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Adaptable Method to Estimate the Loading Developed in the Joint Area of Two Rings or of a Ring Embedded at One End

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Abstract

The paper addresses the assessment methodology to assess the state of loading – strains and stresses – produced under the action of mechanical external loads and/or heat, in the joint area of two rings with different geometries of the walls, building materials of special natures or not. The method involves an adequate number of influence coefficients, adaptable. With the given values the calculation flexibility is easily allowed, maintaining or eliminating certain external loads, in accordance with the actual structure, on one hand, and the finding of the present influences, on the other hand. However, the developed state in a ring embedded at one end can be analyzed, value adapting the indicated coefficients.

Key words: *uniform method; under pressure vessel*

Introduction

The practical needs, subject to continuous development of the mankind, require more profound analysis, of high refinement, allowing obtaining of some mechanical structures, complex, high performance, but reliable in operation, if there are some operating parameters (pressures, temperatures or chemical aggression and/or mechanical) with high values. This thing is achieved through the use both of the traditional materials, as well as some new material, not infrequently less known in terms of the given response longer periods of use. Therefore, the permanent quest of the researchers to assess fairly exactly the loading states values created in mechanical structures, in general, and those working under pressure, in particular it is justified. That is why this paper discusses a unitary method/calculation adaptable for the stress state, calling for continuing deformations produced in different operating conditions between two rings, with different wall thicknesses, identical or different materials, modeling charging by the presence in study of some position appropriate coefficients. A particular case is based on the analysis of a ring embedded at base, by easier modeling. The calculations, which are carried out, consider simplifying assumptions, characteristic to the revolution shells, with characteristic constructive elements, for static loadings [1-8] or dynamic [9-12], even in conditions of instability or damage [13-16].

Connection Loads

Accepting the produced deformations continuity – radial displacements and rotations – in the two rings (fig. 1), considered with lengths greater than:

$$l_s \approx 2{,}5 \cdot \sqrt{r_{m\,i\,j} \cdot \delta_j}\,, \qquad (1)$$

so as the deformations of the 1-2 separation plane of the two rings ($j = 1, 2$) not to be influenced by their ends. This way, the algebraic system will get:

$$\begin{bmatrix} a_1 & a_2 \\ a_3 & a_4 \end{bmatrix} \cdot \begin{Bmatrix} Q_0 \\ M_0 \end{Bmatrix} = \begin{Bmatrix} a_d \\ a_r \end{Bmatrix}, \qquad (2)$$

or:

$$\begin{Bmatrix} Q_0 \\ M_0 \end{Bmatrix} = \begin{bmatrix} a_1 & a_2 \\ a_3 & a_4 \end{bmatrix}^{-1} \cdot \begin{Bmatrix} a_d \\ a_r \end{Bmatrix}, \qquad (3)$$

Q_0, M_0 – representing the cutting effort, respectively the unitary bending moment of connection (see fig. 1). Note that at hypothetic separation of the rings the connection loads have the adequate correlations (fig. 2):

