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ANALYSIS OF STRESS IN THE CONTACTING SEGMENTS OF THE BOOM AT MOBILE CRANE

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Summary: *There are many papers defining the expressions for dimensioning the cross section of auto crane boom. The equations describing the stress are quite complex. The complexity can be considerably simplified by correction factors. They provide easy and reliable description of the stress which is relevant for dimensioning (i.e. geometrical identification of boom cross section). It is usually necessary to know only the value of the stress in the zone which is important for dimensioning without analyzing the entire stress state. The stress analysis is presented in the paper and the expression for maximum stress, which is relevant for dimensioning, is defined. Theoretical results have been verified by experiments, too.*

Keywords: *boom cross section, mobile crane, local stress peak, experiment.*

1. INTRODUCTION

The authors have researched many models and ways of identifying critical value of the stress relevant for dimensioning the boom cross section. However, the contacting zone between two boom segments is exactly the zone in which the stresses are the biggest. In order to determine the stresses in this zone it is necessary to know the geometry of the above mentioned models. The paper, therefore, suggests the methodology for stress determination without precise knowledge of the section geometry.

2. THEORETICAL ASSUMPTIONS

To define the expression for the boom stress there are some assumptions which have resulted from theoretical and experimental research work:

- stresses of the external segment are the biggest at the contacting points with the slide of internal segment,
- the zone where stress peak occurs is small and its maximum value is the height of boom cross section,
- stress peak always occurs at the movable slide of internal segment,
- the biggest stress peak occurs when the internal segment is maximum extended,
- plate deformation in direction of longitudinal axis is similar to the deformation of transversely loaded plate.

The equation for stress change in this zone must be defined to obtain the expression for stress and to prove these assumptions. Dilatations (figure 1) in direction of x and y axes are [1], [2], [3], [4], [5],[6]:

$$\varepsilon_x = \frac{du}{dx} + \frac{\partial^2 w}{\partial x^2} \cdot z \quad \textbf{(1)}$$

$$\varepsilon_y = \frac{w}{H} \quad \textbf{(2)}$$

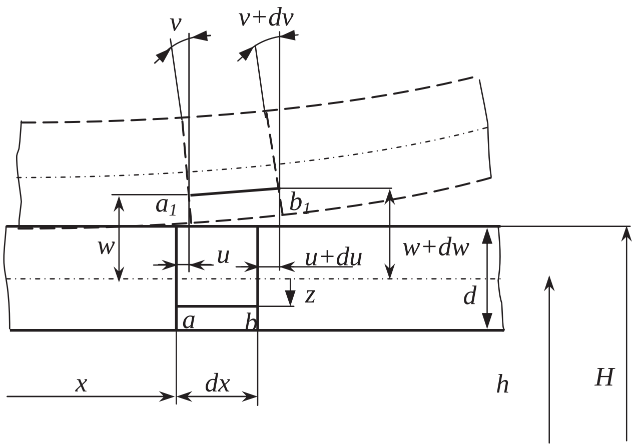

Figure 1: Bending and deformation of the middle surface

- Normal stresses (figure 1) in direction of x and y axes are:

$$\sigma_x = -\frac{E}{1-\mu^2}\cdot\left(\frac{du}{dx}+\frac{\partial^2 w}{\partial x^2}\cdot z+\mu\cdot\frac{w}{H}\right) \tag{3}$$

$$\sigma_y = \frac{E}{1-\mu^2}\cdot\left(\frac{w}{H}+\mu\cdot\frac{du}{dx}+\mu\cdot\frac{d^2 w}{dx^2}\right) \tag{4}$$

Differential equation for the motion of plate elements is obtained by relations known in elasticity theory [2], [4], [5]:

$$\frac{d^4 w}{dx^4}+4\cdot\beta^4\cdot w=\frac{P_k}{D} \tag{5}$$

where:

P_k – concentrated force of the slide acting on the boom plate
D – bending rigidity of the plate
β – geometrical coefficient

$$\beta=\sqrt[4]{\frac{3\cdot\left(1-\mu^2\right)}{H^2\cdot d^2}}$$

The solution of the equation (5) is:

$$w=e^{-\beta\cdot x}\left(A_1\cdot\sin(\beta x)+A_2\cdot\cos(\beta x)\right)+e^{\beta\cdot x}\left(A_3\cdot\sin(\beta x)+A_4\cdot\cos(\beta x)\right)+\frac{P_k}{4\beta^4\cdot D} \tag{6}$$

Since local stress peak is in question, the stress value rapidly lowers if getting far from the application point, i.e. it has small and finite value, whereas the element $e^{\beta\cdot x}$ has extremely high increment, so the constants A_3 and A_4 must equal zero.

