NUMERICAL ANALYSIS OF HYDRAULIC TELESCOPIC MAST CONSTRUCTION

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ABSTRACT
This paper presents a part of the research in the domain of design of a hydraulic telescopic mast construction to meet the needs of lifting loads at the given height. Numerical analysis of the structure is done on the basis of 3D model created by using SolidWorks software, and the complex load simulation performed in it are shown. This section gives an overview of only the construction segment of the overall solution. Based on the conducted analysis, the solution of the optimal construction of a hydraulic telescopic mast which will meet the working conditions is shown.
Keywords: hydraulic telescopic mast, numerical analysis, loads.

1. INTRODUCTION
Telescopic masts are specially designed telescopic cylinders that allow to reach large elevations when lifting loads and at the same time a small height of the assembled construction. It consists of a selected number of segments, each having a certain length, and an internal and an external diameter. They are used in cases where it is necessary to reach a high lifting height, especially when it is necessary to achieve it in a given time period, i.e. when there is no need for a fixed pillar. This feature of these machine configurations enables the mobility of telescopic mast from one working cite to another, especially when the telescopic construction itself is mounted on the vehicle. According to the construction itself and type of operation telescopic mast can be: rope, hydraulic and pneumatic. Hydraulic telescopic masts are used in cases of greater load of the executive parts, while pneumatic applications are found where there is a need for a lower force at the top of the last segment of the mast, [1].

Figure 1. Some examples of tubular masts application

Telescopic masts can be used in a number of applications: on loader bodies, bulldozers, excavators, as masts within the hydraulic base of the wide forehead mechanics in the pits, such as power transmission masts, for lighting on motorways and stadiums, for setting up marketing advertisements, as well as stand-alone masts to which various devices such as antennas, radios, devices for different measurements and the like are mounted. Due to their different functionality and appearance possibilities in a variety of aesthetic designs, their use is very widespread and compared to the lattice masts used for the same purpose, the telescopic masts have less constructive dimensions and are made of a smaller number of parts and thus their use is more adequate.
Figure 1. shows only some of the many possible solutions and ways of using telescopic masts.

2. TELESCOPIC MAST CONSTRUCTION ANALYSIS

The aim of the analysis is to define the optimum construction of the hydraulic telescopic mast construction with special emphasis on the adequacy of the supporting structure from the aspect of strength and complex load. The hydraulic drive analysis, as an essential segment of the construction, is not shown in this paper. The basic limiting conditions for the execution of the calculation are: the height of the construction 3,5 [m], the height of the drawn structure 12 [m], the wind speed 120 [km / h], the weight of the load 100 [kg]. The material selected for the constructional solution is steel Č.1431 (C35E) with the following characteristics: material density $\rho = 7860$ [kg/m^3], tensile strength $R_m = 650$ [MPa], one-way bending durability: $\sigma_{D(o)} = 500$ [MPa].

Table 1. Geometrical characteristics of mast segments

SEGMENT	LENGTH [m]	OUTER DIAMETER [mm]	INNER DIAMETER [mm]
1	3,5	360	330
2	3	310	280
3	2,5	260	230
4	1,5	210	180
5	1,5	160	130

The load on the mast is complex and can be explained by: wind load, which manifests itself as a pressure load and a bending load, stress load on the load bearing the construction and the load on the bucking of the mast. Also, CFD analysis was carried out and a dynamic analysis of the structure of the mast. The pressure with which the wind acts on the mast segments can be replaced by concentric forces acting vertically on the longitudinal section of each segment. These forces cause bending moments in all mast sections, resulting in bending stress, which is greatest at the bottom of the first segment (base) of the mast. The load of the telescopic mast on the pressure comes from the action of the carrying load. The load is placed at the top of the last section (segment) of the mast so that each cross section of the mast is loaded with this type of load. In addition to the load weight, which makes up the largest part of the force perpendicular to the cross sectional cross section, the weight includes the weight of the sections above the observed section of the telescopic mast. Buckling is the loss of mast stability or another slim element constructively loaded with excessive force of pressure. Buckling of the telescopic mast is the greatest problem with regard to the load, as it can easily come to its protrusion because of its high height at the fully drawn construction. The weighing load calculation shown in this paper is performed in relation to the smallest cross section of the telescopic mast, i.e. it is performed against the fifth segment which is most sensitive to the protrusion. One of the most important is the wind load. The basic load to be taken into account is the external wind pressure acting on the outer surface of the structure and defined in section 5.2 of standard ENV 1991-1-4: 2005 with the following expression, [2]:

$$w_e = q_{ref} \cdot c_e(z_e) \cdot c_{pe}(z_e) \qquad \ldots(1)$$

where: q_{ref} - wind pressure, $c_e(z_e)$ - coefficient of wind exposure i $c_{pe}(z_e)$ - external pressure coefficient.

