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Analysis of the Cracks in the Chassis and Elastic-Plastic Behavior of the Structure for Cranes with Telescopic Arm

Laurenţiu Sârbu

Universitatea Tehnica de Constructii Bucuresti – Facultatea de Utilaj Tehnologic
e-mail: laurentiusarbu_utcb@yahoo.com

Abstract

It was determined that at the mobile cranes used in constructions on any type of terrain (for instance, at Tadano Faun ATF 30-21) there are some cracks in the structure of the (4x4x4) – type chassis with motor and driving wheels. The way they appear and the crack evolution in time are not know but it is quite sure they were done by the bad roads of the sites where the crane moves as well as by operating it by blocking the suspension and the automatic control system of stress limiter which increases the induced efforts and stress value in the arm and chassis structure.
Further, there are remarks on the cracking mechanics and crack dynamics, and. some conclusions are drawn regarding the case shown and the way it must be mended.

Key words: *cracks in the chassis, elastic-plastic behavior of the crane structure, scheme of lifting the load on the ground.*

Model description

The metallic construction of the crane with telescopic arm consists of three main parts: the telescopic arm, the revolving platform, and the elastic chassis with pressing parts.

The telescopic arm is a caisson construction consisting in many sections being elastic on the support of the tilting cylinder and fixed at one end by the revolving platform by a joint. On the concentrated mass of the arm a force of inertia $m_1\ddot{y}_1$ and a moment of inertia $y_1\ddot{\varphi}_1$ act. The reduced load at the arm peak is $Q = Q_n$ and the arm weight is $m_1 g \sim G_{1n}$.

From the arm equilibrium it results the reactions of the fixing joint X_1Y_1 and the tilting force in the cylinder F_1. The arm rotation on the vertical under load is φ_1.

The revolving platform. The revolving forces in the arm fixing joint X_1Y_1 , tilting cylinder force F_1, counterweight G_{cg} and platform weight G_p. Vertically act on the platform structure. Inside the platform assembly load centre the force of inertia $m_z\ddot{y}_2$ and the moment of inertia $y_z\ddot{\varphi}_2$ act as a result of the construction deformation under the lifting maximum load action as well as the arm weight, given by the rotation φ_2.

The platform structure supporting is done by the support (considering it to be elastic) when the force F_2 and the joint A_2, act together with the reactions X_z, Y_2 and cylindrical rigidity under bending K_2.

Crane chassis. The superstructure loadings are sent by the rotating coupling of the platform made of the actions F_2,X_2, Y_2 şi K_2.

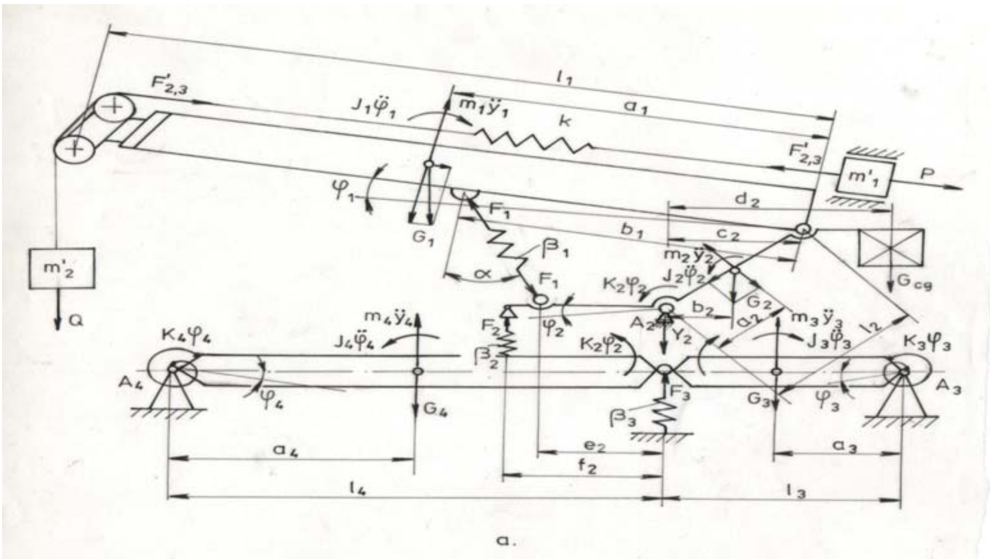
The chassis is considered to be an elastic structure of two masses m_3 and m_4, linked in the middle by a joint with yielding elastic joint where force F_3 and two concentrated moment of the cylindrical rigidity when bending K_2. act.

Additionally, the elastic force F_2 acts on mass m_4.

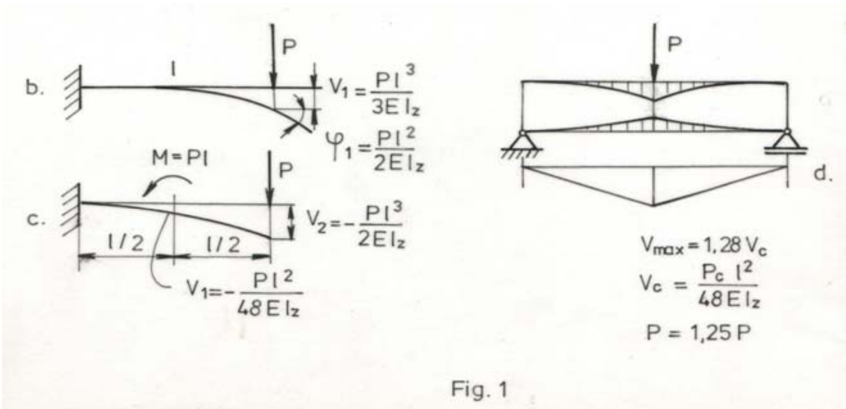
The ends of the two masses of the elastic chassis are coupled with the pressing system by joints A_3,A_4 and cylindrical rigidities at bending K_3, K_4.

