Application of steel sandwich panels to hull structure of two-segment inland navigation passenger ship

Adam Szarnik, M.Sc., Eng.
Aneta Kuryłko, M.Sc., Eng.
DESART Company Ltd.

ABSTRACT

This paper presents a concept of hull structure of novel environment-friendly inland navigation and coastal ships for Polish east-west waterways. In compliance with its assumptions the inland navigation passenger ship is designed in the form of two mutually connected segments : a propulsion segment which contains gastronomy and entertainment infrastructure and crew accommodations and an articulated hotel segment. In this paper attention is focused on solutions of the hotel segment of an innovative structure mainly consisted of steel polyurethane-filled sandwich panels. Similar structural solution is intended for the propulsion segment.

Keywords : inland navigation passenger ship, sandwich panels, sandwich structures.

DESIGN ASSUMPTIONS AND PRELIMINARY DESIGN WORK

The maximum draught of the designed ship was assumed not greater than 1 m because of local limitations of the transit depth of the waterway – to the value of 1.2 m – on the planned route from Berlin via Kostrzyń, Nakło, Bydgoszcz, Toruń, Elbląg to Królewiec, moreover the ship has to be capable of instantaneous increasing its draught over 1 m in order to be able to pass under some bridges in view of a limited water clearance under them. In particular the first condition made it necessary to design the structure of significantly smaller weight than that of classical one, and simultaneously guaranteeing strength features and stiffness conditions comparable with those of the classical structure of the kind. It was decided that it will be feasible if steel laser-welded sandwich panel plating is applied to the hull structure; such panels consist of two external plates and the system of parallel webs and foam filling placed between the plates. Such plate structure made it possible to lower structural weight even by 30%, at maintained high stiffness and increased resistance to local punching. In Fig.1 a fragment of sandwich plate structure is shown. Such structures were planned to be used to the structural elements characterized by distinct flatness and lack of a great number of openings. In the case of the designed ship it concerns bottom and deck structures within the middle body of ship hull, usually very long in inland waterways ships. The bow and stern part structures were assumed to be designed in the traditional form**.** Similarly, the ship side structures, due to many window openings (Fig. 2), had to remain in a traditional form because of a low gain of weight possible to be obtained by using sandwich panels.

The design work was started from elaboration of an effective way of structural modelling for the calculation by means of Finite Element Method (FEM), of structures built of sandwich panels.

Before performing FEM calculations of large fragments of the structure it was necessary to determine such way of modelling as to assure reasonable time of calculations and use of disk space.

Application of solid elements to modelling of a single panel seemed to be natural and providing satisfactory results close to experimental ones. However in many cases such approach

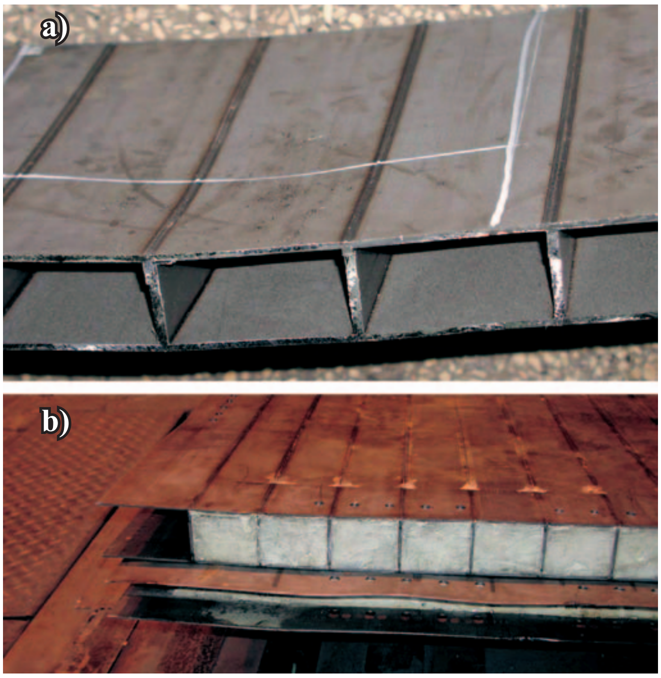

Fig. 1. *An example of sandwich panel plate structure of the following scantlings : – outer plate thickness : 6 mm; – inner plate thickness : 4 mm; – web depth (distance between the plates) : 40 mm; – web thickness : 6 mm;*
a) *sandwich structure free of filling*
b) *sandwich structure with polyurethane filling .*

