Thermal Analysis of Chimneys by Finite Element

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Abstract

The study is concerned with effect of thermal stresses on chimneys, where the thermal loads considerate are based on actual field measurements of temperature variation in Al-Dora chimney- Baghdad.These temperature variations are divided into two parts:

1- Uniform heating.
2- Temperature gradient across the thickness of chimney shell due to flue gases.

Thermal analyses were carried out using ACI-307-08 provisions, and STAAD.Pro-V8i using (3D – plate element).

Comparison studies in thermal analyses were made on four chimneys similar in dimensions, but different in materials, (Reinforced Concrete, Steel, Stainless Steel, and Aluminum). It was found that the metal chimneys give higher results in radial and vertical displacements, while higher results in the bending moments and membrane stresses were found in the reinforced Concrete chimney.

Thermal analyses were carried out to study the effect of chimney shell thickness. It was found that the reactions at the base of the chimney are proportional to the thickness of the shell, but the radial and vertical displacements are inversely proportional with the thickness of the shell, While the effect of changing thickness on the bending moments and membrane stresses was found to be small which indicates that increasing the thickness of shell chimney doesn't lead to smaller thermal stresses. Finally, it was found that the Uniform heating component is more effective on the bending moments, membrane stresses and vertical displacements, while the rotations were not affected much by thermal loads. Winter time is found to be more critical since it gives higher temperatures gradient.

Keywords: Thermal analysis, Chimney, Finite Element

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Symbols:

r_q = Ratio of heat transmission through chimney to lining =0.5;
t=Thickness of chimney shell.
t_s=Thickness of air space or insulation.
t_b=Thickness of lining, (in).
T=Maximum temperature of gas inside chimney.
T_o=Minimum temperature of outside air surrounding chimney.
C_c = 12(Btu·in.)/(h·ft^2·°F) of thickness/h/°F difference in temperature for concrete.
Cs = to be obtained from the manufacturer of the materials used;
C_b = to be obtained from the manufacturer of the lining materials used.
D_{bi}= Inside diameter of lining.
D_b= Mean diameter of lining.
D_s= Mean diameter of space between lining and shell.
D_{ci}= Inside diameter of chimney shell.
D_c= Mean diameter of chimney shell.
D_{co}= Outside diameter of chimney shell.
α = Thermal expansion coefficient.
SQX, SQY = Shear stresses (Force/ unit len./ thk.)
SX, SY, SXY = Membrane stresses (Force/unit len./ thk)
MX, MY, MXY = Moments per unit width (Force x Length/length)
(For Mx, the unit width is a unit distance parallel to the local Y axis. For My, the unit width is a unit distance parallel to the local X axis. Mx and My cause bending, while Mxy causes the element to twist out-of-plane.)

1. Introduction

Chimneys are used in power plants for venting hot flue gases or smoke to the outside atmosphere. In recent years, the height of power plant concrete chimneys has increased to enhance the draw of air for combustion and to disperse pollutants over a greater area to reduce pollutant concentrations. While the number of reported chimney collapses due to an internal fire is very small, the consequences of chimney damage could be costly in terms of economic and human loss. The popularity of fiberglass reinforced plastic (FRP) liners – which are combustible materials – has made the risk of a fire in tall chimneys even more relevant in recent years. The FRP liners are used in reinforced concrete chimneys to protect the chimney shell from the effect of hot flue gases. Some of the possible sources of ignition in chimneys with FRP liners can be hot work inside the chimney during FRP installation or maintenance, ignition of stored flammable materials at the base of the chimney, ignition inside the flue gas desulfurization system or other equipment upstream of the chimney.

A critical effect of an uncontrolled fire in a chimney is the reduction in concrete strength [1], which leads to a decrease in the chimney load carrying capacity and service life. At an elevated temperature, the concrete experiences a variety of chemical and physical changes. For example, large volume changes resulting from non-uniform thermal expansion of aggregates and shrinkage of the cement paste, results in cracking and spalling. Spalling which is usually explosive and critical for structural integrity, is induced by mechanical and thermal stresses and pore pressure [2]. Spalling generally occurs at high temperatures, even though it is also observed at temperatures as low as 200 °C [3]. For spalling to occur, there needs to be a minimum moisture content as well as a temperature gradient of approximately 5–8 K/mm [1]. Temperature gradients induced by heating or uncontrolled fire depend not only on the heating source temperature but also on the heating rate.

Types of chimneys:

A- Metal chimneys,(Shorter construction time, lower weight).

B- Concrete chimneys,(Lower cost if the raw materials are available).

1. Unlined chimneys.
2. Lined chimneys.

   Linings can be classified as:

   a- Independent like brick, concrete, insulated steel, insulated Stainless Steel, or insulated Aluminum.

   b- Corbel supported brick.

   c- Shotcrete.

1.1 Importance of chimney lining:

- Unlined chimneys may leak harmful gases like carbon monoxide.
- Lining reduces thermal stresses and the chance of fire.
- Lining keeps the shell away from the chemical effect of flue and acids vapors.

1.2 Forces acting on chimneys:

The chimney shell shall be designed to resist stresses resulting from the weight of the chimney, the effect of temperature, both vertically and circumferentially, and the effect of either wind or earthquake, whichever is greater.

This paper gives a comparison studies in thermal analyses were made on four chimneys similar in dimensions, but different in materials, (Reinforced Concrete, Steel, Stainless Steel, and Aluminum), the effect of chimney shell thickness on thermal stresses, and the effect of removing the lining of chimney on thermal stresses.

2. Properties of steel under high temperature:

Jyri Outinen [4] studied The high-temperature behavior of structural steel S355 at elevated temperatures with 30 tensile tests. Test results were combined with an earlier test series that was carried out in the same laboratory. The mechanical properties of structural steel S355 determined from the transient state tests are illustrated in Figures 1 and 2.

