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CALCULATION ELEMENTS FOR FLAT, WELDED LUGS, FOR LIFTING OR ANCHORING OVERSIZED INDUSTRIAL EQUIPMENT

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The general technical safety of the mechanical structures with large and oversized masses must be carefully analyzed, both during the lifting and handling phase for installation on foundations, but also during the transport from the supplier to the client. This article shows how to evaluate the stress states developed in the flat, symmetrical lugs, welded to the cylindrical shells, with or without reinforcing plates. It is considered a static load, in the elastic field, the construction materials being considered to be isotropic, continuous and homogeneous.

Keywords: Oversized industrial equipment, flat lugs for lifting or anchoring, stress state, static load.

1. Introduction

The correct operation of industrial technological equipment, after its commissioning, depends, among other things, on how they are loaded, fixed and unloaded from the transportation platforms. Therefore, it is necessary to establish correctly the methods and techniques that lead to minimum mechanical stresses, without having to change the geometry of the construction in question, in the preparatory stages of transportation, during transportation or during the unloading of the equipment from platforms. Particular attention should be paid to vessel-type structures, whose rigidity is not always high enough, without additional stiffening measures. Some of these stiffeners can be used during the lifting operations of the structure on foundations, being subsequently removed.

Also in the sense of the above, it is necessary to adequately support the transportation platforms [1, 2] and ensure the stability of the longitudinal [3-9] and

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transverse movement of the loaded platforms [10 - 15], taking into account the weather conditions, road conditions, outside or inside the construction sites, the effect of the dynamic loads produced and the wind effects. In this order of ideas, the corresponding values of the towing forces of the means used on the whole route or on certain parts of the road must also be ensured [16 - 19]. To ensure a safe transport from the manufacturer to the client, a precise analysis of the maximum loads developed in the constructive elements for lifting or anchoring, such as trunnions [1, 19] or flat, welded, symmetrical or asymmetrical lugs - construction and calculation - [20 - 29, 35 - 40], respectively other types (welded or screwed rings, single or double lugs, cast, welded or screwed [41- 43]) etc.. The intensity of the stress states created both in the lifting or anchoring elements is assessed both analytically and by numerical and experimental methods, respectively on models or on the spot.

This paper presents the way to estimate the state of tensions at the base of a symmetrical flat lug, under spatial action, in the case of anchoring cylindrical equipment on transport platforms. The method of analysis allows the assessment of the bearing capacity of the lug if the geometry of the anchorage is not as prescribed. An appropriate calculation program can allow the acceptance of the construction or the taking of other constructive measures specific to the field.

2. Flat lugs used for anchoring transported equipment

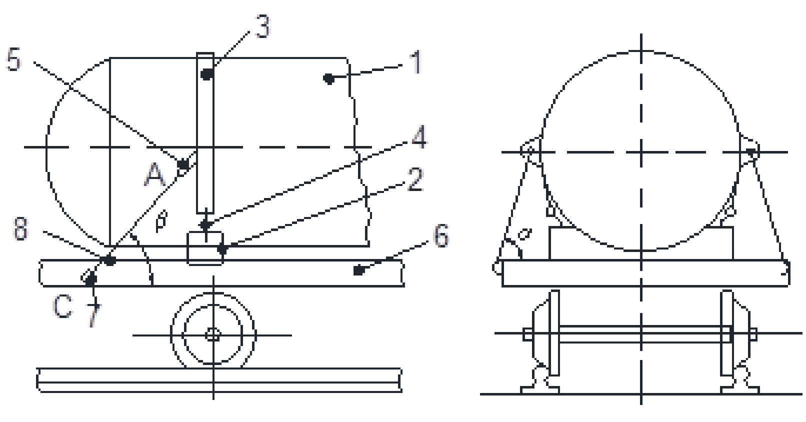

Fig. 1. A way of anchoring technological equipment on transportation platforms (sketch)
1- vessel; 2 – support; 3 – belt; 4 – fixing the belt to the platform; 5 – lug; 6 – platform (wagon or trailer); 7 – platform fixing point (eyelet); 8 – anchoring cable

In such an activity the anchors have one end connected to the eyelets mounted on the side of the transport means (platform or wagon), while the second end is connected to the lugs welded on the outer surface of the technological equipment.

