# SEISMIC RESPONSE OF A LARGE ELECTROSTATIC PRECIPITATOR CONSIDERING NON-LINEAR EFFECTS USING A SIMPLIFIED MODEL

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**ABSTRACT :**

A study of the seismic response considering nonlinear effects of a large electrostatic precipitator obtained from a model based on a simplified representation of the hanging interior components of the system and a standard modeling of the steel support structure is carried out.

The behavior of the casing is represented by a combination of “frame” elements for the ribs and frames and "shell" elements for the casing itself both in the longitudinal direction (flue gas flow direction) and in the transverse direction.

For the internal components, two levels of modeling are considered. The simplified model considers “simple pendulum type elements” with masses distributed along the length and flexural “frame” type elements. The possible interaction (pounding) between the hanging elements and the casing is also considered in the analysis.

For a “second level” model of the interior components, “frame” and “shell” elements are also used, as appropriate to the geometry and characteristics of the components. The mass distributions are obtained from the geometric description of the components considering the different materials. “Added mass” is considered to represent the weight of the dust in the collector plates. The support conditions of the internal elements are modeled using "springs" and nonlinear link elements (“gap”) with properties that represent their mechanical behavior including the possible pounding of hanging elements against the casing or internal beams.

In both cases the support structure is modeled using “frame” elements and “hinges” according to the actual configuration of the attachment of the equipment to the support structure.

The earthquake action is represented by actual ground motion records from different sites where rather extensive earthquake induced damage were observed. Different types of events are considered (near fault records and subduction zone records).

The results of the analyses for different earthquake ground motions are discussed in terms of overall system behavior, internal parts behavior, and maximum loads acting on the support structure and the foundation.

**KEYWORDS:**

ESP supporting structure, pounding, non linear gap, time history analysis, nonstructural components, secondary structures.

## 1. INTRODUCTION

The seismic design for industrial structures is more demanding than seismic design for other structures. The life safety requirement is of course considered but also it is designed to protect also industry life, meaning that essential services must remain functional and the operation shut down time must be reduced to a minimum (INN, 2003; Sezen & Whittaker, 2006).

Design of support structures for heavy industrial equipments is controlled by the process of the equipment itself, resulting in irregular distributions of mass and stiffness. In general, the analysis and design of this kind of structures considers simplified methods (INN, 2003; AISC, 2005), which does not consider the mechanical properties of the equipment itself.

Considering a sophisticated model, relative displacements between interior components and support structure can be calculated and with that some evaluation of the operational behavior can be carried out. If the relative displacements are larger than the gap between them, pounding will occur (Cruz & Valdivia, 2005).

The research work published regarding pounding between structures is mainly focused on analyzing pounding between adjacent independent structures (Chau & Wei, 2005), (DesRoches & Muthukuma, 2002), (Papadrakakis et al, 1996); (Maison & Kasai, 1990).

This study analyzes the effects in the response of the system of pounding between interior components and support structure of a large electrostatic precipitator (ESP) using 3D and 2D simplified models.

## 2. ANALYSIS MODELS USED

### *2.1. Sophisticated 3D Model*

An ESP of 20.6m high and 224 tonf of total weight is modeled in detail using frame elements to model the support structure and finite elements to model the casing of the equipment (Figure 1). The support structure weights 154 ton. In the dynamic analysis it is also considered the dust attached to the collecting plates. The dust maximum weight is 46.6 tonf.

The internal components considered in the model, which represent the rest of the structure weight, are:

- Discharge electrodes: Discharge electrodes are a group of frames of slender pipes attached together. Discharge electrodes create a strong electrical field that ionizes flue gas, and this ionization charges particles in the gas. Discharge electrodes are modeled using frame elements to model every pipe.
- Collecting plates: Collecting plates are flat plates that collect the ionized particles in the gas. Every collection plate is set opposite to a frame of discharge electrodes. Collection plates are modeled using finite elements (shell).

