Problems of strength modelling of steel sandwich panels under in-plane load

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ABSTRACT

Paper presents examples of laboratory test and numerical modelling results of steel sandwich panels under in-plane load. Test and modelling procedure is presented and comparison of numerical and laboratory test obtained results of static compression is discussed.

Keywords : laser weld, laboratory test, strength properties, in-plane load

INTRODUCTION

Rapid development of new technologies, which is observed during last several years have made impact also on shipbuilding structures. Some new materials and new manufacturing techniques have been developed. Among other new ideas, the laser welding techniques start to find their position as alternative methods of joining components of ship structure. Such capabilities create new opportunities of changing the configuration of typical ship structure : instead of the "classical" design consisted of shell plating supported by a grid system of heavy stiffeners one can imagine a design similar to that already applied in glass reinforced plastic structures, namely two shells connected by an internal system of thin stiffeners (webs). This is the idea of sandwich structure – steel or aluminium panels manufactured from two shell plates of 3-4 mm thickness , internally supported by one directional system of stiffeners of about 40 mm in depth, with all components connected by laser welding, Fig.1.

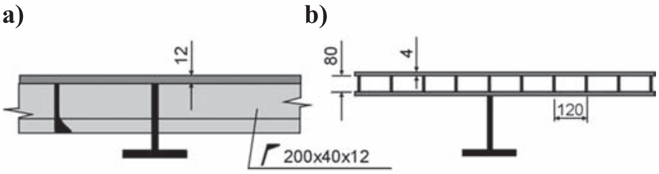

*Fig. 1. Ship deck structure of: **(a)** conventional design **(b)** sandwich design .*

Application of such new structure requires to determine its characteristics by taking into account its strength, corrosion, vibration, fire protection and fatigue properties, in order to get approval – from the side of classification societies – that they are not worse as compared with those of the classical structure. Majority of such parameters are usually obtained from the laboratory tests carried out on models or full-scale structures.

The application of the structure as in Fig.1b in place of the conventional design (Fig.1a) can provide weight reduction by at least 34% and reduction of the manufacturing costs by about 50% [2].

LABORATORY FULL - SCALE TESTS

Ship hull during its service life is subjected to various loads and their combinations : global, regional (zone) and local. Global loads affects the whole ship hull structure causing its bending or torsion which generate loads acting – among others – in planes of decks, bottom shell plating or longitudinal and transverse bulkheads. Compressive stresses can lead to buckling of thin shell plates, pre-deformed during manufacturing process. Due to the fact that the shell plating in sandwich structure is significantly thinner than that in conventional structure one can expect higher sensitivity of sandwich structure in regard to buckling phenomena.

A program of laboratory tests of full - scale sandwich panels was elaborated and performed in order to determine basic characteristics of the steel sandwich structure behavior under in-plane load and – further – to formulate and verify analytical formulae for its proper dimensioning. To determine stiffness characteristics of models in relation to their geometry and manufacturing deformations, the family of 3000 x 500 mm models were designed with taking into account some combinations of the model depth, shell plating thickness, core structure and internal filling, as shown in Fig.2.

For the applied combination of cross-section properties, two core geometries were selected : plate stiffeners (webs) perpendicularly placed against shell plating (I-core) and corrugated webs (V-core), Fig.2. For I-core panels the uniform spacing of 80 mm between stiffeners and their thickness of 4 mm was applied, for V-core – the 2 mm constant thickness of stiffeners was chosen. The axial compression tests were performed on a versatile static/fatigue testing machine of the compressive load capacity up to 4000 kN. A set of joints was used to properly exert and distribute the in-plane load into tested model. Such joints make it possible to apply evenly distributed pure axial forces to both edges of the model. This idea is illustrated in Fig.2. Prior to loading, initial deformations of each of the models were precisely measured.

During the test each of the models was subjected to a compression load step-by-step increasing till the moment of complete loss of load-carrying capacity of the model. At each level of the applied load, strain and displacement measurements by means of appropriate gauges were carried out. It was observed that failure mode of tested models is dependent on their cross-sectional geometry, i.e. type of core, shell plating thickness and depth of stiffeners. The failure modes varied from the whole - model "global" bending without any loss of stability of compressed shell plating - through the "global " buckling, i.e. loss of stability of the whole compressed shell plating – to the "local" buckling, i.e. loss of stability of the whole cross-section of the model in its middle part; the last model presented failure modes dependent on geometrical properties. Fig.3 illustrates the above mentioned failure modes.