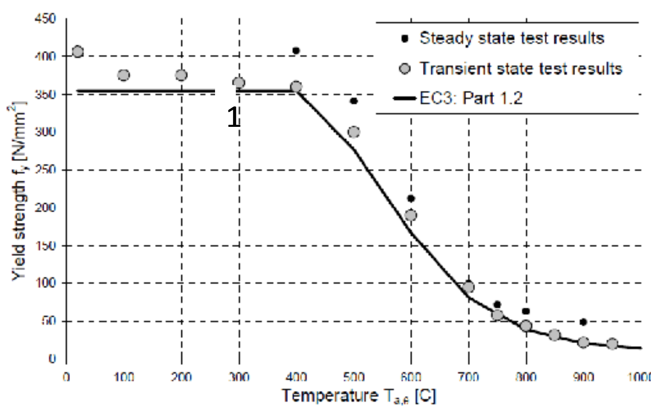


Fig.1 Yield strength of structural steel s355 at temp. 20 ^{o}c-950 ^{o}c

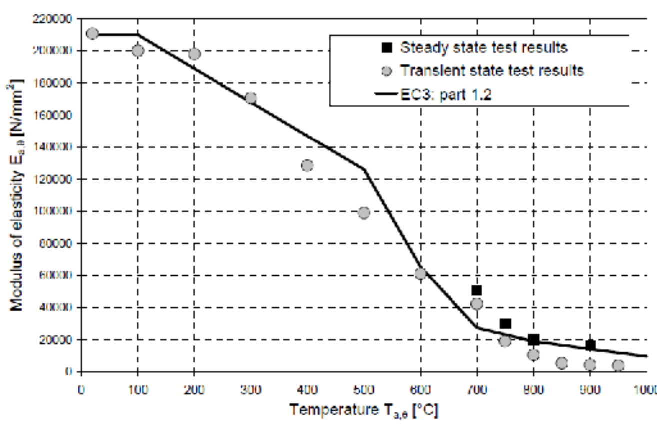


Fig.2 Modulus of elasticity of structural steel s355 at temp. 20 ^{o}c-950 ^{o}c

The effect of heating rate which also affects the strain rate during tests was studied by carrying out transient state tests at a low stress level. Three different heating rates were used varying from 10°C/min to 30°C/min. Test results within these temperature rates for structural steel did not differ much from each other. The behavior of structural steel S355 analyzed on the basis of transient state test results seems to be very near the material model given in Eurocode 3: Part 1.2. It can be concluded that within the limits that are given for that model in Eurocode 3 (EC3), the use of it for structural steel S355 is well-grounded in structural fire design of steel structures.

3. Properties of concrete and reinforcing steel under high temperature:

Malhotra [5] studied the effect of water/cement ratio, state of stress and age on the compressive strength of concrete exposed to fire. He concluded that:

1. The effect of temperature on the compressive strength of concrete is independent of the water/cement ratio within the range normally used in its manufacture.
2. The aggregate/cement ratio has a significant effect on the strength of concrete exposed to high temperature, the proportional reduction being smaller for lean mix than for rich mixes.
3. During the period of heating, the concrete under a constant stress exhibits a smaller reduction in strength than the concrete under no stress.

Harda and Furumura [6] investigated the strength, elasticity and thermal properties of concrete subjected to evaluated temperatures .The results showed that both compressive strength and tensile strength to decrease as temperature increase. The compressive strength at 400 ^{o}C reaches about 60% of its initial value. The modulus of elasticity and thermal diffusivity decrease when temperature increases.

From the previous information, in general, the structural properties of concrete are reduced with increase of temperature except (α).

Fawaz in his study [8] ,concluded that:

1- E_c (the modulus of elasticity for concrete) decreases with increase in temperature, and by Nizamuddin (32) :

For 0≤ T <630°C, $E_c(T)=[1.0-0.001032(T)]xE_{co}$ ………………...(1)

For T≥ 630°C, $E_c(T)=0.35\ E_{co}$ ……………………………………..(2)

where E_{co} is the value of E_c at 0°C.

2- f'_c (the compressive strength for concrete) decrease with increase in temperature

For $0 \le T < 350°C$, $f'_c (T) = f'_{co}$ ……………………………..(3)

For $T \ge 350°C$, $f'_c (T) = [1.0-0.0778(T-350)] x f'_{co}$ …………(4)

where f'_{co} is the value of f'_c at 0°C.

3- α_c (the coefficient of thermal expansion for concrete):

Thermal expansion is a very important free strain associated with fire. It changes rapidly with temperature.

Previous studies have shown an increase in thermal expansion with increase in temperature. The thermal expansion of concrete depends mainly on the thermal expansion of the cement paste and aggregate.

For $0 \le T < 500°C$, $\alpha_c(T) = 10.8x10^{-6}$ /c ……….(5)

For $T \ge 500°C$, $\alpha_c(T) = 16.2x10^{-6}$ /c …………..(6)

4. Thermal stress in cylindrical shells:

1- Uniform temperature distribution [9]:

If a cylindrical shell with free edge undergoes a uniform temperature change, no thermal stresses will be produced. But, if the edges are supported or clamped , free expansion of the shell is prevented , and local bending stresses are setup at the edges . Knowing the thermal expansion of a shell when the edges are free, the values of the reactive moments and forces at the edges for any kind of symmetrical supported can obtained by using many equations given in this reference .

2- Temperature gradient in the radial direction [9]:

Assuming that T_1 and T_2 are the uniform temperatures of the cylindrical wall at the inside and outside surfaces, respectively , and that the variation of the temperature through the thickness is linear. In such a case at points at large distance from the ends of the shell, there will be no bending, and the stresses can be calculated by using the formula :

$$\sigma_x = \sigma_\phi = \pm \frac{E \propto (T1-T2)}{2(1-\mu)} \quad \text{………….. (7)}$$

Which was derived for clamped plates. Thus, the stresses at the outer and the inner surface are represented in this equation where the upper sign refers to the outer surface indicating that a tensile stresses will act on this surface if $T_1 > T_2$.

Near the ends there will usually be some bending of the shell, for example Figure.(3-a), it can be observed that at the edge, the stresses result in uniformly distributed moments Mo of the amount

$M_o = -\frac{E\propto(T1-T2)}{12(1-\mu)}h^2$ …………..(8)

3- Temperature gradient in the longitudinal direction [9]:

If the temperature is constant through the thickness of the wall but varies along the length of cylinder, the problem can easily be reduced to the solution of the equation{ $D\frac{d^4w}{dx^4}+\frac{Eh}{a^2}w=z$}, let T = F(x) be the increase of the temperature of the shell from a certain uniform initial temperature and assuming that the shell is divided into infinitely thin rings by planes perpendicular to the x-axis and denoting the radius of the shell by a, the radial expansion of the rings due to the temperature change is αaF(x). This expansion can be eliminated and the shell can be brought to its initial diameter by applying an external pressure of an intensity z such that:

$$\frac{a^2z}{Eh}=\alpha aF(x)\text{……………………………(9)}$$

Which gives: $Z=\frac{Eh\alpha}{a}F(x)$ ……………………….………(10)

A load of this intensity entirely arrests the thermal expansion of the shell and produces in it only circumferential stresses having a magnitude:

$\sigma_\phi=-\frac{az}{h}=-E\alpha F(x)$ ……………………….(11)

to obtain the total thermal stresses, one must superpose on the stresses of the last equation the stresses that will be produced in the shell by a load of intensity – z.

5. Thermal analysis procedure of ACI-307 08:

According to the ACI-307 08 the chimney shell shall be designed to resist stresses resulting from the weight of the chimney, the effect of temperature, both vertically and circumferentially, and the effect of either wind or earthquake, whichever is greater.

