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Finite Element Analysis of Different Chimney Models used in Egyptian Power Plants Subjected to Lateral Loads

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الملخص العربى

مع حدوث تطورات صناعية واسعة النطاق في جميع أنحاء العالم، أستلزم هذا إنشاء عدد كبير من المداخن العالية مثل مداخن محطات التكرير و البتروكيمياويات و الطاقة الكهربائية. وتتمثل الوظيفة الرئيسية للمدخنة في تفريغ الملوثات في الغلاف الجوي عند ارتفعات وسرعات معينة بحيث تصبح تركيز الملوثات الضارة بالبيئة ضمن حدود مقبولة عند إقترابها من سطح الأرض. ونظرا لتزايد الطلب على الحفاظ علي البيئة، فإن ارتفاع المدخنة قي تزايد منذ العقود القليلة الماضية، وهذه أسباب وجيهة للاعتقاد بأن الاتجاه نحو بناء مداخن أطول سيستمر. وعموما، فإن المداخن هي عبارة عن هياكل رفيعة عالية، لديها مشاكل هيكلية خاصة بها، وبالتالي يجب أن تعامل بشكل منفصل عن الأشكال الأخرى من المباني العالية. وتتمثل الأهداف الرئيسية للدراسة الحالية في إجراء تحليل لسلوك مداخن الخرسانة المسلحة العالية التي تتعرض لأحمال أفقية باستخدام ثلاثة نماذج مختلفة. في الدراسة التحليلية، تم استخدام برنامج للعناصر المحددة للتحري عن السلوك الاستاتيكي والديناميكي للمداخن المستخدمة في محطات الطاقة المصرية تحت احمال الزلازل والرياح. وقد بنيت ثلاثة نماذج للمدخنة باستخدام العناصر الكمرية والصلبة والرقيقة. ويشار إلى النموذج الكمري بالنموذج المبسط ويستخدم أساسا للتحليل الديناميكي. ويشار إلى النماذج الصلبة والرقيقة بالنماذج المفصلة وتستخدم أساسا لفحص الازاحة والاجهادات المركزة حول الفتحات. تم حساب أحمال الرياح باستخدام معادلات الكود الأمريكي ACI 307-08 ، بينما تم حساب احمال الزلازل باستخدام التحليل الطيفي. و اخيرا تم تحليل و مناقشة النتائج للنماذج الثلاثة المقترحة، و وجد انه يوجد توافق جيد بينها.

ABSTRACT

As large scale industrial development is taking place all around the world, a large number of tall chimneys would be required to be constructed every year for petro-chemical, refinery stacks and power plants. The primary function of chimney is to discharge pollutants into atmosphere at such heights and velocities that the concentration of pollutants deemed harmful to the environment are kept within acceptable limits at ground level. Due to increasing demand for air pollution control, height of chimney has been increasing since the last few decades, and these are valid reasons to believe that this trend towards construction of taller chimneys will continue. However, chimneys being tall slender structures, they have different associated structural problems and must therefore be treated separately from other forms of tower structures. The main objectives of the current study are to investigate, analytically, the behavior of tall reinforced concrete chimneys subjected to lateral loads using three different modeling elements. In the analytical study, 3D finite-element (FE) software shall be used to investigate the static and dynamic behavior of the frequently used chimneys in Egyptian power plants under seismic and wind loads. Three models were built for the chimney using beam, solid and shell element. The beam model is denoted as simplified model and is mainly used for dynamic analysis. The solid and shell models are denoted as detailed models and are used mainly for checking deflection and local stresses around openings. The wind loads are computed using the American Concrete Institute ACI 307-08 [1] equations, while the seismic load is computed by using a response spectrum analysis. The results for the three models are discussed and compared and good agreement was denoted.

Keywords: Concrete chimney, Liner, Along-wind, Across-wind, Seismic, Base shear, Stress.

1. INTRODUCTION

A chimney is a structure that provides ventilation for hot flue gases or smoke from a boiler, stove, furnace or fireplace to the outside atmosphere. Chimneys are typically vertical, or as near as possible to vertical, to ensure that the gases flow smoothly, drawing air into the combustion in what is known as the stack, or chimney, effect. In Egypt, and in the last few years, it was a tremendous shortage of electricity due to the lack of electrical power plants. In order to solve this problem, the government started the construction of a plenty of power plants, either fossil, solar or wind farms. The design of a tall chimney, being slender structure, is very sensitive to wind and seismic forces. The American code ACI 307-08 [1] written by the American Concrete Institute shall be considered as the reference code for the chimney design and all used equations are in imperial units (mile, foot, inch, pound and kip), than the output value is converted to metric units (Km, m, mm, Kg and tons).

This paper investigates the behavior of tall reinforced concrete chimneys subjected to lateral loads due to wind and seismic load. The 3D finite element analysis software, STAAD Pro Ver 8i, which was developed at Bentley Systems Inc., has been used to simulate the full-scale chimney model using three types of elements (beam, shell and solid element) and the results were compared. This work is a part of a larger research done by “El-Sadat, A.” [3].

2. EL-SUEZ POWER PLANT CHIMNEY DESCRIPTION

El Suez Power Plant is located near El-Suez governorate directly on the red sea. The reinforced concrete chimney, with the height of 152.0 m and outside diameter of 11.50m, is used to exhaust combustion products from 1x650MW gas/oil fired steam turbine unit.

