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ТЕРМИЧКА АНАЛИЗА НА АБ ОЏАК СО ВИСИНА 120м

РЕЗИМЕ

Во трудот е презентирана термичката анализа на 120 метра АБ оџак „Белградска електрана". Целта на трудот е да ја дефинира дистрибуцијата на внатрешните сили предизвикани од термичките товари кои се резултат на разликата во амбиентната и технолошката температура. Имено, за време на технолошкиот процес повисокиот температурен режим од оној што е предвиден во проектот прадизвикал оштетувања на термичката изолација, вклучувајќи и можна редукција на ултимативната јакост на бетонот и челикот на ѕидот на оџакот. Претпоставена е константна температура на површината и линеарна промена по дебелината на ѕидот. Нумеричката анализа е спроведена со користење на комерцијалниот програм SAP2000 со четири јазолни shell елементи. Моделот на конечните елементи е верифициран со споредување на резултатите од термичката анализа со соодветно достапни во литературата. Анализата покажа дека радијалните термички сили и моменти предизвикани од високите технолошки температури се повисоки од оние предвидени во оригиналниот проект.

Клучни зборови: АБ оџак, термички товар, внатрешни сили, процена

Marina ĆETKOVIĆ[1], Dušan NAJDANOVIĆ[2]

THERMAL ANALYSIS OF 120 HIGH RC CHIMNEY

SYMMARY

This paper deals with the thermal analysis of 120m high, RC chimney. The aim of the study is to find the distribution of internal forces caused by thermal loads, resulting from the difference among the ambient and the operating temperature. Namely, during the operating process, the higher temperature regime than those in the main design, has caused the thermo insulation damage, indicating the possible exceeding of ultimate strength in the concrete and reinforcement of chimney wall. It was assumed that temperature variation is uniform over the surface and linearly varying through the thickness of the chimney. Numerical analysis is performed using four-node shell element and the commercial program SAP2000. The finite element model is verified comparing the results of the thermal analysis with the available ones in the literature. The study shows that thermal radial forces and radial moments, obtained by the higher operating temperatures, are greater then the one in the original design. Furthermore these forces can cause cracks in vertical direction, so appropriate retrofit measures are to be applied.

Keywords: reinforced concrete chimney, thermal load, internal forces, assessment

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1. INTRODUCTION

Industrial chimneys are intended to divert gases, appearing in the operating process, in the atmosphere /1/. Depending on the materials from which they may be produced, we recognize: masonry, reinforced concrete, steel, and in the recent time Fiber Reinforced composite chimneys (FRP). Chimney construction itself consists of a foundation construction and a chimney block. Standard calculations, which have to be carried out when designing a chimney , include the following design stages, that are: 1) technological design, 2) static design, 3) dynamical design 4) thermal design and 5) structural design. By technological design initial dimensions are adopted depending on the requirements of technological process which takes place in the chimney. In static design, internal forces are calculating due to static load (self weight, weigh on external and internal facing and wind load), as well as proof of stability due to possible buckling of chimney block. Dynamical design imply checking chimney resistance on the appearance of forced vibrations due to seismic forces and dynamical wind load. Thermal design defines heat conduction through the chimney wall and calculation of such arising temperature affects in individual structural elements. Structural design are conducted on the basis of calculations under the points 2), 3) and 4).

In this paper thermal analysis of 120m high, RC chimney under the influence of three different temperature regime will be presented, that are: 1) temperature regime with designed insulation, 2) temperature regime with increased service temperature and designed insulation and 3) temperature regime with increased service temperature when insulation drop off between the levels +30m and +40m. Numerical 3D model of chimney will be modeled using commercial program SAP2000 and four node shell finite element /2/. The accuracy of the proposed finite element in the field of thermal analysis will be carried out by comparison with the theoretical model from the literature. The aim of the study is to find distribution of internal forces due to above mentioned temperature regimes and to point to the potential places of damage and that by required retrofit measures.

2. THERMAL ANALYSIS

The difference between the air outside and inside the chimney block (which is defined by the temperature of the gas-smoke) will lead to thermal conduction through all layers of chimney wall, of thickness d'_z, Fig. 1. The following assumptions are included into design: 1) temperature of chimney gas and outside air are constant across the height of the chimney, 2) heat conduction through all layers is perpendicular to the middle surface of the chimney and 3) variation of temperature is linear, because the wall thickness is too small compared to radius of the chimney.