The loads are given by the weight forces as well as the structure component linking forces G_3, G_4, F_2, X_2, Y_2 and K_2.

When the elastic structure with φ_3, φ_4 is rotated inside the mass load centre m_3 and m_4 of the chassis the forces of inertia $m_3\ddot{y}_3$, $m_4\ddot{y}_4$ together with the moments of inertia $y_3\ddot{\varphi}_3$, $y_4\ddot{\varphi}_4$ act, taking into account points A_3 and A_4.



a



b.

Fig.1,a and b. Calculation scheme of the crane structure.

The scheme of the elastic construction used for the chassis (Fig.1, a and b) intends to emphasize the excessive deformations that may appear when working and produce cracks in the chassis structure (Fig.3 and 4). These appeared on the back section, bench the revolving crown when is coupled to the pressing parts boxes. These crack appear at the fixing welding of the section end gusset plates and at the tack welding of the front gusset plates respectively (Fig.2).

Similar cracks appear at the top part of the front caisson base core of the chassis and gusset plates (fig.5) [4].

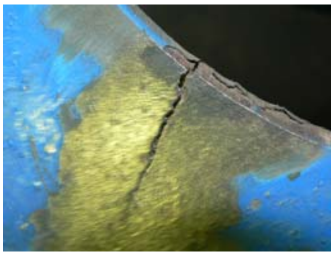


Fig.2 **Fig.3** **Fig.4** **Fig.5**

Figs. 2, 3, 4 and 5. Cracks in the chassis.

Figure 2 shows the right back gusset on which one can see the real cracks in the weldings that set the chassis on the back setting casing. Figure 5 shows the crack in the gusset welding set the left box spare on the front crane casing.

On the top, between the box spare housings a square plate is welded; it is cut at the middle which links the setting casing with the rotation crown support (see photo in Fig 3). At this plate there are now a series of cracks that are arranged along the longitudinal axis and crosswise in the 4 points along the plate diagonals.

It is taken into consideration that actions F_2 , X_2 , Y_2 , K_2 are sent to the chassis and act together with the chassis elasticity that make the joint appear inside the chassis structure. The proposed model used the structure stress of the working maximum load action increased by 25%. If it is considered the process of the load from the support with a loosen lifting cable it must be taken into account the maximum effort $F'_{2,3}$ appeared in cable during the lifting [2].

The equation system show in the revolving of the metallic construction of the telescopic arm crane as follows:

$$-\frac{4}{3}m_1 a_1^2\ddot{\varphi}_1-\beta_1 b_1^2\cos\alpha\cdot\varphi_1+Q_n l_1+G_{1n}a_1=0$$

$$-\frac{4}{3}m_2 a_2^2\ddot{\varphi}_2+\beta_1 b_1\, e_2\cos\alpha\cdot\varphi_2+\beta_2 f_2^2\cdot\varphi_2-X_1\cdot l_2-y_1c_2-G_c\cdot d_2-G_{2u}\cdot a_2=0$$

$$-\frac{4}{3}m_3 a_3^2\ddot{\varphi}_3-\beta_3 l_3^2\cdot\varphi_3+K_3\varphi_3-K_2\varphi_2-Y_2 l_4=0$$

$$-\frac{4}{3}m_4 a_4^2\ddot{\varphi}_4+\beta_2 f_2\left(l_4-f_2\right)\varphi_2+K_2\varphi_2-K_4\varphi_4-Y_2 l_4=0 \quad (1)$$

where: $\varphi_3 l_3=\varphi_4 l_4$

Solving the equation system {1} against the rotation φ_3 an unhomogeneous differential equation results:

$$-\frac{4}{3}\left(m_4a_4^2-m_3a_3^2\right)\dddot{\varphi}_3-\beta_3l_3l_4\ddot{\varphi}_3=-\frac{4}{3}m_2a_2^2\left(1-\frac{l_4}{f_2}\right)\left(1+\frac{3b_1}{4a_1}\right)\dddot{\varphi}_2-$$
$$-\frac{3b_1\left(1-\frac{l_4}{f_2}\right)}{4a_1}\beta_2f_2^2\ddot{\varphi}_2+\frac{3\beta_1\,b_1^2e_2}{4a_1}\left(1-\frac{l_4}{f_2}\right)\ddot{\varphi}_1+\frac{3\beta_1^2b_1^3e_2}{4m_1a^2{}_1}\left(1-\frac{l_4}{f_2}\right)\cos\alpha\cdot\varphi_1- \tag{2}$$
$$-\frac{3\beta_1\,b_1\,e_2}{4m_1a^2{}_1}\left[Q_nl_1+G_{n1}a_1\right]\cos\alpha=0$$

The homogenous equation solution has the formula $\varphi_3=e^{\bar{k}t}$,resulting:

$$\frac{4}{3}\left(m_4a_4^2-m_3a_3^2\right)\bar{k}^4-\beta_3l_3l_4\bar{k}^2=0$$

noting $\bar{k}^2=u$, an incomplete equation results: (3)

$$\frac{4}{3}\left(m_4a_4^2-m_3a_3^2\right)u^2-\beta_3l_3l_4u=0$$

with the roots u_1 =0; $u_2=\frac{3\beta_3l_3l_4}{4\left(m_4a_4^2-m_3a_3^2\right)}$