Height of the chimney: 152.0 m above terrain level
External diameter of the stack at the bottom: 11500 mm
External diameter of the stack at the top: 11500 mm
Number of Flue gas duct: 1
Internal diameter of the of Flue gas duct: 8000 mm
Material of the stack: Concrete 4500 psi & reinforcing steel grade 60 ASTM A615
Material of lining supporting slabs: Concrete 4500 psi & reinforcing steel grade 60 ASTM A615
Openings: 2 x Flue gas ducts 3600 x 8050 mm & 2 x Main door openings 3000 x 4500 mm
Max. Flue gas temperature: 155 → 160°C

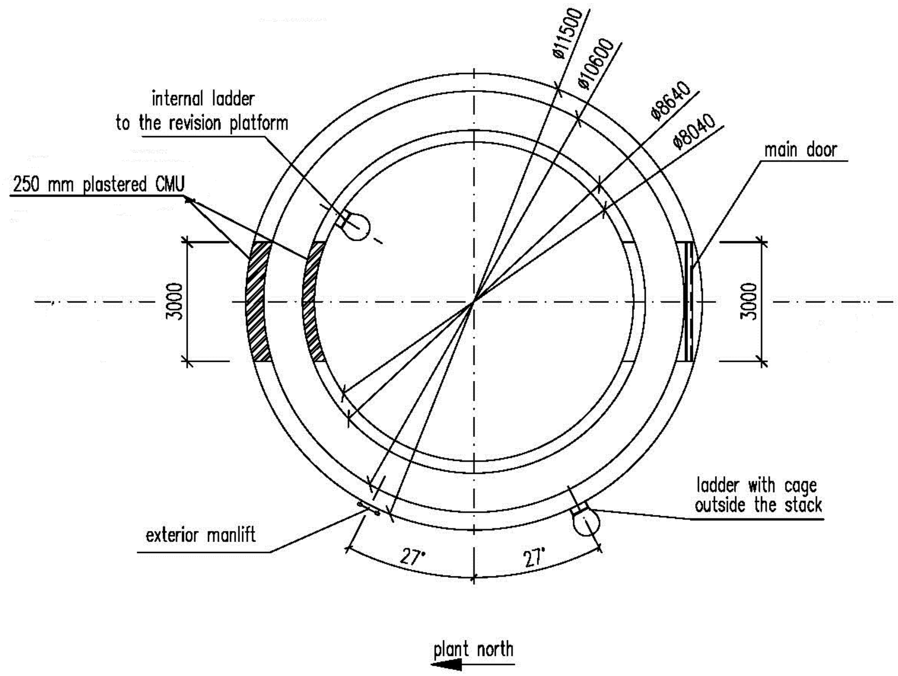

Fig. 1: Chimney section plan at bottom level (0.00)

3.0 CHIMNEY LOADING

3.1 Chimney gravity load

3.1.1 Dead weight of stack

Gravity loading is given by geometric and material characteristics of elements. Loading includes own weight of concrete wind shield. Specific weight for reinforced concrete is 25 kN/m^3.

3.1.2 Liner and supporting slabs

Liner weight is given by 105 mm thickness, inner diameter 8000 mm and specific weight of the shaped bricks 21.1 kN/m^3. Height of each dilatational part is 20000 mm.
$W_{lin} = (4.1052 – 4.002) \times \pi \times 20.00 \times 21.1 = 1128$ kN
Weight of insulation (60 mm of mineral wool), overlapping and special shaped bricks is included by weight increase of 5%.
$W_{sum} = W_{lin} \times 1.05 = 1185$ kN

3.1.3 Calculation of gravity loads

Bottom Level of chimney = -1.00 m
Top Level of chimney = 152.00 m
No. of sections = 24
Chimney height = 153 m
The gravity loads of the chimney shell, liner and supporting slabs shall be summarized in the following table, Table 1:

Table 1: Summary of chimney gravity loads

Section	Height of lower edge (m)	Height in center of the section (m)	External diameter of the stack in the lower end (m)	Internal diameter of the stack (m)	Thickness of the wall (mm)	Area of the section (m2) at the lower end	Moment of inertia of the section (m4) at the lower end	Torsional moment of the section (m4) at the lower end	Section modulus (m3) at the lower end	Projected area in wind direction (m2)	Weight of the section (kN)	Weight of the stack in lower section (kN)	Weight of the liner and slab (kN)	Summed weight in lower edge (kN)
1	145.63	148.81	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	1682	642	2324
2	139.25	142.44	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	3365		4007
3	132.88	136.06	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	5047		5689
4	126.50	129.69	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	6729	1640	9011
5	120.13	123.31	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	8412		10694
6	113.75	116.94	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	10094		12376
7	107.38	110.56	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	11776	1635	15693
8	101.00	104.19	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	13459		17376
9	94.63	97.81	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	15141		19058
10	88.25	91.44	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	16823	1635	22375
11	81.88	85.06	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	18506		24058
12	75.50	78.69	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	20188		25740
13	69.13	72.31	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	21870		27422
14	62.75	65.94	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	23553	1635	30740
15	56.38	59.56	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	25235		32422
16	50.00	53.19	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	26917		34104
17	43.63	46.81	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	28599	1635	37421
18	37.25	40.44	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	30282		39104
19	30.88	34.06	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	31964		40786
20	24.50	27.69	11.50	10.90	300	10.56	165.63	331.27	28.81	73.31	1682	33646	1635	44103
21	18.13	21.31	11.50	10.60	450	15.62	238.82	477.65	41.53	73.31	2490	36136		46593
22	11.75	14.94	11.50	10.60	450	15.62	238.82	477.65	41.53	73.31	2490	38626		49083
23	5.38	8.56	11.50	10.60	450	15.62	238.82	477.65	41.53	73.31	2490	41116		51573
24	-1.00	2.19	11.50	10.60	450	15.62	238.82	477.65	41.53	73.31	2490	43605		**54062**

3.2 Chimney wind load

Wind induced forces on buildings depend on several parameters, such as the building's shape and height, the nature of upwind terrain, the influence of nearby structures and the structural properties of the building (mass, stiffness and damping). Due to the complexity of these dynamic inertial loads, it is convenient to use an equivalent static wind load distribution for structural design computations. The wind resistant design of chimney is to be carried out after taking into account the along-wind load, across-wind load and aerodynamic interference effects. The present trend is to consider wind load as the sum of the two components. One is caused by the mean wind speed and the other by the fluctuating wind gust. The mean wind load contribution is proportional to the square of the reference wind speed. The dynamic component is evaluated using gust factor approaches; which depends upon the natural frequency, damping, geometric properties of the chimney and the Reynolds number. In addition, the hollow circular cross section shall be designed to resist the loads caused by the circumferential pressure distribution.

