

Estimation of Ship Lightweight Reduction by Means of Application of Sandwich Plate System

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Sandwich plate system is an alternative to conventional stiffened plate composition that consists of two metal plates separated by an elastomer core. Considering high strength to weight ratio, simplicity, blast and ballistic properties of the material, SPS has been widely used in a range of industries but its most dominant application has become ship repair. Regarding newbuildings some very brave estimations of possible weight savings can be found, but still no complete hull made of SPS has been actually produced. The idea of this paper is to analyze possibilities of SPS for such application. A typical river barge is used as the basic hull shape. Combining different framing concepts and cargo types 21 different model of conventional hull structure is defined and their weights calculated. Subsequently the same is done presuming that barge hull is built of SPS, and using related Lloyd's Provisional Rules. All results are systematically compared and analyzed.

Keywords: sandwich plate system, lightweight, lightship, hullweight.

1. INTRODUCTION

Sandwich plate system is a lightweight material that consists of two metal plates separated by an elastomer core. Plates, usually made of steel, are joined via perimeter bars on the edges of the plate. Polyurethane elastomer core transfers shear between plates and dissipates strain energy over a large area, reducing load concentrations and possibility for permanent deformations to occur.

Sandwich plate system (SPS) offers alternative to conventional stiffened plate composition. It eliminates the need for secondary stiffeners [1,2], making the structure less complex and its appliance less time consuming. Considering high strength to weight ratio, simplicity, blast and ballistic properties of the material, SPS has been widely used in building bridges, stadiums, floors, blast walls, ship repairs. Sandwich plate system repairing has been proved on thousands of square meters of ship decks, bulkheads and tanktops, converting them from conventional steel to sandwich plates. By avoiding stiffeners, SPS repair makes the process much simpler than traditional "crop and replace" practice.

In order to improve competitiveness with other modes of transport, inland vessel's cargo carrying capacity has to be increased. Regarding river limitations (shallow water) and the fact that more cargo leads to increased weight and draught of the vessel, new lighter structures are explored. In that context the concept of complete hull structure made of SPS appears as a big challenge.

According to various sources, lightweight

possibilities of SPS over the conventional stiffened plate structure may vary from 10 to 70 %. However, no thorough study over complete ship hull sandwich structure is available. The main reason for that might be the lack of tools for establishing the full equivalence in strength requirements between conventional and SPS concept, when applied in model as complex as entire ship hull. Fortunately, in 2006, Lloyd Register has presented the *Rules for the Application of Sandwich Plate Construction to Ship Structure* [3]. The Rules introduce a set of explicit calculating procedures for newbuilding hull structure scantlings and thus allow more mature weight comparison between conventional and "sandwich made" ship.

In this paper, the advantages of SPS are examined in the example of typical Danube barge. Lightship weight for several conveniently built ship type/framing system combinations are compared with complete hull sandwich structure alternative. For both options scantlings are determined according to related Lloyd's Rules [3,4].

2. SHORT HISTORY OF SPS

Sandwich material is known concept of composite material ever since the Second World War, where it has been used in the form of plywood for British combat aircrafts [5]. Modern sandwich plate system (SPS) evolved through 10 years of development since it was presented as a new material for the application in offshore structures subjected to heavy seas and ice in Canadian Beaufort Sea [1,2]. It is used in military, offshore, maritime, civil engineering etc. SPS was patented by the company named Intelligent Engineering (IE), recognized as a dominant producer of sandwich constructions, particularly in ship repair. The first recorded employment of SPS in shipbuilding was the repair of RORO Ferry *Pride of Cherbourg*, approved by Lloyd Register in 1999 [1].

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3. STATE OF THE ART IN SPS APPLICATION

Sandwich plate is made by injecting elastomer into the cavity formed by two metal plates and perimeter bars on four sides of the plate. Two metal faceplates bonded to an elastomer core of the SPS are tailored to give the desired strength and stiffness [3]. Core material is a class of polyurethanes with a high tolerance to mechanical stress. Besides transferring sheer, core's primary role is to bond, provide stability to the faceplates and to preclude local buckling. High strength and buckling properties allow SPS to eliminate the need for secondary stiffeners and make the construction simpler compared to conventional (Fig. 1). The scantlings of the SPS are generally in the range of 3 to 8 mm for the face plate and 15 to 50 mm for the core thickness.

