



## THE STRESS STATE ANALYSIS OF RESCUE SEAT AREA OF SUBMARINE KOBHEN CLASS DURING RESCUE VEHICLE LANDING

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### **Abstract**

*This article includes calculating stamina of seat area construction (stress states) during rescue vehicle type SRC or DSRV docking taking into account the depth of immersion and sea current in CAE program, which are the basis for determining the maximum safe depth for use the emergency system. Lists the documents that contain guidelines for the preparation of the design model using Finite Elements Methods (FEM) [5], reflect the geometry of the object and its discretization, a description of the material, boundary conditions and loads. Posted examples of the results of the stress state in the design of the seat area of submarine Kobhen class rescue obtained from simulation FEM for deep 250 m.*

**Keywords:** *rescue seat area of submarine, DSRV (Deep Submergence Rescue Vehicle), SRC (Submarine Rescue Chamber), NSRS (NATO Submarine Rescue System), FEM (Finite Elements Method), CAE (Computer Aided Engineering), Kobhen class, NAVSEA (Naval Sea Systems Command).*

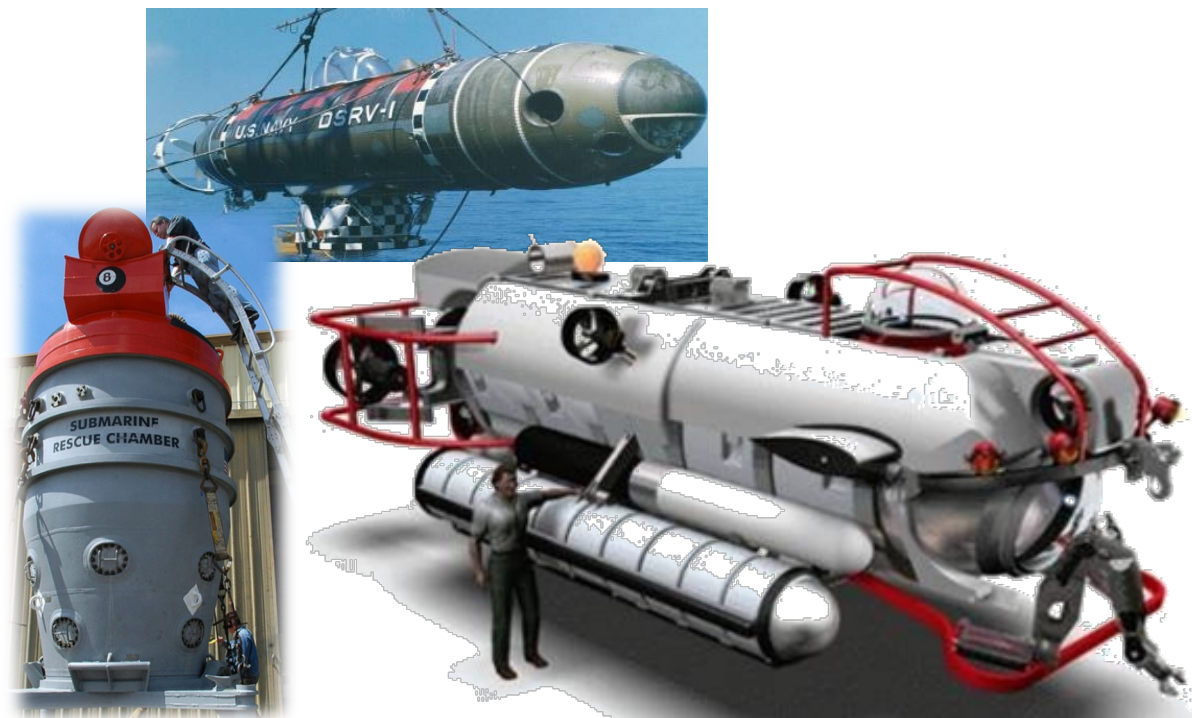
### **1. Introduction:**

The object of the research is a rescue seat area of submarine Kobhen class, which is a part of submarine rescue system (Pic. 1.). Rescue seat area enables landing of rescue vehicles and crew evacuation from damaged submarine by dry method. Rescue seat area was inspected and certificated and results from recent years shows that its dimensions and required thickness reached values below limit. In this situation it is necessary to conduct stamina calculations for current geometry, in order to determine maximum and safe depth for using rescue system.