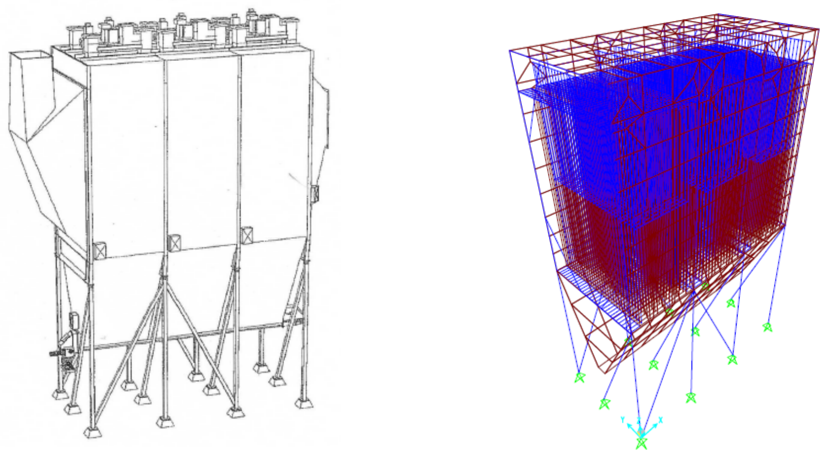


*Figure 1- Sophisticated 3D Model (SAP2000)*

*Table 1– Periods and modal effective weight ratio, Sophisticated 3D Model*

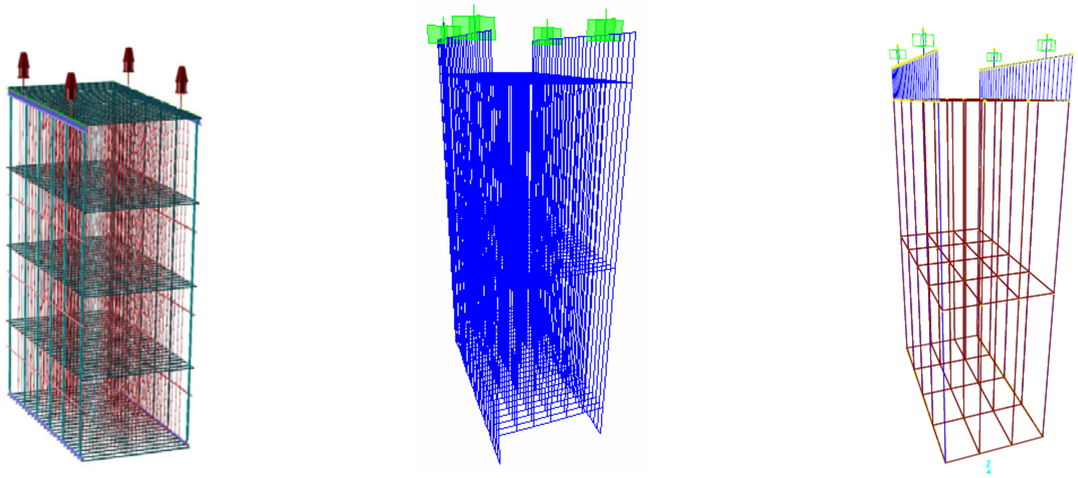
| Mode X | T [s] | UX | UY | UZ | Mode Y | T [s] | UX | UY | UZ |
|---|---|---|---|---|---|---|---|---|---|
| 357 | 0.318 | 39.63% | 0.00% | 0.20% | 330 | 0.479 | 0.00% | 30.66% | 0.04% |
| 355 | 0.325 | 22.22% | 0.03% | 0.09% | 346 | 0.381 | 0.00% | 11.54% | 0.04% |
| 372 | 0.205 | 15.92% | 0.00% | 1.26% | 120 | 2.260 | 0.00% | 9.33% | 0.00% |
| 375 | 0.188 | 5.25% | 0.00% | 1.34% | 247 | 1.234 | 0.00% | 8.53% | 0.00% |
| 358 | 0.315 | 3.99% | 0.00% | 0.02% | 91 | 2.399 | 0.00% | 7.88% | 0.00% |
| 373 | 0.198 | 2.98% | 0.00% | 0.32% | 336 | 0.445 | 0.01% | 5.36% | 0.01% |
| 181 | 1.554 | 2.75% | 0.00% | 0.00% | 384 | 0.126 | 0.00% | 4.65% | 1.57% |
| 343 | 0.407 | 1.74% | 0.00% | 0.01% | 149 | 2.241 | 0.00% | 4.48% | 0.00% |
| 383 | 0.131 | 1.20% | 0.02% | 1.71% | 180 | 2.037 | 0.00% | 2.63% | 0.00% |

### *2.2. Simplified 3D Model*

Both discharge electrodes and collecting plates are modeled separately using tridimensional finite elements ("Solid type" elements). Both models are adjusted to match the dynamic properties of a sophisticated model of discharge electrodes and collecting plates respectively.