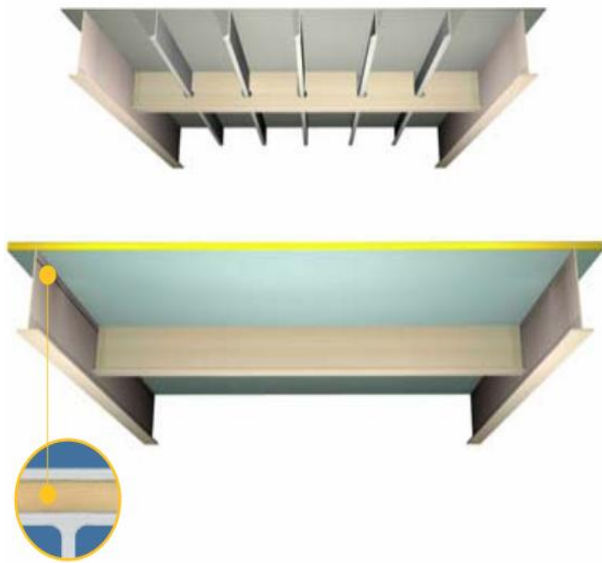


Figure 1. Conventional vs. SPS structure [1]

Although used in a range of industries (civil, military, offshore engineering) [2] SPS' most dominant application has become ship repair. It is used as an alternative to the traditional "crop and replace" repairing, and shows a great promise in future expansion. Up to date, over 80.000 m² of sandwich plates have been installed on ships (repairing) and civil engineering.

Regarding newbuildings, reported are several projects but still no complete new ship – incorporating decks, bulkheads, tanktops, sides and bottoms made of SPS, has been actually produced. For instance, the project of SPS chemical tanker – barge for use on the Rhine River, is finished and approved by Germanischer Lloyd [1,2]. Deck, hull and bulkheads are to be made of sandwich material. Barge's hull is expected to be significantly lighter – but still no precise data on that issue is available.

In a number of articles brave predictions of possible reduction of the ship lightweight by means of application of SPS are stated. They vary from 5 % to over than 50 % [6,7]! However, these percentages are likely to be based on very rough estimations rather than on real study and calculation (like the ones performed for SPS structures in civil engineering).

4. BASIC IDEA OF THIS PAPER

From all said above it is obvious that there are still big questions about the amount of ship lightweight reduction that SPS concept can really deliver. The basic idea of this paper is to explicitly quantify that point by means of direct calculation. In addition, the difference in weight within conventionally built steel hulls but with different framing systems is to be scrutinized.

A typical Danube river barge is used as the basic hull shape in the research. Combining 7 different framing concepts and 3 cargo types (general, bulk and container) 21 model is defined. For each model, hull structure scantlings are defined according to the LR's Rules for conventional ship structures, and their lightweight is accurately calculated. Subsequently, the same is done presuming that barge hull is built of SPS, and using related Lloyd's Provisional Rules. Finally, precise lightweight calculation is conducted for one existing barge of the kind, taking into account for some additional requests for scantlings increase. All results are systematically compared and analyzed.

Being a novelty, Lloyd Register's provisional *Rules for the Application of Sandwich Plate Construction to Ship Structure* are briefly explained in the next section. All analyzed models are described in details in Section 6. Summary of the results is presented and commented in Section 7.

5. LR'S PROVISIONAL RULES FOR SPS

Lloyd's Register, world leading classification society in shipbuilding, in association with Intelligent Engineering Ltd (company that patented SPS), has developed *Provisional Rules for the Application of Sandwich Plate Construction to Ship Structure* [3]. The Rules were published in 2006. They represent a key tool for calculating hull scantlings in order to be approved by Lloyd. The *Rules* cover SPS application in new buildings as well as in ship repair.

