SEISMIC ANALYSIS AND DESIGN OF INDUSTRIAL CHIMNEYS BY USING STAAD PRO

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ABSTRACT
Our project describes a simplified method that allow obtaining the fundamental period of vibration, lateral displacement, shear force and bending moment through a set of equations, obtaining for all cases studied an error below 10%.The results obtained in this study were applied to a total of 9 real chimneys (4 of steel and 5 of reinforced concrete) built in Chile, with the objective of calibrating founded expressions. During the stage of the analysis, it was verified that the criterion of consistent masses provide better results than the criterion of lumped masses, and as a very important conclusion a discrete analysis of the model in twenty segments of the beam is satisfactory. The most representative variables that define the model with which it is possible to carry out a parametric analysis of the chimney. As important parameters we could refer to: slenderness ratio H/D_{inf}, radius ratio R_{sup}/R_{inf}, thickness ratio E_{sup}/E_{inf} and thickness diameter ratio D_{inf}/E_{inf}. Later, by varying each one of the chosen parameters several analyses of representative chimneys of this great family, could be carried out. As seismic loads, the spectrums of accelerations recommended by the code of seismic design for structures and industrial installations in Chile, have been considered. Modal responses were combined using the combination rule CQC.In all the cases studied in this investigation, the influence of the P effect, the soil structure interaction, and the influence on responses that provoke the inclusion of lining, have been disregarded.

KEYWORDS: Seismic Analysis, Design Industrial Chimneys, Staad Pro

1. INTRODUCTION
During the past few years industrial chimneys have undergone considerable developments, not only in their structural conception, modelling and method of analysis, but also in the materials employed and the methods of construction. In this sense the outstanding increase in height should be highlighted as a consequence of a better control of environment pollution in populated areas. With the increment in height the seismic action and wind have become important for working out actuating stresses on this particular type of continuous structures, making it necessary, for this reason, to study the vibratory nature by carrying out a dynamic analysis.

If a modelled chimney is analysed as in a projected beam embedded at the la base and free at its upper end, considering the behaviour of the lineal elastic material, capable of deforming only by the effects of flexion and shear, and that it also has geometric properties (area, inertia, etc.) which vary with height, differential equations will be obtained of the movement that apply both to free and forced vibrations that cannot be resolved exactly. Only for certain laws of geometrical properties of variation, it is possible to express the solution of the differential equation of the movement based upon known functions, as it has been extensively demonstrated in literature on the subject. [Carrióny Dünner, 1999].

The mathematical type of difficulties that the current study presents has made it necessary to simplify the problem, by discretization the continuous structure for its solution, but not worrying to verify the merit of the assumptions involved in the results

2. ABOUT CHIMNEYS
Chimneys are used to vent the products of combustion produced by heating appliances. Chimneys are used for most fuel types (wood, oil, natural & propane gas, and coal). They are not used, for example, on electric appliances.

2.1 CHIMNEY SAFETY CERTIFICATIONS
Factory-built chimneys are required, by code, to be Listed (safety certified) in accordance with a safety certification standard.

2.2 FOR RESIDENTIAL CONSTRUCTION
In the USA – the national standard for factory-built chimneys is ANSI/UL103 – "The Standard for Factory-Built Chimneys, Residential Type and Building Heating Appliance". This standard qualifies the chimney system for use with appliances burning liquid, gas and solid fuels with flue gas temperatures at 1000O F maximum, continuously and with non-positive internal pressure.
In Canada – there are two national standards for factory-built chimneys. ULC-S629 is the standard for 650O C factory-built chimneys and applicable to chimneys intended for use with gas, liquid and solid fuels, with maximum 650O C flue gases continuously and non-positive internal pressure. ULC-S604 is the standard for factory-built chimneys limited to use with gas or oil fired appliances. Certain wood burning fireplaces are Listed for use with certain ULC-S604 Listed chimneys.

2.3 TYPES OF CHIMNEY

The Types of Chimney described are Factory-Built Metal Chimneys and Masonry Chimneys. General anatomy of chimney shown in Figure.1.

2.3.1 Factory-Built

Most Factory-Built Chimneys are similar in that they are constructed of at least two round metal tubes with insulation in between (whether the insulation is simply air, or one of several different 'fibre' types). The major types discussed here are: Solid Pack, Blanket, Triple-Wall and Air-Cooled.

Solid Pack

Solid Pack Chimneys are characterized by a packed-in-place insulation placed between two walls and are known for their high insulating value. Due to the fact that Solid Pack Chimney actually contains more insulating material than other types, they perform better by maintaining higher flue gas temperatures and lower temperatures on the outer casing. These chimneys also feature a slim-line design that allows easier installation. Manufacturers carefully protect the ingredients of their proprietary insulation mix, which may allow some Brands to outperform others. Common Brand Names are: Selkirk Metalbestos, SuperVent, SuperPro, Security Chimney, Hart & Cooley and Energy Vent.