*Pic. 1. Rescue seat area of submarine Kobben class (ORP Sokół) [2]*

Nowadays NATO's equipment is NSRS – (NATO Submarine Rescue System) (pic. 2.) and phase out DSRV (Deep Submergence Rescue Vehicle) and SRC (Submarine Rescue Chamber).



*Pic. 2. Rescue vehicles: old DSRV, SRC and modern NSRS [8,9,10]*

Stamina calculations of seat area construction during rescue vehicle landing in function of the immersion depth and sea current were conducted in CAE program [3]. Rescue seat area stamina analysis were conducted on basis:

- Defense Standard NO-42-A207:2001, submarines – rescue seat areas. Requirements;
- STANAG 1297 Requirements for a NATO Common Rescue Seat;
- ATP-57(B) The Submarine Search and Rescue Manual;
- International Submarine Rescue Requirements Manual and Instruction Manual for Mating with U.S. Navy Rescue Assets” (NAVSEA SS700-AA-INS-010).

Stamina calculations were conducted in CAE program in the following parts:

1. Measurement of rescue seat area construction, preparing auxiliary drafts and photographic documentation of rescue seat area with segment of strong hulk;
2. Imitation of rescue seat area solid geometry in CAD programs;
3. Rescue seat area discretization and verification of solid geometry;
4. Determination of rescue seat area burdens in draught function and sea current speed;
5. Execution of mating seat stress and deformation calculations using CAE programs;
6. Analysis of results;

## 2. Define the real dimensions of rescue seat area

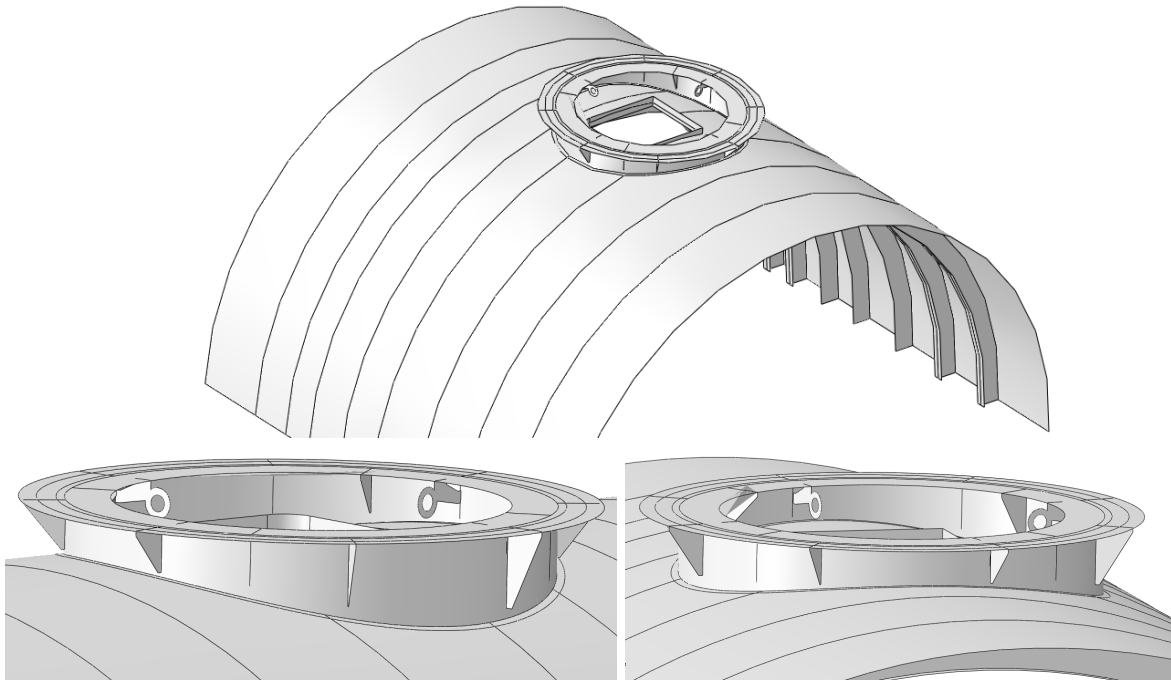
Measurements of seat area elements was conducted in Gdynia harbor during submarine standstill. Measurements was conducted with use certified measuring equipment with precision to 1 mm. Measure of thickness was conducted certified supersonic measures made by Metrison with precision to 0,1 mm. Supporting construction was also measured together with element of strong hulk. Elements not having influence on stamina construction were skipped – e.g. devices installed inside on the submarine hulk. Drafts and auxiliary drawings were created on basis of measuring results (pic. 3).