The philosophy of the *Rules* is to ensure that designs utilising steel sandwich construction are equivalent in strength and safety to conventional steel construction. The thicknesses of the top (t_1) and bottom (t_2) plate and core (t_c) of the SPS are determined on the basis of scantlings (plate thickness t_{rule} and stiffener section moduli Z_{rule}) calculated according to the LR Rules for steel ship of conventional structure [4]. Thus, the obtained scantlings of the SPS are checked for strength index criteria by formula given in the Rules. If the strength is not satisfied, the chosen thicknesses are to be increased. The process is iterative (Fig. 2).

6. MODELS AND CALCULATIONS

Typical river barge of conveniently simple hull structure is chosen to be the raw model for lightweight reduction analysis. Her principal dimensions are $L = 77$ m, $B = 11$ m, $T = 2.5$ m, $H = 2.8$ m; designed cargo capacity is 1700 t. Keeping those features invariant a series of particular models is defined by means of combining three ship types (general cargo, bulk and container carrier) and seven *framing concepts*. The term framing

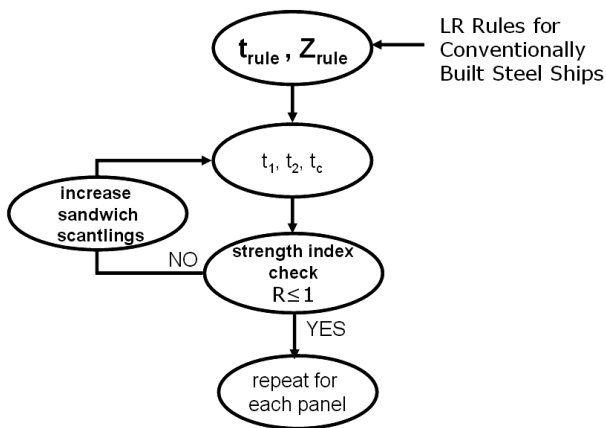


Figure 2. Algorithm for SPS scantlings determination according to LR's provisional Rules

concept is used to denote particular combination of longitudinal and transverse framing systems in double bottom, double sides and deck. To distinguish them in following figures and tables each is assigned with three letters: first one relating to double bottom, second to double sides, third to deck structure, *L* standing for longitudinal and *T* for transverse framing. Although not all of those concepts (21 in total) are realistic they are included in analyses for better identification of weight tendency. Special consideration is given to two most lifelike cases:

- completely longitudinally framed barge, which is expected to be of minimum weight (Fig. 3) and
- combination of transversally framed double bottom with longitudinally framed double sides and deck, favored for its robustness and durability, especially for barges intended to carry pebble and sandstone in bulk (Fig. 4).

It is worth noticing that conveniently built general cargo and bulk carrier barges have the same structural arrangement (although not the scantlings), so the Figures 3 and 4 refer to both types. On the other hand, container barge has additional elements that help supporting the containers, so structurally the model is slightly different (Fig. 5).

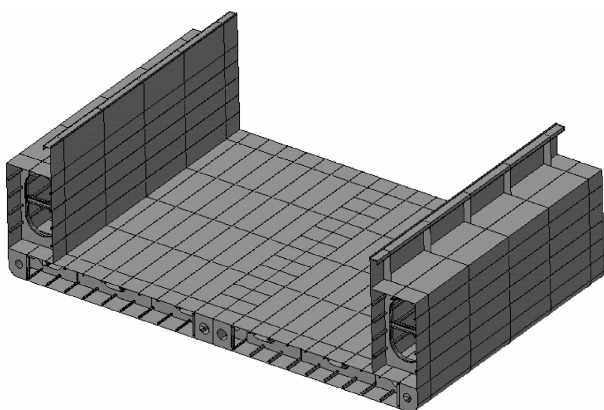


Figure 3. Mid structure of conveniently built completely longitudinally framed (L + L + L) barge

For entire series of models, scantlings of all structural members are calculated according to relevant LR Rules and resulting ship lightweights obtained.