3.2.1 Along-wind load

Basic wind speed (V) is 135 km/hr, importance factor (I) for building category IV is 1.15, Then:

$$V_r = (I)^{0.5} \times V = 1.15^{0.5} \times 135 = 144.77 km/hr \text{ ………………… (1)}$$

At a height z(ft) above ground, the mean hourly design speed $\overline{V}(z)$ in ft/sec shall be computed from equation:

$$\overline{V}(z) = 1.47 \text{ x } V_r \text{ x } (z/33)^{0.154} \text{ x } 0.65 \text{……………………….(2)}$$

The along wind load w(z) shall be the sum of the mean load w(z) and fluctuating load w´(z). The mean load $\overline{w}(z)$ in Ib/ft shall be computed from equation:

$$\overline{w}(z) = C_{dr}(z) \text{ . } d(z) \text{ . } \overline{p}(z) \text{…………………………….(3)}$$

Where wind pressure in psf is:

$$\overline{p}(z) = 0.00119 \text{ . } K_d \text{ . } [\overline{V}(z)]^2 \text{.......................................(4)}$$

Where;

K_d = 0.95 for circular chimneys and shape factor is:

$$C_{dr}(z) = 0.65 \text{ for } z < h - 1.5d(h) \text{………………………..(5)}$$

$$C_{dr}(z) = 1.00 \text{ for } z > h - 1.5d(h) \text{………………………..(6)}$$

Shape factor $C_{dr}(z)$ contains influence of ladder or platforms and shall be increased by 10% in this case (calculation on safety side). Wind effects for the mean load are evaluated in the next table, Table 2.

Following step of the fluctuation part calculation is evaluation of the dynamic factor Gw´, as follows:

$$G_w{}' = 0.30 + [11.0 \text{ x } (T_1 \text{ x } \overline{V}(33))^{0.47}] / (h + 16)^{0.86} \text{……………(7)}$$

Where;

T_1 is natural period of the chimney in sec, here 2.8

$\overline{V}(33)$ wind speed in 33 feet in ft/sec, here 85.95 ft/s (26.2 m/s)

h height of the chimney, here 498.69 ft (152 m)

Hence:

$G_w{}' = 0.30 + [11.0 \text{ x } (2.8 \text{ x } 85.95)^{0.47}] / (498.69 + 16)^{0.86} = 0.974$

Fluctuating along-wind load w'(z) per unit length in KN/m at height z:

$$w'(z) = (3.0z \text{ x } G_w' \text{ x } Mw(b)) / h^3 \text{………………………….(8)}$$

Where;

Mw(b) is base bending moment due to w(z), here is 83,442 kNm

$w'(z) = (3.0z \text{ x } 0.974 \text{ x } Mw(b)) / 152^3$

$= (3.0z \text{ x } 0.974 \text{ x } 83{,}442) / 152^3$

$= 0.0694\ z$

Table 2: Summary of mean along-wind load

Section	Height of lower edge above ground (m)	z Height in center of the section above ground (m)	*d(z)* Outside diameter of chimney in the lower end (m)	$C_{dr}(z)$ Drag coefficient for diameter of the section and basic wind load	C_{dr} Drag coefficient increased due to ladder and platforms	Area of the section (m^2) at the lower end	Projected area in wind direction *A(z)* (m^2)	$V(z)_{mean}$ Mean hourly design wind speed at height z (m/sec)	$p(z)_{mean}$ Pressure due to mean hourly design wind speed at height z (kPa)	$w(z)_{mean}$ Mean along-wind load at height z (kN)	Input data for fluctuation part of dynamic windload
1	145.63	148.81	11.50	1.00	1.10	10.56	73.31	39.7	0.92	73.9	Height
2	139.25	142.44	11.50	1.00	1.10	10.56	73.31	39.4	0.90	73.0	152.00
3	132.88	136.06	11.50	0.65	0.72	10.56	73.31	39.1	0.89	46.8	Speed VR
4	126.50	129.69	11.50	0.65	0.72	10.56	73.31	38.8	0.88	46.1	144.77
5	120.13	123.31	11.50	0.65	0.72	10.56	73.31	38.5	0.87	45.4	
6	113.75	116.94	11.50	0.65	0.72	10.56	73.31	38.2	0.85	44.6	
7	107.38	110.56	11.50	0.65	0.72	10.56	73.31	37.9	0.84	43.9	
8	101.00	104.19	11.50	0.65	0.72	10.56	73.31	37.6	0.82	43.1	
9	94.63	97.81	11.50	0.65	0.72	10.56	73.31	37.2	0.81	42.2	
10	88.25	91.44	11.50	0.65	0.72	10.56	73.31	36.8	0.79	41.4	
11	81.88	85.06	11.50	0.65	0.72	10.56	73.31	36.4	0.77	40.5	
12	75.50	78.69	11.50	0.65	0.72	10.56	73.31	36.0	0.75	39.5	
13	69.13	72.31	11.50	0.65	0.72	10.56	73.31	35.5	0.73	38.5	
14	62.75	65.94	11.50	0.65	0.72	10.56	73.31	35.0	0.71	37.4	
15	56.38	59.56	11.50	0.65	0.72	10.56	73.31	34.5	0.69	36.3	
16	50.00	53.19	11.50	0.65	0.72	10.56	73.31	33.9	0.67	35.0	
17	43.63	46.81	11.50	0.65	0.72	10.56	73.31	33.2	0.64	33.7	
18	37.25	40.44	11.50	0.65	0.72	10.56	73.31	32.5	0.61	32.2	
19	30.88	34.06	11.50	0.65	0.72	10.56	73.31	31.6	0.58	30.5	
20	24.50	27.69	11.50	0.65	0.72	10.56	73.31	30.6	0.55	28.6	
21	18.13	21.31	11.50	0.65	0.72	15.62	73.31	29.4	0.50	26.4	
22	11.75	14.94	11.50	0.65	0.72	15.62	73.31	27.8	0.45	23.7	
23	5.38	8.56	11.50	0.65	0.72	15.62	73.31	25.6	0.38	19.9	
24	-1.00	2.19	11.50	0.65	0.72	15.62	73.31	20.7	0.25	13.1	

