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WAYS OF STANDARDIZING HIGH-DENSITY POLYETHYLENE HULL STRUCTURES PARAMETERS FOR SMALL VESSELS

ШЛЯХИ НОРМУВАННЯ ПАРАМЕТРІВ КОРПУСНИХ КОНСТРУКЦІЙ З ПОЛІЕТИЛЕНУ ВИСОКОЇ ЩІЛЬНОСТІ ДЛЯ МАЛИХ СУДЕН

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Abstract. Alternative structural materials are of great importance in the construction of small craft. There are convincing justifications for the effectiveness of their use for certain types of small craft. In the practice of world small craft construction, high-density polyethylene has long been used as a material for hull structures.
At the same time, there are serious gaps of rationing the parameters of hull structures made of HDPE, which complicates the process of designing these structures.
Problems are associated with the lack of formalized requirements for structural parameters in regulatory documents, such as the Requirements of Classification Bodies, including ISO group international standards – Small craft. The Rules for the Classification and Construction of Small Vessels of the Shipping Register of Ukraine (SRU) and the ISO Small craft – Hull construction and Scantlings-Part 1: Materials standard do not consider HDPE as a structural material for small vessels. Turkish Lloyd only comprises temporary rules for the design of HDPE small vessels.
Since the Shipping Register of Ukraine still does not have formalized requirements for HDPE structures, although the relevant work on the inclusion of requirements for HDPE structures in the rules is currently underway, it requires an appropriate definition in the technical policy of the SRU, in terms of the use of HDPE as a material for hull structures. Ignoring this structural material leads to the need for certification of vessels manufactured by domestic manufacturers outside Ukraine. In this respect, rationing of the parameters of hull structures made of high-density polyethylene is an urgent task.
The purpose of the work is an attempt to substantiate the application of the approach to normalization of the parameters of body structures of ISO standards of the Small Craft group.
Since there are no requirements for the structures of small vessels in this standard, a general scheme for determining the parameters of hull structures adapted to the material used is to be considered. The parameters of the bottom floor with a longitudinal framing system (panel thickness and section modulus of the beams of the regular set) were additionally determined by direct calculations and according to the requirements of the Turkish Lloyd.
A comparison of the results is made and conclusions for the application of ISO standards to determine the parameters of structures of the adapted scheme are proposed.
Key words: small craft; hull structure; design requirements; high density polyethylene; ISO standards.

Анотація. Альтернативні конструкційні матеріали мають велике значення у будівництві малих суден. Існують переконливі обгрунтування ефективності їх застосування для окремих типів суден малого флоту. У практиці світового малого суднобудування досить давно використовується у якості матеріалу корпусних конструкцій поліетилен високої щільності.
Разом з тим, у світовій практиці нормування параметрів корпусних конструкцій із HDPE існують серйозні прогалини, що ускладнює процес проєктування даних конструкцій.
Проблеми пов’язані з відсутністю формалізованих вимог до параметрів конструкцій в нормативних документах, таких як Вимоги Класифікаційних органів, у тому числі міжнародних стандартів ISO групи Small craft. У Правилах класификації і побудови малих суден Регістру судноплавства Украины і у стандарті ISO Small craft – Hull construction and Scantlings-Part 1:Materials, HDPE у якості конструкційного матеріалу для малих

суден не розглядається. Турецький Ллойд містить лише тимчасові правила для конструювання малих суден з HDPE.
Оскільки, Регистр судноплавства України досі не має формалізованих вимог до конструкцій із HDPE, хоча відповідні роботи щодо включення вимог до конструкцій з HDPE до складу правил зараз ведуться, зазначене потребує відповідного визначення у технічній політиці РСУ, у частині, що стосується використання HDPE у якості матеріалу корпусних конструкцій.
Ігнорування даного конструкційного матеріалу призводить до необхідності сертифікації суден, які виготовляють вітчизняні виробники, за кордонами України. У зв'язку з цим нормування параметрів корпусних конструкцій з поліетилену високої щільності є актуальним завданням.
Мета роботи полягає у спробі обґрунтування підходу до нормування параметрів корпусних конструкцій стандартів ISO групи Small Craft.
Оскільки, вимоги до конструкцій малих суден у цьому стандарті відсутні, приймалася загальна схема визначення параметрів корпусних конструкцій адаптована до матеріалу, що застосовується. Параметри днищового перекриття із поздовжньою системою набору (товщина панелей та моменти опору балок регулярного набору) додатково визначалися прямими розрахунками та за вимогами Турецького Ллойду.
Виконано порівняння результатів та запропоновано висновки щодо застосування для визначення параметрів конструкцій адаптованої схеми стандартів ISO.
Ключові слова: малі судна, корпусні конструкції, вимоги до конструкції, поліетилен високої щільності, стандарти ISO.

SUBSTANTIATION OF THE PROBLEM

Currently, when designing small vessels with high-density polyethylene (HDPE) structures, a number of problems associated with determining the strength dimensions of hull structures arises.

The problems are associated with the lack of formalized requirements for structural parameters in regulatory documents, such as the Requirements of Classification Bodies, including ISO international standards of the Small Craft group. For example, the Rules for the Classification and Construction of Small Vessels of the Shipping Register of Ukraine [1] and the ISO Small craft – Hull construction and Scantlings-Part 1: Material standard [2] does not currently provide for HDPE as a structural material for small vessels. There are tentative rules for polyethylene craft in Turkish Lloyd (TL) [3]. The situation with certification of small vessels with HDPE structures currently provides for a special review procedure by the classification authorities, which creates certain obstacles to the dissemination of this material in small craft construction. In view of the above, it is considered expedient to create and approve engineering algorithms for determining the parameters of the structures of the ship hull structures.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

It should be noted that the SRU is currently working at the implementation of these requirements for HDPE design in to the rules [1]. Small vessels supervised by these Rules have a number of restrictions on the use of HDPE. The peculiarities of the material causes doubt in the possibility of its use for sailing and motor yachts due to the difficulty of providing aesthetic criteria. At the same time, high efficiency of HDPE application for service, traveling, patrol and unmanned small craft, is indicated in [4].