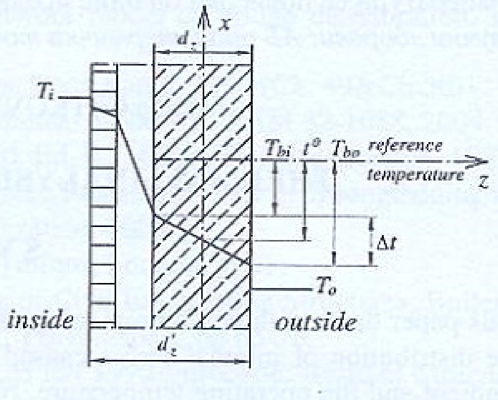

Figure 1. Heat coduction through the chimney wall

Linearly varying temperature field, from the temperature T_{bo} on the outside to temperature T_{bi} on the inside RC chimney wall, is given by the following function:

$$T(x,z) = t^0(x) + \Delta t(x)\frac{z}{d_z} \tag{1}$$

where: $t^0(x) = \frac{T_{bo}+T_{bi}}{2}$ is middle surface temperature and $\Delta t(x) = T_{bo} - T_{bi}$ temperature gradient through the chimney wall with the value zero in the middle surface, Figure 1.

It should be underlined that despite the flat plates in which, due to the nature of their physical behavior, are possible independently to analyze middle surface temperature and temperature gradient, in cylindrical shells one differential equation describes both problems, so there is no need for their separate observation. Namely, either type of temperature distribution, in conjunction with clamped or simply supported boundaries, will lead to both membrane loading and bending about the shell wall middle surface /3/.

Above mentioned statements will be checked in the next example of cylindrical shell loaded by the temperature field given in equation (1).

2.1 Verification of model

A cylindrical shell /4/ of radius r=3m, wall thickness d_z=0.30m and height H=9m made of material with the following properties: $\mu = 1/6$, $E = 2{,}1x10^6 MPa/m^2$, $\alpha_t = 10^{-5} 1/^0C$ is analyzed. Shell is fixed at the bottom and free at the top. Temperature on the inside shell wall is $T_{bi} = 20^0 C$, and at the outside is $Tbo = 0^0 C$. Therefore, middle surface temperature will be $t^0(x) = \frac{20+0}{2} = 10^0 C$, and temperature gradient will be $\Delta t(x) = 0 - 20 = -20^0 C$, or:

$$T(x,z) = 10 - 20\frac{z}{0.30} \tag{2}$$

Numerical 3D cylindrical shell model will be formed using commercial program SAP2000 and four node shell finite element.

Figure 2 shows distribution of radial forces N_φ through the height of cylindrical shell. We observe that fluctuations of radial forces N_φ, due to temperature field (2), are present only at the ends of the shell. At the fixed end shell is locally compressed, while tension forces occur at the free end. Moving away from the ends, radial forces tend to zero values.

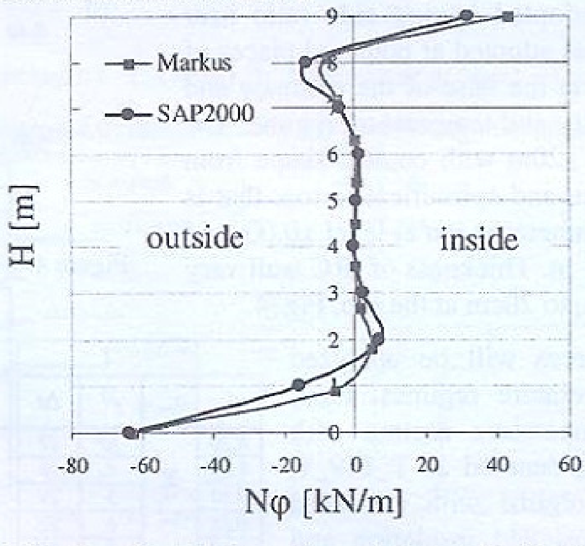

Figure 2. Distribution of radial forces through the height of cylindrical shell

Figure 3 shows distribution of radial M_φ and vertical M_y bending moments through the height of cylindrical shell, due to temperature field (2). We notice that as in the case of radial forces, both moments have abrupt change of their values only at the ends of the shell. Between these values occurs almost pure bending.

