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STRESS IN A SALVAGE FAYING FACE OF A SUBMARINE WHILE MOORING A RECOVERY VESSEL

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Abstract

The article presents stress distribution in a seat face of a submarine while docking a submergence recovery vessel. Rescue faces (salvage faying faces) in submarines are used to dock emergency vehicles. Both submergence recovery vessels and submarines possess special seat faces which enable the transition of a crew from a sunken ship to an emergency vehicle. Due to corrosion environment, seat faces in submarines undergo degradation, which requires periodic inspection of their condition. With accordance to the valid standards, the minimum thickness of faying faces cannot be less than 25,4 mm on account of the stresses and dislocations. Seat measurements made it possible to carry out simulation studies to determine their strength, distribution of stresses and displacements. The obtained results of seat strength allow for a submersion of a submarine to a maximum depth according to the current standards.

Keywords: *salvage (rescue) faying face, thickness of contact plate, measurements of seat face condition, simulation calculations of seat strength, permissible submergence of a submarine*

1. Introduction

Submarines of the Polish Navy were built in the 70's. Later, the ships were modified by changing components used in their construction, as well as changing the shape of the hull, conning tower and location of rudder. These units have one emergency scuttle that allows the crew to evacuate in case of failure of the ship. Evacuation of crew takes place through scuttles of the ship and the rescue vessel that are opened when an the vehicle seat face connects with the salvage faying face of a submarine. The next step is to pump out water from the space between faces and pressure equalization. After this, the scuttles can be opened and the crew is evacuated to an emergency vehicle (Fig. 1) [11].

Due to the poor technical condition of the submarines it was necessary to check the surface adhesion of the submarine seat face to the face of the rescue vehicle [5 ÷ 8, 11]. In order for the faces to adhere properly to each other, they must meet the requirements of the International Standard NAVSEA and the Polish Defence Standard NO-42-A2007 [9, 10]. The main parameters regarding the condition of a seat are its thickness, roughness and geometry. Fig. 1 shows the rescue seat location on a submarine.

Salvage faying face is exposed to the maritime environment, hence its thickness gradually decreases [5 ÷ 8, 11]. Changing the thickness of the seat is a consequence of the removal of corrosion by grinding the ship when in the harbor.

The main purpose of this study is to make strength calculations of a rescue seat face to determine its capacity. Therefore, it was necessary to carry out numerical simulations involving the analysis of stresses and displacements in order to determine the current capacity of the seat and to indicate the minimum thickness of the seat at the maximum depth submergence of the submarine.

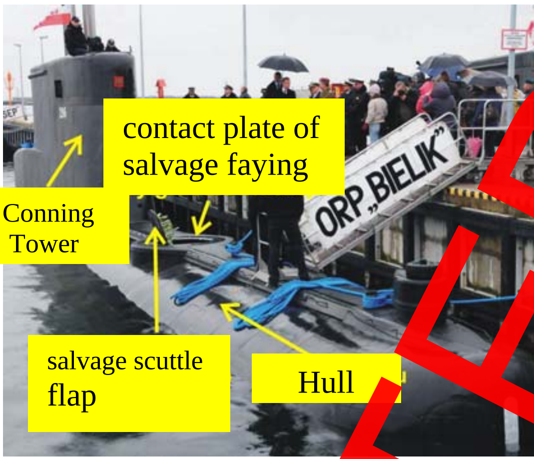

Fig. 1. The location of a salvage (rescue) scuttle on a submarine

2. Geometric and strength requirements of the rescue seat

Both the American NAVSEA Standard and Polish Defence Standard NO-42-A2007 identify the location and dimensions of the seat face (Fig. 2, 3):

- minimum outside diameter 1676,4 mm, maximum inner diameter 1143 mm,
- thickness of contact plate 25,4 mm, surface roughness should be no more than R_a = 6,3 µm,
- the location of the seat face should be centered relative to the vertical centering line of the emergency scuttle.