Figure 1 shows the performance indicators of the material considered in comparison with conventional. The indicators take into account the full range of applied materials for structures of small vessels from design to disposal at the end of operation. Since the service life of different materials of hull structures differ significantly, the comparison regarding the relative costs per 1 year of operation will be more indicative. See Figure 2.

UNSOLVED PARTS OF THE GENERAL PROBLEM

The General requirements for the design of HDPE small vessels are to be established and approved by the classification structures, which allow, within the framework of general certification, to harmonize the parameters of the structures with the rules of supervisory authorities.

THE PURPOSE OF THE ARTICLE

The purpose of the article is aimed at analyzing the existing practices of rationing the parameters of HDPE structures and offering a unified approach to rationing the strength dimensions of structures of small vessels.

PRESENTATION OF THE PRINCIPAL MATERIAL

In general, direct calculations are required (that imply both appropriate experts and software), which are not available for most designers of small vessels, and, moreover it involves the counterparties that result in higher cost. For the normal operation of designers, when creating small vessels with HDPE structures, it is necessary to supplement the Rules and relevant standards with requirements for the material under consideration and its structures in a form accessible to designers.

To create appropriate sections of regulatory documents that allow direct design of hull structures made of HDPE, it is necessary to develop and include the following additional sections into the standards:

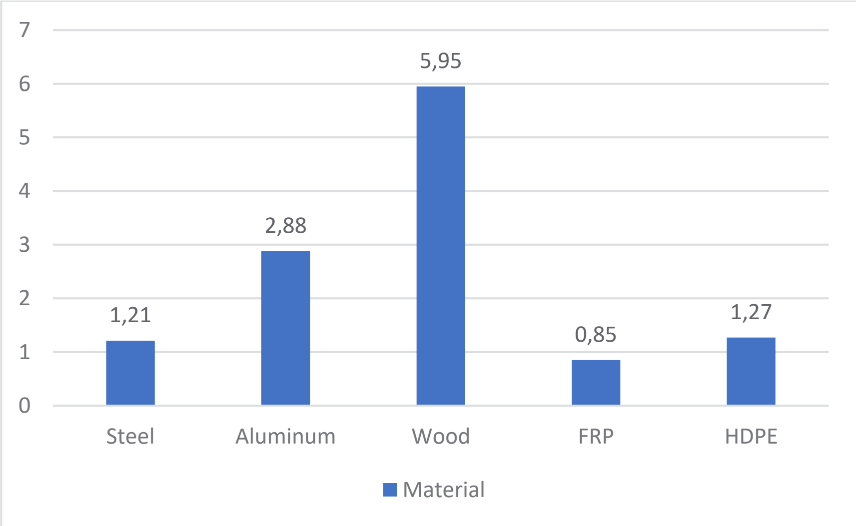


Figure 1. Relative costs for the manufacture and operation of structures

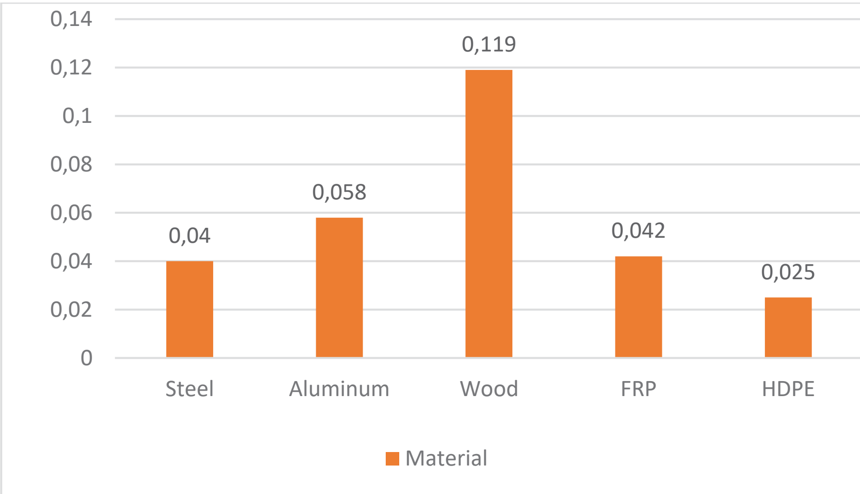


Figure 2. Relative costs per year of service of structures

1) Requirements for the physical and mechanical characteristics of HDPE used for the manufacture of structures taking into account technological features;

2) Requirements for production conditions and technological process;

3) The scheme for determining the strength dimensions of the elements of body structures (thicknesses of panels of cladding and decking, moments of inertia and section modulus of the set beams);

4) The amount of allowed stresses for individual structural elements.

1. Requirements for the physical and mechanical characteristics of HDPE used for the manufacture of structures can be considered formalized, taking into account the availability of manufacturers of this material certificates of compliance with international standards (for "marine" use). The relevant material characteristics presented by the manufacturer can be used directly to determine the strength dimensions of the elements of the ship's hull. Characteristics are defined for both, rotary and welding technologies.

2. The conditions for the production of structures and restrictions on the technological process are also regulated by the manufacturers of the material.

3. The determination of the strength dimensions of hull structures depends on the magnitude of the design loads acting on the hull structures. Currently, the value of the design loads, regulated by the requirements of ISO standard [5], is considered quite correct and is used for direct calculations of structures. According to the algorithm for calculating external loads, their value depends on the purpose of the vessel, the geometry of the hull, the area of operation and the speed of navigation.

