ZIBELINE INTERNATIONAL PUBLISHING

Journal of Water Resources (JWR)

DOI : http://doi.org/10.26480/jwr.01.2018.01.05

ISSN: 2327-7262 (Print)
ISSN: 2327-7688 (Online)

CODEN : JWROB9

THE IMPACT PROPERTY OF CARGO HATCHCOVER WITH STEEL-POLYURETHANE SANDWICH PLATE

Lin Wang[1], Gan Su[2]*, Yiming Huang[3]

[1]School of Architecture and Civil Engineering, Jiangsu University of Science & Technology, Zhenjiang 212000, China
[2]School of Naval Architecture and Ocean Engineering, Jiangsu University of Science & Technology, Zhenjiang 212000, China
[3]Department of offshore engineering, Shanghai Waigaoqiao Shipyard, Shanghai 200137, China
**Corresponding Author E-mail: sgjust@163.com*

ARTICLE DETAILS

Article History:

Received 12 November 2017
Accepted 12 December 2017
Available online 1 January 2018

ABSTRACT

Steel-Polyurethane sandwich plate, a new composite material, which has features of light, impact resistance and well-heat insulation, had been widely used in ship manufacturing and repairing. The main aim of this issue are offering a reference for hatchcover design and manufacture. This issue mainly used Dytran to carry out a finite element numerical simulation and analysis the deformation and energy absorption on adapting SPS hatchcover and steel structure hatchcover, then made a comparison. At last, as the limits of impact conditions, the advantages were not very large but the analysis still shows that the SPS has a good prospect in ship manufacturing.

KEYWORDS

SPS, hatchcover, impact property, Dystran.

1. INTRODUCTION

With Nowadays, most of hatchcovers on cargo ships are made of steel AH36 and some of them are 30mm thick with longitudinal frame and many small members. So it caused a problem that hatchovers are always very heavy and the errors are usually over standards. Based on a study, the loss on water-tightness of hatch may damage the reserve buoyancy and makes the whole ship in danger [1].

According to a research, Steel-Polyurethane sandwich plate (SPS) has great advantages in mechanical properties and impact resistance comparing with the steel plate [2]. There is a research shows the application of SPS in hatchcover and RO-RO ship deck manufacturing will reduce about 15% production costs [3]. By the way, many small members of steel-only structure could be canceled as the better mechanical properties, such as small longitudinal, stiffeners on top plate. A scholar said limited by working environment, it is inevitable that cargo would fall on the hatchcover [4]. This issue mainly talk about the impact properties of SPS and original (steel-only) hatchcover and make a comparison.

2. FINITE ELEMENT MODEL (FEM)

2.1 Material Parameters and Failure Criterion

The material of fallen object is defined as rigid. According to the drawings, the hatchcover's material is defined as linear elastic-plastic to simulate the ship steel [5]. In SPS, polyurethane is defined as elastic material. Considering the impact is a dynamic response process, the materials dynamic performance could not be ignored. As the influence of strain rate, here use Cower—Symonds constitutive Equation (1) as reference.

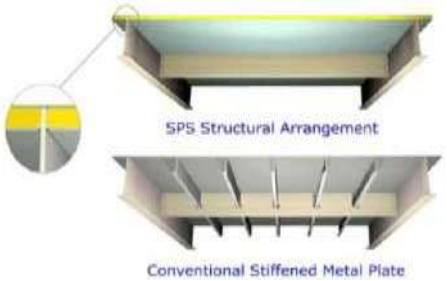

Figure 1: Overview of SPS.

σ': The dynamic yield stress when plastic strain is ε; σ_0: The static yield stress when plastic strain is ε; D, p: constant, in this issue, D=40, p=5

Referencing the equal mass principle, the thickness of SPS is set to 60 mm [6]. The top and under surface plates are set to 6 mm.

Table 1: Mechanic properties of materials involved in this issue.

