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Research Article

INVESTIGATION OF RETROFITTING OF WATER VAPOR CHIMNEYS OF ONE OF THE OIL COMPLEXES

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ABSTRACT

Earthquake always is considered as one of the most terrible disasters and till now it caused so much losses life. So we must secure the buildings and structures as much as possible. Between these, life lines, especially petroleum industry and the related structures to this industry has especial place and needs that such structures be identified and in case of emergency reconstruction or retrofitting be performed. Here we want to study and investigate the steel boiler chimney of water steam unit in one of the Iran refineries which has more than 40 years history by using Abaqus software. In this way the weak points of the chimney will be talked and if need to its reformation according to related regulations, the reformation plan will be suggested and investigated.

INTRODUCTION

Non-building structures, such as tanks, chimneys, stores, cooling towers, telecommunication towers and … are considered as useful structures and because of this most of the valid earthquake regulations of the world, in a separate chapter they pay to concepts, equations, and the details related to these structures (A. T. Council *et al*. 1991, Mualchin and Krinitzsky 2003, Titaya 2016).

Tall chimneys behavior in direction of perpendicular to the windhas different mechanisms which in different times and conditions each causes Excitation factor of the chimney while interference of these mechanisms is another problem (Livaoglu 2014). Importance and complexity of some powerhouse structures, also the nature of some entered powers to these structures, make dynamic analysis of such structures when designing inevitable. So a suitable dynamic behavior must be selected that can consider real behavior of these structures and this selection needs to exact knowledge of these structures (Al-Kayiem *et al*. 2014, Górski 2015). In this study the investigation of seismic and dynamic features of an industrial chimney will be presented numerically. Frequencies, mode shapes and the structure behavior under seismic loading are the features of this study. The chimney design is done for dead loads (including the loads from parts and additional parts weight and the weight of ashes and the materials that after a while stick to chimney body), wind load, earthquake load, the loads from pressure difference in and out of two doors, thermal loads, ice load and the loads of traffic and snow (van Koten 1984, Arunachalam and Lakshmanan 2015, Solomin 2016).

The spectrum of standard design are presented spectrum in valid regulations like standard 2800, UBC regulation… that their scaling coefficients are determined based on earthquake danger analysis specific structure or by help of earthquake danger zoning maps. According to this, structures calculation is performed in each main length separately and without considering other directions. There is no need to simultaneous consideration of earthquake powers in two directions (Bachman and Bonneville 2000).

Ivora *et al* in their research paid to an analysis of a brick chimney which was built in 1940 and now is in cultural heritage list. This is in August city in Spain and was not used for industrial utilization. This structure is exposed to ever winds from beach and is in 12 Km far from beach and there is no barrier between beach and this structure. Because of ever effect of such winds and chimney geometry features and lack of proper maintenance, there are linear cracks and creep in used materials in the chimney. Then after exact checking of the structure condition and its building technique and also the cracks on it they paid to numerical analysis affected by weight and wind. Then they studied its dynamic behavior, including usage of response spectrum and periodical record history of earthquake to estimate structure resistance. Finally, they succeeded to present exact analysis of structure behavior under mentioned loadings to facilitate the way for real examines in

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the future and also effective retrofitting techniques such as using poli composite fibers. Importance and complexity of some powerhouse structures, also the nature of some entered powers to these structures, make dynamic analysis of such structures when designing inevitable. So a suitable dynamic behavior must be selected that can consider real behavior of these structures and this selection needs to exact knowledge of these structures. In this study the investigation of seismic and dynamic features of an industrial chimney will be presented numerically. Frequencies, mode shapes and the structure behavior under seismic loading are the features of this study (Ivorra *et al*. 2014).

MATERIALS AND METHODS

The material of studied chimney is SA-283 GRADE D which its features are in Table1.

Table 1 the features of utilized steel in chimney

Material		$\boldsymbol{\nu}$	$\boldsymbol{E}$ (	$\boldsymbol{F_y}$	$\boldsymbol{F}$	$\boldsymbol{F_t}$(	$\boldsymbol{F_a}$(
SA-283 GRADE D	7850	0.31	1.97e5	227.3	413.4	413.4	117.8

It must be mentioned that in this table, the elasticity modulus of body sheet is obtained according to 90° out of the chimney. You can see the photos of these chimneys in Figure 1.