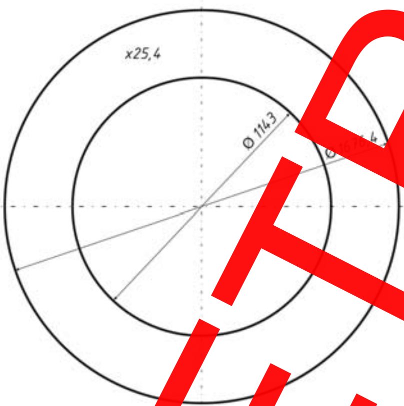

Fig. 2. Principal dimensions of submergence recovery vessel

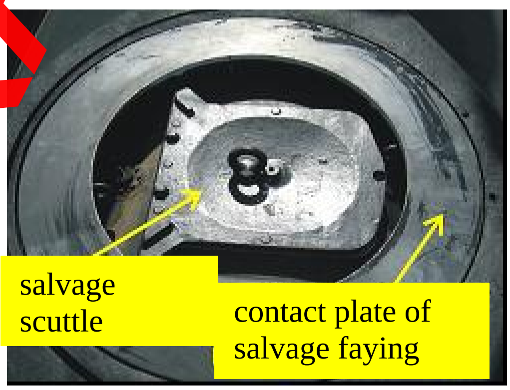

Fig. 3. View of submarine seat face

Measurements of contact plate thickness is performed along 8 measuring lines at 24 measuring points (Fig. 4). In each measurement line from A to H there are made three measurements of thickness. The measurements were made using an ultrasonic method with an approved measuring instrument SONO M310. Fig. 5 shows the dimensions of the face flange of an emergency vehicle docked on a seat of a submarine.

In the absence of data concerning the steel the faces are made of, further calculations were based on 10GHMBA steel parameters [13]. Flange of the adapting basket has dimensions of shown in Fig. 5. The standard also illustrates the distribution of the forces acting on the surface of the seat (Fig. 6).

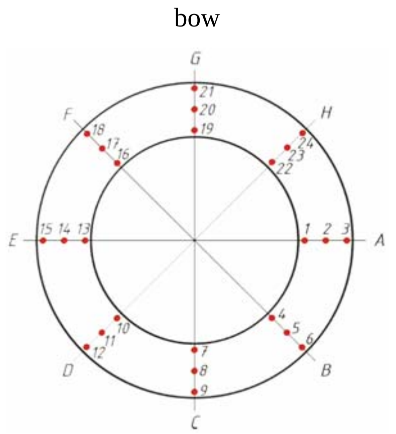

Fig. 4. View of the measuring points of the seat contact plate thickness bow

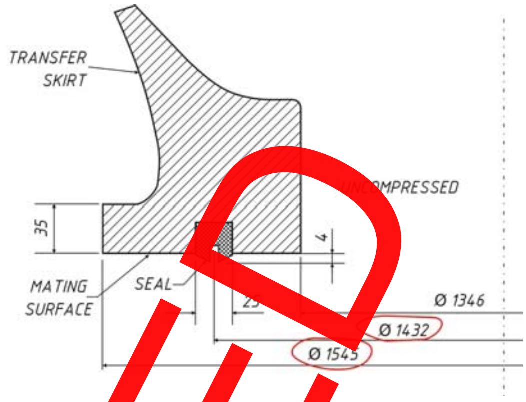

Fig. 5. Flange dimensions of emergency vehicle seat

Dead load caused by hydrostatic pressure P_c | *Additional load caused by side current P_L* | *Total load*

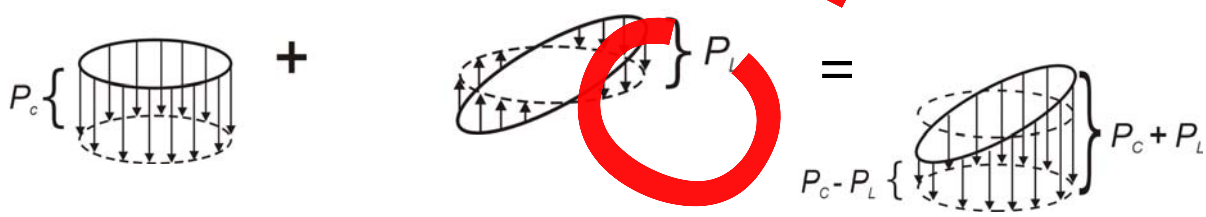

Fig. 6. Distribution of surface forces on the seat face

3. The results of measurements of a salvage faying face of a submarine

NAVSEA Standard contains detailed information on the construction of emergency vehicles, their dimensions and how to dock such vessels. Table 1 shows the results of measurements of the thickness of the seat of one submarine in accordance with NAVSEA and the Polish Defence Standard, using the scheme presented in Fig. 4.

Table 1. List of seat face thickness in characteristic points

No of point	Thickness, mm	No of point	Thickness, mm
1	24,5	13	25,8
2	-	14	-
3	23,8	15	25
4	25,1	16	26,6
5		17	-
6	23,1	18	24,6
7	25,4	19	24,2
8	-	20	-
9	22,4	21	21,3
10	25,2	22	24,4
11	-	23	-23,9
12	23,3	24	-

In characteristic points 2, 5, 8, 11, 14, 17, 20 and 23 no measurements were made due to the high roughness of the surface. The average thickness of the plate was 24,29 mm. On average, reduction in thickness of the contact plate was 1,11 mm, while the largest point reduction in seat plate thickness was more than 4 mm. Thus, it became necessary to carry out the numerical analysis for determining the actual seat face capacity and to determine the minimum thickness of the contact plate for particular submergence depth of the submarine.