For the right number the following general solutions are taken $\varphi_2=e^{\bar{k}t}$ şi $\varphi_1=e^{\bar{k}t}$.
Resulting in φ_2 for the differential equation:

$$-\frac{4}{3}m_2a_2^2\left(1+\frac{3b_1}{4a_1}\right)\bar{k}^4-\frac{3b_1\beta_2f_2^2}{4a_1}R^2=0$$

where $\bar{k}^2=0$, so:

$$-\frac{4}{3}m_2a_2^2\left(1+\frac{3b_1}{4a_1}\right)u^2-\frac{3}{4}\frac{b_1}{a_1}\cdot\beta_2f_2^2u=0\,,$$

with the roots $u_1^{(2)}$ =0 ; $u_2^{(2)}=-\frac{9\beta_2f_2^2b_1}{16m_2a_1a_2^2\left(1+\frac{3b_1}{4a_1}\right)}$ (4)

For the right number differentia equation in φ_1 a characteristic equation results:

$\frac{3\beta_1b_1^2e_2}{4a_1}\bar{k}^2-3\frac{\beta_1^2b_1^3e^2}{4m_1a_1^2}\cos\alpha=0$ This is an incomplete equation: $ax^2+c=0$, with the roots:

$$k_{1,2}^{(1)}=\pm\sqrt{\frac{\beta_1b_1\cos\alpha}{m_1a_1}} \tag{5}$$

The particular solution given by the arm rotation is as follows:

$$C_o = \frac{Q_n l_1 + G_{1n} a_1}{\beta_1 b_1^2 \left(1 - \frac{l_4}{f_2}\right)} \tag{6}$$

The general solution of the unhomogenous differential equation in φ_3 results:

$$\varphi_3 = A_1 \cos U_3 T - A_2 \cos u_2 t + A_3 \cos k_1 t - B_3 \sin k_2 t + C_o \tag{7}$$

having the initial conditions:

$$\varphi_3(0) = \varphi_1(0) = C_o;\ \dot{\varphi}_3 = 0;\ \ddot{\varphi}_3 = \frac{\sqrt{CI}}{A};\ \dddot{\varphi}_3 = 0;\ \ddddot{\varphi}_3 = 0; \tag{8}$$

where:

$$\sqrt{\frac{CI}{A}} = \sqrt{\frac{9\beta_1 b_1 e_2 \left(Q_n l_1 + G_{1n} a_1\right)\cos\alpha}{m_1 a_1^2 \left(m_4 a_4^2 - m_3 a_3^2\right)}} \tag{9}$$

Depending on sloping angle of the tilting cylinder one may calculate Q_n, G_{1n} an the lengthes l_1, a_1 are modified if the arm is telescoped. The load Q_n modifies according to load diagram.

The algebric equation system for calculating the integrating constants A_1, A_2, A_3 is as follows:

$$\begin{cases} \{A_1 - A_2 + A_3 + C_o = 0 \\ -U_3^2 A_1 + U_2^2 A_2 - K_1^2 A_3 = \sqrt{\frac{CI}{A}} \\ U_3^4 A_1 + U_2^4 A_2 + K_1^4 A_3 = 0 \end{cases} \tag{10}$$

It results from calculus:

$$A_1 = \frac{C_o U_3^2 \left[U_3^2\left(U_2^2 - U_3^2\right) + \left(U_2^4 - U_3^4\right)\right] - \sqrt{\frac{CI}{4}}\left(U_2^4 + U_3^4\right)}{\left(U_2^4 + U_3^4\right) - \left(U_3^2 + K_1^2\right)\left(U_2^2 - U_3^2\right)} \cdot \frac{U_2^2 - 2U_3^2 + K_1^2}{\left(U_3^2 - K_1^2\right)\left(U_2^2 - U_3^2\right)};$$

$$A_2 = \frac{\sqrt{\frac{CI}{A}} - U_3^2 C_o}{\left(U_2^2 - U_3^2\right)} - \frac{C_o U_3^2 \left[U_3^2\left(U_2^2 - U_3^2\right) + \left(U_2^4 - U_3^4\right)\right] - \sqrt{\frac{CI}{A}}\left(U_2^4 + U_3^4\right)}{\left(U_2^2 - U_3^2\right)\left[\left(U_2^4 + U_3^4\right) - \left(U_3^2 + K_1^2\right)\left(U_2^2 + U_3^2\right)\right]}; \tag{11}$$

$$A_3 = \frac{C_o U_3^2 \left[U_3^2\left(U_2^2 - U_3^2\right) + \left(U_2^4 + U_3^4\right)\right] - \sqrt{\frac{CI}{A}}\left(U_2^4 + U_3^4\right)}{\left(U_3^2 - K_1^2\right)\left[\left(U_2^4 + U_3^4\right) - \left(U_3^2 + K_1^2\right)\left(U_2^2 - U_3^2\right)\right]}$$

The coefficients (11) have been computed from static rotation conditions $\varphi_1(0) = C_o$ of the loaded arm and the acceleration value $\ddot{\varphi}_3(0) = \sqrt{\frac{CI}{A}}$.

Solving the equation system (1) depending on rotation φ_4, it results:

$$\ddddot{\varphi}_4\left(\frac{4}{3}m_4-\frac{a_4^2}{l_4}+\frac{4}{3}m_3\frac{a_3^2 l_4}{l_3^2}\right)-\ddot{\varphi}_4\left(\frac{K_3 l_4^2+K_4 l_3^2}{l_3^2 l_4}-\beta_3 l_4\right)+\left[\frac{(l_3+l_4)K_2}{l_3 l_4}+\frac{\beta_2 f_2(l_4-f_2)}{l_4}\right]\cdot\frac{\beta_1^2 b_1^3 e_2\cos\alpha}{\frac{4}{3}m_1 a_1^2\cdot\beta_2 f_2^2}\varphi_1-$$

$$-\left[\frac{(l_3+l_4)K_2}{l_3 l_4}+\frac{\beta_2 f_2(l_4-f_2)}{l_4}\right]\cdot\frac{\frac{4}{3}m_2 a_2^2}{\beta_2 f_2^2}\ddddot{\varphi}_2-\left[\frac{(l_3+l_4)K_2}{l_3 l_4}+\frac{\beta_2 f_2(l_4-f_2)}{l_4}\right]\cdot\frac{\beta_1\cdot b_1 e_2}{\beta_2 f_2^2}\cdot\frac{Q_n l_1+G_{1n}a_1}{\frac{4}{3}m_1 a_1^2}=0 \quad (12)$$

