COMPOSITE HATCH COVER FOR BULK CARRIERS

Philippe M. Noury[1], Ragnar E. Hansen[2] and Bjørn Høyning[3]

[1]DNV GL
Veritasveien 1, 1363 Høvik, Norway
Email: philippe.noury@dnvgl.com, web page: http://www.dnvgl.com

[2]Hansen Engineering and Consulting
Beverveien 39, 3470, Norway
Email: ragnar.e.hansen@heac.no

[3]FiReCo
Storgata 15, 1607 Fredrikstad, Norway
Email: bjorn.hoyning@fireco.no, web page: http://www.fireco.no

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ABSTRACT

In 2011, DNV GL together with its strategic partners launched several joint programs to develop greener ships of the future. Several technical solutions were investigated for a series of environmentally friendly and efficient bulk carriers, one of which included a glass-fiber-reinforced plastic (GRP) hatch cover.

A GRP composite concept was first developed. Its feasibility was then evaluated technically and economically. The results from the study showed that significant weight saving, eradication of sealing damage and reduction of machinery cost could be achieved. Less maintenance was also expected thanks to superior corrosion properties and a more flexible structural response. Solutions for outfitting equipment based on conventional equipment solution were also identified. Simple production methods and process well established in the marine composite industry were also selected.

In 2012, in order to achieve statutory approval, the project team decided to address fire safety equivalence. A fire risk assessment was then performed in accordance with SOLAS II-2 Reg.17 and the IMO MSC/Circ.1002 Guidelines. The preliminary assessment concluded that the fire risk for the novel composite hatch cover was considered equivalent to that implied by the prescriptive requirements of SOLAS. Following acceptance of the preliminary assessment (in qualitative terms) by the appointed classification society, the selected design fire scenarios were then further studied in a quantitative assessment. The results from fire simulations and analysis finally confirmed the initial conclusions i.e. that, with inexpensive risk control measures implemented, the fire risk for the novel composite hatch cover could be considered equivalent to that implied by the prescriptive requirements of SOLAS.

This paper describes the decisive parts of the studies performed in order to achieve class and statutory approval for a novel design of hatch covers for a Panamax bulk carrier.

The design is the world's first composite hatch cover to have ever received statutory approval from a flag authority. An international patent has been filed for the essential parts of the design solution presented in this paper.

1 INTRODUCTION

In 2011, DNV Legacy launched together with its strategic commercial partners several joint programs to develop the greener ships of the future. The projects were a natural response to the

increasing environmental focus, both from a regulatory and commercial point of view, as well as to the increasing cost of fuel. The resulting concept designs had a number of innovative yet feasible features.

Several key technical features for a series of greener bulk carriers were investigated, including a glass-fiber-reinforced plastic (GRP) hatch cover. The aim was then to develop a GRP composite concept and evaluate whether such a solution was technically and economically feasible. The evaluation of the feasibility accounted for the various concerns e.g. structural capacity, weight, vibrations, outfitting, production friendliness, price, impact resistance, and durability and reparability. Rules and regulations (and also deviations) applicable to hatch cover and composite components were also examined.

The results from the feasibility study shows that it is possible to achieve significant weight saving, eliminate cracking and sealing damage, and hence minimize cargo damage from water ingress, reduce cost from machinery weight on deck (hydraulics).

This paper describes two major elements of the design studies performed in order to achieve class and statutory approval for a novel design of hatch cover for a Panamax bulk carrier. These were:

- structural analysis,
- fire risk assessment.

An international patent has been filed for the essential parts of the design solution presented in this paper.

2 DESIGN AND STRUCTURAL ANALYSIS

2.1 Background

In 2013, Oshima Shipbuilding Co. Ltd completed the initial design of the novel GRP composite hatch cover. The GRP hatch cover design solution was developed to be applicable to all sea-going ships.