5.1—Vertical temperature stresses

5.1.1 The maximum vertical stresses in the concrete and steel, f_{CTV}'' and f_{STV}'', in psi, occurring at the inside of the chimney shell due to temperature shall be computed by Eq. (12) and (13), respectively

$f_{CTV}'' = \alpha te \times c \times Tx \times Ec$ …….(12)
$f_{STV}'' = \alpha te(c - 1 + \gamma 2) \times TxnEc$ …….(13)
where

$c = -\rho n(\gamma 1 + 1) + \sqrt{[\rho n(\gamma 1 + 1)]^2 + 2\rho n[\gamma 2 + \gamma 1(1 - \gamma 2)]}$ ……………(14)

and
$n = Es / Ec$ …………………….(15)

The temperature gradient across the concrete shell, *Tx*, shall be computed by Eq. (6-5) through (6-8), or by using a complete heat-balance study for all operating conditions.

a. For unlined chimneys

$$Tx = \frac{t\ dci}{Cc\ dc}\left(\frac{Ti - To}{\frac{1}{Ki} + \frac{t\ dci}{Cc\ dc} + \frac{dci}{Ko\ dco}}\right) \quad .....(16)$$

b. For lined chimneys with insulation completely filling the space between the lining and shell

$$Tx = \frac{t\ dbi}{Cc\ dc}\left(\frac{Ti - To}{\frac{1}{Ki} + \frac{tb\ dbi}{Cb\ db} + \frac{ts\ dbi}{Cs\ ds} + \frac{t\ dbi}{Cc\ dc} + \frac{dbi}{Ko\ dco}}\right) ....(17)$$

c. For lined chimneys with unventilated air space between the lining and shell

$$Tx = \frac{t\ dbi}{Cc\ dc}\left(\frac{Ti - To}{\frac{1}{Ki} + \frac{tb\ dbi}{Cb\ db} + \frac{dbi}{Kr\ db} + \frac{t\ dbi}{Cc\ dc} + \frac{dbi}{Ko\ dco}}\right) ....(18)$$

d. For lined chimneys with a ventilated air space between the lining and shell

$$Tx = \frac{t\ dbi}{Cc\ dc}\left(\frac{Ti - To}{\frac{1}{rq\ Ki} + \frac{tb\ dbi}{rq\ Cb\ db} + \frac{dbi}{Ks\ ds} + \frac{t\ dbi}{Cc\ dc} + \frac{dbi}{Ko\ dco}}\right) ....(19)$$

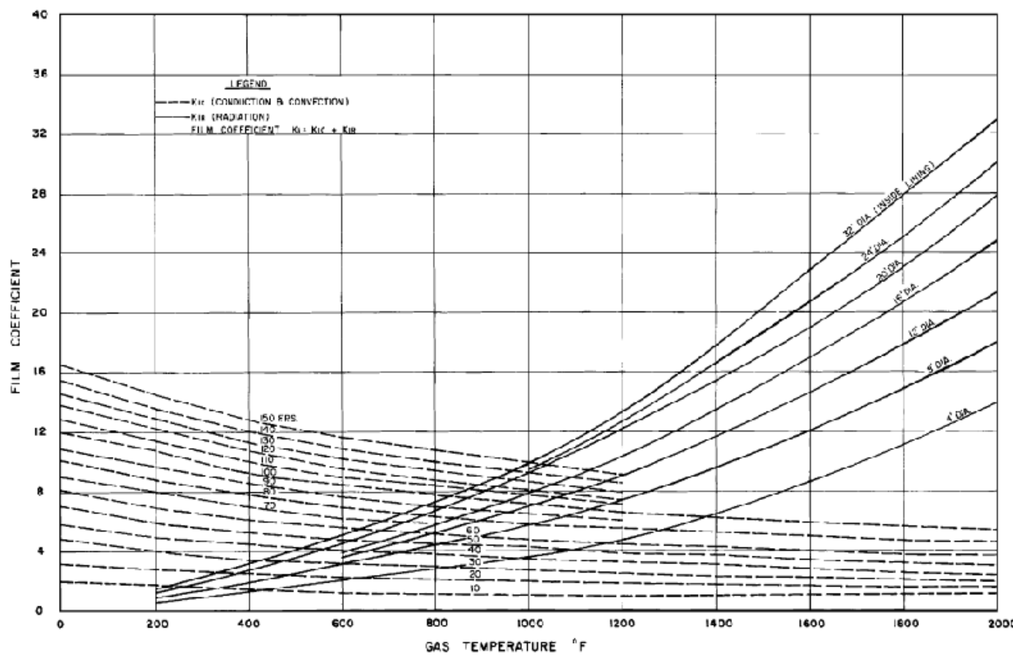
where:

r_q = Ratio of heat transmission through chimney to lining =0.5;
t=Thickness of chimney shell, in.
t_s=Thickness of air space or insulation, in.
t_b=Thickness of lining, in.
T=Maximum temperature of gas inside chimney, deg F.

T_o=Minimum temperature of outside air surrounding chimney, deg F.
C_c=12(Btu·in.)/(h·ft2·°F) of thickness/h/°F difference in temperature; fo concrete ;
Cs = to be obtained from the manufacturer of the materials used;
C_b = to be obtained from the manufacturer of the lining materials used;
K_i = to be determined from curves in Fig.4;
K_o = 12 Btu/(ft2·h·°F);
K_r = Ti/120; and
K_s = Ti/150.
d_{bi}=Inside diameter of lining, ft.
d_b=Mean diameter of lining, ft.
d_s=Mean diameter of space between lining and shell, ft.
d_{ci}=Inside diameter of chimney shell, ft.
d_c=Mean diameter of chimney shell, ft.
d_{co}=Outside diameter of chimney shell, ft.

The value of rq = 0.5 shall apply only where the distance between the lining and the chimney shell is not less than 4 in. Throughout the entire height of the lining and air inlet and outlet openings are provided at the bottom and top of the chimney shell. The area of the inlet and outlet openings, in square feet, shall numerically equal two-thirds of the inside diameter in feet of the chimney shell at the top of the lining. Local obstructions in the air space between the lining and the chimney shell shall not restrict the area of the air space at any horizontal section to be less than that specified for air inlet or outlet.

5.1.2 The research data available to establish the coefficients of heat transfer through the chimney lining and shell, especially as they concern the heat transfer from gases to the surfaces and through ventilated air spaces between lining and shell, are somewhat meager. Unless complete heat balance studies are made for the particular chimney, it is permissible to use constants as determined or stated in this standard.



Flue gas film coefficient

Fig. 3 Curves for determining Ki.

