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A PHOTOGRAMMETRIC METHOD FOR ESTABLISHING THE HEELING-ANGLE OF A VESSEL DURING THE TEST OF TRANSVERSE STABILITY

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Abstract

Before delivery from the ship yard, a new life-boat was tested for transverse stability by being dragged 360° around its axis. Later the boat capsized in a storm, and a discussion about its seaworthyness arose. Fortunately an 8 mm amateur film was taken of the transverse stability test.

A commission of inquiry wanted the heeling-angle determined for each of the 350 pictures of the film. The interior and the exterior orientation of the camera was derived from coordinates to points on the shore, and the orientation of the boat was derived from points on the boat.

The accuracy of the heeling-angle was approx. 1°.

A more reliable photogrammetric method for future test of stability is proposed.

PREFACE

In December 1980 a special-built lifeboat capsized during a rescue-action in a strong storm off the coast of West-Jutland. All 6 men onboard perished.

The lifeboat was, however, constructed in such a way that it ought not to capsize.

In the conditions of delivery it was claimed amongst other things that a transverse stability test should be carried out, before approval of the vessel. The stability test was made in such a way that there was questions about the validity of its results.

2 years after the catastrophy, however, a journalist succeeded in procuring an amateur-film (Super 8 mm), which showed this stability test. It was presented in television and thereafter caused some doubt as to whether the test was able to confirm that the vessel was uncapsizable.

A commission was appointed in order to place the responsibility for the catastrophy and this commission requested our Institute to determine the heeling-angle of the boat.

The transverse stability test

The test was carried out in the following way: Two ropes were fastened to the starboard searailing from which they were carried under the keel and fastened to a crane on the port side of the vessel. Then the crane dragged the vessel 360° around its length-axis without stopping. The whole sequence was taken with the above mentioned 8 mm camera, making up a total of 350 pictures.

The geometrical basis for the photogrammetric measurements

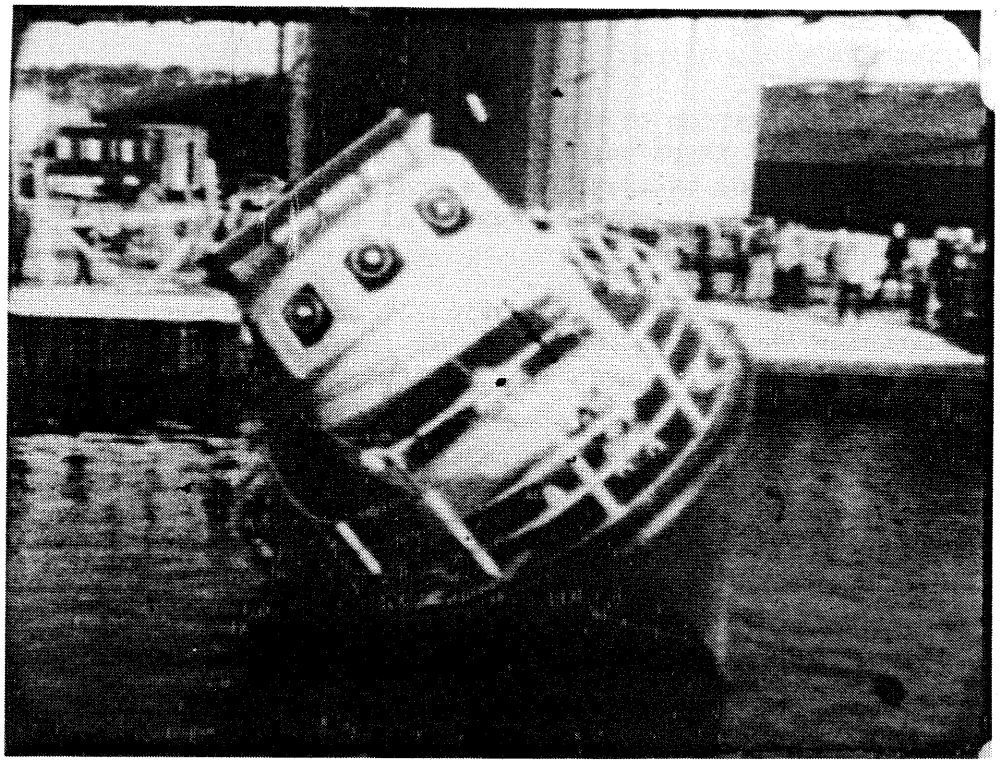
The first condition for using the pictures is to know the internal orientation of the camera. The camera, which was used, was a hired one, and was not available, when we got involved in the problem. For that reason it was not possible to carry out a normal cameracalibration by means of a testfield. Instead the two first pictures of the whole film were used for calibration.

In those pictures a number of points was selected, which could be identified on land (building corners, windows and on the sheet-piling of the quay).