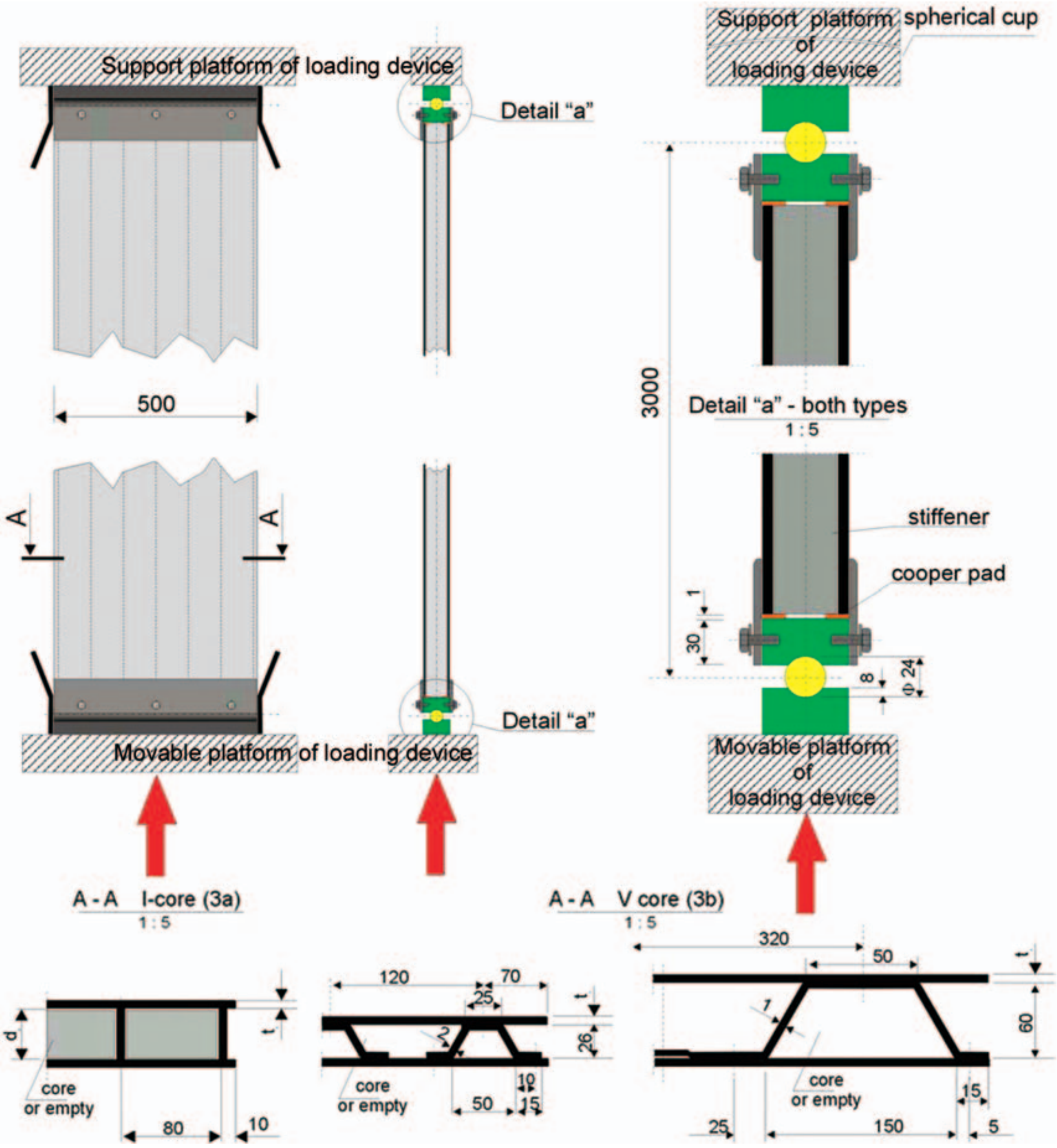

***Fig. 2.** In-plane load geometry and loading scheme of the tested models .*

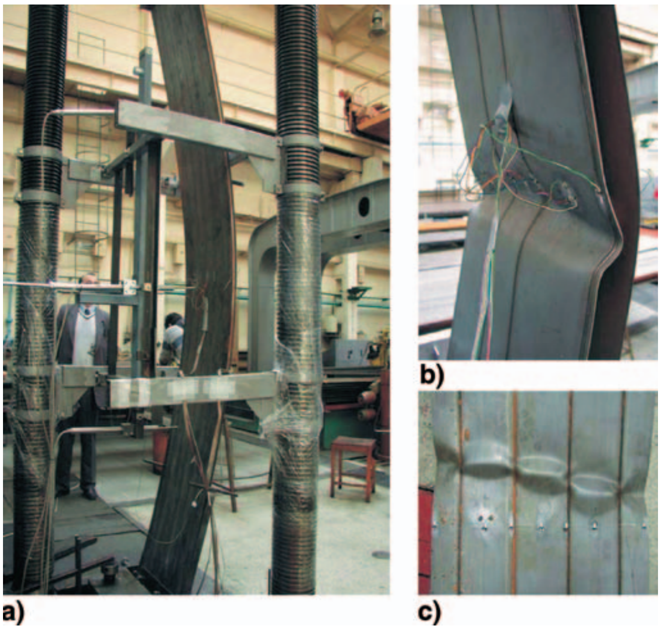

***Fig. 3.** "Global" bending failure mode: **a)** pure bending, **b)** global buckling, **c)** local buckling .*

After systematisation, the tests results showed that two general failure modes can be distinguished. Fig.4 presents the relationship of nominal compressive stresses and longitudinal displacement. Models of certain geometries showed the typical "buckling" curve with almost linear load-displacement characteristics up to critical load level and a subsequent sudden

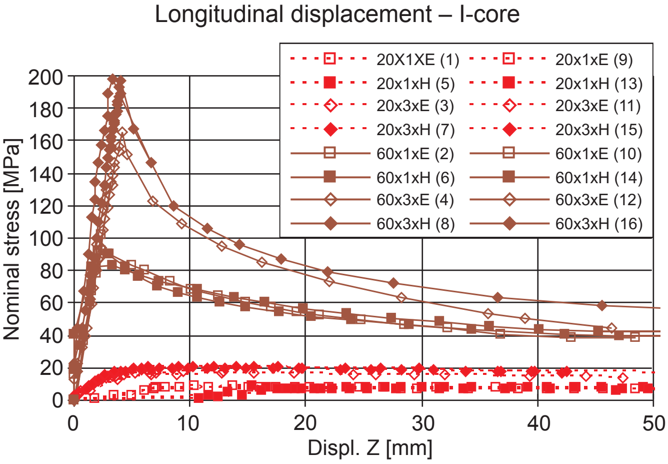

***Fig. 4.** Results of static compression test of the model of I-core geometry .*

collapse; such behaviour is characteristic for the models with high - depth stiffeners, and – to a smaller extent – depending on shell thickness. Models of some other geometries presented the "global bending", i.e. the behaviour characterized by a smooth load - displacement relationship.

The following notation was used
to describe each of the models :

for example – 20x1xE stands for : "20" – stiffener depth of 20 mm, "1" – shell plating thickness of 1mm, "E" – no filling material , i.e. " Empty" model, and alternatively "H" – high density core (balsa wood).

It was observed that the failure modes of the tested models were strongly influenced also by initial deformations which usually occur in every welded structure as a result of the manufacturing and transport processes.

NUMERICAL MODELLING

On the basis of the previous studies on behaviour of laser-welded T-joint [1] it was assumed that the numerical modelling of sandwich structure should be done very carefully to reflect its particular properties. To this end, SOLID186 finite element from ANSYS library, was applied. It is 20-node solid element of quadrilateral shape function and three degrees of freedom in each nodal point (UX, UY, UZ). To the presented calculation the variant of 14 integration points was applied. Fig . 5 presents the whole model and a detail of precise mesh in the laser weld region. Due to symmetry of the analysed body, only 1/4 of the real structure was modelled. In order to reflect particularities of the joint the real width of laser weld as well as a gap between stiffener and shell plate was modelled.

