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ANALYSIS OF THE INFLUENCE OF THE REINFORCED CONCRETE CHIMNEY GEOMETRY CHANGES IN THE CHIMNEY SHAFT

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Abstract. *Analysis of the reinforced concrete chimney geometry changes and their influence on the stresses in the chimney mantle was made. All the changes were introduced to a model chimney and compared. Relations between the stresses in the mantle of the chimney and the deformations determined by the change of the chimney's vertical axis geometry were investigated. The vertical axis of chimney was described by linear function (corresponding to the real rotation of the chimney together with the foundation), and by parabolic function (corresponding to the real dislocation of the chimney under the influence of the horizontal forces - wind). The positive stress pattern in the concrete as well as the negative stress pattern in the reinforcing steel have been presented. The two cases were compared. Analysis of the stress changes in the chimney mantle depending on the modification in the thickness of the mantle (the thickness of the chimney mantle was altered in the linear or the abrupt way) was carried out. The relation between the stresses and the chimney's diameter change from the bottom to the top of the chimney was investigated. All the analyses were conducted by means of a specially developed computer program created in Mathematica environment. The program makes it also possible to control calculations and to visualize the results of the calculations at every stage of the calculation process.*

1 INTRODUCTION

Analysis of the reinforced concrete chimney geometry changes and their influence on the stresses in the chimney mantle is presented in the paper. In order to carry on this analysis special computer program was created. The program enables simple modification of the geometrical data of the chimney structure chosen by the user and verifying the calculations at each phase – beginning from the statement of loads and up to calculation of the bending moments and stresses.

The obtained results can be applied to optimization of the chimney structures in their designing stage or can provide an answer to the problem of stresses occurrence in the reinforced concrete mantle in case when geometrical imperfections appear during their construction or exploitation stage.

2 ANALYSED MODEL

The results obtained from the calculations made on the designed and previously erected reinforced chimney were analyzed. The dimensions of the structure are as follows: height – 100 m, external diameter of the chimney shaft of the lower part near foundation – 12 m, external diameter of the chimney shaft outlet, thickness of the reinforced concrete mantel – 0,60 m at the base and 0,30 m at the outlet. The thickness changes abruptly adequately to each ring – segment of the structure (Fig.1). The chimney's convergence is 2%. Thermo insulation was made of mineral wool along the whole height of the structure. The mineral wool layer is 0.16 m thick and the brick lining is 0.12 m thick. The following materials were used to design the chimney:

– B- 30 concrete (characteristic strength of concrete for compression is f_{ck} = 25 MPa, while the elasticity module is E_{cm} = 30,5 GPa),

– A–I / St3S-b reinforcing steel (characteristic strength of steel for stretching is f_{yk} = 240 MPa, while the elasticity module is E_s = 200 GPa).

There were no additional objects or equipment mounted on the chimney shaft which could influence the dynamics of the system. The chimney pulls out gases from $180°C$ up to $200°C$, in emergency up to $250°C$.

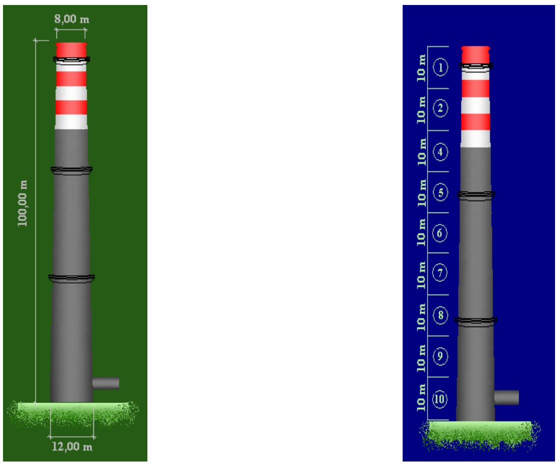

Fig.1. General dimensions of the model chimney and the shaft division into ring segments

3 PROGRAM APPLIED TO ANALYSIS - MATHEMATICA ENVIRONMENT

Special computer program was created in order to carry on the analysis of stress dependences from strain in the reinforced concrete silo mantel. The program was written in the environment of Mathematica according to all standard indications connected with the reinforced chimney designing.

The program allows monitoring separate stages of its work and modification of variables and constant values. It helps to model all constructional imperfections of the chimney.

