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CAN BASIN EFFECTS BE QUANTIFIED WITHIN 1D GROUND RESPONSE ANALYSIS? MEXICO CITY NEW AIRPORT CASE

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Abstract

The seismic ground response of the site for the New International Airport for Mexico City (NAICM) has been assessed towards a seismic performance-based design of the different structures in the airside.

One additional seismic scenario, corresponding to the 1985 Michoacán great earthquake was made to verify the 1D equivalent-linear (E-L) models to local measurements and identify possible site effect by surface waves in the Mexican Valley basin. In this scenario the response from two points within the NAICM site is compared to the available measurements at one station (TXSO) near the site. Furthermore, a zonation of the site was made deriving maps of some ground motion parameters representing the site-specific ground response of the NAICM site during that event. Within the quantified outputs, peak ground acceleration, response spectra, time histories are used for the compassion; in combination with criteria from the site natural periods, shear strains and strain indexes.

The 1D E-L ground response during the 1985 earthquake is in agreement with the TXSO registers for the northwestern part from the NAICM, at spectral periods up to 2.3 seconds. Towards the south, the response varies, as the soil condition varies as well. The overall trend in amplification throughout the NAICM site is in agreement with the reported measurements throughout the Mexican Valley. This is valid for the measured site periods (T=1.6-2.9 seconds). Based on the response spectra validation and the overall response, it is found a reliable response from the 1D E-L models for this seismic scenario for periods up to 2.3 seconds. Towards larger periods the E-L response appears over-damped, due to the surface waves related to the basin effect, which cannot be captured by that method. To account for basin effect within seismic design it is recommended to incorporate a factor either to the design spectra or ground motion prediction equation for the Mexican Valley for periods larger than 2.3 seconds.

Keywords: ground response, surface waves, basin effects, equivalent linear, Mexico

1. Introduction

The site effects on the ground response from the Mexico valley soft soils has been recognized and studied during various decades, after the Michoacán great earthquake in September 19, 1985 (e.g. [1], [2], [3]). This article summarizes the varied interpretations and findings from literature and aims to verify and discuss the applicability of traditional 1-D equivalent-linear for this particular geological setting. For this, extensive ground investigation and seismic studies recently made for the design of the new airport for Mexico City (NAICM) are used (e.g. [4],[5]). A specific scenario from the 1985 was assessed throughout the NAICM and the responses compared to available measurements nearby.

The basin effect refers to the influence of a basin structure on the ground motion and includes body wave reflections and surface waves generated at the basin edges by diffraction of body waves. The curvature of a basin or basin edge can trap body waves and cause some incident body waves to propagate through the softer soils as surface waves ([6],[7]). This results in total internal reflection at the base or lateral boundaries of the layer. Near-field seismic sources are named coincident source and site basin locations (CBL), and far-field seismic sources distinct site and source basin locations (DBL) by [8] in an attempt to distinguish patterns (**Fig. 1**). Basin effects are important for periods (T) higher than 0.7 seconds [8].