All values of mean and fluctuating wind load are shown in the following table, Table 3, including moment in chimney bottom. Final wind load is given by the following formula:

$$w(z) = \overline{w}(z) + w'(z) \qquad (9)$$

Table 3: Fluctuating and summed wind load evaluation

Section	Height of lower edge above ground (m)	z Height in center of the section above ground (m)	*d(z)* Outside diameter of chimney in the lower end (m)	*p(z)_{mean}* Pressure due to mean hourly design wind speed at height z (kPa)	*w(z)_{mean}* Mean along-wind load at height z (kN)	M_w(b) Bending moment at base due to mean along-wind load *w(z)_{mean}* at height z (kNm)	*w'(z)* Fluctuating along-wind load at height z (kN)	*w(z)* Total nominal along-wind load at height z (kN)	Nominal bend.moment in the lower edge of the section (kN-m)	Design bend.moment in the lower edge of the section (kN-m) * 1.6
1	145.63	148.81	11.50	0.92	73.9	11004	65.9	139.8	446	713
2	139.25	142.44	11.50	0.90	73.0	10392	63.1	136.0	1771	2833
3	132.88	136.06	11.50	0.89	46.8	6362	60.2	107.0	3870	6192
4	126.50	129.69	11.50	0.88	46.1	5975	57.4	103.5	6640	10624
5	120.13	123.31	11.50	0.87	45.4	5594	54.6	99.9	10059	16094
6	113.75	116.94	11.50	0.85	44.6	5218	51.8	96.4	14103	22566
7	107.38	110.56	11.50	0.84	43.9	4850	48.9	92.8	18751	30002
8	101.00	104.19	11.50	0.82	43.1	4487	46.1	89.2	23979	38366
9	94.63	97.81	11.50	0.81	42.2	4131	43.3	85.5	29763	47621
10	88.25	91.44	11.50	0.79	41.4	3783	40.5	81.8	36081	57730
11	81.88	85.06	11.50	0.77	40.5	3442	37.7	78.1	42909	68655
12	75.50	78.69	11.50	0.75	39.5	3108	34.8	74.3	50223	80357
13	69.13	72.31	11.50	0.73	38.5	2783	32.0	70.5	57999	92798
14	62.75	65.94	11.50	0.71	37.4	2467	29.2	66.6	66211	105938
15	56.38	59.56	11.50	0.69	36.3	2159	26.4	62.6	74836	119737
16	50.00	53.19	11.50	0.67	35.0	1862	23.5	58.6	83846	134154
17	43.63	46.81	11.50	0.64	33.7	1576	20.7	54.4	93217	149147
18	37.25	40.44	11.50	0.61	32.2	1301	17.9	50.1	102921	164673
19	30.88	34.06	11.50	0.58	30.5	1040	15.1	45.6	112929	180687
20	24.50	27.69	11.50	0.55	28.6	793	12.3	40.9	123213	197141
21	18.13	21.31	11.50	0.50	26.4	563	9.4	35.9	133742	213988
22	11.75	14.94	11.50	0.45	23.7	354	6.6	30.3	144482	231171
23	5.38	8.56	11.50	0.38	19.9	171	3.8	23.7	155394	248630
24	1.00	2.19	11.50	0.25	13.1	29	1.0	14.1	166426	266282
						83442				

3.2.2 Across-wind load

The across wind (lift) force is recognized as a significant source of wind excited motion of tall chimneys. Due to complexity, of the problem, no analytical model based on an understanding of the flow field around circular chimneys has been established that might satisfactorily predict the aerodynamic response of chimneys in atmospheric boundary layer flows.

Across wind loads due to vortex shedding in the first mode shall be considered if critical wind speed V_{cr} in m/sec is between 0,50 and 1,30$\overline{V}(z_{cr})$ where $\overline{V}(z_{cr})$ is the mean hourly wind speed at (5/6)h, here 126.78 ft/sec (38.64 m/sec) by using equation (2)

$$V_{cr} = f \cdot d(u) / S_t \quad \ldots\ldots (10)$$

Where;

f, is the first mode frequency, here 0.36 Hz

d(u) chimney outer diameter, here 11.50 m

S_t Strouhal number, and equals:

$$S_t = 0.25 \text{ x } F_{1A} \quad \ldots\ldots(11)$$

Where;

$$F_{1A} = 0{,}333 + 0{,}206 \text{ x } \log_e(h/d(u)) \quad \ldots\ldots(12)$$

but not >1.0 or <0.6, here is

$F_{1A} = 0{,}333 + 0{,}206 \text{ x } \log_e(152/11{,}5) = 0.333 + 0.532 = 0.865$

F_{1A} lies in required range, then;

$S_t = 0.25 \text{ x } 0.865 = 0.216$

$V_{cr} = 0.36 \text{ x } 11.50 / 0.216 = 19.02 < 0.50 \text{ x } \overline{V}(z_{cr}) = 0.5 \text{ x } 38.64 = 19.32$m/sec

Across-wind load in the first mode can be neglected.

Across-wind response in second mode shall be considered if critical wind speed V_{cr2} in m/sec is between 0.50 and 1.30 $\overline{V}(z_{cr})$, where $\overline{V}(z_{cr})$ is the mean hourly wind speed at (5/6)h, and equals:

$$V_{cr2} = 5d(u) / T_2 \quad \ldots\ldots(13)$$

Here; $V_{cr2} = 5 \text{ x } 11.50 / 0.48 = 119.91 > 1{,}30 \,.\, \overline{V}(z_{cr}) = 1.30 \text{ x } 38.64 = 50.23$ m/sec. Analysis, performed according to ACI 307-08 [1], proved, that all across-wind effects can be neglected.

3.2.3 Circumferential bending

Circumferential bending due to non-uniform division of wind pressure along the horizontal section perimeter is given by formulas only. The maximum circumferential bending moments due to the radial wind pressure distribution shall be computed as follows:

$$M_i(z) = 0.31p_r(z)[r(z)]^2, \text{ ft-lb/ft (tension on inside)} \quad \ldots\ldots(14)$$

$$M_o(z) = 0.27p_r(z)[r(z)]^2, \text{ ft-lb/ft (tension on outside)} \quad \ldots\ldots(15)$$

$$p_r(z) = p(z) \times G_r(z), \text{ lb/ft}^2 \quad \ldots\ldots(16)$$

$$G_r(z) = 4.0 - 0.8.\log_{10} z, \text{ except } G_r(z) = 4 \text{ for } z \leq 1.0 \text{ ft} \quad \ldots\ldots(17)$$

The pressure $p_r(z)$ shall be increased by 50% for a distance 1.5d(h) from the top (Note: 1.5d(h) shall not exceed 50 ft (15.2m)).