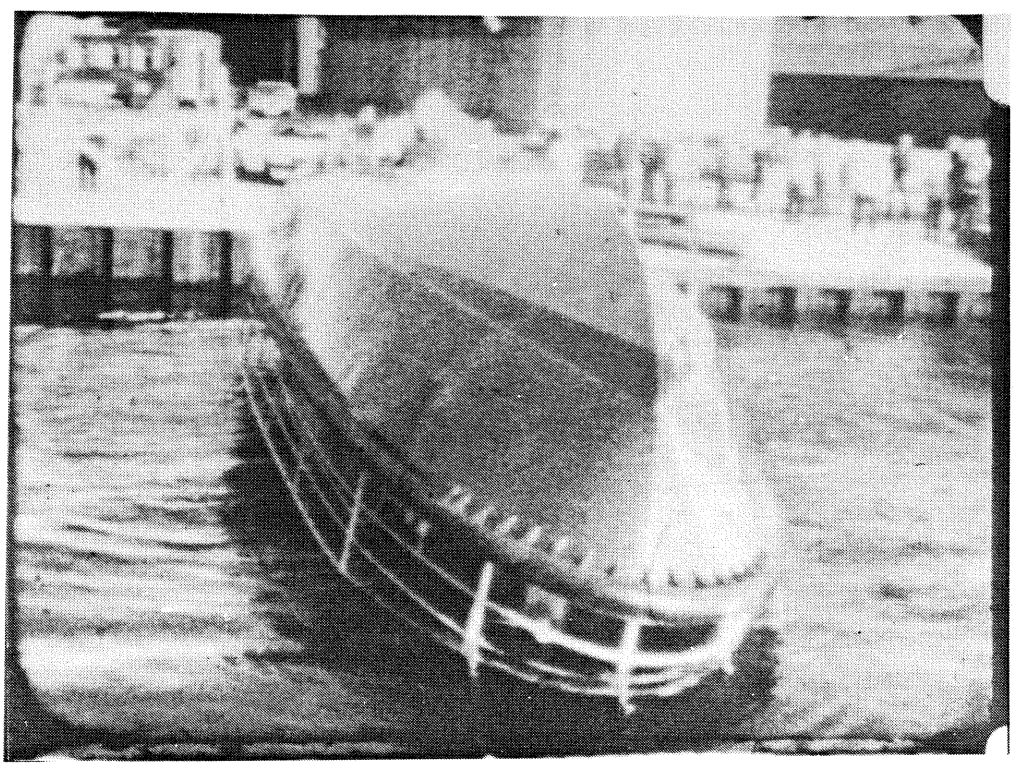
A local coordinate-system $\underline{X}$ = (X,Y,Z) was established and a total of 18 points was measured in this system with a standard deviation of 2 cm.

By determining the X,Y,Z-coordinates to these points on land and measuring the image coordinates in a stereocomparator it was possible to calculate the focal length, the principal point in proportion to the corners of the picture, and the lens distortion. The focal length was determined to 11.09 mm with a standard deviation of 0.10 mm. The residuals in the picture - after correction of the lens distortion - was 0.005 mm. The internal orientation fixed in this way was hereafter kept for the remaining pictures.

The following two pictures are enlargements from the original 8 mm film:



Heeling-angle app. 20 degrees.



Heeling-angle app. 175 degrees.

The camera was handheld during the exposure, and the operator was standing on the deck of a floating boat, so we must assume that the external orientation of the camera is changed from picture to picture.

With a fixed internal orientation of the camera, its position X_o, Y_o and Z_o as well as Omega, Phi and Kappa was calculated on the basis of the same points on land as used for the calibration. Depending on the direction in which the camera was pointing, a variable number of these points could be measured in each picture.

Normally about 14 points were used for the calculation of the external orientation. The accordance between these points was comparatively good, as the residuals in the picture were less than 0.010 mm with a standard deviation about 0.005 mm.

After the catastrophy the lifeboat was hauled on land and a part of the superstructure and the sea-railing was removed. As a consequence it was limited, how many points on the boat it was possible to measure. This number furthermore was reduced, as only a small section of the boat was seen on the film.

A coordinate system $\underline{U}$ = (U,V,W) was established with the U-V plane defined according to the designed waterline, and the W-axis going through the foremost upright of the sea-railing. A few well-defined points on the removed superstructure might, however, be coordinated according to the constructional drawings. Fig. 1.

The placing of the boat in the landbased coordinate system is indicated by a rotation-matrix $\underline{\underline{R}}$ and a translation vector B.