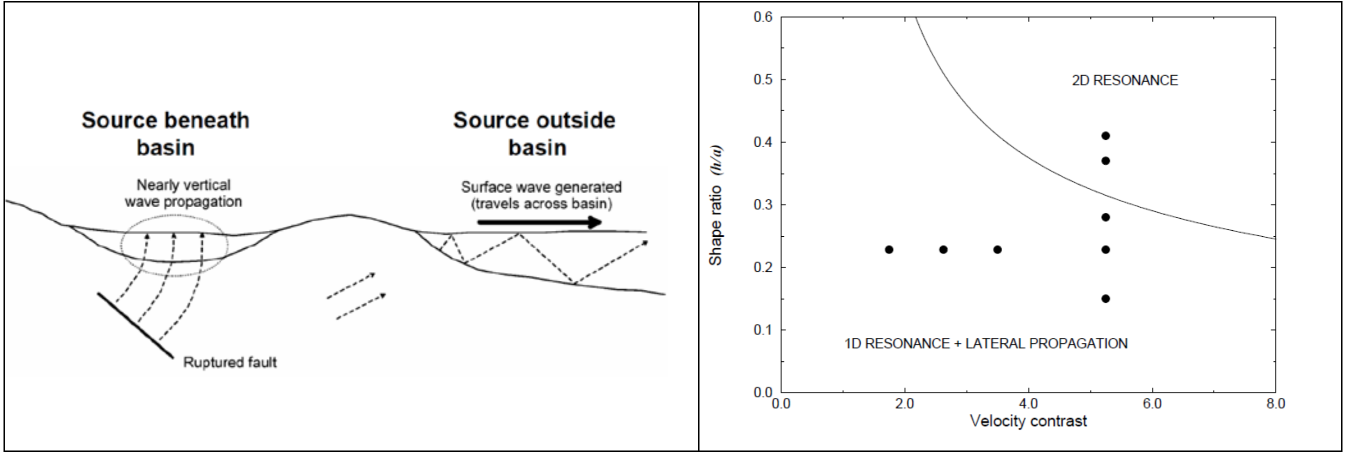

Fig. 1 – Left: Basin response models with near or far sources [8]. Right: 1- and 2-D resonance in alluvial valleys for SH waves, in function of velocity or impedance contrast and shape ratio [11].

Recorded motions in soils, show larger amplitudes and duration due to interference of the incoming surface waves generated by the basin edge. Softer soils result on longer duration of shaking at the surface, due to back and forth propagating surface waves generated at the edges ([3], [9]). While body-wave arrivals have no dispersion (due to intrinsic attenuation), the lateral dispersion of surface waves forms long oscillating wave trains. Their duration increases with distance of propagation. Another important feature of surface waves is their strong decay in their amplitudes with depth. Due to this, earthquakes deeper than the recorded wavelengths will produce significantly reduced or no surface waves [10], unless generated as basin edge effect or other complex effects.

The ground response of different basin geometries has been studied by several researchers (e.g. [11], [12], [13]). A distinction between the response of shallow and deep basins is provided by [11]. For shallow basins, there is agreement that the 1D assumption, due to the impedance contrast of wave propagation is a good approximation of the amplification function due to lateral propagation, with exception of the edges. For deep basins, or basins with irregular shape, the situation is more complex due to locally generated surface waves and 2D resonance effects, and the 1D assumption is generally not in agreement with 2D- or 3D amplification functions [11]. To explain this, [11] use a basin shape ratio h/a, where a is the basin or valley half-width and h its maximum depth (**Fig. 1**). This shape ratio in combination with the sediment/bedrock velocity contrast determines whether the response is governed by 1D- or 2D site effects. 2D site effects amplify ground motion by a factor of 2 to 3 in addition to 1D spectral amplification (Ibidem).

Models of basin effects show reliable estimates at periods longer than about 2 seconds, but at shorter periods, the response is more stochastic [14]. The mean-basin effect is period dependent and larger than 1-D predictions for periods larger than 2 seconds [15].

Different features can influence the ground motion amplitudes, including the depth of the earthquake, distance of the earthquake from the basin edge, effects that can depend on the location of the earthquake and of the site within the basin, as well as on the basin depth and distance of the site from the basin edge [16]. The basin edge can act also as bounding fault where surface waves are generated by interference of direct waves with the edge. Concentration of damages along fault-controlled basins is reported in some cases, e.g. 1994 Northridge and 1995 Kobe [14]. This basin-edge-effect can be evidenced by abrupt lateral contrast in shear wave velocities and is not expected to occur at basin edges with smooth concave bedrock profiles (not controlled by faulting). Large ground displacements can take place near the basin-edge due to the interference of surface/diffracted waves with the direct waves and their multiples [17].

Site effects depend on the impedance contrast. Lateral irregularities can increase this amplification by a variable amount. “If the impedance contrast is large, the lateral variations of that additional amplification can be neglected and a single factor can be used throughout the valley” [18]. In Mexico City, “the first and most important factor in the observed response is the impedance contrast between a thin layer of extremely soft clay and its volcanic substratum” [18], nevertheless this factor is insufficient to explain site response because it is incomplete. The observed long duration “is the result of a very long excitation wave field, produced by the distance between Mexico City and the epicentral zone and the diffraction of the incident wave field by the geological heterogeneities that plague the crustal structure in central Mexico”. This means, site effects in Mexico City have to account for path effects from the subduction zone to the city [18].

