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Friction and sliding process modeling in weldless joints of the structural elements by numerical and analytical potential end finite element method “LIRA-SAPR 2014”

The vast majority of structural solutions currently applied in joints of reinforced concrete elements are performed by welding. As limitation in joints of both precast and cast-in-situ concrete structures implemented by means of manual electric-arc welding or semiautomatic bath welding is considered the emergence of residual stresses with the maximum value, which according to the test results carried out by (RF) Concrete and Reinforced Concrete Research Institute may reach up to 65% yield strength of rebars [1,2].

Weldless RC joints are referred those with a force transfer from one joint element to another by means of mechanical joining of reinforcement (image 1) [2, 3, 4]. This type of joints secures rapidity and minor labor inputs when performing joints without decreasing the strength of joint elements.

In theoretical studies and design practices the design values of indicated details are performed based on simplified diagrams not providing the exact image of stresses distribution in joints.

The most typical feature of weldless joint performance under big tensions is the force that is transferred from a screw rebar to a buckle by means of reinforcement shear and bearing stress cross projections: hence, here appears the necessity of considering the profile when defining mode of deformation of rebar and its sliding effect on contact surfaces.

Currently, in terms of computer modeling and numerical methods development for deflected mode of structures, realization of effective algorithms, modeling interaction of contacting elements in the process of deformation, is reasonably implemented by means of numerical and analytical potential method, where one of the most basic moments for formulation of contact objectives is the method through which the topological expressions of interacting elements joints within contact limit are determined.

Design diagram can be presented as a composite construction with the design elements, which is the screw rebar and the buckle.

For obtaining resolving relations of numerical and analytical potential method, each element of the composite construction is refereed as a separate body Sk (k=1, 2,…, n) with the outer boundary Гk and interface areas Гk1 and between the elements Sk and S1. When separating S1 from endless areas of S in compliance with physical and mechanical properties of materials and using the universal auxiliary ratio describable by the Kelvin formulas [5, 6, 7], for solving boundary problem we build up an integral representation of the components for the arbitrary point *kεs*. In the process of linear deformation of materials the body forces can be omitted which shall lead to the following formulas by Somilyan:

$$U_i = P_j(N)\int_{\Gamma} U_{ij}^*(K,N)d\Gamma - U_j(N)\int_{\Gamma} P_{ij}^*(K,N)d\Gamma, \tag{1}$$

Wherein

$U_{ij}^*(K,N)$_и_$P_{ij}^*(K,N)$ – are the components of displacement and the stresses of auxiliary state.

$U_j(N), P_j(N)$ – are the conformable components of fundamental states of N points, placed on the design elements boundary.

When approximating the boundary surface of each design element by linear sections Гl and Гm, in the range of which the density of assumed function we believe is constant, we can get the following algebraic analogue of the Solilyan's formula:

$$U_i(K) = \sum_{l=1}^{S1} P_j(N_1)\int_{\Gamma_l} U_{i\,j}^*(K,N_1)d\Gamma_1 - \sum_{l=1}^{S2} U_j(N_1)\int_{\Gamma 1} P_{i\,j}^*(K,N_1)d\Gamma_1 +$$
$$+\sum_{m=1}^{S3} P_j(N_m)\int_{\Gamma_m} U_{i\,j}^*(K,N_m)d\Gamma_m - \sum_{m=1}^{S4} U_j(N_m)\int_{\Gamma 1} P_{i\,j}^*(K,N_m)d\Gamma_m \tag{2}$$

When applying the Coulomb's law (inverse-square law) on friction of contact surfaces, we get the following:

$$\tau = F * \sigma^{(n)} \tag{3}$$

Wherein τ and $\sigma^{(n)}$ are tangent and normal forces appearing in every contact point: F = ratio of the friction force.