The general homogenous equation solution (12) in φ_4 has the form $\varphi_4 = e^{kt}$
We have:

$$\frac{4}{3}\left(m_4\frac{a_4^2}{e_4}+m_3\frac{a_3^2 l_4}{l_3^2}\right)\bar{K}^4-\left(\frac{K_3 l_4^2+K_4 l_3^2}{l_3^2 l_4}-\beta_3 l_4\right)\bar{K}^2=0$$

$\bar{K}^2=U$, it results:

$$\frac{4}{3}\left(m_4\frac{a_4^2}{l_4}+m_3\frac{m_3^2 l_4}{l_3^2}\right)U^2-\left(\frac{K_3 l_4^2+K_4 l_3^2}{l_3^2 l_4}-\beta_3 l_4\right)U=0$$

with the roots: $U_1^{(4)}=0$;

$$U_2^{(4)}=\frac{\frac{4}{3}\left(m_4\frac{a_4^2}{l_4}+m_3\frac{a_3^2 l_4}{l_3^2}\right)}{\frac{K_3 l_4^2+K_4 l_3^2}{l_3^2 l_4}-\beta_4 l_4} \quad (13)$$

For the differential equations in the right number of the equation (12), the following solutions are choosen:

$$K_{1,2}^{(2)}=\pm\sqrt{-\frac{\beta_2 f_2^2}{\frac{4}{3}m_2 a_2^2}};(14)\quad K_{3,4}^{(2)}=\pm\sqrt{\frac{\beta_1 b_1^2\cos\alpha}{\frac{4}{3}m_1 a_1^2}}; \quad (15)$$

It results the general solution form of the rotation φ_4 :

$$\varphi_4=A_1\cos U_4 t+C_1\left[A_2\cos K_1^{(2)}t-B_2\sin K_2^{(2)}t\right]+C_2\left[A_3\cos K_3^{(1)}t-B_3\sin K_4^{(1)}t\right]+C_o' \quad (16)$$

where:

$$C_1=\left[\frac{(l_4+l_3)K_2}{l_3 l_4}+\frac{\beta_2 f_2(l_4-f_2)}{l_4}\right]\cdot\frac{\beta_2 f_2^2}{\frac{4}{3}m_2 a_2^2}; \quad (17)$$

$$C_2=-\left[\frac{(l_3+l_4)K_2}{l_3 l_4}+\frac{\beta_2 f_2(l_4-f_2)}{l_4}\right]\square\frac{\beta_1^2 b_1^3 e_2\cos\alpha}{\frac{4}{3}m_1 a_1^2\beta_2 f_2^2}; \quad (18)$$

$$\frac{C_3}{A}=\frac{\left[\frac{(l_3+l_4)K_2}{l_3 l_4}+\frac{\beta_2 f_2(l_4-f_2)}{l_4}\right]\cdot\frac{\beta_1 b_1 e_2}{\beta_2 f_2^2}\cdot\frac{a_n e_1+G_m a_1}{\frac{4}{3}m_1 a_1^2}}{\frac{4}{3}\left(m_4\frac{a_4^2}{l_4}+m_3\frac{a_3^2}{l_3}\right)} \tag{19}$$

$$C_o^{'}=\frac{Q_n l_1+G_m a_1}{\beta_1 b_1^2\cos\alpha} \tag{20}$$

The initial conditions are set:

$$\varphi_4(0)=\varphi_1(0)=C_o^{'};\ddot{\varphi}_4(0)=0;\ddot{\varphi}_4(0)=\sqrt{\frac{C_3}{A}};\dddot{\varphi}_4(0)=0;\ddddot{\varphi}_4(0)=0. \tag{21}$$

where the relations (19) and (20) are used to calculate $C_0^{'}$ and $\sqrt{\frac{C_3}{A}}$.

The algebric equation system for calculating the integrating constants A_1 , A_2 , A_3 is as follows:

$$\begin{cases} A_1^{'}+C_1A_2+C_2A_3^{'}+C_0^{'}=0 \\ -A_1^{'}U_2^2-C_1K_1^2A_2^{'}-C_2K_3^2A_3^{'}=\sqrt{\frac{C_3}{A}} \\ -A_1^{'}U_2^4+C_1A_2^{'}K_1^4+C_2A_3^{'}K_3^4=0 \end{cases} \tag{22}$$

It results:

$$A_1^{'}=-\frac{1}{C_1}\left\{\begin{array}{l}\frac{\sqrt{\frac{C_3}{A}}U_2^4}{K_1^2\left(K_1^2-U_2^2\right)}-\left[\frac{\sqrt{\frac{C_3}{A}}-U_2^2C_0^{'}}{U_2^2+K_1^2}-\frac{\sqrt{\frac{C_3}{A}}U_2^4}{K_1^2\left(K_1^2-U_2^2\right)}\right]\cdot\frac{1}{1-\frac{U_2^2-K_3^2}{U_2^2+K_1^2}\cdot\frac{K_1^2-U_2^4}{K_3^2\left(K_3^2+U_2^4\right)}}+ \\ +\frac{1}{1-\frac{K_3^2\left(K_3^2+U_2^4\right)}{K_1^2-U_2^4}\cdot\frac{U_2^2-K_3^2}{U_2^2+K_1^2}}\end{array}\right\} \tag{23}$$

