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June, 2020

Issue 33

PGESCo

Engineering Magazine

Design of Different Chimney Models Subjected to Lateral Loads using Finite Element Analysis....P11

Editor's Note..

With such exceptional work situation, where many of PGESCo Engineers work from home due to Corona Virus reduced office work, and the effect of reduced working hours for the Month of RAMDAN, we were able with the help of our talented Authors; to produce this June issue of the Magazine marking the beginning of its Ninth year.

The first article written by members of Rendering and Physical Modeling Group; Eng. Mohamed Mostafa Abd-Elaziz, Eng. Engy Tarek Fathy & reviewed by Eng. Sherif El-Ganady, presenting the group successful works in competitions since 2013 and Titled **"PGESCo FIRST CONTRIBUTION TO BENTLEY SYSTEMS, YEAR IN INFRASTRUCTURE COMPETITION"**.

The second article by Dr. Eng. Atef El-Sadat presents a summary of part of his PhD Thesis titled **"DESIGN OF DIFFERENT CHIMNEY MODELS SUBJECTED To LATERAL LOADS USING FINITE ELEMENT ANALYSIS"**. The study investigates 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 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.

The 3rd article by Eng. Sarah Omar titled "**GREYWATER: THE GOLDEN OPPORTUNITY**" discuss scarcity of fresh water supply and ways and means of using **Greywater** which is considered amongst these alternative water resources. It is all wastewater that is discharged from a house/building, excluding black water (toilet water).

Wish all our readers to enjoy reading these interested articles, and awaiting your contribution for our next issues.

Dr. Mohamed ElBanhawy.

In This Issue

The Magazine Cover about

Design of Different Chimney Models >>>>

PGESCO FIRST CONTRIBUTION TO BENTLEY SYSTEMS, YEAR IN INFRASTRUCTURE COMPETITION

Article By : Engy Tarek Fathy

Mohamed Mostafa

Sherif ElGanady

Introduction

Rendering and Physical Modeling Group was first established inside PGESCo in 2018 as a group of engineers and designers from different engineering disciplines in the company. Our scope of work – beside our main discipline individual responsibilities - is basically 3D Physical Modeling, Rendering & producing high-resolution images and walkthrough videos of both running projects and proposal projects.

Beside that, we have been active in participating in number of global Customer-Based-Competitions like Hexagon PPM Golden Valve Competition every year since 2013, and we successfully managed to receive pole-position awards for our work such as 1st an 3rd places globally in 2019 by contributing with two rendered pictures generated basically from two different projects.

In 2019, Rendering and Physical Modeling Group of PGESCo participated for the first time in "Year In Infrastructure competition" by Bentley Systems. Two nominee certificates were awarded for the two project entries submitted Al-Atf and Giza north power plants.

Following paragraphs will cover the detail of the competition, categories, selection criteria, Nominated Projects and received acknowledgment. In addition to our Future work for YII2020 round of the competition.

Bentley Systems

Bentley Systems is a software development company that supports the professional needs of creating and managing the world's infrastructure, including roadways, bridges, airports, skyscrapers, industrial and power plants as well as utility networks. Bentley delivers solutions for the entire lifecycle of the infrastructure asset, tailored to the needs of the various professions – the engineers, architects, geospatial professionals, planners, contractors, fabricators, IT managers, operators and maintenance engineers - who work with that asset over its lifetime.

PGESCo depends on number of Bentley tools. Most drawings from different engineering disciplines are drawn, edited and issued using MicroStation. Project Wise helps project teams to manage, share, distribute, view, search query and inter discipline coordination of engineering project content in a single platform. STAAD is used in PGESCo for structure analysis of steel and concrete design, dynamic analysis and design of machine foundation and complex structures. PLAXIS is used in Geotechnical Finite Element Analysis FEA analysis, and Navigator is used for dgn-based 3D model review.

Year in infrastructure Competition Introduction

Bentley's YII in Infrastructure Awards is an exciting and well-regarded global competition that recognizes the "going digital" advancements in infrastructure. These awards are an integral part of the Year in Infrastructure Conference, which brings together infrastructure professionals and members of the media from around the globe to share innovative practices in infrastructure project design, engineering, construction, and operations, The entries were published describing how Bentley software programs had supported projects in an innovative way regarding all disciplines and departments involved. [1]

Categories

The Competition includes nineteen categories which are: [1]

- 4D Digital Construction
- Bridges
- Buildings and Campuses
- Digital Cities
- Geotechnical Engineering
- Land and Site Development
- Manufacturing
- Mining and Offshore Engineering
- Power Generation
- Project Delivery
- Rail and Transit
- Reality Modeling
- Roads and Highways
- Road and Rail Asset Performance
- Structural Engineering
- Utilities and Communications
- Utilities and Industrial Asset Performance
- Water and Wastewater Treatment Plants
- Wastewater and Stormwater Networks

Selection Criteria

Bentley technology must be used (alone or in combination with ProjectWise, Navigator, or other software) by engineering and construction firms, 4D service providers, and owners. Submissions should discuss how BIM models are linked with the 4D time dimension to intrinsically and immersivity synchronize, through digital workflows, the construction strategy, work breakdown structure, schedule, costs, resources, supply chain logistics, and progress. The schedule must be linked to the 3D geometry and data to enable a virtual simulation of the project or specific aspects of the project. The 4D models should optimize the ideal construction path prior to actual construction and/or deliver critical construction and fabrication information directly to the materials controls and project controls systems. Models should also show how they identify and resolve clashes and demonstrate multidiscipline coordination prior to construction. Submissions should demonstrate a combination of technical innovation, good project management, and a clear return on investment. [1]

Credit will be given to submissions where progress is recorded on-site.

Projects Submitted to YII2019

As mentioned before, PGESCo strongly depends on Bentley products in many of engineering activities of some projects. Two projects were used to participate in Bentley YII competition lase year 2019:

- Giza North Power Plant (Combined Cycle 3x750MW)
- El Atf Power Plant (Combined Cycle 750MW).

The most common software programs in these projects by Bentley are:

- Micro station
- Project wise
- STAAD
- Bentley navigator

1) Nominated Projects

Al Atf power Plant Project

Al Atf 750MW combined cycle power plant project site is located within the boundaries of the Rashid line of the river Nile, approximately 60KM south east Alexandria city. The facility will be designed to include a power block consisting of [3]

- Two 250MW (ISO) combustion turbine generator (CTGs), each feeding exhaust gases to its respective Heat Recovery Steam Generator (HRSG)
- Steam Generated from the two HRSGs is feeding one 250 MW (nominal), reheat, condensing steam turbine generator (STG)
- The estimated facility net output is approx. 750MW (ISO,nominal) each.
- The steam exhausted from the steam Turbine is discharged into a once-through cooling, single-pass, divided water-box condenser
- Power generated is stepped up through main transformers and fed to the unified grid via a 220 KV switchyard at el Atf
- Cooling water demand for the El Atf is obtained the Nile River.

The Notice to proceed for El Atf Scope of services was issued in August 2006. Also El Atf had achieved 13,706,625 of safe man hours which is the highest compared with other PGESCo projects in the period of construction.

Bentley Software Used in El Atf Project

- MicroStation
- Navigator
- ProjectWise
- STAAD

The type of Modeling Used In El Atf Project

- Design Modeling
- Analytical Modeling

Submitted Pictures For El Atf Project

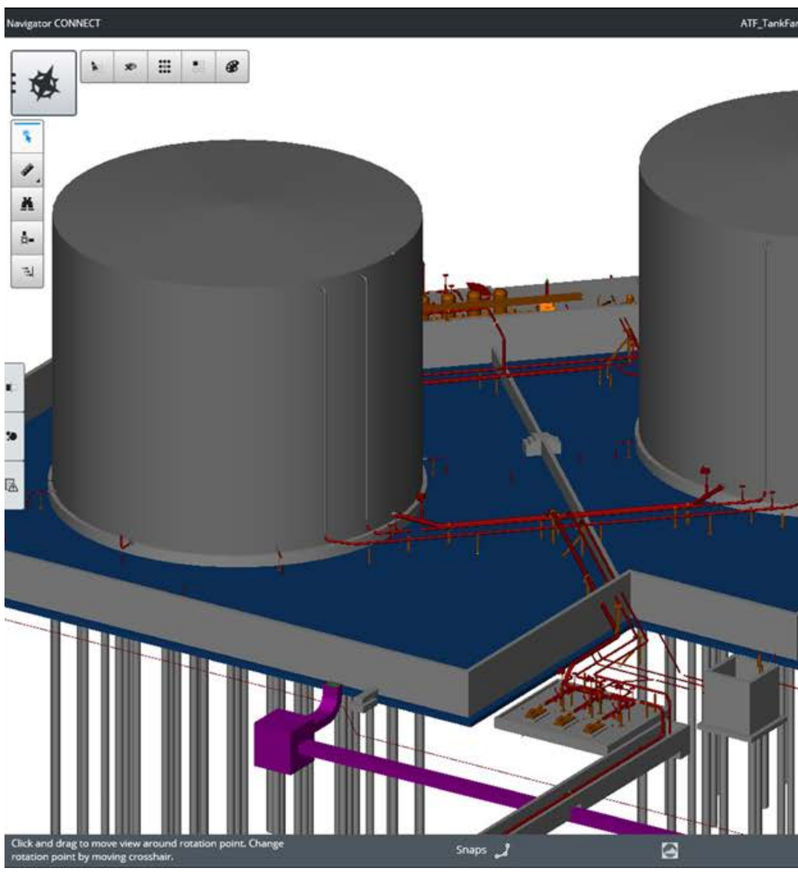

Fig 2. El Atf Project -Bentley Navigator

Giza North Power Plant Project

Fig 1. El Atf Project 3D Model Rendered

Giza North project is located 22 km north of Qanater city on the way of Khatatba and is overlooking El Behairy canal, in 6 October governorate, Egypt. The project consists of three modules, each is a 2x2x1 Combined Cycle configuration with gas/oil fired gas turbine units, delivering a total of 3x750MW interconnected with the Egyptian National Unified Power System (NUPS) through 500/220 KV GIS breakers. The project was implemented through seventeen contract packages and purchase orders. The project includes a power block consisting of the following: [4]