The lugs are fixed in the horizontal longitudinal plan (Fig. 2) - when the diameter of the equipment is smaller than the width of the platform – or below the angle γ (Fig. 4) - when the diameter of the equipment is larger than the platform width.

For sizing or checking the lugs, we first determine the forces acting along the chosen reference system (Fig. 2 and 4): axis *A x*, parallel to the horizontal axis of the equipment; axis *A y*, along the radius of the equipment, located in the horizontal plan; axis *A z*, in the vertical direction.

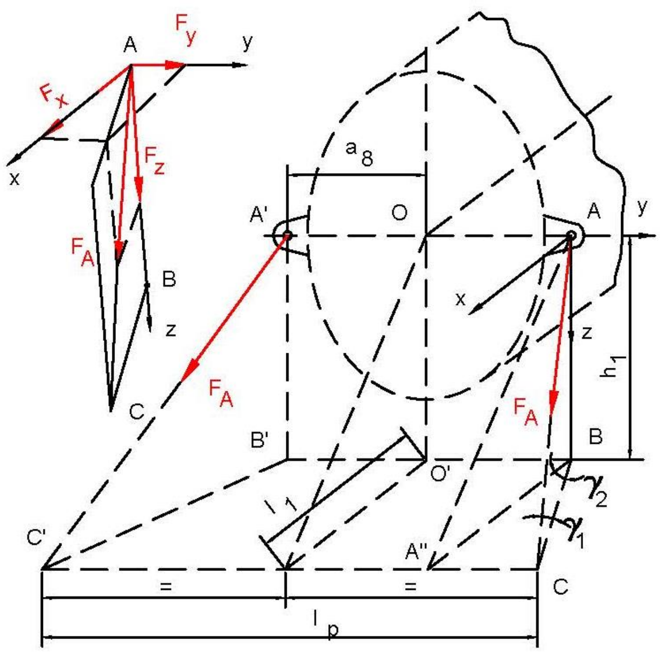

Fig. 2. Anchoring equipment with an outer diameter smaller than the width of the transport platform (sketch) [1].

2. 1. Forces developed in the lug structure

2. 1. 1. Sizing or checking the geometry of a lug

The following hypotheses are considered: **a)** the effects produces by the curvature of the external surface of the lifted or anchored equipment in the lug area are neglected; **b)** the structure is considered as a non-deformable massif; **c)** the lug material is homogeneous and isotropic; **d)** the stress on the lug is in the elastic range; **e)** the forces are considered concentrated in their points of application; **f)** the lifting and handling is done slowly, without shocks.

2. 1. 1. 1. The diameter of the equipment is smaller than the width of the transportation platform (Fig. 2)

Accepting, in a first phase that the lugs are normal to the longitudinal axis of the transported equipment, the force F_A resulting from the tensioning of the anchors, decomposes along the three axes of the reference system (where this time the axis Ay is along the radius OA), as follows:

$$F_x = F_A \cdot \cos\gamma_1 \cdot \cos\gamma_2 ; F_y = F_A \cdot \cos\gamma_1 \cdot \sin\gamma_2 ; F_z = F_A \cdot \sin\gamma_1, \quad (1)$$

where:

$$\gamma_1 = \arcsin\frac{h_1}{\sqrt{h_1^2 + \left(0.5 \cdot l_p - a_8\right)^2}} ; \gamma_2 = \arccos\frac{l_1}{\sqrt{l_1^2 + \left(0.5 \cdot l_p - a_8\right)^2}}, \quad (2)$$

respectively: h_1 - the height of the lug from the lateral eyelet of the platform; l_p - width of platform; a_8 - the distance from the center of the lug to the vertical plan passing through the longitudinal axis of the equipment; l_1 - the distance measured horizontally from the anchor fixing eye to the wagon platform, to the vertical plan containing the anchoring lugs.

Table 1.