$$Q_o^{\square} = \left(r_{m1} / r_{m2} \right) \cdot Q_0\,; \qquad (4)$$

$$M_o^{\square} = \left(r_{m1} / r_{m2} \right) \cdot M_0\,. \qquad (5)$$

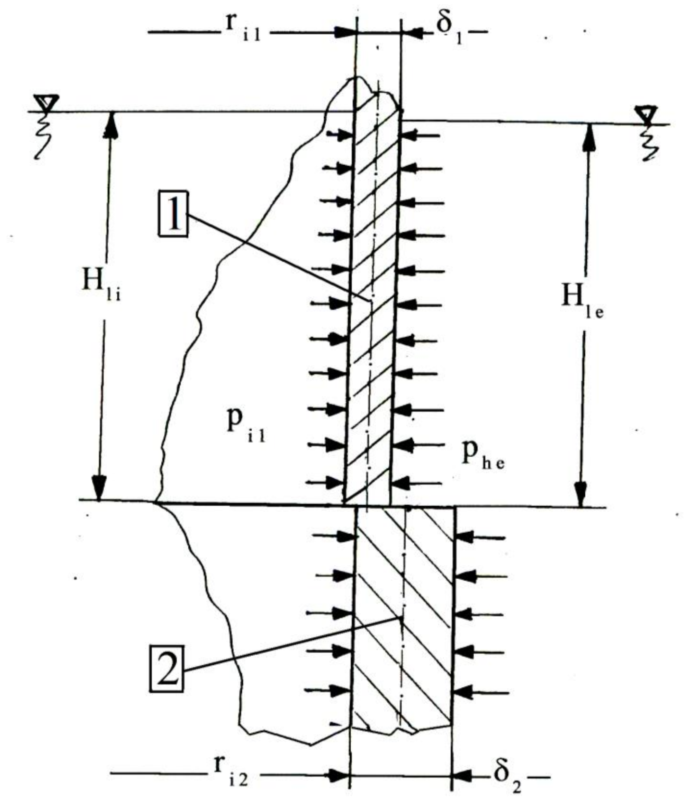

Fig. 1. Junction of two rings having different geometries

In the equalities (2) and (3) the following expressions shall be taken into account:

$$a_1 = \frac{1}{2} \cdot \left(\frac{1}{k_1^3 \cdot \Re_1} + \frac{1}{k_2^3 \cdot \Re_2} \cdot \frac{r_{m1}}{r_{m2}} \right); \qquad a_2 = -\frac{1}{2} \cdot \left(\frac{1}{k_1^2 \cdot \Re_1} - \frac{1}{k_2^2 \cdot \Re_2} \cdot \frac{r_{m1}}{r_{m2}} \right); \qquad (6)$$

$$a_3 = -\frac{1}{2} \cdot \left(\frac{1}{k_1^3 \cdot \Re_1} - \frac{1}{k_2^3 \cdot \Re_2} \cdot \frac{r_{m1}}{r_{m2}} \right); \qquad a_4 = \frac{1}{2} \cdot \left(\frac{1}{k_1^2 \cdot \Re_1} + \frac{1}{k_2^2 \cdot \Re_2} \cdot \frac{r_{m1}}{r_{m2}} \right); \qquad (7)$$

$$a_d = \sum_{m=1}^{10} a_{d\,m} \cdot b_m : \qquad a_r = \sum_{n=1}^{8} a_{r\,n} \cdot c_n\,, \qquad (8)$$

the selecting coefficients b_m ($m = \overline{1, 10}$) and c_n ($n = \overline{1, 8}$), having a position shown in Figure 3.

The expressions for assessing the displacements and rotations generated by the external loads, that are part of the equalities (8), take the form:

$$a_{d1} = \frac{2 - \nu_1}{2 \cdot E_1} \cdot \frac{r_{m1}^2}{\delta_1} \cdot p_{i1}\,; \qquad a_{d2} = -\frac{2 - \nu_2}{2 \cdot E_1} \cdot \frac{r_{m2}^2}{\delta_2} \cdot p_{i2}\,; \qquad (9)$$