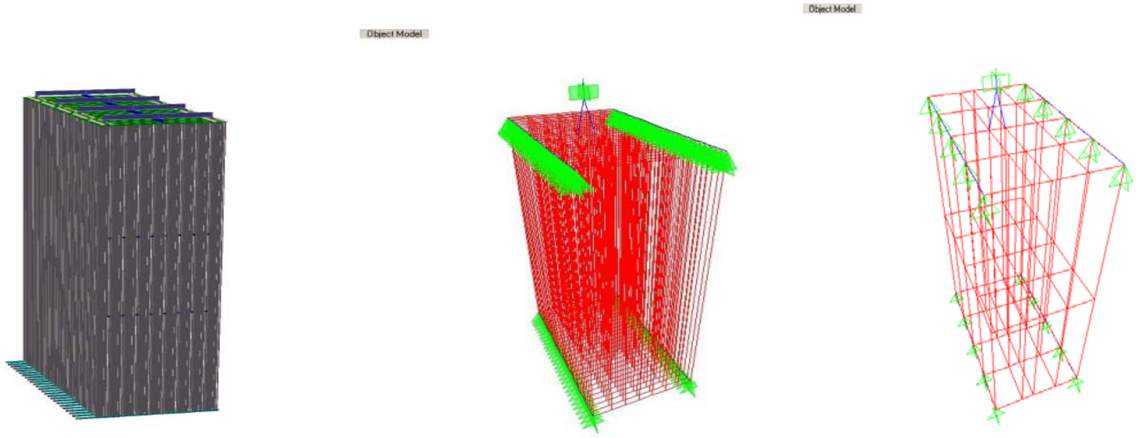
The adjustment of the characteristics of the model of both components is made by defining the material of the solid element. In order to have different dynamic properties in each direction it is necessary to consider an anisotropic material.

Considering that solid type elements only have displacements degrees of freedom (dof) on its nodes, in order to hang a solid element from the top of the roof of the structure it is necessary to place frame elements that connect the roof of the structure to the solid elements at the top, middle, and bottom nodes.



Actual physical characteristics | Sophisticated Model | Simplified Model

*Figure 2 - Discharge electrodes models, Sophisticated and simplified*




Actual physical characteristics Sophisticated Model Simplified Model

*Figure 3 - Collecting plates models, Sophisticated and simplified*

Using the same support structure of the sophisticated model, a simplified model of the ESP is built using the simplified models of discharge electrodes and collecting plates described above.

*Table 2 - Periods and modal effective weight ratio, Simplified 3D Model*

| Mode X | T [s] | UX | UY | UZ | Mode Y | T [s] | UX | UY | UZ |
|---|---|---|---|---|---|---|---|---|---|
| 60 | 0.33 | 54.10% | 0.00% | 0.40% | 48 | 0.40 | 0.00% | 21.30% | 0.10% |
| 104 | 0.22 | 25.00% | 0.00% | 1.60% | 35 | 0.47 | 0.00% | 16.10% | 0.00% |
| 61 | 0.32 | 3.30% | 0.00% | 0.00% | 2 | 2.31 | 0.00% | 11.40% | 0.00% |
| 7 | 1.54 | 2.40% | 0.00% | 0.00% | 29 | 0.50 | 0.00% | 10.40% | 0.00% |
| 8 | 1.53 | 1.70% | 0.00% | 0.00% | 1 | 2.38 | 0.00% | 9.30% | 0.00% |
| 122 | 0.19 | 1.40% | 0.00% | 0.20% | 13 | 1.23 | 0.00% | 8.60% | 0.00% |
| 9 | 1.52 | 0.05% | 0.00% | 0.00% | 3 | 2.30 | 0.00% | 2.90% | 0.00% |

To analyze the effects of pounding between internal components and the support structure, a non linear link element or "gap" element is placed between every bottom node and the support structure node where pounding is expected. The corresponding definitions are illustrated schematically in Figure 4, and are defined as follows:

- G1: Gap between Discharge electrodes – Support structure (X direction). 30 link elements.
- G2: Gap between Discharge electrodes – Support structure (Y direction). 24 link elements.
- G4: Gap between Collecting plates – Support structure (Y direction). 18 link elements.