Therefore, we can conclude that an excellent agreement of internal forces obtained by program SAP2000 with theoretical solution from the literature was achieved /4/. Also the above mentioned statement, by which temperature field given by the equation (1) induce simultaneous membrane and bending state of stresses, was verified /3/. It should be emphasize that vertical stresses given in terms of moment M_y will be no longer considered in the analysis, since they are getting reduced by the stresses due to self weight. In the following we will analyze only radial forces and radial moments, due to which horizontal stresses arise, as the main cause of cracks appearance in vertical direction.

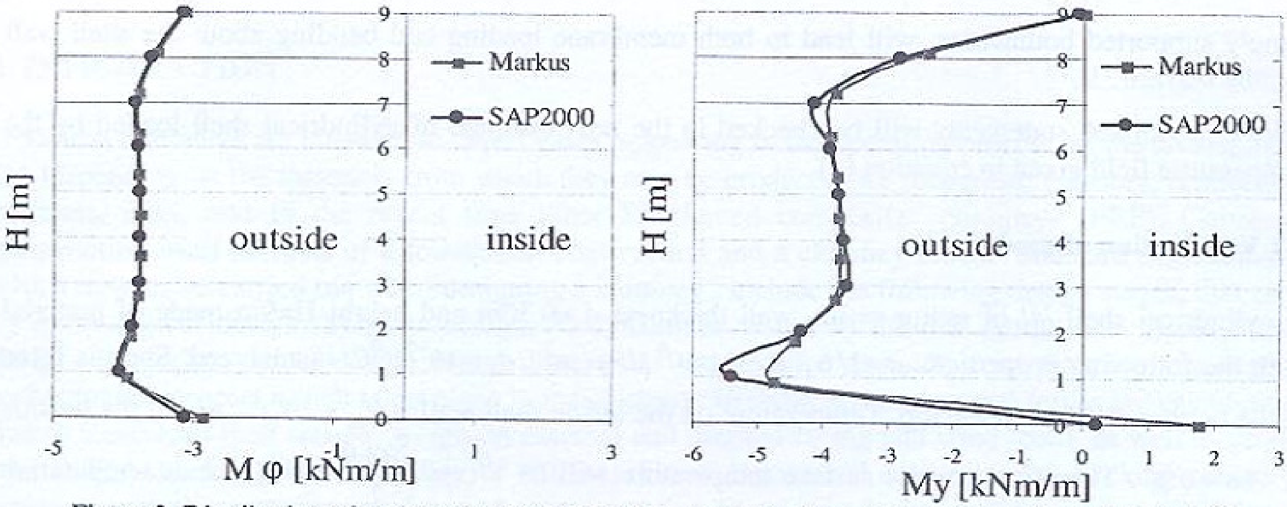

Figure 3. Distribution of radial and vertical bending moments through the height of cylindrical shell

3. THERMAL ANALYSIS OF CHIMNEY

Since we have confirmed in the previous example the reliability of shell finite element in the field of thermal analysis, we can now create 3D numerical model of 120 high, RC chimney. Material properties of the chimney are: ν=0.2, E= 2.1 10^7 kN/m^2, α_t= 10-5 1/^{0}C. Boundary conditions are fixed support at the base and free edge at the top of the chimney. FEM model was created using commercial program SAP2000 /2/, Fig. 4. A four node shell finite element mesh was adopted having side ratio near unity. A finer FEM mesh was adopted at potential places of stress concentration, that is at the base of the chimney and at abrupt changes of geometry and temperature regime. The height of chimney block is 120m with conical shape from the level ±0.00 up to +30 m, and cylindrical to top, that is up to level +120m. Outer diameter is 9m at level ±0.00, and from level +30 to top is 5.5 m. Thickness of RC wall vary from 40cm in the lover parts, to 20cm at the top, Fig. 4.