*Pic. 3. Pictures of seat area construction during standstill in harbor [2]*

## 3. Image of rescue seat area solid geometry and discretization:

Solid geometry of rescue seat area construction was imitated in CAD program. On base of prepared drafts, drawings and pictures all seat area elements were create, and then they were integrated (pic. 4).



*Pic. 4. Geometry of seat area with a part of strong hulk [2]*

Solid geometry of seat area was discretized by 125224 linear coating elements, designated in space by 125442 nodes (Pic. 5.), what constitutes a task with 752652 degrees of freedom. Irregular elements net was used, thickened in area of seat area construction, where the distance between nodes carries out 5 mm. Considering strong hulk, outside seat area construction, elements net were diluted, assumed distance between nodes up to 100 mm.



*Pic. 5. Solid geometry discretization of rescue seat area*

#### **4. Stamina analysis of rescue seat area:**

Stamina calculations of rescue seat area were conducted by licensed software *CAE* according to NAVSEA SS700-AA-INS-010 requirements.

Seat area deformation caused by the pressure of docking rescue vehicle is determined by solving the finite element equation

$$\mathbf{K}(\boldsymbol{\varepsilon}_{pl})\mathbf{U} = \mathbf{F}[p_c(h), p_l(v)] \quad (1)$$

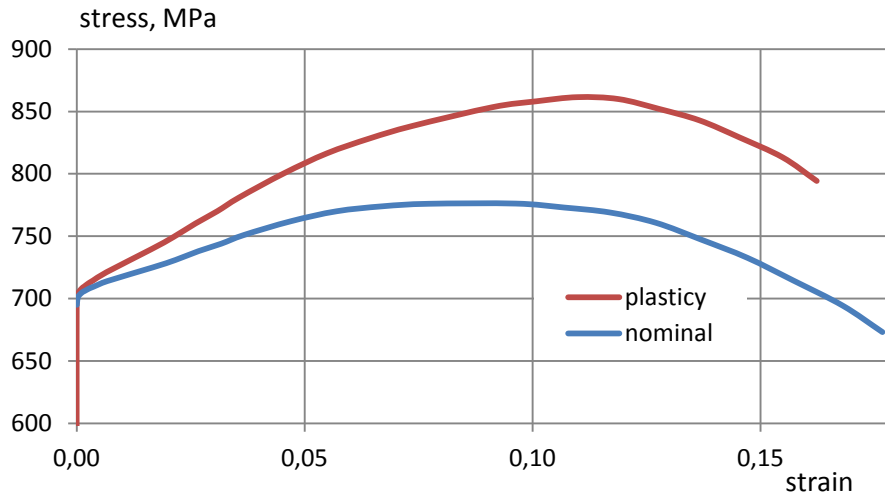
where:

- $\mathbf{K}(\boldsymbol{\varepsilon}_{pl})$  – stiffness matrix takes into account the structure of plastic material model;
- $\boldsymbol{\varepsilon}_{pl}$  – vector of plastic strain;
- $\mathbf{U}$  – displacement vector;
- $\mathbf{F}$  – burden vector;
- $p_c(h)$  – emphasis of the docking vehicle ring depends on the depth of immersion;
- $p_l(v)$  – emphasis of the docking vehicle ring depends on the sea current speed;
- $h$  – depth of immersion, m;
- $v$  – speed of the sea current.