	Face plate of SPS &original structure	polyurethane
Materials	AH36	polyurethane
Poisson ratio(μ)	0.3	0.44
Density(ρ)	7850 kg/m^3	1200 kg/m^3
Yield stress （ σ_s）	355 MPa	26 MPa
Elastic Modulus (E)	2.1×10 ^{5} MPa	820 MPa
maximum plastic strain	0.3	0.7

2.2 Contact Definition

According to a study, the features of whole contact process: (1) determined by time; (2) the shape of contact surface and the status of dynamics are unknown before contact; (3) company with the material nonlinearity and geometric nonlinearity process [7]. This issue adopt master-slave contact. For SPS the contact is divided into ball-steel structure contact and ball- polyurethane contact.

2.3 Impact Parameters

According to the cargo-ship unloader parameters and ship main parameters, 2500 kg falling ironstone is replaced by a rigid ball with its radius 0.5m, just as the unloader's one-grab weight [8,9]. The height of falling object is set to 5m. Because of the equation (2), initial impact speed is 10m/s with air resistance ignored.

$$v = \sqrt{2gh} \qquad (2)$$

As the limits of falling height, when the ball hit on the center of plate panel, it could not breakthrough the cover but cause some deformations and failures. So in this issue the hit point is set to upon the gear bar (at the center of hatchcover bottom) to see if the deformation could damage open-closing facilities (vertical deformation at gear bar should not exceed 25mm according to manufacturer's standard). Select the conditions that hatchcover is open and set two lower short edges as fixed constraint to simulate movement limit devices and supporting guides.

Table 2: Impact data.

Properties	Value
Falling mass (kg)	2500
Initial speed (m/s)	10
Height in calculation (m)	0.1
Impact position	Top plate, upon the gear bar

2.4 Models

According to drawings, two models are built. Hatchcover with SPS omit small longitudinals and stiffeners. Because this issue mainly discuss the replacement of top plate, small members (width <100 mm, length <500 mm) are not included in the models to reduce the calculation time.

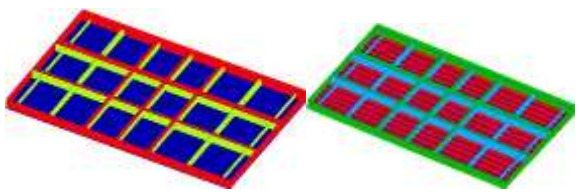

Figure 2: Overview of FEM models (hatchcovers replaced by SPS and original one).

3. SIMULATION AND ANALYSIS

3.1 Ending Time

Ship-ship or ship-bridge collision always end as the main structure failure or the loss kinetic energy reaches a certain level. Here, as the boundary and impact conditions, the fallen ball is rebounded after 0.02 s, so the whole hatchcover would keep vibrating for a while (>2 s). That means this simulation could not get a stable kinetic energy line as ship-ship or ship-objects collision, but the data around 0.2 s are enough to carry on analysis.

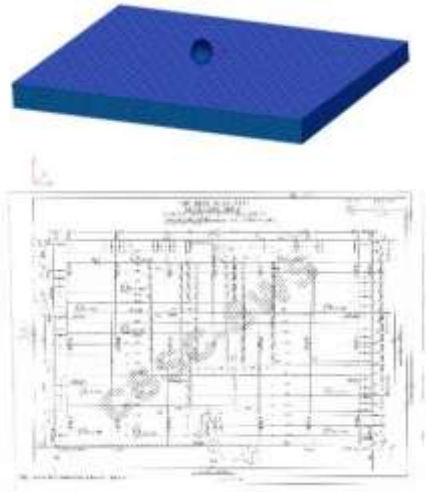

Figure 3: Overview of FEM model and drawings.

3.2 Impact Process

Figures below are showing the velocity and displacement changes of two fallen ball in z direction during the impact process. As the difference between two hatchcovers, two rigid balls are rebounded with different velocity.

Both two velocities in z direction respectively in two models are declining sharply in 0.02 s. That proves the impact process is an instantaneous dynamics process. For SPS model, the falling object reaches the maximum penetration -0.1698 m at 0.024 s, while for original model, the falling object reaches the maximum penetration -0.1476 m at 0.02s.

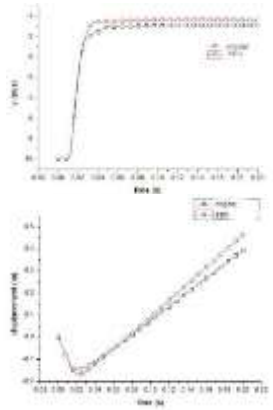

Figure 4: Comparison on velocity and displacement of falling ball on two structures.