Block diagram of the program calculating stresses in the chimney mantel was created as general diagram. It does not show particular calculations carried in the program but indicates the dependences present in the process of the program operation (Fig.2). The variables employed in the beginning of the calculation are marked blue, while the constants introduced into the program externally throughout calculating are marked pink. Violet colour is given to particular stages of calculation and yellow indicates final comparison of the obtained results with the standard limit stresses. These comparisons provide information regarding load capacity of the structure.

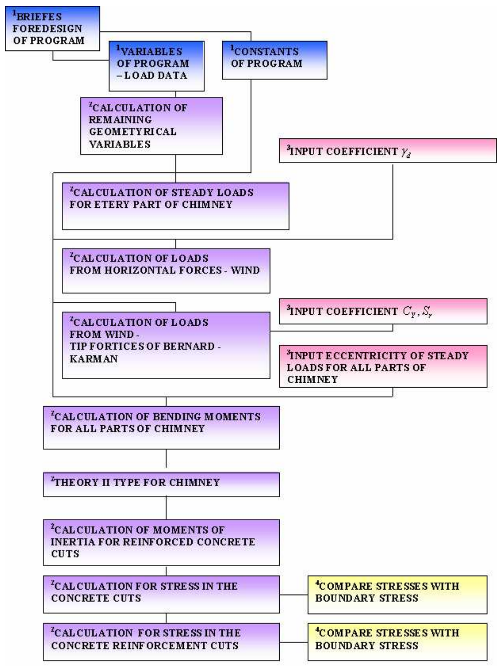

Fig.2. Block diagram of the program applied to calculation of stresses in the structure mantel

4 ANALYSIS OF STRESSES IN THE CHIMNEY MANTEL DEPENDING ON THE CHIMNEY'S VERTICAL AXIS STRAIN

Stresses that can occur in the chimney mantel at the time when the shape of vertical axis of the structure is changed were analysed. Two most frequently observed cases were calculated:

– linear strain of the axis describing chimney's rotation at the foundation level

– parabolic strain of the vertical axis describing chimney's axis deflection under horizontal pressure (for example wind).

4.1 Vertical axis described by linear function

Axis strain is a linear function with a constant slope coefficient towards perpendicular position. Four cases regarding the vertical axis slope of chimney were calculated. Value of the point located in the highest part of the structure successively equals to: 0,20 m, 0,33 m, 0,50 m, 0,67 m (Fig. 3). Pressure stresses in concrete exceed value of the permissible stresses equal to 16,25 MPa only in case when the chimney slopes from the perpendicular position for about 0,67 m. Stretching stresses in steel did not exceed limit stress value equal to 156 MPa in any of the above cases. The chimney's stability loss due to the displacement of the vertical axis of the structure are caused by stresses in concrete.

In the upper part of the shaft, stresses in concrete for the separate cases differ to such a small degree that this occurrence can be ignored. The same situation takes place in case of stresses in the reinforcing steel.

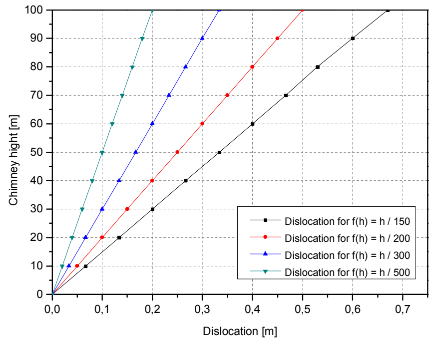

Fig.3. Dislocations of vertical axis described by linear function

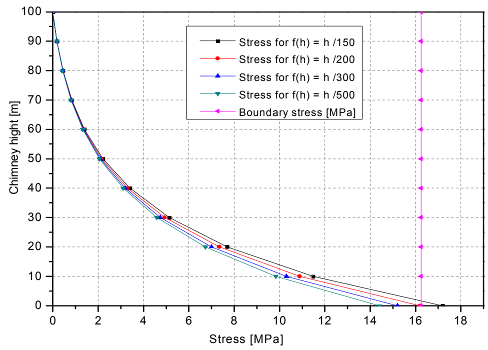

Fig.4. Pressure stresses in concrete for dislocations of vertical axis of the chimney described by linear function

