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DETERMINING OF THE SHIP'S HULL TOTAL DEFORMATIONS IN REAL SAILING AND SERVICE CONDITIONS

The paper describes the method and procedures in determining the ship's hull bending deformations in the longitudinal horizontal plane in the real sailing and service conditions. The ship's hull bending is determined on the basis of the reading of digital inclinometers inclination data, obtained from the ship's hull measurement network. The method of absolute and relative measurement point shifts calculations is described, as well as the determining of the defined neutral line. The impact of ship's hull bending in longitudinal vertical plane and of torsion ship's hull deformation on the bending in longitudinal horizontal line is included in deformations calculations method.

Key words: hull, control, sailing, inclination, deformation

1. INTRODUCTION

The paper is aimed to integrate the Part 1 of the research project "The Ship Hull Control in Real Sailing Service Conditions". The project is divided in two research parts. The Part 1 comprises definition of theoretical basics of the project and consists of six phases. The Part 2 is planned to comprise experimental research in real conditions and final evaluation of the research. The project "The Ship Hull Control in Real Sailing Service Conditions" is aimed to obtain necessary data about ship hull motions, deformations and stresses in service conditions using developed methods and already available equipment. The project Part 1 phases of research are: information technology application to navigation elements (parameters) selection and the possible criteria for the elements selection; hull deformations control using digital inclinometers and accelerometers network; ship hull bending deformations using the measuring points angles of inclination data; hull deformations cases and related

deformations data [1]; procedure for hull stresses calculation during sailing (should be presented in the paper for OTO International Conference, Kobe, November 2004.)

2. THE PROJECT PART 1 PHASES AND RESULTS

Phase A Information technology application to navigation elements (parameters) selection and the possible criteria for the elements selection are presented in paper [5]. The design, building and exploitation of ship (ship hull) are, in many ways, specific in technical practice.

The ship hull design procedure consists of the procedure for load definition and the calculation of structure elements dimensions, stresses and hull local and overall deformations procedure. In the structure elements calculation process the very accurate FEM or BEM analysis is applied and if there was a way of exact determination of the loadings acting to the hull in service, the results could be considered as reliable one.

In the process of the hull building technological reasons and building expenses are cause of the solutions that influence essentially to the ship hull service reliability, for example mixing of building systems (connection of the longitudinally framed cylindrical part of the hull and transversely framed engine room area as well as the fore peak area and wide application of "scallop" connection between longitudinal and transversal structure and all types of structure elements passages. Variety of stress concentrations are caused by structural elements misplacements during the building process, high tensile steel application and welding.

During the service the ship hull is exposed to loadings caused by cargoes, sea waves and wind. Aiming to prevent the hull damages caused by irregular cargo conditions, various LS computer applications are used. The speed and course of navigation essentially influence to ship hull accelerations and distribution of ship displacement and to the hull stresses and local and overall deformations. In present time the hull stresses and deformations control in service conditions is left to the ship crew free estimation based on experience and practice.

Phase B The ship hull deformations control using digital inclinometers and accelerometers network are presented in papers [3] and [4];