1.1 Basin effects within codes and engineering practice

For engineering practice, some factors have been proposed to account for basin effects, modifying seismic spectra (e.g. [11], [19]). To apply a factor 2 on the 1D response is suggested by [11], to reach a 2D response. That factor is function of the basin shape and local impedance contrast. For southern California (deep basin), [15] found relations among subsoil thickness to a certain shear wave (Vs) value (1.0 or 2.5 km/s), implemented within ground motion prediction equations (GMPE’s) of the New Generation Attenuation (NGA) at long periods (T>2 s). These GMPE’s have been derived for shallow continental earthquakes, therefore, are not applicable to the hazard context of Mexico City. Another attenuation model for subduction earthquakes, considering basin effects is under development within the NGA-West2 project for southern California (written -comm. J. Stewart, 07-03-2015). These type of models help design practice in order to incorporate this type of site effect, kept in some extension aside until recently. In engineering practice superficial 1D ground response analysis is the regular base towards more specific and complex (2- or 3-D) structural models. 2- or 3-D ground response analyses are not common in seismic design. Therefore, the site effect from basins is simplified and needs to be considered through other was as the mentioned factors and GMPE’s.

1.2 Basin effects in the Mexican valley

There are different hypothesis on the generation of surface waves and the associated basin effects that can influence the seismic ground response from the Mexican basin, such as:

- Surface waves are generated at the basin edge and propagate back and forth resulting in long duration and long period ground response ([3],[20],[21],[22]).
- Lateral heterogeneities and possible presence of small sub-basins could be the cause of long durations [3]. Fundamental frequency and amplification depends on the number of soil layers and geometry of the sub basins.
- The long duration registered at some soil stations (e.g. CDAO) may be related to dispersion and multi pathing of long-period surface waves, from the source to the site and/or multi pathing within the valley ([2],[23]).

- Peak amplification from 1D models correspond to the minimum level of observed spectral ratios described by [2] were estimated by [3]. A difference from 30% to 100% to match 1D models to measured values was quantified by [3]. This means a factor of 1.3 to 2.0 to be multiplied to the 1D response. Average spectral ratios for periods between 3 and 5 seconds are 60% larger than that for periods between and 3 seconds [3] (**Fig. 11**).
- The ground response is governed by the impedance contrast (1D effect), but there are various contributing factors with different order of importance, e.g. lateral heterogeneities that split incoming wave trains (waves travelling in the same direction and spaced at regular intervals) ([18],[23],[24]). Locally, the interaction of diffracted wave trains of Rayleigh waves and the very soft upper clay layer (FAS) also play a role [25].
- Source-site path effects play also a role, as surface waves can also be generated somewhere between the epicenter and the valley [26]. Furumura and Kennett (1998) in [25] proposed a relation between the crustal structure and the incident wave field at Mexico City. This hypothesis is supported by the large velocity contrast measured between Guerrero Terrain and the Trans-Mexican Volcanic Belt (TMVB), which amplifies the S-waves [27].
- In the Mexican Lake zone, 1D ground response analysis (GRA) has predicted the natural periods of vibration and response spectrum well [21]. The observed records in the Lake Zone are well reproduced by 1D propagators using Hill Zone records as sources ([1], [23]). Hill zone records refers to the measurements coming from the reference stations, located on the hills around the valley, e.g. CU01, used in the seismic response analysis study.
- Another relevant issue in the ground response studies from the region is whether the Hill Zone records are representative of the motion below the soft soil layers in Mexico City [25].

2. NAICM site conditions

The new international airport will be located at the northeastern side of Mexico City, at the former Texcoco Lake (Fig. 2). The soil profile is summarized in Table 1. It consists of a desiccated crust (DC) of clay at the top, near 1 m thick. Below is upper very soft clay (FAS) of 23 m in average, followed by near 2.4 m of a very dense sandy silt (CD). Underneath is the intermediate firm clay (FAI) of around 10 m thickness. Below that clay, is a very dense silty sand/sandy silt (DP), considered as engineering bedrock or seismic base layer for the seismic ground response analysis (GRA). The soil layers are dipping and thickening southwards. From East to West the soil layers are sub-horizontal.