- Six 250MW Combustion Turbine Generators (CTGs), each feeding exhaust gases to its respective Heat Recovery Steam Generator (HRSG).
- Six Heat Recovery Steam Generators, each two HRSGs will feed one 250 MW (nominal), reheat, condensing Steam Turbine Generator (STG).
- Three 250MW Steam Turbine Generators (STGs).
- The estimated net output is approximately 3x750MW (ISO, nominal). This output is achieved when burning natural gas in the Combustion Turbines. The steam exhausted from the Steam Turbine is discharged into a once-through cooling, single-pass, divided water-box Condenser
- The facility is connected to the EEHC unified grid system through the 500/220KV switchyard
- Power generated is stepped up through main transformers and fed to the unified grid via take off gantry switchyards.

In terms of safety, Giza North project had achieved 14'099'464 of safe man hours, which is the highest compared with other PGESCo projects in the period of construction.

Bentley Software Used in Giza North Project:

- MicroStation
- Navigator
- ProjectWise
- STAAD

The type of Modeling Used in Giza North Project:

- Design Modeling
- Analytical Modeling

Submitted Pictures for Giza North Project

Fig 3. Giza North Project 3D Model Rendered

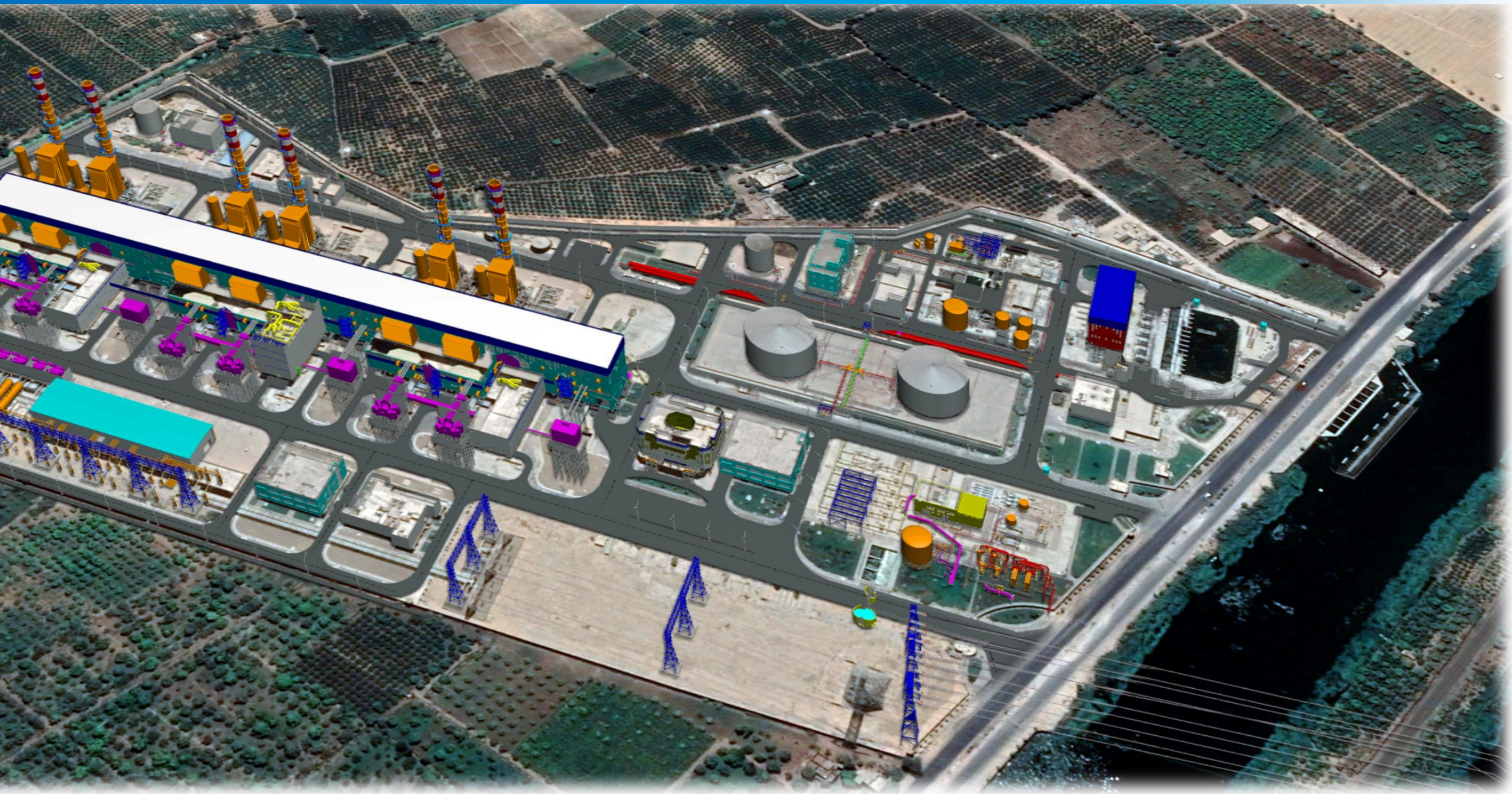

Fig 4. Giza North Project 3D Model

PGESCo Received Certificates

Submitted projects were successfully listed as nominated projects, we have received two participation certificates for each project, two original hard copy of Bentley's 2019 Infrastructure Yearbook. [2]

Fig 5. Nominee Certificate for El Atf Power Plant Project

Fig 6. Nominee Certificate for Giza North Power Plant Project

Future Work in Extended Participation in Global Design Competitions

In 2020, we are preparing to participate with number of recent infrastructure projects by PGESCo where the latest technology and engineering tools are applied by our Engineering department. In Bentley YII2020 and Hexagon PPM Golden Valve competitions. YII submission deadline is extended to

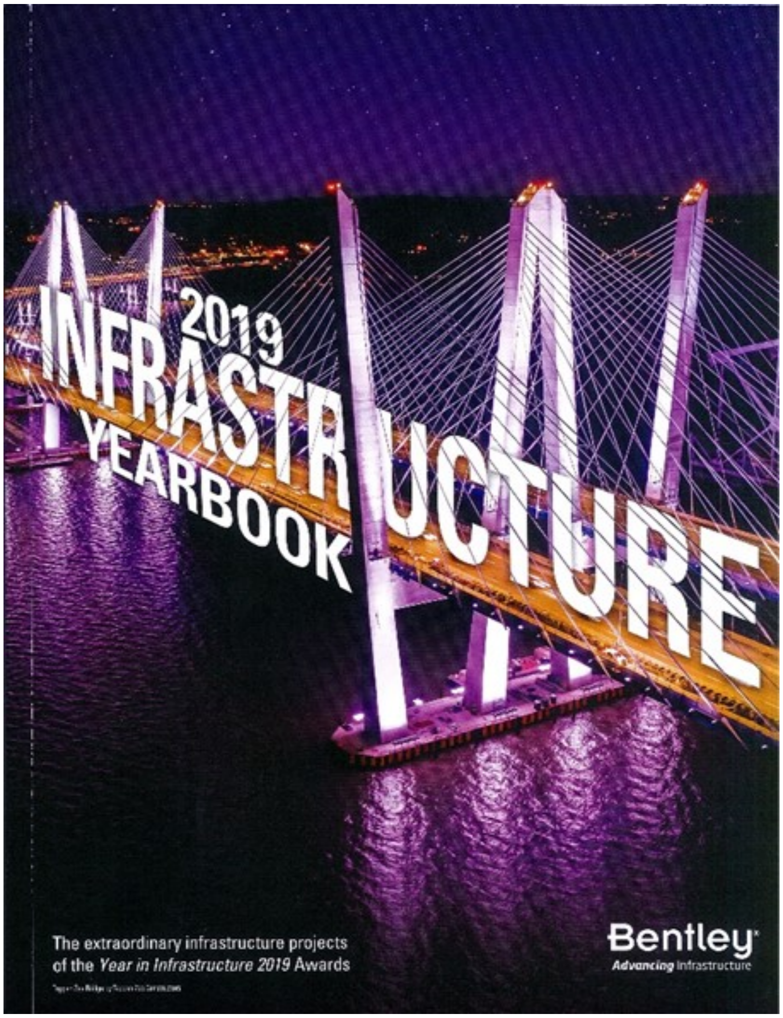

Fig 7 2019 Year in Infrastructure Book [2]

June 5th, 2020.

Winners announcement and Awards ceremony will be in Vancouver: October 15th, 2020 hopefully in case the pandemic case is over!

The team currently is working remotely due to the situation of COVID19 takeover to finalize the entries. We will be posting regularly about our progress.