Employing LR Provisional Rules the scantlings of all structural members of exactly the same hull – but as built of SPS are calculated. Barge hull consists of

middle structure (67 m) and bow and stern structure (10 m). All calculations are made for the middle structure of the vessel assuming that in all cases bow and stern structures (53 t) remain conventionally built, and have the same scantlings as on the existing barge. Presented results refer to complete hull of the barge. All three cargo types are taken into account (Figs. 6 and 7). Obtained scantlings of SPS are generally in the range of 3 to 5 mm for the top and bottom plate while core thickness is 15 mm in all analyzed cases. Again, resulting ship lightweights for all models are calculated.

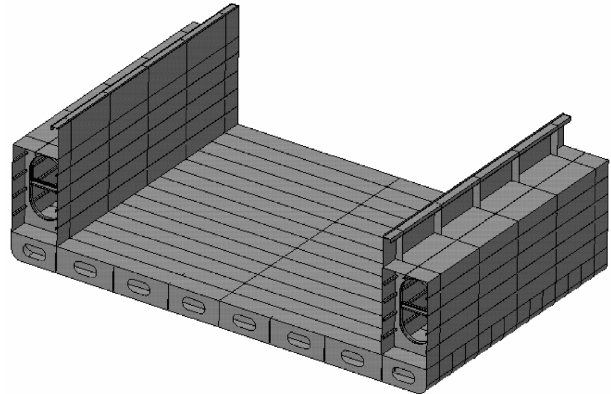


Figure 4. Mid structure of typical conventionally built mix framed (T + L + L) barge

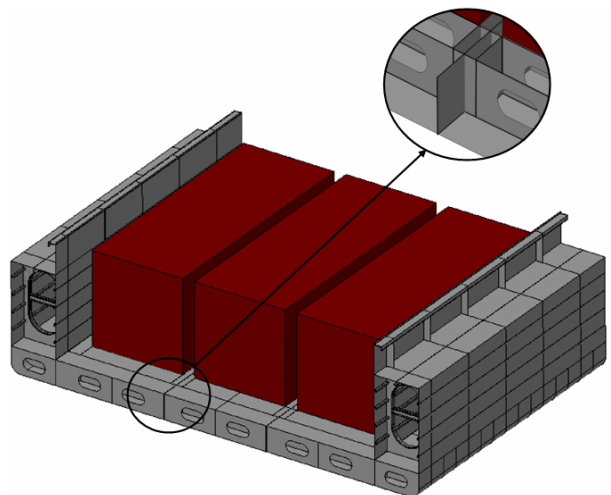


Figure 5. Mid structure of conventionally built mix framed (T + L + L) barge intended to carry containers