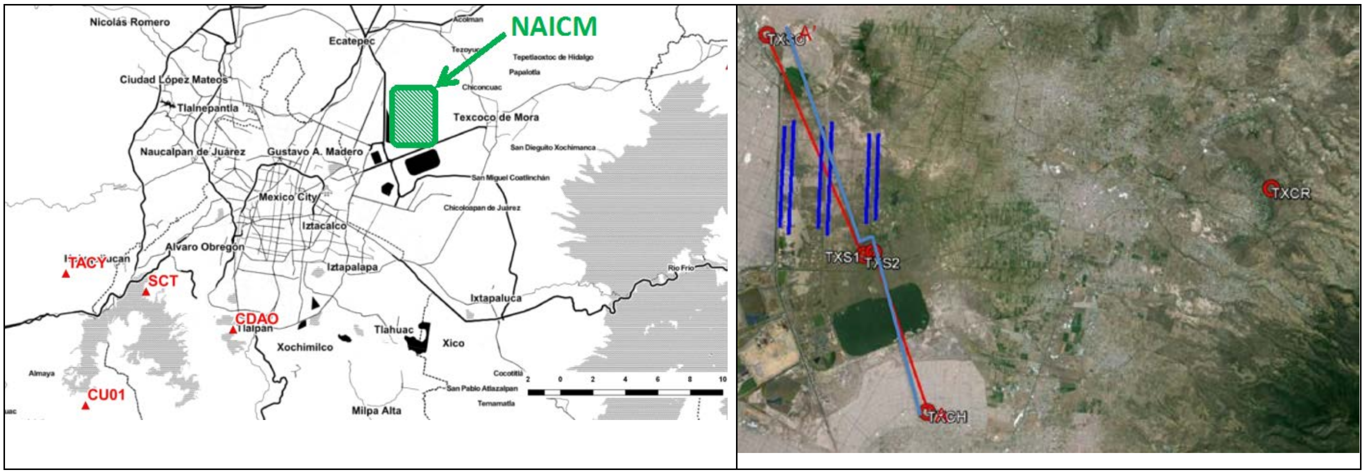

Fig. 2 – Left: New airport location and some reference seismic stations (retrieved from the Mexican strong motion database). Right: accelerograph stations near the NAICM site. All are on soil, only TXCR is on rock. Dark blue lines represent approximate positioning from planned runways (after [30])

3. Geotechnical description

There is plenty geotechnical ground investigation from the NAICM, but that is out of the scope of this publication. Hereby are summarized only the main parameters necessary for the GRA, after ([4],[5],[29],[30]).

Table 1 – Soil units from 2012-2013 ground investigation [4]

Soil unit	Soil description	Thickness mean range [m]
SU1A	Desiccated Crust (DC): Medium stiff to stiff, high plasticity, desiccated clay;	0.4-2.4 (0.9)
SU1B	Formación Arcillosa Superior (FAS): Very soft to soft, greyish green CLAY of high plasticity (CH); interbedded with thin layers of loose, fine silty sand and occasionally dense volcanic glass;	16.5-34.2 (23.3)
SU2	Capa Dura (CD): Very dense, greyish green, slightly cemented sandy silt to silty sand (MH to SM);	0-5.5 (2.4)
SU3	Formación Arcillosa Inferior (FAI): Firm, becoming stiff with depth, greyish green CLAY of high plasticity (CH); interbedded with thin layers of loose to dense, fine silty sand and very dense volcanic glass;	5.8-15.6 (10.4)
SU4	Depósitos Profundos (DP): Interbedded layers of very dense, greyish green silty sand / sandy silt (SM / MH) and firm to stiff clay (CH).**	Top of DP*, on average at 37 m depth

*DP: Depósitos Profundos (deep deposits); ** clayey part from DP are frequently refered as the third Formación Arcillosa, or Formación Arcillosa Profunda (FAP).

The ground profile that governs the NAICM site response comprises different soil units until the seismic base layer (SBL), defined as the layer where an important impedance contrast is found (**Table 1**). The complete soil column above the SBL has a mean shear wave velocity (Vs) of 107 m/s. The SBL is a subunit from SU4 at near 60 m depth. The mean Vs of from SBL is approximately 500 m/s. A 3D spatial geomodel was built in Rockworks for the NAICM site [4], from which the 1D soil columns grid were extracted for the GRA.