5.1.3 The maximum stress in the vertical steel, f_{STV}, in psi, occurring at the outside face of the chimney shell due to temperature shall be computed by Eq. (20).

f_{STV} = αte × (γ2 – c) × Tx × Es ……..(20)

5.2—Circumferential temperature stresses

5.2.1 The maximum circumferential stress in concrete, f_{CTC}'', in psi, occurring at the inside of the chimney shell due to temperature, shall be computed by Eq. (21).

f_{CTC}'' = αte × c′ × Tx × Ec ……(21)

where

$$c' = -\rho' n(\gamma_1' + 1) + \sqrt{[\rho' n(\gamma 1' + 1)]^2 + 2\rho' n[\gamma 2' + \gamma 1'(1 - \gamma 2')]} \quad \text{…….(22)}$$

and Tx = value determined for vertical temperature stresses. All other notations are the same as for vertical temperature stresses.

5.2.2 The maximum stress in psi in the outside circumferential reinforcement f_{STC} due to temperature shall be computed by Eq. (23).

f_{STC} = αte × (γ2′ – c′) × Tx × Es ……(23)

5.3 Conversion of U.S. Customary Units to SI Units :

1 in.= 25.4 mm , 1 ft = 0.304 8 m , 1 psi= 0.006 895 N/mm^2 ,
1 kip = 4.448 222 kN , $F^o = (C^o \times 9/5) + 32$

6. Field measurements:

This study was stimulated by the availability of field data taken from al-Dora chimney in Baghdad, the temperatures of air and concrete shell were taken in summer and winter in 1999, to provide a real thermal load case for any chimney in Baghdad and to make a comparison between the thermal load case in summer and winter. Any other important information was taken from control office in al-Dora power plant.

Table (1)

Air and concrete temperatures measurements at al-Dora chimney, in centigrade degrees, at Sep.

Date	Air Temp.		Afternoon concrete temp. at each station, ^{o}c								
	8-9 A.M.	3-4 P.M.	Station A @315^o	St. B @0^o	St. C @45^o	St. D @90^o	St. E @135^o	St. F @180^o	St. G @225^o	St. H @270^o	&T
14-9	29.75	40	41	41.5	41	37	36.25	36	36.75	39.75	5.5
15-9	28.75	39	40	40.75	40	36	35.25	35	35.75	38.75	5.75
16-9	26	35.75	39.5	41	39.5	35.5	35.25	35.5	36	40	5.5
Average	28.17	38.25	40.17	41.08	40.17	36.17	35.58	35.5	36.17	39.5	5.58
&Tm	0	10.08	12	12.91	12	8	7.413	7.33	8	11.33	

where : &Tm=Change in temp. from Morning average of 28.17 ^{o}c
&T=Temp. of station B (@ 0^o) – Temp. of station F(@ 180^o)

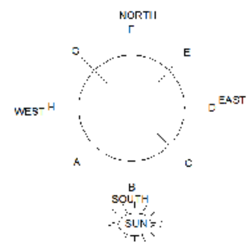


Fig. 4 Field measurements stations

Table (2)

Air and concrete temperatures measurements at al-Dora chimney, in centigrade degrees, at Dec.

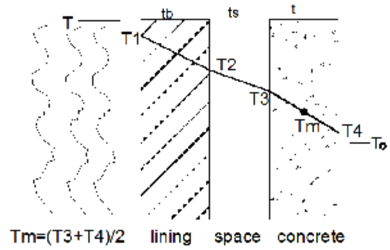
Date	Air Temp.		Afternoon concrete temp. at each station, °c								
	8-9 A.M.	3-4 P.M.	Station A @315°	St. B @0°	St. C @45°	St. D @90°	St. E @135°	St. F @180°	St. G @225°	St. H @270°	&T
28-12	12.75	20.75	25	30	27.5	22	19.5	19.5	19.5	21	10.5
29-12	12.5	20	24.75	30	27.25	21.75	19	19	19	20.5	11
30-12	13	21.5	25.5	30	28	22.5	20	20	20	21.5	10
Average	12.75	20.75	25	30	27.5	22	19.5	19.5	19.5	21	10.5
&Tm	0	8	12.25	17.25	14.75	9.25	7.75	7.75	7.75	8.25	

where: &Tm=Change in temp. From Morning average of 12.75 °c
&T=Temp. Of station B (@ 0°) – Temp. Of station F (@ 180°)

6.1 Distribution of temperatures in chimney:

Using the equations for thermal stresses of ACI 307 08, the distribution of temperatures has been calculated as shown below:

$$Tx = T3 - T4 = \frac{t\ dbi}{Cc\ dc}\left(\frac{Ti - To}{\frac{1}{rq\ Ki} + \frac{tb\ dbi}{rq\ Cb\ db} + \frac{dbi}{Ks\ ds} + \frac{t\ dbi}{Cc\ dc} + \frac{dbi}{Ko\ dco}}\right) \quad \ldots\ldots\ldots(24)$$



Uniform temp. increase =Tm-Tb, Temp. gradient =T3-T4

Fig. 5 Distribution of temperatures in chimney

All temperature distribution have been calculated according to ACI 307 08, where:

T=170^{o}C for ordinary case =338^{o}F

=598^{o}C for ordinary case =1100^{o}F

T_o = temp. of air at each month = 0,5,10,……,

T = 225 mm=8.858 in, Cc=12 Btu/ft^2 . in.hr.F, C_b=6, d_c=21.572 ft=6.6 m, r_q = 0.5, k_1 =7.58, d_b=12.008 ft=3.66 m, t_b=4.724 in=120 mm, d_{bi}=11.811ft=3.6 m, k_s=2.25, d_s= 16.89 ft=5.15 m, k_o=12, d_{co} =22.31ft=6.8m.

Table (3)

Distribution of temp. in ^{o}C through chimney shell and lining in al-Dora chimney, for Ordinary case, where T=170 ^{o}C.

To	Tx	Tm	T4	T3	T2	T1
0	27.5	16.5	3	30	50	154
5	26	21	8	34	53.6	154.3
10	25.4	25.7	13	38.4	57.2	154.7
15	24.6	30.3	18	42.6	60.8	155
20	23.8	34.9	23	46.8	64.4	155.3
25	23	39.5	28	51	68	155.7
30	22.2	44.1	33	55.2	71.6	156
35	21.4	48.7	38	59.4	75.2	156.3
40	20.6	53.3	43	63.6	78.8	156.7
45	20	58	48	68	82.4	157
50	18	62.5	53	72	86	157.3
55	18.2	67.1	58	76.2	89.6	157.7
60	17.4	71.7	63	80.4	93	158

Table (4)

Distribution of temp. in ^{o}C through chimney shell and lining in al-Dora chimney, for Emergency case, where T=598 ^{o}C.