To determine material data requires „cut-out” samples from seat area construction. On base of literature data, NATO submarines from years ‘60 –‘70 last century were made with steel HY 80 or HY100. Taking into account data for steel HY 100 is suggested by instruction NAVSEA SS700-AA-INS-010. In General Engineering Laboratory<sup>1</sup> precisely tested steel with similar properties marked 10GHMBA. Therefore steel data 10GHMBA was taken to calculations with following properties. It is high-quality steel used for responsible marine structures. Mechanical properties [7]:

density	$\rho = 7830 \text{ kg/m}^3$	plasticity limit $R_e = 695 \text{ MPa}$
Poisson's	$\nu = 0.3$	stamina limit $R_m = 759 \text{ MPa}$
Young's module	$E = 2.09 \cdot 10^5 \text{ MPa}$	

Plastic characteristics of material are based on the so-called nominal characteristics  $\varepsilon_{nom} - \sigma_{nom}$  obtained from the testing machine, according to algorithms described in the literature [3, 5] (pic. 6).



Pic. 6. Nominal characteristic  $\varepsilon_{nom} - \sigma_{nom}$  and plastic  $\varepsilon_{pl} - \sigma_{true}$

Taking as a model material

$$\sigma_{pl} = A + B\varepsilon_{pl}^n \quad (2)$$

<sup>1</sup> General Engineering Laboratory, Institute of Bases Machines Construction, Naval Academy in Gdynia

coefficient values for steel 10GHMBA are as follows:

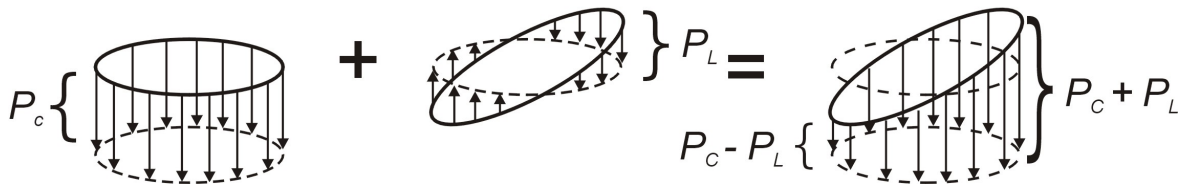
$$A = R_e = 700 \text{ MPa};$$

$$B = 640 \text{ MPa};$$

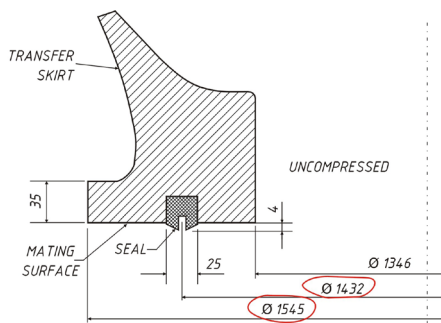
$$n = 0,6.$$

Seat area was burden by pressure which is exert by surface (pic. 8, 9), the point of contact with rescue vehicle while landing on the depths from 100 to 300 meters regarding sea currents, according to NAVSEA SS700-AA-INS-010. During rescue vehicle landing, after sealing and water pump out, it causes pressure on seat area construction by column of water pressure on limited surface by outside diameter of rescue vehicle collar. Sea current (side) were assumed as a linear variable pressure  $p_l$  counting  $\pm 2 \text{ MPa}$ (pic. 7). The burden of contact plate for depth of immersion including sea current running is given by model:

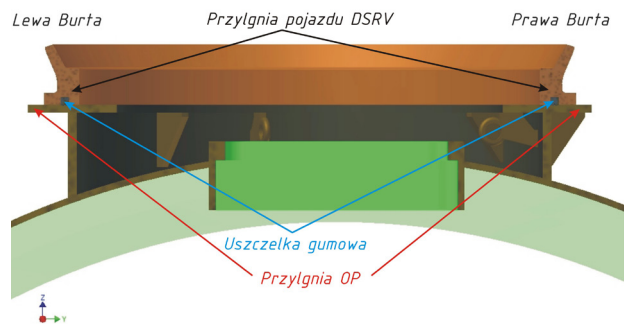
$$p = p_c + p_l \quad \text{MPa} \tag{3}$$



Pic. 7. Burden of seat area according to NAVSEA SS700-AA-INS-010 [6]

