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RETROFITTING THE SUPERSTRUCTURE OF A LARGE PASSENGER SHIP USING COMPOSITES – A DEMONSTRATION

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ABSTRACT

In this work, the superstructure of a RoPax ferry has been redesigned using composite materials and the new design has been compared to the existing steel superstructure from a structural perspective. To this end, FE models have been developed and the superstructures have been subjected to loading conditions as prescribed from the regulations. Additionally, the effects that the composite superstructure has on the weight of the ship have been calculated. Results indicate that there is a large potential for retrofitting and building new passenger ships with composite superstructures as long as the design procedure and its acceptance by the regulatory bodies are simplified.

1 INTRODUCTION

As sustainability and climate change have come on the political agenda, the shipping industry will have to be operating energy efficient ships that are environmentally friendly. One efficient way to reduce fuel consumption is by weight reduction, which in the shipbuilding industry translates to reducing the lightship mass of the vessel. An appealing way to achieve this is, by designing superstructures made out of composite materials. The benefits of a light superstructure become more prominent in large passenger ships, as the superstructures constitute a significant percentage of the lightship; additionally, depending on the size of the ship, the superstructure may tower several decks above the weather deck, affecting the stability of the ship.

Until recently, the existing regulatory frame did not allow for the use of composites on ships, as combustible materials were not accepted by the SOLAS convention. In 2002, SOLAS was extended by the so-called Rule 17 [1], enabling the use of combustible composite materials as long as the same level of safety could be demonstrated. This regulation, however, has rarely been used in practice, as both the technical safety analysis as the appropriate regulatory approval is very complex and time-consuming, and therefore costly.

The work presented here has been performed under the scope of the COMPASS project. This project aims at providing a standardized approach for the implementation of composite superstructures for designers, ship-owners and authorities alike, through new Rule 17 based guidelines combined with pre-fire proven composite standard structural components.

To this end, the superstructure of a RoPax ferry has been redesigned using composite materials. The effects that the new design has on the mass of the ship as well as the structural response of the superstructure have been compared to the already existing steel design. For the latter, finite element models have been created for the steel and composite cases and subjected to the same loading conditions.

2 STRUCTURAL DESIGN

2.1 Case Study

The ship selected as a case study is a double-ended RoPax ferry called PRINSESSE BENEDIKTE (Fig.1) and is operated by Scandlines. Her main characteristics are listed in Table 1. The superstructure height from the main deck to the upper deck, excluding the wheelhouse, is 15.00 m. It was decided, to focus on the wheelhouse and the passenger decks and thus the part to be retrofitted lies above 17.7 m measuring from the baseline (Fig. 2). The deck positioned at 17.7m was made out of steel for both cases.

		Identification
Gross tonnage	[-]	14822
Length oa	[m]	142
Breadth	[m]	24.8
Depth	[m]	8.5
Draught	[m]	5.8
Service speed	[kn]	18.5
Displacement tonnage	[t]	9600
Lightship	[t]	7000

Table 1: Ship Characteristics.

Figure 1: RoPax ferry PRINSESSE BENEDIKTE

There is a plethora of different design constraints and objectives to be considered when designing/ retrofitting a ship, these typically reflect the interests of the various ship design stake holders such as the ship owners/operators, classification societies and shipyards to name but a few. Depending on the set of design requirements, which are often conflicting, an optimum design is sought [2].

In this work, it was decided to keep the same general arrangement of the superstructure, given that the original requirements and constraints were unknown. Bearing this in mind, it is evident that the resulted design might not be the optimal one with respect to the ships' life cycle.