The main objectives for the design development were to:

- improve fuel efficiency and thus lower the emissions to air;
- improve the performance of the hatch cover and thus improve safety and economic value for the ship owner;
- provide a new manufacturing process and thus improve the economic value for the manufacturer.

In this paper, only the design solution for Panamax bulk carriers with side-rolling hatch covers is presented.

2.2 Design basis

The ship and ship data used for the conceptual design of GRP hatch covers is a Panamax bulk carrier of 77,000 DWT built by Oshima. The ship size is 220.00 m long, 32.26 m wide and the hull girder is 19.79 m deep (Fig.1). The cargo type carried onboard this vessel is coal, grain, iron ore and cement.

Each hatch cover consists of two side-rolling panels of size about 8x17 m (Fig.2). The materials properties of the GRP single skin plates are for resin-infused glass laminate with a fiber volume of about 55%.

Figure 1: Oshima Panamax bulk carrier

Figure 2: Steel hatch cover panels

Acceptance criteria for stresses in fiber-reinforced plastic construction from Pt.3 Ch.4 of the DNV Rules for High Speed Light Craft [1] have been used as rules basis. DNV rules also specify the buckling acceptance criteria for the GRP structure. The allowable stresses in steel outfitting parts are specified in IACS Common Structural Rules for Bulk Carriers [2]. The deflection criteria given in ICLL Res. MSC.143 (77) Reg.16 [3,4] that requires maximum mid-span deflection to be less than 0.56% of the longest span will not be satisfied for this GRP design solution.

2.3 Design loads

The design loads on the GRP hatch cover are identical to the loads applicable to steel hatch cover and are defined in the IACS Common Structural Rules (CSR). The different types of loadings are:

- sea pressure on whole hatch cover; the actual value depends on the longitudinal position of the hatch cover;
- pressure on hatch cover vertical sides; this load case is designed to make sure that the hold-down devices will keep the hatch cover in place when waves are breaking onto the deck;
- imposed deflections and accelerations from the hull girder when the ship moves in a seaway.

In addition to the IACS CSR requirements, loads imposed by temperature variation and loads from

helicopter landing have been considered. The different loadings are combined as described in the IACS CSR.

2.4 The design solution

Some of the most important design principles and objectives are as follows:

- the functionality of the GRP hatch cover is the same as for a steel hatch cover, i.e. same safety level of structural strength, water ingress protection, weather tightness and equivalent fire protection;
- the higher flexibility of GRP structures is taken advantage of in the design;
- the main structural strength is provided by longitudinal corrugation beams;
- the hatch cover is a semi-open box with less torsional stiffness compared to a pontoon steel hatch cover;
- the hatch cover has continuous support along the lower outer edge;
- the seal system shall be more efficient compared to traditional rubber/compression bar solutions.

The general arrangement of one panel of the new GRP hatch cover is presented below (Fig.3). The GRP design has flush, smooth surfaces and very little outfitting is needed. All the outfitting parts are attached to the hatch cover or to the top of the hatch coaming. There are no resting pads since the hatch cover has a continuous support along the transverse and longitudinal edge. The main load carrying members are six longitudinal corrugations. These are supported by vertical edge plates and a top plate.

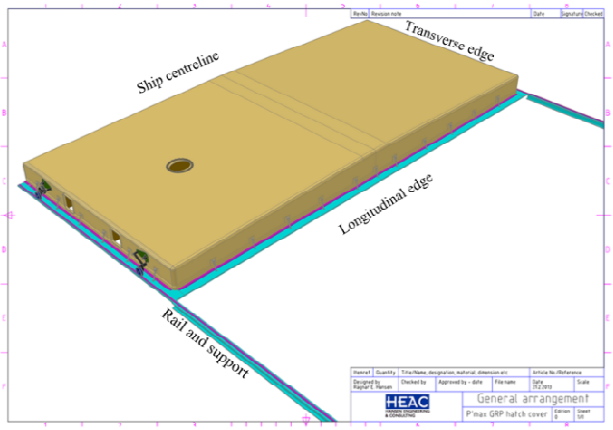

Figure 3: GRP hatch cover panel

2.5 Strength assessment

Due to load pattern and geometric reasons, there are four different designs of hatch covers for the Panamax bulk carrier considered but in this paper only hatch cover no.3 is discussed.