Blanket

Blanket Insulated Chimneys are similar to Solid Pack designs, except they use Insulation Blankets that are cut to size and applied inside the Chimney's walls. Blanket Insulated Chimneys typically contain less insulating material than Solid Pack designs, yielding a lighter weight product. Common Brand Names are: ICC/Excel, Dura-Vent (Dura-Tech), Metal Fab.

Double-Wall, insulated Class-A Chimney (both Solid pack and Blanket types) keep your house protected by insulating - keeping your flue gasses hot. This method of chimney design does not hamper a strong draft the way Triple-Wall system does.

Triple-Wall (Combo & Air-Cooled)

There are two types of triple wall chimney designs – Combination (blanket & air) and Air (only)-cooled. The combination blanket / air cooled Triple-Wall Chimney design typically combines some fibre blanket insulating material with an air-insulated section. The air-cooled triple wall system (also know as a thermal syphon system) relies strictly upon movement of air between walls to keep the system cool. The outside diameter of Triple-Wall Chimneys are typically larger than Solid Pack or Blanket Insulated designs. Common Brand Names for combination air / fiber insulated triple wall chimneys are: Dura-Vent (Dura-Plus) and Ameritec Air Jet is the most common Brand name for the air-cooled triple wall designed. Triple-Wall Class-A chimney keeps your house protected by cooling vent gasses. Cold air is drawn in to the venting between the outer and second pipe and cools the inner liner where flue gasses are passing through. Cooling down hot flue gasses will decrease drafting (chimney effect), increase moisture (where hot meets cold) and promote creosote formation, which potentially lead to Chimney fires.

Double Wall Air-Cooled – (Limited Use)

Certain factory-built fireplaces are offered with a Double Wall, Air-Cooled chimney system. This is NOT A GENERAL USE CHIMNEY and is limited to use with only the specific fireplace(s) with which it is Listed (safety certified). As the name implies, Double Wall Air-Cooled Chimney relies on air to provide insulation between the inner and outer pipes. Double wall Air-Cooled fire place chimney designs typically rely upon air taken from within the structure to assist in cooling and are characterized by large outside diameters. In cold climate areas, these systems are often criticized as being sources of cold air infiltration when the system is not in use. As such, they tend be be more popular and perform better in areas with warm climates and at low altitude. This type of Chimney is commonly found on built-in, factory-built wood burning fireplaces. As indicated above, they are NOT designed, certified or intended as any type of a general use chimney system and should NEVER BE USED WITH ANY APPLIANCE EXCEPT THAT FOR WHICH IT IS LISTED. Few, if any wood stoves are ever approved for use with this type of chimney. Common Brand Names are: Heatilator, Majestic, Temco.

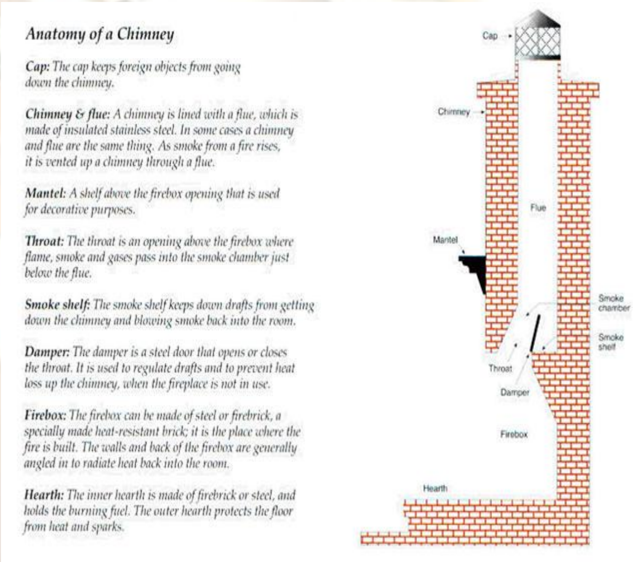


FIGURE.1.GENERAL ANATOMY OF CHIMNEY

2.3.2 Masonry

- Large internal/external dimensions
- Square / rectangular
- May have a clay-tile or metallic liner

A conventional masonry chimney, made of brick, block or stone could be a suitable option, depending on the appliance you choose. There are several types and brands of liners that can be installed in masonry chimneys to improve their performance. If yours is a high performance appliance, you should consider an upgraded liner. Note that full stainless steel liners for fireplace insert installations are mandatory in Canada, and strongly recommended everywhere

3.ABOUT SEISMIC LOADS

Earthquake engineering is the scientific field concerned with protecting society, the natural and the man-made environment from earthquakes by limiting the seismic

risk to socio-economically acceptable levels.[1]
Traditionally, it has been narrowly defined as the study of the behavior of structures and geo-structures subject to seismic loading, thus considered as a subset of both structural and geotechnical engineering. However, the tremendous costs experienced in recent earthquakes have led to an expansion of its scope to encompass disciplines from the wider field of civil engineering and from the social sciences, especially sociology, political sciences, economics and finance.