In the early rebounding period, the ball's velocity is increasing, which means the plate is rebounding and offering the contact force.

3.3 Structural Response

Select contact point and gear fixing point as two reference points. Because of the plate thickness, displacements between two points would be different.

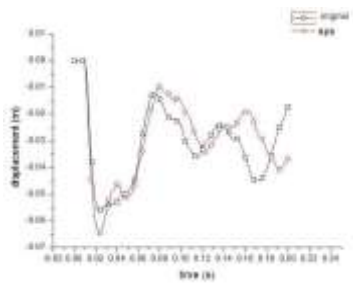

Figure 5: Comparison on z-Displacements at contact points.

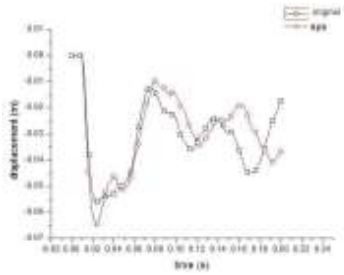

Figure 6: Comparison on z-Displacements at gear fixing points.

From the figures above, deformations on top of SPS model are bigger than the original one, but deformations at the gear fixing point of SPS is smaller. That's because the compressibility and elasticity of SPS are better than steel plate. Besides, at the gear fixing point, the deformation of original structure is a little greater than 25mm while the SPS one is not. It suggests the gear of original structure is out of guide.

Due to impact parameters, boundary conditions and zero-g (gravity is ignored) environment, the hatchcover will keep vibrating for a very long time after impact, so it presents a fluctuating diagram. But the vibration data after 0.06s is not enough useful as a reference in this impact.

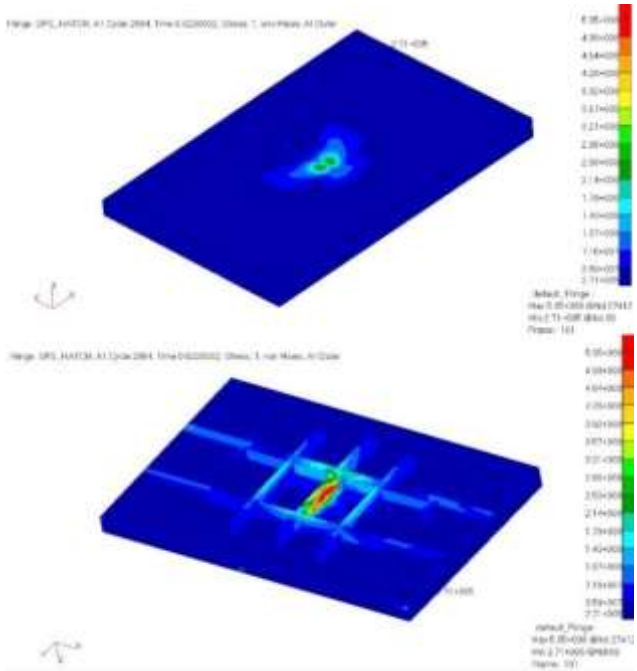

Figure 7: Overview of SPS stress nephgrams at 0.022 s.