$$A_2^{'}=\frac{1}{C_1K_1^2}\left\{\frac{\sqrt{\frac{C_3}{A}}U_2^4}{K_1^2-U_2^4}-\frac{C_2\left[\frac{\sqrt{\frac{C_3}{A}}-U_2^2C_0^{'}}{U_2^2+K_1^2}-\frac{\sqrt{\frac{C_3}{A}}U_2^4}{K_1^2\left(K_1^2-U_2^4\right)}\right]}{1-\frac{U_2^2-K_3^2}{U_2^2+K_1^2}\cdot\frac{K_1^2-U_2^4}{K_3^2\left(K_3^2+U_2^2\right)}}\right\}$$

$$A_3^{'}=\frac{\dfrac{\sqrt{\dfrac{C_3}{A}}-U_2^2C_0^{'}}{U_2^2+K_1^2}-\dfrac{\sqrt{\dfrac{C_3}{A}}U_2^4}{K_1^2\left(K_1^2-U_2^4\right)}}{C_2\left[\dfrac{K_3^2\left(K_3^2+U_2^4\right)}{K_1^2-U_2^4}-\dfrac{U_2^2-K_3^2}{U_2^2+K_1^2}\right]}$$

Also, the coefficients $A^{'}_1$, $A^{'}_2$, $A^{'}_3$ where calculated using the static rotation condition $\varphi_1(0)=C_0^{'}$ of the loaded arm and the value of the construction rotating acceleration $\ddot{\varphi}_4(0)=\sqrt{\dfrac{C_3}{A}}$. The particular solutions of the two rotation differential equations in φ_3 , φ_4 given by the relation (6, 20); as well as the acceleration expressions $\sqrt{\dfrac{C_I}{A}}$ and $\sqrt{\dfrac{C_3}{A}}$ given by the relation (9) and (18) contain the lifting load Q.

To correctly represent the rotations φ_3 , φ_4 of the chassis structure when lifting the load it will be taken into account the lifting process of the load on the ground when the cables of the lifting tackle are loosen.

The scheme of lifting the load on the ground shown in fig.6, together with the calculus scheme of the telescopic arm crane construction fig.1, shows the way the transit regime calculus scheme modifies to the lifting mechanism represented by a sustem of two masses [2].

In fig.6,a the link between the two masses (m_1 lifting mechanism mass reduced at hois and m_2 - lifting load mass), is characterized by the play Δ.

In fig 6,a the mass $m^1{}_1$ moves with a constant acceleration under a constant traction force of the hoist P.

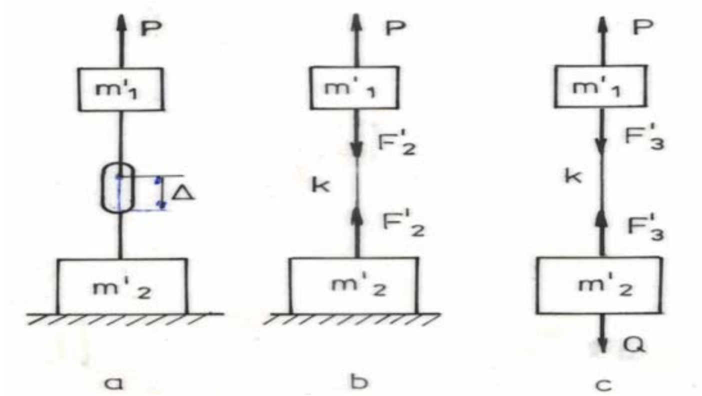


Fig. 6. Scheme of lifting the load on the ground [2].

Duration of the first stage:

$$t_1=\sqrt{\frac{2m_1^{'}\cdot\Delta}{P}} \tag{24}$$

and the speed at its end (the begining of the second stage) will be:

$$\dot{X}_{11} f = \dot{X}_{22} 0 = \sqrt{\frac{2 \cdot \Delta \cdot P}{m_1^{'}}} \tag{25}$$

In the second stage the tension $F^{'}_2$ (fig.6,b) appear in the elastic cable, now being smaller than the load Q coresponding the mass m_2, as the last one is stil non-operative.
The movement differential equation is as follows:

$$m_1^{'} \ddot{x}_{12} = P - F_2^{'} \tag{26}$$

where: $F^{'}_2 = k \cdot x_{12}$ (27)
k is the cable elastic constant.

From the relation (26) it is obtained the effort law in the lifting cable.

$$F_2^{'} = A_2 \cos \sqrt{\frac{k}{m_1^{'}}} + B_2 \sin \sqrt{\frac{k}{m_1^{'}}} t + P \tag{28}$$

where the integrating constant are: $A_2 = -P, B_2 = \sqrt{2Pk\Delta}$ (29)

The duration of the second stage is obtained from the time necessary to increase the tension in cable $F^{'}_2$ from 0 to Q. The expression of t_2 is:

$$t_2 = \sqrt{\frac{m_1}{k}} \left[\arcsin \frac{Q - P}{\sqrt{P(P + 2k\Delta)}} + arctg \sqrt{\frac{P}{2k\Delta}} \right] \tag{30}$$

In the third stage the mass m_2 is moved too (fig.6,c). The movement differential equations have the following form [2]:

$$m_1^{'} \ddot{x}_{13} = P - F_3^{'}; \qquad m_2^{'} \ddot{x}_{23} = F_2^{'} - Q \tag{31}$$

where: $F_2^{'} = Q + k(x_{13} - x_{23})$ (32)

or:

$$F_3^{'} = A_3 \cos \sqrt{\frac{k\left(m_1^{'} + m_2^{'}\right)}{m_1^{'} m_2^{'}}} t + B_3 \sqrt{\frac{k\left(m_1^{'} + m_2^{'}\right)}{m_1^{'} m_2^{'}}} t + D_3 \tag{33}$$