3.1 SEISMIC LOADING

Seismic loading means application of an earthquake-generated excitation on a structure (or geo-structure). It happens at contact surfaces of a structure either with the ground [1], or with adjacent structures, or with gravity waves from tsunami.

3.2 SEISMIC PERFORMANCE

Earthquake or seismic performance defines a structure's ability to sustain its main functions, such as its safety and serviceability, *at* and *after* a particular earthquake exposure. A structure is, normally, considered *safe* if it does not endanger the lives and well-being of those in or around it by partially or completely collapsing. A structure may be considered *serviceable* if it is able to fulfill its operational functions for which it was designed.

Basic concepts of the earthquake engineering, implemented in the major building codes, assume that a building should survive a rare, very severe earthquake by sustaining significant damage but without globally collapsing .[5] On the other hand, it should remain operational for more frequent, but less severe seismic events.

3.2.1 Seismic performance assessment

Engineers need to know the quantified level of the actual or anticipated seismic performance associated with the direct damage to an individual building subject to a specified ground shaking. Such an assessment may be performed either experimentally or analytically.

3.2.2 Experimental assessment

Experimental evaluations are expensive tests that are typically done by placing a (scaled) model of the structure on a shake-table that simulates the earth shaking and observing its behavior.[6] Such kinds of experiments were first performed more than a century ago.[7] Still only recently has it become possible to perform 1:1 scale testing on full structures. Snapshot from shake-table video of a 6-story non-ductile concrete building (Figure.2.) destructive testing. Due to the costly nature of such tests, they tend to be used mainly for understanding the seismic behavior of structures, validating models and verifying analysis methods. Thus, once properly validated, computational models and numerical procedures tend to carry the major burden for the seismic performance assessment of structures.

FIGURE.2. SNAPSHOT FROM SHAKE-TABLE VIDEO OF A 6-STORY NON-DUCTILE CONCRETE BUILDING DESTRUCTIVE TESTING

4. ANALYTICAL/NUMERICAL ASSESSMENT

Seismic performance assessment or, simply, seismic structural analysis is a powerful tool of earthquake engineering which utilizes detailed modelling of the structure together with methods of structural analysis to gain a better understanding of seismic performance of building and non-building structures. The technique as a formal concept is a relatively recent development. In general, seismic structural analysis is based on the methods of structural dynamics.[8] For decades, the most prominent instrument of seismic analysis has been the earthquake response spectrum method which, also, contributed to the proposed building code's concept of today.[9]

However, such methods are good only for linear elastic systems, being largely unable to model the structural behavior when damage (i.e., non-linearity) appears. Numerical step-by-step integration proved to be a more effective method of analysis for multi-degree-of-freedom structural systems with significant non-linearity under a transient process of ground motion excitation.[10] Basically, numerical analysis is conducted in order to evaluate the seismic performance of buildings. Performance evaluations are generally carried out by using nonlinear static pushover analysis or nonlinear time-history analysis. In such analyses, it is essential to achieve accurate nonlinear modeling of structural components such as beams, columns, beam-column joints, shear walls etc. Thus, experimental results play an important role in determining the modeling parameters of individual components, especially those that are subject to significant nonlinear deformations. The individual components are then assembled to create a full nonlinear model of the structure. Thus created models are analyzed to evaluate the performance of buildings. The capabilities of the structural analysis software are a major consideration in the above process as they restrict the possible component models, the analysis methods available and, most importantly, the numerical robustness. The latter becomes a major consideration for structures that venture into the nonlinear range and approach global or local collapse as the numerical solution becomes increasingly unstable and thus difficult to reach. There are several commercially available Finite Element Analysis software's such as CSI-SAP2000 and CSI-PERFORM-3D which can be used for the seismic performance evaluation of buildings. Moreover, there is research-based finite element analysis platforms such as Open Sees, RUAUMOKO and the older DRAIN-2D/3D, several of which are now open source.