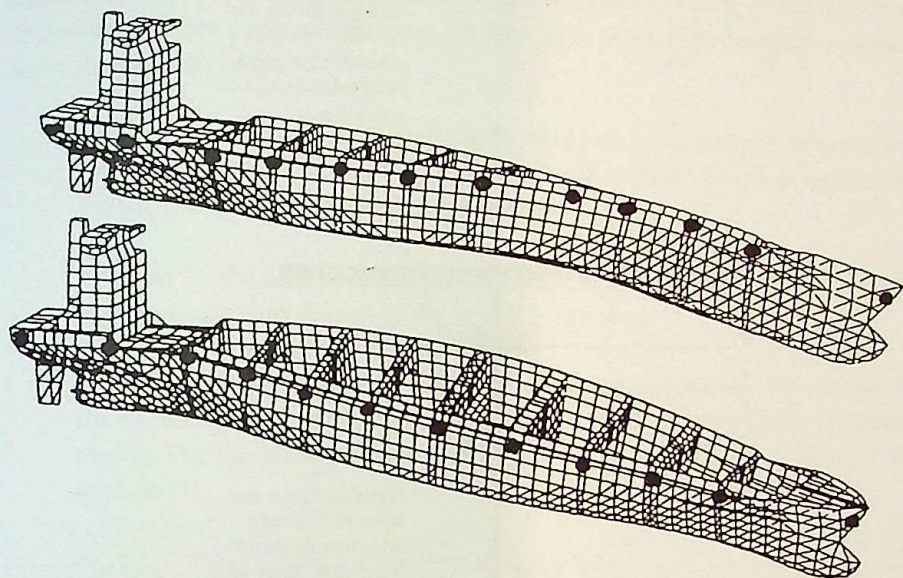


Figure 1. Deformed measuring point line

Measuring point position is selected according to the criterion of the highest local structure stiffness of the ship's hull. The selected places of measuring points are connections of the deck, the central longitudinal bulkhead and the transversal bulkhead or connections of sheer strake and deck stringer at the transversal bulkhead as shown in the figure 1.

The measuring points comprise two or three digital inclinometers each, directed to measure the inclinations in the longitudinal vertical plane of symmetry, transversal planes and in the longitudinal horizontal plane. The measuring point allocation alongside the ship hull is defined as distance of the point to the aft perpendicular.