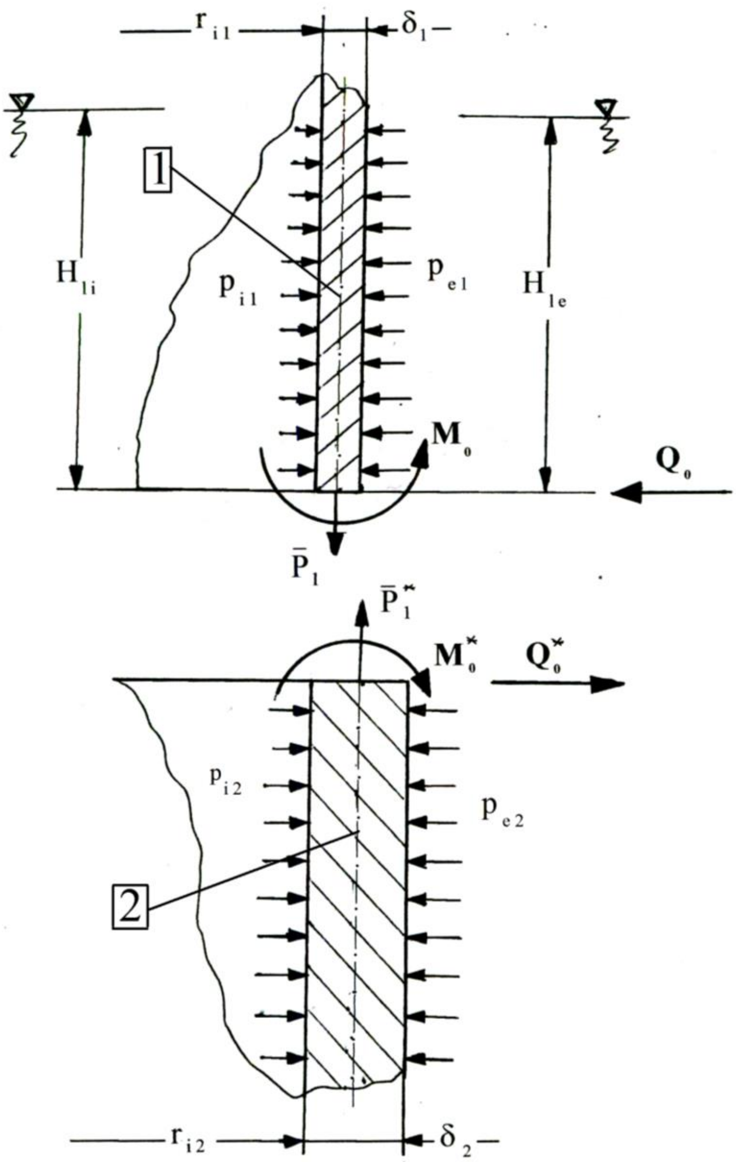

Fig. 2. Separation (hypothetical) of the two rings

$$a_{d3} = -\frac{2-\nu_1}{2\cdot E_1}\cdot\frac{r_{m1}^2}{\delta_1}\cdot p_{e1}; \qquad a_{d4} = \frac{2-\nu_2}{2\cdot E_1}\cdot\frac{r_{m2}^2}{\delta_2}\cdot p_{e2}; \tag{10}$$

$$a_{d5} = \alpha_{T1}\cdot r_{m1}\cdot\left(T_{i1} - T_0\right); \qquad a_{d6} = -\alpha_{T2}\cdot r_{m2}\cdot\left(T_{i2} - T_0\right); \tag{11}$$

$$a_{d7} = -\frac{F_{axT}}{8\cdot\pi}\cdot\frac{\nu_1}{k_1^2\cdot\Re_1\cdot r_{m1}^2}; \qquad a_{d8} = \frac{F_{axT}}{8\cdot\pi}\cdot\frac{\nu_2\cdot r_{m1}}{k_1^2\cdot\Re_1\cdot r_{m2}^3}; \tag{12}$$

$$a_{d9} = \alpha_{T1}\cdot r_{m1}\cdot\left(T_{e1} - T_0\right); \qquad a_{d10} = -\alpha_{T2}\cdot r_{m2}\cdot\left(T_{e2} - T_0\right); \tag{13}$$

$$p_{ij}\left(h_{ij}\right) = p_{0ij} + k_{hij}\cdot\rho_{lij}\cdot g\cdot h_{lij} + k_{gij}\cdot K_{gij}\cdot\rho_{gij}\cdot g\cdot h_{gij}; \quad j = 1,\ 2; \tag{22}$$

$$p_{ej}\left(h_{ej}\right) = p_{0ej} + k_{hej}\cdot\rho_{lej}\cdot g\cdot h_{ej} + k_{gej}\cdot K_{gej}\cdot\rho_{gej}\cdot g\cdot h_{gej}; \quad j = 1,\ 2; \tag{23}$$

$$K_{gij} = \frac{1-\sin\varphi_{gij}}{1+\sin\varphi_{gij}};\ K_{gij} = \frac{1-\sin\varphi_{gij}}{1+\sin\varphi_{gij}};\ K_{gej} = \frac{1-\sin\varphi_{gej}}{1+\sin\varphi_{gej}}; \tag{24}$$