Based on this the wind pressure is calculated in the level of each segment of the mast: w_{e1}=0,3 [kN/m^2], w_{e2}=0,3 [kN/m^2], w_{e3}=0,34 [kN/m^2], w_{e4}=0,69 [kN/m^2], w_{e5}=0,74 [kN/m^2]. This determines the pressure applied by the wind to the segments of the masts. In a simplified case, pressure is perceived as a continuous load by which the wind acts on the longitudinal section of the segments. For calculating the load on the bending of the telescopic mast as the relevant forces of wind pressure on each segment of the mast:

$$F_w = w_e \cdot A_U \qquad \text{...(2)}$$

where: w_e - pressure on the segment of the mast, A_U - segment longitudinal section.

The smallest force at which bending occurs is the winding force F, as Euler's critical force:

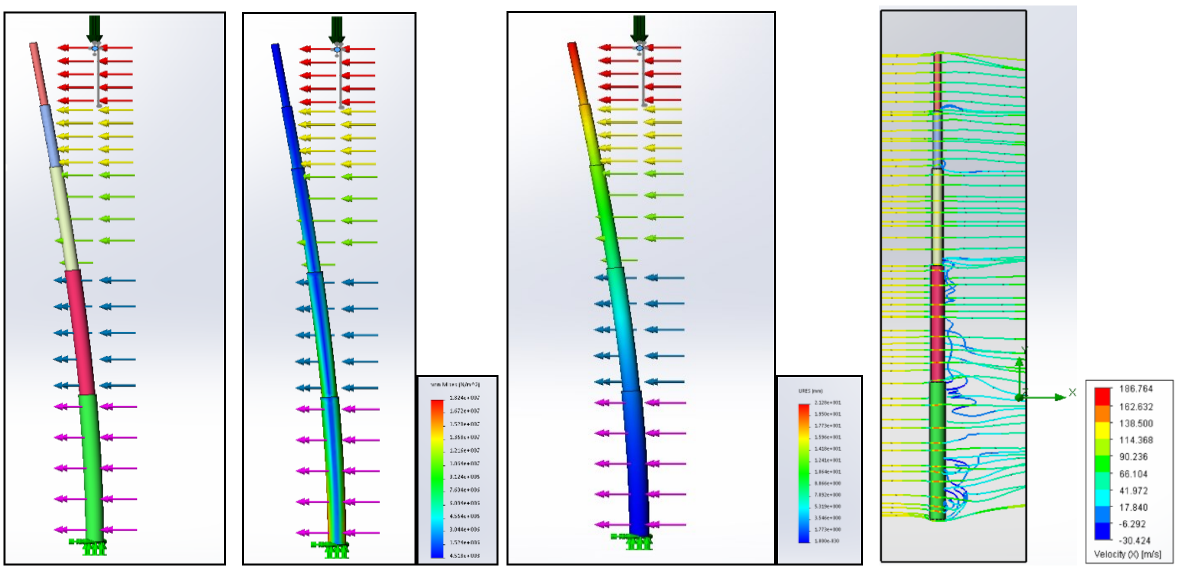
$$F = \frac{\pi^2 \cdot E \cdot I}{S \cdot L_K^{\ 2}} \left[N\right] \qquad \text{...(3)}$$

where: E = 2,1 x 10^5 [N/mm^2] - Young's elasticity module for steel, I - moment of inertia of the column (observed cross section), S = 3,5 ÷ 6 – safety coefficient, L_K – free length of buckling.

Due to the limited space for displaying the results of the work, no detailed analysis of the analytical calculation will be given or detailed explanations of the forms used.

Figure 2.a) shows the model of the telescopic mast on which external loads are applied: weight load and wind pressure on individual segments, which are calculated in analytical terms, and here is a representation of numerical simulation and analysis.

In Figure 2.b), an equivalent stress is shown according to the von Mises hypothesis of material destruction.



a) b) c) d)

Figure 2. Numerical analysis of mast construction: a) External load of the telescopic mast, b) equivalent stress values on the mast, c) mast deformation, d) wind load

A load schedule is given, where it is clearly seen that the bottom of the first segment is the most heavily loaded part of the telescopic mast contour. It leads to the conclusion that each section of the segment satisfies because the bending stress in all sections is less than the one-way flexural endurance of the material that is presented. In Figure 2.c), a lateral displacement of the mast construction due to the load action is given. It is clear that the largest displacement will be at the very top of the mast, due to the largest distance from the fixed surface, i.e. the bottom of the first segment. By simulating the loading of the column, it was found that the greatest lateral displacement was 21.28 [mm].

