BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LX No. 3A/2008	223 - 228	Seria Tehnică

The Evaluation of the Stress and Strain Condition for the Mast MU 320 Made Out of U and I Profile Beams

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Abstract

In this paper, the authors determined, using the finite element method (MEF), the stress and strain condition for the mast MU 320 made out of U and I profiles, that kind of mast being used in the oil drilling processes. The analysis was made for all the standardized loading cases.

Key words: *stress, strain, mast, finite element method (MEF)*

The mast MU 320, made out of U and I profiles, used in the oil drilling processes, is a spatial construction which in its cross-section has the “U” letter form. It is made out of five left-right transoms: mast leg, followed by other four. The monkey board is placed at the inferior part of the transom 3 and, at the superior part of the transom 4, the crown block is placed (see figure 1).
The five transoms, which constitute the left part and, respectively, the right part of the mast, are made out of pillars, traverses (horizontal beams) and across-corner dimensions. The left and right parts of the mast are stiffened one to another by traverses and across-corner dimensions hinged to the two parts` pillars. Both traverses and across-corner dimensions of the mast’s two faces (left-right) are rigidly fixed (by welding) to the pillars.
The mast is mostly made out of I and U profile beams, excepting a few across-corner dimensions, which are built of hollow section beams. At the mast construction they were used, for the pillars, the euro-profiles HEB 400, 360, 280, 220, 200, for the traverses the euro-profiles HEA 160, IPE 220 and 360 and, for the across-corner dimensions, the euro-profiles HEA 160 and IPE 120.
All the these resistance elements, which belong to the mast’s construction, are built of S355 J2 G3 (SR EN 10025-2 2004) material, having the yield strength $R_{p0,2}$ = 345 MPa and the ultimate strength R_m =(490…630) MPa.
The mast’s principal technical characteristics are: the maximum rated static hook load (on 10 cables at the hook-block): 3200 kN; the overload force: 4000 kN; number of cables at the hook-block: 10; the maximum allowed wind velocity, under the action of the hook load and drill pipe stands at the monkey board: 72 km/h; the stack capacity at the monkey board: 6210 for 4 ½ in drill pipes and 5000 m for 5 in drill pipes.

The model

From the static point of view, the mast represents a spatial structure, statically indetermined, made out of many beams, having rigid or articulated nodes. For such a structure, the most advantageous method to determine the stresses and displacements is, obviously, the displacements method, which is the finite elements method's basis. In this case, each beam can become one finite element or many finite elements.

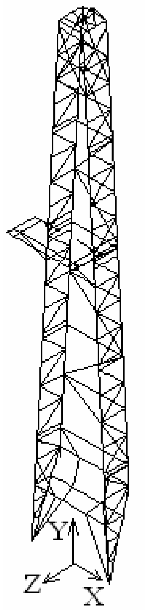

Fig.1. The MU 320 model

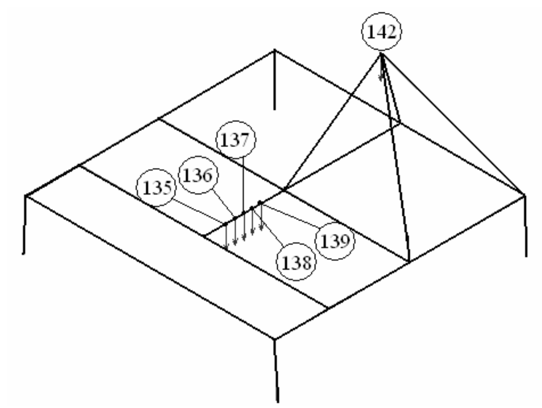

Fig.2. Points for applying the forces at the crown block

Following these considerations, the authors elaborated a calculus model (having the form presented in figure 1), in order to make the finite element analysis. They used two types of elements from the ANSYS program library: BEAM 3D (spatial beam element type with elastic nodes) and LINK 3D (spatial network beam type for elements with articulated edges).

The BEAM 3D elements are defined by three nodes: *I* and *J* nodes- which define the element's edges- and the *K* node- for the element's section orientation. This element has six degrees of freedom at each edge, three displacements *u,v,w* and three rotations φ_x, φ_y, φ_z, which are positive when they have their vectors in the same direction with the coordinate axis, both in node I and node J of the element. The LINK 3D elements have as parameters the edges` displacements and, there, only axial forces may occur. In the local axis system, the *x* axis is positive when it is oriented from the *I* edge to the *J* edge of the element. The calculus model of the mast is defined by establishing the structure's nodes and the elements between these ones. So, the resulted model had 2490 nodes and 1565 finite elements.
For the static calculus of the mast they considered as links to the ground the ball joints in the join points with the substructure, which means the points: 1, 1148, 2391 and 2397 (see Figure 3). The mast was considered to be in the vertical position.