Figure 1 the photos related to studied chimneys

From the foundation to the height of 18.2 M of the chimney is in the shape of cone frustum. Bottom diameter of cone frustum is 5.53 M and top of it (in height 18.2 M) has inner diameter of 3.048 M. from height 18.2 M to 76.2 the chimney continues like roller and its inner diameter is fixed (3.048). The thickness of chimney metal body is variable, this thickness from foundation is till height 18.2 M (cone shape part) 2.22 Cm and other parts as below:

From height 18.2 M till 30.4 M from foundation 1.91 cm.
From height 30.4 M till 39.55 M from foundation 1.58 cm.
From height 39.55 M till 48.70 M from foundation 1.27 cm.
From height 48.70 M till 76.20 M from foundation 0.95 cm.

Chimney foundation is composed from two parts of main foundation with diameter D=7316 mm and height t=635 mm, and another part which is octahedral with diameter d=5943 mm and height h=919 mm. Chimney body is put on a ring sheet with dimension PL 203*38 mm and diameter B.C.=5664 mm and is joined to the foundation by 24 screw$2\frac{1}{2}$. In figure 2 you can see the map the details of the foundation.

Modal and Seismic analysis

Modal analysis in fact is a kind of primary analysis which is useful to get structure dynamic behavior and its vibration behavior prediction and is not considered a complete analysis lonely. But according to the importance of this analysis in calculation of lateral loads it is used widely. In this analysis, the goal is identifying structure dynamic features. These dynamic features include natural frequencies, modes shapes and attenuation of each mode. In vibrations of each system there is a linear combination of its modes shape that after combination of these modes by using different concepts related to February series we can get real shape change of the structure.

Seismic analysis using time history

Time history analysis is applicable in both the structures with linear behavior and non-linear behavior, and its all results are acceptable if all effecting conditions are considered correctly and must be considered in second design of structure. As it was mentioned this kind of analysis is only for extra control after structure design and its goal is to identify weak points of structure design and removing them and this method isn't used in initial design.

In this research three earthquakes were selected to apply to structure as below.

1. Bam earthquake in 2003 in Kerman.
2. Elsentro earthquake in 1940 in California.
3. Tabas earthquake in 1978 in Khorasan.

These seismic records were selected from PEER website as earthquake acceleration record and were processed by Seismo Signal software to get speed and mobility components in a table based on time. Then these tables were given to Abaqus software as entry and finally earthquake is applied to structure in Y line and the results were compared.

Initial design

First step in simulation and numerical analysis in Abaqus software is geometric design of used parts in total process of simulation. As it was mentioned in last section, the chimney which was chose for this research is a steel chimney that all its dimensions and connections were describes in last section. Final height of this chimney is 76.2 from foundation which is built in Abaqus software as Solid 3D model of Revolution kind. In this modeling method, the part that must be rotated was designed and then is rotated around considered axis to the extent that is necessary (here 360degree) till finally all considered 3D is obtained. In Figure 2, two-dimensional part is shown according to chimney map and final 3D model.

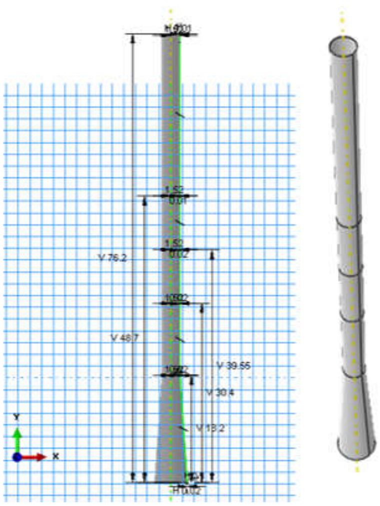

Figure 2 the modeled chimney in software.

Boundary conditions and analysis steps

There are different steps to solve a physical process that are selected according to physical features.

In this research we can refer to below steps. It is necessary to explain that these steps are not used simultaneously and each of them (or a combination of them) according to considered analysis type (static, spectrum, time history) is used.

1. Static step (implied): in which static powers of weight or wind and the tensions of it are analyzed.
2. Modal analysis step: in which structure modes are extracted.
3. Response spectrum step: in which according to design spectrum which was extracted by structure features and chimney placing part from regulations, structure response spectrum along with created tensions in structure and their corresponding strains will be obtained. It is clear that this response is denied by assumption of obtained materials of linear behavior and the behavior of material being non-linear, but structure dynamic behavior is considered according to extracted modes.
4. Dynamic step (implied): in which a time history analysis is performed completely by considering non-linear behavior of structure and is the most complete analysis that we can perform on it but there is same need to time and cost to do analysis.

Response spectrum step always is after modal analysis. In analysis of structure response spectrum, according to the spectrum of defined plan in regulation for considered place and according to structures features, structure response to this spectrum for each mode (which was extracted in last step) is extracted and by static methods are super positioned. In this research Square Root of the Sum of Squares [SRSS] is used for superposition.