From a structural analysis point of view, the current hatch cover design has several non-linear behaviors that should be considered. The most important non-linearities are:

1. the hatch cover panels are placed on top of the hatch coaming; thus, forces between the GRP hatch cover and the steel hatch coaming are only translated where there is contact, i.e. deflection dependent;
2. the hold down devices (cleating system T-bars) carry only tension forces;

3. the hatch cover panels may slide horizontally within limits imposed by stopper bars on the hatch coaming top; the horizontal contact forces are thus deflection dependent;
4. when the hatch cover panels slide horizontal friction forces are created;
5. the rubber gasket is extensively compressed and will have a strongly non-linear response.

Non-linearity no.1 to 3 have been represented in the stress analyses presented in this paper.

The GRP material properties are considered to be orthotropic.

Since it is important to represent the interaction between the ship's hull and the hatch cover, a full CSR finite element (FE) model has been used, i.e. three cargo holds extent. The FE model of the GRP hatch cover has then been connected to the steel model respecting the non-linearities described above. The full global model is shown below (Fig.4).

The contact forces between hatch cover and hatch coaming and the tensile forces in the hold-down T-bars have been established in an iteration process.

Output from this FE model is used for two purposes:

- deflections, forces and stresses are compared to acceptance criteria for static loads,
- and contact forces and T-bars tensile forces are input to the buckling strength of the FE model.

The FE model used for buckling calculations cover half a panel and has four times more elements than the equivalent part in the static analysis. This means that a typical buckling mode half-wave will be represented by sixteen elements.

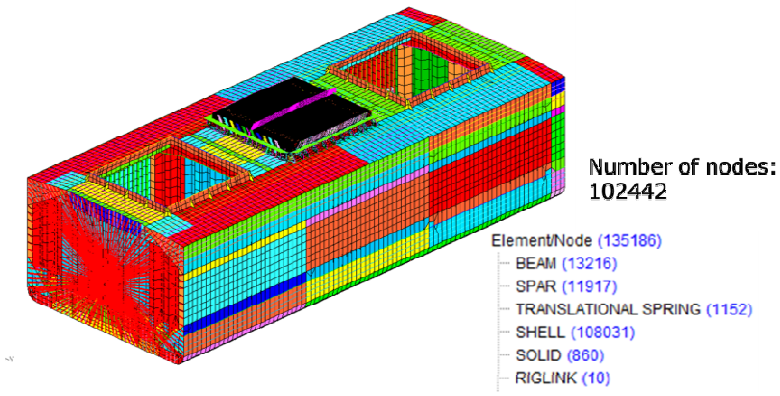

Figure 4: Global finite element model

For a GRP hatch cover with 37% weight compared to its steel equivalent the results show that:

- stresses in GRP and hatch coaming are below acceptance levels;
- stresses in the hold-down and stopper system are acceptable;
- mid-point deflection of 234 mm is above the International Convention on Load Lines (ILLC) acceptance criteria for steel hatch covers; this deviation from regulation (the only one for the design) will require a special review from the maritime authority;
- the relative vertical deflection between hatch coaming top and hatch cover will enable the rubber gasket to be weather tight under all loadings;
- the buckling strength is acceptable.

2.6 Thermal calculations

There are no statutory or class requirements to hatch cover performance under thermal loading. However, in order to be conservative, the structural design has been checked against two thermal load cases:

- all structure has a uniform temperature of +45º C;
- the top plate is +75º C, heated by sun radiation. The rest of the structure (GRP and steel hull) is at +45º C.

This study does not reveal any structural or performance weaknesses with the proposed GRP hatch cover design.