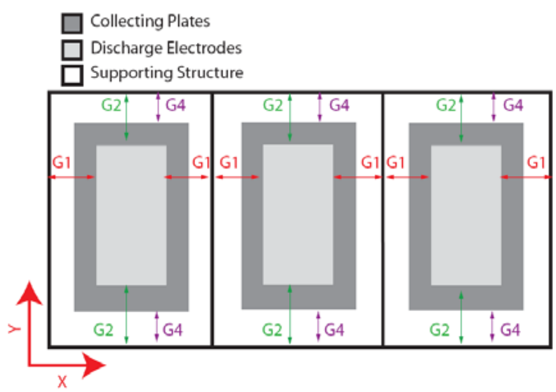
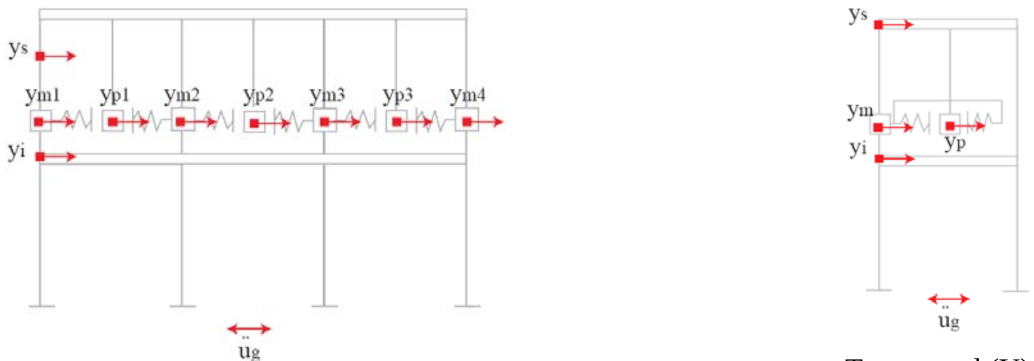



*Figure 4 – Schematic representation of positioning of gap elements.*

### *2.3. Simplified 2D Model*

Two simplified 2D models are used to analyze the structure in both directions. The model for the longitudinal direction has 9 lateral displacement dof and six gap link elements. The model for the transverse direction has 4 displacement dof and one two-sided gap link element (see Figure 5). Every link element is placed between a $y_p$ dof and the adjacent $y_m$ dof, where $y_p$ and $y_m$ represent the lateral displacements of discharge electrodes and the position of the support structure where pounding by the discharge electrodes is expected, respectively.

The stiffness of the supporting structure is defined trying to reproduce the fundamental vibration periods obtained using the sophisticated 3D model (Table 1, modes 330 and 357).




Longitudinal (X)

Transversal (Y)

*Figure 5 - 2D Models*

## 3. SEISMIC LOADS

Five different real earthquake records (
Simplified 3D models are analyzed with two different earthquake intensity levels in the longitudinal direction and four different earthquake intensity levels in the transverse direction. Considering that the non linear analysis of the simplified 2D models is extremely fast, thirty different earthquake intensity levels are used for the analysis in the transverse direction and fifteen in the longitudinal direction.
), obtained at locations where rather extensive earthquake induced damage was observed, are used in the time history analysis: Sylmar (SY), Chi-Chi (CC), Melipilla (MP), Llolleo (LL), and Mexico (MX). The details of the record identification are included in Table 3.

*Table 3- Peak ground accelerations and velocities of earthquake records used in the analysis*

| Sig | Event | Station | PGA [cm/s$^2$] | PGV [cm/s] | $I_{HIN}$ [cm s] | f($I_{HIN}$) |
|---|---|---|---|---|---|---|
| MP | Valparaiso,Chile 3-3-1985 | Melipilla | 673 | 34 | 0.137 | 1 |
| LL | Valparaiso, Chile 3-3-1985 | Llolleo | 698.3 | 40.2 | 0.256 | 0.535 |
| SY | Northridge, California 17-1-1994 | SylmarHospital | 827.3 | 129.3 | 0.705 | 0.194 |
| CC | Chichi, Taiwan 20-9-1999 | CWB9999 | 949.1 | 107.5 | 0.568 | 0.241 |
| MX | Cd. De Mexico 9-19-1985 | SCE | 167.9 | 60.4 | 0.865 | 0.158 |

The Sylmar and Chi- Chi records represent an impulsive type movement of the ground generated by a near fault event, the Melipilla and Llolleo records have a large duration of strong motion generated by a subduction zone earthquake event, and the Mexico record is the longer record analyzed, and its most distinctive characteristic is the long predominant period of the ground motion, induced by a distant earthquake and a site with very soft soil conditions.