The shear wave velocity (Vs) was measured with direct and indirect methods: 7 PS-L logging, 1 seismic dilatometer test and 11 H/V ambient vibration tests, with depths from 40 to 99 m ([29], [30]). In order to have a wider and deeper coverage throughout the site, an empirical correlation was developed to predict Vs based on CPT cone tip resistance (qc), sleeve friction (fs), soil behaviour type index (I_c), effective stress (σ'_v), depth (z), and in situ void ratio (e_0) [5]. This relation is based on the works from [31], [32], [33]. The Vs were calculated for each geotechnical unit. Mean values were implemented in the GRA (**Table 2**), excepting for SBL. The SBL was interpreted as the mean +1 standard deviation for conservative purposes to prescribe higher impedance.

Table 2 – Geotechnical parameters for GRA (after [5]); SU4C=SBL

Soil unit	Mean thickness [m]	Mean depth top unit [m]	Mean Vs [m/s]	Saturated unit weigth [kN/m^2]	Plasticity index (PI) ±1 standard deviation [%]	Small strain shear moduly (G_0) [MPa]
SU1A	0.9	0.0	n.a.	n.a.	n.a.	n.a.
SU1BA	9.4	0.9	50	11.9	200±63	3
SU1BB	8.7	10.3	60	12.4	185±36	4.1
SU1BC	5.2	19.0	78	12.5	157±71	6.6
SU2	2.4	24.2	115	18.0	25	24.3
SU3	10.4	26.7	133	13.0	131±66	21.4
SU4A	9.3	37.1	205	18.0	54±36	87.2
SU4B	11.4	46.4	185	18.0	90±49	79.4
SU4C	n.a.	57.9	472	18.0	n.a.	451

The modulus reduction and damping curves were selected after Mexican literature, combined with the available laboratory tests from the project: resonant column and cyclic triaxial tests. Units FAS (SU1), FAI (SU3) and DP (SU4) follow [34]. Mean PI (+/-1standard deviation) were used to define the curves, adjusted with the laboratory test results as well as combination with curves from [35]. For the sandy to silty Capa Dura (CD) layer (SU2) conservative upper/lower bound curves for cohesionless soils from [36] were selected. These curves display a good match to curves with low plastic behaviour (PI = 25%). Example curves are given in **Fig. 3**. The small strain shear modulus (G_0) is simply derived from $Vs = \sqrt{(G_0/\rho)}$, where ρ is the soil density.

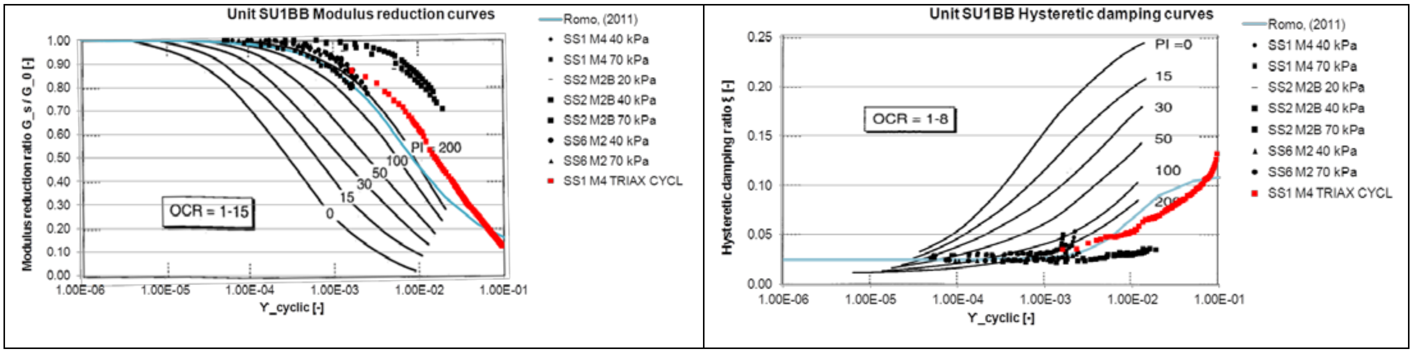

Fig. 3 – Modulus reduction (left) and damping (right) curves from unit SU1BB: blue [34]; background [35]; resonant column (black dots) and cyclic triaxial (red dots) tests (after [5]).

4. Seismic aspects: site hazard and 1985 Michoacan earthquake

The seismic hazard of the site was provided by IIUNAM ([29], [30]) for various return periods (Tr), as base to determine the structure-specific design parameters. The sources governing the seismic hazard are two: subduction earthquakes and intermediate depth, cortical events. The subduction earthquakes occur along the plates boundary in the Pacific coast, more than 280 km from Mexico City and more than 300 km from the NAICM site. Magnitudes from this source can reach up to 8.4 [29]. The intermediate events are product from the subduction process as well, but these are local. Intermediate events have focal depths between 30 and 120 km and their estimated maximum magnitude is 8.1 [29]. The peak ground accelerations (PGA) at reference level are listed on **Table 3**.