The effects of forces F_x, F_y, F_z (Fig. 2) [30 – 32]

Force	**Stress state**	**No. equation**
F_x	Shear: $\tau_x = \left[F_x/\left(s \cdot l_u\right)\right] \cdot \left(1.5 - 6 \cdot x^2/s^2\right)\ x \in [0;\ s/2]$;	(3)
	Bending: $\sigma_x = \pm\left[12 \cdot M_x/\left(s^3 \cdot l_u\right)\right] \cdot x = \pm\left[12 \cdot F_x \cdot c/\left(s^3 \cdot l_u\right)\right] \cdot x$	(4)
F_y	Tensile: $\sigma_y = F_y/\left(s \cdot l_u\right)$,	(5)
F_z	Shear: $\tau_z = \left[F_z/\left(s \cdot l_u\right)\right] \cdot \left(1.5 - 6 \cdot z^2/l_u^2\right);\ z \in [0;\ l_u/2]$;	(6)
	Bending: $\sigma_z = \pm\left[12 \cdot M_z/\left(s \cdot l_u^3\right)\right] \cdot z = \pm\left[12 \cdot F_z \cdot c/\left(s \cdot l_u^3\right)\right] \cdot z$;	(7)

The stress state developed by the components F_x, F_y, F_z the base of the lug is ilustrated in Table 1.

Note : The plus and minus signs in relations (4) and (7) are easy to choose, taking into account Figure 3.

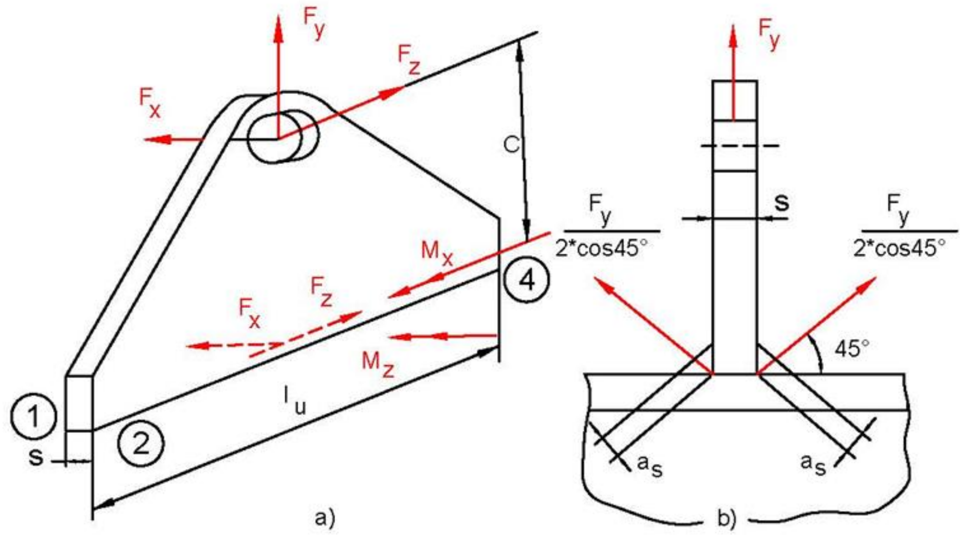

Fig. 3. Determining the signs of bending stresses of the lug (sketch)

a – the positioning of the total force components that act on the lug; b – decomposition of component Fy into the longitudinal weld seams at the base of the lug [1].

The equivalent stress is calculated with the relation:

$$\sigma_{ech} = \sqrt{\left(\sigma_x + \sigma_y + \sigma_z\right)^2 + 3\left(\tau_x^2 + \tau_z^2\right)}, \tag{8}$$

in which it was taken into account that all stresses $\sigma_x, \sigma_y, \sigma_z$ act along the Ay axis.

Using the appropriate stress expressions, formula (8) becomes:

$$\sigma_{ech} = \left[1/\left(s \cdot l_u\right)\right] \cdot \sqrt{f(x,z)}, \tag{9}$$

$$\frac{c}{l_u} < \sqrt{\frac{3}{8}}; \quad \frac{l_u^4 \cdot c^2}{4} \cdot \left(\frac{2 \cdot c \cdot x}{s^2} \cdot \frac{F_x}{F_z} + \frac{1}{6} \cdot \frac{F_y}{F_z}\right)^2 + \frac{1}{9}\left(\frac{2 \cdot c^2}{3} - \frac{l_u^2}{4}\right)^3 \geq 0. \tag{10}$$