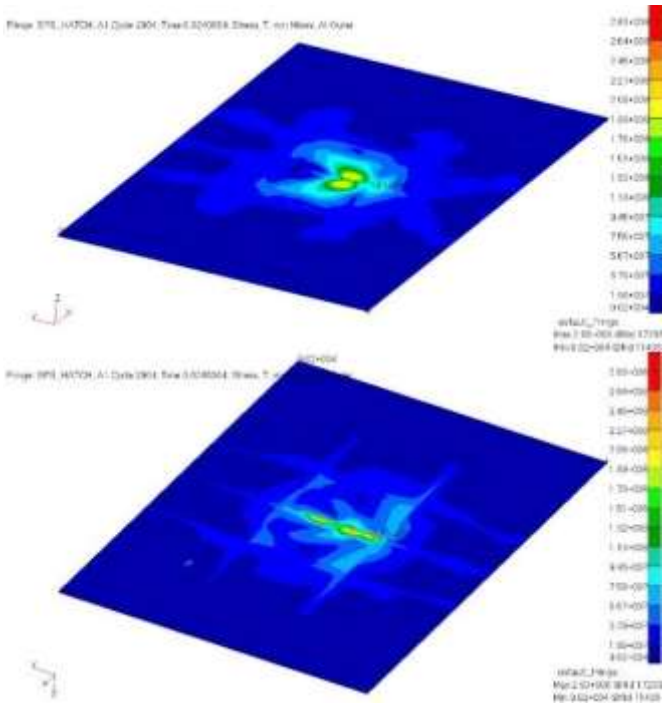

Figure 8: Stress nephgrams of SPS at 0.022s (upper is face plate, under is bottom plate).

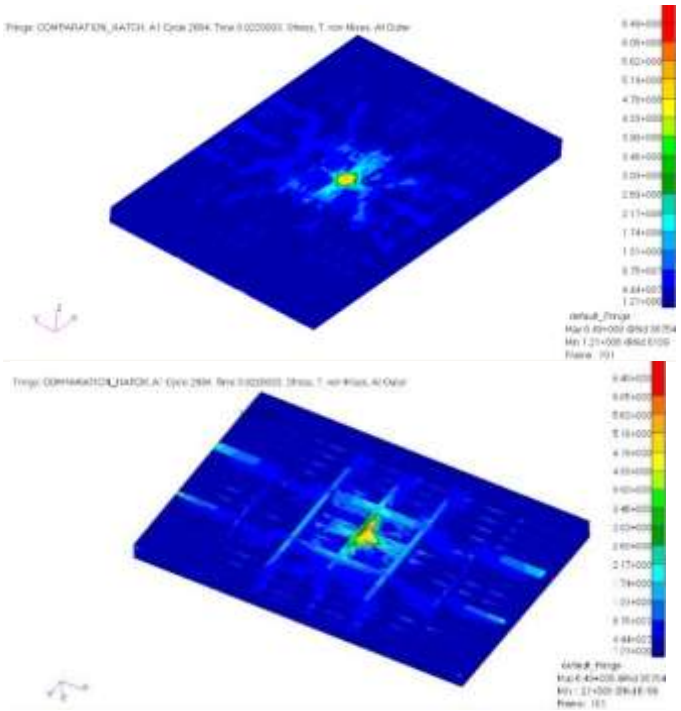

Figure 9: Overview of original structure stress nephgram at 0.022 s.

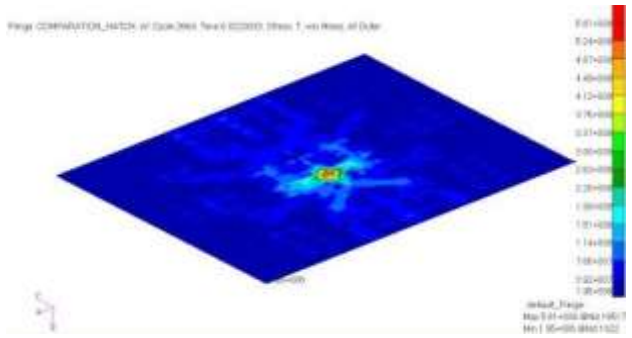

Figure 10: Original top plate stress nephgram at 0.022 s.

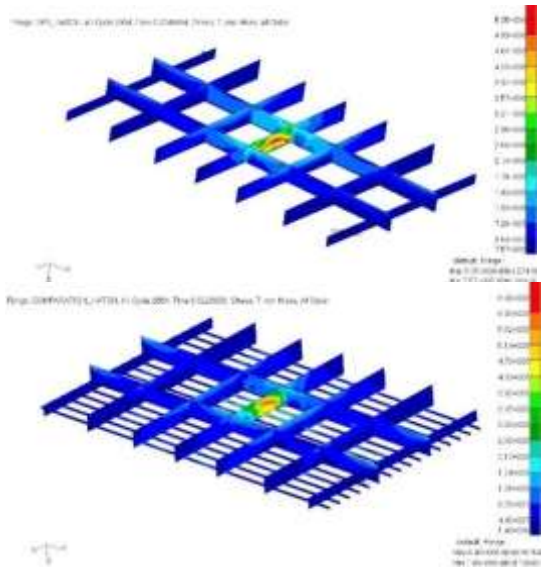

Figure 11: Stress nephograms of two frames (left is SPS).