5. ABOUT THE SOFTWARE

STAAD or (**STAAD.Pro**) is a structural analysis and design computer program originally developed by Research Engineers International in Yorba Linda, CA. In late 2005, Research Engineer International was bought by Bentley Systems. An older version called Staad-III for windows is used by Iowa State University for educational purposes for civil and structural engineers. The commercial version STAAD.Pro is one of the most widely used structural analysis and design software. It supports several steel, concrete and timber design codes.It can make use of various forms of analysis from the traditional 1st order static analysis, 2nd order p-delta analysis, geometric non linear analysis or a buckling analysis. It can also make use of various forms of dynamic analysis from modal extraction to time history and response spectrum analysis. In recent years it has become part of integrated structural analysis and design solutions mainly using an exposed API called Open STAAD to access and drive the program using an VB macro system included in the application or other by including OpenSTAAD functionality in applications that themselves include suitable programmable macro systems. Additionally STAAD.Pro has added direct links to applications such as RAM Connection and STAAD.Foundation to provide engineers working with those applications which handle design post processing not handled by STAAD.Pro itself. Another form of integration supported by STAAD.Pro is the analysis schema of the CIMsteel Integration Standard, version 2 commonly known as CIS/2 and used by a number modelling and analysis applications.

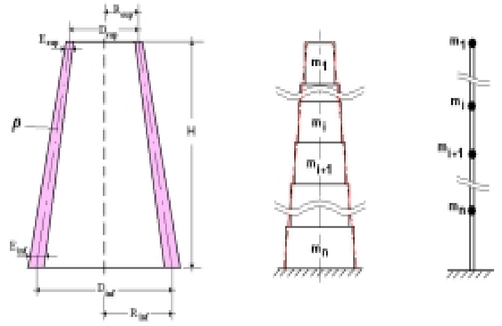
6. DISCRETING THE STRUCTURE

Due to the complexity that means trying out one of the four particular solutions that the differential equation presents governing the movement of a continuous element like a chimney type, (see Figure.3), it was decided to solve the problem by discretization the structure.

For this purpose, two discretion criteria were used lumped masses criterion and consistent masses criterion. The most simple method to consider the properties of a dynamic system is to concentrate the mass of the structure on the nodes that define transfer displacements, that is why it is called lumped masses criterion. On the other hand, the consistent masses criterion (Mc), unlike the lumped masses criterion which depends upon the rigidity to bend, cross section of element, form factor, shear module; also, unlike the lumped masses criterion, it considers coupling between rotational and translation degrees of freedom. Therefore, the matrix of consistent masses corresponds to a full matrix that includes the effects of flexion, shear and rotational inertia.

Sensitivity Analysis

An analysis was performed for the purpose of responding to the following queries: In how many elements is it necessary to discrete a chimney? What discreting criterion is the most adequate: lumped masses or consistent masses? What effects must be considered in the representative model of a chimney type continuous element? In this manner by means of this study on particular chimneys it is possible to estimate the results of any structure of this type.



a) Geometry of a variable section
b) Model of a chimney according
c) Model of a chimney according

FIGURE 3. GEOMETRY OF A CHIMNEY, ACCORDING TO THE CONSISTENT MASSES AND LUMPED MASSES CRITERIA

TABLE.1. GEOMETRIC CHARACTERISTICS AND SEISMIC DATA OF SOME REAL CHIMNEYS BUILT IN CHILE (CANADA,1984)

N°	LOCATION	USE	MATERIAL	HEIGHT (m)	DIAMETER (m)		THICKNESS (mm)		Seismic Data		
					Top	Bottom	Top	Bottom	Zone	Soil	[illegible]
Ch-1	Paipote Chile	Cu Foundry	Steel	27	1.35	1.35	8	8	3	II	2
Ch-2	Huachipato Chile	Siderurgical Plant	Steel	53	3.50	5.50	8	10	3	II	2
Ch-3	Huachipato Chile	Siderurgical Plant	Steel	47	2.90	5.00	8	10	3	II	2
Ch-4	Con Con Chile	Cu Refinery	Steel	130	4.50	12.00	8	15	3	III	2
Ch-5	Con Con Chile	Chilectra	Reinforced concrete	61	4.60	7.60	152	279	3	II	5
Ch-6	Renca Chile	Chilectra	Reinforced concrete	53	3.40	6.10	152	254	2	II	5
Ch-7	La Calera Chile	Cement Industry	Reinforced concrete	60	2.90	5.40	152	330	3	II	5
Ch-8	Tocopilla Chile	Thermal Plant	Reinforced concrete	75	4.60	7.30	180	450	3	II	5
Ch-9	Con Con Chile	Cu Refinery	Reinforced concrete	155	9.60	17.40	230	420	3	III	5

The information on Table 1, shows the most important dimensions and pertinent data that will be useful for the subsequent seismic analysis of some industrial chimneys.

Each one was analysed under the following considerations:

- Employing lumped masses and consistent masses criteria.
- Varying the number of discreted elements (NE) in 10, 15, 20 and 25 elements.
- Considering the following effects
  Flexion (lumped masses criterion)
  - Flexion, shear and rotational Inertia (consistent masses criterion)

With these considerations the fundamental periods of vibration were considered employing the computation program CALUC [Vásquez, 1977] and comparing their responses with those obtained through: analytical solution (solution to the differential equation considering a chimney of constant section and flexion effect) and Method of Finite Elements (MEF).