Loadings

According to STAS 1909-89 and API-4F, the loadings that are applied to the mast are divided in three categories: permanent loadings, temporary loadings and exceptional loadings.

The permanent loadings are due to:

a) the mast's weight force;
b) loadings at the draw works drum socket and the blind end of the rotary line due to hoisting equipment's weight (hook-block and cable), all of them having the value Q_m=100 kN. From the hoisting equipment's weight, it resulted the force at the draw works drum socket S_a= 12329 kN and the force at the blind end S_m= 8329 kN. These

two forces were introduced at block level, along the draw works drum socket direction and, respectively, along the blind end of the rotary line's direction.

The temporary loadings are divided as it follows:

a) Main temporary loadings:

- the drill pipe string's weight. This was considered to be, for the calculus, Q = 2400 kN and was applied to the hook, simultaneously with the drill pipes stands stack weight and the wind action. Its value resulted after dividing the maximum rated static hook load, Q_{max} = 3200 kN, at a 1,6 coefficient and the result was multiplied with a dynamic coefficient Ψ = 1,2.

- the loadings from the draw works drum socket and the blind end, resulted from the drill pipe string's weight S_a = 295,898 kN and S_m = 199,898 kN, respectively.

- loadings due to drill pipes stands stack. The maximum capacity for the stack at the monkey board for 5 in drill pipes is 5500 m. Knowing the fact that the 5 in drill pipes have an average linear weight of 415 N/m, it results the half-stack's weight of 1120 kN. For a 1,5^o inclination angle of the stack, it results F_{pd}^1 = 15400 N- the value of the horizontal component of the stack's weight at the monkey board. For the calculus, they considered both the drill pipes stand stacks, but also the possibility for stacking only on a single side of the symmetry axis of the monkey board.

b) Secondary temporary loadings

- the loading due to the maximum rated static hook load Q_{max} = 3200 kN, that appears only during the well casing or during the workover. It is considered, for the calculus, to action only with the permanent loadings, in the absence of the wind action or the drill pipes stands stacks` weight.

- the loadings due to the wind action. The wind action is simulated by horizontal distributed loads on the mast's elements, following the wind's action direction. These ones can occur on the mast's elements, on the block and the crown block, on the drill pipes stands stacks etc.

The wind pressure on the elements` surfaces is determined using the following mathematical relation:

$$P_v = k_v \cdot g_v \cdot A_v \quad (1),$$

where k_v is a shape coefficient; g_v - basic dynamic pressure; A_v - area of the surface exposed to the wind.

For the mast's component elements, by A_v we understand the section width along the wind direction and so, using (1), the pressure P_v can be calculated as a uniform pressure on the element's length (N/mm).

The values for k_v, for different kind of elements, are: for the elements made out of rolled profiles, k_v = 1,6; for hollow sections, $k_v = 1{,}25$; for the drill pipes stand stack, $k_v = 1{,}25$; for the block and guard panels, $k_v = 1{,}2$ (STAS 1909/89).

The basic dynamic pressure is determined using the expression:

$$g_v = v^2 / 1630 \quad (2),$$

in which, by introducing the wind velocity in m/s, we obtain g_v in kN/m^2.

For the static calculus of the mast we considered, for the wind velocity, three values given by the beneficiary or by the actual standards: 70 km/h, 120 km/h and 160 km/h.
For the wind with v = 70 km/h = 19,444 m/s velocity, we obtained $g_v = 0{,}232$ kN/m^2.

In the case with v = 70 km/h velocity (which corresponds to the working condition), the basic dynamic pressure is considered to be constant along the mast's height and for v = 120 km/h this one is variable and it is multiplied with a coefficient c_v, which has values between 1 and 1,3, depending on the mast's height.