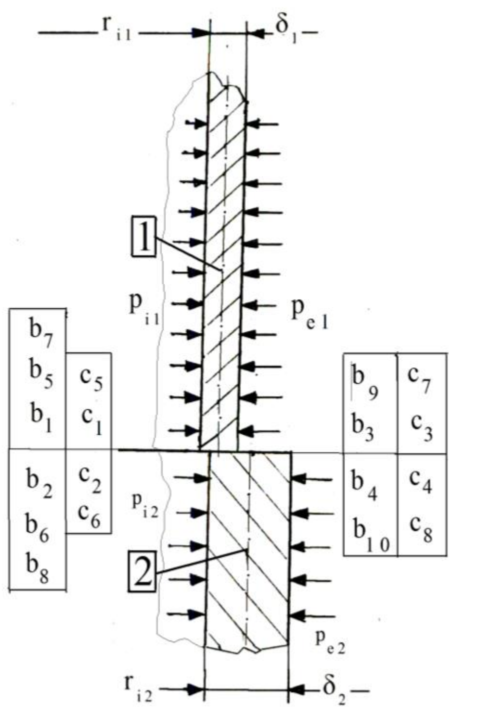

Fig. 3. Positioning of the selection coefficients of the external loads

$$a_{r1} = -\frac{2-\nu_1}{2\cdot E_1}\cdot\frac{r_{m1}^2}{\delta_1}\cdot\rho_{li1}\cdot g\cdot k_{hi1}; \quad (14)$$

$$a_{r2} = \frac{2-\nu_2}{2\cdot E_2}\cdot\frac{r_{m2}^2}{\delta_2}\cdot\rho_{li2}\cdot g\cdot k_{hi2}; \quad (15)$$

$$a_{r3} = \frac{2-\nu_1}{2\cdot E_1}\cdot\frac{r_{m1}^2}{\delta_1}\cdot\rho_{le1}\cdot g\cdot k_{he1}; \quad (16)$$

$$a_{r4} = -\frac{2-\nu_2}{2\cdot E_2}\cdot\frac{r_{m2}^2}{\delta_2}\cdot\rho_{le2}\cdot g\cdot k_{he2}; \quad (17)$$

$$a_{r5} = -\alpha_{T1}\cdot r_{m1}\cdot\frac{dT_{i1}}{dh}\cdot k_{Ti1}; \quad (18)$$

$$a_{r6} = \alpha_{T2}\cdot r_{m2}\cdot\frac{dT_{i2}}{dh}\cdot k_{Ti2}; \quad (19)$$

$$a_{r7} = -\alpha_{T1}\cdot r_{m1}\cdot\frac{dT_{e1}}{dh}\cdot k_{Te1}; \quad (20)$$

$$a_{r8} = \alpha_{T2}\cdot r_{m2}\cdot\frac{dT_{e2}}{dh}\cdot k_{Te2}; \quad (21)$$

$$F_{axT}^{(s,r)} = \pi\cdot r_{m1}^2\cdot p_{0i1} - G_{iz}^{(s,r)} - G_{pm}^{(s,r)} - G_{is}^{(s,r)} - G_{l}^{(s,r)}. \quad (25)$$

Stresses State

Once the connection loads, developed between the considered rings are settled, proceed to assess the produced stresses in various current sections of the structure, to determine the area with the maximum loading and the comparison with the portent capacity offered by the used building materials. Therefore, the relationships associated with normal and shear stresses are present in the forms [3]:

- **For the shell 1** (fig. 2):

$$\sigma_{11}(x_1) = \frac{r_{m1}}{2\cdot\delta_1}\cdot\left(p_{i1} - p_{e1}\right) + \left(\operatorname{sgn} F_{axT}^{(s,r)}\right)\cdot\frac{F_{axT}^{(s,r)}}{2\cdot\pi\cdot r_{m1}\cdot\delta_1} \pm \frac{6\cdot M_{01}(x_1)}{\delta_1^2}; \quad (26)$$

$$\sigma_{21}(x_1) = \frac{r_{m1}}{\delta_1}\cdot\left(p_{i1} - p_{e1}\right) \pm \frac{6\cdot\nu_1\cdot M_{01}(x_1)}{\delta_1^2} + \frac{T_1(x_1)}{\delta_1}; \quad (27)$$

$$\tau_1(x_1) = Q_1(x_1)/\delta_1, \quad (28)$$

with the appropriate notations:

$$M_{01}(x_1) = M_0\cdot\left[\cos(k_1\cdot x_1) + \sin(k_1\cdot x_1)\right]\cdot\exp(-k_1\cdot x_1) - \\ -\frac{Q_0}{k_1}\cdot\left[\exp(-k_1\cdot x_1)\right]\cdot\sin(k_1\cdot x_1); \quad (29)$$