TABLE.2. COMPARISON OF VIBRATION PERIODS EMPLOYING THE DIFFERENT CRITERIA. FOR CHIMNEY 9

Criteria	MC		Mc								MEF
Effects	Flexion		Flexion		Flexion + Shear		Flexion + I Rot		Flexion + Shear + I Rot		Flexion + Shear + I Rot
NE	T*	Error	T*	Error	T*	Error	T*	Error	T*	Error	T*
10	2.061	(8.59 %)	1.842	(2.50 %)	1.852	(1.94 %)	1.848	(2.16 %)	1.868	(1.07 %)	1.888
15	1.981	(4.69 %)	1.829	(3.23 %)	1.843	(2.44 %)	1.833	(3.00 %)	1.864	(1.29 %)	1.888
20	1.939	(2.63 %)	1.901	(0.68 %)	1.827	(3.34 %)	1.837	(2.78 %)	1.863	(1.34 %)	1.888
25	1.916	(1.46 %)	1.791	(5.42 %)	1.767	(6.85 %)	1.774	(6.43 %)	1.856	(1.72 %)	1.888

From the analysis carried out, it may be assured that the criterion of consistent masses estimates the fundamental period of vibration, considering the effect of flexion is more accurate than that obtained employing the lumped masses criterion.

When the chimney is analysed considering simultaneously the three effects of flexion, shear and rotational inertia, the number of elements to be discreted is no longer important. This is because the height of the element discreted is controlled by the shear effect h/D < 2, and by the effect of flexion if h/D □ 2, in that h is the height of such element. This allows concluding that the analysis if industrial chimneys is controlled by the effect of flexion since according to Table 1, most of these structures possess H/D > 8 slenderness, therefore, the shear effect in the analysis may be ignored.

Analysing chimneys with 20 discrete elements is recommended, employing the consistent masses criterion and the effect of flexion since the error committed when evaluating the fundamental period of vibration does not exceed 1.13%.

From Table.2, it may be concluded that the effect of rotational inertia does not influence determining the fundamental period and by not considering it errors not exceeding 3% will be obtained for all cases.

7. CHARACTERISTICS PARAMETERS

Geometric Parameters

The purpose of establishing parameters is to identify the most important characteristics which define chimneys in order to allow representing a vast universe of such structures. The geometric parameters (see Figure 1) used in this study were as follows:

HD = H / D_{inf} = Ratio of slenderness

R_{inf} : Radius of section at the base of chimney

R_{sup} : Radius on top section of chimney

RE = E_{sup} / E_{inf} = Ratio of thickness

E_{sup}: Thickness of mantle at the top section of chimney

DE = D_{inf} / E_{inf} = Ratio of diameter thickness

E_{inf} : Thickness of mantle at the base of chimney

Seismic Parameters

In order to carry out a spectral modal analysis of adimensional form, the spectrum was set in parameters according to Chilean standard NCh 2369.c97 [INN, 1997]. Since the design spectrum is applied to real structures and not to adimensional structures, a parameter called seismic parameter will be introduced:

TT* = *T** / *T' = Ratio of Periods

T* : Fundamental period of structure, expressed in seconds.

T' : Parameter depending on the type of soil, expressed in seconds, per Table 6 [INN, 1996].

Parameter *TT* or Ratio of Periods, is reflected in the seismic coefficient of the design spectrum per Chilean Standard NCh 2369.c97 [INN, 1997] as follows

$$C = \frac{2.75 A_0}{gR}\left(\frac{T'}{T^*}\right)^n \left(\frac{5}{\xi}\right)^{0.4} \quad \Rightarrow \quad C = \frac{2.75 A_0}{gR}(TT)^{-n}\left(\frac{5}{\xi}\right)^{0.4} \qquad (1)$$

Since it is rather laborious finding a factor to transform responses of a dimensional chimneys to real response values of the structure considering all effects (flexion, shear and rotational inertia), the chimneys were modelled employing the following considerations:

- Criterion of consistent masses.
- Deformation by flexion effect.
- Discreting with 20 elements.

Errors obtained due to such considerations do not exceed 2%.

As a consequence of the parametric analysis carried out, it should be mentioned that responses obtained through such methodology have no physical interpretation. However, it is possible to establish parameters for this type of structures, obtaining a low percentage of errors between estimated values of the real response and the adimensional response amplified by the factors of response modification. On Table.3 geometric and seismic parameters have been considered in the present study, represented in 4 terms each.