2.7 Vibration assessment

Free vibration of the GRP hatch cover panel has been studied by FE methods. The lowest Eigen-frequencies representing global vibration modes are outside the frequencies of excitation sources such as propeller, engines and waves.

2.8 Conclusions

The overall conclusion from the strength assessment is that GRP hatch covers are structurally feasible for Panamax bulk carriers.

3 FIRE RISK ASSESSMENT

3.1 Background

In 2012, DNV Legacy carried out a fire risk assessment for the novel GRP composite hatch cover. The assessment was performed in accordance with the SOLAS II-2 Regulation 17 [5,6] and the IMO MSC/Circ.1002 Guidelines [7].

The key reason for the assessment is that, according to several SOLAS II-2 regulations, a combustible GRP composite hatch cover is considered as an alternative arrangement (with respect to fire safety). The fire risk assessment aims at demonstrating that the total fire risk for an alternative design can be considered equivalent to that implied by the prescriptive requirements of SOLAS. Fire risk assessment of this kind usually includes two parts: a preliminary, qualitative assessment and a quantitative assessment.

3.2 Preliminary assessment

A general description of the design is given earlier in this paper.

The firefighting appliances are comparable to those of the prescriptive design (e.g. portable fire extinguisher, fire main deck service line etc.) but include several extra features and measures such as self-extinguishing outside surface of the GRP composite and the implementation of all recommendations from the International Maritime Solid Bulk Cargoes (IMSBC) Code [8]. The firefighting appliances do not include firefighting and fire detection equipment in the cargo hold and the hatch cover has no added protection to improve inherent fire resistance or fire reaction properties.

The rules and regulations used as basis for the assessment (i.e. general rules for classification of ships, specific rules related to fire safety, SOLAS regulations, IMSBC Code regulations and national regulations) are systematically reviewed. Fire safety objectives and functional requirements of SOLAS II-2 Reg.2 are also examined and deviations discussed. Out of the five fire safety objectives, Objectives 1. and 5. of SOLAS are fulfilled, as these are governed by prescriptive requirements that are not connected to the alternative design. Objectives 2. to 4. must however be taken into account in the base design, the risk control measures and the trial alternative designs (TAD); i.e. the fire risk

assessment must demonstrate that Objectives 2. to 4. can be met. Out of the eight functional requirements, six are intrinsically fulfilled, whereas the objectives on restricted use of combustible materials and containment and extinction of any fire in the space of origin must be addressed by fire risk assessment and the TADs. Several regulations are also clearly challenged by the alternative design: e.g. SOLAS Ch.2-II Reg.9 on containment of fire and Reg.10.7 on fire fighting.

Fire hazards are identified in a high-level HAZID workshop and systematically recorded for a rigorous selection of the design fire scenarios. Fire hazards related to three key locations are focused upon. These location are: inside the cargo hold, on the deck close to the hatch cover and on the GRP hatch covers. Four main cargo types (coal, grain, cement and ore) relevant for this particular vessel are taken into consideration. Coal is selected as the most critical cargo type due to its self-heating, self-igniting characteristics and its combustibility. Based on these information, two critical design fire scenarios are identified by the design team. These are:

- a coal fire in the closed cargo hold at sea up to one week from harbor for unloading;
- a deck fire close to hatch cover at sea or at berth.

At this stage of the assessment, the two design fire scenarios are specified in details and in qualitative terms. The descriptions include information related to e.g. fuels, ventilation or fire protection system. For the first design fire scenario i.e. coal fire in cargo hold with hatch closed at sea, two variants are selected for further study: one with a sealed cargo hold (i.e. normal conditions) and one with an air leakage. For the second design fire scenario i.e. deck fire on or near cargo hold at sea, several variants are selected for further study: a Molotov cocktail fire, a mooring rope fire, a wooden pilot ladder fire and a hydraulic oil pool fire.