In order to normalize the size of the different earthquakes considered, and to have some equivalence between the expected values of the relative displacements of the dof where pounding is expected a modified version of the Housner Intensity Index is used, as defined in the following equation:

$$I_{HIN} = \int_{1.5}^{2.4} S_d(T,\xi)\, dT \quad (1)$$

Sd (T,ξ) is the Spectral ordinate of the displacement response of a singe dof system with period T and damping ratio ξ. The integral is limited to the range 1.5 - 2.4 seconds which is representative of the natural periods of the internal component sub-assemblies that create the pounding effects.

Simplified 3D models are analyzed with two different earthquake intensity levels in the longitudinal direction and four different earthquake intensity levels in the transverse direction. Considering that the non linear analysis of the simplified 2D models is extremely fast, thirty different earthquake intensity levels are used for the analysis in the transverse direction and fifteen in the longitudinal direction.

## 4. NUMERICAL RESULTS

A comparison between the results of the time history analysis, considering pounding (using the non-linear models) and neglecting pounding (linear analysis) is made for the 3D and the 2D models.

The results are compared in terms of the displacements at the "gap" elements defined and also looking at the overall response in terms of maximum base shear forces developed in the support structure.

In Figure 6, a comparison between the relative displacements G2 is shown. The available gap in the actual structure between them is marked with a solid line (10 cm), while an approximation of the gap in the opposite direction (-10cm) is shown with a dashed line.

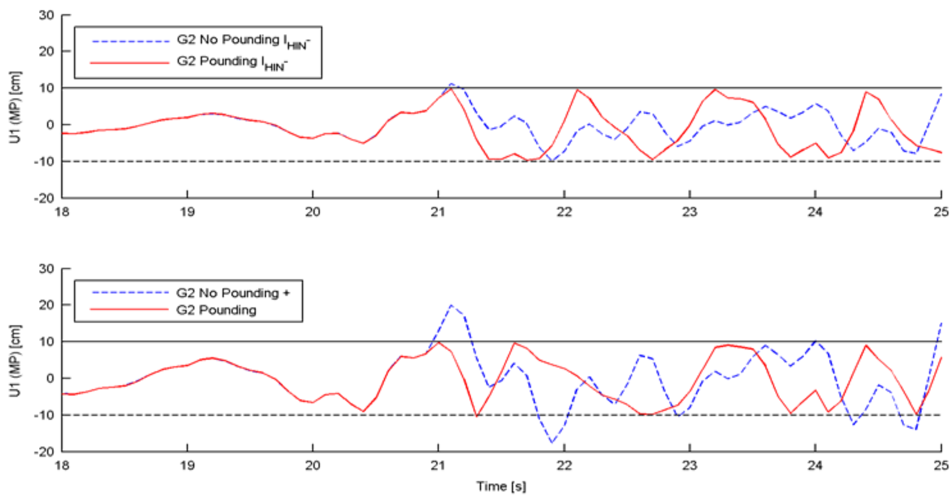



*Figure 6 - Typical time history axial deformations of a G2 element.*

In the analysis using simplified 3D models, the MX and the SY records induce large amplifications of the base shear in the transverse direction of analysis, while the rest of the records do not show significant variations of the base shear (see Figure 8). These amplifications are especially critical considering that the support structure is weaker in the transverse direction.

The amplification observed in the base reactions induced by pounding using the 2D models are much larger than those calculated using the 3D models, especially for the MX record, where amplifications reach 900%.

The amplifications of the 2D analysis show a trend to diminish to a constant value as the intensity of the input increases (see Figure 9).