4. Geometric representation of the submarine salvage faying face

Based on the ship's documentation, sketches and photographs, there was formed the basis for the seat, on which the contact plate is attached. Next the geometry of the pressure hull was mapped using CAD software [1, 2]. Then the geometry of the scuttle was mapped, which was followed by creation of geometry of contact plate reinforcement. The final step was creating frames strengthening the pressure hull from the inside (Fig. 7).

Fig. 7. Top view of faying face

When creating the geometry of the seat some simplifications were used to facilitate the creation of the computational model. In the geometric model of the face the weld seams were omitted. In the course of the work aiming at mapping the faying face, it was found that all the welds were in perfect condition [5 ÷ 8]. In addition, some of the dimensions in the geometric model were averaged (e.g. a constant contact plate thickness was adopted, assuming the worst option).

An analysis of free vibration of the system was carried out to determine the continuity of the geometry. The notion of free vibration of the system means that the structure deflected out of balance is affected only by the internal forces caused by the deflection. Analysis of free vibration frequency allows to predict the behavior of the structure during motion [3, 4].

In MES free vibrations of the system are described by the following relation:

$$K \cdot U + M \cdot \ddot{U} = 0 \,, \tag{1}$$

where:

K – stiffness matrix,
U – node displacements vector,
Ü – self-acceleration vector,
M – inertia matrix for one element represented in the formula:

$$M^e = \rho \int_V N^T \cdot N dV \,, \tag{2}$$

where:
N – form function matrix,
ρ – density,
V – volume of element.

In equation (2) the following substitution shall be applied:

$$U = X \cdot \sin \omega t \,, \tag{3}$$

where:

U – displacements vector,
X – amplitude vector,
ω – ring frequency.

$$\lambda = \frac{1}{\omega^2} \,, \tag{4}$$

where:
λ – proper value.

The above equations are solved with Lanczos method [3, 4]. In order to verify the continuity of the geometry of the 3D model, free vibrations of the first 10 forms were analyzed. To do this, the analysis of free vibration built-in the CAE environment was used.

Geometry of the face was made as one element and before calculations for the simulation it was divided into 101 parts (partitioning). The division was made to achieve an independent digitization of individual seat elements. First, the base of the seat was separated from the pressure hull, thus getting two parts. Then, the contact plate was separated from the base and the strengthening brackets, dividing it into two parts. In subsequent steps individual brackets were separated I order to get independent elements. Besides, the base was divided into 26 parts. In the final stage the internal strengthening elements with a holder were divided into two elements. The division of a face model resulted in independent digitization of its individual components. It was possible to make calculations in a solver [12]. The model was digitized with 31693 tetragonal 4-nodal elements, and 42261 hexagonal 8-nodal elements [1, 2, 4]. The constructed model of pressure hull sector together with the construction of salvage face were supported along the edge of the cutoff part of the pressure hull, thus depriving the nodes lying on it all degrees of freedom (Fig. 8). The salvage faying face of a submarine was loaded with pressure exerted by the contact surface of the submergence recovery vessel while docking at a depth of 100 to 400 m with regard to the forces induced by side sea currents (Fig. 6) that must be taken into consideration according to the guidelines included in the standards [9, 10].

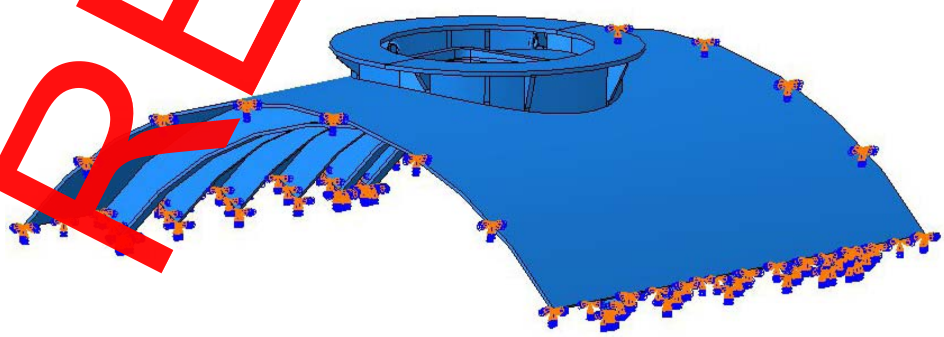

Fig. 8. View of faying face support with regard to boundary conditions

In the moment of connecting an emergency vehicle seat with the contact plate of a submarine rescue seat (salvage faying face), the buoyancy force balances the gravity. When pumping out water from the space between the faces, the force acting on the seat is determined by a simple relation.