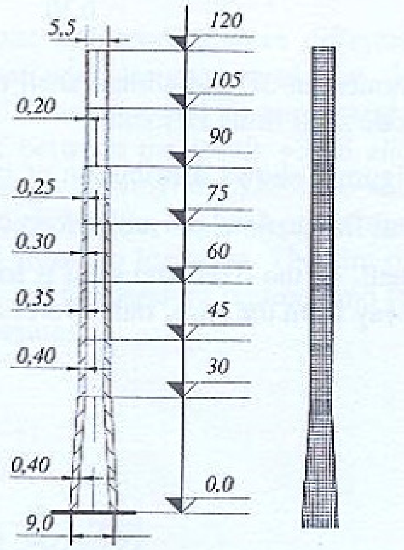

Figure 4. Geomety and FEM of chimney

Distribution of internal forces will be analyzed under three different temperature regimes. First, denoted as T_180, or temperature regime with designed insulation, second, denoted as T_219_1, regarded as temperature regime with increased service temperature and designed insulation and third, denoted as T_219_2 related to temperature regime with increased service temperature when insulation drop off between levels +30m and +40m.

	I			II			III		
d		t^0	Δt		t^0	Δt		t^0	Δt
0.20	T_180	10	22	T_219_1	14	26	T_219_2	14	26
0.25		4	16		7	20		7	20
0.30		5	19		8	23		8	23
0.35		6	22		10	27		10	27
0.40		3	19		6	22		64	104

Table 1. Chimney temperature regime

In wish to underline the contribution of each component, that is mid surface constant temperature t^0 and linearly varying temperature gradient Δt equal zero in the middle surface, on the deformation and internal forces, Fig. 5 and Fig. 6, show distribution of temperature, radial displacements u_z, radial forces N_φ and radial moments M_φ under the temperature regime T_180, Tab. 1, through the chimney height.

From the Fig. 5 we observe that due to mid surface constant temperature t^0, radial displacements Fig. 5b are in good agreement with temperature regime variation, Fig. 5a. As a result of restrained shrinkage at the bottom, chimney is locally compressed up to level 2m above the base with considerable radial compressive force. Removing from the base, internal forces tend to zero values. Local fluctuations in internal forces through chimney height, again arise at locations of abrupt changes

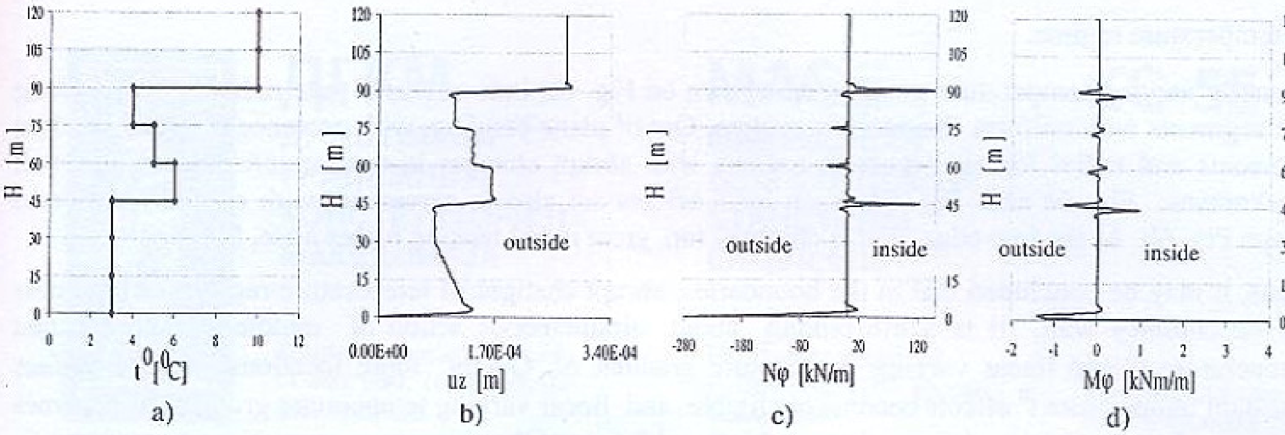

Figure 5. First temperature regime T_180: a) t^o surface constant temperature b) radial displacement, c) radial force and d) radial bending moment through the chimney height