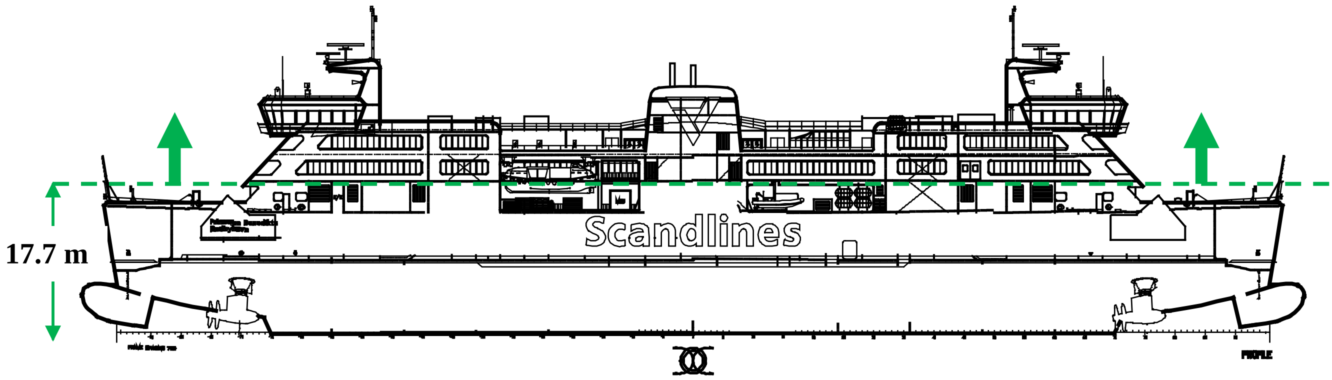

Figure 2: Part of the superstructure for retrofitting

2.2 Materials

The composite superstructure was designed using GBX450L-1250 E-glass Stitched fabric and Prime 20LV epoxy resin, the structural core selected is Divinycell P100 which provides good fire, smoke and toxicity properties and high temperature performance. The original superstructure is made of typical marine grade steel. The material properties are listed in Table 2.

Material	Engineering constant		Identification
Lamina	E_1	[GPa]	21.2
	E_2	[GPa]	21.2
	ν_{12}	–	0.14
	G_{12}	[GPa]	3.05
Core	Ec	[GPa]	0.10
	Gc	[GPa]	0.028
Steel	E	[GPa]	203
	ν	–	0.3

Table 2: Material Properties

2.3 Design loads and scantling requirements

The design loads for the composite superstructure were calculated according to the DNV Rules for Classification of Ships [3] while the scantling calculations were performed according to DNV's Rules for Classification of High Speed, Light Craft and Naval Surface [4,5]. The sandwich panel ply sequence is listed in Table 3.

Superstructure	Structural Bulkheads	Accommodation deck	Wheelhouse deck	Wheelhouse
1x 600g/m^2,Woven Roving 0^o/90^o	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*1x 600g/m^2, Woven Roving 0^o/90^o*	*1x 600g/m^2, Woven Roving 0^o/90^o*	*1x 600g/m^2,Woven Roving 0^o/90^o*
2x 450g/m^2,Stitched fabric 0^o/90^o	*2x 450g/m^2, Stitched fabric +/-45^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2,Stitched fabric 0^o/90^o*
1x 450g/m^2,Stitched fabric +/-45^o	*+ local reinforcement*	*2x 450g/m^2, Stitched fabric +/-45^o*	*1x 450g/m^2, Stitched fabric +/-45^o*	*2x 450g/m^2,Stitched fabric +/-45^o*

2x 450g/m^2,Stitched fabric 0^o/90^o		*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2,Stitched fabric 0^o/90^o*
Core 40mm	*Core 40mm*	*Core 50mm*	*Core 50mm*	*Core 40mm*
2x 450g/m^2, Stitched fabric 0^o/90^o	*2x 450g/m^2, Stitched fabric +/-45^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*
1x 450g/m^2,Stitched fabric +/-45^o	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2, Stitched fabric +/-45^o*	*1x 450g/m^2, Stitched fabric +/-45^o*	*2x 450g/m^2,Stitched fabric +/-45^o*
2x 450g/m^2 Stitched fabric 0^o/90^o	*+ local reinforcement*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	*2x 450g/m^2, Stitched fabric 0^o/90^o*	

Table 3: Ply sequence of superstructure components

In order to determine if the superstructure was considered as a longitudinal strength member, the moment of inertia of the midship section was calculated using the vessels steel drawings. The minimum required thickness values were calculated according to DNV rules, where these were not listed in the drawings. Only the elements between the base line and the main deck were considered. The calculated moment of inertia was subsequently compared to the minimum required value for the midship section of inertia prescribed in DNV's Rules for Ships (Table 4). The difference between the moments of inertia is less than 3% which is reasonable considering that some simplifications were made during the calculation of the moment of inertia. The results indicate that the superstructure in the original design was not considered as a load bearing element of the vessel's structure. In other words, the superstructure is not effectively connected to the hull which means that the hull girder loads are not transmitted from the latter to the former and only local acting loads should be considered in the design and analysis of the superstructure. Therefore only the local loads acting on the superstructure were taken into account.

Midship moment of Inertia	Identification	
Calculated	[cm^4]	1.40e9
Minimum Required (according to DNV)	[cm^4]	1.44e9
Difference	[-]	2.92%

Table 4: Midship moments of inertia

3 FINITE ELEMENT MODELING

3.1 Description of the finite element model

Simplifications to the real geometry were made to facilitate the creation of the finite element models. The FE models were created using the commercial finite element program ABAQUS CAE. Conventional 4 node linear shell elements where used for the plating. Standard 2-node linear beam elements were used to model the supporting pillars between decks and the stiffeners in the transverse and longitudinal direction. For the composite case the ply lay-up and orientation were implemented using the composite layup feature and the composite stiffeners using the general meshed cross section feature [6]. The global element size was approximately 500mm. All degrees of freedom were constrained in the lowest part of the superstructure. The loading applied was uniformly distributed pressure acting on the accommodation decks with a magnitude of 0.25 t/m^2.