In the near future, the development of small HDPE craft involves the creation of vessels with a dynamic mode of navigation. In this respect, we are primarily interested in the dynamic component of the load. The calculated dynamic pressure. Impact pressure is a function of the following 11 parameters:

$P_{b1}=f(C,L_{WL}, B_{WL},B_c,\Delta,V,\beta,\tau,b,l,k_L)$, where:

– C – Parameter for the area of operation;
– L_{WL} – Length of the waterline;
– B_{WL} – Waterline beam;
– B_c – Chine beam, supporting width;
– Δ – Displacement mass;
– V – Maximum speed for a given displacement;
– β – Deadrise angle;
– τ – Running trim angle;
– b – Shorter dimension of plate;
– l – Unsupported longer dimension of plate panel;
– k_L – Pressure distribution factor.

An alternative determination of the design load (according to TL [3] recommendations) involves defining the design load according to the nomogram, taking into account only two parameters – the length of a vessel and the speed of navigation. Other object parameters are ignored. The computational algorithm should be perceived as an attempt to assign restrictions “from above”.

Since the main task of creating formalized requirements for hull structures of small vessels is the emergence of these requirements as a part of current standards, the ISO standard algorithm should be considered applicable when designing structures with HDPE.

Algorithm for determining the strong dimensions of hull structures for plates and beams of the framing, manufactured from isotropic material, looks quite simple. The thickness of the sheathing and decking plates, the necessary moments of inertia and the resistance points of the set beams are determined. The permissible stress is assumed at the level of 90% of the yield strength of the material or 60% of the tensile strength. The question arises of applying this algorithm to determine the dimensions of structures from the material under consideration.

The simplest test of the adaptability of the algorithm is possible by comparing the parameters of the strength dimensions of the structural elements for a particular vessel in comparison with the results of direct calculations. It is clear that this scheme is applicable only for a rough assessment of the possibility of adapting the algorithm. For the sake of comarison, a plate of bottom plating and beams of a longitudinal regular set where chosen. Its required thickness and parameters of the longitudinal set are determined by direct calculation and in accordance with the requirements of the standard. In parallel, the required thickness is determined according to the recommendations of the Turkish Lloyd [3].

The project boat (GS 7300 Project) with the following main dimensions was chosen as an object for calculations. See Table 1.

Table 1. The main dimensions of the vessel

L_H, m	L_{WL}, m	B_H, m	B_{WL}, m	T_C, m	Δ, kg	B_C, m	$V, knot$
7,3	6,34	2,45	2,3	0,3	2500	1,92	30

The vessel was designed by the company “Gulf Stream” (Nikolaev). The appearance and shaping of the body are shown in Figure 3 and 4.

The calculated load was determined both by the ISO standard algorithm and by the Turkish Lloyd standards. The design is provided for welding, with a longitudinal

Figure 3. Outward appearance of the vessel

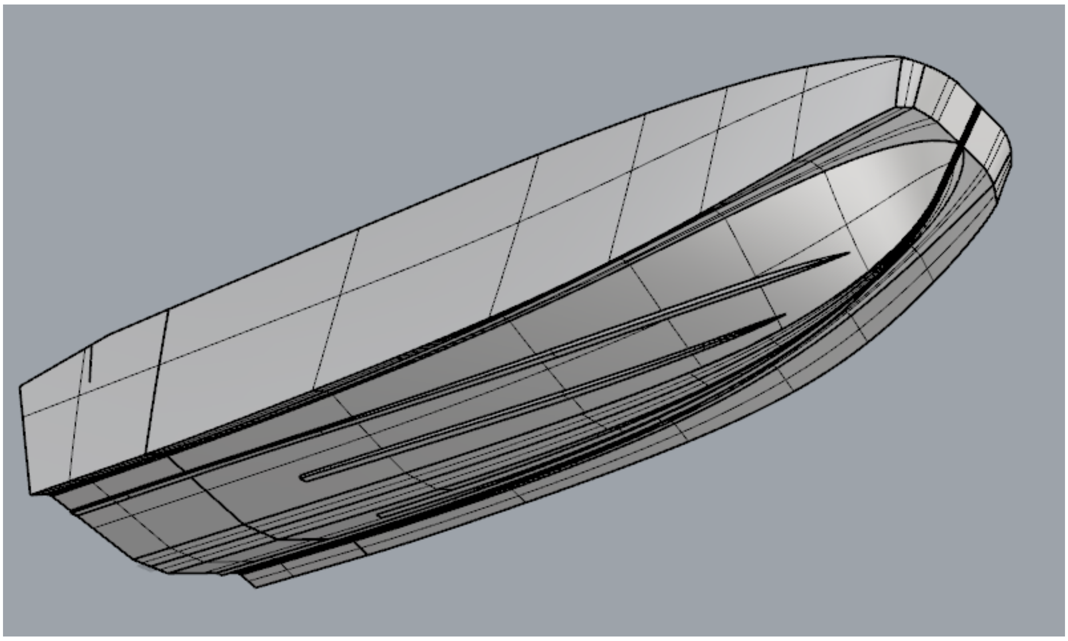


Figure 4. Shaping of the body

framing system. The space on the transverse frame is fixed – 1000 mm. Stringer space varies from 200 to 400 mm. Variations of spars are necessary to take into account the dynamic component of the external load. This adjustment is made according to the ratio of the size of the loaded plate. Permissible stresses were assumed as follows – Table 2.

Table 2. Maximum design stress

Material	HDPE
σ_y, MPa	25
σ_d, MPa	22,5

The values of the design loads depending on the size of the space and the results of calculations of the required plate thickness are given in Table. 3.

Table 3. Design loads and required plate thickness

l, mm	1000		
b, mm	200	300	400
$P_{b1}, kN / m^2$	69,9	54,9	45,2
t_{HE}, mm	7,9	10,5	12,7

Direct calculations of the required plate thicknesses were carried out by the finite element method (ANSYS) under the influence of design loads. For similar sizes of spars, the thickness of the plate varied. Iterations are suspended when the maximum values of the permissible voltages (22.5 MPa) were achieved. Results are referred to Table 4.