To	Tx	Tm	T4	T3	T2	T1
0	94	57	10	104	112	151
5	93.25	61	15	108	121	184
10	92.5	65	20	112	130	217
15	91.75	69	25	116	139	250
20	91	73	30	121	148	283
25	90.25	77	35	125	157	316
30	89.5	81	40	129	166	349
35	88.75	85	45	133	175	382
40	88	89	50	137	184	415
45	87.25	93	55	141	193	448
50	86.5	97	60	146	202	480
55	85.75	101	65	150	211	513
60	85	104	70	155	220	543

7. Comparison of construction materials studies

Chimneys of different construction materials with same dimensions are studied for thermal response analysis. These chimneys are linearly tapered from base up to the top.

The chimneys are concrete, steel, stainlesssteel, and aluminum. The dimensions of all chimneys are:

Height =45 m ,   Base diameter =3.2m,   top diameter =2 m

Thickness of shell =14 mm (accept for concrete chimney =15 cm)

Table (5)

Name	E kN/mm2	Poisson's Ratio	Density kg/m3	Alpha @/°C
STEEL	205.000	300E-3	7833.413	12E-6
STAINLESSSTEEL	197.930	300E-3	7833.413	18E-6
ALUMINUM	68.948	330E-3	2712.631	23E-6
CONCRETE	21.718	170E-3	2402.615	10E-6

In this study STAAD.Pro V8i software with plate finite element was used. The STAAD plate finite element is based on hybrid finite element formulations. A complete quadratic stress distribution is assumed. For plane stress action, the assumed stress distribution is as follows:

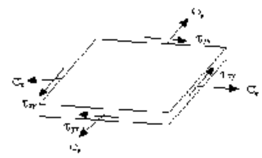


Fig. (6)

The following quadratic stress distribution is assumed for plate bending action:

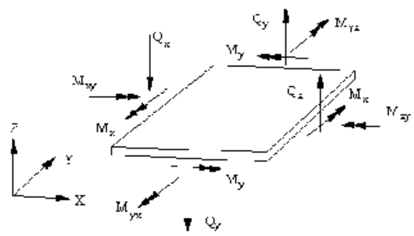


Fig. (7)

S_{QX}, S_{QY} = Shear stresses (Force/ unit len./ thk.)
S_X, S_Y, S_{XY} = Membrane stresses (Force/unit len./ thk)
M_X, M_Y, M_{XY} = Moments per unit width (Force x Length/length)
*(For M_x, the unit width is a unit distance parallel to the local Y axis, For M_y, the unit width is a unit distance parallel to the local X axis. M_x), and M_y cause bending, while M_{xy} causes the element to twist out-of-plane.)

8. Results of analyses

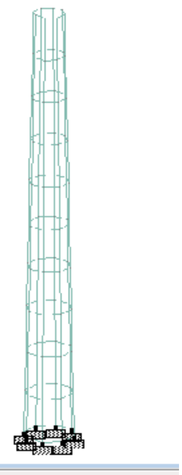


Fig.(8) Finite Element Idealization of chimney

8.1 Effect of material of shell:

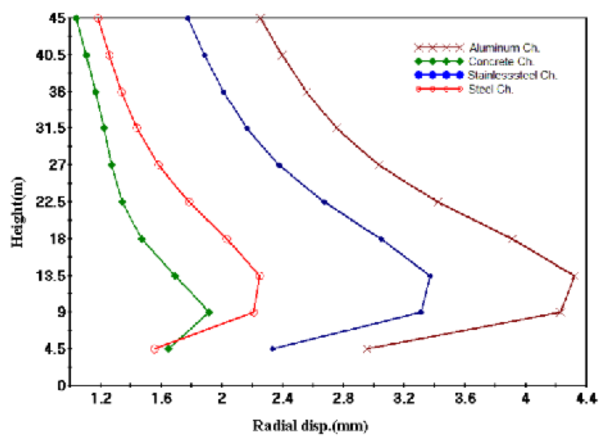


Fig. (9) Radial displacement due to thermal stresses, for the four chimneys.

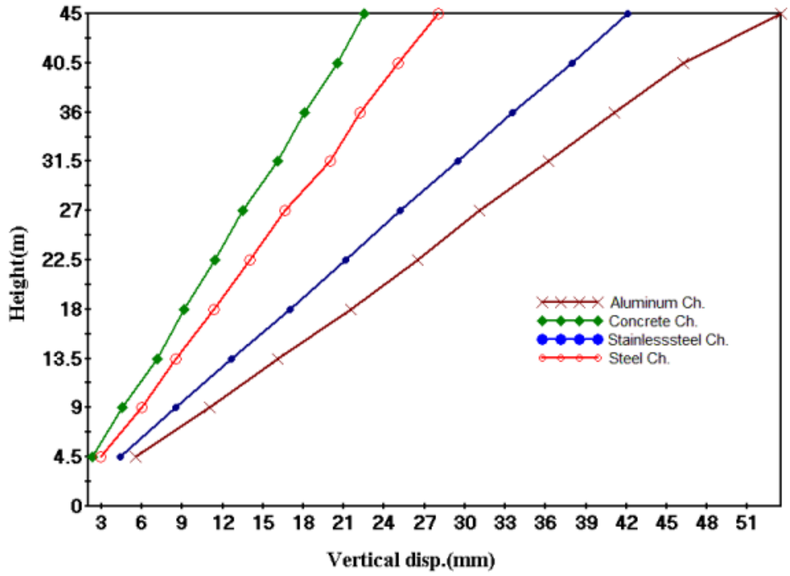


Fig. (10) Vertical displacement due to thermal stresses, for the four chimneys.

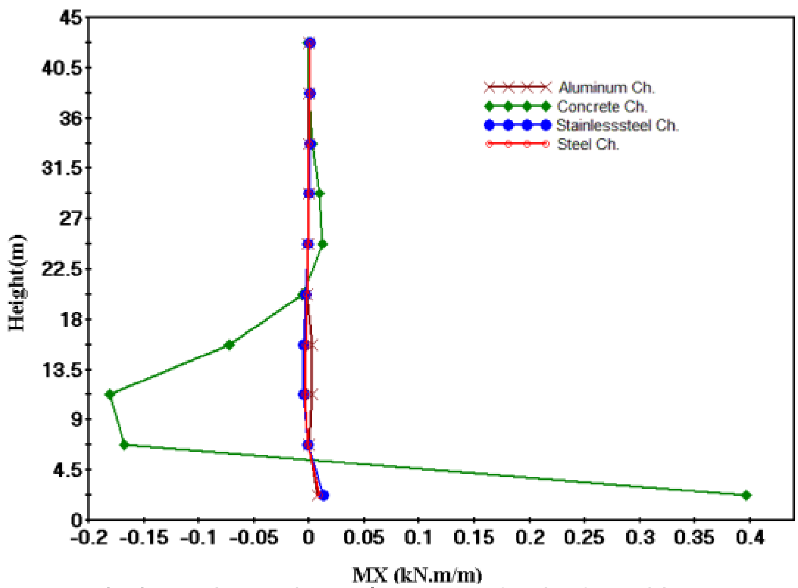


Fig. (11) M_X due to thermal stresses, for the four chimneys.