Bending moment in the top of the stack will be obtained:

$G_r(z) = 4{,}0 - 0{,}8 \,.\, \log_{10} 498.70 = 1.84$ (height in feet)

$p_r(z) = 0.92 \text{ x } 1.84 \text{ x} 1.5 = 2.54$ kPa

$M_i(z) = 0.31 \text{ x } 2.54 \text{ x } 5.6^2 = 24.7$ kNm

$M_o(z) = 0.27 \text{ x } 2.54 \text{ x } 5.6^2 = 21.5$ kNm

3.3 Chimney seismic load

Referring to ACI 307-08 [1], section 4.3.2, it states that the shears, moments, and deflections of a chimney due to earthquake shall be determined using a response spectrum and the elastic modal method. Input data for seismic calculation: Occupancy category III, Table 1.1 of ASCE 7-02 [2]; Seismic use group II, Table 9.1.3 of ASCE 7-02 [2]; Seismic importance factor IE = 1.25, Table 9.1.4 of ASCE 7-02 [2], Site class D, Seismic design category SDC = C, Table 9.4.2.1(a) or Table 9.4.2.1(b) of ASCE 7-02 [2], whichever results in the most severe category; Spectral response acceleration at short periods $S_S = 0.417$; Spectral response acceleration at 1 second periods $S_1 = 0.106$; 5% dumped design spectral response acceleration at short periods $S_{DS} = 0.408$; 5% dumped design spectral response acceleration at 1 second periods $S_{D1} = 0.168$. The response modification factor R shall be taken as 1.5. For chimneys of circular cross section, the horizontal earthquake force shall be assumed to act alone in any direction.

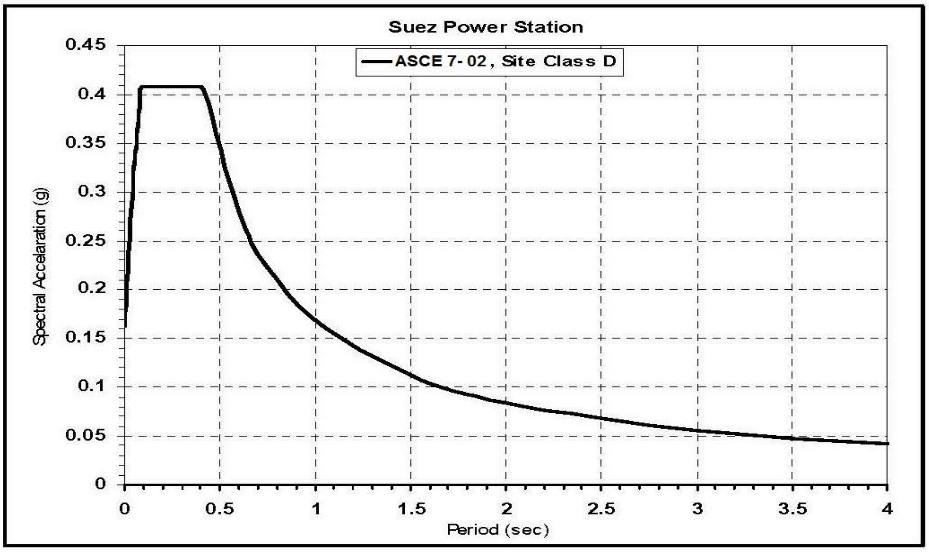

Fig.2: Design Acceleration spectrum for site class D for Suez site

4.0 CHIMNEY MODELING BY FINITE ELEMETS

4.1 Global effects, Simplified model

Simplified beam model is used in this case to compute bending moments along the chimney height. Model has 24 beam elements as shown in the next figure:

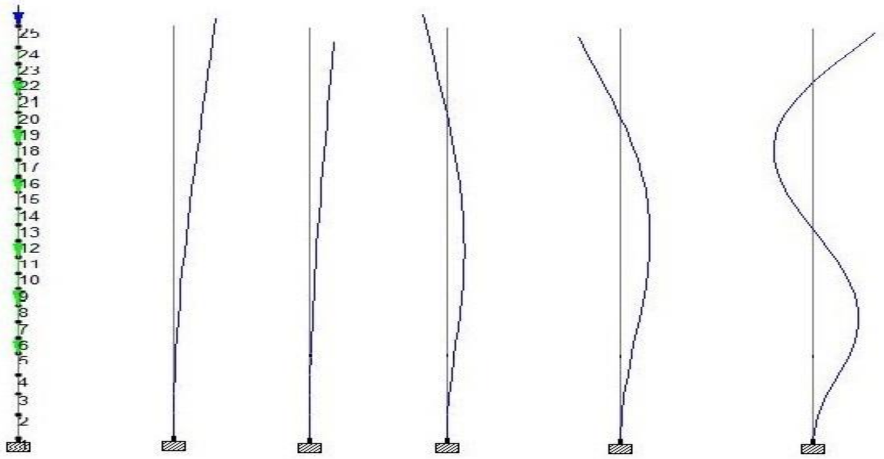

Fig. 3: Simplified seismic beam model with the first 5 mode shapes

4.2 Chimney solid model

The model was created according to the next principles:

Carrying structures are modeled, i.e. stack with R.C. annular plate at the chimney-top and corbels at the level of supporting slabs.

All openings with influence to state of stress of the stack are included into the model. These are both openings in the chimney bottom with dimensions 3000×5500 mm for the main door and 3600x8050 for the F.G.D inlet.

Model is created by 22,580 solid elements. No additional masses are assumed.