If on contact surface Гm the shearing stresses are expressed by normal friction ratio (3), then the formula (2) shall be as follows:

$$U_i(K) = \sum_{l=1}^{S1} P_j(N_1)\int_{\Gamma_l} U_{i\,j}^*(K,N_1)d\Gamma_1 - \sum_{l=1}^{S2} U_j(N_1)\int_{\Gamma 1} P_{i\,j}^*(K,N_1)d\Gamma_1 +$$
$$+\sum_{m=1}^{S3} P_j(N_m)\int_{\Gamma_m} U_{i\,j}^*(K,N_m)d\Gamma_m + F\int_{\Gamma_m} U_{i2}^*(K,N_m)d\Gamma_m$$
$$-\sum_{m=1}^{S4} U_j(N_m)\int_{\Gamma 1} P_{i\,j}^*(K,N_m)d\Gamma_m \tag{4}$$

Such iterative process is continued till reaching allowable values at local points of transferring contact stresses to all contact sections by means of shearing stresses. When calculating the proposed procedure, redistribution shall take place at the expense of increasing normal forces and decreasing shearing (tangential) forces, due to calculating friction ratio as equal to F=0.3, for contact surfaces in the range of each section.

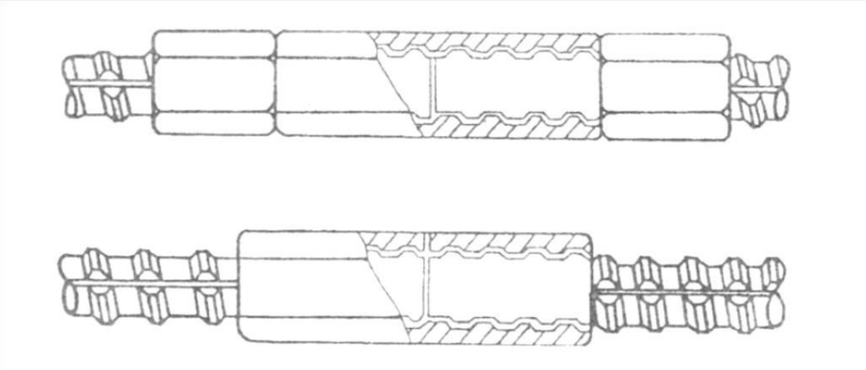


Image 1: Bar reinforcement connection with a screw profile by means of joints:

a) w/ lock-nuts tightening;
b) w/ filling gaps by epoxy compound.