Table 4. Required plate thickness (calculated)

l, mm	1000		
b, mm	200	300	400
$P_{b1}, kN / m^2$	69,9	54,9	45,2
t_{HE}, mm	**6,8**	**9,3**	**11,4**

Thicknesses determined in accordance with the requirements of TENTATIVE RULES FOR POLYETHYLENE CRAFTS 2014Turkish Lloyd in [3] are shown in Table 5.

Table 5. Required panel thickness (TL)

l, mm	1000		
b, mm	200	300	400
$P_{b1}, kN / m^2$	44,7		
t_{HE}, mm	**8,1**	**12,2**	**16,2**

A comparison of the required thicknesses is shown in the diagram, see Figure 5.

The required plate thicknesses, determined by the calculation method, according to the requirements of the ISO standard and according to the recommendations of the TL with different sizes of spars diverge quite significantly. The ISO requirements and TL recommendations exceed the calculated panel thickness values of 200, 300, 400 mm, 36 and 67%, 32 and 60%, 50 and 100%, respectively.

The regulatory requirements (ISO and TL) for regulatory strategies are “constraints from above». The increase

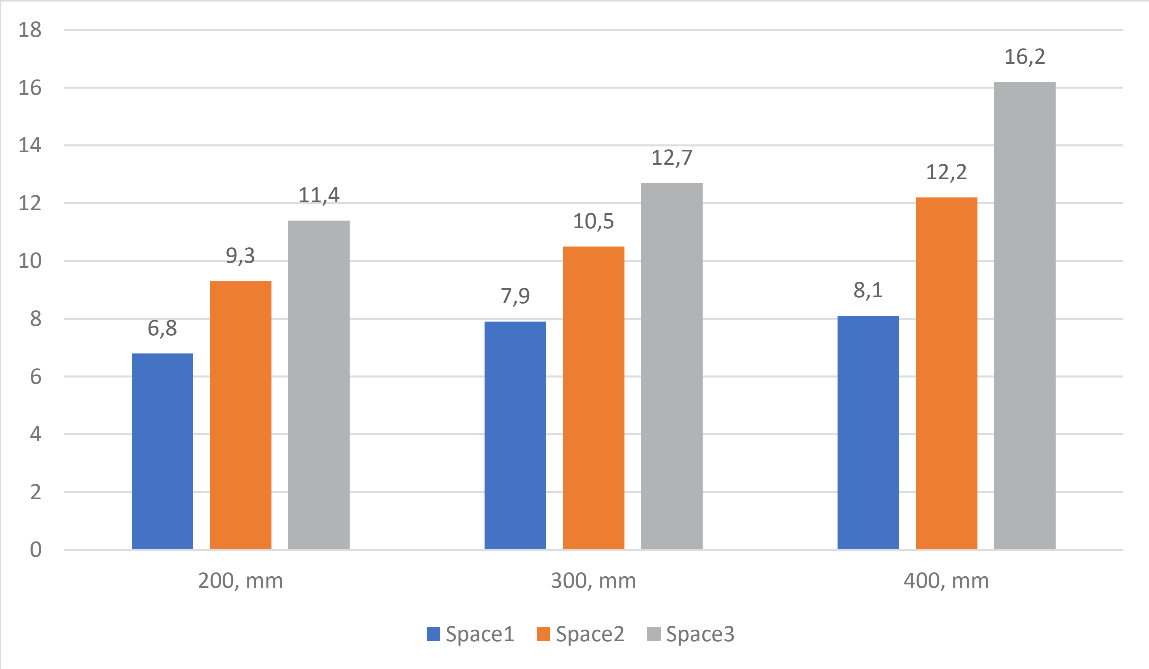


Figure 5. Comparison of required thicknesses

in discrepancy with the growth in the space size is due to the same reasons. In general, the requirements of the ISO standard for panel thickness in this case may be considered justified, and TL recommendations excessive.

The question of permissible stresses for the material of structures, first of all, is associated with the high malleability of polyethylene, since the rationing of strength is quite reasonable. In Figure. 6-8 shows the stress and strain diagrams for the calculated case under consideration, with spaces of 200, 300, 400 mm.

According to the simulation results, it was established that with an estimated space of 200 mm. the plate is affected by a pressure of 69.9 MPa, while a voltage of 22.6 MPa and a maximum deformation of 8.5 mm occur in the plate.

Increasing the calculated space to 300 mm and 400 mm causes stresses of 22.5 MPa and 22.6 MPa and deformations of 13.3 mm and 18.7 mm, respectively.

Direct calculations of the required elements of longitudinal stiffeners were carried out by the finite element method (ANSYS) under the influence of calculated linear loads. For similar spar sizes and previously obtained bottom plate thicknesses, the width of the attached belt was calculated. The required ISO value of the section modulus was taken according to the appropriate standard.

Subsequently, the height of the wall of the stiffener was varied with a constant thickness of 10 mm. Iterations stopped when the maximum values of the permissible voltages (22.5 MPa) were reached. Stiffeners were similarly selected in the case of direct calculation and calculation according to TL requirements. The dimensions of the attached belt in all cases were accepted according to the requirements of the ISO standard. Results are presented in Table. 6.