Model has 45,440 active nodes, each of them has three degrees of freedom, 124 nodes are supported using fixed support, and whole number of free D.O.F. is 135,948. The basic schemes of the solid model are shown in the following figures 4&5:

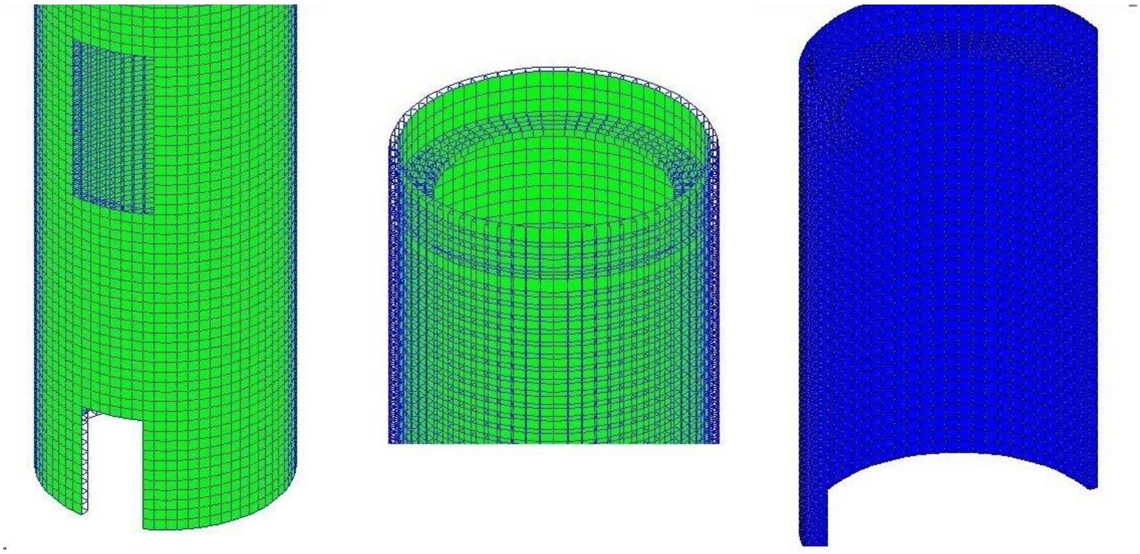

Fig. 4: Solid model lower part with door and flue gas duct openings, upper part with top slab & vertical half-section in upper part

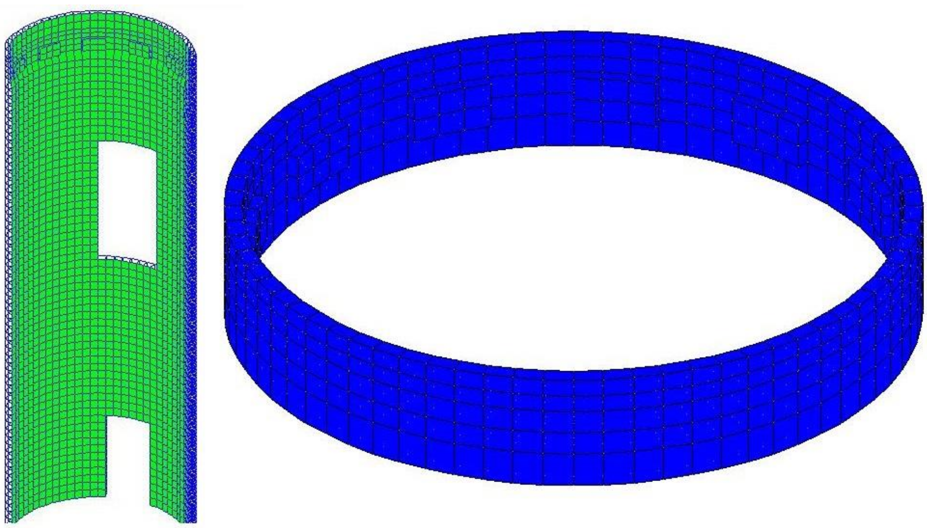

Fig. 5: Solid model vertical half-section in lower part & corbels at the annular plates levels

4.3 Chimney shell model

The model was created according to the next principles:
Carrying structures are modeled, i.e. stack with R.C. annular plate at the chimney-top and corbels at the level of supporting slabs.
All openings with influence to state of stress of the stack are included into the model. These are both openings in the chimney bottom with dimensions 3000×5500 mm for the main door and 3600x8050 for the F.G.D inlet.
Model is created by 21,860 shell elements. No additional masses are assumed.

Model has 22,072 active nodes, each of them has six degrees of freedom, 62 nodes are supported using fixed support, and whole number of free D.O.F. is 132,060. The basic schemes of the shell model are shown in the following figures 6&7:

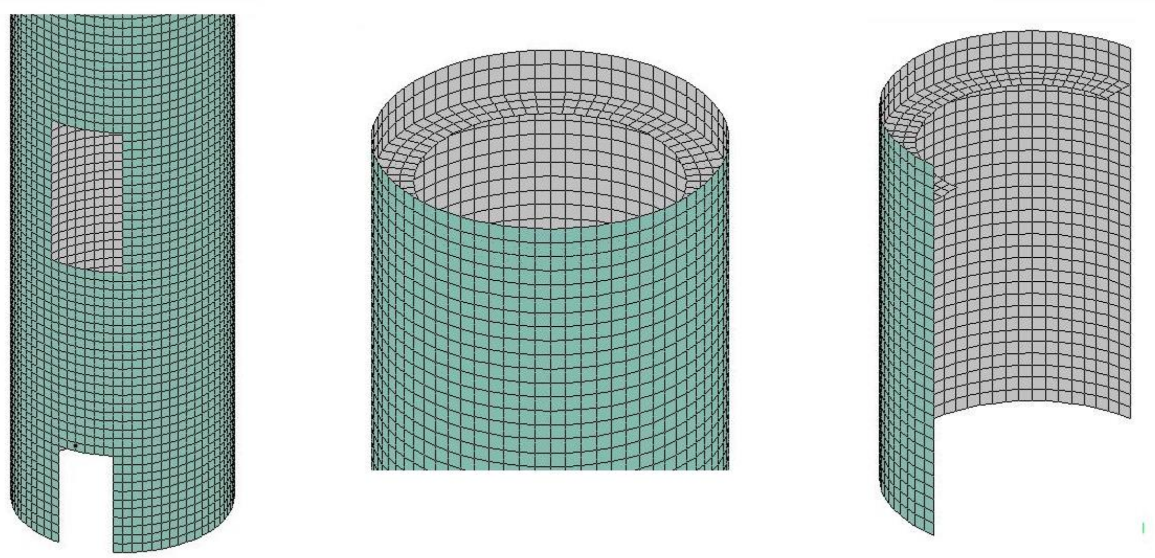

Fig. 6: Solid Model lower part with door and flue gas duct openings, upper part with top slab & vertical half-section in upper part