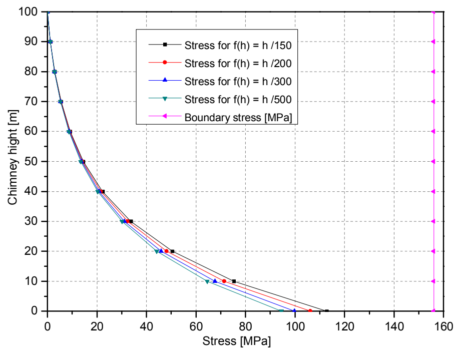

Fig.5. Stretching stresses in steel for dislocations of vertical axis of the chimney described by linear function

4.2 Vertical axis of the chimney described by parabolic function

Analysis deals with the case when dislocation of the vertical axis of chimney from perpendicular position is described by parabolic function (Fig.6). The point located in the highest part of structure dislocates successively for about: 0,22 m; 0,27 m; 0,36 m i 0,55 m. And also in this case, the limit stresses are exceeded in the chimney shaft's mantle due to pressure stresses in concrete (Fig.7). Nevertheless, it occurs sooner than for the axis described by linear function, namely for linear function it is 0,67 m while for the axis described by parabolic function it is 0, 55m. In both cases, axis strain has rather small influence on stretching stresses (Fig.8) occurring in the structure. Similarly to the previous case, only slight differences appear between stresses for the calculated slope of the vertical axis of chimney, both in concrete and in steel.

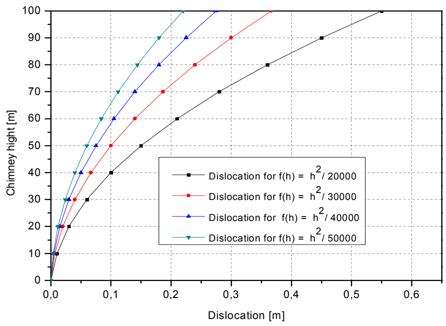

Fig.6. Dislocations of vertical axis described by parabolic function

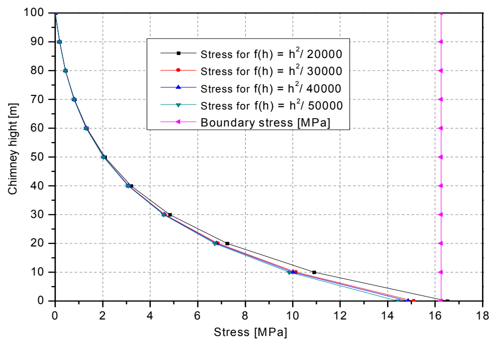

Fig.7. Pressure stresses in concrete for dislocations of vertical axis of the chimney described by parabolic function

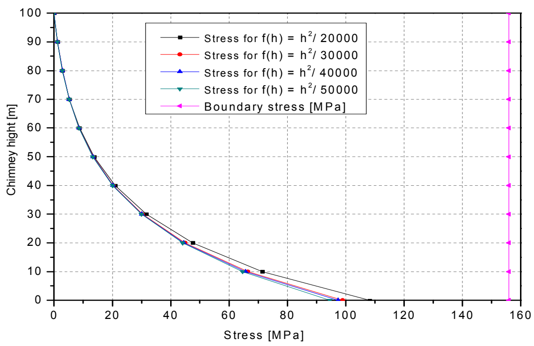

Fig.8. Stretching stresses in steel for dislocations of vertical axis of the chimney described by parabolic function

5 ANAYSIS OF STRESSES DEPENDING ON EXTERNAL DIAMETER CHANGES

Analysis of stresses in mantle of the reinforced concrete chimney with regard to the external diameter of the shaft was conducted for six cases. Constant convergence of chimney was left at 2% and thickness of the reinforced concrete mantel was left unchanged. The following cases were analyzed for external, lower diameter successively equal to: 11,00 m, 11,20 m, 11,40 m, 11,60 m, 11,80 m, 12,00 m.

Value of limit stresses was exceeded for the chimney with external shaft diameter equal 11.00 m (Fig.9). Stresses in steel (Fig. 10) do not exceed values of limit stresses. Stresses for all the analysed chimneys are close to each other for the chimney's height equal to 50,00 m. Differences in values of stresses caused by the modification of the external diameter of the mantle are observable below 50 m.