Solution z_1 is interesting, which belongs to the domain $\left[0;\ l_u/2\right]$, where:

$$z_1 = \sqrt[3]{-q_z/r + \sqrt{q_z^2/4 + p_z^3/27}} + \sqrt[3]{-q_z/r - \sqrt{q_z^2/4 + p_z^3/27}}\ , \quad (11)$$

where:

$$p_z = 2\cdot c^2/3 - l_u^2/4;\quad q_z = l_u^2\cdot c\cdot\left[2\cdot c\cdot x/s^2 + F_x/F_z + F_y/\left(6\cdot F_z\right)\right]/3. \quad (12)$$

When z_1 satisfies the required condition, it is then calculated further:

$$\sigma_{ech,z_1} = \sqrt{f\left(0.5s;\ z_1\right)}/\left(s\cdot l_u\right)\ . \quad (13)$$

The maximum equivalent stress, developed in the simple lug, is determine by the relation:

$$\sigma_{ech,M} = \max\left\{\sigma_{ech,2};\sigma_{ech,5};\sigma_{ech,7};\sigma_{ech,8};\sigma_{ech,z_1}\right\}, \quad (14)$$

when $z_1 \in \left[0;\ l_u/2\right]$, or

$$\sigma_{ech,M} = \max\left\{\sigma_{ech,2};\sigma_{ech,5};\sigma_{ech,7};\sigma_{ech,8}\right\}, \quad (15)$$

when $z_1 \notin \left[0;\ l_u/2\right]$.

For the calculation of the stresses $\sigma_{ech,2}, \sigma_{ech,5}, \sigma_{ech,7}, \sigma_{ech,8}$ the following functions are used:

$$f\left(0.5\cdot s;\ 0.5\cdot l_u\right),\quad f\left(0.5\cdot s;\ 0\right),\quad f\left(0;\ 0.5\cdot l_u\right),\quad f\left(0,0\right).$$

In the case of checking the lug geometry , $\sigma_{ech,M} \le \sigma_{au}$, where σ_{au} is the allowable stress of the lug material, determined by the relation $\min\left\{\sigma_c/c_c;\sigma_r/c_r\right\}$, where σ_c, σ_r - yield strength and tensile strength of the lug material; $c_c = 1{,}5$ and $c_r = 2.4$ - safety factors for yield and tensile strength of the material [33, 34]. When dimensioning the lug, taking into account, as a rule, its thickness, equal to that of the shell or of the stiffening plate, the length l_u is determined from the equality $\sigma_{ech,M} = \sigma_{au}$. Once the sizing of the lug base is finished, the configuration of the upper area of the lug will begin, taking into account the size of the anchor that passes through the lug hole for holding the cable for anchoring [1, 42].

2. 1. 1. 2. The diameter of the equipment is larger than the width of the transportation platform (Fig. 4)

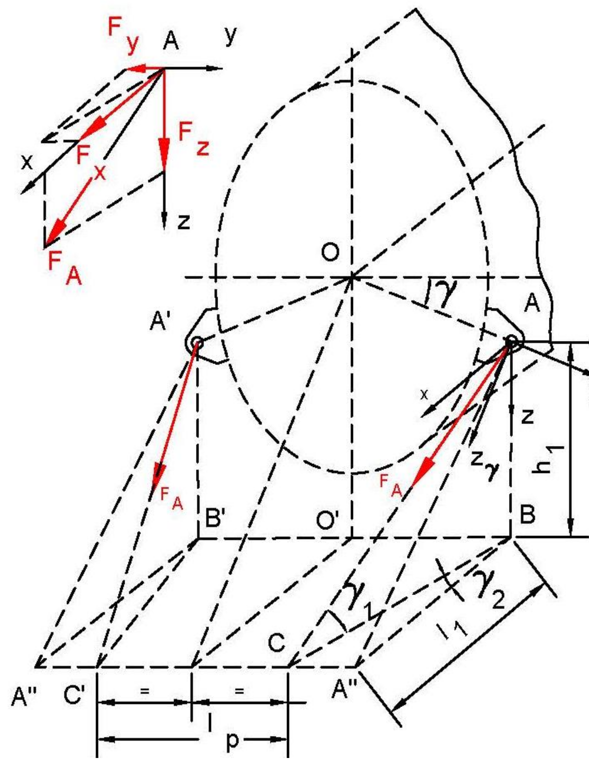

Fig. 4. Anchoring equipment with an outer diameter larger than the width of the transport platform (sketch) [1].