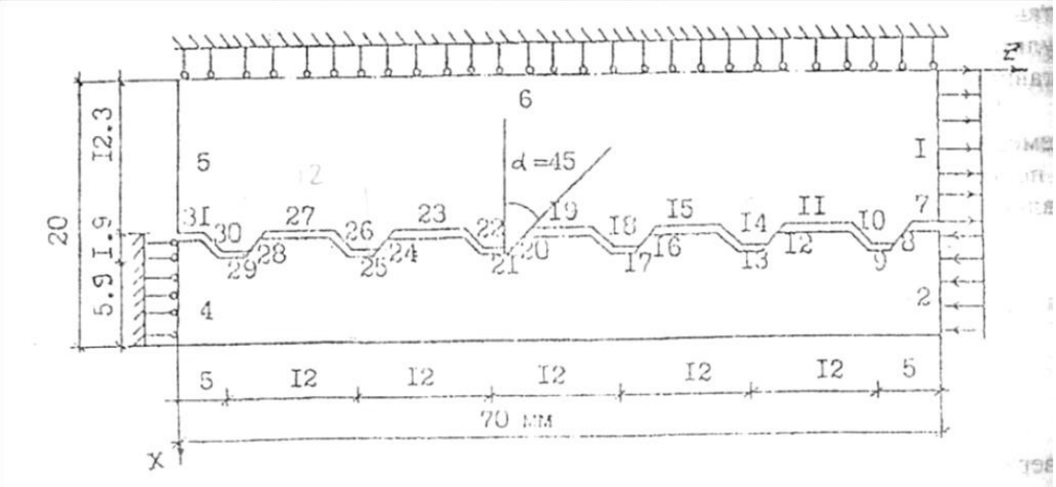


Image 2

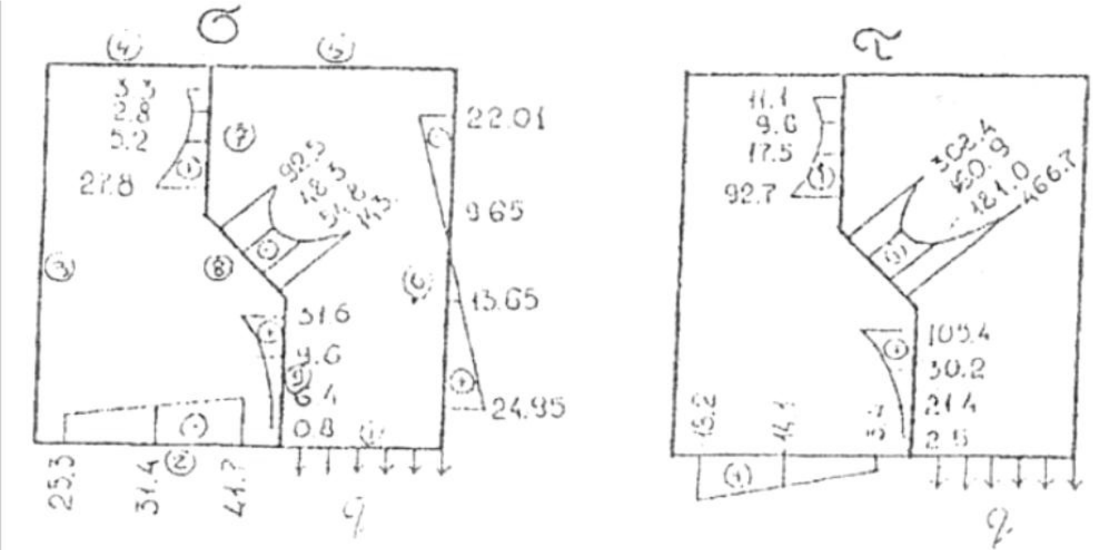


Image 3: Distribution of stresses σ and τ on contact surfaces of elementary fragment of a screw reinforcement and a buckle without accounting the friction ratio.

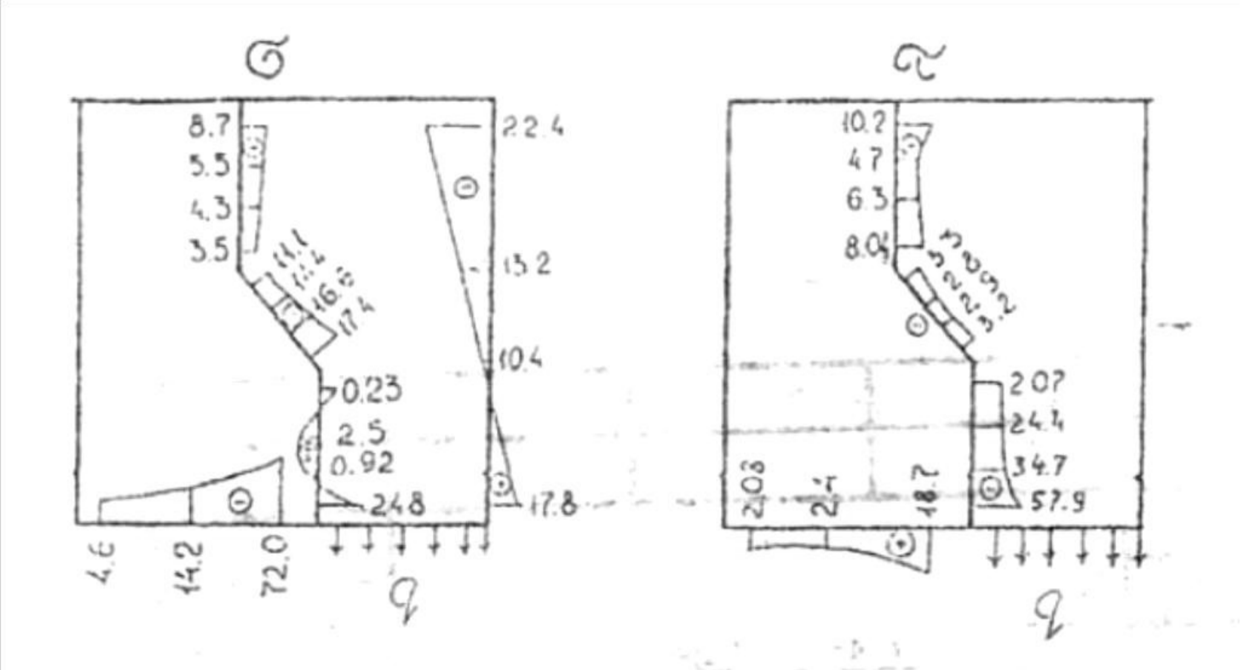


Image 4: Distribution of stresses σ and τon contact surfaces of elementary fragment of a screw reinforcement and a buckle without accounting the friction ratio.