References:

(1) https://yii.bentley.com/en/awards
(2) https://www.bentley.com/en/infrastructure-yearbook?_ga=2.237808576.1748290597.1586738380-916775001.1586738380
(3) https://www.pgesco.com/projects/el-atf-power-plant-750-mw/
(4) https://www.pgesco.com/projects/giza-north-i-ii-iii-power-plant-3-x-750-mw/

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DESIGN OF DIFFERENT CHIMNEY MODELS SUBJECTED TO LATERAL LOADS USING FINITE ELEMENT ANALYSIS

Article By : Dr. Atef El-Sadat

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

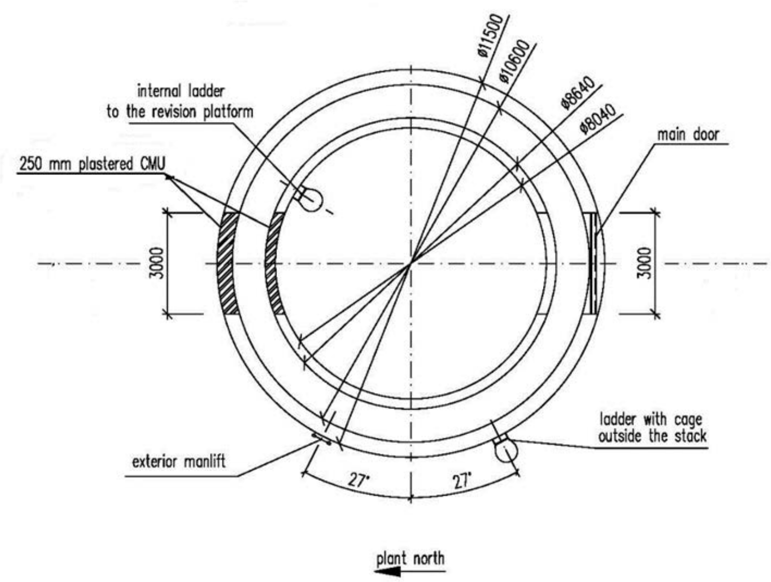

Fig. 1: Chimney section plan at bottom level (0.00)

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) x π x 20.00 x 21.1 = 1128 kN

Weight of insulation (60 mm of mineral wool), overlapping and special shaped bricks is included by weight increase of 5%.

$W_{sum} = W_{lin} x1.05 = 1185$ 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

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**

Table 1: Summary of chimney gravity loads

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:

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

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

$$\bar{V}(z) = 1.47 \times V_r \times (z/33)^{0.154} \times 0.65 \ldots\ldots\ldots\ldots (2)$$

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

$$\bar{W}(z) = C_{dr}(z) \cdot d(z) \cdot \bar{P}(z) \ldots\ldots\ldots\ldots (3)$$

Where wind pressure in psf is:

$$\bar{P}(z) = 0.00119 \cdot K_d \cdot [\bar{V}(z)]^2 \ldots\ldots\ldots\ldots (4)$$

Where;

K_d = 0.95 for circular chimneys and shape factor is:

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

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

Shape factor Cdr(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:

$$G_w' = 0.30 + [11.0 \times (T_1 \times \bar{V}(33))^{0.47}] / (h + 16)^{0.86} \ldots\ldots\ldots\ldots (7)$$

Where;

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

$\bar{V}(33)$ 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:

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

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

$$w'(z) = (3.0z \times G_w' \times Mw(b)) / h^3 \ldots\ldots\ldots\ldots (8)$$

Where;

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

$$w'(z) = (3.0z \times 0.974 \times Mw(b)) / 152^3$$

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

$$= 0.0694\ z$$

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)	$C_{df}(z)$ Drag coefficient for diameter of the section and basic wind	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	

Table 2: Summary of mean along-wind load

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:

$w(z) = \overline{W}(z) + w'(z)$……………………………………(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 $\bar{V}(z_{cr})$ where $\bar{V}(z_{cr})$ is the mean hourly wind speed at (5/6)h, here 126.78 ft/sec (38.64 m/sec) by using equation (2)

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

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:

$$S_t = 0.25 \times F_{1A} \quad \text{......(11)}$$

Where;

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

but not >1.0 or <0.6, here is

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

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

$S_t = 0.25 \times 0.865 = 0.216$

$V_{cr} = 0.36 \times 11.50 / 0.216 = 19.02 < 0.50 \times \overline{V}(z_{cr}) = 0.5 \times 38.64 = 19.32$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:

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

Here; $V_{cr2} = 5 \times 11.50 / 0.48 = 119.91 > 1{,}30 \,.\, \overline{V}(z_{cr}) = 1.30 \times 38.64 = 50.23$ 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:

$M_i(z) = 0.31pr(z)[r(z)]^2$, ft-lb/ft (tension on inside)..........(14)

$M_o(z) = 0.27pr(z)[r(z)]^2$, ft-lb/ft (tension on outside)......(15)

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

$G_r(z) = 4.0 – 0.8.\log_{10} z$, except $G_r(z) = 4$ for $z \le 1.0$ ft ....(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)

$p_r(z) = 0.92 \times 1.84 \times 1.5 = 2.54$ kPa

$M_i(z) = 0.31 \times 2.54 \times 5.6^2 = 24.7$ kNm

$M_o(z) = 0.27 \times 2.54 \times 5.6^2 = 21.5$ 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.

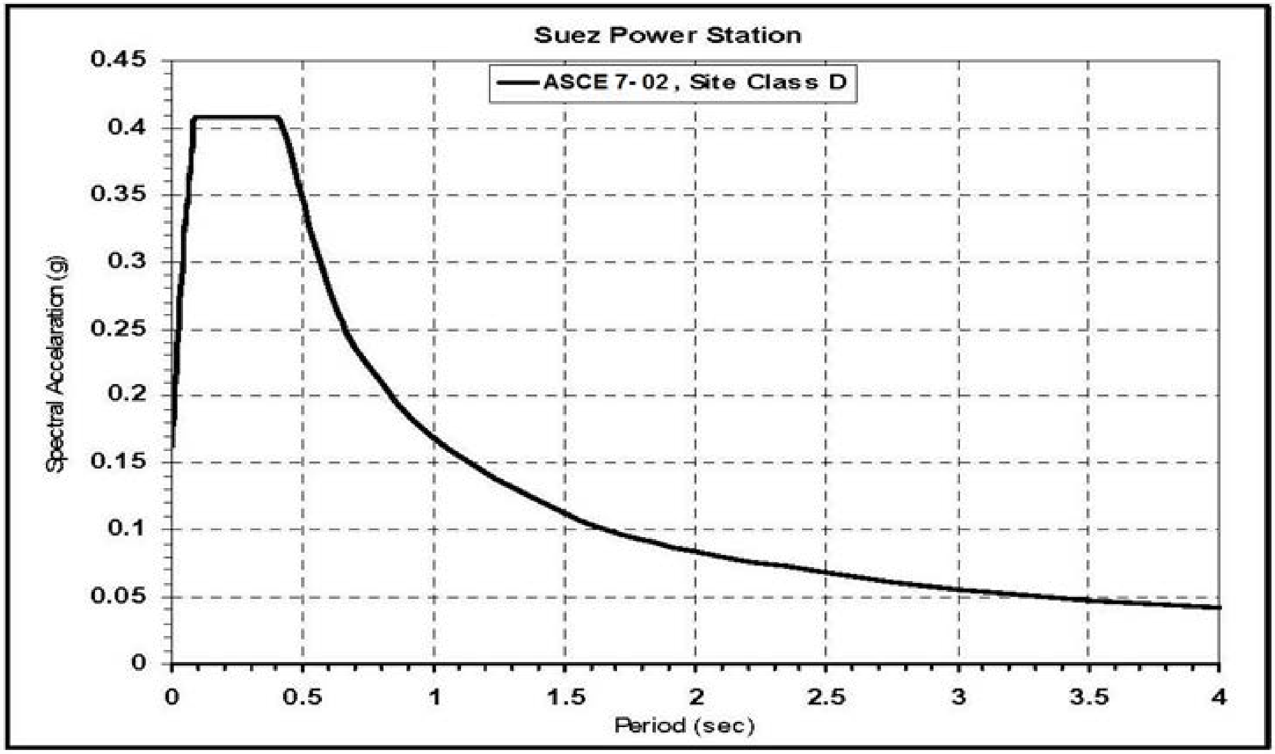

Fig.2: Design Acceleration spectrum for site class D for Suez site

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:

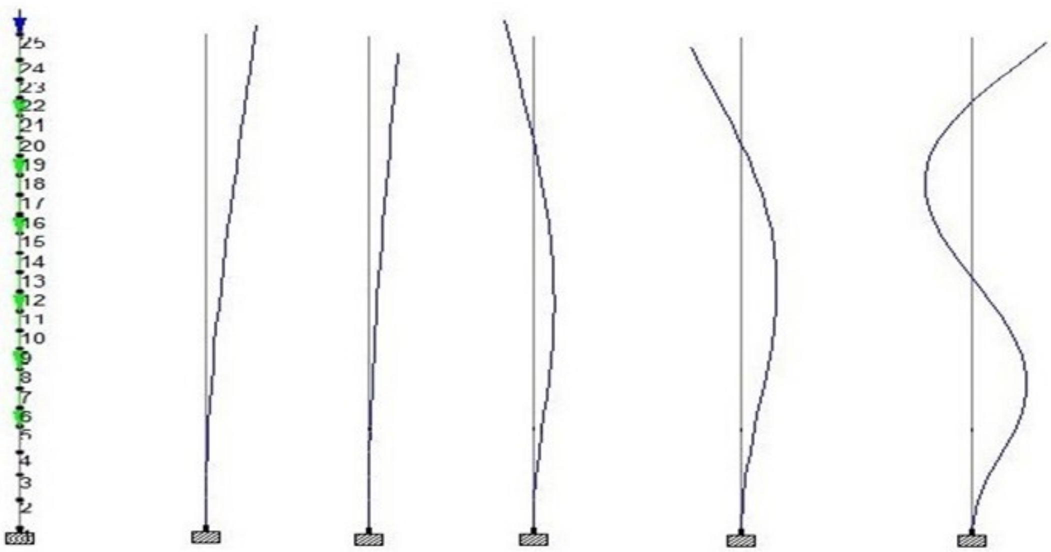

Fig. 3: Simplified seismic beam model with the first 5 mode shapes

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:

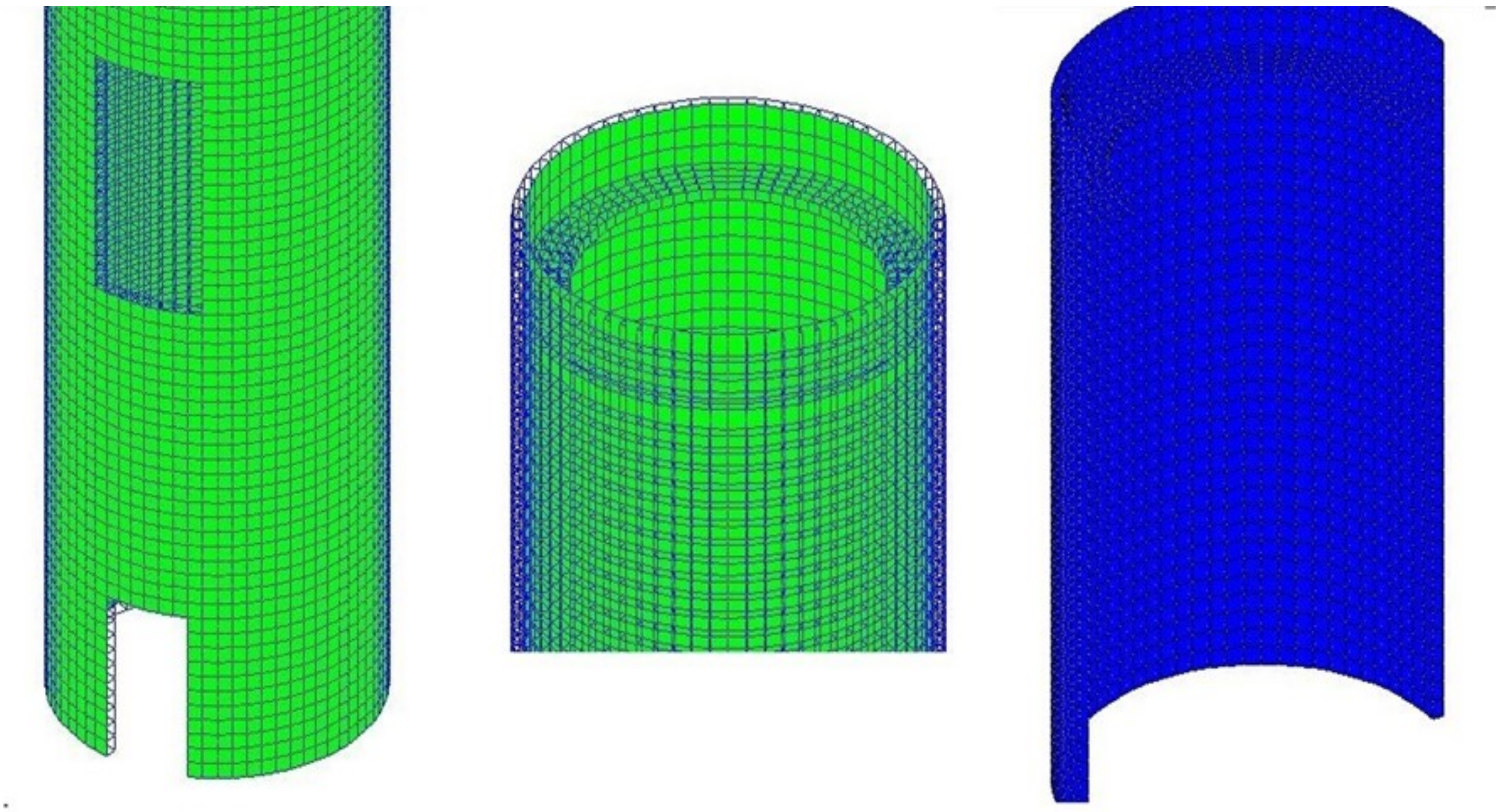

Fig. 4: Solid model lower part with door and flue gas duct openings, upper part with top slab & vertical half-section in upper part

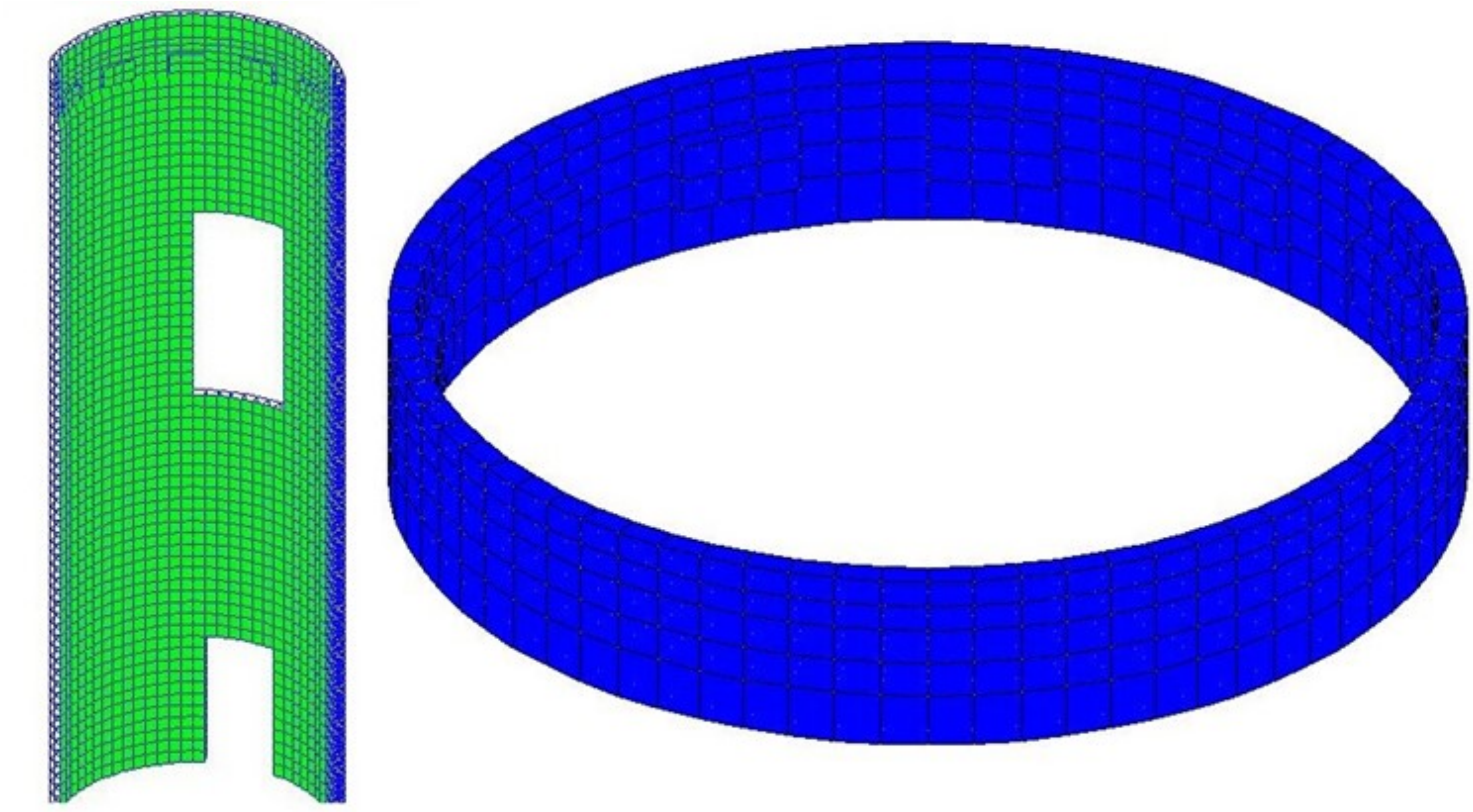

Fig. 5: Solid model vertical half-section in lower part & corbels at the annular plates levels

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:

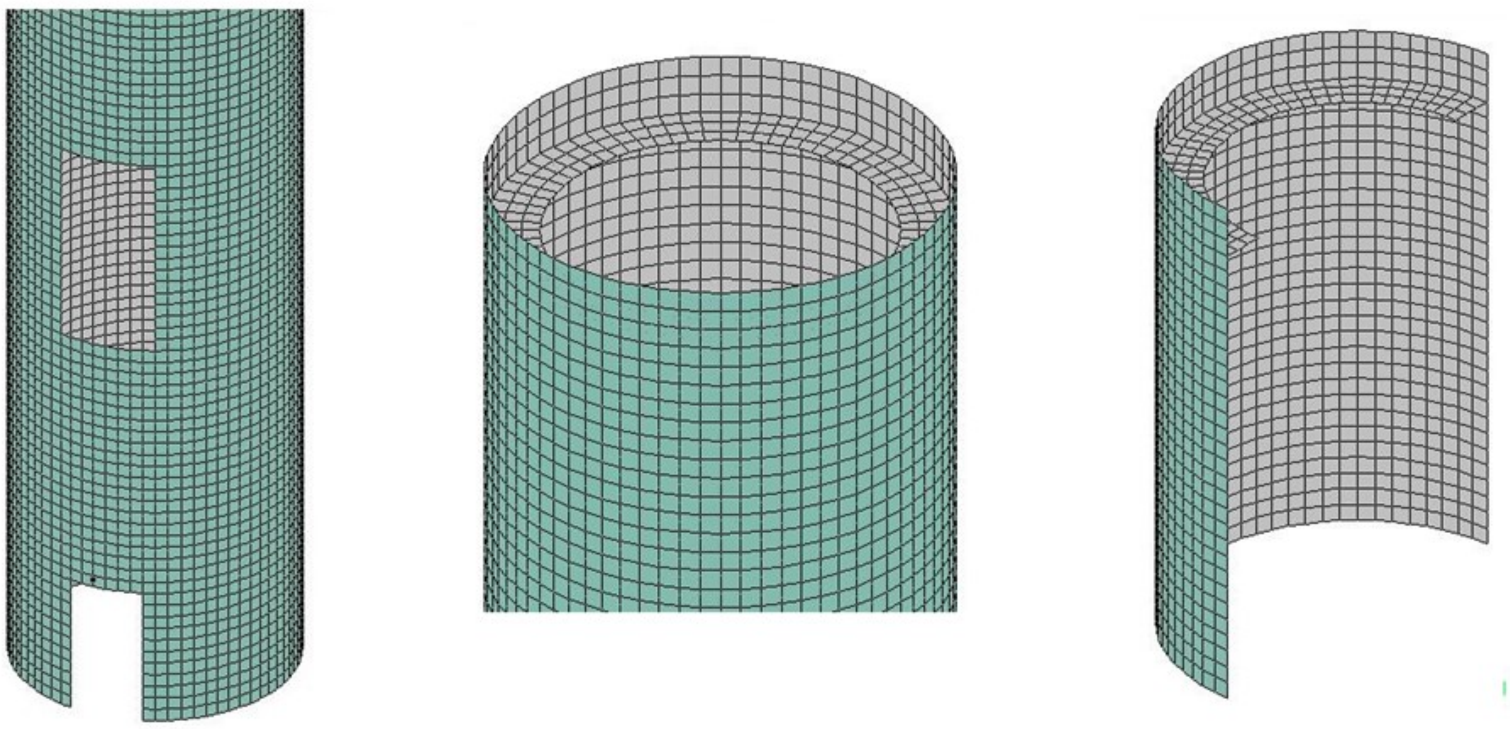

Fig. 6: Solid Model lower part with door and flue gas duct openings, upper part with top slab & vertical half-section in upper part

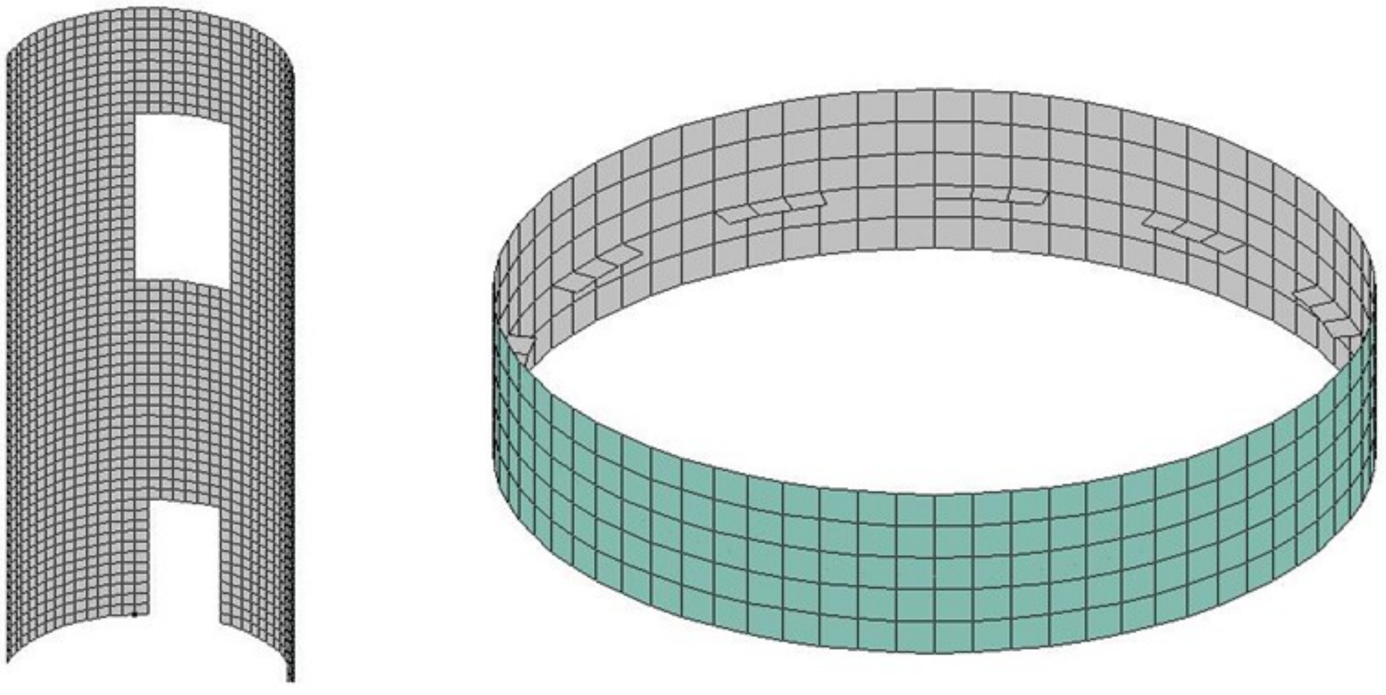

Fig. 7: Solid Model vertical half-section in lower part & corbels at the annular plates levels

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

		Units	Simplified Model	Detailed 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 Wind Loading	Displacements				
	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 Results Seismic Loading	Displacements				
	Displacement X	mm	181	200	201
	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

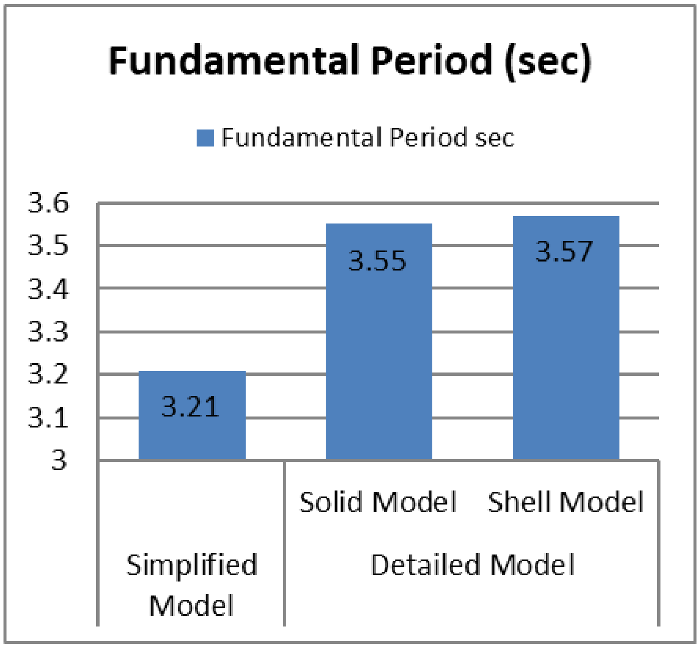

Fig. 8: Comparison of fundamental period for simplified and detailed models

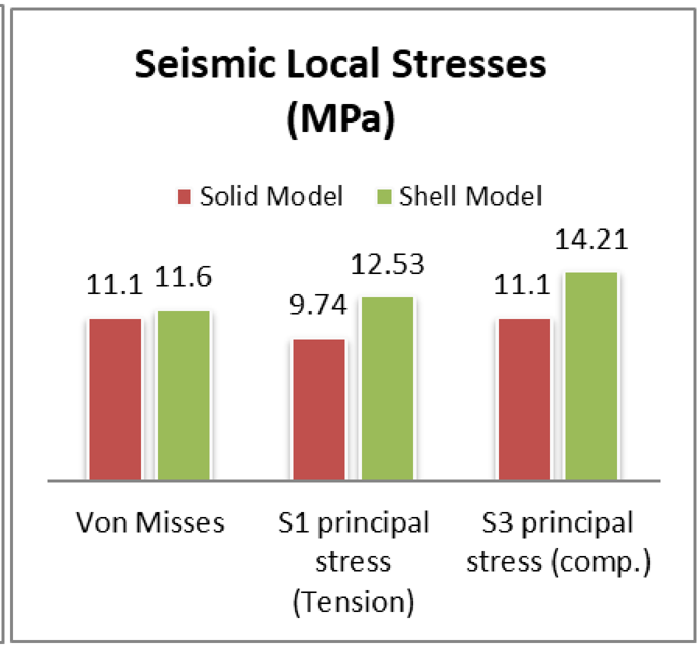

Fig. 9: Comparison of seismic local stresses for detailed models

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.