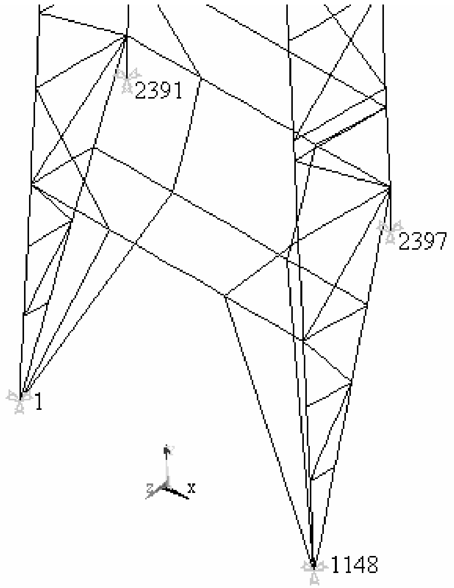

Fig.3. Mast's links with the ground

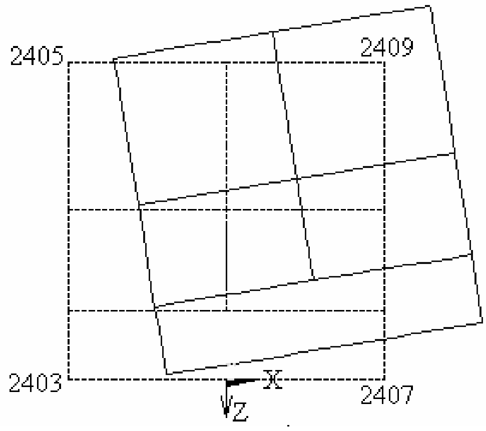

Fig.4. Crown block's displacements due to the overload simulation

The exceptional loading consists on the overload force $Q_p = 1{,}25 \cdot Q_{max} = 4000$ kN. It is applied to the mast together with the corresponding forces (the force at the draw works drum socket and the force at the blind end of the rotary line) and with the permanent forces. The derived forces from the overload force $Q_p = 4000$ kN are introduced at the calculus model's nodes, at the block level (fig. 2). Thus, in the points 136, 137, 138 and 139 (see figure 2), we introduced forces along the principal axis *Y* (vertical) with values of –800 kN and in the points 135 and 142 forces with values of –400 kN along the principal axis *Y*. Also, we introduced forces of 400 kN, having inclined directions as the draw works drum socket and the blind end of the rotary line's directions really are.

According to STAS 1909/89, with some API adaptations, for the static calculus of the mast we considered 18 loading hypotheses. Based on these hypotheses, we identified and studied 11 loading cases.

Results

After running the program for the eleven loading cases, we ascertained that the most unfavourable situation corresponds to the overload situation.

The strained form of the crown block due to the overload case simulation is presented in figure 4, where the general axis *X* and *Z* are also presented (the *Y* axis is vertical). In the *XZ* plane, the mast's cross-section (having the "U" letter form) is, approximately, not deformed at the crown block's level, but it have a rotation in respect of the general axis *Y*, that means a mast torsion along the horizontal component of the force at the draw works drum socket of the rotary line.

Due to the overload force, the maximum displacements occur in node 2407 (see figure 4) and have the values: $u_x = 31$ mm, $u_y = -27{,}3$ mm and $u_z = -21{,}3$ mm; the deformed form of the mast is presented in figure 5.

The lateral wind action, along the general direction *X*, with a 70 km/h velocity, during the working with drill pipes stands stacks, produce lateral displacements (along the *X* axis) of 67 mm at the monkey board's level and of 45,8 mm at the crown block's level; the displacements are more important at the monkey board's level because of the wind action on the drill pipes stands stacks.

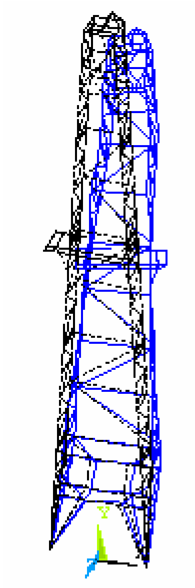

Fig.5. Strained form of the mast MU 320 due to the overload force

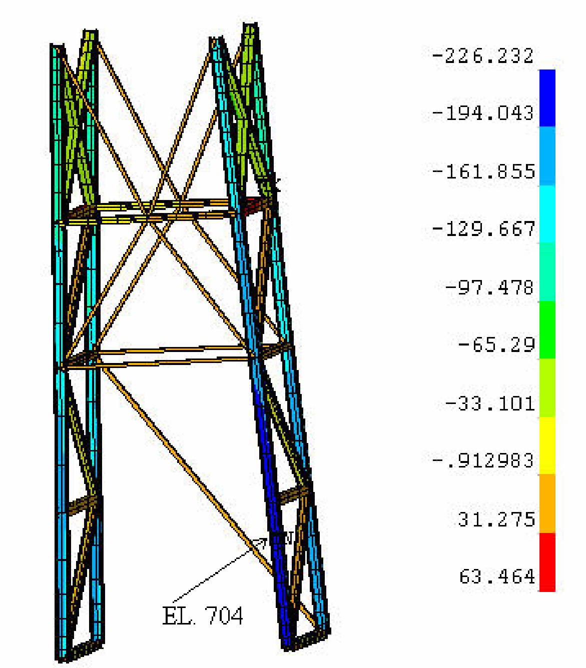

Fig.6. Stresses distribution in the transom 4 of the mast MU 320 due to the overload force

The wind action with 120 km/h velocity, in the resting position of the mast (with drill pipes), along the general axis X direction, produce at the monkey board's level a maximum displacement of 84,7 mm; the wind action along the Z axis produce a maximum displacement of 39 mm at the monkey board's level and of 85 mm at the crown block's level. We concluded that the mast has a rigid behaviour to wind action along the Z axis.