If following boundary conditions are used:

$$x=0 \qquad \Rightarrow \frac{dw}{dx}=0 \text{ i } Q_0=-\frac{P_k}{2}$$

the expression for movement w is obtained in the zone close to the application point:

$$w=\frac{P_k}{8\beta^3\cdot D}\left[e^{-\beta\cdot x}\left(sin(\beta x)+cos(\beta x)\right)+\frac{2}{\beta}\right] \tag{7}$$

The stress caused by the local bending is:

$$\sigma_l=-\frac{3P_k}{2\beta\cdot b\cdot\delta^2}e^{-\beta\cdot x}\cdot\left(sin(\beta x)-cos(\beta x)\right) \tag{8}$$

The force "P_k" which depends on the extension length of the first boom segment can be defined (figure 2) as follows [7]::

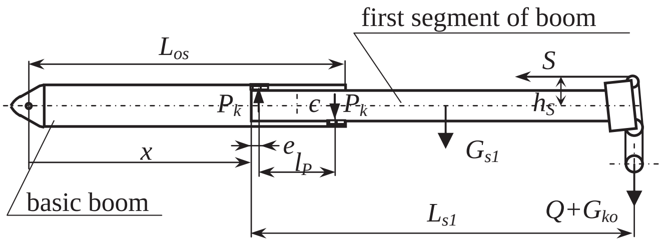

Figure 2: Determination of P_k force as depended on the extension lenght of the first boom segment

$$P_k = \frac{(Q+G_{ko})\cdot(2L_{s1}-L_{os}+x-2.1\cdot h_s)+G_{s1}\cdot(L_{s1}-L_{os}+x)}{4\cdot(L_{os}-x-2e)} \quad \textbf{(9)}$$

The influential zone of stress peak (figure 3) is very small and visible right beneath the application point. The function of local stress asymptotically tends towards zero when coordinate x is being increased in both directions.

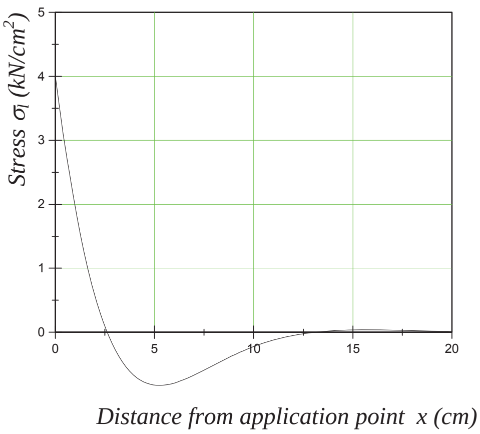

Figure 3: Local stress peak

The total bending stress in the section beneath the moving slide is:

$$\sigma = \frac{M_s}{W_x} + \frac{3P}{2\beta\cdot b\cdot\delta^2}e^{-\beta\cdot z}\cdot(sin(\beta z) - cos(\beta z)) \quad \textbf{(10)}$$

where z - coordinate of local stress distribution from the application point of moving slide.

Ovaj izraz se može znatno uprostiti ako se prethodno nacrta dijagram momenta savijanja a za lokalni skok napona izabere se tačka gde je $z=0$, (neposredno ispod pokretnog klizača). Tada je izraz za napon:

$$\sigma = \frac{M_s}{W_x} + \frac{3P}{2\beta\cdot B\cdot h^2} \quad \textbf{(11)}$$

Diagram presenting the stress changes (11) for maximum extended boom x = 400cm (measuring point MM1) and for position of moving slide x = 290cm (measuring point MM11) is shown in Figure 4. These data are applied to the off-road mobile crane TD-6/8 (figure 5) made by DDIMK "14. oktobar", Krusevac.
If the boom is less extended the stress peak is lower because the force of slide acting on the basic boom is lower.

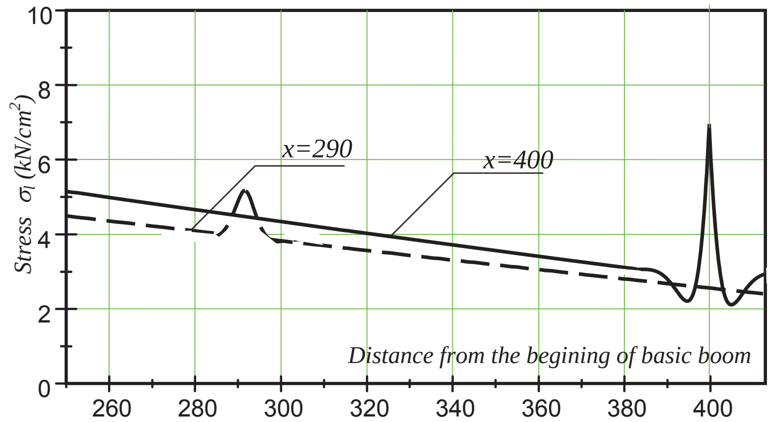

Figure 4: Stress at measuring points 1 and 11-equation (11)

3. EXPERIMENTAL VERIFICATION

The experimental testing has been done in order to test the theoretical results regarding the boom stress.
The off-road mobile crane TD-6/8, made by DDIMK "14. oktobar", Krusevac (figure 5), has been tested. The layout of measuring points is shown in figure 6.