Table 6

l, mm	1000		
b, mm	200	300	400
ISO Small craft			
$P_{b1}, kN/m^2$	69,9	54,9	45,2
t_{HE}, mm	7,9	10,5	12,7
w, mm	99,6	132,3	160,1
SM, cm^3	51,8	61	67
$t/h,\ mm$	10/143	10/149	10/153
MCE			
t_{HE}, mm	6,8	9,3	11,4
w, mm	85,7	117,2	143,7
SM, cm^3	51,8	61	67
$t/h,\ mm$	10/143	10/146	10/148
σ, MPa	22,13	22,23	22,11
TL			
$P_{b1}, kN/m^2$	100		
t_{HE}, mm	8,1	12,2	16,2
w, mm	102	153,7	204,2
SM, cm^3	74	111	148
$t/h,\ mm$	10/173	10/201	10/226

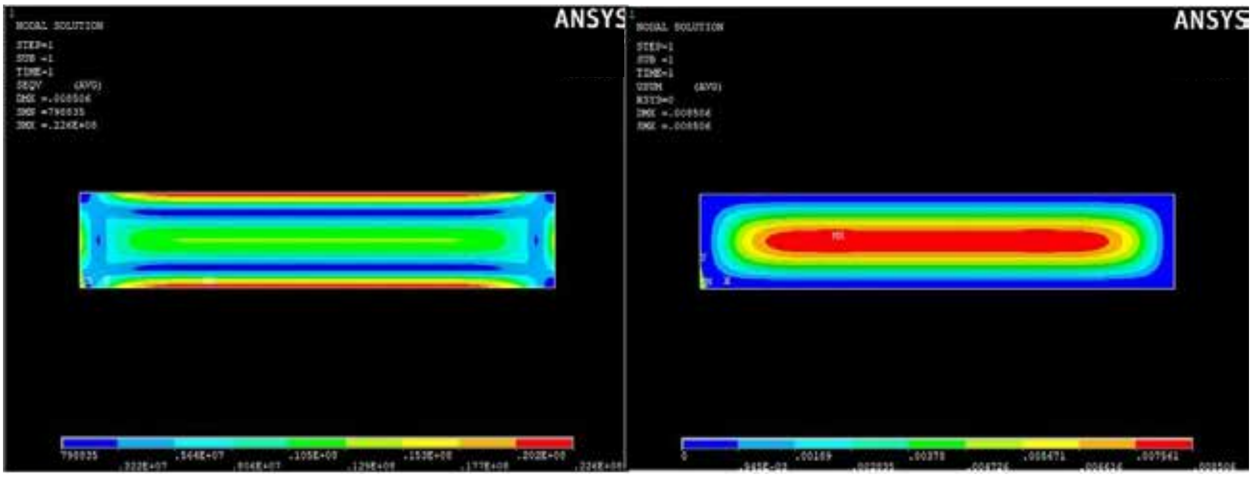


Figure 6. Stress and displacement diagrams at 200 mm space

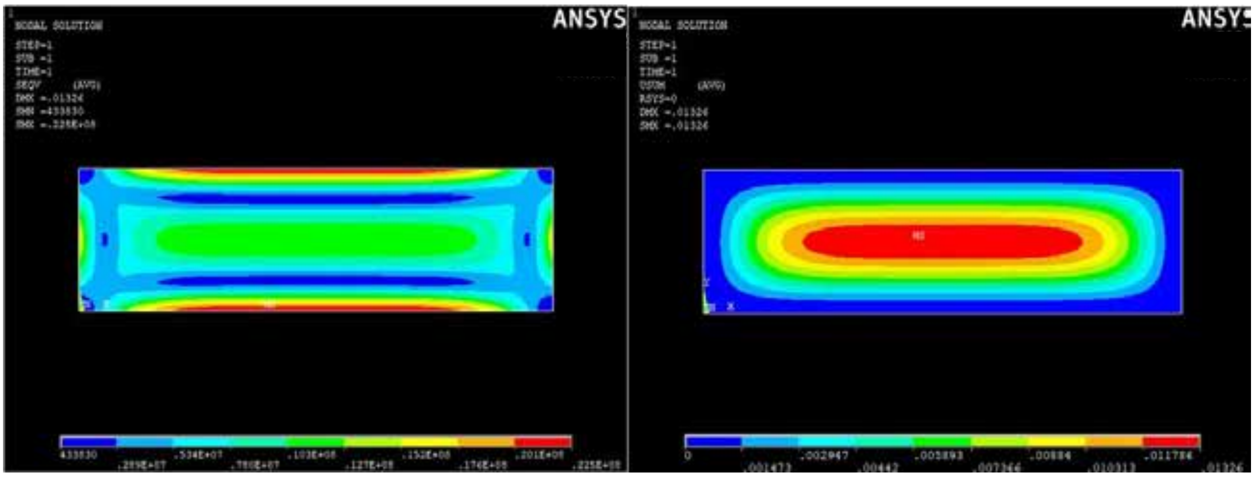


Figure 7. Stress and displacement diagrams at 300 mm space

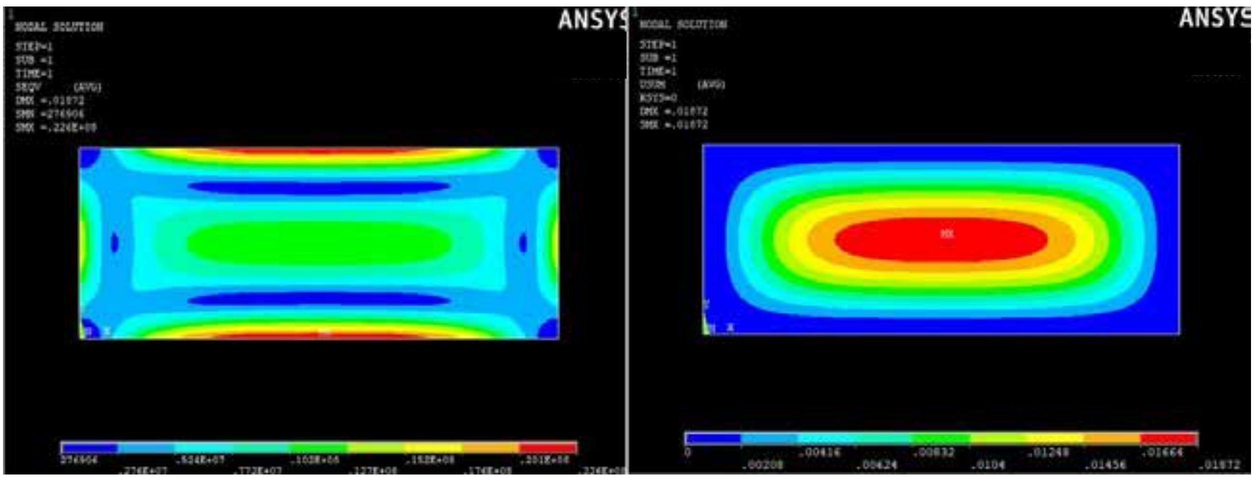


Figure 8. Stress and displacement diagrams at 400 mm space

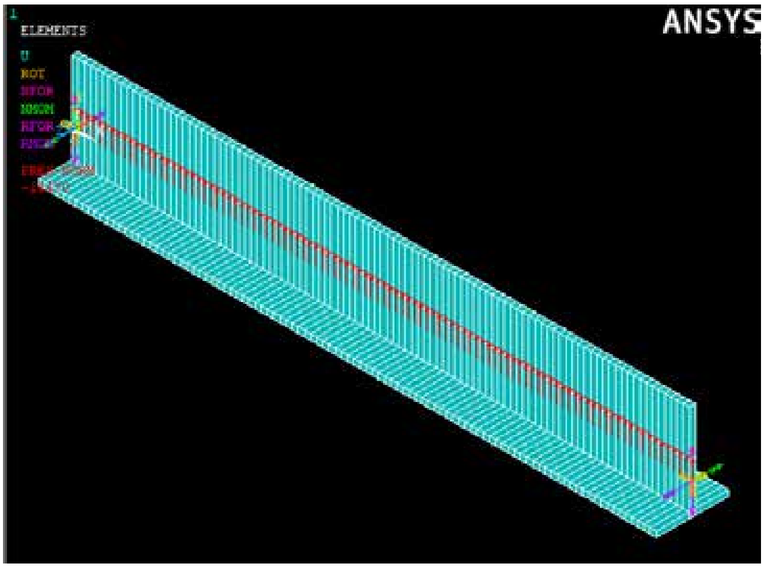


Figure 9.