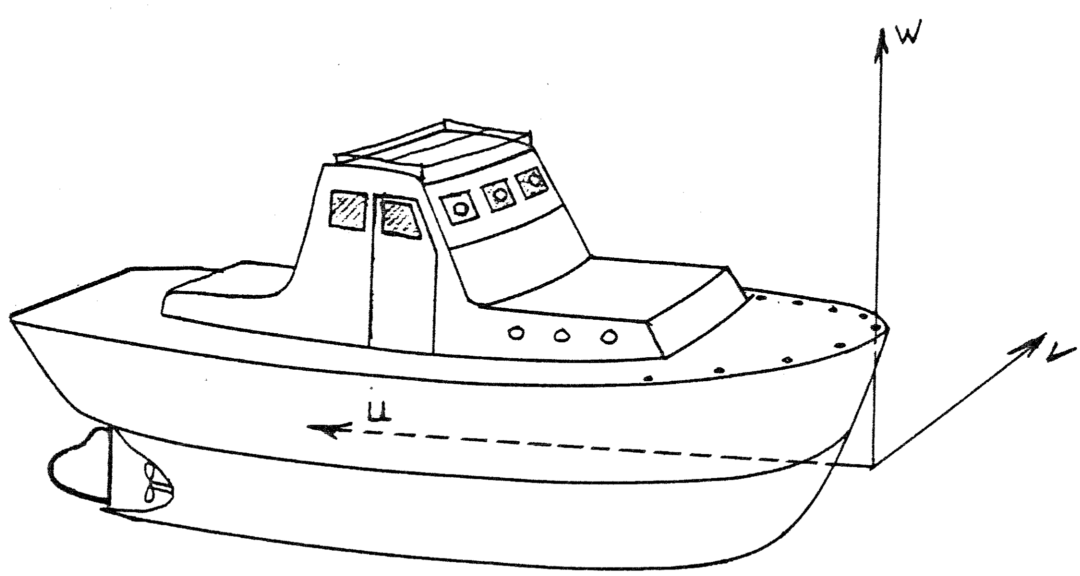


Fig. 1. The boat's coordinate system.

Points on the boat can be transformed from the coordinate system $\underline{U}$ on the boat to the coordinate system $\underline{X}$ on land by

$$\underline{X} = \underline{U} \times \underline{\underline{R}} + \underline{B}$$

From the coordinate system $\underline{X}$ the same points can be transformed to the projectioncenter of the camera, rotated to the main axis of the camera and finally through a perspective projection to the image plane.

This results in the following 12 unknowns all referring to the land based system.

The boat's position: X_B, Y_B, Z_B

The rotation of the boat: $Omega_B$, Phi_B and $Kappa_B$

The position of the camera: X_K, Y_K, Z_K

The rotation of the camera: $Omega_K$, Phi_K, $Kappa_K$

As every point measured in the comparator will cause 2 observation-equations, at least 3 points on land and 3 on the boat has to be measured to ensure the system.

The calculation was carried out by using least squares adjustment. The searched angle of heel is one of the unknowns in this adjustment. The standard deviation of this quantity was given in the covarians matrix of the elements.

RESULTS

Measurements of the pictures were carried out using a Zeiss Jena Stecometer with automatic recording. Theoretical accuracy 0.001 mm. All the pictures in the film were numbered in succession before the measuring took place, so the operator could control the number regularly.

A computer-program in PASCAL was developed to accomplish the calculations for each of the 350 pictures. Apart from the two first pictures where the internal orientation of the camera was calculated and printed, the output for each picture consisted of the picture-number, the external orientation of the camera, the heeling-angle of the boat and the corresponding standard deviation.

Generally the heeling-angle is determined with a standard deviation ranging from 0.5 to 1.0 degrees. In certain cases it rises to more than 2 degrees. This is due to the fact that there were only few points available to measure on the vessel when it was placed upside down. At the same time these few points were concentrated in the bow and therefore caused a slack geometrical solution.

Figure 2 shows the progress of the heeling-angle as a function of the picture number. At picture number 160 (heeling-angle 150 degrees) the angle changes from still increasing to suddenly falling again. Then it continues increasing until it is back in normal position. This confirms exactly what the film implied, namely that the vessel at a certain time in fact "take over" the crane.