Figure 5: Mobile crane TD-6/8 made by DDIMK "14. oktobar", Krusevac

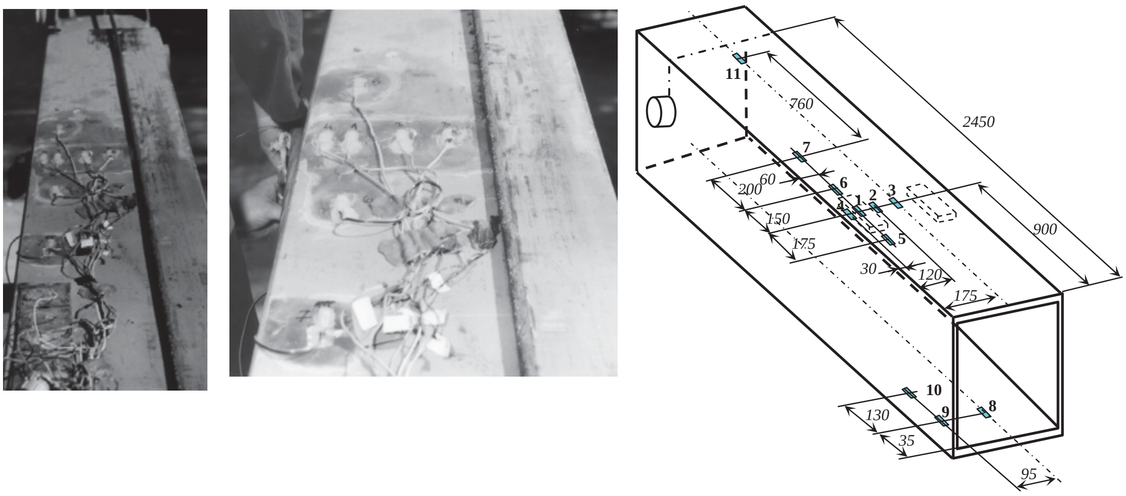

Figure 6: Layout of measuring points

The cross section is quadrantal. Eight measuring points are located at the top of basic boom at one half because of symmetry while three measuring points are located at the bottom (figure 6).
General dimensions of box-like carrier of the basic boom are:

- H = 350mm - carrier height
- B = 350mm - carrier width
- δ = 10mm - thickness of vertical and horizontal plates

A large number of measurements have been made. The results obtained beneath the measuring points MM7 and MP11 (figure 8) are presented in the paper because local stress peak is visible there when the slide moves over the measuring points. The comparative analysis of experimental measurements (figure 8) and theoretical results obtained by equation (11) shows high compatibility.