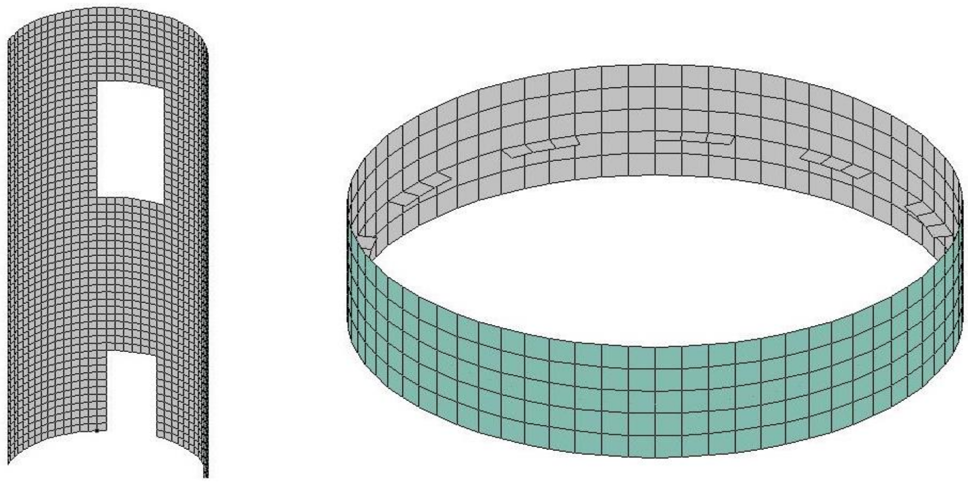

Fig. 7: Solid Model vertical half-section in lower part & corbels at the annular plates levels

5.0 RESULTS OF FINITE ELEMENT ANALYSIS

5.1 Analysis of results

For wind loading, the static method is used for determining the normal forces, shear forces and bending moments along the whole height of the chimney, while the detailed model is used for computing chimney displacements and local stresses around openings. For seismic loading, the simplified beam model is for determining the normal forces, shear forces and bending moments along the whole height of the chimney, while the detailed model is used for dynamic properties such as Eigen values, mass participation and mode shapes beside local stresses around openings. The following table, Table 4, will summarize the results obtained from the simplified chimney model and the detailed model for both solid and shell models in case of wind and seismic loading. The comparison shall be made for Eigen values, mass participations, base shear, displacements and local stresses due to wind and seismic loadings. First, the comparison shall be made between the simplified and the detailed model, then the comparison shall be held between the solid and shell model.

Table 4: Summary of results for simplified and detailed models

				Detailed Model	
		Units	Simplified Model	Solid Model	Shell Model
Eigen Values	Fundamental Period	sec	3.21	3.55	3.57
	Highest Frequency	Hz	53.8	16.54	15.79
	Mass Participation X Direction	%	95.1	94.54	94.19
	Mass Participation Z Direction	%	95.1	96.41	96.43
Static Results	Displacements				
Wind Loading	Displacement X	mm	NA	231	232
	Displacement Z	mm	NA	193	194
	Local Stresses				
	Von Misses	MPa	NA	24.1	24.7
	S1 principal stress (Tension)	MPa	NA	12.9	13.5
	S3 principal stress (comp.)	MPa	NA	24	30.6
Dynamic	Displacements				
Results	Displacement X	mm	181	200	201
Seismic Loading	Displacement Z	mm	181	182	183
	Modal Base Actions				
	Total SRSS Shear X-Dir	kN	3,359	3,079	3,106
	Total SRSS Shear Z-Dir	kN	3,359	3,357	3,396
	Total SRSS Base Mom X-Dir	kNm	182,000	157,824	158,991
	Total SRSS Base Mom Z-Dir	kNm	182,000	173,687	175,117
	Local Stresses				
	Von Misses	MPa	NA	11.1	11.6
	S1 principal stress (Tension)	MPa	NA	9.74	12.53
	S3 principal stress (comp.)	MPa	NA	11.1	14.21

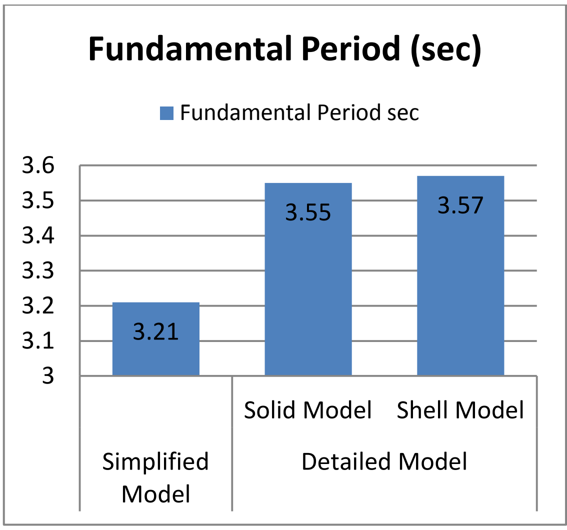

Fig. 8: Comparison of fundamental period for simplified and detailed models

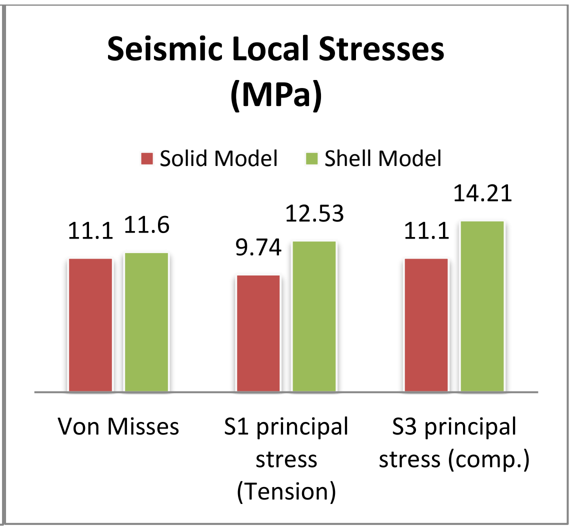

Fig. 9: Comparison of seismic local stresses for detailed models

The period of the structure is inversely proportional to its stiffness. Consequently, the simplified beam model with the higher stiffness, where the gas flue duct and door openings are not taken into account, will have the lesser fundamental period than the detailed models as shown in Fig. 8. Local stresses around openings are only obtained from the detailed model. Comparison is made between solid and shell models for Von Misses and principal stresses for both wind and seismic loadings. Comparative stress von Misses is sufficient for approximate or preliminary analysis of the structure. It shows that the shell model exceeds the solid model 4.5% in seismic loading, while for principal stresses differences ranges up 20% due to the number of nodes and accuracy of each element as shown in Fig. 9.