Table 3 – Pseudoaccelerations from uniform hazard (5% critical damping) for bedrock, in cm/s^2 (after [29])

Tr [years]	**47.5**	**125**	**250**	**475**	**2475**
PGA (T=0.05s)	56.8	86.9	117	150	271

The site-specific GRA followed ASCE 7 [37] using a minimum of five recorded horizontal ground motion time histories, scaled and matched to each target spectrum, from events having magnitudes, fault distance, and source mechanisms consistent with those that control the hazard [5]. But for this specific study, a record from the 1985 great earthquake measured near the site is used to compare the 1-D GRA from the NAICM site. The horizontal components from that event, recorded at reference level (bedrock or seismic base layer), were loaded to the whole grid of 1D models from the site.

Within and near the NAICM site are some accelerographs (**Fig. 2**). Most are on soil, only TXCR is founded on rock. From those stations, only TXSO (Texcoco Sossa) registered the great Michoacán earthquake in 1985. That station is near 3 km northwest from the site and is used to compare with the GRA response from the 1D models at the northwestern corner of the NAICM site. Two stations from the Mexican valley were used as reference stations at engineering bedrock. These are CU01, founded on rock, and TACY founded on hard soil (**Fig. 2**). Other available measurements from two stations on soil (CDAO, SCT) from the southern side of Mexico City are used to review the site effects during the 1985 Michoacán event (**Fig. 2**).

Some of the ground motion parameters measured at the soil stations are listed in **Table 4**. The horizontal peak accelerations and velocities at rock or seismic base layer (SBL) range between 27 and 34 cm/s^2, and 8.2-10.5 cm/s at CU01 and TACY reference stations respectively.

Table 4 – Ground motion parameters from horizontal components, 1985 Michoacán event measured on stations on soil

Station	**CDAO**		**SCT**		**TXSO**	
Component	N00E	N90E	N00E	N90E	N00E	N90E
Max. Aceleration [cm/sec^2]	61.59	78.26	103.15	165.305	103,04	102,97
Max. Velocity [cm/sec]	29.97	34.06	35.8	58.02	9,836	8,98
Max. Displacement [cm]	19.72	21.8	15.6	22.11	27,57	17,6
Arias Intensity: [m/sec]	1.13	1.02	1.2	2.24	0,319	0,237

5. GRA at NAICM

The GRA was executed with 1-D equivalent-linear (E-L) method with STRATA [38]. In this method, vertically propagating, horizontally polarized SH shear waves (in-plane) propagate through a site with assumed infinite horizontal layers, above a half-space (seismic base layer). In principle, within this simple method the possible occurrence of surface waves due to the basin effect is not incorporated. A comparison for verification was made with the software Deepsoil (V.6.1, from Univ. of Illinois at Urbana-Champaign and Y. Hashash). A regular grid throughout the site with 400 m spacing and a total of 329 points was used to quantify the GRA for various seismic scenarios towards the design of several structures. **Fig. 4** shows an overview of the site with its respective interpolated site periods determined at each point of the grid with the mean Vs and depth to the seismic base layer (first mode natural frequency). At each point, the soil model was extracted from the 3-D geomodel and 1-D models were automatically generated for their GRA. This publication shows only the response from the 1985 Michoacán event. The input parameters and the seismic scenarios are described in Sections 3 and 4.