In seismic analysis real records of earthquake are used which directly and like time history are applied to chimney base as displacement on time. It is necessary to say that chimney base is considered perfectly bound.

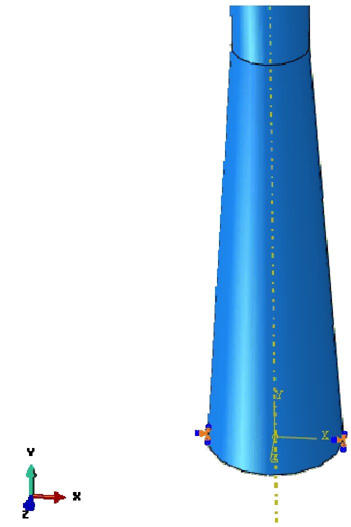

Figure 3 the connection of chimney base is considered completely bound.

In fact, the assumption of this record was that the design of chimney connections to foundation is completely flawless and each buckling, being non-linear or rupture only occur in chimney body and so only the response of chimney body to entered loads were analyzed and its connection to foundation was considered flawless. It is clear that when earthquake occurring the displacements of shaking are applied to this support. You can see the figure of this support in Figure 3.

Applied powers and meshing

Also the element type which was selected to analyze is kind of standard 3D element, which in first time was decreased by integral method (brick, reduced integration, hourglass control-C3D8R8-node linear), which is suitable for dynamic 3D analyses with minor plastic deformation (which is predicted to occur in this research) (Figure 4).

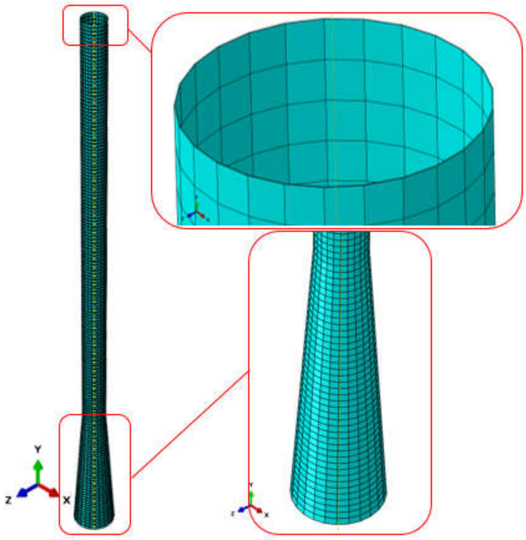

Figure 4 Performed meshing on body of steel chimney

Wind load

In this research to static analysis of wind load from UBC97 (SECTION 1620) for top of chimney is calculated based on PSF. According to increasing of wind pressure in higher elevations of chimney than its cone part which is in eq. 1, it can be that by good approximation and to facilitate, the received pressure be applied on side level of chimney uniformly.

$$P = C_e \quad C_q \quad q_s \quad I_w = 2.165 \quad 0.8 \quad 12.6 \quad 1.15 = 25.097 \text{ psf} = 1202 \text{ Pa} \qquad \text{(eq. 1)}$$

As you see Fon-Mises tensions in pressure dimension was more than tensional(Figure 5) but its measure doesn't go more than 40 Pascal that shows the structure tolerates well in front of wind load and significant distance from submission tension (which its measure in 90° is 227 Pascal).

RESULTS AND DISCUSSION

Non-linear static method (Pushover)

In this method, similar to static method it is supposed that seismic loading is applied to structure equivalent with equivalent static loading by this difference that to consider non-linear behavior of structure instead of we first enter final power and then check the occurred displacement in structure (power control method), we first enter power and them step by step observe structure displacement till it goes to non-linear phase and finally be destroyed completely (displacement control method).

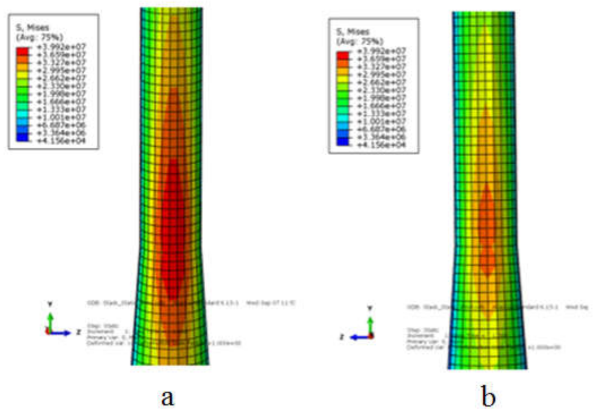

Figure 5 Fon-Mises tensions in structure, a) tension dimension b) pressure dimension.