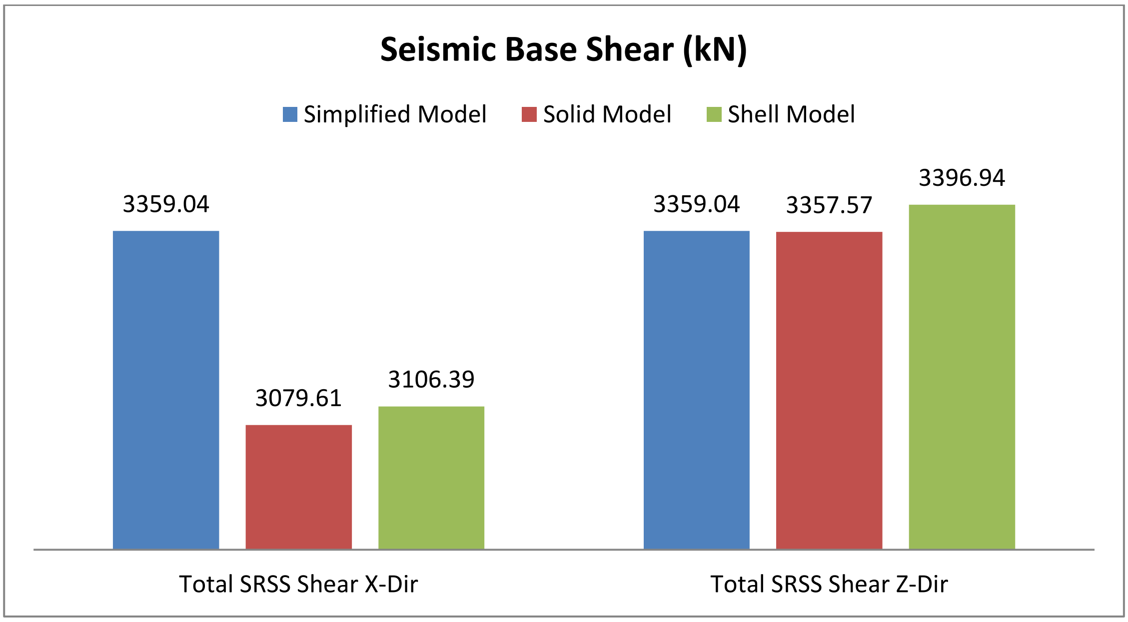

Fig. 10: Comparison of seismic base shear for simplified and detailed model

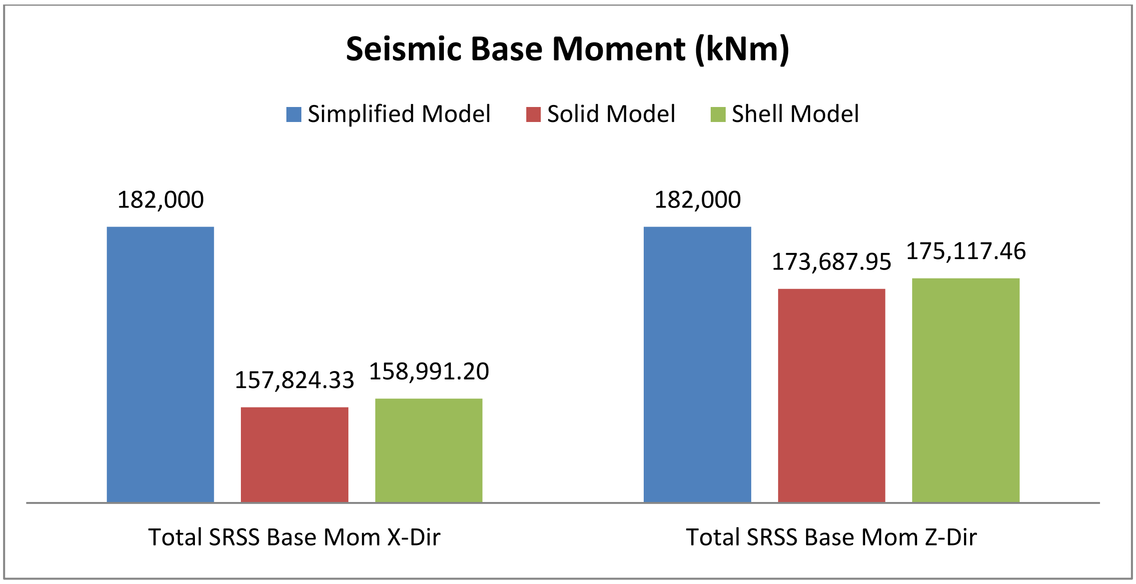

Fig. 11: Comparison of seismic base moment for simplified and detailed models

The modal base actions of the simplified model due to seismic loading shows a reasonable value for the base shear in the strong direction Z-direction compared to the detailed models as shown in Fig. 10. Regarding the base moment, the simplified model shows a conservative value in the strong direction between 4 to 5% compared to the detailed models as shown in Fig. 11.

6. CONCLUSIONS

From the obtained results and analysis, the followings can be concluded:

- The simplified beam model is a good presentation of the concrete chimney shell for seismic loading to get bending moments, shear and normal forces, even dynamic properties such as Eigen values and Mass participation are very close to the detailed models.
- The chimney displacement in the weak X-direction for the simplified beam model, where the gas flue duct and door openings are reducing the stiffness and are not taken into account, is less than the detailed model where these openings are completely modeled. In the other hand, the chimney displacement in the strong Z-direction for the simplified beam model, where there is no stiffness reduction, is equal to the detailed model for both solid and shell models.
- The shell element gives higher values and is more conservative than the solid element. In case of local concentrations of stresses around openings for the shell element, and where the value of one node exceeds the allowable stress, it's better to use the center stresses in lieu of corner stresses or to use the average values for two or more plates.
- It is recommended to use the shell model instead of solid model for the detailed analysis as it is easier and quicker for building and it saves a lot of time in running and displaying the results. Another benefit, it can also show values for plate bending, shear and normal forces. Besides that, it gives more conservative values for local stresses around openings.

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