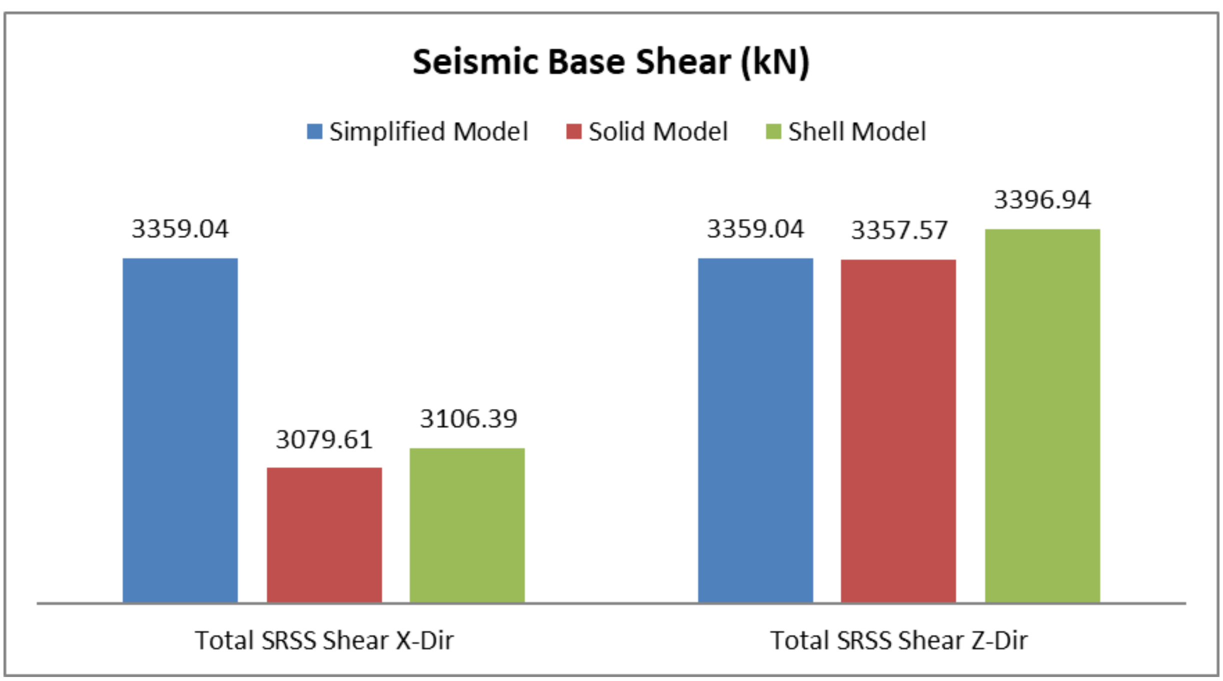

Fig. 10: Comparison of seismic base shear for simplified and detailed model

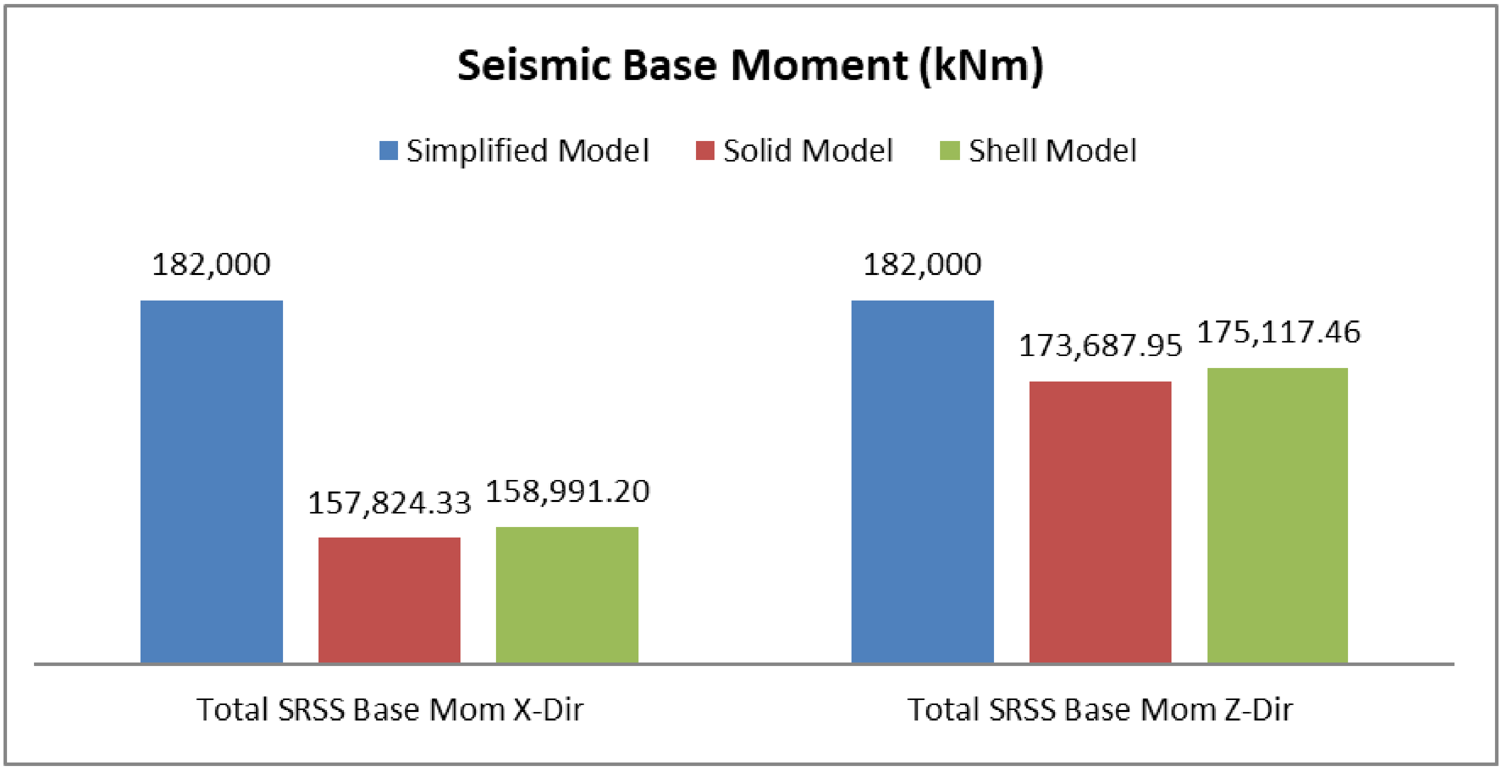

Fig. 11: Comparison of seismic base moment for simplified and detailed models

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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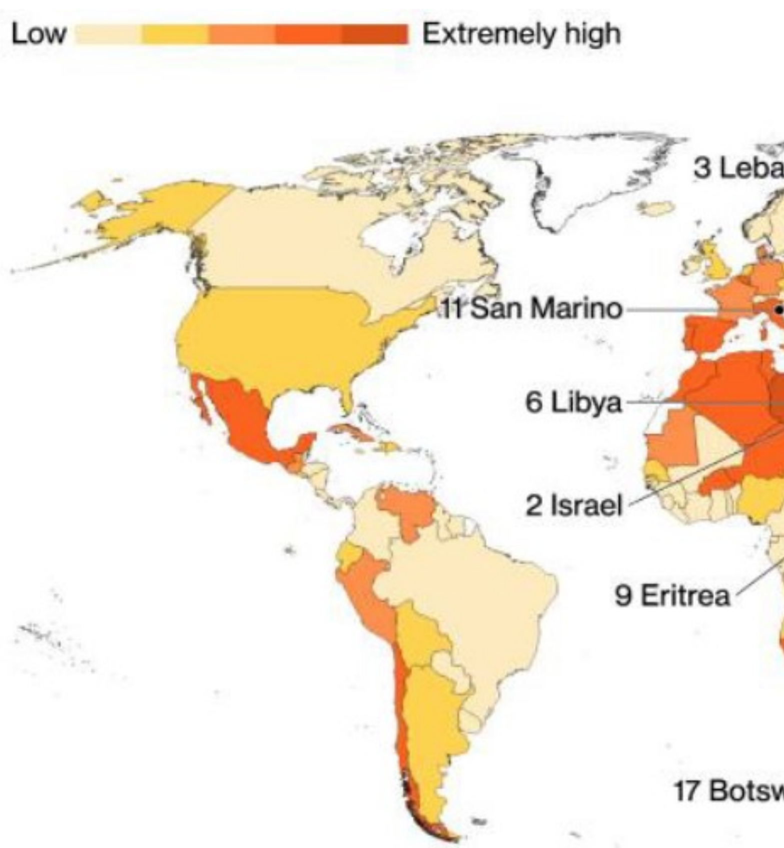
GREYWATER: THE GOLDEN OPPORTUNITY

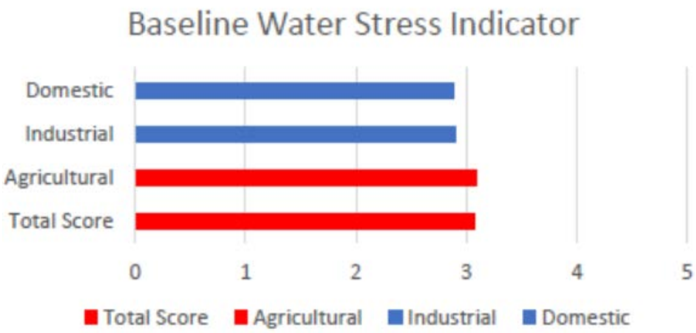
Article By : Sarah Omar

With the booming population and its corresponding water consuming activities such as domestic, industrial and agricultural activities, a non-stop growing demand on fresh water increases causing stress on the limited existing fresh water resources. Globally, water consumption has become twice the population growth rate with increasing number of regions that are reaching the water scarcity limits, in the last century. Not only the population affects water scarcity, but also climate change, demographic changes, urbanization, world development requirements and bio-energy demands pose sophisticated challenges on water supply systems [1] [2].