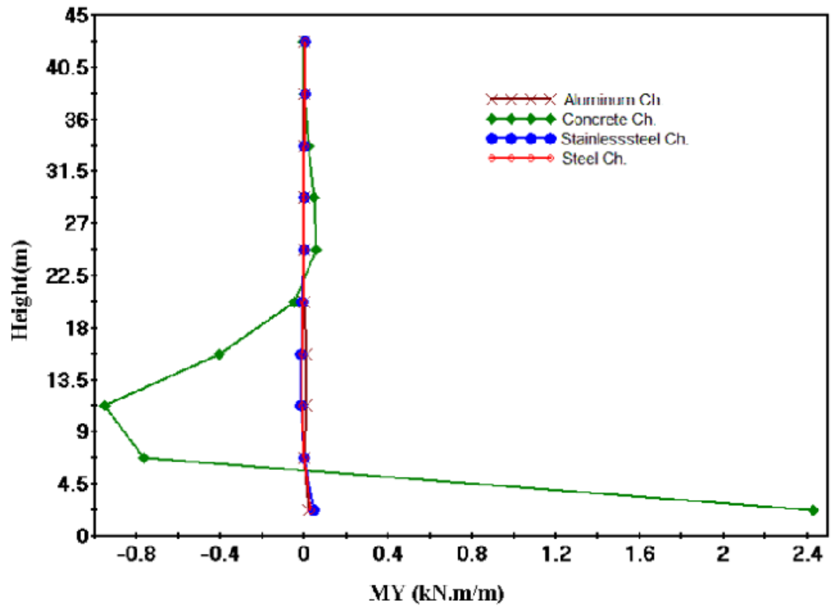


Fig.(12) M_Y due to thermal stresses, for the four chimneys.

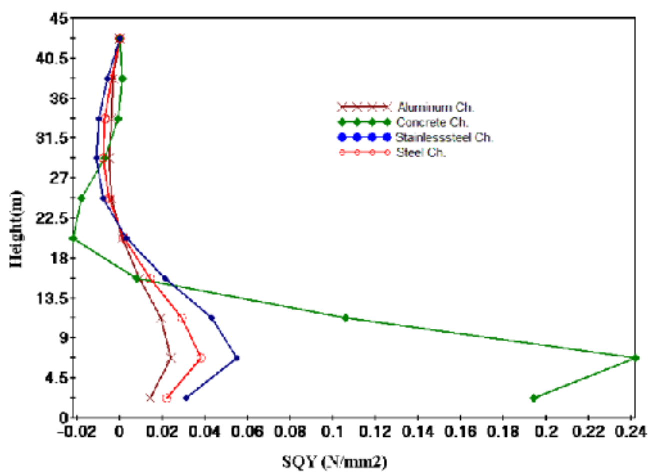


Fig.(13) S_{QY} due to thermal stresses, for the four chimneys.

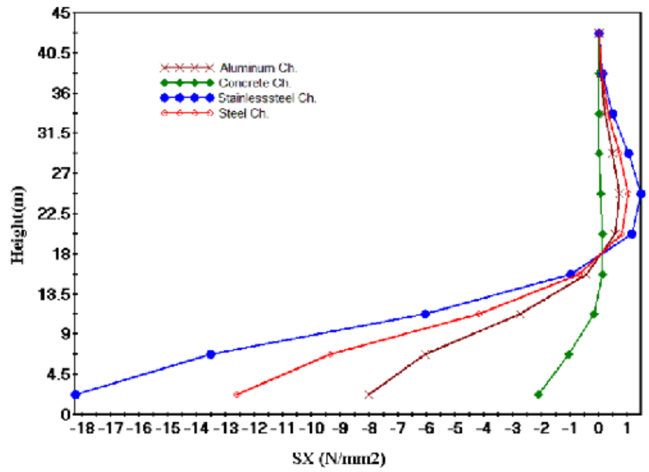


Fig.(14) S_X due to thermal stresses, for the four chimneys.

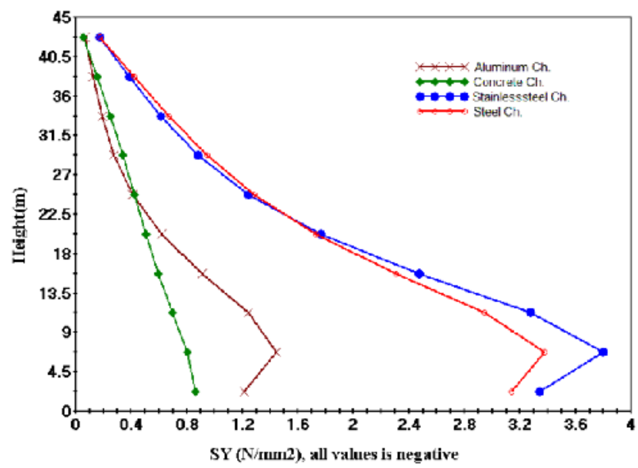


Fig.(15) S_Y due to thermal stresses, for the four chimneys.

Table.6 (Reactions for the four chimneys.)

Chimney type	Weight of shell (kN)	Radial force at base, (kN)	Vertical force at base, (kN)	Moment at base, (kN.m)
Aluminum chimney	133.41	734.507	16.693	146.393
Stainlesssteel chimney	385.255	1147.787	48.182	231.579
Steel chimney	385.255	1660.04	48.194	336.521
Concrete chimney	1266.031	1588.464	158.257	478.272

8.2 Effect of changing thickness of shell:

Two similar concrete chimneys with difference thicknesses (15 and 25 cm) were taken, the results were as shown below:

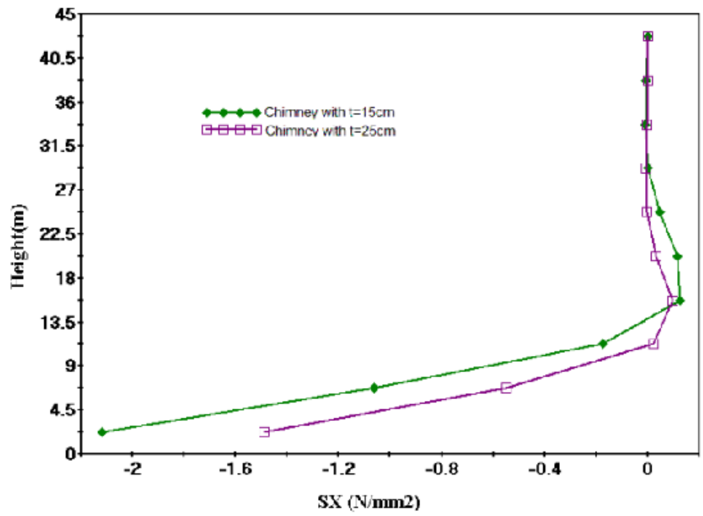


Fig.(16) S_X due to thermal stresses, for the two chimneys.