In order to be able to use the relations (3 … 7), the initial reference system will rotate around the Ax axis with the angle γ (Fig. 4), so that the Ay axis is along the radius of the equipment at contact with the lug, and the Az axis is parallel to the tangent at the circumference of the equipment, in the same place. The forces necessary to calculate the stress state, according to the methodology presented above, will have the expressions (the lug is normal to the symmetry axis of the structure):

$$F_x = F_A \cdot \cos\gamma_1 \cdot \cos\gamma_2;\; F_y = F_A \cdot (\sin\gamma_1 \cdot \sin\gamma + \cos\gamma_1 \cdot \sin\gamma_2 \cdot \cos\gamma);$$

$$F_z = F_A \cdot (\sin\gamma_1 \cdot \cos\gamma - \cos\gamma_1 \cdot \sin\gamma_2 \cdot \sin\gamma). \qquad (16)$$

Note : When the lug is inclined at an angle γ_a to the axis of the equipment, the components of force F_A along the reference system axes have the expressions:

$$F_x^* = F_A \cdot \left[\cos\gamma_1 \cdot \cos\gamma_2 \cdot \sin\gamma_a - \cos\gamma_a \cdot \begin{pmatrix} \sin\gamma_1 \cdot \cos\gamma - \\ -\cos\gamma_1 \cdot \sin\gamma_2 \cdot \sin\gamma \end{pmatrix} \right];$$

$$F_y^* = F_A \cdot [\sin\gamma_1 \cdot \sin\gamma + \cos\gamma_1 \cdot \sin\gamma_2 \cdot \cos\gamma];$$

$$F_z^* = F_A \cdot \left[\cos\gamma_1 \cdot \cos\gamma_2 \cdot \cos\gamma_a + \sin\gamma_a \cdot \begin{pmatrix} \sin\gamma_1 \cdot \cos\gamma - \\ -\cos\gamma_1 \cdot \sin\gamma_2 \cdot \sin\gamma \end{pmatrix} \right]. \qquad (17)$$

3. Conclusions and perspectives

In the above presentation was discussed the case of transporting oversized cylindrical equipment and large masses, with a diameter smaller or larger than the width of the transport platform, in difficult conditions, conditioned by the route configuration, weather conditions and directions of action. In this context, the problem of secure anchoring was approached, using symmetrical, welded flat lugs, positioned perpendicular to the geometric axis or inclined (the geometry of the cast, welded or glued lugs was not taken into account, along the base or on the side). In this analysis the forces are considered static. They can be corrected with dynamism coefficients, with values accepted for the approached case. The results can also be applied in the stability analysis of equipment fixed on foundations, such as columns, chimneys, support pillars, etc., taking into account the effects of wind or seismic loads and, why not, plastic deformations of the foundations.

The developed analysis considers the correct dimensioning of the base of the lugs, for an accepted geometry, including its *optimization*. It is a restrictive approach, as the overall optimization is strictly necessary to establish the minimum value of the stress state in the ensemble : transported equipment - anchoring lugs (respectively their geometry: rectangular shape with non-chamfered, chamfered or rounded top, semicircular, semi-elliptical, triangular, symmetrical or not, etc.) - unstiffened anchoring position or not - presence or not of a consolidation plate between the lug and the cylindrical body - geometry of the welding seams.

The final conclusion must be established after comparing the results of the analytical analysis, the numerical and / or experimental analysis, for a given case, as suggested in the structure of the accepted bibliography for this article.

R E F E R E N C E S

[1]. *Iatan I. R., Vasilescu, I.,* Transportarea utilajelor tehnologice agabaritice (Transportation of oversized technological equipment), Editura Matrix Rom, Bucureşti, 2002.

[2]. *Iatan I. R.,* Aspecte privind rezemarea echipamentelor pe platforme de transport (Aspects regarding the support of equipment on transport platforms, Car construction), Construcţia de maşini, 54, nr. 1-2, 2002, p. 9 -12 (ISSN 0573 -7419).

[3]. *Iatan I. R., Dumitrescu V.,* Longitudinal stability of platforms for the transportation of technological no gauge equipments (I), Modelling and Optimization in the Machines Building Field, Romanian Academy, Branch Office of Iaşi, MOCM 8, 2002, p. 78 – 84 (ISSN 1224 – 7480).