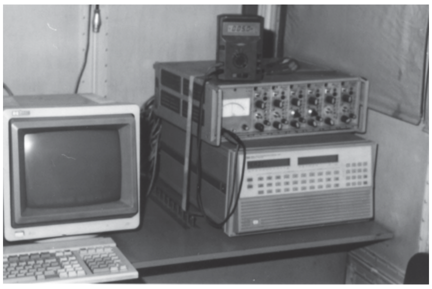

Figure 7: Measuring equipment

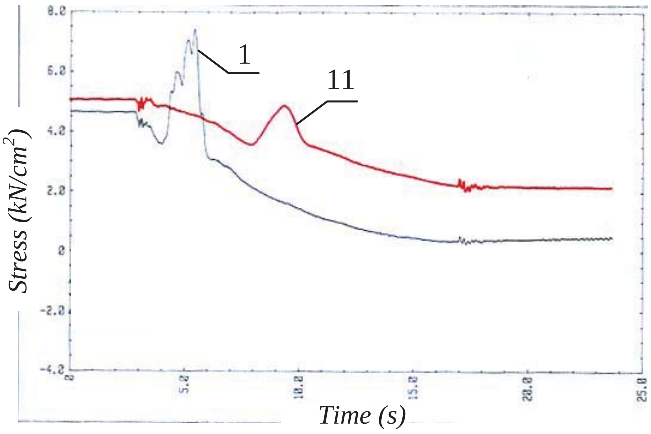

Figure 8: Stress at measuring points 1 and 11-experimenal values

4. COMPARATIVE ANALYSIS AND CONCLUSION

The testing can be done by comparing the experimental results at other measuring points and the results of the models presented in literature (figure 9) to the theoretical model (equation 11).
At the measuring point 11 shown in figure 8, the stress is increased when the slide passes beneath it and its value is (σ=*4.8 (kN/cm^2)*. The stress at the same point when the slide is beneath the measuring point 1 is (σ=*7.2 (kN/cm^2)*
Thus the accuracy of suggested model can be verified for any measuring point. The error is small (it does not exceed 10%) so the suggested model can be used for dimensioning the boom of mobile crane with satisfactory accuracy.
The comparative results of an experimental testing (extension of the boom up to maximal position with lifted load) are shown in figure 9.

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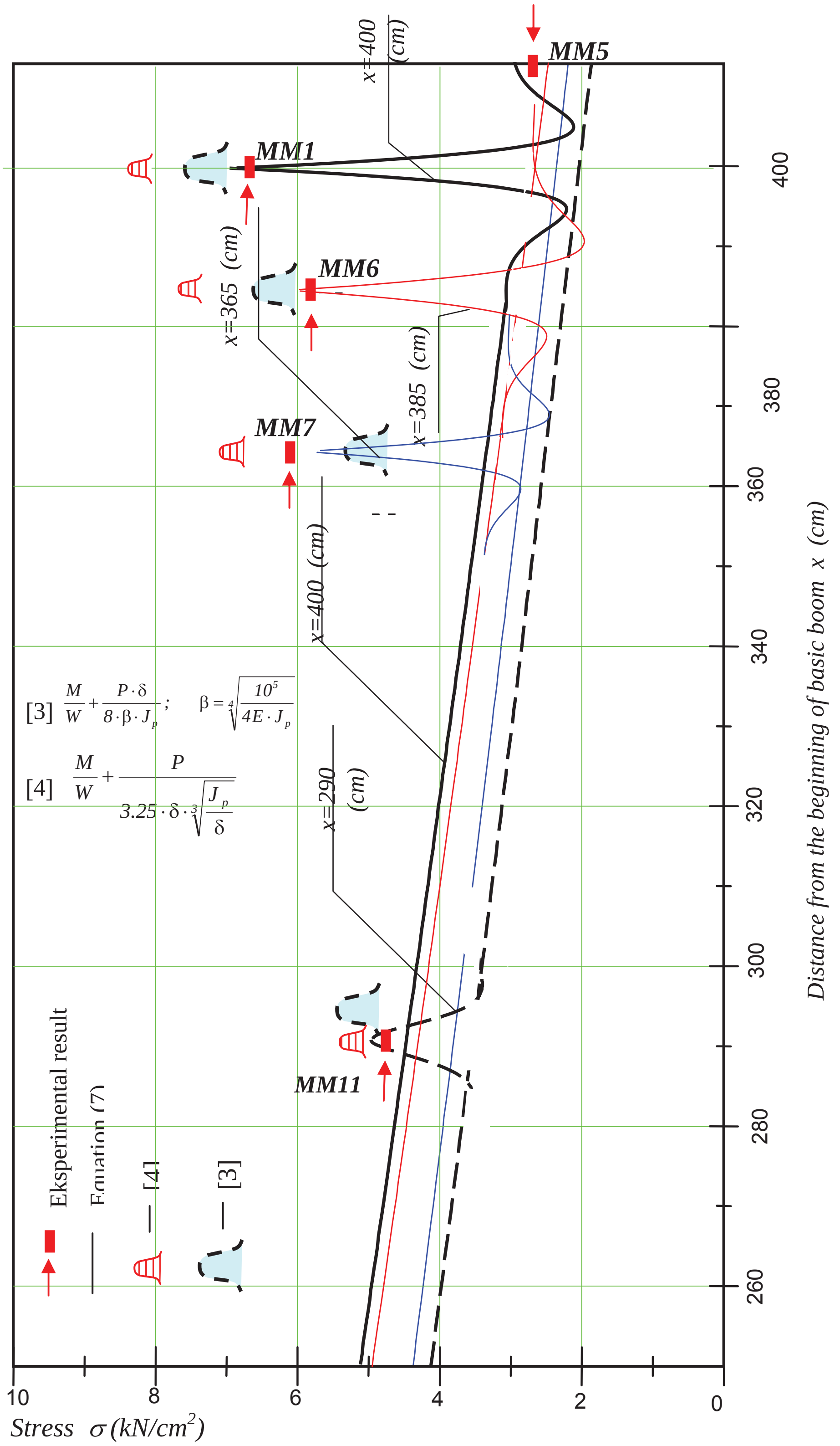

Figure 9: Stress comparaive review of the theoretical model and experiment measurements