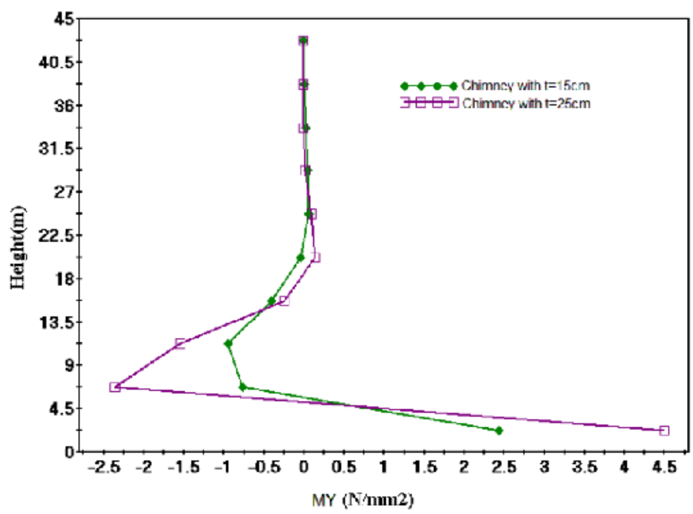


Fig.(17) M_Y due to thermal stresses, for the two chimneys.

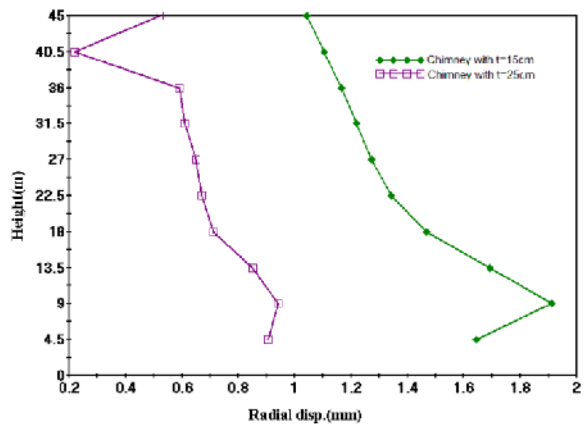


Fig.(18) Radial disp. due to thermal stresses, for the two chimneys.

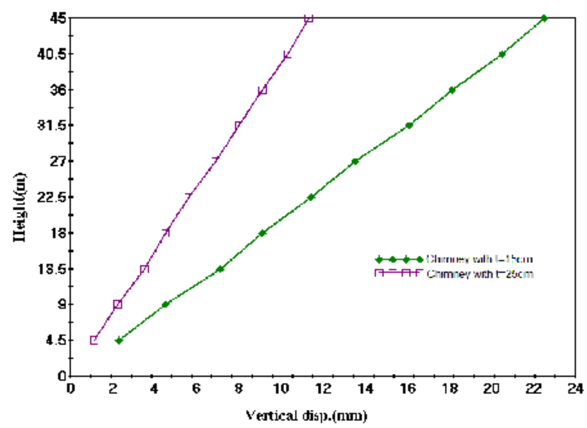


Fig.(19) Vertical disp. due to thermal stresses, for the two chimneys.

Table.7 (Reactions for the two chimneys.)

Chimney type	**Weight of shell (kN)**	**Radial force at base, (kN)**	**Vertical force at base, (kN)**	**Moment at base, (kN.m)**
Concrete chimney with t=15cm	1266.031	1588.464	158.257	478.272
Concrete chimney with t=25cm	2110	1634	264	606

8.3 Effect of lining on the chimney:

Two similar concrete chimneys were taken, the first with air space and brick lining(thickness=12cm) and the other without lining, so the last one will take a higher thermal load to a temperature about 550 ^{o}C which means that the value of modulus of elasticity and thermal expansion must changes, the results are as shown below:

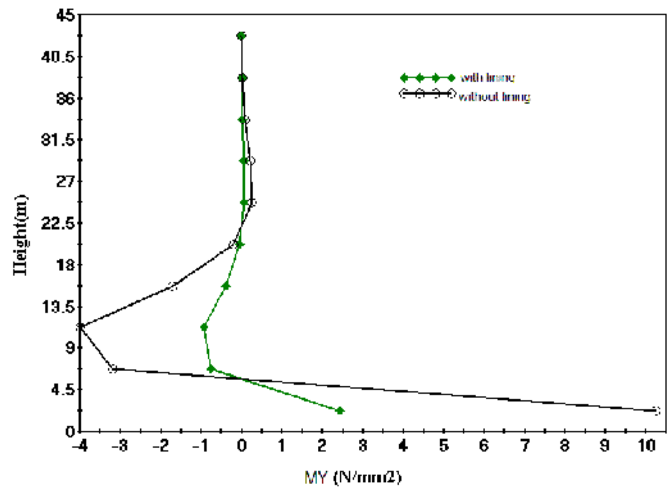


Fig.(20) M_Y due to thermal stresses, for the two chimneys.

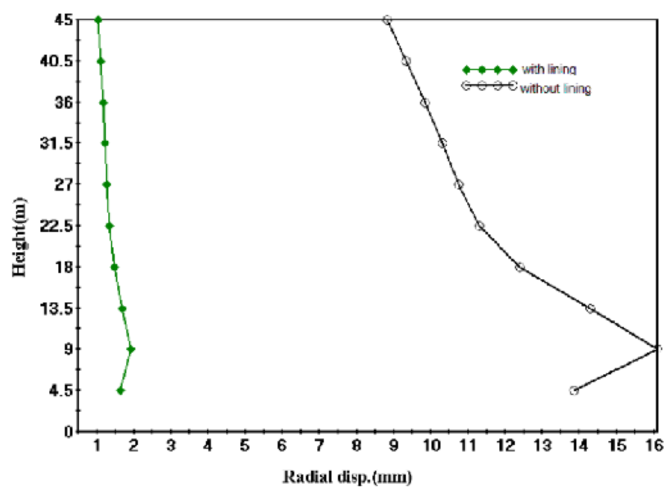


Fig.(21) Radial disp. due to thermal stresses, for the two chimneys.