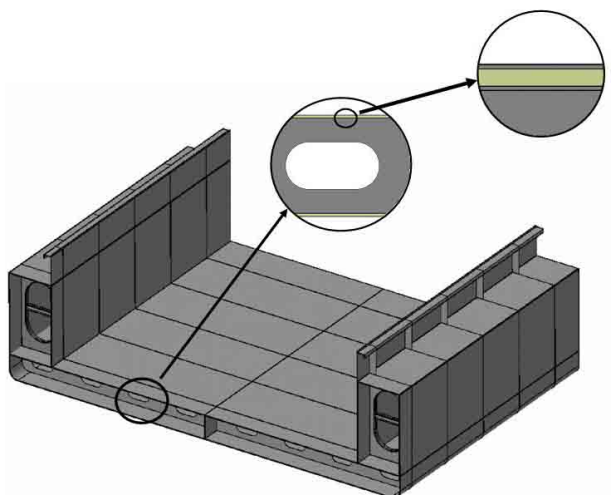


Figure 6. Mid structure of general/bulk cargo SPS barge

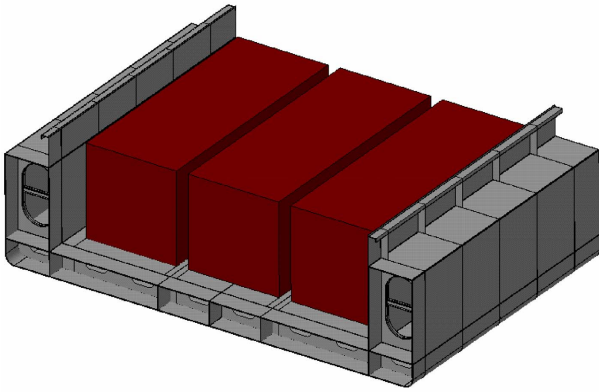


Figure 7. Mid structure of SPS container barge

Finally, precise lightweight calculation is conducted for one existing general/bulk cargo barge, conventionally built with mix ($T + L + L$) framing arrangement (Fig. 4). Although of the same shape and dimensions as other examined models, it is of somewhat increased scantlings compared to minimum Rule values – to fulfill longitudinal strength requirements and (on owners request) for prolonged life.

7. SUMMARY OF THE RESULTS

The most significant results of the research are condensely presented and commented in proceeding. Displayed and compared are the weights calculated for the total number of 25 models described in previous section, namely:

- 21 model of conventionally built barges,
- SPS barges designed as general cargo, bulk and container carrier and

- one existing, conventionally built barge, with customly increased scantlings.

In Figure 8 calculated ship lightweightes for all models are plotted. In Figure 9 the differences in weight between SPS and all conventional structures are explicitly presented, both in tons and percentages.

Going over the diagrams leads to conclusions as follows.

Weights of conventionally built barges vary between 260 and 290 t, depending on the framing system. As might be expected, completely longitudinally framed barge is of the lowest weight and completely transversally framed barge is the heaviest. The main contribution to that is due to double bottom – significantly heavier when transversally framed. The influence of the framing system on weight is most pronounced in the case of general cargo barge.

Rules require 2 to 3 mm thicker inner bottom plates for bulk carrier than as for general cargo barges leading to, on average, 20 t heavier hull.

Due to additional girders required in double bottom in line of container sides, the container barge is slightly heavier than the bulk carrier in all framing systems.

The SPS general cargo barge offers weight savings between 5 to 15 % in comparison to conventionally built one. Weight savings of the SPS bulk carrier and SPS container barge are even less: 6 to 13 % and 4 to 12 % respectively. That is due to the fact that their structure includes more primary elements (girders, floors) that are not allowed to be built of sandwich plates.

Direct comparison of the existing conventionally built barge with other models is not completely sound. It is included in diagrams merely to illustrate lifelike weight margin. As explained earlier, it is significantly