TABLE 3: SUMMARY CHART OF GEOMETRIC AND SEISMIC PARAMETERS

Material	Geometric parameters				Seismic Parameter			Models
	RR	*RE*	*HD*	*DE*	*TT*	Zone		
Steel	0.25	0.25	8	170	0.10			
	0.50	0.50	12	380	0.77	1		
	0.75	0.75	16	590	1.44	2	2	3,072
	1.00	1.00	20	800	2.11	3		
Reinforced concrete	0.25	0.25	8	16	0.10			
	0.50	0.50	12	24	0.77	1		
	0.75	0.75	16	32	1.44	2	5	3,072
	1.00	1.00	20	40	2.11	3		
							Number of Models	6,144

Where Zone and □ are parameters which depend on the seismic zone and material of chimney that have been tabulated in Chilean seismic code NCh 2369.c97 [INN, 1997].

Transformation Factors

The necessity arising to find factors that may transform dimensional responses of chimneys with established parameters to real responses of the structure including their geometric properties, four factors were obtained which modify the a dimensional response to real one in function of three variables: two dependant on the structure material, elasticity module E and the density of the material mass and the last and most important, the height of chimney H, since all parameters are in function of height.

A table follows containing transformation factors of the dimensional response to the real one, for each of the responses (periods, displacements, shear forces and bending moment), the percentage of error obtained when using transformation factors is also shown in Table.4.

TABLE.4. TRANSFORMATION FACTORS OF RESPONSES

RESPONSE	TRANSFORMATION FACTOR	MAXIMUM ERROR
Vibration Periods	$F_T = \sqrt{\frac{\rho}{E}}H$	1.2%
Maximum Lateral Displacements Estimated by CQC	$F_D = \frac{\rho}{E}H^2$	3.0%
Maximum Shear Stress Estimated by CQC	$F_V = \rho H^3$	3.4%
Maximum Bending Moments Estimated by CQC	$F_M = \rho H^4$	3.2%

8. SIMPLIFIED METHOD FOR OBTAINING RESPONSES

For the purpose of providing simple tools for seismic analysis on industrial chimneys in Chile, a study has been carried out on this special type of continues structures in order to establish a simplified method that may allow evaluating the follows responses: periods of vibration, lateral displacement, shear force and bending moment.

This has been done by making an analysis of the response of 6,144 chimneys contained in a data base (see Table.5)
3) and which allowed establishing a dynamic behaviour law for any steel or reinforced concrete selfsupporting industrial chimney.

The analysis performed is summarised in the following expressions that allow estimating the fundamental period of vibration, lateral displacement, shear force and bending moment shown below:

- Fundamental period of vibration

$$T_1 = \left[4.99 \cdot RR^{0.092} RE^{0.266} (HD + 0.12)\right] \sqrt{\frac{\rho}{E}} H \quad (2)$$

- Maximum Lateral Displacement

$$D_{máx} = \left[0.59 HD^{1.978} RE^{0.398} \left(TT^3 - 4.74TT^2 + 7.26TT + 0.28\right) \cdot Z\right] \frac{\rho}{E} H^2 \quad (3)$$

- Maximum Shear Force

$$V_{máx} = \left[1.1 \frac{(RE + 0.433)(RR + 0.149)}{HD^{2.02} DE^{1.004}} \left(TT^3 - 4.60TT^2 + 6.78TT + 1.55\right) \cdot Z\right] \rho H^3 \quad (4)$$

- Maximum Bending Moment

$$M_{máx} = \left[0.55 \frac{(RR + 0.45)(RE + 0.30)}{HD^{2.02} DE^{1.004}} \left(TT^3 - 4.68TT^2 + 7.06TT + 0.48\right) \cdot Z\right] \rho H^4 \quad (5)$$

where:

ρ = density of material mass.
E = elasticity module of material.
H = total height of chimney.
Z = value depending on seismic zone, per Table 7

The simplified method proposed provides errors not exceeding 10% in the estimate of all responses.

TABLE 5: EQUATIONS 2, 3, 4 AND 5 VALIDATION

		Chimneys									Units
		Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	
T_1	Real	0.53	0.45	0.39	1.05	0.64	0.62	0.85	1.00	1.95	*Sec*
	Equation 2	0.53	0.46	0.39	1.07	0.67	0.64	0.86	0.97	1.88	
	Error	0.7%	1.4%	0.3%	2.5%	4.9%	3.0%	0.9%	2.7%	3.7%	
$D_{Máx}$	Real	0.05	0.04	0.03	0.25	0.09	0.06	0.16	0.26	0.79	*m*
	Equation 3	0.05	0.04	0.03	0.26	0.09	0.06	0.17	0.28	0.76	
	Error	6.0%	0.4%	3.8%	4.5%	5.7%	2.7%	10.0%	7.2%	4.2%	
$V_{Máx}$	Real	3.6	21.1	16.5	91.7	232.7	112.2	171.6	482.3	2,057.0	*Ton*
	Equation 4	3.7	22.3	16.6	92.8	218.0	102.5	166.4	506.4	1,878.5	
	Error	3.5%	5.3%	0.2%	1.1%	6.7%	9.5%	3.1%	4.8%	9.5%	
$M_{Máx}$	Real	46.0	578	404	6,453	7,008	2,992	5,168	19,430	153,300	*Tonm*
	Equation 5	47.0	597	403	6,741	6,621	2,780	5,103	19,007	149,134	
	Error	2.6%	3.3%	0.3%	4.5%	5.5%	7.1%	1.3%	2.2%	2.7%	