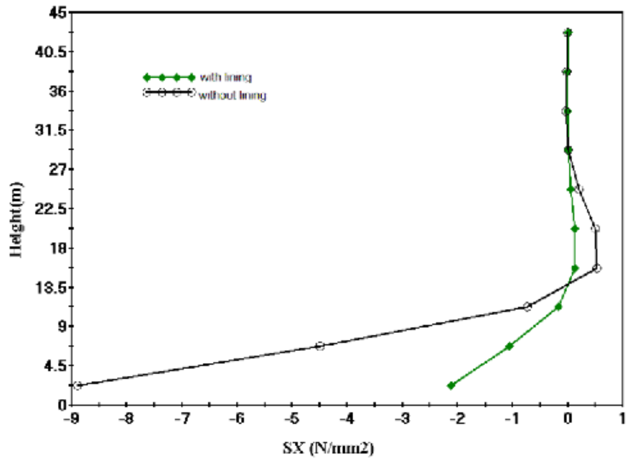


Fig.(22) S_X due to thermal stresses, for the two chimneys.

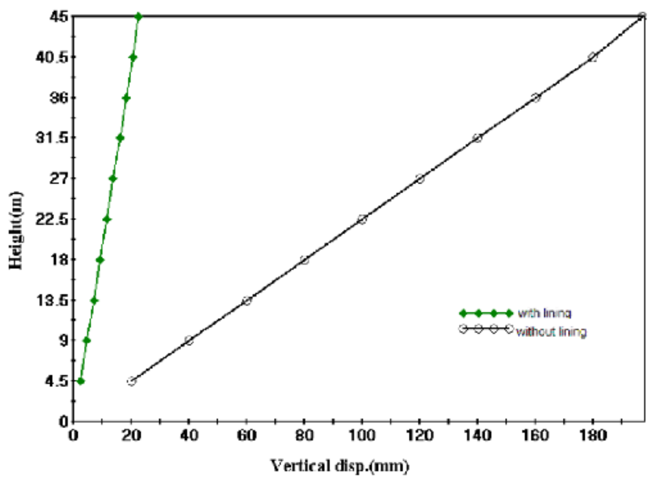


Fig.(23) Vertical disp. due to thermal stresses, for the two chimneys.

Table.8 (Reactions for the two chimneys.)

Chimney type	Weight of shell (kN)	Radial force at base, (kN)	Vertical force at base, (kN)	Moment at base, (kN.m)
Concrete chimney with t=15cm	1266.031	1588.464	158.257	478.272
Concrete chimney with, t=15cm, without lining	1266.031	6676	158.264	2048.7

9. Conclusions:

1- The analysis of the four chimneys give a result of vertical and radial displacements with descending sort (Aluminum, Stainless Steel, Steel, and concrete chimneys), this is because of the value of modulus of elasticity, density and thermal expansion coefficient.
2- Bending moments and shear stresses have similar values for the metal chimneys, but the concrete chimney has different values because of the difference in thickness and mechanical properties.
3- The four chimneys give results of membrane stresses (S_x and S_y) with a descending sort (Stainless Steel, Steel, Aluminum, and concrete chimney).

Chimney type	S_x (N/mm^2)	S_y (N/mm^2)
Stainlesssteel chimney	13.51	3.81
Steel chimney	9.51	3.41
Aluminum chimney	6.1	1.51
Concrete chimney	1.1	0.71
These values at level =6.75 m from the base of chimney		

4- The four chimneys give results of reactions at the base with a descending sort (concrete, Steel, Stainless Steel, and Aluminum chimney),so the concrete chimney will need a larger footing.
5- The lining reduces the thermal stresses to the (25-50)%, by reducing heat which reaches the chimney shell, while increasing in the thickness of the shell has no effect on thermal stresses except at the shell base where the boundary conditions must be satisfied.
6- The thickness of the shell is proportional to the reactions at the base of the chimney and inversely proportional to the radial and vertical displacements.
7- Winter time is found to be more critical since it gives higher temperature difference.
8- The Uniform heating component is more effective on the bending moments, membrane stresses and vertical displacement than the second component (temperature gradient), while the rotations are not affected much by thermal loads.

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التحليلات الحرارية للمداخن باستخدام طريقة العناصر المحدد

م.م.بشار فيصل عبدالكريم

المستخلص

هذا البحث يعنى بدراسة تأثير الاحمال الحرارية على المداخن ، حيث ان الاحمال الحرارية المأخوذة بنظر الاعتبار في هذا البحث مبنية على القياسات الحقلية الواقعية لتغاير درجات الحرارة على مدخنة الدورة وبالتالي اعتبارها كبيانات واقعية لدرجات الحرارة لاي مدخنة يتم انشاؤها في بغداد .
وهذه التغيرات الحرارية تقسم الى قسمين من حيث التأثير وهما:
1- التسخين المنتظم (Uniform heating).
2- الانحدار الحراري (Temperature gradient) عبر سمك قشرة المدخنة نتيجة لمرور الابخرة والغازات خلال المدخنة.
تم انجاز التحليلات الحرارية باستخدام اشتراطات المواصفة الأمريكية (ACI-307-08) وذلك لحساب الاحمال الحرارية ومن ثم استخدام برنامج STAAD.Pro-V8i و بتعريف المنشأ باستخدام عنصر 3D - plate element.
تم دراسة سلوك اربعة مداخن متشابهة بالشكل والابعاد ولكنها تختلف بمواد انشاؤها(الخرسانية المسلحة، الحديدية، الحديدية غير القابلة للصدأ، والالمنيومية)، وقد وجد بان المداخن المعدنية تعطي نتائج اعلى للازاحة الشعاعية والعمودية ,بينما بالنسبة لعزوم الانحناء (bending moments) والاجهادات الغشائية (Membrane Stresses) وردود الافعال فأن المدخنة الخرسانية المسلحة اعطت نتائج اكبر من المداخن المعدنية.
تم دراسة تأثير تغير سمك قشرة المدخنة ، ووجد بان الازاحة الشعاعية والعمودية تتناسب عكسيا مع سمك قشرة المدخنة لكن ردود الافعال عند قاعدة المدخنة تتناسب طرديا مع سمك قشرة المدخنة، إما تأثير السمك على عزوم الانحناء (bending moments) والاجهادات الغشائية (Membrane Stresses) فهو قليل وبالتالي لا داعي لتكبير سمك قشرة المدخنة بهدف تقليل الاجهادات الحرارية وانما الاعتناء بطبقة التبطين والتهوية لانها الاكثر تأثيرا بتقليل الاجهادات الحرارية.
وأخيرا وجد ان مركبة الحمل الحراري الاولى (Uniform heating) هي الاكثر تأثيرا على الاجهادات الغشائية والعزوم والازاحة العمودية وان الدوران لا يتأثر كثيرا بالاحمال الحرارية، و بان فصل الشتاء هو الاكثر خطورة لانه يعطي الانحدار الحراري الاكبر في قشرة المدخنة.

*كلية المنصور الجامعة