In order to obtain target displacement in structure we can use the relationships in FEMA-356 regulation (Eq. 2).

The method to find target displacement

$$\delta_T = C_0 C_1 C_2 C_3 C_4 \frac{T_e^2}{4\pi^2} g = 1.5 * 1 * 1 * 1 * 0.63 * \frac{1.32^2}{4\pi^2} * 9.81 = 0.4095\,(m) \cong 41(cm) \quad \text{(eq.2)}$$

As it was told, the effect of higher modes of structure behavior is so important and must be considered in loading pattern which is applied on structure and using triangle loading pattern or first mode lonely cannot answerable to this structure analysis because in this structure higher modes has significant effect on structure seismic behavior.

So the number of modes which are going to be used in analysis becomes 8 modes (means modes 1, 3, 8, 15, 19, 29, 40 and 50) which are shown in Figure 6.

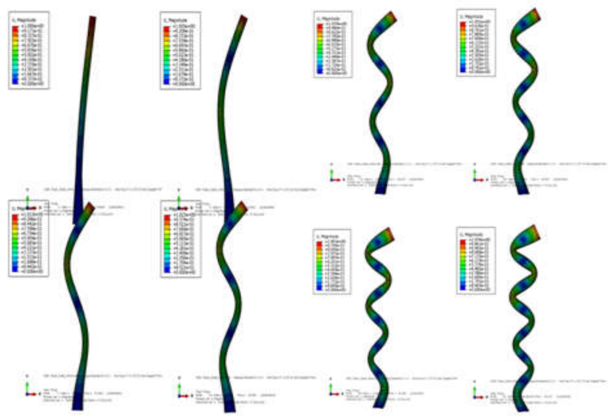

Figure 6 selected modes for non-linear static analysis.

The calculated modes have orthogonality properties to each other that each mode will not effected by other modes. We must pay attention that a natural mode is structure or model's properties. If the structure isn't bound completely, means boundary conditions aren't sufficient, the mode will have rigid appearance and in this condition the natural frequency of system will be zero. According to this, by superposition of top modes and using SRSS method we can obtain lateral load applying pattern. This pattern is shown in Figure 7.

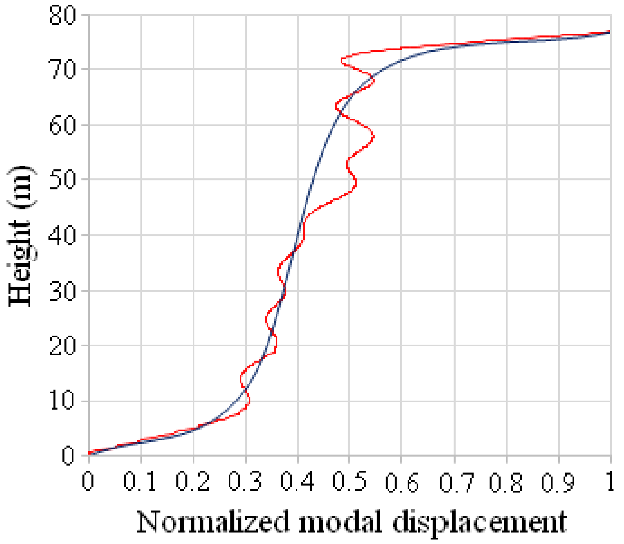

Figure 7 applied lateral load pattern to structure by non-linear static method (Pushover).

Displacement curve is shown in top of chimney based on cutting power in chimney base (Figure8) and shows that the structure till measures 2 m displacement on top of it has linear behavior (Figure9) and after that will enter to non-linear level and figures comparison show that the tensions will not go more than 280 mega Pascal.

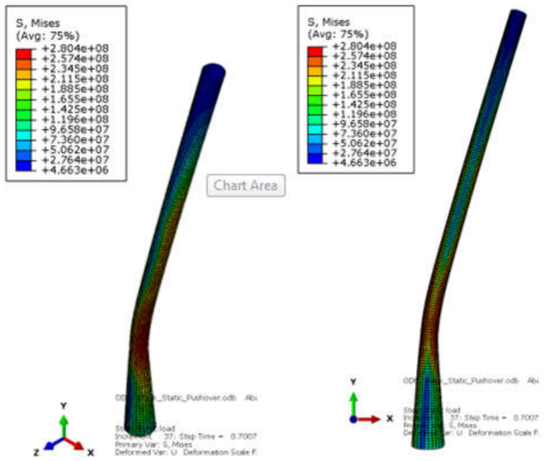

Figure 8 Created tensions in chimney structure after Pushover analysis.