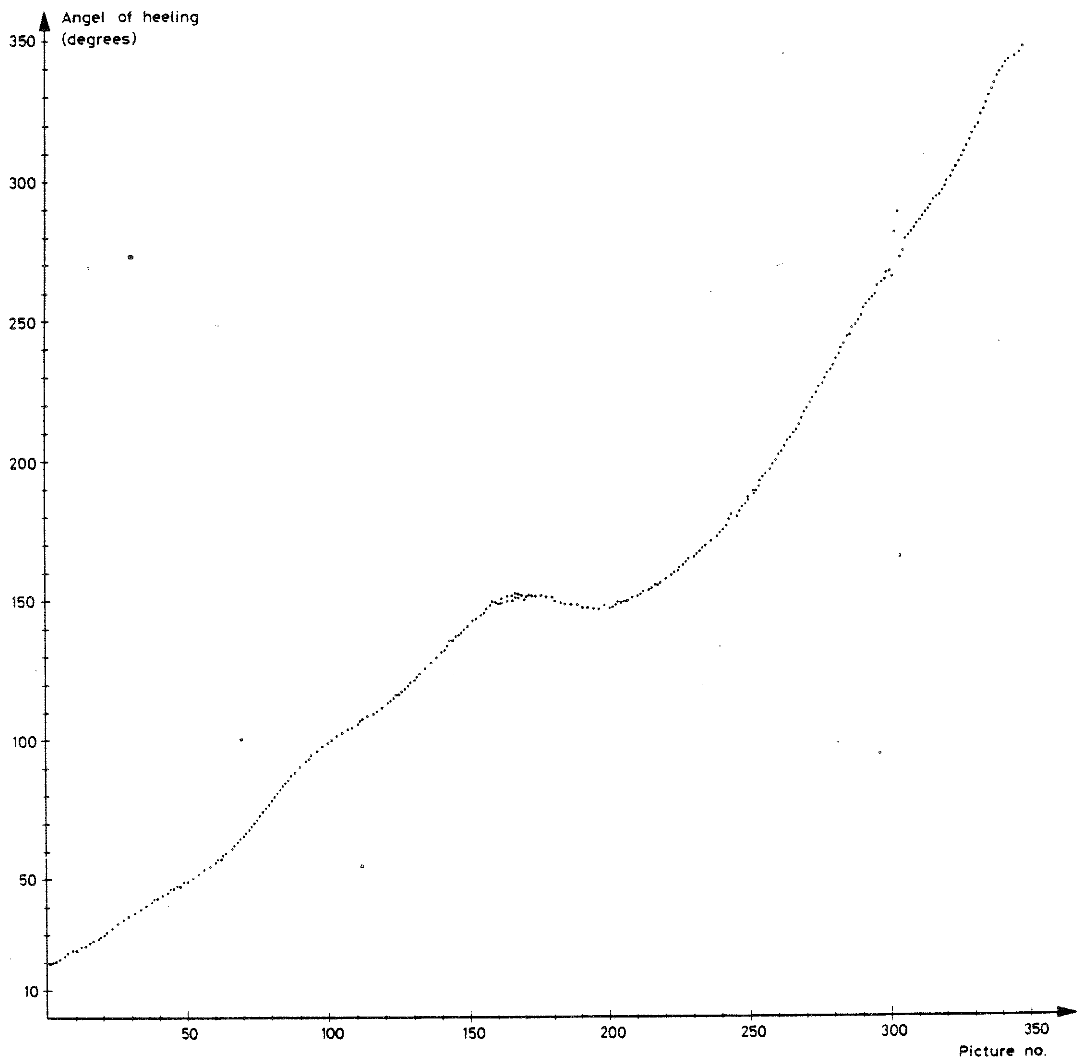


Fig. 2. The heeling-angle as a function of the picture

CONCLUSION

An investigation of the different parameter which are estimated to influence the heeling-angle has been carried out. It is obvious that the use of a 16 mm movie camera under any circumstances is better than a 8 mm camera.

A change of the focallength by 1 mm changes the heeling-angle approximately 0.4 degrees and the corresponding accuracy increases with 0.6 degrees. On the other hand, the lens distortion has less influence. A calculation carried out without this correction leads to a change of the heeling-angle of approximately 0.05 degrees, which in this connection is insignificant.

The selection of points on land and on the vessel was - as mentioned before - limited by what could be seen on each separate picture. Furthermore the camera was a little bit out of focus, hence all the pictures were blurred. The result was that the pointing of the measuring mark on certain points in the stecometer was uncertain. That leads to a disproportionately great standard deviation of the heeling-angle. By excluding some of these points in the calculations, the heeling-angle changed only 0.1 degree, whereas the accuracy was improved about 30%.

Considering the above-mentioned conditions, it is possible to determine the heeling-angle in a similar transverse stabilitytest with a standard deviation better than 0.2 degrees.

The conditions are as follows:

Using a 16 mm movie camera.
Carrying out a normal cameracalibration, using a testfield. Especially the determination of the focal length is important.
Before the test - and when the vessel is placed on land - measuring and marking a series of well-placed points, distributed both on the superstructure and on the hull, especially below the waterline. The points can be measured either by using photogrammetry or by intersection.
Finally, measuring a series of points in the background, distributed in such a way that they provide a good geometrical base for the determination of the external orientation of the camera.

A standard deviation of 2 cm for the points on land and on the boat should be sufficient.