$$T_1(x_1) = 2\cdot k_1^2 \cdot r_{m1} \cdot M_0 \cdot \left[\cos(k_1 \cdot x_1) - \sin(k_1 \cdot x_1)\right] \cdot \exp(-k_1 \cdot x_1) - \\ - 2\cdot k_1 \cdot r_{m1} \cdot Q_0 \cdot \left[\exp(-k_1 \cdot x_1)\right] \cdot \cos(k_1 \cdot x_1); \tag{30}$$

$$Q_1(x_1) = 2\cdot k_1 \cdot M_0 \cdot \exp(-k_1 \cdot x_1) \cdot \sin(k_1 \cdot x_1) - \\ - Q_0 \cdot \exp(-k_1 \cdot x_1) \cdot \left[\cos(k_1 \cdot x_1) - \sin(k_1 \cdot x_1)\right]. \tag{31}$$

Note: In the previous relations sgn $F_{a\,x\,T}^{(s,\,r)}$ is envisaged – positive when the traction loading is manifested, respectively minus when the analyzed area compression is produced.

- **For the shell 2** (fig. 2):

$$\sigma_{12}(x_1) = \frac{r_{m2}}{2\cdot\delta_2}\cdot\left(p_{i2} - p_{e2}\right) + \left(\operatorname{sgn} F_{a\,x\,T}^{(s,\,r)}\right)\cdot\frac{F_{a\,x\,T}^{(s,\,r)}}{2\cdot\pi\cdot r_{m2}\cdot\delta_2} \pm \frac{6\cdot M_{02}(x_2)}{\delta_2^2}; \tag{32}$$

$$\sigma_{22}(x_2) = \frac{r_{m2}}{\delta_2}\cdot\left(p_{i2} - p_{e2}\right) \pm \frac{6\cdot\nu_2\cdot M_{02}(x_2)}{\delta_2^2} + \frac{T_2(x_2)}{\delta_2}; \tag{33}$$

$$\tau_2(x_2) = Q_2(x_2)/\delta_2, \tag{34}$$

with the appropriate notations:

$$M_{02}(x_2) = M_0\cdot\frac{r_{m1}}{r_{m2}}\cdot\left[\cos(k_2\cdot x_2) + \sin(k_2\cdot x_2)\right]\cdot\exp(-k_2\cdot x_2) + \\ + \frac{Q_0}{k_2}\cdot\frac{r_{m1}}{r_{m2}}\cdot\left[\exp(-k_2\cdot x_2)\right]\cdot\sin(k_2\cdot x_2); \tag{35}$$

$$T_2(x_2) = 2\cdot k_2^2\cdot r_{m2}\cdot M_0\cdot\frac{r_{m1}}{r_{m2}}\cdot\left[\cos(k_2\cdot x_2) - \sin(k_2\cdot x_2)\right]\cdot\exp(-k_2\cdot x_2) - \\ - 2\cdot k_2\cdot r_{m2}\cdot Q_0\cdot\frac{r_{m1}}{r_{m2}}\cdot\left[\exp(-k_2\cdot x_2)\right]\cdot\cos(k_2\cdot x_2); \tag{36}$$

$$Q_2(x_2) = 2\cdot k_2\cdot M_0\cdot\frac{r_{m1}}{r_{m2}}\cdot\exp(-k_2\cdot x_2)\cdot\sin(k_2\cdot x_2) - \\ - Q_0\cdot\frac{r_{m1}}{r_{m2}}\cdot\exp(-k_2\cdot x_2)\cdot\left[\cos(k_2\cdot x_2) - \sin(k_2\cdot x_2)\right]. \tag{37}$$

Note: In the (26) and (32) relations will choose the sgn $F_{a\,x\,T}^{(s,\,r)}$ (positive) sign when the traction loading is manifested, respectively minus when compression loading of the considered constructive elements is manifested. The plus sign of the unitary bending moment effect is chosen for the interior fibers of the cylindrical elements (fig. 2), and minus sign for the exterior fibers (the sign of the calculated bending moment is inserted into account, in which case the loading may change or not).

The x_1, x_2 dimensions are measured along the cylindrical elements from their plane of separation (fig. 2).