The next important stage of such iterative process modeling is the modeling of contact surfaces sliding at full absence of shearing (tangential) forces on sections:

$$P_2^{(1)} = P_2^{(2)} = 0 \qquad (7)$$

In this case, the full reactive stress in the range of fragments of contact surfaces is only normally transferred.

In accordance with the proposed methodology, the design model of interaction between the screw reinforcement and a buckle is composed; their boundaries consist of 31 fragments marked with numbers (Image 2). Boundary states remain unchanged in the range of each fragment. Fragment 6 is given a symmetry condition; the fragment 4 shows the lack of normal displacement.

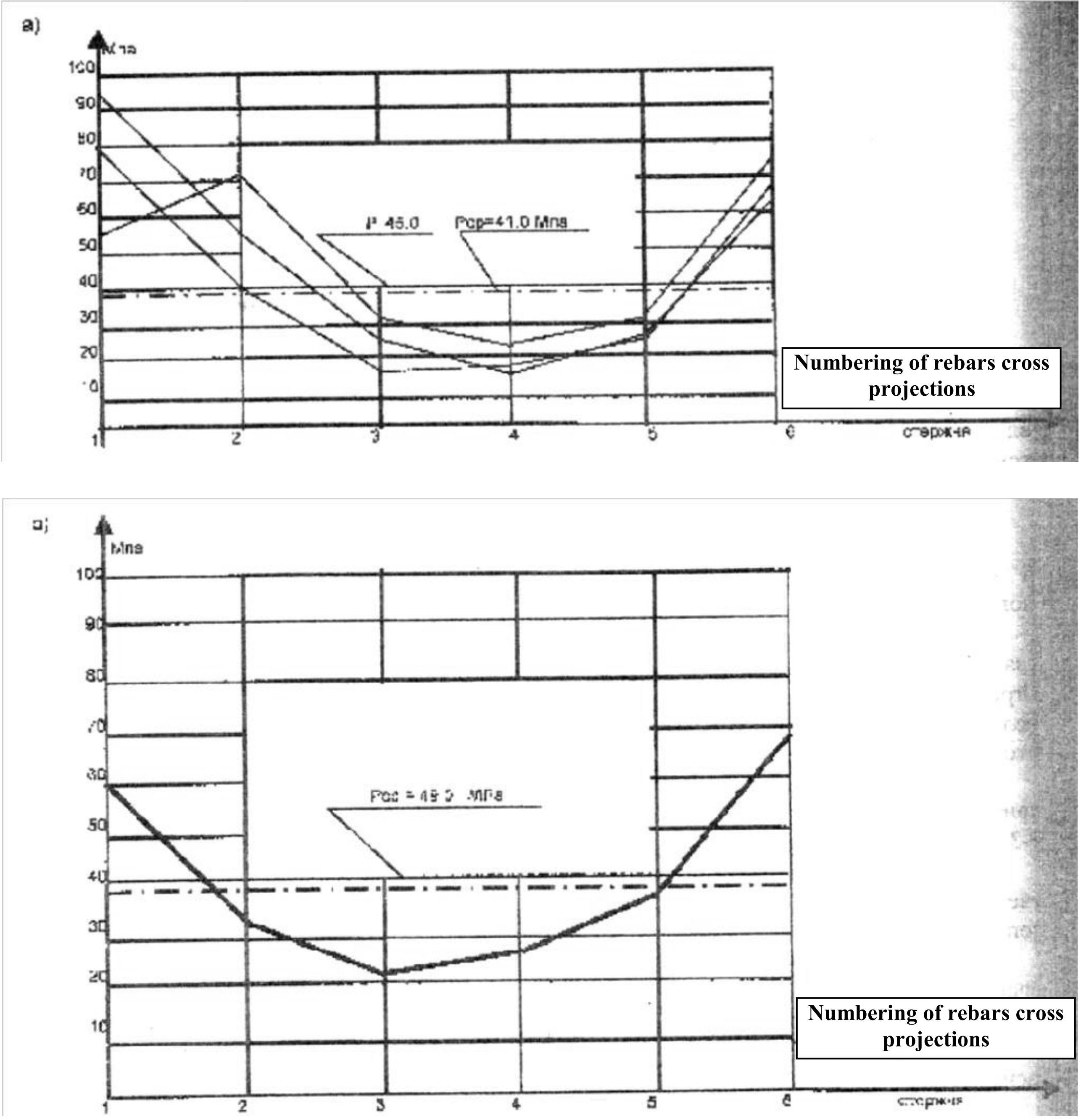
Joint behavior of the reinforcement and the buckle is provided by contact on fragments 8, 12, 16, 20, 24, 28. The absence of stresses is assumed on the rest lines of contacts on fragments 7-31.