From pictures above, the deformations and failures caused by impact mainly concentrate in contact area and frames such as web plate and longitudinals under it. From the view of whole structure, it has not been damaged in this simulation.

The damages on SPS mainly are deformations of top plates and failures of web plate. It is obvious that stress of response area on top and bottom face is about 246 MPa not exceeding 300 MPa in Fig. 8. So, it is very likely that the damages on SPS mainly are elastic deformation. However, the maximum stress on web plate is 535MPa, which indicating failures are occurring on it.The damages on original structure mostly are deformations and failures on top plate, longitudinals, and web plate. From Fig. 9-Fig. 11, the maximum stress on top plate is 561 MPa; the maximum stress on frames is 649 MPa. All members involved in impact area has failures.

Furthermore, according to the comparisons, the response area of SPS is wider than original one. It suggests the SPS would make the stress dispersed during the process while the original structure could not.

3.4 Energy Absorption

Most energy are transformed to kinetic energy(EKIN) during impact process and it makes the whole hatchcover engaging a forced vibration, so the diagram of kinetic energy would similarly present a stable sine-curve theoretically at last. For this reason, the value of kinetic energy should be a mid-value of the similar-sine-curve. But by the structural factor, such as thickness uneven distribution, the curve would not be a perfect sine shape. So, values here are chosen as accurate to averages as possible. Here are two tables illustrating the energy absorption of different members in two structures. EDIS is short for Deformation energy. EKIN is short for kinetic energy.

Table 3: Scale of energy absorption on SPS structure.

Structure	Energy Form	Value	Percentage
Hatchcover adapted SPS	*EKIN of steels without top*	8943	8.1%
	EDIS of steels without top	59986	54.7%
	EKIN of SPS	11002	10%
	EDIS of SPS	26781	24.4%
	Other forms	4524	2.7%
	Total	109688	

The kinetic energy of two structures are accounting for 18.1% and 18.9% respectively. It shows that the difference between fallen object impact and ship collision, whose deformation energy is hundreds times of kinetic.

For the deformation energy, the two kinds of steel frame are all playing the main absorption role by deformation. The reason why SPS have not absorb too much energy is determined by the elasticity of polyurethane. But as the wide contact area SPS structure had, its deformation reaches 24% as well.

Table 4: Scale of energy transformation on original structure.

Structure	Energy Form	Value	Percentage
Original structure (steel-only)	*EKIN of steels without top*	9035	7.9%
	EDIS of steels without top	64948	57%
	EKIN of angle- top structure	12971	11%
	EDIS of angle- top structure	23767	20%
	Other forms	3029	2.6%
	Total	113750	

Kinetic energy of SPS accounts for 10% and deformation energy absorption accounts for 24.4%; the original steel angle-top structure occurs failures, with kinetic energy 11%, deformation energy 20% respectively.

The reason of above is the original structure absorbed a part of impart energy with more members failure. However, the SPS could get the stress dispersed uniformly to the subordinate structure, which brings few members failure.

Though SPS structure have not got obvious advantages in energy absorption, the SPS hatchcover is lighter than original one, because angles and small members are canceled.

3.5. Weight Reduction

As hatchcover keep closed by the limiting devices rather than using the gravity of hatchcover, it is practical to reduce the weight of hatchcover.

Table 5: Minimum weight reduction.

Angle properties	Number	length(m)	Meter weight (kg/m)
L125x75x10	14	14.52	15
Total weight(kg)	**Weight of hatchcover(kg)**	**Reduction percentage**	
3049.2	37000	8%	

4. CONCLUSIONS

Through the analysis of falling objects on two kinds of hatchcover, conclusions as follows: Deformation caused by impact on SPS hatchcover is smaller than steel-only hatchcover. If there is faster or heavier dropping objects in some other conditions, the advantages of protecting and energy absorpting would be more obvious. The energy absorption of SPS is not very obvious, but its function of dispersing stress is useful to keep members from being failure. The feature of SPS production process determines that it is viable to use SPS in hatchcover manufacturing. The wielding problem could be solved by changing wielding process.

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