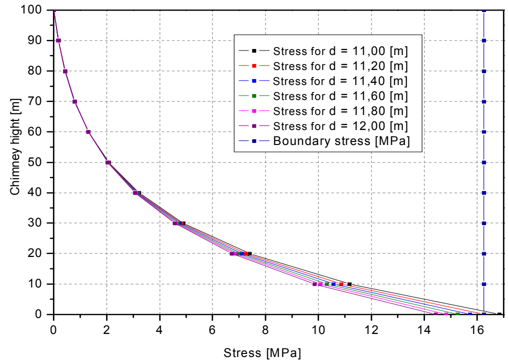

Fig.9. Pressure stresses in concrete for different diameters of the chimney's shaft

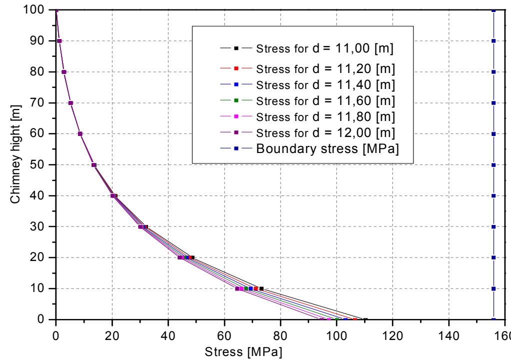

Fig.10. Stretching stresses in steel for different diameters of the chimney's shaft

6 ANALYSIS OF STRESSES DEPENDING ON MODIFICATION OF MANTLE THICKNESS OF THE REINFORCED CONCRETE CHIMNEY

Analysis of stresses in the structure mantle depending on the modification of mantle thickness of the reinforced concrete chimney was conducted for four cases. The first and the second case are chimneys with mantles changing in the abrupt manner at the height of 40 and 80 m.

The third case is a chimney with mantle thickness changing only once at the height of 50 m. The fourth case is variable, linear mantel thickness. For chimneys with the reinforced concrete mantles changing in the abrupt manner stress skipping also occurs. Linear modification of the mantle thickness is more advantageous for the structure. Similarly to the previous analyses regarding the exceeded limit pressure stresses are crucial.

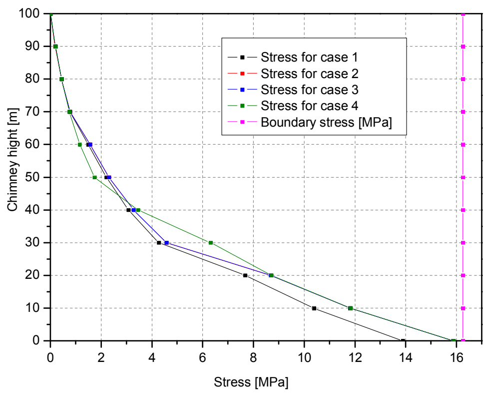

Fig.12. Pressure stresses in concrete for different thicknesses of the reinforced concrete chimney's mantel

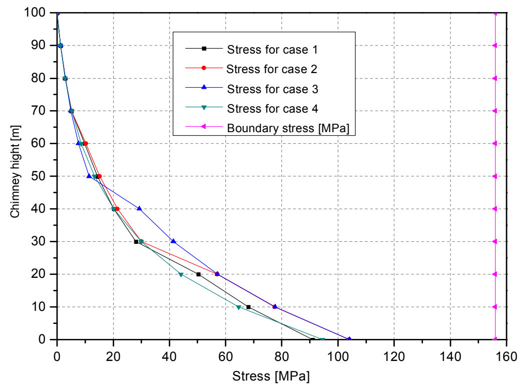

Fig.13. Stretching stresses in steel for different thicknesses of the reinforced concrete chimney's mantel

7 CONCLUSIONS

The purpose of this article was to present technical problem and provide program to analyse it. It is original and authorial program with a structure which helps to investigate the influence of the particular parameters on the stresses occurring on the whole height of chimney. It can be easily utilized for other similar reinforced concrete structures, such as aerial masts, telecommunication towers, supporting structures in wind power stations.

The presented model examples prove that the type of deformation of the vertical axis of chimney has considerable influence on the distribution of stresses in the chimney's mantle. It was also confirmed that the chimney's load depends to a considerable extent from pressure stresses in concrete.

Such analyses can be performed for different geometrical and material variables. The user of the program can decide by himself which parameters are to be considered constant and decisive variables. This program can be applied to analysis of stresses in the chimney's mantle both at the exploitation stage and assembly process. It may also be helpful to determine permissible imperfections which can be used to optimization of dimensions of full scale structures.

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