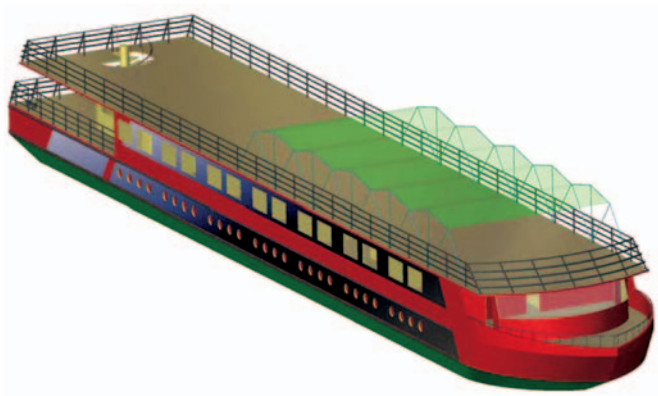

Fig. 2. *Image of the hotel segment hull .*

would make it impossible to conduct calculations of more complex structures than a single panel, because of required vast calculation time and computer memory and disc space. An alternative appeared to be the application of shell layer elements combined with beam ones, that made it possible to effectively simplify the structural model and shorten time of calculations.

To build an equivalent shell model of sandwich panel was aimed at, having the features equivalent to those of a solid model, to a degree which could make it possible to build 3D model and conduct FEM calculations of a large fragment of the segment's hull structure, rationally. It was necessary to so select characteristics of the used elements as to obtain sufficiently accurate approximation of displacement and stress distributions yielded by the solid model (reference) and shell-beam one (equivalent) under a given load.

All calibrating calculations were performed by using ANSYS software. Illustrative comparison of the displacement distributions achieved from one of the tasks aimed at calibrating element characteristics, is presented in Fig.3 and 4.

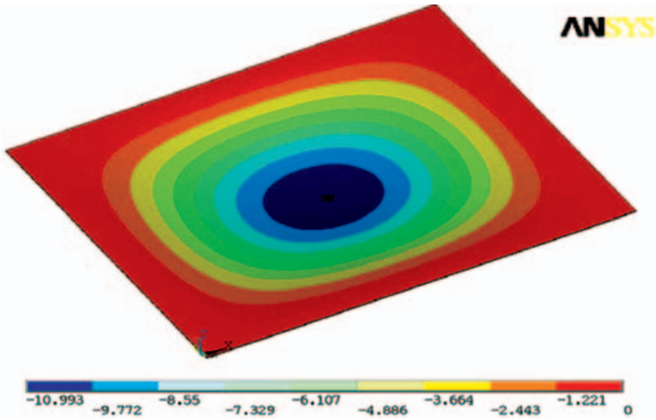

Fig. 3. The vertical displacements UZ – obtained from the solid model (reference) .

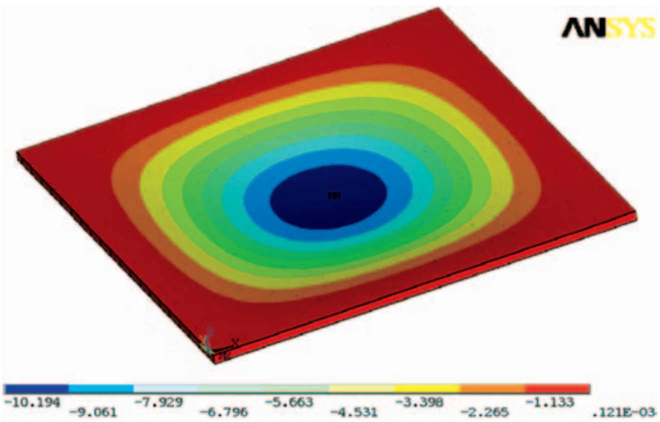

Fig. 4. The vertical displacements UZ – obtained from the shell-beam model (equivalent) .