Images 3 and 4 – design diagram as a result of calculation done with and without accounting the friction ratio on a contact surface for the elementary fragment of cross projection of the reinforcement bar and the buckle.

Besides, there is no displacement in all directions on fragment 2, whilst fragment 6 shows only normal displacement.

Emergence of tensile stresses on fragment 9 proves that on given fragment, there is the state (7) realized; derived solution requires a relevant correction for the next step of calculation.

Numerical studies had been carried out for the whole construction with changing thickness of the buckle. It should be noted that the stress pattern of cross projections did not substantially change. The resulted graphics of distribution of forces between the screw reinforcement ribs and the buckle (Image 5a) shows that by increasing the thickness of the buckle by 2 mm, the concentration of stresses on cross projections gets like unevenly distributed, thus in a less degree as compared with the previous task (Image 5b).



Numbering of rebars cross projections

Numbering of rebars cross projections

Image 5: the diagram of forces distribution between the bearing surfaces of screw reinforcement and a socket joint.

a) In case of lock-nuts tightening;
b) When applying the epoxy compound.

In these specific states of numerical analysis the most reasonable is the use of 70 mm long buckles together with corresponding thickening of the buckle section on the fragment 4 (Image 2). This makes the distribution of stresses possible in the buckle more evenly and provides necessary stiffness. Numerical analysis in joint behavior of screw reinforcement and a buckle enables to design the optimal structures that in massive production of such joints are the guarantee of its high economical efficiency.

Such approach at transferring outer stress from one to another element through the contact surfaces makes possible to carry out the calculation of tangential sliding of contact surfaces relatively to one another with any previously known friction ratio.

The numerical and experimental studies carried out made possible to make a conclusion that for reinforcement bars d=25mm, the length of anchorage in turn buckles makes 70 mm; when applying proposed cylindrical s (3, 4) for joining reinforcement projections with epoxy filler compound at the length of anchorage=5d, the stresses exceed the rebar yield strength for the class AIII, at the length of anchorage=7, 5 - 8d - the tensile failure of rebars is reached.

The results of computer modeling and structural design by using "LIRA-CAD 2014":