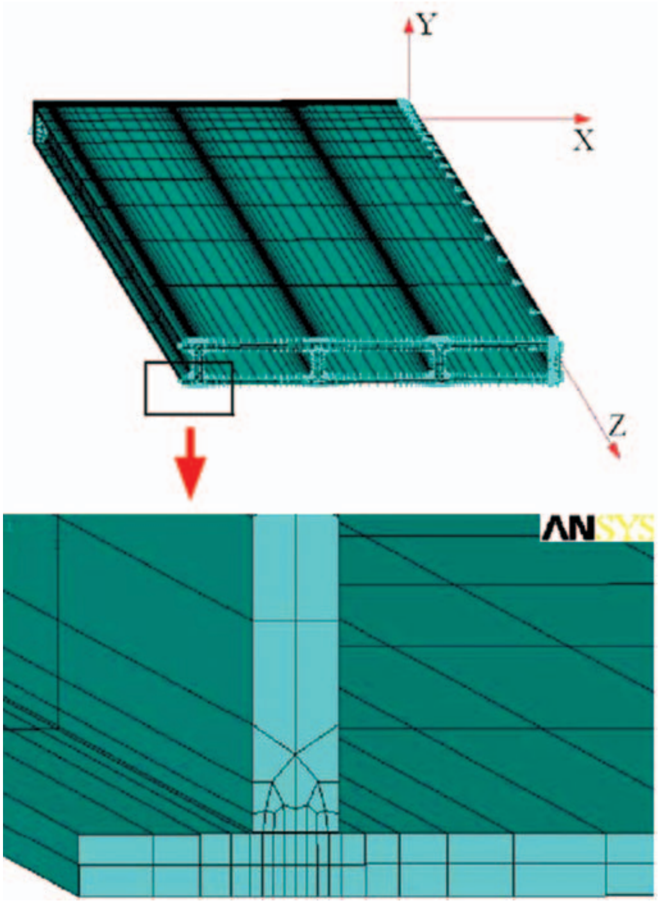

Fig. 5. Numerical computation model and detail of its mesh .

Stress distribution image resulting from the example calculations (Fig.6) confirms the fact of collaboration of shell plating and stiffeners in the compressed region of the failed structure. Such phenomena underline the importance of proper modelling in this region.

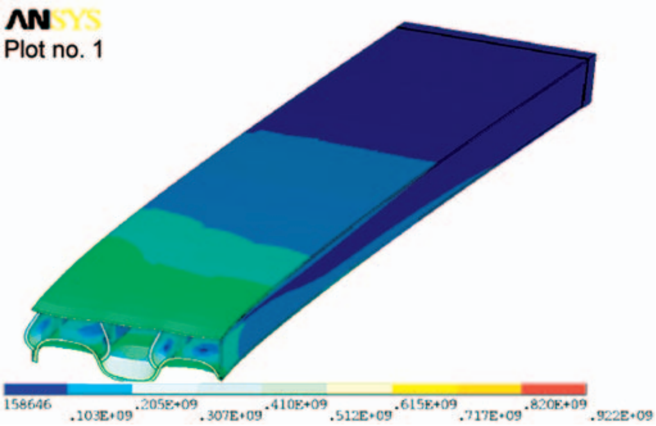

Fig. 6. Stress distribution in shell plating and stiffeners .

The comparison between results of numerical calculations and laboratory tests (Fig.7) shows that the maximum calculated load carried by the analysed structure is lower than that recorded during the real full-scale model test. This difference is probably caused by the fact that the numerical model reflects only the bending of the laser weld. Contact phenomena which occur in the real structure was not modelled at all.

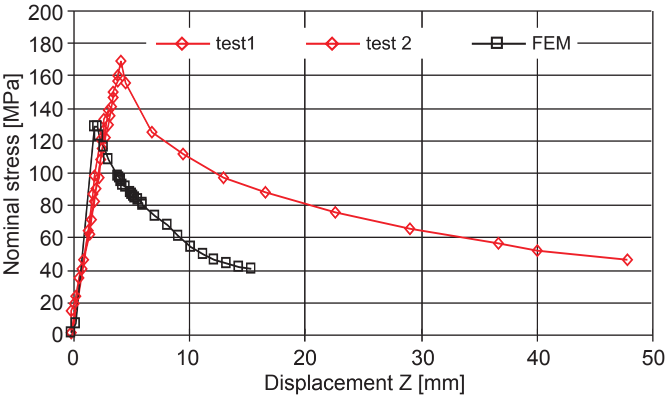

Fig. 7. Comparison of the results obtained from numerical calculations and laboratory tests .

CONCLUSIONS

A series of full-scale steel sandwich models was tested under in-plane compression load. The models having the same dimensions varied by geometric properties of the their cross-section as well as core material density. During the tests the load - response relationships of the models were investigated and recorded.

The combined effect of stiffener depth and filling material was also observed. For different geometrical properties the effect of the filling material is complex and stronger for lower values of shell plating thickness.

However it was observed that the stiffener depth and shell plating thickness influence the stiffness of the structure considerably stronger than the presence of filling material and its density.

The tests indicated that failure mechanism (mode) depends on geometrical properties of model's cross-section – especially on the ratio of stiffener depth and shell plating thickness. The observed failure mechanisms (modes) were as follows :

- global bending of the whole model
- global loss of stability of the whole compressed shell plate
- local damage of model's cross-section due to a combined loss of stability of compressed shell plate and adjacent parts of stiffeners.

From the qualitative comparison of I-core and V-core geometry of stiffeners it results that I-core stiffener system has more favourable properties regarding in-plane-load response characteristics.