$$p_w \cdot \Delta S = p_h \cdot S_k \text{, thus } p_w = \frac{p_h \cdot S_k}{\Delta S} . \quad (5)$$

Section of internal surface of a face measured from the end of the seal $S_w = \frac{\pi \cdot d_w^2}{4}$,

Surface area of the contact plate of an emergency vehicle seat $S_k = \frac{\pi \cdot d_k^2}{4}$, thus the ring area $\Delta S = S_k - S_w$,

where:

p_h – hydrostatic pressure at the depth of submergence,
p_w – pressure in the space between the faces,
S_w – internal area (to the outside edge of the seal),
S_k – surface area of an emergency vehicle seat contact,
d_w – diameter of a wheel limited by the circle to end the seal,
d_z – outside diameter of the contact plate seat of an emergency vehicle.

The calculations omitted salinity of the Baltic Sea and adopted specific weight of water equal 10.000 N/m^3. Table 2 shows load of the faces at a given depth of submarine submergence.

Tab. 2. Load of the faces at a given depth of submarine submergence

Depth of docking, m	Pressure at the depth, MPa	Load of face, MPa
100	1	6,21
200	2	12,41
300	3	18,62
400	4	24,82

5. Numerical calculations of the strength of the submarine rescue seat

Numerical simulations of reduced stresses were determined with use of Huber's Strength Hypothesis for the thickness of contact plate of 25,4 and 23 mm, and the submarine submergence at a depth of 100 ÷ 400 m. Exemplary stress and displacement patterns in a face of 25,4 mm thickness, loaded with pressure at a depth of 100 m is presented in Fig. 9 and 10. Table 3 includes results of the conducted simulations for a 25,4 mm thick contact plate.

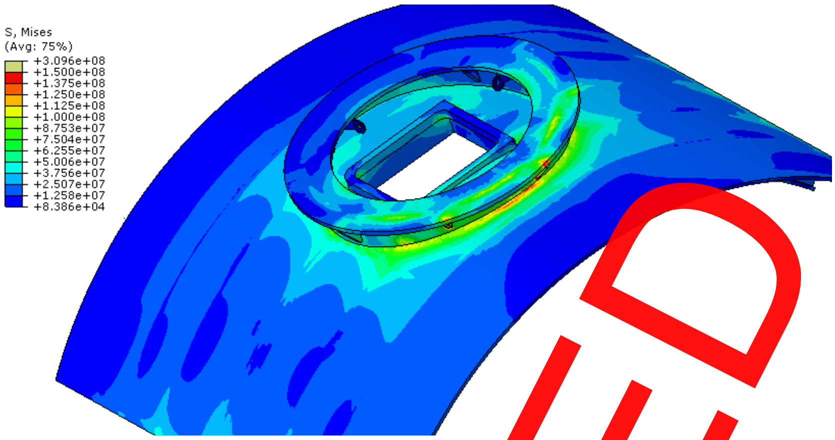

Fig. 9. Reduced stresses pattern in a submarine faying face of 25,4 mm thickness at a depth of 100 m

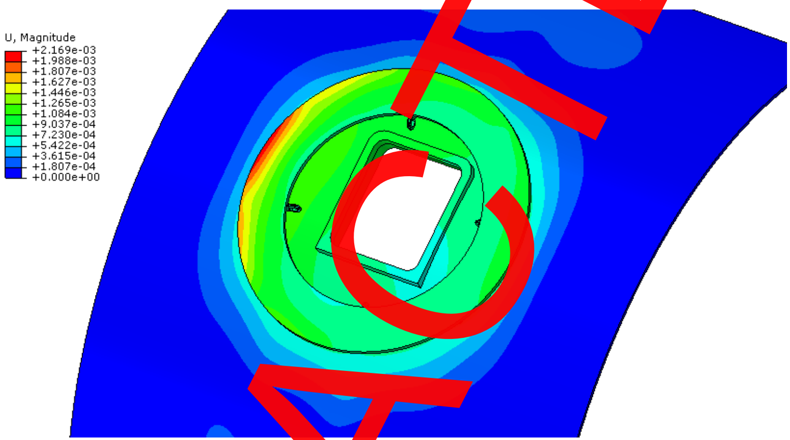

Fig. 10. Displacements pattern in a submarine faying face of 25,4 mm thickness in vertical direction at a depth of 100 m