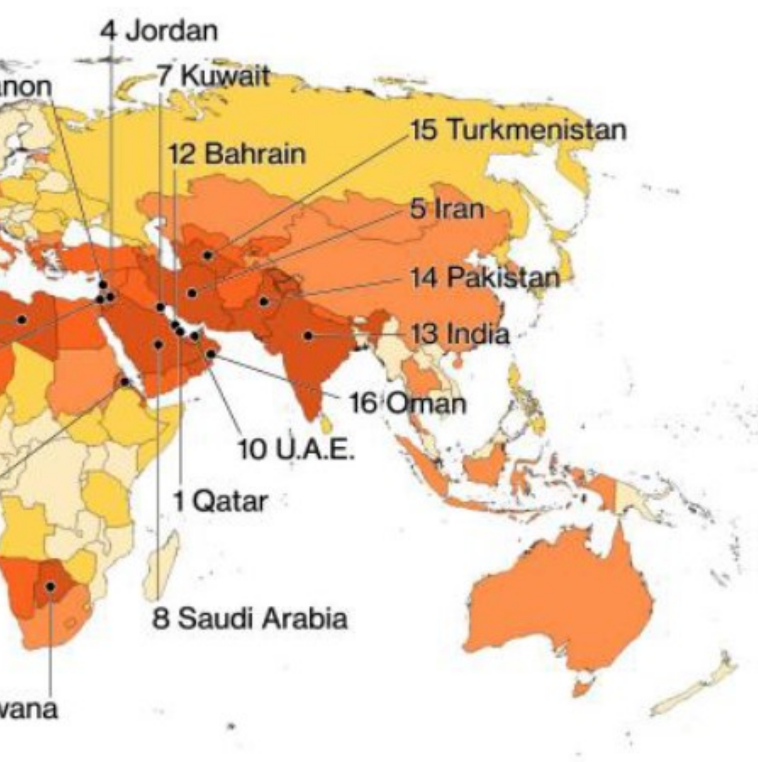
It has been estimated that half of the world's population will live under water-stressed conditions by 2025 [3]. World Resources Institute (WRI) has updated the Water Risk Atlas to find out that 17 countries which are home to 25% of the world's population (1.7 billion people) encounter "extremely high" water stress conditions, in 2019. In an average year, these countries consume up to 80 % of their available surface and groundwater for agriculture, industry, and municipalities. The results of mapping the water risks showed that the Middle East and North Africa are the most water stressed region on Earth to date and that 12 out of the 17 countries are in the MENA region [4]. In addition, the highest expected economic loss due to climate-related water scarcity is estimated to be 6-14 % of GDP in the MENA region by 2050 [5].



According to WRI, Egypt, ranked #43, lies in the second category of "high baseline water stress" with a total score of 3.07 distributed as 3.10, 2.91, and 2.89 for Agricultural, industrial and domestic sectors, respectively [5].



These scores represent the average exposure to water risk indicators set by WRI, showing the agriculture with the highest exposure. Furthermore, according to United Nations (UN) [6], it is considered to be in water scarcity when annual water supplies drops below 1000 m3 per capita which is the case in Egypt as of 2017 data where total water withdrawal is 846.9 m3/capita. Egypt relies almost entirely on surface water from the River Nile [5], which is a threat in case of the occurrence of any climate change worse scenarios, or active upstream projects on the River Nile (e.g. Ethiopian Dam) that affect its flow and quantity. Another issue Egypt encounters is the water productivity. It can be defined as the economic output per water volume used. Egypt is registered as the water productivity lowest value of less than 5 % US$/ m3 after Iraq in the MENA region, which is below the middle-income economies average [5].



Despite these facts, a massive potential lies in wastewater reuse since up to 82 % of wastewater in the MENA region is not recycled which can significantly reduce the gap between the supply and demand. For Egypt, it has been found that only 57% of collected municipal wastewater is treated while the remaining is returned to the environment untreated, causing subsequent health and environmental hazards and wasted water resources. Although this 57% can be considered significant, reuse implementation on a big scale is still a limitation since only almost 2% of the treated wastewater is reused. This can be great opportunity in responding to landscape irrigation, agricultural, industrial or other water demanding activities at a relatively low cost [7].

Hence, finding new ways to preserve our natural resources and maximize the water use and reuse efficiencies is a must for survival. It is worth noting that over 50% of the water demand from domestic and industrial applications could be met by water of lower quality than fully treated water, including applications such as process water, toilet flushing, garden water, car washing, and landscaping. This raises a flag to the necessity of re-managing the water resources and exploiting alternative resources that meet the demand and reduce the stress on the fresh water resources [8].

Greywater is considered amongst these alternative water resources. It is all wastewater that is discharged from a house/building, excluding black water (toilet water). Greywater reuse is considered the highest potential water resource which accounts for up to 80% of total domestic water use [9]. It has been estimated that greywater reuse in toilet flushing may save up to 30% of the house water demand [10].

Greywater can be used after treatment, according to laws and regulations, in various applications, main of which are landscape irrigation and toilet flushing. This contribution could have great merits in reducing load on wastewater treatment plant and all related direct and indirect cost, and saving water on the domestic level. It can also contribute positively to water-energy-food nexus issues by reducing allocated energy load on wastewater collection facilities and treatment plants as well as saving fresh water for food production. Furthermore, using greywater will significantly reduce the need for fresh water in a building/household, and, subsequently, reduce water bills and its burden on the individuals and the broader community. Accessibility, low risk and low infrastructure required to collect and reuse greywater also make it superior to other wastewaters.

This article will briefly focus on the greywater characteristics, quality and quantity, risk and benefits, regulations and standards. While, different treatment systems, especially the electrocoagulation, will be addressed in another article.

Greywater characteristics

Greywater quality and quantity vary significantly from one place to another and within the same day depending on geographic location, living standards, social and cultural habits, available infrastructure, and different daily household activities based on water usage.

Greywater quality is an important factor that shall be taken into consideration for defining the reuse applicability and the treatment feasibility as well as its associated health and environmental implications [12]. It is characterized by its physical and chemical parameters. Physical parameters cover temperature, conductivity, SS, turbidity, and color. Whereas, chemical parameters include pH, dissolved organic matter (BOD, COD, TOC), recalcitrant organic compounds such as xenobiotic organic compounds XOC, nutrients (N and P), residual chlorine and heavy metals. Pollutant load can be estimated from the source whether it is heavy or not. For instance, light GW is the waste water from bathroom, and wash basin, whereas heavy GW is from kitchen sink and laundry. Based on the source, the greywater possible constituents vary as shown in Table 1. In addition, it is worth noting that greywater storage time could play an important role in either enhancing or deteriorating the greywater quality. Dixon et al. [13] found that storing greywater for at least 24 hours enhances its quality for both COD and TSS associated with the settlement phase, which subsequently reduces the load on the following treatment process. However, more than 48-hour storage time was found to cause DO depletion and potential aesthetic problems.

Greywater quantity has been estimated in different research works. Its production can be based on the domestic water usage. According to the Ministry of Water Resources and Irrigation (1997), it has been reported that the average water use of an Egyptian household is divided as shown in the following figure [16].

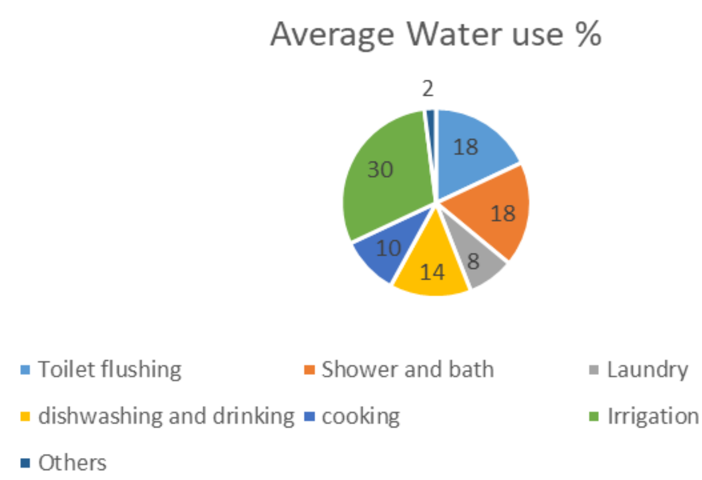


***Table 1: Possible constituents of greywater** [15]*

Graywater Source	Possible Contents
Automatic Clothes Washer	suspended solids (dirt, lint), organic material, oil and grease, sodium, nitrates and phosphates (from detergent), increased salinity and pH, bleach, heat
Automatic Dishwasher	organic material and suspended solids (from food), bacteria, increased pH and salinity, fat, oil and grease, detergent material, heat
Bathtub and Shower	bacteria, hair, organic material and suspended solids (skin, particles, lint), oil and grease, soap and detergent residue, heat
Sinks, including Kitchen	bacteria, organic matter and suspended solids (food particles), fat, oil and grease, soap and detergent residue, heat
Swimming Pool	chlorine, organic material, suspended solids

Over different countries, greywater accounts for a range of 41-91 % of wastewater volume generated in a household [11] [17], 44-62% of which represents light greywater [11]. In numbers, depending on the aforementioned variables of location, lifestyle and available infrastructure, it is indicated that the typical greywater amount ranges from 90 to 120 l/d per person and it can get as low as 20-30 l/d per person in low income countries that have water shortage and simple water supplies [18].