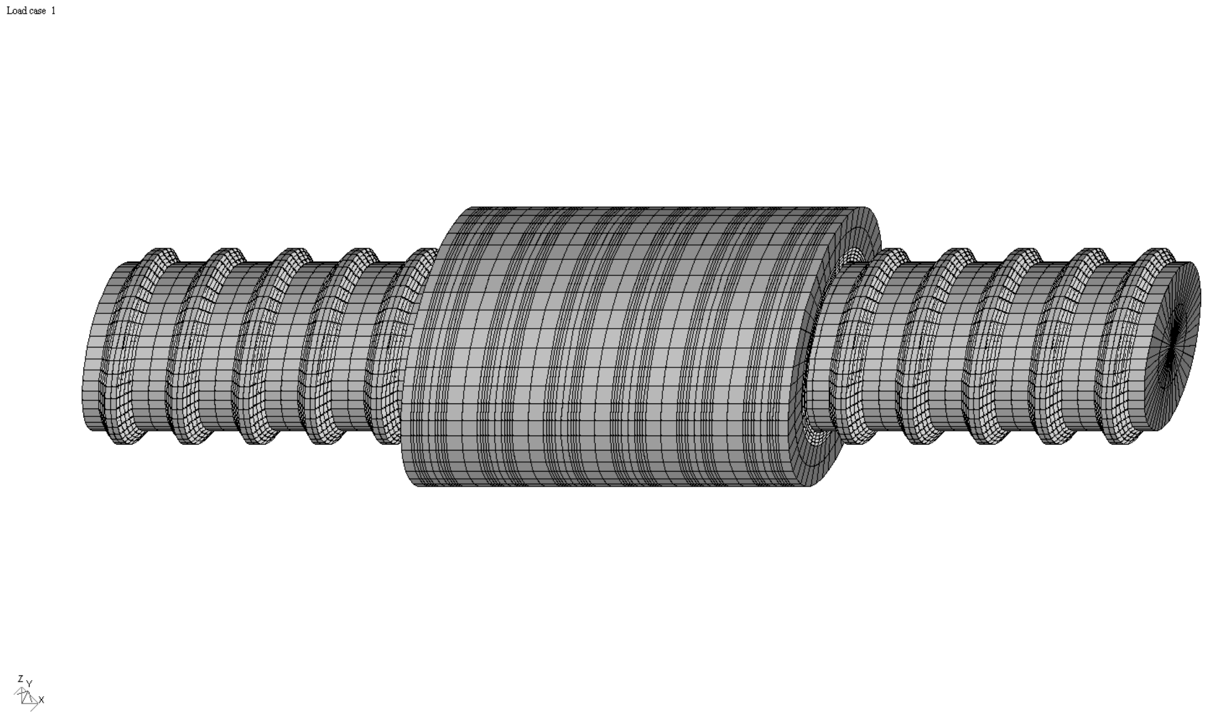


Image 6: the structural design model of reinforcement bars (d=25mm) and their socket joint with the FE software complex of the "LIRA-CAD 2014”.