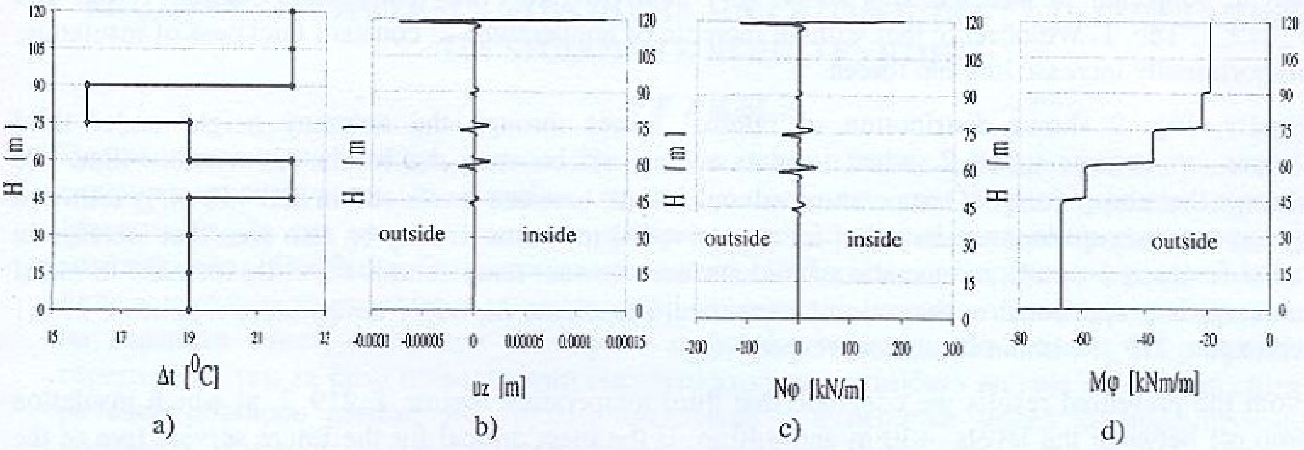

Figure 6. First temperature regime T_180: a) Δt temperature gradient b) radial displacement, c) radial force and d) radial bending moment through the chimney height

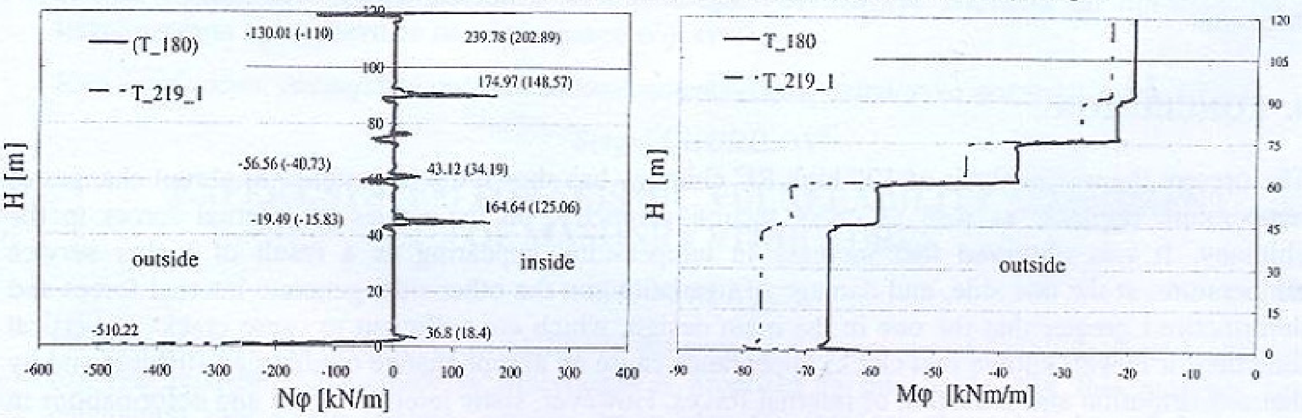

Figure 7. Radial forces and radial bending moments under first T_180 and second T_219_1 temperature regime