The behaviour of the vibration period, lateral displacement, shear force and bending moment, normalised at maximum value, are identical to each other (see Figure 2), regardless of the material and geometry of the chimney. Thus, coefficients may be found providing important responses each 0.05 Y/H and the period for the first 20 modes of vibration. (See Table.6 & 7).

TABLE.6. COEFFICIENTS TO OBTAIN RESPONSES AND PERIODS OF VIBRATION

Y/H	D/D_{Max}	V/V_{Max}	M/M_{Max}
0.00	0.00	1.00	1.00
0.05	0.00	0.96	0.90
0.10	0.01	0.91	0.80
0.15	0.03	0.84	0.71
0.20	0.06	0.78	0.62
0.25	0.08	0.71	0.54
0.30	0.12	0.65	0.47
0.35	0.16	0.59	0.40
0.40	0.20	0.53	0.34
0.45	0.25	0.47	0.28
0.50	0.31	0.47	0.23
0.55	0.37	0.42	0.18
0.60	0.43	0.36	0.14
0.65	0.49	0.31	0.11
0.70	0.56	0.26	0.08
0.75	0.63	0.21	0.05
0.80	0.70	0.17	0.03
0.85	0.77	0.12	0.02
0.90	0.85	0.08	0.01
0.95	0.92	0.04	0.01
1.00	1.00	0.00	0.00

MODE	T_i/T_1
1	1.0000
2	0.2168
3	0.0854
4	0.0449
5	0.0275
6	0.0185
7	0.0133
8	0.0100
9	0.0078
10	0.0062
11	0.0051
12	0.0043
13	0.0036
14	0.0031
15	0.0027
16	0.0023
17	0.0020
18	0.0018
19	0.0016
20	0.0014

TABLE .7. VALUE Z AND I

Seismic Zone	Z	A_0
1	1.0	0.2 g
2	1.5	0.3 g
3	2.0	0.4 g

Soil Type	T' sec	Description [INN, 1996]
I	0.20	Rock: natural material, with wave travelling velocity (V_S) > 900 m/s.
II	0.35	Soil with V_S > 400 m/s, coarse gravel, coarse sand, hard cohesive soil .
III	0.85	Permanent non-saturated sand, non-saturated gravel or sand, cohesive soil

9.STAAD PRO ANALYSIS APPLICATION EXAMPLE PROGRAMME

Consider chimney of height 12 m and circular dia of 3m which is placed on the ground level. An seismic load of 5 kn has assing in joints of the members for find out the stress distribution from top to bottom with safety measures.

9.1 ANALYSIS OUT PUT

After STAAD PRO Analysis the following outputs Structure Full View (Figure.4), 3d Rendered View(Figure.5), Displacement Due To Seismic Load (Figure.6),, Structure With Seismic Loading(Figure.7),, Stress Distribution Due To Seismic Load(Figure.8) were found.