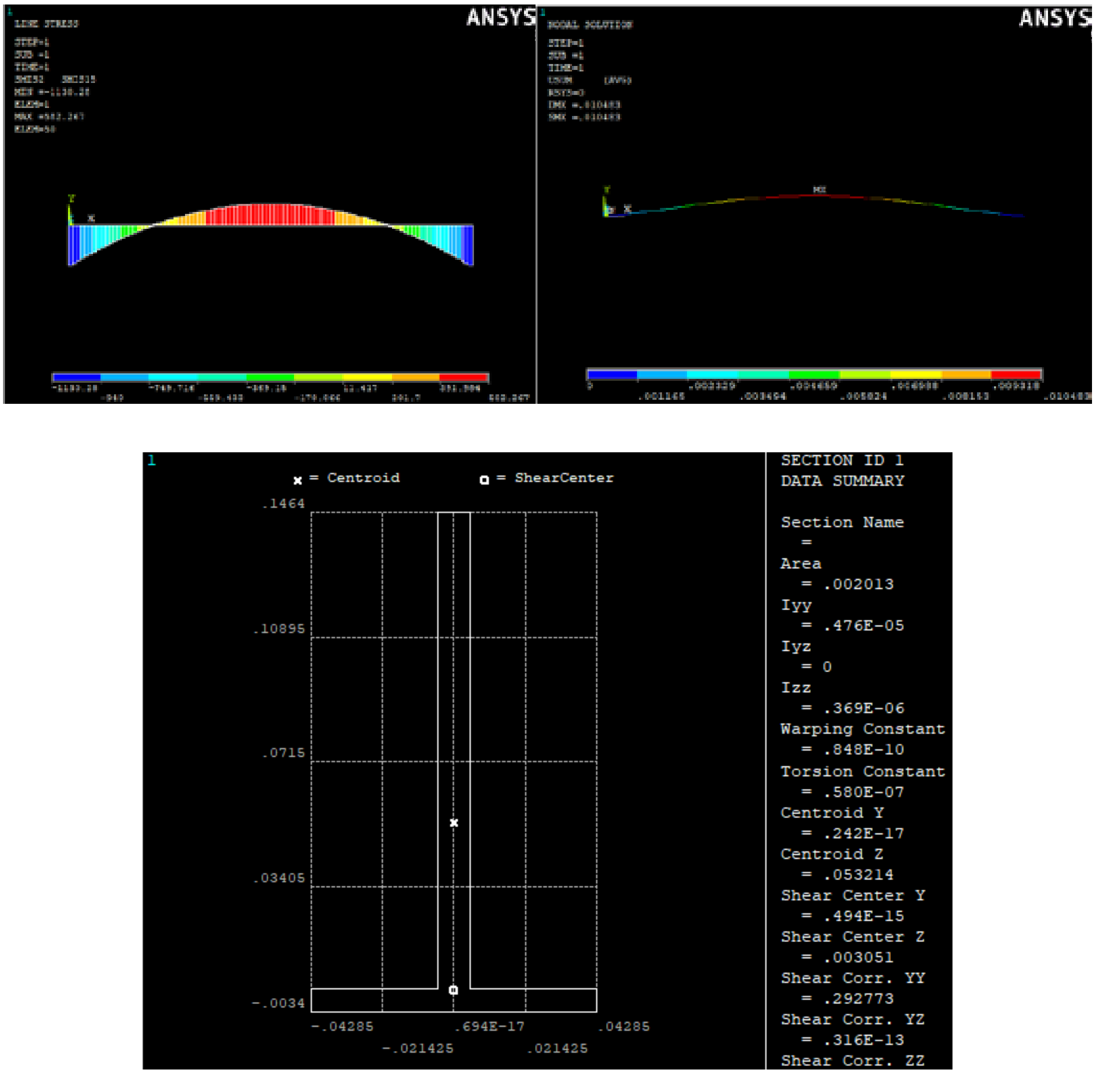
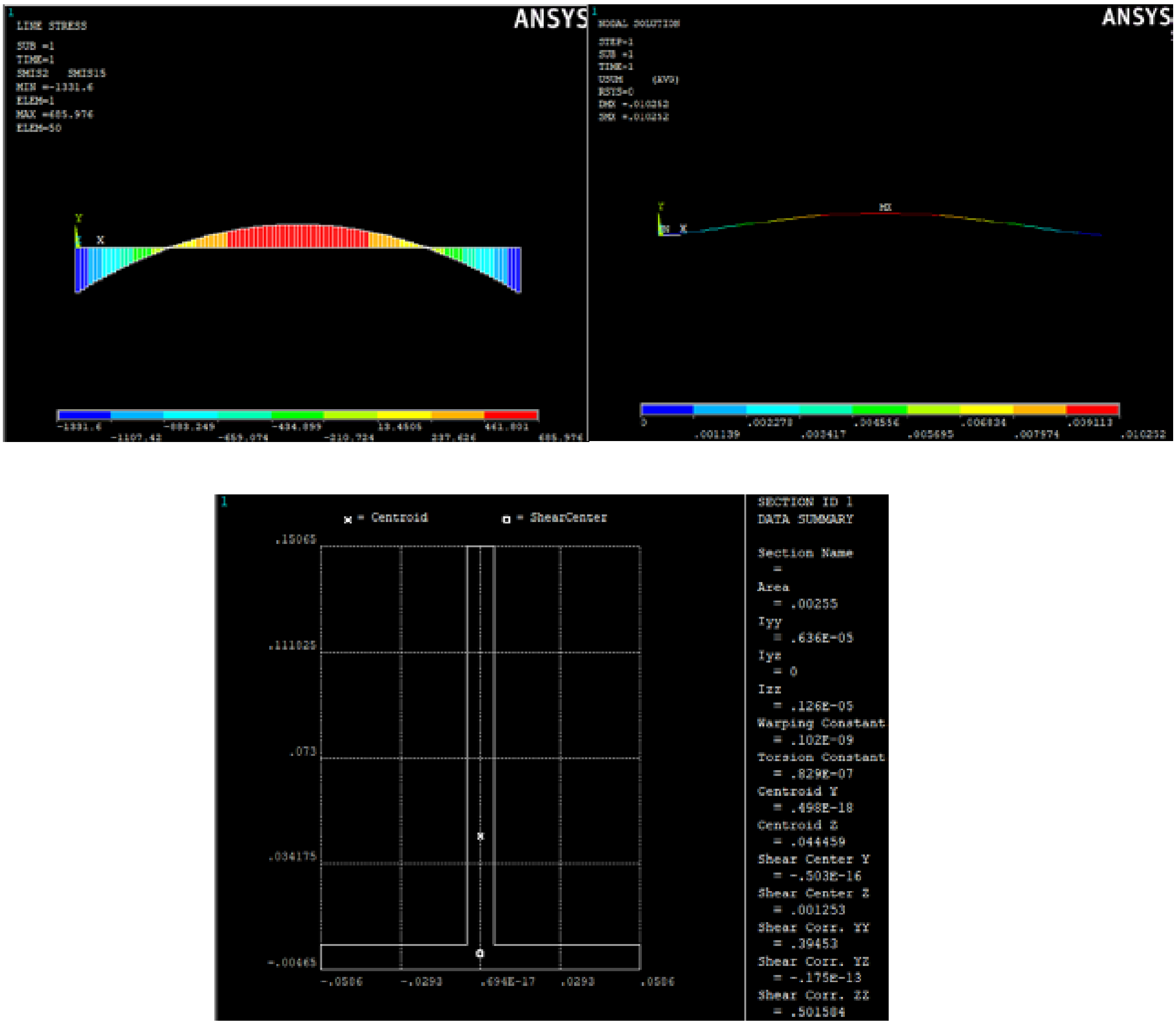


Figure 10.


ANSYS
LINE STRESS
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TIME=1
SMIS2 SMIS15
MIN =-1331.6
ELEM=1
MAX =685.976
ELEM=50
Y
X
-1331.6 -1107.42 -883.249 -659.074 -434.899 -210.724 13.4505 237.626 461.801 685.976
ANSYS
NODAL SOLUTION
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SUB =1
TIME=1
USUM (AVG)
RSYS=0
DMX =.010232
SMX =.010232
MX
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X
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× = Centroid
□ = ShearCenter
.15065
.111825
.073
.034175
-.00465
-.0586
-.0293
.694E-17
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DATA SUMMARY
Section Name
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Area
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Iyy
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Iyz
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Izz
= .126E-05
Warping Constant
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Torsion Constant
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Centroid Y
= .498E-18
Centroid Z
= .044459
Shear Center Y
= -.503E-16
Shear Center Z
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Shear Corr. YY
= .39453
Shear Corr. YZ
= -.175E-13
Shear Corr. ZZ
= .501584

Figure 11.