Considering the resting position of the mast and taking into account the presence of the safety anchors from the crown block's level, the wind action as a hurricane, with 160 km/h velocity, produces along the X axis a displacement of 169,4 mm and along the Z axis of -82,5 mm (at the monkey board's level).

For the S355 J2 G3 steel, from which the mast's elements are made of, the allowable stress, being the same both for tension, compression and bending, is determined according to STAS 1909-89, by dividing the yield limit to a safety coefficient corresponding to a group of loadings. So, according to STAS 1909/89, the safety coefficient is:

- $c = 1{,}5$ for the main fundamental loadings, in this case the allowable stress being $\sigma_a = 230$ MPa;
- $c = 1{,}35$ for the secondary fundamental loadings, in this case the allowable stress being $\sigma_a = 256$ MPa;
- $c = 1{,}25$ for the special loadings, in this case the allowable stress being $\sigma_a = 276$ MPa;

The maximum stress in pillars due to the overload force (special group of loadings) is $|\sigma|^{mont}_{\max} = 226$ MPa $< \sigma_a = 276$ MPa and it occurs in the element 704 situated on the right-front pillar. This element belongs to transom 4 and its position on the transom is presented in figure 6. Stresses from all elements situated on the horizontal beams and on the across-corner dimensions have small enough values ($\sigma^{oriz}_{\max}$ =63 MPa, $\sigma^{diag}_{\max} = 45$ MPa), these beams having, in addition, a role for the pillars` stiffening. Also, bigger stresses ($\sigma = 103$ MPa) occur in the horizontal and the across-corner dimensions from the left-right pillars.

For the loading case corresponding to the work condition with drill pipes stand stacks and longitudinal wind, along X axis, with v = 70 km/h (secondary fundamental loading), the maximum stresses occur also in the pillars of transom 4, the maximum value being $|\sigma|_{\max}^{mont}$ = 156 MPa $< \sigma_a = 256$.

In the case of the resting position, we must take into account the following: the mast's weight, the workover system's weight and the forces from the draw works drum socket and the blind end of the rotary line, longitudinal wind with 120 km/h speed working from the lateral side both on the mast and drill pipes. It is a group of loadings from the fundamental loadings category and the resulted maximum stress was $|\sigma|_{\max}$ = 135,82 MPa $< \sigma_a = 256$.

The same case of loading as the previous one, but taking into account a 160 km/h wind velocity, leads to the maximum value of the stress $|\sigma|_{\max}$ = 172,4 MPa $< \sigma_a = 256$ MPa.

Conclusions

The mast MU 320, made out of U and I profiles, used in the oil drilling processes, is a spatial construction made out of many beams, having rigid or hinged nodes, statically indetermined. For all the loading cases stipulated by STAS 1909/89 and API-4F, the stress and strain analysis was made using the finite element method (MEF).

As a result of the analysis made using the ANSYS program, for the eleven loading cases, we concluded:

- for all the loadings, the stresses have smaller values than the allowable stress determined according to STAS 1909/89;
- the most dangerous loading is the overload force, for which the maximum stress value is $|\sigma|_{\max}^{mont}$ = 226 MPa $< \sigma_a$ = 276 MPa;
- the biggest values of the displacements occur at the crown block's level and reach the maximum value of 31 mm, during the overload simulation;
- in the case of the wind action with 160 km/h velocity, with the mast in resting position and taking into account the presence of the safety anchors from the crown block's level, the maximum displacement is 169,4 mm and occurs at the monkey board's level.

Therefore, the mast's behaviour, for all the loading cases, remains in the elastic domain of proportionality and this observation leads to the conclusion that the mast MU 320, analyzed in the present paper, is a safe structure for the oil drilling processes.

References

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Evaluarea stării de tensiuni şi deformaţii în mastul MU 320 din profile deschise

Rezumat

In articol sunt determinate, folosinnd metoda elementelor finite (MEF), tensiunile şi deformaţiile în mastul MU 320 din profile deschise utilizat în cadrul procesaului de foraj a sondelor, pentru toate cazurile standardizate de încărcări.