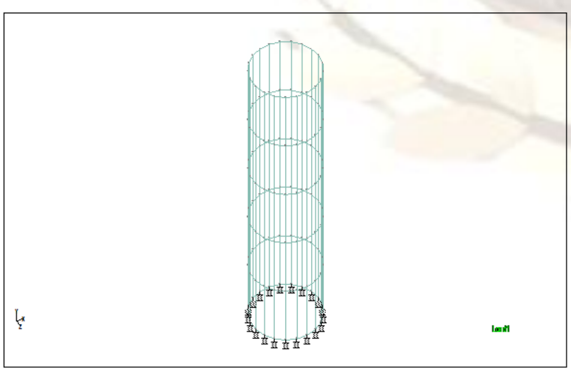


FIGURE.4 STRUCTURE FULL VIEW

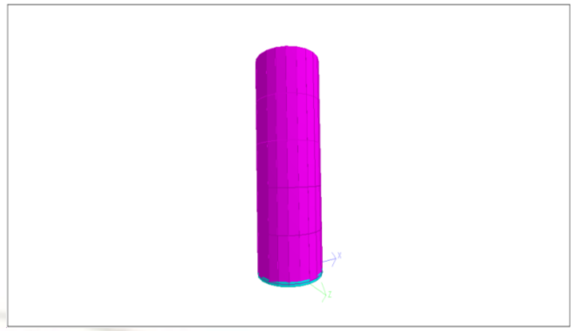


FIGURE.5. 3D RENDERED VIEW

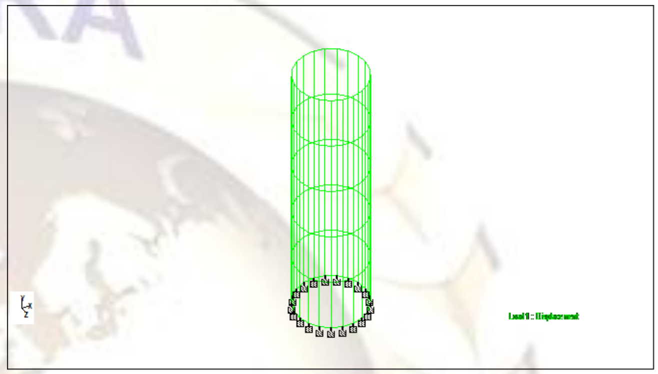


FIGURE.6. DISPLACEMENT DUE TO SEISMIC LOAD

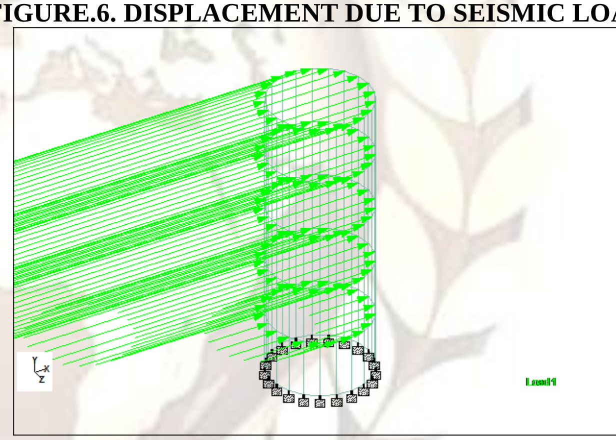


FIGURE.5. STRUCTURE WITH SEISMIC LOADING

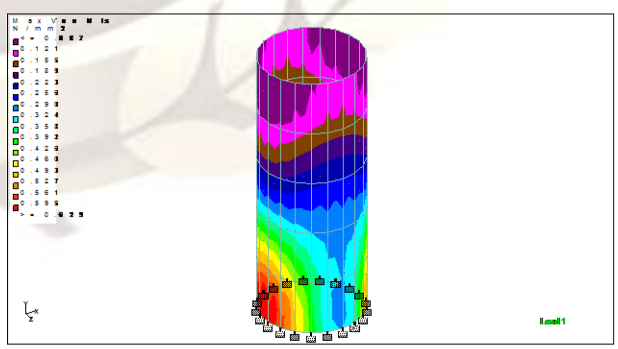


FIGURE.5. STRESS DISTRIBUTION DUE TO SEISMIC LOAD

10. CONCLUSIONS

1) When the chimney is analysed by the three effects (flexion, shear and rotational inertia), the number of

elements to be discreted no longer influences the estimated responses because the height of the element is controlled by the shear if h/D < 2, and by flexion if h/D > 2, h the height of the element.

2) To estimate the fundamental period of vibration, considering only the effect of flexion, the consistent masses criterion is more accurate. The percentage of error obtained, compared to the exact solution given by MEF is 1.13%

3) Since it is very laborious job finding a factor to transform adimensional response values to real response values considering all effects (flexion, shear and rotational inertia), good results can be obtained in the analysis of steel and reinforced concrete industrial chimneys modelling the structure employing the following considerations: Consistent masses criterion, effect of flexion, and discreted in 20 elements. Maximum errors committed as a result of such considerations are under 2%.

4) It is possible to carry out an analysis of a chimney parametrically, finding a factor that will transform these adimensional values into real responses of the structure. The maximum error obtained considering the 4 responses studied (period of vibration, lateral displacement, shear force and bending moment) is 3.5%.

5) The simplified method proposed in this paper provides responses with errors not exceeding 10%. As normalised response curves do not vary, regardless of the material and geometry of the chimney, they allow obtaining coefficients providing important responses every 0.05 Y/H and the period for the first 20 modes of vibration.

6) Through our problem we conclude that the seismic effect will cause more damages to the structure which will stabilise when it will analysis and constructed based on the stress condition which is highlighted in the diagram

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HD = H / D_{inf} = Ratio of slenderness

R_{inf} : Radius of section at the base of chimney

R_{sup} : Radius on top section of chimney

RE = E_{sup} / E_{inf} = Ratio of thickness

E_{sup}: Thickness of mantle at the top section of chimney

DE = D_{inf} / E_{inf} = Ratio of diameter thickness

E_{inf} : Thickness of mantle at the base of chimney