One trial alternative design is finally selected for further study in the quantitative assessment. It includes the two risk control measures (RCM): an emergency kit for hatch cover sealing and an improved-fire-reaction surface of the GRP composite against deck fire.

Relevant historical and statistical data on past fire history, frequency and severity are also examined. The data are constructed on a statistical basis of 56064 ship years from the IHS Fairplay database [9] for the period ranging from 1991 to 2011. The frequency and the severity of fire incidents and accidents are compared with other main risks at sea (collision, grounding etc.). The data show that the occurrence of fires in cargo hold or deck on board bulk carrier is very low in comparison to other types of fires (engine room, accommodation) and that the historic loss of life is lower than in other accident scenarios. The data also show that the risks associated with cargo hold fires or deck fires are very low.

3.3 Acceptance by classification society

Following acceptance of the preliminary assessment (in qualitative terms) by the appointed classification society, the selected design fire scenarios and RCMs were then further studies in quantitative assessment, as required by the IMO guidelines.

The aim of the quantitative assessment was to quantitatively substantiate the findings of the preliminary assessment. This included the quantification of the designated design fire scenarios, quantitative expressions of selected performance criteria, quantitative evaluations of prescriptive designs and quantitative evaluations of trial alternative designs against performance criteria.

3.4 Quantitative assessment

The quantification the cargo hold fires focus on the spontaneous coal combustion. Such combustion includes three main stages i.e. slow oxidation (up to 50°C) intermediate stage of oxidation with increasing rate with temperature and self-sustained combustion (200-250°C).

Results from simulations of the self-heating of coal in the cargo hold shows that the maximum temperature of the hatch stays below 100°C during the time period the ship needs to reach harbor. If ventilation control fails causing an inflow of 0.02 m^3/min from one ventilation hatch (400 x 670 mm) the maximum temperature of the hatch also stays below 100°C.

For temperatures up to approximately 100°C, the composite hatch remains structurally unaffected by heat, as the heat distortion temperature (HDT) of normal marine grade resin systems for GRP are in the range from 85 to 120°C, and the laminates with at least 50% weight of continuous fibers are more resistant to heat. Therefore, when the hatch is closed and completely sealed, the structure cannot collapse due to fire exposure; also in the unlikely case that ventilation control fails (causing a significant inflow of up to 0.2 m^3/min) structure collapse cannot occur.

The quantification of the deck fires includes several alternatives: a Molotov cocktail fire, a mooring rope fire, a wooden pilot ladder fire and a hydraulic oil pool fire. Series of conservative predictions and experimentations shows that these design fires are either not sufficient to ignite the GRP hatch covers, or that the total probability of fire ignition is incredible (total probability of ignition of the order 10^{-7}) or rare (total probability of ignition of the order of 10^{-4}) under very unfavorable conditions. In such event chain, the fire would nonetheless spread in a fashion that fire extinguishment would be easily manageable and that consequences from local fire escalation would be minor.

Three performance criteria are used to evaluate the trial alternative design: 1) No life shall be lost, i.e. sufficient time and tenable conditions for firefighting and evacuation shall be ensured; 2) The hatch cover shall be capable of maintaining its structural integrity for a period of one week, i.e. to remain weather-tight with opening and closing possibilities and a structural strength up to ULS level (this, in order to control the risk of fire escalation, ensure the possibility of suppressing overheating/smoldering fire, prevent flooding and further damages or consequences); 3) Fire in the hatch cover caused by exposure from local deck fire shall not escalate out of control.

3.4 Conclusion

The overall conclusion of this fire risk assessment is that, even without the improved fire-reaction surface, the fire risk for the novel composite hatch cover is found to be equivalent to that implied by the prescriptive requirements of SOLAS. Nevertheless, it is recommended to adopt improved fire reaction surface materials, primarily to ensure robustness during building and maintenance.

The final acceptance by the national authority was given in December 2014. The design is the world's first composite hatch cover to have ever received statutory approval from a national authority.

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