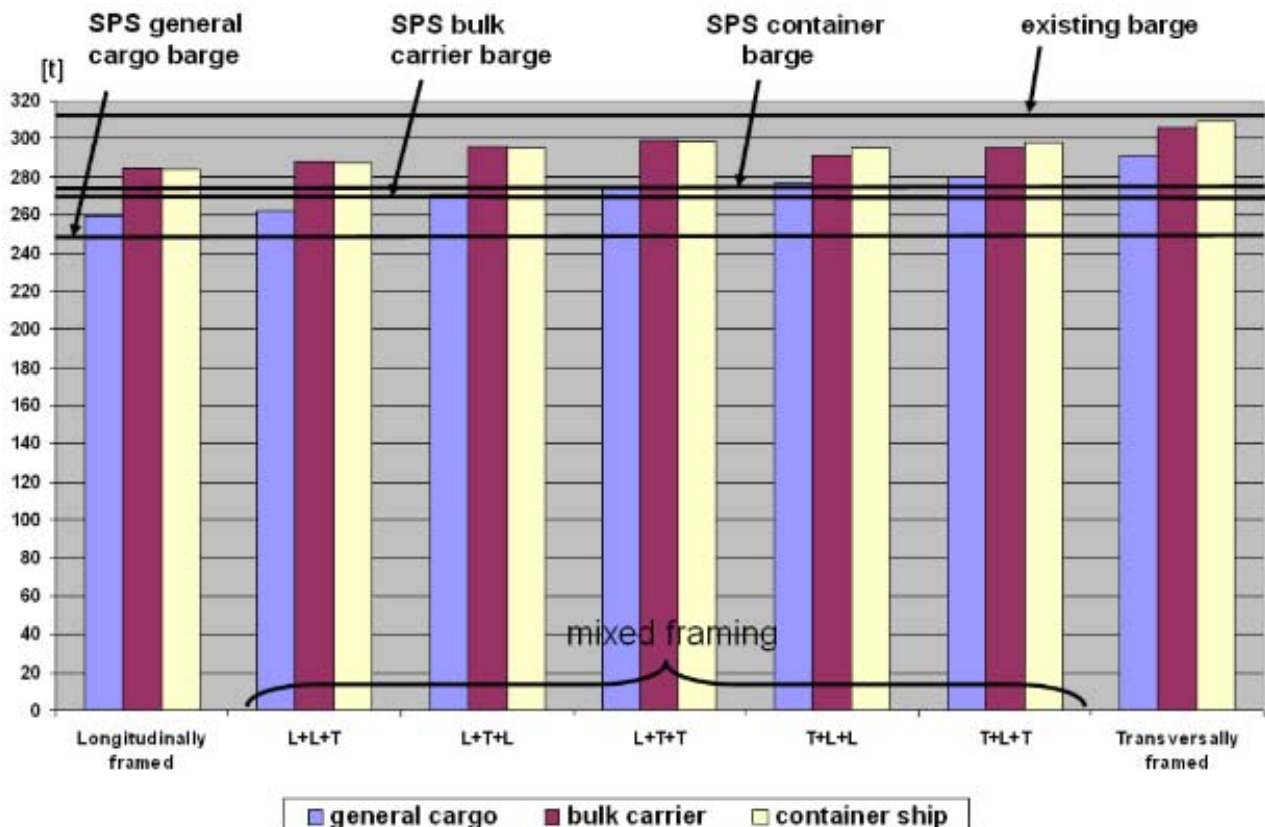


Figure 8. Calculated ship lightweightes

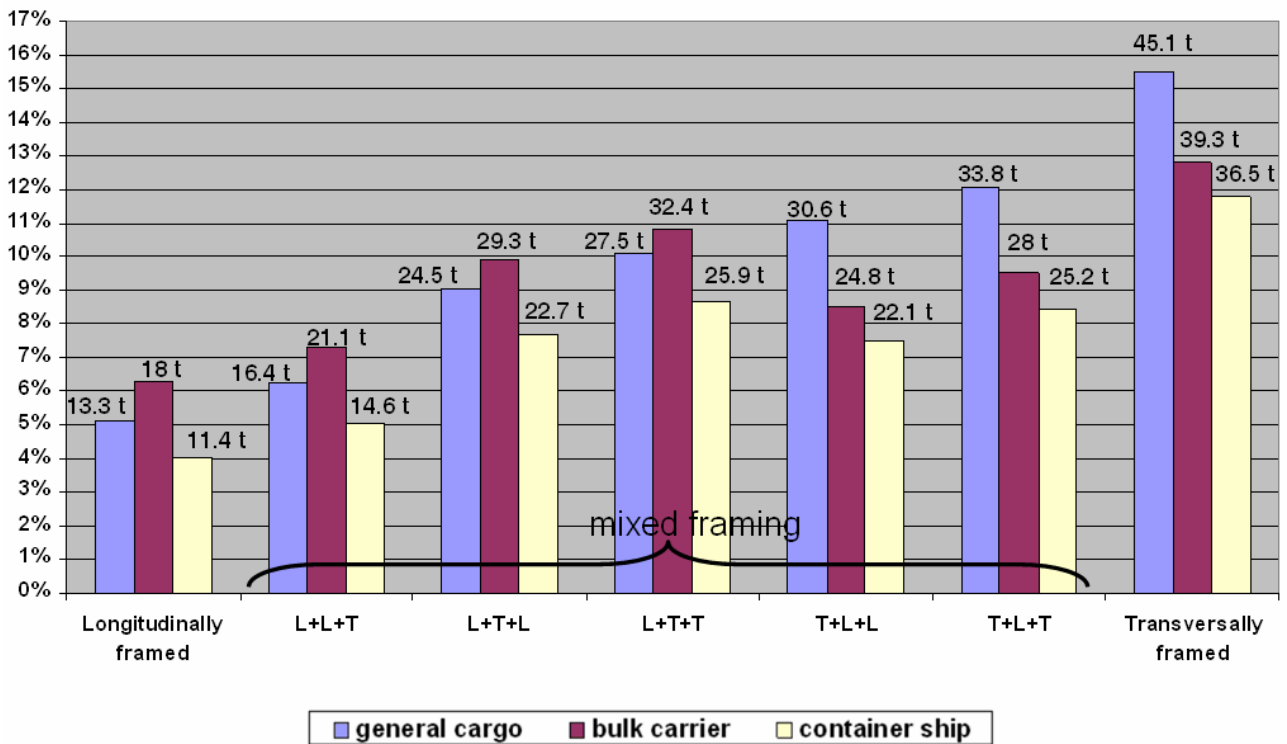


Figure 9. SPS barges weight savings in comparison to conventionally built barges of all types and framing systems

heavier due to longitudinal strength and prolonged life requirements – the aspects which were not accounted for in herein dimensioned models. However, that does not discredit conclusions deduced from comparison of those models among themselves since required increase of scantlings on stated accounts would be very much alike for all of them.

8. CONCLUSION

The main objective of this paper was to give reliable evaluation of weight reduction that can be gained by application of SPS in building the complete ship hull structure. According to this research, in no case it can be greater than 15 %, mostly varying between 5 and 8 %. This conclusion is deduced from analyses conducted on a series of simple river barge structures and may be slightly, but not considerably, different for other hull shapes. Thus, some brave estimations about the weight savings even greater than 50 %, that can be sporadically found, have to be considered as incorrect projections of SPS possibilities from some other types of constructions. It should be noted, however, that this poor mark in no way relates to SPS application in ship repair.

For the sake of comparison with SPS structures a whole series of conveniently built barges were modeled and their hull weights calculated. That allowed meticulous inspection of the framing system and cargo type influence on ship lightweight. Although nothing unexpected or unusual is found out, systematically presented results on those items are illustrative.