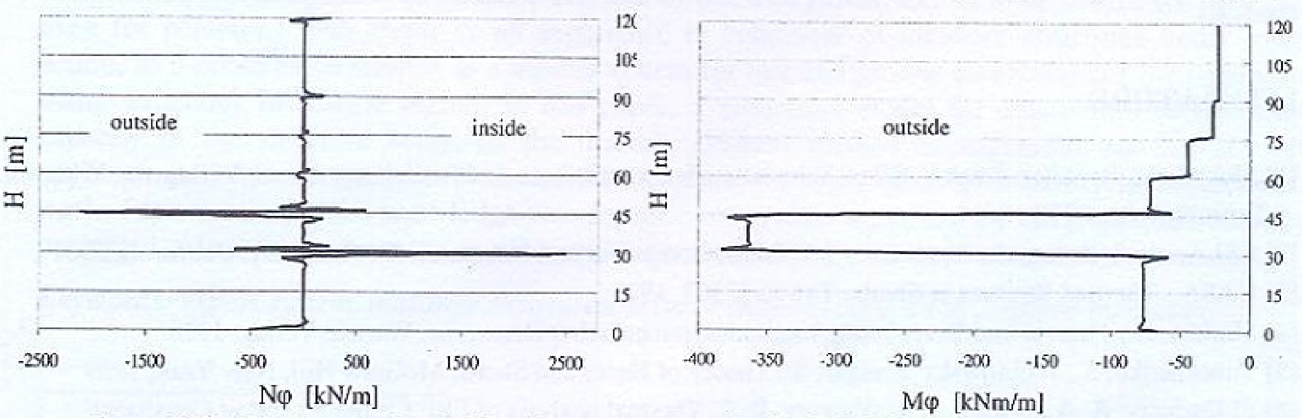

Figure 8. Radial forces and radial bending moments under third T_219_2 temperature regime

in temperature regime.

Linearly varying temperature gradient Δt, shown on Fig. 6a, induce nearly pure radial bending, along the segments with uniform temperature regime. Out of plane bending, with presence of radial bending moments and radial forces, occurs in regions with abrupt changes in temperature regime and wall thicknesses, Fig. 6c and Fig. 6d. Such local effects are also in agreement with chimney deflected shape Fig. 6b. At the free edge, that is chimney top, great radial tension forces arise, Fig. 6c.

Thus, it may be concluded that at the boundaries, abrupt changes of temperature regime, or thickness of the chimney wall, it is worth talking about simultaneous action of middle surface constant temperature t^0 and linear varying temperature gradient Δt. Out of these locations middle surface constant temperature t^0 effects become negligible, and linear varying temperature gradient Δt becomes dominant factor affecting deformations and internal forces of the chimney.

Fig.7 and Fig. 8 show distribution of radial forces and radial bending moments through the chimney height, subjected to simultaneous action of t^0 and Δt, under the temperature regime T_180 and T_219_1, Tab. 1. We observe that with an increase of temperature, at constant thickness of insulation, proportionally increase internal forces.

Finally, Fig. 9 shows distribution of internal forces through the chimney height under third temperature regime t_219_2, when insulation drop off between the levels +30m and +40m. We observe that abrupt jump of temperature value t^0 and Δt, between levels +30 m and +40 m, is followed by the same abrupt increase in radial forces and radial moments. It may be also seen that increase in radial forces is proportional to ratio of mid surface constant temperatures t^0, while increase in radial moments is proportional to the ratio of temperature gradients Δt, under temperature regimes t_219_1 with and t_219_2 without insulation, respectively.

From the presented results we conclude that third temperature regime T_219_2, at which insulation drop off between the levels +30 m and +40 m, is the most critical for the future service live of the chimney. It is known that the Polish regulations for chimneys /1/ permit temperature gradient no higher that 70^0C, indicating that this value itself is sufficient for the crack appearance. Hence, we conclude that in zone between the levels +30 m and +40 m cracks appearance is expected in vertical direction.

4. CONCLUSION

The present thermal analysis of 120 high RC chimney has shown the importance of abrupt changes of temperature regimes, as well as cross section geometry, on the values of internal forces in the chimney. It was observed that increase in temperature, appearing as a result of higher service temperature, at the one side, and damage of insulation, on the other side, generate internal forces and deformations greater that the one in the main design, which are sufficient to cause cracks in vertical direction. It is well known that cracks appearance cause an abrupt change of chimney stiffness and by that redistribution and reduction of internal forces. However, static internal forces and deformations in the chimney under equilibrium state with cracked section may be the objective of some future analysis.

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