[4]. *Iatan I. R., Dumitrescu V.,* Longitudinal stability of platforms for the transportation of technological no gauge equipments (II), Modelling and Optimization in the Machines Building Field, Technical Sciences Academy of Romania, University of Bacău, MOCM 9, 2003, vol.1, p. 47 – 51 (ISSN 1224 – 7480).

[5]. *Iatan I. R., Dumitrescu V.,* Stabilitatea longitudinală a platformelor pentru transportarea utilajelor tehnologice agabaritice (Longitudinal stability of platforms for transporting oversized technological equipment - III), Buletinul ştiinţific al celei de a XXVIII-a Conferinţă Naţională de Mecanica Solidelor, Secţiunea 4, Universitatea Valahia din Târgovişte (The Scientific Bulletin of the XXVIII National Conference on Solid Mechanics, Section 4, Valahia University of Târgovişte), 28 – 29 mai 2004, p. 60 – 64 (ISBN 973 – 86834 – 5 – 9).

[6]. *Iatan I. R.,* Stabilitatea longitudinală a platformelor pentru transportarea utilajelor tehnologice agabaritice (Longitudinal stability of platforms for transporting oversized technological equipment - IV), Buletinul ştiinţific al celei de a XXVIII-a Conferinţă Naţională de Mecanica Solidelor, Secţiunea 4, Universitatea Valahia din Târgovişte (The Scientific Bulletin of the XXVIII National Conference on Solid Mechanics, Section 4, Valahia University of Târgovişte), 28 – 29 mai 2004, p. 65 – 69 (ISBN 973 – 86834 – 5 – 9).

[7]. *Iatan I. R., Salca Cristina, Stătescu M.,* Stabilitatea mişcării longitudinale a platformelor tip 4 x 4 pentru transportarea echipamentelor tehnologice agabaritice (The stability of longitudinal movement of 4 x 4 type platforms for transporting oversized technological equipment), Sinteze de Mecanică Teoretică şi Aplicată (Synthesis of Theoretical and Applied Mechanics), vol. 7, nr. 1, 2016, p. 51 – 62 (ISSN 2068 – 6331)

[8]. *Iatan I. R., Stătescu M., Salca Cristina,* The stability of longitudinal movement during the transportation of industrial oversized equipment on a platform with an even number of axles. General case, The Scientific Bulletin of VALAHIA University MATERIALS and MECHANICS, vol. 15, nr. 12, 2017, p. 43 – 47 (ISSN 1844 – 1076).

[9]. *Stătescu M., Iatan I. R., Durbacă I., Enăchescu Georgiana Luminiţa,* Aspecte privind siguranţa transportării echipamentelor industriale agabaritice. Stabilitatea mişcării longitudinale a mijloacelor pentru tractare rutieră (Aspects regarding the safety of transporting oversized industrial equipment. The stability of longitudinal movement of road towing devices), Sinteze de Mecanică Teoretică şi Aplicată (Synthesis of Theoretical and Applied Mechanics), 10, nr. 4, 2019, p. 231 – 246 (ISSN 2068 – 6331).

[10]. *Iatan, I. R., Sima T.,* Stabilitatea transversală a platformelor pentru transportarea utilajelor tehnologice agabaritice (Transverse stability of platforms for transporting oversized

technological equipment - I), Construcţia de maşini (Car construction), 55, nr. 4, 2003, p. 53 – 56 (ISSN 0573 – 7419).

[11]. *Iatan I. R., Sima T.,* Stabilitatea transversală a platformelor pentru transportarea utilajelor tehnologice agabaritice (Transverse stability of platforms for transporting oversized technological equipment - II), Construcţia de maşini (Car construction), 55, nr. 5, 2003, p. 53 – 60 (ISSN 0573 – 7419).

[12]. *Iatan I. R., Sima T.,* Stabilitatea transversală a platformelor pentru transportarea utilajelor tehnologice agabaritice (Transverse stability of platforms for transporting oversized technological equipment - III), Construcţia de maşini (Car construction), 55, nr. 7 - 8, 2003, p. 34 – 38 (ISSN 0573 – 7419)

[13]. *Iatan I. R.,*The transversal stability of the platforms for the transportation of the great technological equipment (IV), Modelling and Optimization in the Machines Building Field, MOCM – 10, University of Bacău, vol. 1, 2004, p. 62 – 67 (ISSN 1224 – 7480).