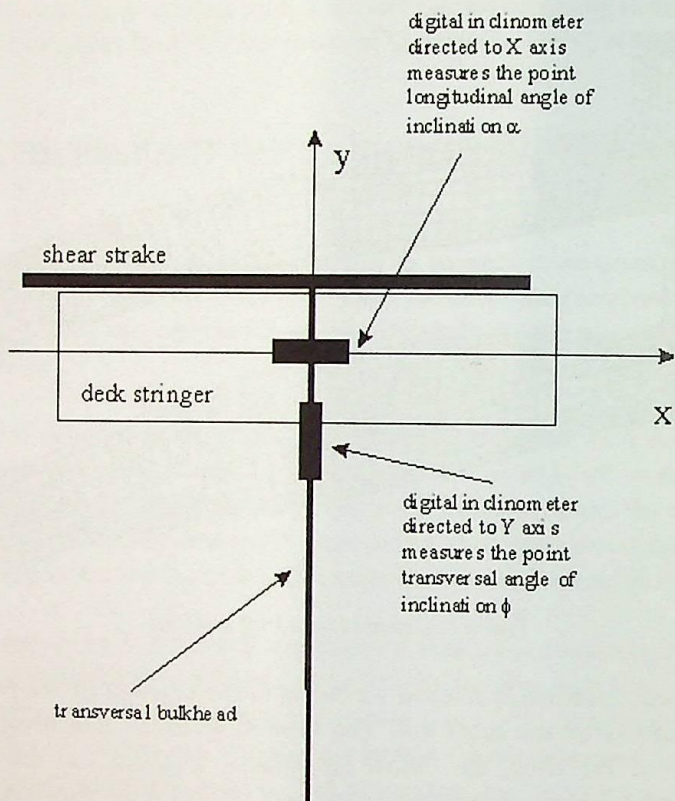


Figure 2. Measuring point according to figure 1

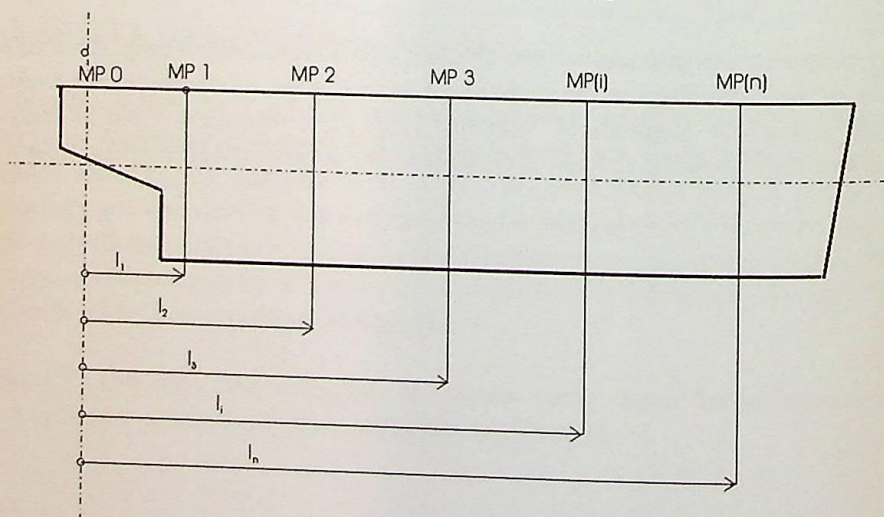


Figure 3. Measuring points allocation

Phase C The ship hull bending deformations using the measuring points angles of inclination data are presented in paper [2]. The point shifts determination is defined under the presumptions:

The hull deformations between the measuring points are small and deformations sizes can be considered as the second order of magnitude with respect to the distances between measuring points.

The size of the total hull deformation can be considered as the second order of magnitude with respect to the length of the ship.

The hull deformation between two measuring points one can approximate by the circular arc whose chord is the same as the distance between the measuring points. The calculation of the measuring point relative shift is defined by the relation (1):

$$ds_{i+1} = \frac{l_{i+1} - l_i}{2} \cdot \sin(\alpha_{i+1} - \alpha_i) \quad (1)$$

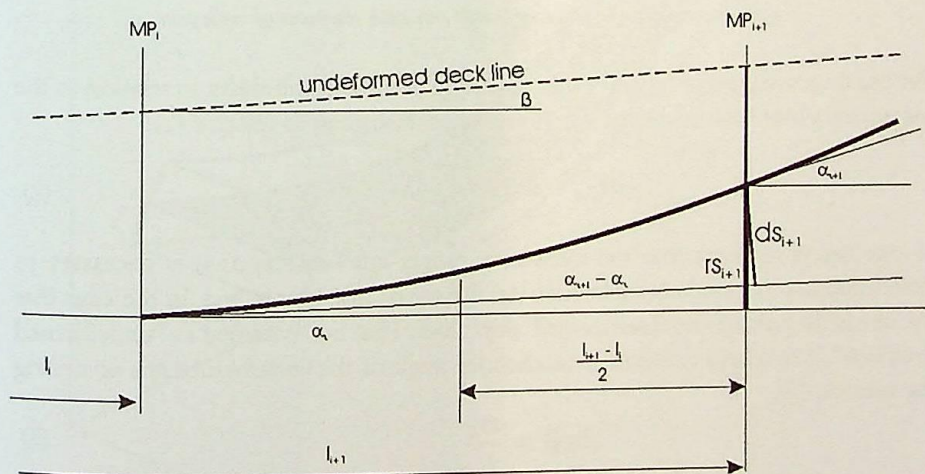


Figure 4. Measuring point relative shift

Figures 5 and 6 show the deformed measuring point line (neutral line) and the way for calculation of total shift of measuring point and total deflection of the measuring point line for two main cases, deformed line without the point of inflexion and with one as well.