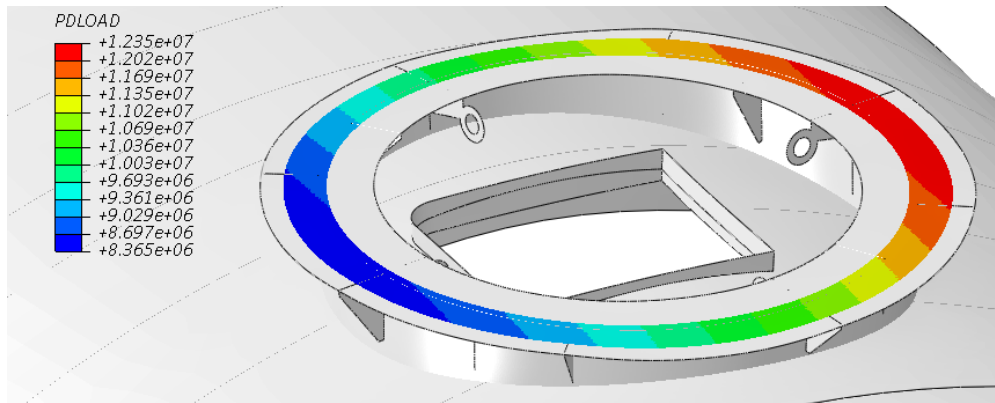


Pic. 8. Collar intersection of landing DSRV [6]



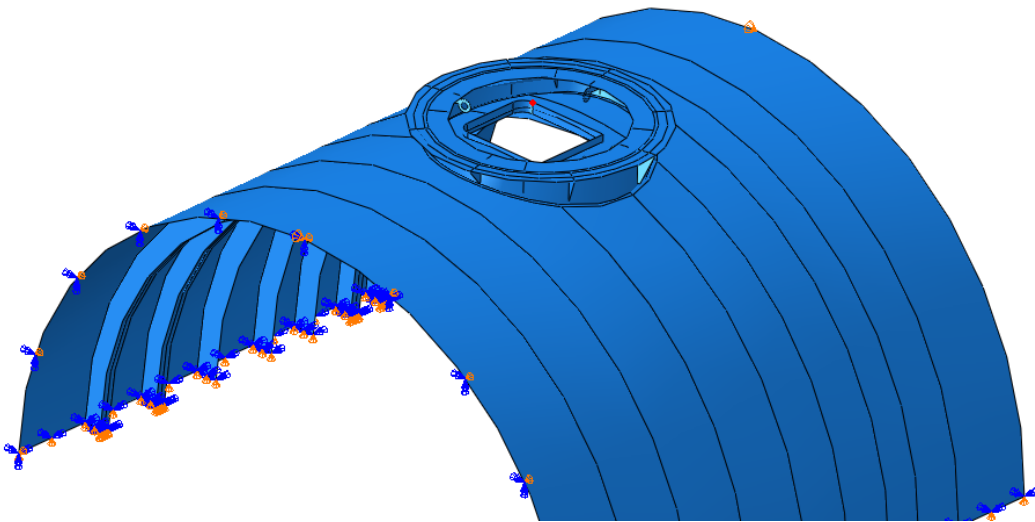
Pic. 9. Illustrated contact of vehicle ring with seat area [1]

Next, analyzed section of strong hulk together with seat area construction were supported along cut edge of hulk, taking away to all laying there nodes possibility of movement in normal direction to the cut plane and rotation in other direction. For example, pressure exerted on seat area surface created by stress of rescue vehicle on the depth 250 m with regard side undercurrent carries out out  $8.36 \div 12.35 \text{ MPa}$  (pic. 10).