[14]. *Iatan I. R.,*The transversal stability of the platforms for the transportation of the great technological equipment (V), Modelling and Optimization in the Machines Building Field, MOCM – 10, University of Bacău, vol. 1, 2004, p. 68 – 72 (ISSN 1224 – 7480).

[15]. *Stătescu M., Iatan I. R., Durbacă I., Enăchescu Georgiana – Luminiţa,* Aspecte privind siguranţa transportării echipamentelor industriale agabaritice. Stabilitatea transversală a mişcării vehiculelor pentru transportare şi a platformelor încărcate (Aspects regarding the safety of transporting oversized industrial equipment. Transverse stability of the movement of transport vehicles and loaded platforms), Sinteze de Mecanică Teoretică şi Aplicată (Syntheses of Theoretical and Applied Mechanics), vol. 11, nr. 1, 2020, p. 43 – 56 (ISSN 2068 – 6331).

[16]. *Iatan I. R., Stătescu M., Durbacă I., Enăchescu Georgiana Luminiţa,* Considerations concerning the evaluation of towing forces for road transportation of agabaritical mechanical equipmwnt, Journal of Engineering Studies and Research (JESR), vol. 26, nr. 3, 2020, p. 75 – 87 (ISSN 2068 – 7559).

[17]. *Rehnberg A.,* Suspension design for off-road constructions machines, Thesis, Royal Institute of Technology, Stockholm, Sweden, 2011.

[18]. *Lechner D.,* Analyse du comportement dynamigue des vehicules routiers legers developpement d'une methologie appliquee à a la securité primaire, Thesis, École Centrale de Lyon, France, 2002.

[19]. *Iatan I. R., Popa T.C., Dobra S.G., Dumitrescu V.,* Unele aspecte de calcul al butonilor pentru ridicarea utilajelor tehnologice (Some aspects regarding the calculation of trunnions for lifting technological equipment), Buletinul Universităţii Petrol-Gaze din Ploieşti, vol. LIV, seria Tehnică (The Bulletin of the Petroleum-Gas University of Ploieşti, vol. LIV, Technical series), nr. 3, 2002, p. 105 –114 (ISSN 1221 – 9371).

[20]. x x x GOST 13716 – 73, Ustroitsva stropovâe dlia sosudov i apparatov – Tehnicieskie uslovia, Mejgosudarstvennâi Standard, IPK Isdatelstvo Standartov, Moskva - https://meganorm.ru/Data2/1/4294837/4294837596.pdf.

[21]. x x x Fracture mechanics analysis of an attachement lug, Aeroelastic and Structures Research Laboratory, Cambridge, Massachusetts 02139, Technical Report AFFDL – TR – 75 – 51, January 1976
- https://apps.dtic.mil/dtic/tr/fulltext/u2/a021280.pdf.

[22]. *Iatan I. R., Alămoreanu Elena, Chiriţă R.,* Optimizarea constructivă şi poziţională a urechilor simetrice simple pentru ancorarea utilajelor transportate (Constructive and positional

optimization of simple symmetrical lugs for anchoring transported equipment), Buletinul Universităţii Petrol – Gaze din Ploieşti (Bulletin of the Petroleum-Gas University of Ploieşti), vol. XLVII – L (1995 – 1998), nr. 8, 1998, p. 153 – 158 (ISSN 1221 – 9371).

[23]. *Iatan I. R., Alămoreanu Elenea, Chiriţă R.,* Elemente de calcul al cârligelor de ridicare de tip “Gama” (Calculation elements of “Gama” type lifting hook), Buletinul Universităţii Petrol – Gaze din Ploieşti (Bulletin of the Petroleum-Gas University of Ploieşti), vol. XLVII – L (1995 – 1998), nr. 8, 1998, p. 159 – 164 (ISSN 1221 – 9371).

[24]. x x x TSF – 26 PM2A half-tank lifting lugs design, Project No. :2000-096, 2003 - https://ar.icp.doe.gov/images/pdf/200502/2005022300974KAH.pdf.

[25]. *Ricker T. D.,* Design and construction of lifting beams, Engineering Journal/American Institute of Steel Construction, 2003, p. 149 – 158 (file:///C:/Users/3456/Downloads/lifting_beams.pdf).