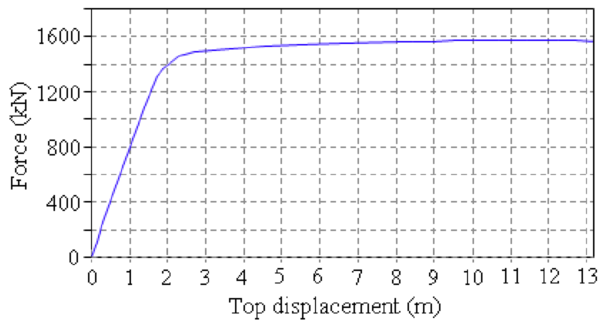

Figure 9 power curve (base cutting) – displacement (top of the structure).

Time history analysis

Abaqus software gets earthquake acceleration as entry to determine earthquake and by receive the features of acceleration recorder, after analyzation, will calculate structure climax displacement in different times and draw different answer curves including displacement, speed and acceleration.

Bam, Elsentro and Tabas earthquake

The entry which was gave to the software as variable induction with time, the acceleration of Bam, Elsentro and Tabas earthquake was in two directions of X and Z which was applied to the base directly and the analysis results are shown in Figures 10 to 12.

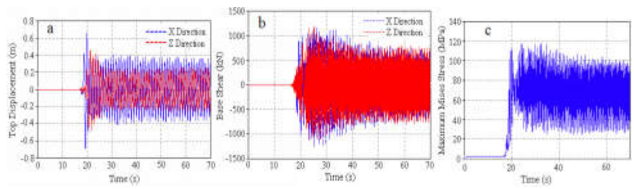

Figure 10 a) Displacement curvein top of structure b) Base cutting curve c)Fon-Mises stress curve,per time in two directions X and Z for Bam city.

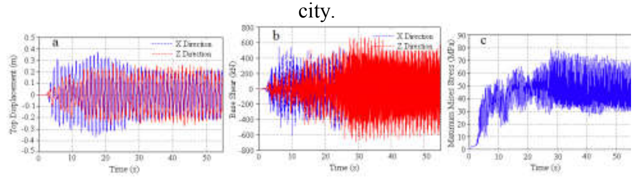

Figure 11 a) Displacement curvein top of structure b) Base cutting curve c)Fon-Misesstress curve,per time in two directions X and Z for Elsentrocity.

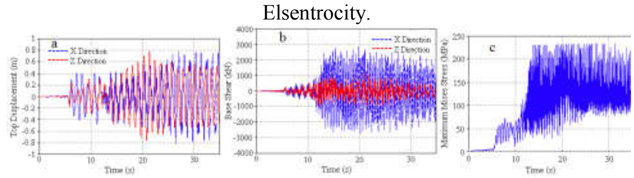

Figure 12 a) Displacement curvein top of structure b) Base cutting curve c)Fon-Mises stress curve, per time in two directions X and Z for Tabascity.

As you see, from available records the most critical situation obtained for Tabas earthquake. According to related curves, the maximum displacement for this earthquake was more than 77 MM and the maximum stress more than 234, so the structure was responder to our need and there is no need to resistant structure.

CONCLUSION

In this study a research was performed on dynamic behavior of a chimney as a tall and thick structure. By using numerical analysis and using Abaqus software two non-linear analysis, means Non-linear static analysis (Pushover) and non-linear dynamic analysis (time history analysis) were performed on the structure. In this section the results of numerical analyses were presented.

1. The performed analysis was dynamic type because the effects of applied powers (that mostly the applied power was from structure weight) are important during the time.
2. In top analysis it is better that standard analysis method (implied) be used because shaking time is long using

clear method isn't good and may cause that the analysis being longer.

3. Structure power in a separate step and statically is applied on structure. The reason of this is that this power has static nature and is applied during the time and because of this in order to avoid from unwanted dynamic effects to structure we apply it statically.
4. In first step, the power slowly from zero goes to final measure in step end. So there wasn't extra dynamic energy in structure and will have most similarity to real behavior in beginning of earthquake.
5. According to participation coefficient of effective modes in seismic behavior it was observed that because of high height of structure and also its thickness many modes were contributed in its dynamic behavior and in pattern of applying static equivalent load, by non-linear static analysis method (Pushover) to structure one of the accepted methods be used to combine modes effects. In this thesis SRSS method is used for this which is from acceptable methods in FEMA-440 instruction. As it was observed, the obtained pattern of this method is pattern shaped like Open-S and after its connection to structure it was observed that the most vulnerable part of chimney body is where cone part of it change to roll.
6. After applying timehistory records to structure it was observed that the structure resisted very well and the occurred stresses and deformations will remain acceptable.

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