The equivalent stresses can be calculated using the equalities [3]:

- **according to the fifth resistance theory**:

$$\sigma_{ech}^{(v)}(x_j) = \left\{\left[\sigma_{1j}(x_j)\right]^2 + \left[\sigma_{2j}(x_j)\right]^2 - \left[\sigma_{1j}(x_j)\right]\cdot\left[\sigma_{2j}(x_j)\right] + 4\cdot\tau_j(x_j)\right\}^{0,5}; \tag{38}$$

- **according to the third resistance theory**:

$$\sigma_{ech}^{(III)}\left(x_j\right)=max\left\{\left[\sigma_{1j}\left(x_j\right)\right];\left[\sigma_{2j}\left(x_j\right)\right];0\right\}-min\left\{\left[\sigma_{1j}\left(x_j\right)\right];\left[\sigma_{2j}\left(x_j\right)\right];0\right\}, \tag{39}$$

where $j=1,\ 2$ is the constructive element to which it relates, both for interior and its exterior surface.

Notations: $l_s -$ half-wave length, characteristic of a cylindrical shell; $r_{ij} -$ the interior radius of the ring „ $j=1,2$”; $\delta_j -$ the wall thickness of a ring; $r_{mij}=r_{ij}+0,5\cdot\delta_j -$ the average radius of a ring „ $j=1,2$”'; $Q_0, M_0 -$ connection loads; $a_1, a_3 -$ weighting factors of the cutting effort in the value of the radial displacement, respectively rotation, in the plane of rings separation; $a_2, a_4 -$ weighting factors of the connection unitary bending moment in the value of the radial displacement, respectively rotation, in the plane of rings separation; $a_d, a_r -$ total radial displacement defined by the external loads acting on the rings, respectively the total rotation created by the same loads; $p_{ij}\left(h_{ij}\right) -$ the internal pressure to the inside of the j ($j=1,\ 2$) ring, at the h_{lij} quote , measured from the free level of the liquid or of the granular layer, as appropriate, at the h_{gij} level (fig. 1); $g -$ the gravity acceleration; the h_{li2} quote can be measured from the separation plane level of the rings or value including the H_{li} quote, too (fig. 1); $p_{0i1}, p_{0i2} -$ the gas pressure above the free level of the liquid in the ring 1, or the one in the upper part of the ring 2 (in the case of the continuity of the fluid in the vessel: $p_{0i1}=p_{0i2}$); $\rho_{lij} -$ the liquids density inside the rings ($j=1,2$), considered homogeneous on the height (for a single liquid found inside the vessel: $\rho_{li1}=\rho_{li2}$); $p_{ej}\left(h_{ej}\right) -$ the pressure on the outside of the ring 1 or 2, given of the gas pressure above the H_{le} free level, or below the separation plane of the rings (for different liquids $\rho_{le1}\neq\rho_{le2}$, and in the case of a single liquid: $\rho_{le1}=\rho_{le2}$; the h_{e2} quota can be measured at the separation plane level or may include the H_{le} value - fig. 1; the coefficients of liquids presence can be introduced taking into account the previous observations for the liquids inside the vessel rings); K_{gij}, $K_{gej} -$ correlation factors of the vertical pressure/lithostatic and lateral pushing of the granular material found inside or outside the rings; φ_{gij}, $\varphi_{gej} -$ the internal friction angle of the granular material from inside or outside; $T_{ij}=T_{0ij}+k_{Tij}\cdot T_{ij}\left(h_{ij}\right) -$ the interior ambient temperature to the h_{ij} quota, measured as mentioned above; $T_{0ij} -$ the temperature of the gaseous medium above the liquid in the ring 1, respectively below the separation plane level (if it is a single fluid, the variation in temperature over the whole height of the liquid, both for the ring 1 and for the ring 2 is accepted); $T_{ij}\left(h_{ij}\right) -$ the temperature variation law on the heights of the liquid/liquids or of the granular materials inside the vessel; $T_{ej}=T_{0ej}+k_{Tej}\cdot T_{ej}\left(h_{ej}\right) -$ the outside temperatures of the analyzed rings; $T_{0ej} -$ the temperature of the gaseous medium, above the liquid in the outer part of the ring 1, respectively below the plane of separation (if it is a single fluid, the variation in temperature on the whole height of the liquid, or of the granular medium, both for the ring 1 and for the ring 2 is accepted); $T_{ej}\left(h_{ej}\right) -$ the temperature variation law on the heights of the liquid/liquids, or of the granular medium/mediums outside the vessel;