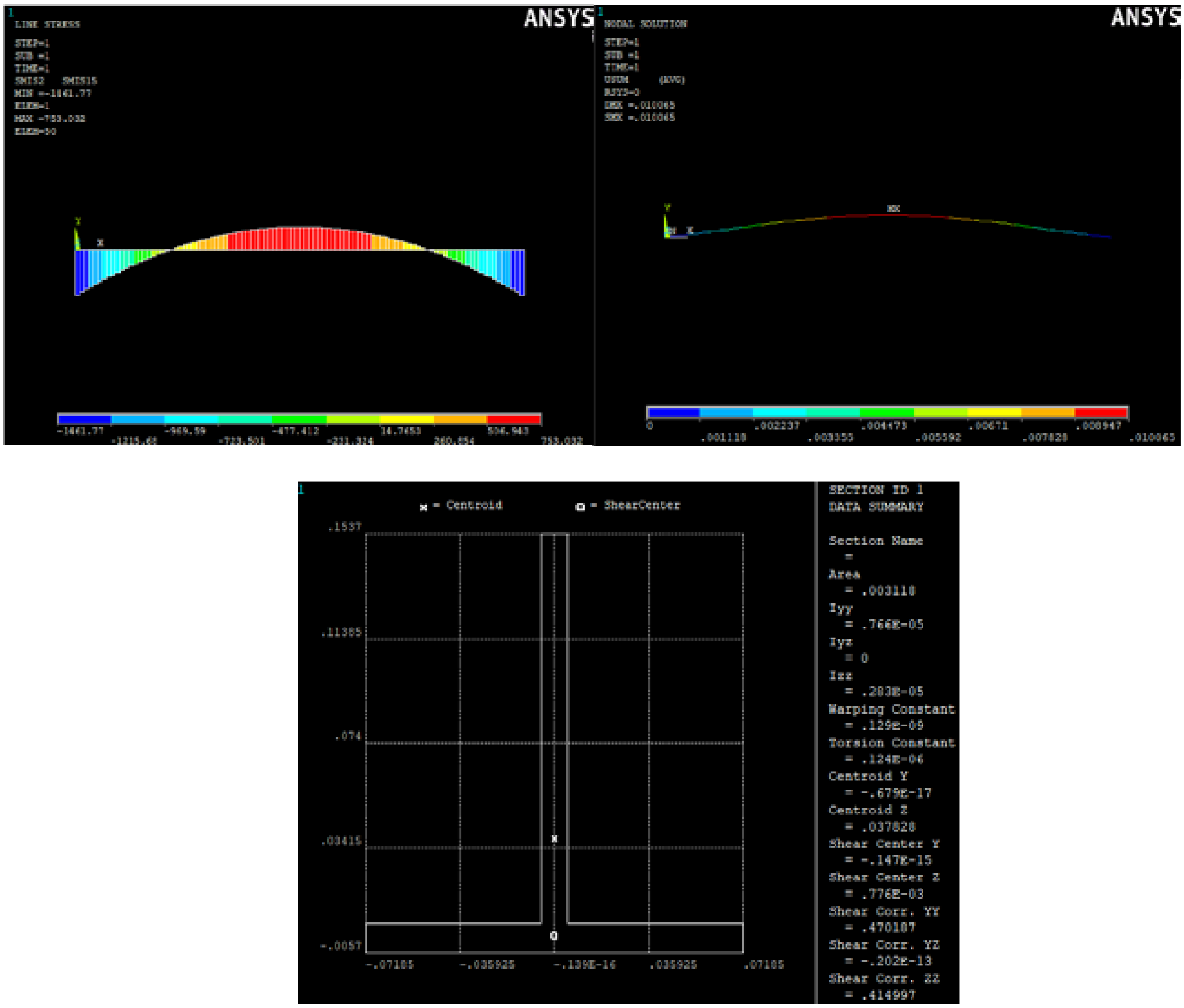

Figure 12.

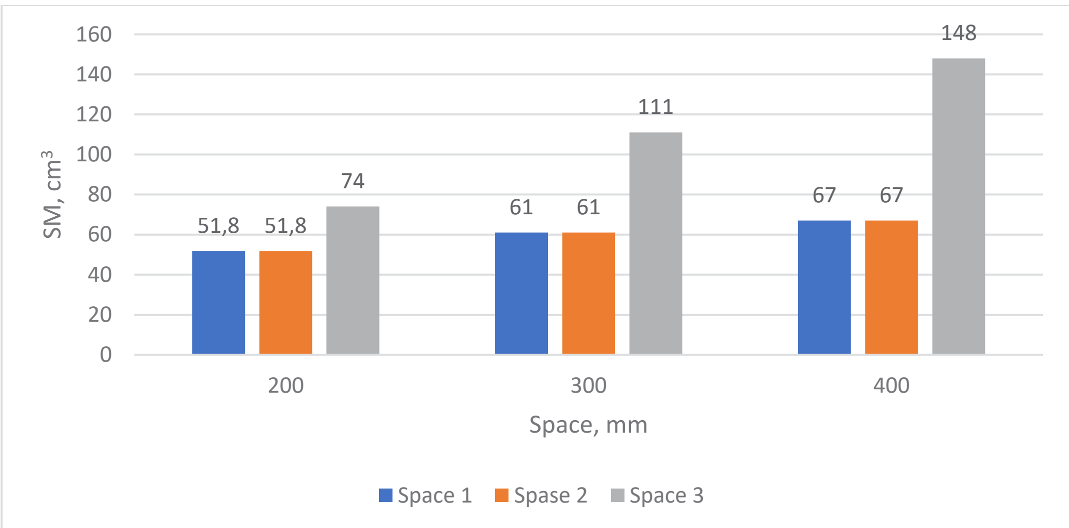

Figure 13. Comparison of the required section modulus values

In this case, the final calculations of the stress values for the asymmetrical beam were calculated separately, based on the data obtained as a result of simulation. The simulation results can be found in Figures 9, 10, 11, 12.

Comparison of the values of the required resistance moments is shown in Figure 13.

The section modulus determined by the requirements of the ISO standard and the calculation method are almost the same. The section modulus determined by the TL Rules is much higher. First and formost it is due to excessive design loads.

CONCLUSIONS

The results of the study demonstrate the possibility of adapting the requirements of the ISO standards of the Small craft group for the design of high-density polyethylene hull structures for small vessels. It is advisable to conduct more extensive research with the inclusion of frame connections in their area. It is necessary to additionally consider the requirements for permissible stresses and deformations of structures manufactured from HDPE.

Since the studies were conducted at the stresses allowed at 90% yield strength of the material and the deformation where quite significant, in future, it is considered appropriate to conduct research on their limitations in real structures. For this material, the issues of regulation of allowed stresses and deformations are quite important.

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