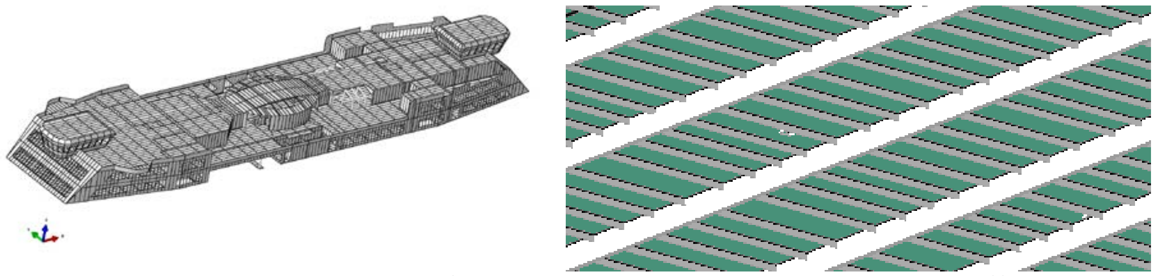

Figure 3: Superstructure FE model (left), steel decks' longitudinal and transverse stiffeners (right)

For the steel case the maximum deflection of the structure was equal to 15mm, while for the composite one the maximum deflection was less than 20mm (Fig. 3). The stresses were considerably low for both cases apart from a few stress concentration points which were introduced to the analysis during the geometry simplification process. Submodelling introducing the precise geometry in combination with finer meshing is needed for the correct interpretation of stresses at these points. However this was out of the scope of the present study.

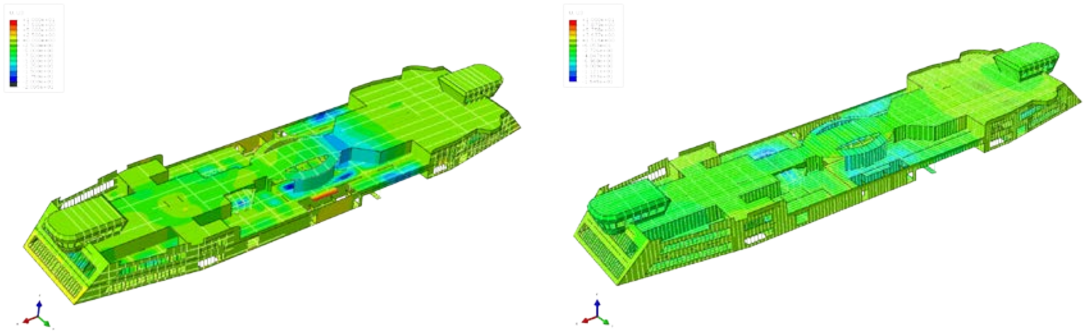

Figure 3: Deflection of the superstructure, composite left, steel right

4 WEIGHT CALCULATIONS

The steel deck lying at17.7 m from the base line was not included in the calculations as it is present in both models. The original, steel part of the superstructure weighs 476 tons which constitutes 6.8% of the vessel's lightship weight. The respective composite part weighs about 140 tons. This signifies that the composite structure weighs about 29% of the equivalent steel one. The lightship of the vessel was reduced by 4.8% moreover, the retrofitted composite part accounts for 2.1 % of the new lightship.

		Steel	Composite	Reduction
Weight of the superstructure to be retrofitted	[t]	476	140	29.41 %
Lightship	[t]	7000	6664	4.80 %
Ratio of Superstructure part to lightship	[%]	6.80	2.10	-

Table 5: Effects on ship

5 CONCLUSIONS

Results indicate that there is a large potential for designing or retrofitting composite superstructures on passenger ships, and that it is feasible from a load-bearing point of view. The inherent versatility that characterizes composites can lead to more efficient vessels as long as the driving parameters of the design are well-defined. The main obstacle for implementing these materials on a SOLAS Ship is the complexity associated with the appropriate regulatory approval. However, there is an increasing interest for introducing composites on large commercial ships, and new material systems are being developed that exhibit good properties under fire and elevated temperatures. These developments will facilitate the design, acceptance and implementation of composites on SOLAS ships.

ACKNOWLEDGEMENTS

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