b_m, c_n – the selection coefficients of the external loads; $k_j = 1{,}316 \cdot \sqrt[4]{1-\nu_j^2} \Big/ \sqrt{r_{mj} \cdot \delta_j}$ – attenuation factors of the effect of the contour loads on the rings length/height ($j = 1, 2$); $\Re_j = 0{,}083 \cdot E_j \cdot \delta_j^3 \Big/ \left(1-\nu_j^2\right)$ – the cylindrical bending rigidities characteristic of the two rings; E_j – the longitudinal elasticity modules of the analyzed rings (for the same material $E_1 = E_2$); ν_j – the transversal contraction coefficients of the rings materials (for the same material $\nu_1 = \nu_2$); α_{Tj} – thermal deformation factors for the rings material (for the same material $\alpha_{T1} = \alpha_{T2}$); T_0 – the outside medium temperature (ambient); $F_{axT}^{(s,r)}$ – the axial force acting in the plane of separation of the rings, in case of the suspension vessel, respectively its leaning; $G_{iz}^{(s,r)}$, $G_{pm}^{(s,r)}$, $G_{ss}^{(s,r)}$, $G_{l}^{(s,r)}$ – the weight of the insulation, of the metallic part above the separation plane of the rings or below this plane, the weight of the superstructure above the plane or below the separation plane, the weight of the liquid column (or of the granular medium) inside the vessel, which may subtracts the force corresponding to the hydrostatic pressure, developed on the bottom of the vessel in its immersion case(the suspension is in a higher plane than the rings separation plane, while the leaning is located below this plane).

Influence coefficients: k_{hij} – hydrostatic influence factor or not of the fluid inside the considered ring, in the expressions of the displacements and rotations ($j = 1, 2$); k_{hej} – hydrostatic influence factor of the liquid outside the considered ring, in the displacements and rotations expressions ($j = 1, 2$); k_{gij} – influence factors corresponding to the granular material inside the rings; k_{gej} – influence coefficients corresponding to the granular material from the rings outside; k_{Tij} – thermal influence factor for the interior of the vessel (if a $T_{0i1} = T_{0i2}$ constant temperature is considered, in the whole interior space, $k_{Tij} = 0$); k_{Tej} – thermal influence factor for the vessel outside (if a $T_{0e1} = T_{0e2}$ constant temperature is considered, in the whole outside space, $k_{Tej} = 0$).

Note: The influence coefficients, mentioned above, can have value one when the respective load is present, minus one if it has changed sense, or zero when it is lacking.

Conclusion

The paper presents the assessment methodology of the stresses states developed in two cylindrical elements with different geometries, joined end to end, without considering the effect of the connection weld seam. The external loadings caused by internal and/or external pressure, the axial loads of traction or compression, or differentiated temperature or not are taken into consideration. By introduction to the mathematical configuration of some influence coefficients, that may affect properly the study, the method will be adaptable to the given case, meaning that some of the general external loads can be neglected/removed and, obviously, their effects, too. The study takes into account different geometries of the joined cylindrical elements, and special elastic-mechanical characteristics, as appropriate. In the future, the exposed methodology can be developed if the presence of weld seam of the jointing, and its influence on the stresses state are considered.

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Metodă adaptabilă pentru evaluarea solicitării dezvoltate în zona de îmbinare a două virole sau a unei virole încastrate la un capăt

Rezumat

Lucrarea abordează metodologia de apreciere a evaluării stării de solicitare – deformaţii şi tensiuni – produse sub acţiunea unor sarcini exterioare mecanice şi/sau termice în zona de îmbinare a două virole cu geometrii diferite ale pereţilor, materiale de construcţie de naturi deosebite sau nu. Metoda implică un număr adecvat de coeficienţi de influenţă, adaptabili. Prin valorile date este permisă lesnicios flexibilizarea calculului, menţinând sau eliminând anumite sarcini exterioare, în concordanţă cu structura reală, pe de o parte, dar şi a constatării influenţelor prezente. Totodată, se poate analiza starea dezvoltată într-o virolă încastrată la unul din capete, adaptând valoric coeficienţii indicaţi.