[26]. *Pulickal A., Reddy D.,* Design structural analysis and fatigue calculation of wing fuselage lug attachment of a transport aircraft, International Journal and Magazine of Engineering, Technology, Management and Research, vol. 4, no. 8, 2017, p. 60 – 65 (ISSN 2348 – 4895).

[27]. *Stătescu M., Vasilescu Ş.,* A strength calculation for a lifting ear used for a cylindrical shell, Buletinul Universităţii Petrol-Gaze din Ploieşti, vol. LXXI, nr. 1, 2019, p. 80 – 85 (ISSN L 1221 – 8495 ; ISSN (online) 2247 – 8574).

[28]. *Stătescu M., Vasilescu Ş.,* Experimental strain gauge measurements around a lifting ear from a cylindrical shell, Buletinul Universităţii Petrol-Gaze din Ploieşti, vol. LXXI, nr. 2, 2019, p. 74 – 82 (ISSN L 1221 – 8495 ; ISSN (online) 2247 – 8574).

[29]. x x x Design and verification of lifting lugs - https://www.mec-engineering-spreadsheets.com/categories/pin-connections-and-lifting-lugs/lifting-lugs-design/.

[30]. *Alămoreanu Elena, ş. a.,* Îndrumar de calcul în ingineria mecanică (Calculation guide in mechanical engineering), Editura Tehnică, Bucureşti, 1996.

[31]. *Buzdugan Gh., ş. a.,* Culegere de probleme din rezistenţa materialelor (Collection of problems the strength of materials), Editura Didactică şi Pedagogică, Bucureşti, 1975.

[32]. *Buzdugan Gh., ş. a.,*Rezistenţa materialelor (Strength of materials), Editura Tehnică, Bucureşti, 1980.

[33]. *Jinescu V. V.,* Calculul şi construcţia utilajului chimic, petrochimic şi de rafinării (Calculation and construction of chemical, petrochemical and refining equipment), vol. 1, Editura Didactică şi Pedagogică, Bucureşti, 1980.

[34]. *Jinescu V. V.,* Utilaj tehnologic pentru industrii de proces (Technological equipment for process industries), vol. 2, Editura Tehnică, Bucureşti, 1988.

[35]. x x x DIN 28087 – May 1994, Top head type lifting lugs on apparatus for monting. Dimension and allowable loading.

[36]. x x x GOST 26202 – 84, Sosuda i apparatî. Normî i metodi rasceta na procinosti obeciaek i dnişci ot vozdeitviia opornâh nagruzok.

[37]. x x x GOST 33168 – 2014, Kranî gruzonodemnâe, Metallicieskie konstrukţii podtverjdenie nesuşciei sposobnosti, Mejgosudarstvennâi Standard, Moskva – https://meganorm.ru/Data2/1/4293762/4293762955.pdf.

[38]. x x x Rules for classification and construction industrail service, 1z – Part 6, GL 2007 - http://rules.dnvgl.com/docs/pdf/gl/maritimerules/gl_iv-6-4_e.pdf .

[39]. x x x NORSOK STANDARD – Lifting equipment – https://www.standard.no/Global/PDF/Petroleum/r002u2u2%20med%20warning.pdf (accesat la 28.12.20).

[40]. x x x Lifting lug design in detail, HEXAGON PPM
https://pvtools.weebly.com/uploads/3/7/9/4/37946983/lifting_lugs_design.pdf .

[41]. x x x 9. Podiemnâe prouşinî, Kaklift
- https://bmrazvitie.com/upload/haklift2020/9-rymy.pdf (accesat la 08.01.21).

[42]. *Saleh S. H.*, *Kakay S.*, *Siriwardane S.*, Ultimate capacity of pad eyes for lifting operations: experimental and numerical simulations, Int. J. Comp. Meth. And Exp. Meas., vol. 6, no. 3, 2018, p. 605 – 613.

[43]. *Apostolescu N.*, *Lozici – Brinzei D.*, An applicationto calculate the factors which are used to determine the tensile rupture load of a lug under axial, transverse or oblique loading, INCAS Bulletin, vol. 5, issue 1, 2013, p. 19 – 28 (ISSN 2066 – 8201).