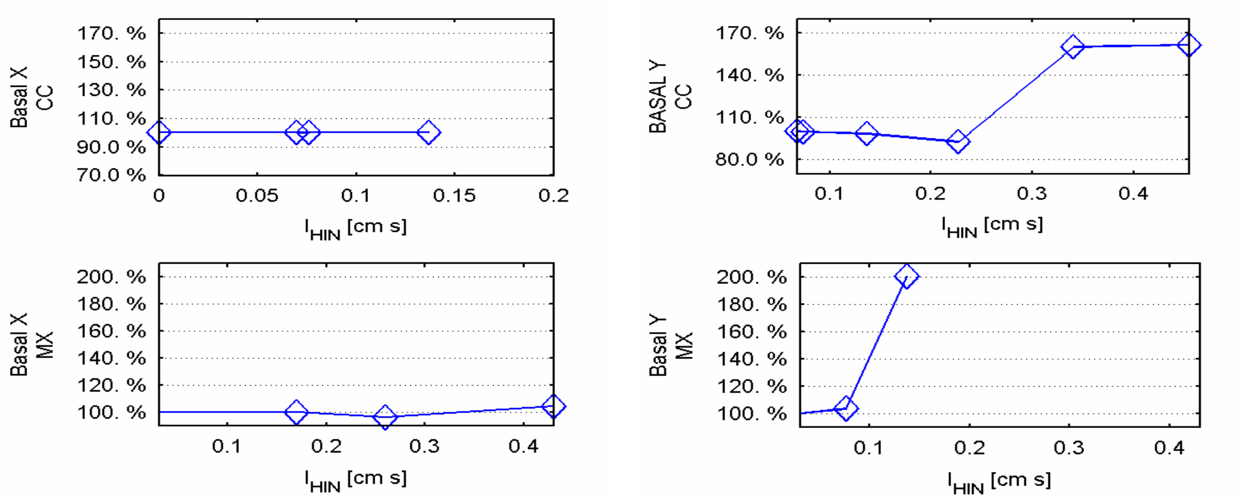



*Figure 7 - Base Shear (pounding)/Base Shear (no pounding) for different intensities of the records CC and MX , simplified 3D Models.*

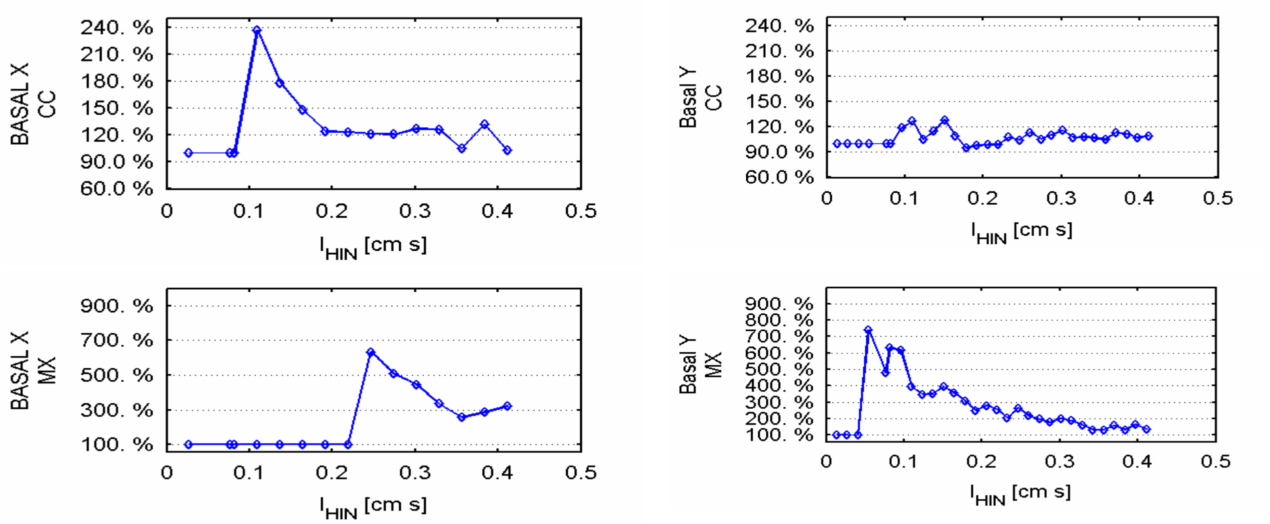



*Figure 8 - Base Shear (pounding)/Base Shear (no pounding) for different intensities of the records CC and X, simplified 2D Models.*

## 5. CONCLUSIONS

The earthquake response of a large ESP considering pounding between the internal components and the supporting structure has been investigated. A simplified 3D model, in which the internal components of the equipment are modeled using solid elements with anisotropic material, and simplified 2D models based on a limited number of degrees of freedom, are used to analyze the effects of considering the pounding between interior components and the supporting structure.

Pounding between internal components and the supporting structures induces important changes in the base shear results of the analyzed models. The variations are dependant of the characteristics of the seismic load. The pounding analysis for 2D simplified models overestimates the base shear calculated by the 3D model, especially for analysis considering low intensity of earthquake motion.

Neglecting the possible pounding effect of a structure with hanging interior components can lead to a non-conservative evaluation of base reactions which could in turn lead into an non-conservative design of the supporting structure

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