Risks and Benefits

Using greywater without proper treatment poses a potential risk to the public health and the environment. Health risk is attributed to the exposure of microorganisms that spread diseases and viruses, especially in case of reusing it in toilet flushing and irrigation applications [12]. The exposure to microorganisms related diseases can take place in different forms, some of which are direct contact with greywater, through watering edible plants [20], and ingestion and inhalation of aerosols [12]. Fecal coliform has been used as an indicator for the microorganisms and upon which some guidelines were based, as shown in the next section. In addition, sulphide content in greywater could cause public nuisance by its aggressive odor [12]. furthermore, long time storage may cause mosquito nuisance [14] and odor.

From the environmental point of view, soil, plants and groundwater can be highly affected by the high load of pharmaceutical, laundry and personal care product. Although greywater can be beneficial for plants, especially when it is rich in nutrients (nitrogen and phosphorus), it may also cause harmful effect due to the presence of unfavorable content to some plants such as sodium, chloride, boron, metals and high salts concentration, accumulation of xenobiotic organic compounds (XOCs) causing salt built-up and increasing alkalinity, which in return will adversely affect the soil productivity and ability to retain water and adsorb nutrients. Groundwater also can be affected by the seepage of the harmful greywater constituents [12][16][20]. Therefore, proper treatment of greywater shall be taken into consideration prior its use.

Using treated greywater could have a great impact and potential in saving up to 46% of potable water in non-potable water consuming activities such as toilet flushing, gardening, floor cleaning, and car washing [11]. In addition, the positive public perception of the greywater can facilitate its consideration and application [19]. For the individual consumer, greywater reuse can reduce water and sewage bills. For the general public, GW can be of great value in many aspects. It acts as an additional accessible water resource which supports water security and may postpone the need to develop new resources. It reduces energy required for water abstraction, water treatment, and water distribution. In addition, the amount of chemicals used for water/wastewater treatment is decreased. Furthermore, area allocated for treatment plants and required infrastructure can be significantly reduced [20]. From environmental point of view, reducing such amount of energy would definitely reduce its contribution to greenhouse gas emissions. In addition, nutrient-rich 10 treated greywater may serve as fertilizer that contributes to plants growth [18], hence increasing water productivity.

Policy and regulations

Globally, different regulations have been considered for greywater reuse in different countries, some of which are USA and Australia. These regulations highlight the technical requirements that are concerned with site and soil evaluations, design criteria, installation and operation of on-site facilities and sustainable management, in addition to awareness and guidelines related to how to use greywater and the prohibition of its use [21]. Their main objectives are to ensure public health and safety, environment protection and sustainability [18]. Some guidelines and standards that control wastewater usage in different applications were issued to identify the effluent water quality limits, according to different global organization US EPA [22], Central Pollution Control Board and World Health Organization [23] as shown in Table 2 [14]. It is worth noting that some standards highlight clearly the consideration of GW such as WHO, while others generalize the limitations to include the reuse of all wastewater such as US EPA. In most of the Middle Eastern countries, e.g. Oman, Jordon, their guidelines do not distinguish between black and greywater [24]. Egypt, as well, has general wastewater discharge guidelines and criteria without specifying greywater. However, it might be used as a preliminary guidance for the water quality limits in case of using treated greywater for agricultural purposes. These limits can be found in the Egyptian code of practice (ECP) 501/2015, which focuses on the use of treated wastewater in agriculture. It defines the limits for TSS, Turbidity, BOD5, E. Coli and Intestinal nematodes for the treated municipal wastewater. Their limits vary based on the end use classification which is divided into four groups (A, B, C, D), as illustrated in Table 3.

Table 2: Wastewater reuse guidelines and standards [14]

Type of reuse	Reclaimed water quality	References
Urban reuse: all types of landscape irrigation, toilet flushing, fire protection, commercial air conditioners	pH=6–9, BOD ≤10 mg/L, turbidity≤2 NTU, FC=no detectable faecal coli/100 ml, chlorine (Cl_2=1 mg/L residual (minimum)	United States Environmental Protection Agency 2004
Restricted access area irrigation—sod farms, areas where public access is prohibited	pH=6–9, BOD≤30 mg/L, TSS≤30 mg/L, FC≤200 faecal coli/100 ml, Cl_2=1 mg/L residual (minimum)	
Agricultural reuse—food crops not commercially processed—surface or spray irrigation	pH=6–9, BOD≤10 mg/L, turbidity≤2 NTU, FC=no detectable faecal coli/100 ml, Cl_2=1 mg/L residual (minimum)	
Construction—soil compaction, dust control, washing aggregate, making concrete	BOD≤30 mg/l, TSS≤30 mg/L, FC<200 faecal coli/100 ml, Cl_2=1 mg/L residual (minimum)	
Indirect potable reuse—groundwater recharge by injection into potable aquifers	Includes, but not limited to, the following: pH=6.5–8.5, turbidity≤2 NTU, TC=no detectable total coli/100 ml, Cl_2=1 mg/L residual (minimum), TOC≤3 mg/L, TOX≤0.2 mg/l, Meet drinking water standards	
Discharge into inland surface water	SS<100 mg/L, pH5.5 to 9.0, O&G<10 mg/L, ammonical nitrogen (as N)<50 mg/L, BOD<30 mg/L, COD<250 mg/L, As<0.2 mg/L,	Central Pollution Control Board 2012
Discharge into land for irrigation	SS<200 mg/L, pH5.5 to 9.0, O&G<10 mg/L, BOD<30 mg/L, As<0.2 mg/L,	
Restricted irrigation	Helminth eggs<1/L, *E. coli*<100,000 (relaxed to 10,00,000 when exposure is limited or regrowth is likely)	World Health Organization 2006
Unrestricted irrigation of crops	Helminth eggs<1/L, *E. coli*<1,000 (relaxed to 10,000 for high growing leaf crops or drip irrigation)	

Table 3: Egyptian limit values of the Treated wastewater for agricultural reuse applications

Treatment Grade Requirements		A	B	C	D
Effluent limit values for physic-chemical	TSS (mg/l)	15	30	50	300
	Turbidity (NTU)	5	Unspecified	Unspecified	Unspecified
	BOD_5 (mg/l)	15	30	80	350
	E.coli count in 100 ml	20	100	1000	Unspecified
Effluent limit values for biological parameters	Nematode cells or Eggs per liter	1	Unspecified	Unspecified	Unspecified

Grade	Agricultural Group	Plants or Crops
A	G1-1: Plants and trees grown for greenery at educational facilities, private and public parks	Palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees.
	G1-2: Fruit crops	Fresh edible crops such as apples, apricots, peaches, grapes, etc
B	G2-1: Dry grain crops	Wheat, corn, barley, rice, beans, lentils, sesame
	G2-2: Trees producing fruits with epicarp.	On condition that they are produced for processing purposes such as lemon, mango, date palm and almonds.
	G2-3: Medical crops	Anise, hibiscus, Cummins, marjoram, mogat, fennel, chamomile, Al-Marmariyah
C	G3-1: Dry grain crops, fruit crops and medical crops mentioned in Group B	Same crops mentioned in Group B, in addition to beet and sunflower plants, on the condition of not using spray irrigation
	G3-2: Non-edible seeds	Wheat, corn and all vegetables seeds, on the condition of planting these seeds in their permanent spots afterwards
	G3-3: All types of seedlings which are later transferred to their permanent fields	Athel tamarix (salt tree), pomegranate, bananas, mango, apples, fruit producing trees, date palm and olive trees
	G3-4: Roses & Cut Flowers	Local rose, eagle rose, onions (e.g. gladiolus).
	G3-5: Trees used for green belts around cities and a forestation of high ways or roads	Casuarina, camphor, athel tamarix (salt tree), oleander, fruit producing trees, date palm and olive trees
	G3-6: Fiber Crops	Flax, jute, hibiscus, sisal
	G3-7: Fodder/ feed crops	Sorghum sp.
	G3-8: Mulberry for the production of silk	Japanese mulberry
	G3-9: Nursery Plants	Nursery plants of wood trees, ornamental plants and fruit trees
D	G4-1: Industrial Solid Crops	All crops that could be turned into coal pills like: willow, poplar and Moringa
	G4-2: Industrial Oil Crops	All organic diesel producing crops like: Jojoba and Jatropha
	G4-3: Cellulose-producing crops	All non-edible crops used for glucose production like: ethanol and acetic acid
	G4-4: Wood Trees	Caya, camphor and other wood trees.

To conclude, Greywater can be considered as a golden opportunity that can make a notable impact on the economy, water natural security and the environment; however, important treatment measures should be taken to verify its quality for the different reuse applications.

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