be seen that the zone of sand responding to this increment of load extends approximately from 0.125 B to 2.0 B to the side of the plate anchor and a clear discontinuity of displacements can be seen in figure 6. The vertical displacement diminishes as the distance above the plate increases. The horizontal displacements are insignificant and occur mainly above the side of the plate. It was observed that at this stage the sand has begun to fall into the cavity left below the plate anchor as it rises. The shear has developed and is extending in a generally vertical direction upward from the edge of the plate anchor. The immediate effect of this propagation is depicted in figure 7. In this case, the shape of the failure surface is defined by the shape of the boundary of the disturbed zone of sand (i.e. a frustrum of cone).



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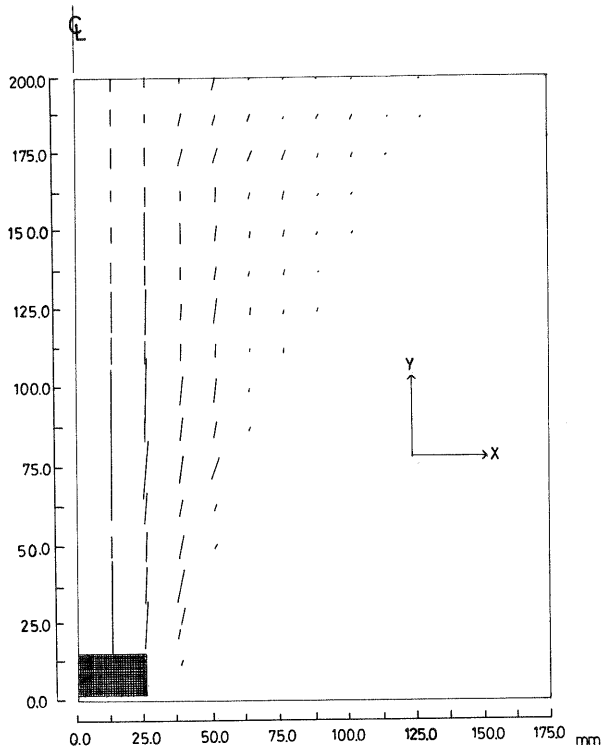


FIG. 6: DISPLACEMENT FIELDS IN LEIGHTON BUZZARD SAND $D/B = 4$ $ID = 75\%$ $\delta = 2.7\text{mm}$

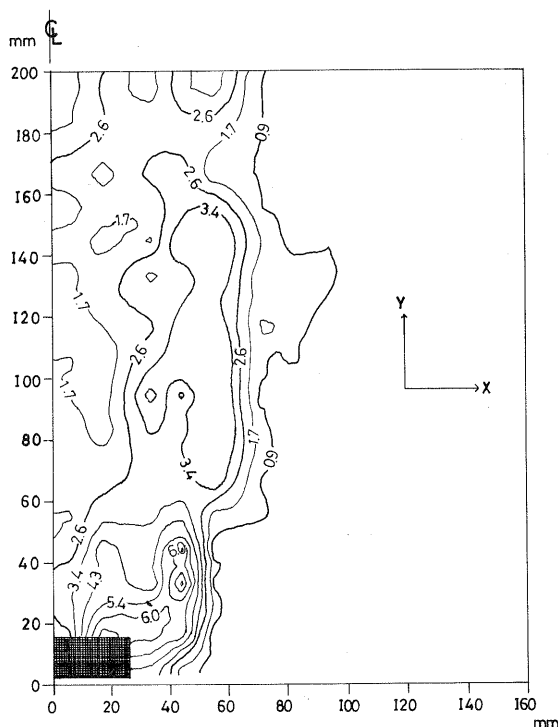


FIG. 7: CONTOURS OF MAXIMUM SHEAR STRAIN IN LEIGHTON BUZZARD $D/B = 4$ $ID = 75$ $\delta = 2.7\text{mm}$