Next, was prepared and then realized a concept of preliminary strength calculations of the hotel segment's structure and the propulsion segment's (pusher) structure consisted to a large extent of steel sandwich panels with polyurethane filling.

Certain number of variants of the structural arrangement were considered. On the basis of the previously gained experience, the decision was taken as to the selection of the final form of hull structure of the two-segment passenger ship. The selected hull structure form of the considered barge and pusher served as a basis for subsequent design work on ship power plant, ship systems and equipment, as well as for further improvements of the structure itself. In the elaborated solution was utilized the initial concept of the structural arrangement consisting in using sandwich polyurethane-filled panels for prevailing part of the hull structure though in the earlier concepts their application to bulkheads and some parts of side plating was not taken into account for manufacturing and functional reasons. Bottom, deck and side structures of the hotel segment's hull were divided into three zones : stern, midship and bow one. Below, the particular zones of the hull structure are described in order to provide an overall idea of its arrangement.

Bottom structure

The bottom midship zone has to be built of sandwich polyurethane-filled panels having webs parallel to the ship's longitudinal axis. The panels are mutually connected with the use of rectangular pipe profiles intended also for strengthening the bottom structure. The profiles are located both in longitudinal and transverse directions respective to ship axis. The stern and bow zones of the bottom have to be built as classical single-shell structures.

Deck structure

The midship zone of deck structure has to be constructed of sandwich polyurethane-filled panels longitudinally stiffened and mutually connected with the use of rectangular pipe profiles directed longitudinally and transversely. The stern and bow zones of the deck structure have to be built in the form of classical single-shell structures. The deck plating is transversely stiffened. The stiffeners are supported by a deck girder or longitudinal bulkhead. In the extreme part of ship's bow the deck is longitudinally stiffened by plate girders.

Structure of ship sides and transom

In the midship zone up to the height of 1000 mm over the base plane (PP), the ship side structure has to be built of sandwich polyurethane-filled panels having longitudinal webs. The panels are mutually connected by means of the rectangular pipe profiles in the same way as in the case of the bottom and deck structures. The side and bottom panels are connected to each other with the use of a flat bar to which they are welded with tee-fillet joint. The side panels are closed from the top by bulb profiles.

Above the height of 1000 mm over the base plane, as well as in the stern and bow zones, the sides have to be built in the form of classical single-shell structures vertically stiffened. In the same way the transom structure has to be made.

Structure of longitudinal and transverse bulkheads

Both the longitudinal and transverse bulkheads are designed as vertically stiffened single – shell structures. Ends of their stiffeners (webs) have to be welded to rectangular pipe profiles in the case when a given bulkhead is placed in the region where sandwich panels are used, or the web ends have to be fixed by brackets when a given bulkhead is connected with a single-shell structure. The typical midship section of the barge hull is shown in Fig.5.