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NOMENCLATURE

t_1	top plate thickness of the sandwich material [mm]
t_2	bottom plate thickness of the sandwich material [mm]
t_c	core thickness of the sandwich material [mm]
t_{rule}	plate thickness of the steel structure [mm]
Z_{rule}	stiffener section modulus of the steel structure [cm ³]
R	strength index of sandwich panel
L	length of the ship [m]
B	breadth of the ship [m]
T	draught of the ship [m]
H	height of the ship [m]

АНАЛИЗА УШТЕДА У СОПСТВЕНОЈ ТЕЖИНИ КОНСТРУКЦИЈЕ ТРУПА БРОДА ПРИМЕНОМ СЕНДВИЧ ПАНЕЛ СИСТЕМА ГРАДЊЕ

Никола Момчиловић, Милорад Моток

Сендвич панел систем представља алтернативу конвенционалном ребреном панелу и састоји се од

два метална лима раздвојена испуном од еластомера. Узимајући у обзир висок однос чврстоће и тежине, једноставност конструкције, отпорност на ударе и експлозију, СПС је широко распрострањен у многим индустријама, а највише у ремонту бродова. Мада се често наводе веома оптимистичке прогнозе у вези потенцијалних уштеда у укупној тежини конструкције, чињеница је да још ниједан комплетан труп брода од СПС-а није заиста направљен. Идеја овог рада је да се анализирају могућности СПС-а у овој намени. Као пример трупа брода је узета типична речна баржа. Комбинујући различите концепте градње и типове бродова, укупно 21 модел конвенционалне конструкције брода је дефинисан и њихове тежине су детаљно срачунате. Исто је урађено под претпоставком да је баржа направљена од СПС-а, користећи „Lloyd's Provisional Rules“. Сви резултати су систематски поређени и анализирани.