Tab. 3. Results of numerical simulations for a contact plate of 25,4 mm thickness

Depth of docking submergence recovery vessel, m	Load value, MPa	Reduced stress, MPa		Relative vertical displacement, mm
		max	local extremum	
100	6,21	150	310	0,621
200	12,41	330	618	1,434
300	18,63	450	928	2,165
400	24,82	600	1237	2,892

Value of stresses in a submarine faying face at a depth 100 m amounted 0,008 ÷ 310 MPa, while displacements in vertical direction achieved 0,621 mm (Fig. 9, 10). At a depth of 400 m local value of reduced stresses exceeded 1200 MPa, and the displacements were close to 3 mm (Table 3). Results of simulation calculations of stresses and displacements for a contact plate of 23 mm thickness while docking submergence recovery vessel at depths of 100, 200, 300, 400 m are presented in table 4.

For the thickness of contact plate of 23 mm, and the depth of docking submergence recovery vessel of 100 ÷ 400 m, reduced stresses amount 0,172 ÷ 1536 MPa, and the displacements exceed 3 mm for the submergence depth of 400 m.

Table 4. Results of numerical simulations for a contact plate of 23 mm thickness

Depth of docking submergence recovery vessel, m	Load value, MPa	Reduced stress, MPa		Relative vertical displacement, mm
		max	local extremum	
100	6,21	179	384	0,671
200	12,41	370	767	1,538
300	18,63	550	1152	2,307
400	24,82	700	1536	3,077

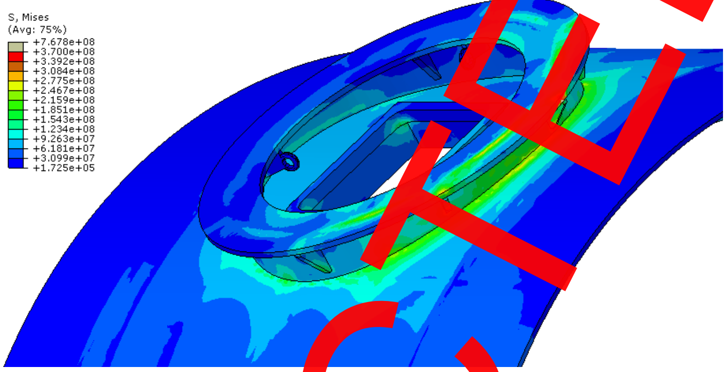

Fig. 11. Reduced stresses pattern in a submarine faying face of 23 mm thickness at a depth of 200 m

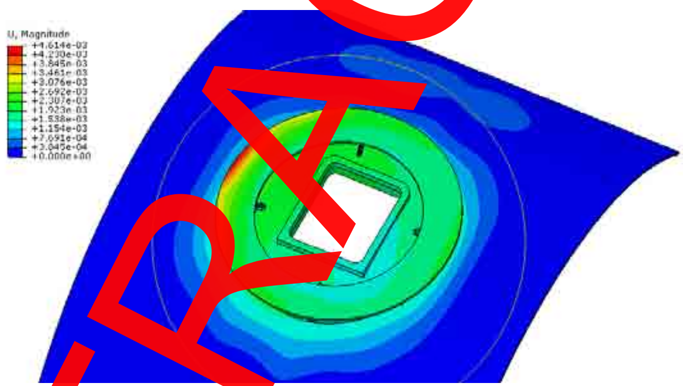

Fig. 12. Displacements pattern in a submarine faying face of 23 mm thickness in vertical direction at a depth of 200 m

Exemplary stress and displacement patterns in a face of 23 mm thickness, loaded with pressure at a depth of 200 m is presented in Fig. 11 and 12.

6. Conclusions

1. Simulation calculations proved that docking a submergence recovery vessel on a submarine faying face (when its thickness complies with the applicable standards) is safe at a depth up to 200 m. Nevertheless, at a depth of 200 ÷ 300 m the locally appearing stresses exceed the yield point of the matter.
2. For 23 mm thick contact plate it is safe to dock an emergency vessel at a depth up to 100 m. Docking a submergence recovery vessel at a depth up to 100 ÷ 200 m may result in permanent local deformations of the faying face construction. In the case of docking at a depth above 200 m the stresses significantly exceed the yield point of the matter.

3. More than forty years of operation of submarines caused a wear of the seats (faying faces) and thus limited the secure depth of submergence, taking into account safety conditions of the crew.
4. In order to maintain safety conditions a submarine should not submerge to a depth exceeding 200 m.

7. References

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