Manufacturing deformations considerably affected the load-displacement characteristics of compressed model. This is one of the most important parameters affecting the buckling characteristics of steel sandwich panel; hence establishing appropriate accuracy tolerances for manufacturing the panels and maintaining the final product within the assumed accuracy limits is crucial for reaching the proper buckling strength of panel.

The numerical modelling of the laser-welded steel sandwich structures should be very carefully performed and its results should be dealt with a caution because of particular properties of laser-welded joints as well as a sensitivity of real structure to presence of manufacturing deformations.

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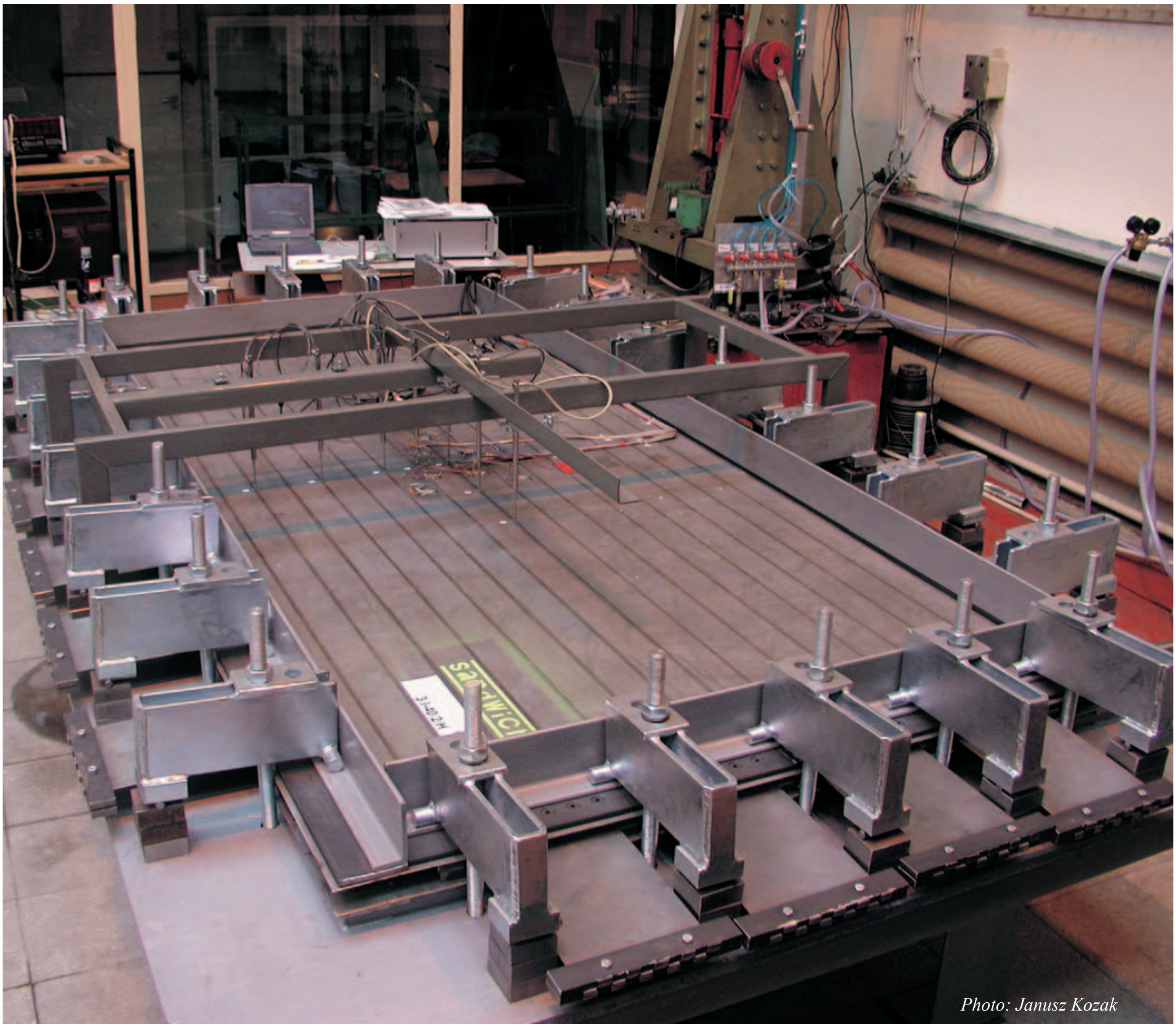
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Sandwich panel during test under water pressure loads .