The integrating constants expression and the particular solution from (11) are:

$$A_3 = -\frac{(P - Q) m_2}{m_1 + m_2}; \qquad B_3 = \sqrt{\frac{m_2^{'}}{m_1^{'} + m_2^{'}}} \cdot \left[2Pk\Delta + Q(2P - Q)\right]$$

$$D_3 = \frac{P m_2 + Q m_1}{m_1 + m_2} = Q + \frac{(P - Q) m_2}{m_1 + m_2} \tag{34}$$

The maximum value of the effort in cable $F^{'}_3$ is given by the relation [2]:

$$F'_{3\max} = \frac{Pm'_2 + Qm'_1}{m'_1 + m'_2}\left[1 + \sqrt{\frac{1 + m'_1\left(m'_1 + m'_2\right)\left(km_2\dot{x}_{120}^2 - Q^2\right)}{\left(Pm'_2 + Qm'_1\right)}}\right] \quad (35)$$

where:

$$\dot{x}_{120} = \frac{B_2}{\sqrt{km'_1}} \quad (36)$$

When Δ=0 the maximum effort in the cable is:

$$F'_{\max} = \frac{Pm'_2 + Qm'_1}{m'_1 + m'_2}\left[1 + \sqrt{1 + \frac{Q^2\left(m'_1 + m'_2\right)m'_1}{\left(Pm'_2 + Qm'_1\right)^2}}\right] \quad (37)$$

For the general rotating laws φ_3 and φ_4 given by the relation (2) and (12) it will be taken into account the stages of the load lifting through the effort developed in the cable computed according to the relation (28), (33), (36) and (37).
To calculate the general solution of rotating the linked supports of the chassis φ_3 and φ_4, depending on the load lifting there are necessary 3 sets of values computed for C_0 (C'_0); $\sqrt{\frac{C_I}{A}}\left(\sqrt{\frac{C_3}{A}}\right)$, and integrating constants A_1, A_2, A_3 (A'_1, A'_2, A'_3), for 3 stages as follows:

Stage I: for calculating the efforts for pulling the cable F'_2 with relation (28) up to reaching the load value Q(t=7s);

Stage II: at t=7s (for the given example) this stage is completed; it follows an increase of the effort in cable F'_3 calculated by the relation (33) at times: t = 8,9,10 s, when reaching the maximum value, relations (36) and (37).

Stage III: Then, at t = 17 s, the effort in cable reaches again the value of the lifting load.

The three stages correspond to the solving of 3 particular solution (7) and (16) for which 3 values are calculated: C_0 (C'_0); $\sqrt{\frac{C_I}{A}}\left(\sqrt{\frac{C_3}{A}}\right)$ şi A_1, A_2, A_3 (A'_1, A'_2, A'_3).

Calculus example

It is taken a terrain telescopic arm crane (4x4x4) having crane load Q = 30 – 35 t, minimum radius R = 2,7 m, nominal moment M_n = 35 x 2,7 = 94,5 tm, total rolling mass M = 24 t, counterweight maximum mass m_{cg} = 5,2 t, telescopic arm lenght 8,56 – 21,6 m.

To lift the load we use the following notations:

m'_1 – redused mass at hoist, m'_1 = 1800 – 3600 kg.
m'_2 – lifting load mass, m'_2 = 30000 kg;
P - traction force of hoist on 11 cable branches P= 32000 daN;
Δ - cable linking play, Δ = 6 10^{-4} : 0,1 m;
K - cable elastic constant, k = 1890 – 5440 kN/m

To construct the crane::

m_1 - telescopic arm mass, m_1 = 3600 kg;

m_2 - revolving platform mass, counterweight, tilting cylinder, bearing, cage, m_2 =10400 kg;
$m_3 + m_4$ – chassis mass, pressing pasts, axle trees, chassis cab, reservoirs, transmissions, control equipment:

$$m_3 = 5163 \text{ kg} ; \quad m_4 = 6737 \text{ kg}$$

I_z – two arm section moment of inertia, $I_z = 23020$ cm^4;

V_1 –arrow at the arm peak $V_1 = -\frac{Pl^3}{3EI_z}$;

β_1 -coefficient of arm elasticity $\beta_1 = \frac{P}{V_1} = 144111$ daN/m;

V_2 - arrow of revolving platform: $V_2 = -\frac{Pl^2}{48EI_z}$

β_2 - coefficient of platform elasticity $\beta_2 = \frac{P}{V_2} = 242862$ daN/m

Iz_{31} Iz_4 – moments of inertia of chassis masses: $Iz_3 = 78500$ cm^4 ; $Iz_4 < Iz_3$
V_3 – arrow of chassis hole in elastic-plastic regime;

$$V_e = \frac{P_e \cdot l^2}{48\varepsilon I_z}; P = 1,25P_e; V_{\max} = 1,28V_e$$

P – maximum vertical load on chassis:
β_3 , β_4 – coefficients of back (front) chassis elasticity; $\beta_3 = P/V_e$;

β_3 = 1653150 daN/m; β_4 = 1211850 daN/m

K_2 , K_3 , K_4 – cylindrical rigidity when bending K_2 = 243546,7 daNm, K_3 = 1-332187 daNm; K_4 – 17041640,6 daNm

Dimensions: l_1 = 8,56 – 21,6 m; l_2 =m 2,14 m; l_3 =2,5 m; l_4 = 3,75 m; a_1 = (4,28 – 8,67) m; b_1 = 4m; e_2 =1,2 m; a_2 = 1,2 m; a_2 = 0,9 m; a_3 = 1,25 m; a_4 = 1,87 m; f_2 = 1,3 m.

Angles: tilting arm $\theta = 0 – 75^0$;arm cylinder tilting $\alpha = 42 – 117^0$.