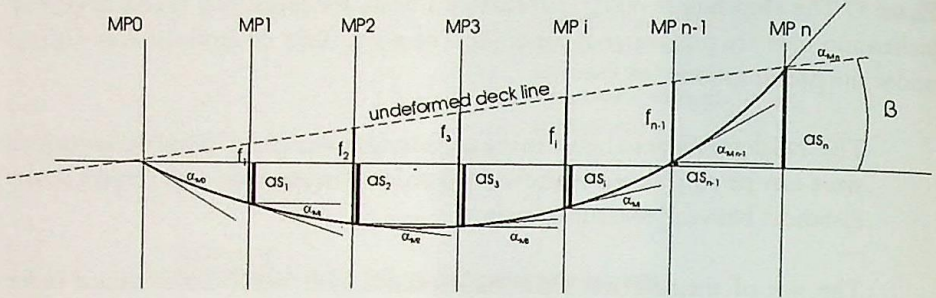


Figure 5. Deformed measuring points line without the point of inflexion

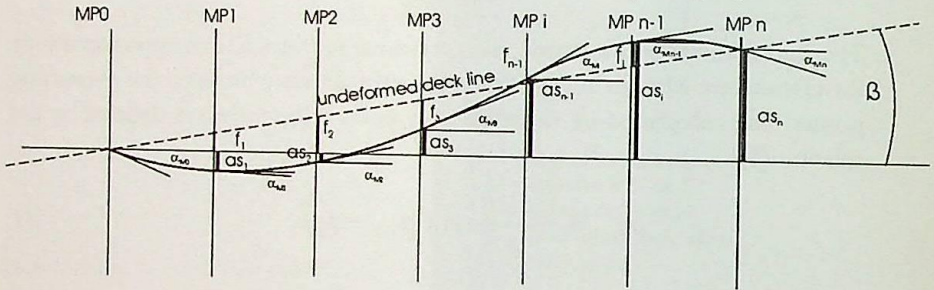


Figure 6. Deformed measuring points line with the point of inflexion

For the measuring point $(i+1)$ on the measuring point line, the shifts, in relation to the measuring point horizontal line, are determined according to relation (2).

$$as_{i+1} = as_i + rs_{i+1} \quad (2)$$

If one wants to determine the measuring points line deflections it is necessary to determine the longitudinal inclination of the measuring points line, in the case that the line is the part of the absolute stiff ship's hull. That line is named as "undeformed deck line". The relation determines inclination angle of the undeformed line according the relation (3).

$$\sin \beta = \frac{as_n}{l_n} \quad (3)$$

If one considers β as very small angle then:

$$\hat{\beta} = \frac{as_n}{l_n} \quad (4)$$

The measuring points line deflections related to the absolute stiff hull, in relation to the referential horizontal line at the measuring points position, one can define

according to relation (5).

$$f_i = l_i \cdot \hat{\beta} + as_i \tag{5}$$

Phase D This phase is done to define the real value and meaning of the measured angles of inclination of measuring point as it is presented in the paper [1]. Co-ordinate system of the measuring point (MP) in the hull undeformed shape is $x_0 y_0 z_0$ co-ordinate system that is parallel to the main ship hull co-ordinate system xyz . The co-ordinate systems of the measuring point (MP) in the hull deformed shape are $x'y'z'$ or $x''y''z''$, as it is shown in the figure 7.