Cross-section 25050 mm distant from AP

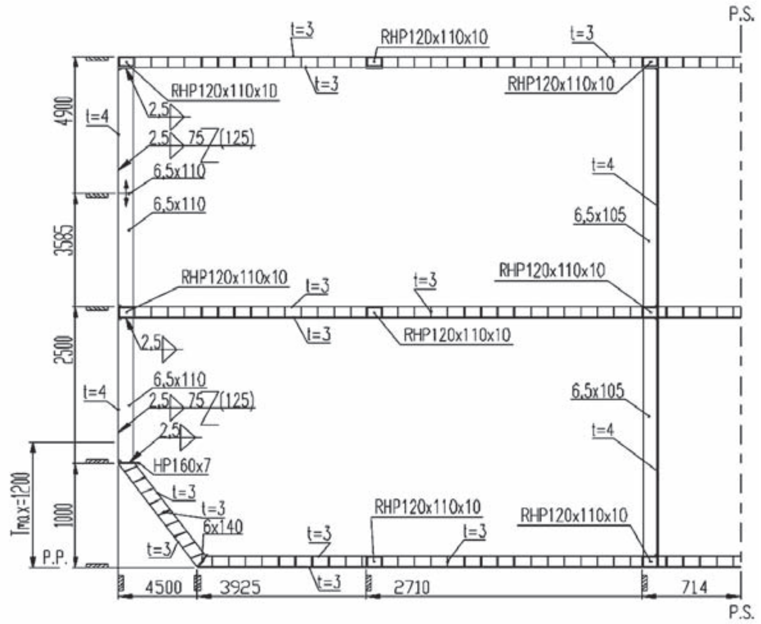

Fig. 5. The typical midship section of the barge hull,
where : t – side plating thickness, RHP – rectangular pipe profile .

Structural calculations

In order to determine stresses occurring in sandwich panels preliminary structural strength calculations were performed by using the Finite Element Method (FEM).

The analysis was conducted on two levels :

- zone level (the structural models cover the length of a whole living cabin and two halves of neighbouring cabins)
- local level with the aim of determining stresses which occur in the panel joints (detail models of selected joints).

The 3D models, calculations and visual presentation of their results were elaborated with the use of the ANSYS software. In Fig. 6 and 7 geometrical features of the models are presented. As regards local strength of the classical hull structures (plating and stiffeners) the authors based on the requirements of the *Rules for the classification and construction of inland waterways ships,* Part II (Hull) of Polish Register of Ships (PRS), published in 2004.

The estimated stresses resulting from FEM analysis of the zone and local structural models, reach their maximum values which do not exceed permissible levels. Also, the total normal stresses due to overall bending, determined on the basis of the PRS rules, as well as the stresses in X- direction, determined from FEM calculation, do not exceed permissible ones.

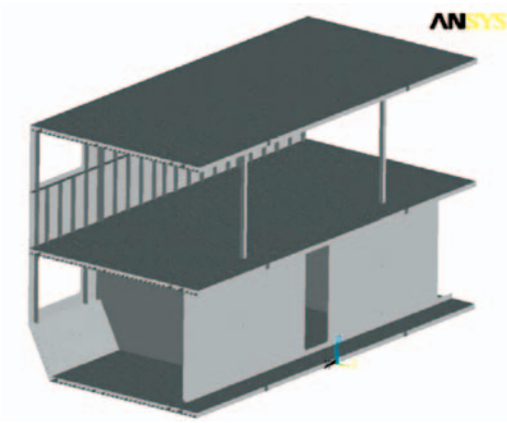

Fig. 6. Zone model geometry .

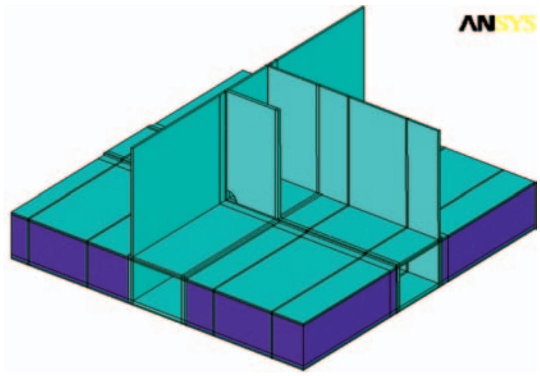

Fig. 7. Geometry of a selected structural joint .

RECAPITULATION

- Basing on the so far performed work one can state that the concept of building articulated inland waterways ship whose main part consists of sandwich polyurethane-filled panels, is feasible and fulfils the assumptions for preliminary design stage, both as regards ship mass and maximum gabarites of hull structural elements, assuring sufficient easiness and comfort of moving and staying on board the ship for passengers and crew members.
- This work bore fruits consisting in gaining experience in the area of designing relatively „risky" and innovative structural solutions, as well as of modelling and computing the structures consisted of sandwich panels.
- However one should be aware of that this is still the preliminary stage of the design, which contains several simplifications and not yet solved problems such as e.g. strength assessment criteria for sandwich panel structures, based on FEM calculations.
- During the next stages of ship design a more detailed strength analysis of sandwich panels and their joints will be necessary.

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