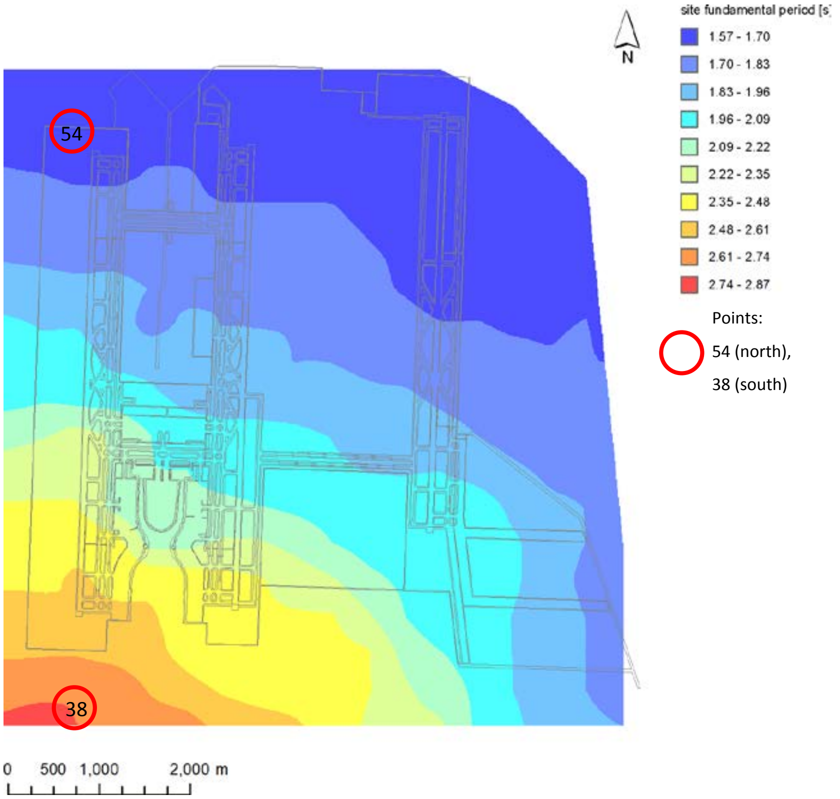

Fig. 4 –Site periods (Ts). Red circles indicate points 54 and 38, used for the analysis

The input time histories loaded into the 1D models are the two horizontal components from the records from CU01 and TACY stations. The ground responses at surface are compared then to the surface response measured at TXSO station (**Fig. 2**). The outputs from one point towards the northwestern corner of the NAICM site are used (point 54 named north herein, **Fig. 4**), as considered the closest point to station TXSO. The outputs from another point from the southern edge of the site are used as well in the analysis (point 38 named south herein, **Fig. 4**).

The peak ground accelerations from the north-western sector are similar to the measured values at TXSO (**Fig. 5** and **Table 4**). But a larger range of values appears towards the south, where appear thicker soft clays and larger Ts. To account for the complete period range, the ground response is compared in terms of response spectra (**Fig. 5**). A good agreement is found among the measured spectral response from TXSO and the response from the northern point to a single signal (CU, north component: CUN00E). The fit among the measured response and mean horizontal responses is less good but the overall shape of the spectra remains similar. The fit among the measured TXSO and modeled CUN00E response spectrum is good up to a period of near 2.3 seconds. The E-L response at periods above 2.3 seconds appears over-damped. Furthermore, the same E-L model has a higher peak spectral acceleration (PSA) near the natural period (Ts) of the soil column, suggesting resonance. E-L is known to show a stronger resonant response ([38],[39]). Such amplification could be decreased with a nonlinear model, however the period range is narrow, in general the E-L approximation is good. At higher seismic loads this effect of nonlinearity might become a more relevant issue. At the north point the soil column has 55.6 m depth to the seismic base layer with a Ts=1.65 seconds. The southern point displays a shift towards longer periods in the spectral response, in relation to the reference from TXSO (**Fig. 5**). The soil column there is deeper (around 70 m) with a higher Ts (2.5 s), coinciding with the larger PSA. The spectral response from the southern point clearly differs from the one at the north and TXSO station (**Fig. 5**).