In Figure 2.d), an outline of the wind behavior around the stack segment is given, with a wind speed of 120 [km/h]. The mast is placed in a simulated wind tunnel and at the set wind speed the simulation of the flow is started. The assumption is that the wind flows in the X direction of the coordinate system, and the turbulent flow is taken into account. The image clearly shows the path that are graded in color depending on the speed of the wind at the positions in front, around and behind the mast. In Figure 3.a) to 3.e), a dynamic/frequency analysis of the construction solution is given. Dynamic analysis shows the critical value of the first oscillation frequency, [3,4,5].

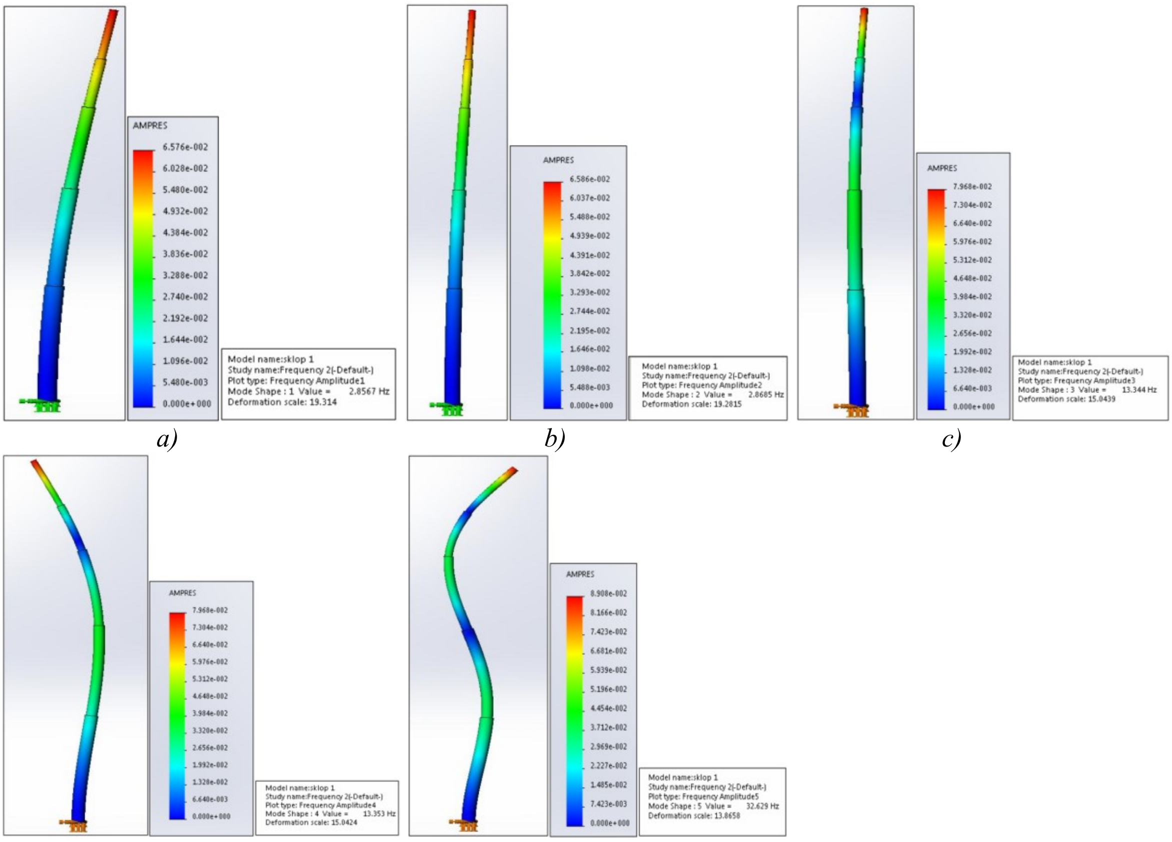


Figure 3. Frequency analysis of mast construction: a) to e) first to fifth frequency mode of oscillation

Based on the buckling effect analysis in the critical segment of the mast, it was found that Euler's critical force is due to the buckling of the fourth segments of the column being smaller than the force that is pressed to the column, i.e. in that case there will be no buckling on the mast.

3. CONCLUSIONS

The paper presents a static and dynamic calculation of the concept of hydraulic telescopic loading. The calculation has obtained that the dimensional characteristics satisfy the given load and that such construction will be able to withstand the required working conditions. Based on the 3D model of the mast, a numerical simulation was performed showing the load distribution along the entire mast construction and the results of the equivalent stress from all loads were obtained. It has been confirmed that the construction of the mast will withstand the loads that will occur during the work of the hydraulic telescopic mast. CFD structural analysis as well as frequency analysis of dynamic behavior have been applied, which is a specific approach to the analysis of this type of construction.

4. REFERENCES

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