For the example given there are 3 solutions for the rotations φ_3 , φ_4 , as follows:

on t = 7s

A) Rotations for elastic fixing φ_3 :

I) $\varphi_3(7) = 1,2925\cos0,121 \cdot t + 0,27958\cos4,664\, t – 0,2082\cos(-2,32)t – 0,0585$;

II) $\varphi_3(8\text{-}10) = = 1,14077\cos0,121 \cdot t + 0,39376\cos4,664t – 0,32246\cos(-2,32)t -$
$-0,01355$ (38)

III) $\varphi_3(17) = 0,24757\cos0,121\cdot t – 0,02244\cos4,664 \cdot t – 0,09574 \cos(-2,32)t – 0,04475$

B) Rotations for elastic fixing φ_4 :

at t = 7s

I) $\varphi_4(7) = - 0,37248\cos0,0578\, t + 0,172889\cos6,05\, t – 0,19959$ (39)

at t = 8, 9, 10 s

II) $\varphi_4(8\text{-}10) = - 0,5546\cos0,0578\, t + 0,00147\cos6,05\, t – 0,60428$

III) $\varphi_4(17) = -0,3421\cos0,0578\cdot t + 0,001473\cos6,05\cdot t – 0,260835$

The graphics of the general solutions for rotations $\varphi_3(t)$ and $\varphi_4(t)$ are shown in fig 7.
- curve I where it was taken into account the vertical possition of effort $F'_{2,3}$ of the lifting cable in the free term structure from the relations of type (38) and(39) ;

- curve II – free terms, in the expressions from the relation (38) and (39) $F'_{2,3}$ in the cable without a vertical positioning.

The elasticity coefficients computed for the given example are: β_1 = 144111 daN/m; β_2 =245862 daN/m**;** β_3 = 1653150 daN/m; β_4 = 1211850 daN/m.

It is possible that the great values given for the rotations φ_3, φ_4 to show that the chassis undetermined system of the statically linked bars to be transformed into a mechanism with yielding joints having cylindrical rigities when bending.

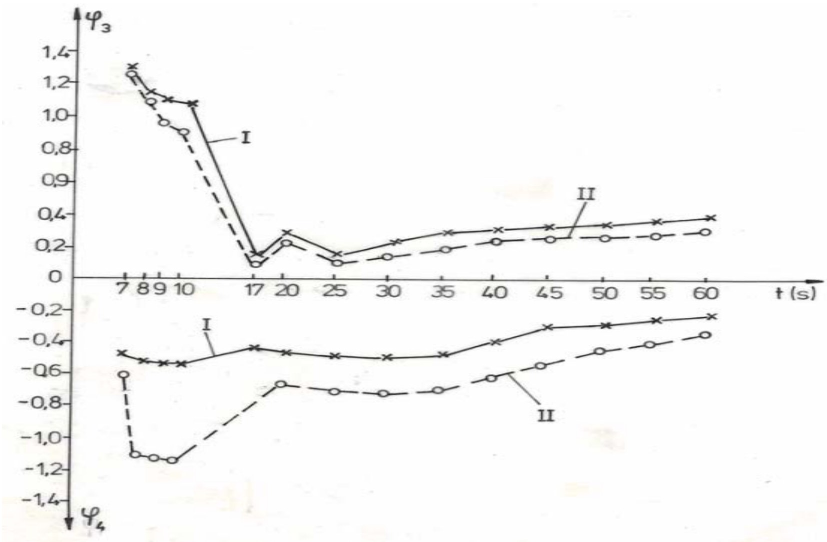


Fig.7. Graphics of the general solutions for rotations $\varphi_3(t)$ and $\varphi_4(t)$.

For the undetermined static sistem of bars with the above-mentioned joints and cylindrical rigidities that depend (in their turn) on the elasticity constants β_2 , β_2 , β_3 it was analysed the determinant D = 0, consisiting of three movement equations,i.e. one for the arm in φ_1 , one for the revolving platform in φ_2 and the equation in φ_4 for the crane construction. On the basis of characteristic equation analysis obtained from the determinant development it may be obtained certain criteria of construction stability or values for β_2 , β_3 şi K_2 , K_3 , K_4 .

For the given example the imposed limits for K_3, β_2, β_3 are as follows:

For K_3: $K_3 = 2{,}69 \cdot 10^6$ daNm ; $K_3 = 2{,}14 \cdot 10^5$ daNm;

For β_2 : $\beta_2 = 1{,}62 \cdot 10^6$ daNm ; $2{,}3 \cdot 10^4$ daNm ; $- 6{,}4 \cdot 10^4$ daNm ; $4{,}55 \cdot 10^5$ daNm ;

For β_3 : $\beta_3 = 56 \cdot 10^6$ daNm ; $- 64 \cdot 10^6$ daNm ;

It is evident the ratio between the elasticity coefficients from the revolving platform and the chassis:

$$\frac{\beta_2}{\beta_3} = \frac{1624497}{1653150} = 0{,}9827 \qquad (40)$$

proving that the section between the 2 elastic forces F_2 , F_3 shown on a plate is subjected to a force couple $F_2 \approx F_3$ on the vertically opposed sides.
Under these conditions for the support corresponding to φ_3 it was supposed an elasticity coefficient

$B_5 = 56 \cdot 10^6$ daNm .

We think that the effort of the force couple in the central part of the core, facing the rotation crown, F_2 , F_3 that interchange the sign is further transmitted to the vertical reactions of the supports φ_3 , φ_4 .

It results the vertical oscillation of the masses m_3 , m_4 (here, decoupled by the effect of the rotations φ_3 , φ_4) that can be evaluated dependent on time.