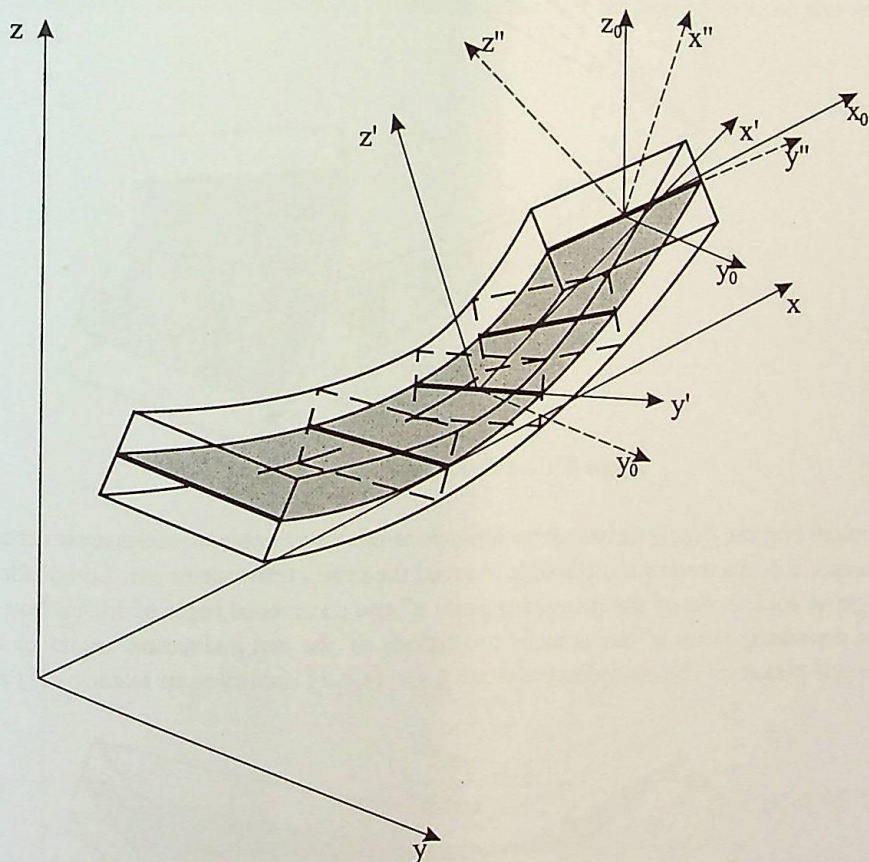


Figure 7. Measuring point co-ordinate systems

The inclined co-ordinate systems $x'y'z'$ or $x''y''z''$ are derived by rotation around the x_0 axis, y_0 axis and z_0 axis according to the figure 7.

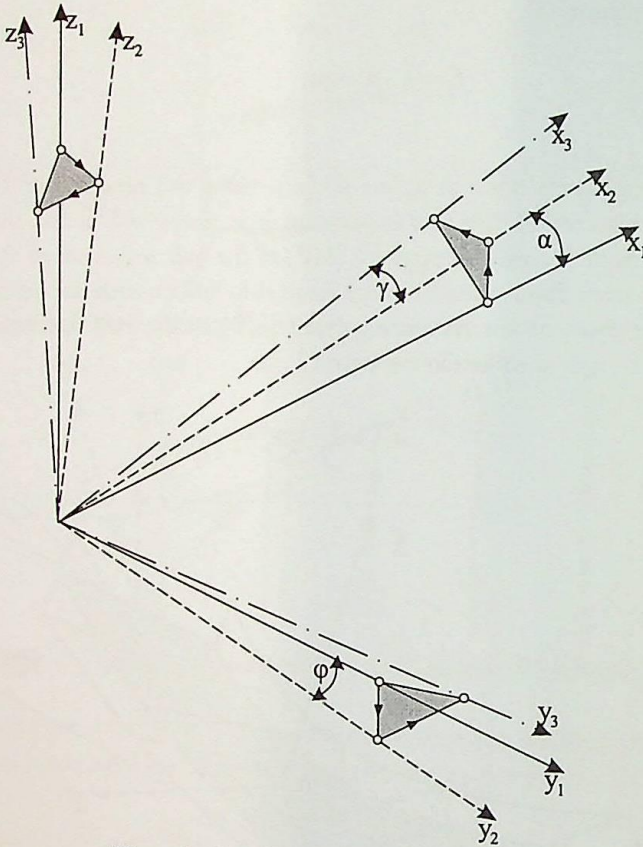


Figure 8. Co-ordinate systems after rotations

Considering the digital inclinometer limitations related to angle of inclination vertical components measuring it is possible to avoid the third inclinometer use. Longitudinal angle of inclination of the measuring point α'' and transversal angle of inclination of the measuring point φ'' are actually projections of the real inclination angles to the vertical planes of the co-ordinate system x_1, y_1, z_1 (x_0, y_0, z_0) according to relations (6) and (7).

$$\alpha = \frac{\alpha''}{\cos \varphi''} \quad (6)$$

$$\varphi = \frac{\varphi''}{\cos \alpha} \quad (7)$$

Further corrections of the point angles of inclination, due to their mutual influence, are not useful because the correction procedure is not convergent so one should correct

the inclination angles only once. The real value of the hull point angle of inclination that is indicator of the hull bending deformations in the horizontal longitudinal plane one can find using relations (8) and (9):

$$\alpha'' = \gamma'' \tag{8}$$

$$\gamma = \alpha \cdot \text{ctg}\varphi'' \tag{9}$$

Relations (8) and (9) define the angle of inclination of the ship hull measuring points that are relevant to the hull deformations calculation in the specific, ship's coordinate system. Those are bending deformation in the ship's longitudinal vertical plane, bending in the ship's longitudinal horizontal plane and the hull torsion, as shown in figure 9.