*Pic. 10. Seat area burden  $p_c + p_l$  on the depth 250 m*

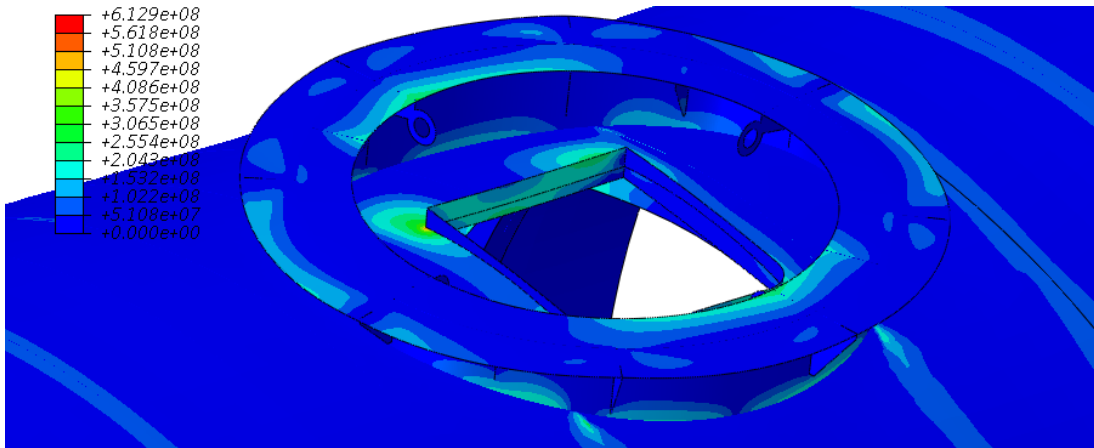
Analyzed section of strong hulk together with seat area construction were supported along cut edge of hulk, taking away to all laying there nodes possibility of movement in normal direction to the cut plane and rotation in other direction (pic. 11).



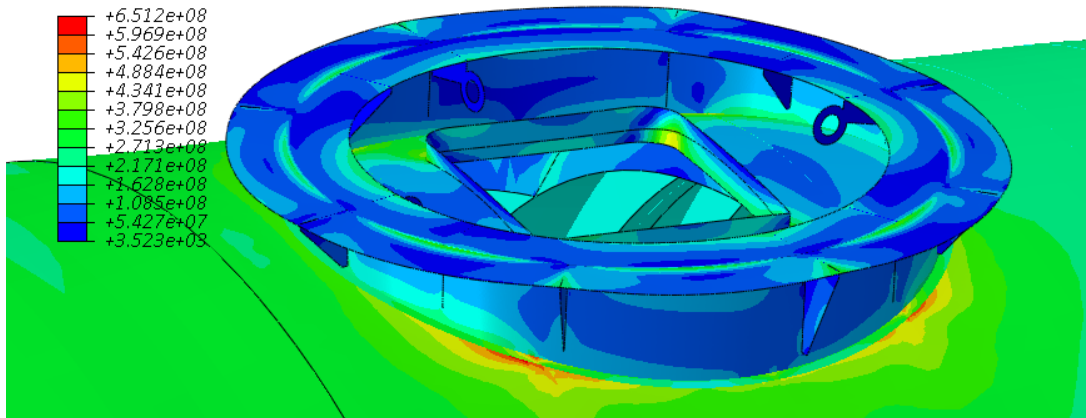
*Pic. 11. Boundary conditions – seat area support*

## **5. State of stress and displacement on the depth 250 m:**

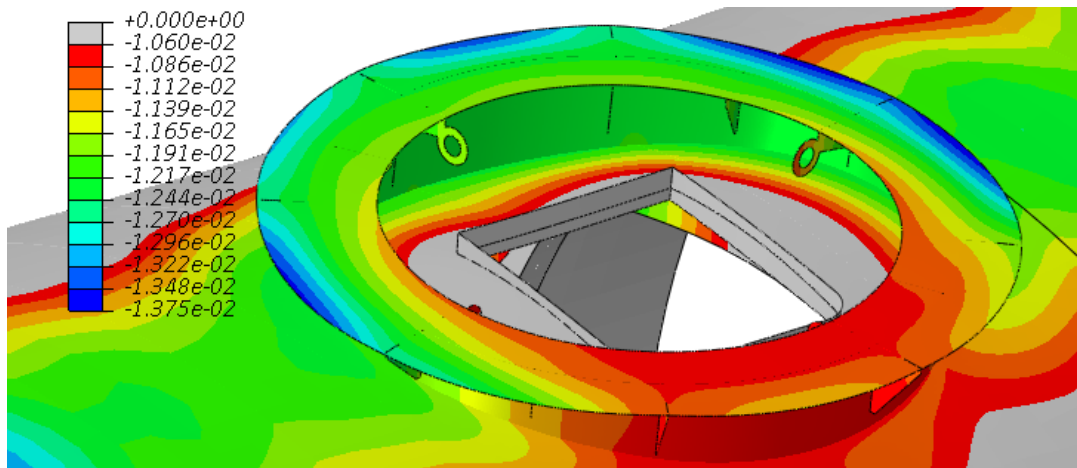
Maximum main stress on the depth 250 m, are locate in interval  $0 \div 613$  MPa (pic. 12). Reduced stress according to hypothesis HMM (Hubera - Misesa - Hencky'ego) achieving values 651 MPa (pic. 13). Local concentration of stress appear on connection seat area postument with hulk. Displacements of seat area surface in vertical direction are located in interval  $-10.6 \div -13.75$  mm (pic. 14), maintain flatness.