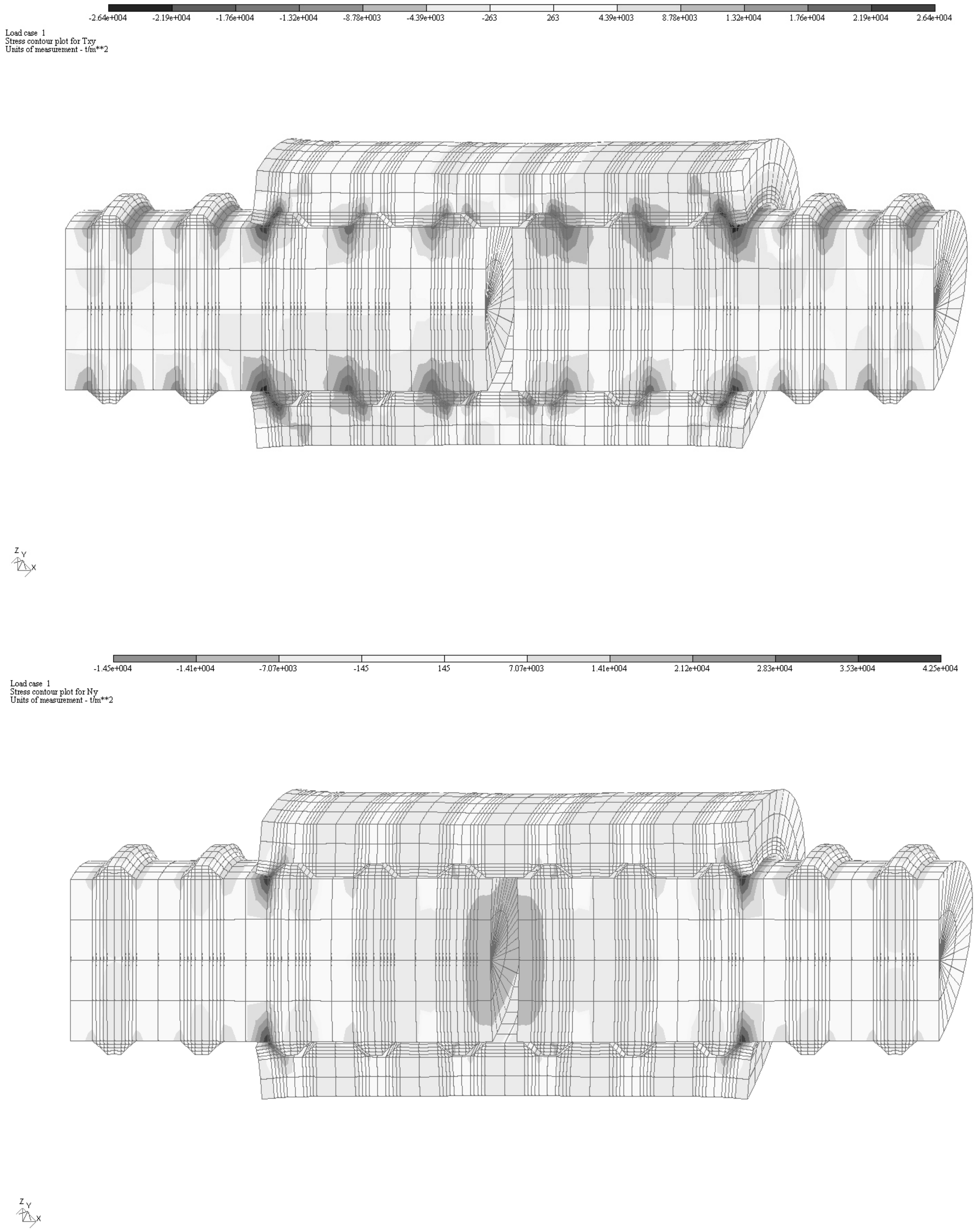


Image 7: the stress distribution in the structural elements and contact surfaces according to the structural design model of reinforcement bars (d=25mm) and their socket joint using the FE software complex of the "LIRA-CAD 2014".

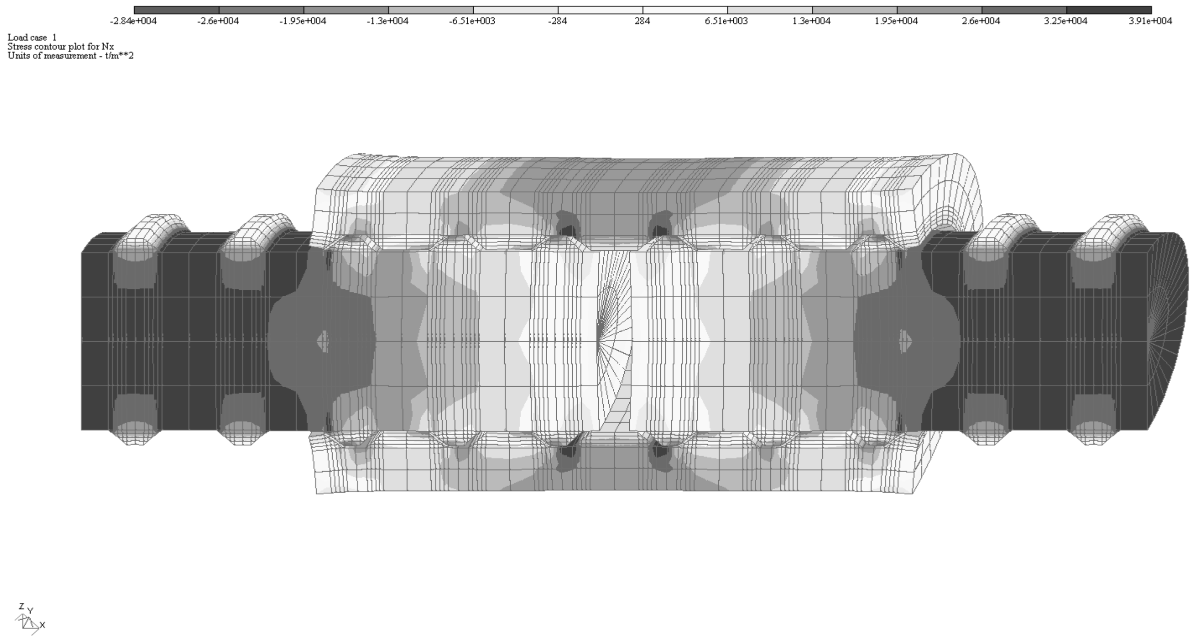


Image 7: normal stress distribution in the structural elements and contact surfaces according to the structural design model of reinforcement bars (d=25mm) and in their socket joint body using the FE software complex of the "LIRA-CAD 2014".

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