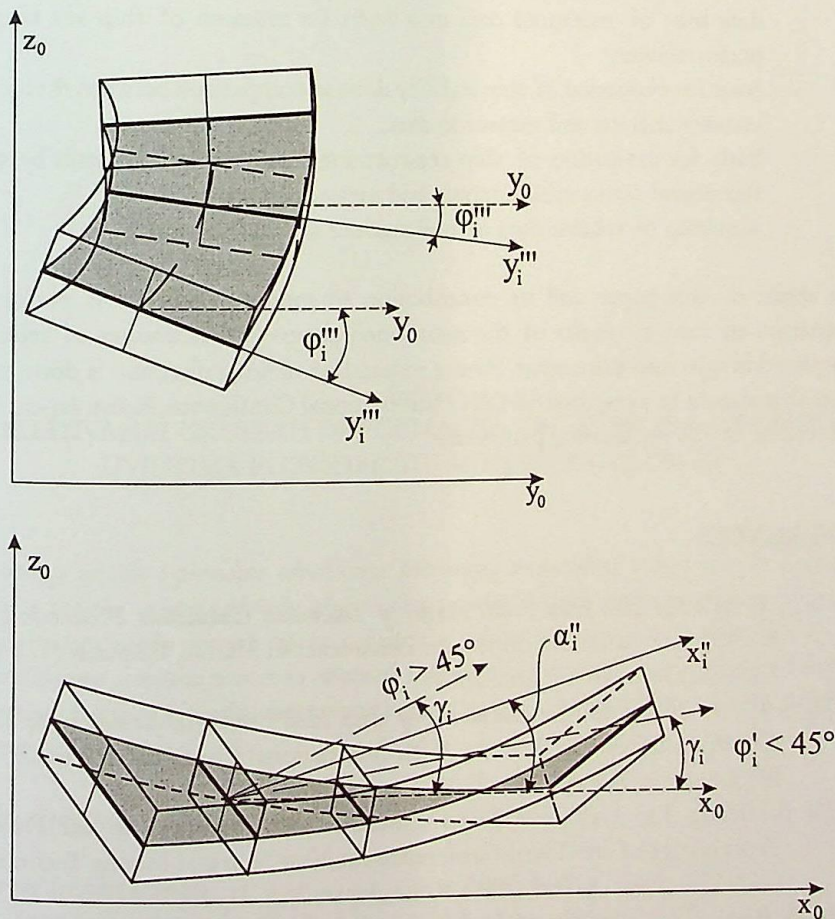


Figure 9. Measuring point inclinometers scanning results

3. CONCLUSION

The project "The Ship Hull Control in Real Sailing Service Conditions" aimed to solve the hull continuous control in real service sailing condition, defined through the parts 1 and 2 is described in papers [1], [2], [3], [4] and [5]. The papers are focused to certain phases of the project part 1. Expected benefits from the project one can define as:

- outline design request for the ship hull monitoring system, as hardware (ship equipment);
- monitoring procedure and data warehouse software;
- data base of measured and calculated data regarding hull motions, deformations and stresses;
- data base of measured data as a basis for research of ship sea keeping performances;
- basis for evaluation of ship stability done as comparison between theoretical stability analysis and measured data;
- basis for evaluation of ship seaworthiness done as comparison between theoretical sea keeping analysis and measured data;
- acquiring of reliable data of hull stresses and deformations.

The result of this paper and its contribution to maritime practice is performed integration of various results of the mentioned papers and definition of relatively completed insight into the matter. Future research in defined direction is done in the paper that should be presented on OTO International Conference, Kobe, Japan, 2004 with theme of the monitoring procedure.

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Sažetak

ODREĐIVANJE UKUPNIH DEFORMACIJA TRUPA BRODA U REALNIM UVJETIMA PLOVIDBE TIJEKOM EKSPLOATACIJE

Rad opisuje metodu i procedure određivanja deformacija trupa broda u uzdužnoj horizontalnoj ravnini u realnim uvjetima plovidbe tijekom eksploatacije. Savijanje broda određuje se na temelju očitavanja kuteva nagiba mjernih točaka s digitalnim inklinometrima spojenim u brodsku mjernu mrežu. Opisana je metoda proračuna relativnih i apsolutnih pomaka mjernih točaka te određivanje oblika neutralne linije. Utjecaj savijanja trupa u uzdužnoj vertikalnoj ravnini i torzije trupa uključen je u postupak proračuna.

Ključne riječi: trup, nadzor, plovidba, nagibi, deformacije

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