Pic. 12. Scheme of maximum main stress inside seat area on the depth 250 m [2]



Pic. 13. Scheme of reduced stress according to HMH hypothesis on the depth 250 m



Pic. 14. State of displacement in vertical direction on the depth 250 m [2]

Extreme values of calculated stress and displacements, generated in seat area construction during rescue vehicle landing at assumed depth are presented in schedule 1.



*Schedule 1. Summary of numerical simulation results [2]*

Landing depth	maximum main stress	maximum reduced stress according to HMH	Vertical displacements
m	MPa	MPa	mm
100	241	277	-2.46 ÷ -5.43
200	491	514	-6.47 ÷ -9.44
250	613	651	-10.6 ÷ -13.75
300	741	762	-10.2 ÷ -13.63

## 6. Conclusions:

Calculated values of main and reduced stress according to hypothesis HMH for depth 250 m locally reach yield point, on depth 300 m reached stamina limit what means that it is limit depth on which damage of seat area construction can occur during landing a rescue vehicle. Therefore calculations for larger depth of immersion are pointless. In case of landing DSRV, SRC, SRDRS, NSRS, URF and similar rescue vehicle on submarine Kobben class rescue seat area on the depth 300 m, in area where seat area postument is connected to strong hulk, local and permanent deformation will occur what will lead to strong hulk crack and unseal.

Based on the results received from CAE simulations states that, landing of DSRV, SRC, SRDRS, NSRS, URF and similar rescue vehicles on analyzed seat area is safe to the depth 250 m. In case of landing on the depth 300 m in area where seat area postument is connected to strong hulk, local and permanent deformation will occur what will lead to strong hulk crack. Maximum immersion for submarine Kobben class is assumed 200 m, therefore border immersion is estimated at approximately 300 m (permissible x 1.5).

## 7. Bibliography

- [ 1] Bohn M., Projekt pierścienia do dokowania pojazdu ratowniczego na powierzchni przylgni okrętu podwodnego, praca inżynierska pod kierownictwem Szturomski B, Gdynia AMW 2010 r.;
- [ 2] Jurczak W., Świątek K., Bohn M., Szturomski B., Report No: 12/Sokół/LPT/2012, Expert opinion about rescue seat area submarine 294 ORP „Sokół”, Part I i II, Naval Academy in Gdynia, 2012 r.;
- [ 3] Abaqus 6.12, PDF Documentation, Theory Manual, Simulia, Dassault Systems 2012;
- [ 4] Bohn M., Wpływ geometrii przylgni okrętu podwodnego typu kobben na rozkład naprężeń, praca magisterska pod kierownictwem Szturomski B, Gdynia AMW 2012 r.;
- [ 5] Szturomski B., Inżynierskie zastosowanie MES w problemach mechaniki ciała stałego na przykładzie programu ABAQUS, Wydawnictwo Akademickie AMW - Gdynia 2013;
- [ 6] International Submarine Rescue Requirements Manual and Instruction Manual for Mating with U.S. Navy Rescue Assets” (NAVSEA SS700-AA-INS-010);
- [ 7] Flis L., Sperski M., Badania odporności balistycznej pancerzy ze stali 10ghmba na ostrzał pociskami 12,7 mm, Zeszyty Naukowe Akademii Marynarki Wojennej, ROK LII NR 3 (186) 2011;
- [ 8] [http://en.wikipedia.org/wiki/McCann\\_Rescue\\_Chamber](http://en.wikipedia.org/wiki/McCann_Rescue_Chamber) (28.05.2014);
- [ 9] <http://www.adventurersclub.org/images/DSRV-1.jpg> (28.05.2014);
- [ 10] <http://www.meretmarine.com/fr/content/les-europeens-ont-enfin-leur-sous-marin-de-sauvetage> (28.05.2014);