The differential equations of masses m_3 and m_4 independent movement have the following form

$$m_3\ddot{y}_3 + y_3 \cdot \beta_3 = \frac{F_{2\max}^{calc.}}{\beta_2} = 0,0366m \tag{41}$$

With the solution:

$$y_3 = -0,0366\cos 104,146r + 0,0366 \tag{42}$$

and

$$m_4\ddot{y}_4 + y_4\beta_3 = \frac{F_{2\max}^{calc.}}{-\beta_3} = 0,03199m \tag{43}$$

with the solution:

$$y_4 = 0,0319\cos 97,466t - 0,03199 \tag{44}$$

The force $F_{2_{\max}} = \beta_2 \cdot f_2 \cdot \varphi_2$ is calculated using the different values obtained from the stability condition imposed to the construction, i.e. the analysis of the determinant D=0.

It is known m_3 , m_4 ,β_3 , F_{2max}. In equation (43): we have $\beta_3 = -64 \cdot 10^6\, daN/m$, consisting for the joint with elastic support, elastic force F_3 moment K_2, $\beta_3 = 56 \cdot 10^6\, daN/m$ respectively.

The graphs of the general solutions of mass m_3 , m_4 vertical movement are shown in fig 8 where there are the negative values for $y_4(t)$ and the positive ones for $y_3(t)$.

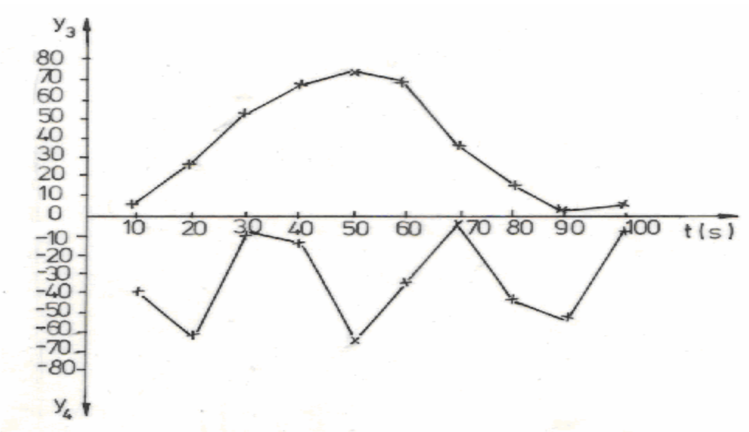


Fig.8. Graphs of the general solutions of mass m_3, m_4 vertical movement.

Conclusions

The relation (40) shows the possibility of creating of the fourth joint of a possible yielding, thus permitting the differential equation of the independent movement for the two masses m_3, m_4.

The determined values for elasticity coefficients β and bending cylindrical rigidity coefficients K, using D=0, lead the studied problem into the elastic-plastic domain.

The calculus in the elastic-plastic deformation domain basis on the fact that sometimes some permanent deformations may appear into the most stressed section, without destroing it completely or taking it out of use. If the plastic deformations increase too much, it may reach a limit state that correspond to a limit load which value may destroy the construction. The permitted load [1] is:

$$P_a = \frac{P_{\lim}}{C} \tag{45}$$

where: P_{lim} – limit load: $P_{\lim} = \frac{6M_{\lim}}{l}$ *sau* $\frac{8M_{\lim}}{l}$ (46)

dependent on the used calculus scheme for the yielding mechanism of the chassis on the whole (beam loaded with the fixed load and the single or jointed beam);

C – safety coefficient ($C = \varphi_{max} / \varphi_{stat}$; y_{max} / y_{static});

References

1. Buzdugan, Gh, s.a – *Manualul inginerului mecanic, materiale, rezistenţa materialelor, stabilitate elastică, vibraţii*, Editura Tehnică Bucureşti.
2. Darabont, Al. – *Socuri şi vibraţii. Aplicaţii în tehnică*, Editura Tehnica, Bucureşti, 1988.
3. Boleţeanu, L, Dobre, I. – *Aplicaţii ale mecanicii solidului deformabil în construcţia de maşini*, Editura Facla, 1978.
4. Sarbu, L. – Starea de tensiune a fisurilor apărute în structura şasiului de macara mobilă pentru orice categorie de teren folosită în construcţii. A *5-a Conferinţă Internaţională Integritatea Structurală a Construcţiilor sudate. Incercarea şi evaluarea riscului la realizarea materialelor avansate şi a sudurilor*, 20-21.11.2007, Timişoara pag.259-268.
5. Sârbu, L. – *Maşini de tracţiune, sisteme de transport şi echipamente grele pentru construcţii*, vol.II, Editura Economică, Bucureşti, 2008.
6. * * * *Indrumător matematic şi tehnic,* Editura Tehnică, Bucureşti.
7. * * * *Cartea macaralei Tadano Faun All-Terrain* ATF 30-2L, ISO 9001, planşe şasiu şi nervuri de întărire.

Analiza fisurilor în şasiu şi comportarea elasto-plastică a structurii la macaralele cu braţ telescopic

Rezumat

La macaralele mobile pentru orice categorie de teren folosite în construcţii (ex. macaraua Tadano Faun ATF 30-2L), s-au constatat existenţa unor fisuri în structura şasiului de tipul (4x4x4), tip clasic cu 4 roţi motoare şi directoare. Modul de apariţie şi evoluţia în timp a fisurilor nu este cunoscută, dar cu certitudine ele au fost generate de drumurile proaste pe care se deplasează macaraua în şantier, şi respectiv, de funcţionarea ei cu blocarea suspensiei si sistemului automat de control al limitatorului de sarcină, care creşte valoarea stării de eforturi şi tensiuni în structura braţului şi a şasiului.
In continuare, se fac unele aprecieri asupra mecanicii ruperii şi dinamica fisurilor, şi se trag concluzii asupra cazului prezentat cum trebuie remediat.