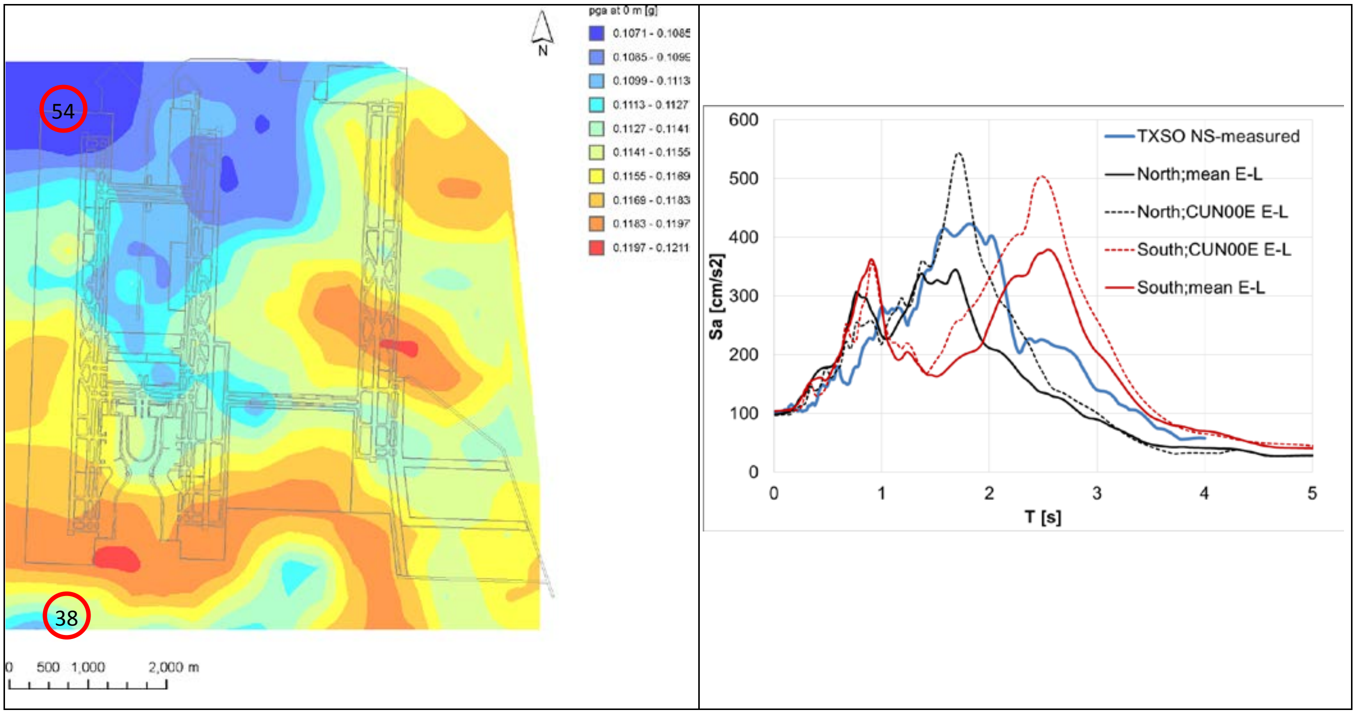

Fig. 5 – Left: Peak ground acceleration during the 1985 Michoacán earthquake at NAICM site obtained from the 1-D GRA. Right: Response spectrum 1985 Michoacán earthquake measured at TXSO station (blue); compared to calculated response spectrum with 1D E-L at north (black) and south (red) points; continuous curves represent mean response and dotted curves the response from a single component from CU01 station.

A common limitation from E-L models is a higher PGA and over-damped high frequencies [39]. However, for this site and at this level of seismic load this does not occur. The 1D E-L model captures well the spectral shape on the low period but is less alike towards the higher (**Fig. 5**). This difference can be an indicator of the basin effect acting at the higher periods as pointed by [15], although nonlinearity effect there cannot be discarded. Besides the possible basin effect on the ground response, one might wonder as well if the nonlinear

(N-L) response is well captured on such E-L models. To gain further insight on this, the maximum shear strains are plotted in depth for the north and south points in **Fig. 6**. In the same figure is also illustrated the strain index (γ,ind) from both sites. This index corresponds to the peak ground velocity at bedrock (PGV;r) divided by the mean shear wave velocity form the upper 30 m (Vs;30) [39].

Until date, there is no full consent on an onset of nonlinearity but recent proposals suggest a certain shear strain (γmax), for instance, [41] sets a 0.4%, but adds that can be as low as 0.1%; while [39] points it is typically around γmax~0.5-1.0% . Both interpretations are included in **Fig. 6**, and it is clear that for the 1985 earthquake, the strains calculated at the northern point are below possible nonlinearity (stiffer) and the ones at the southern point near the onset. The strain indexes provide a similar insight: the northern point is less soft with low γ,ind and the southern point is softer. According to [39], site response is not affected by nonlinear soil behavior at periods T>0.7 s. The E-L models capture well the nonlinear response from this seismic scenario, excepting around the natural frequency of the soil, where resonance amplifies the E-L response, in agreement with [40].

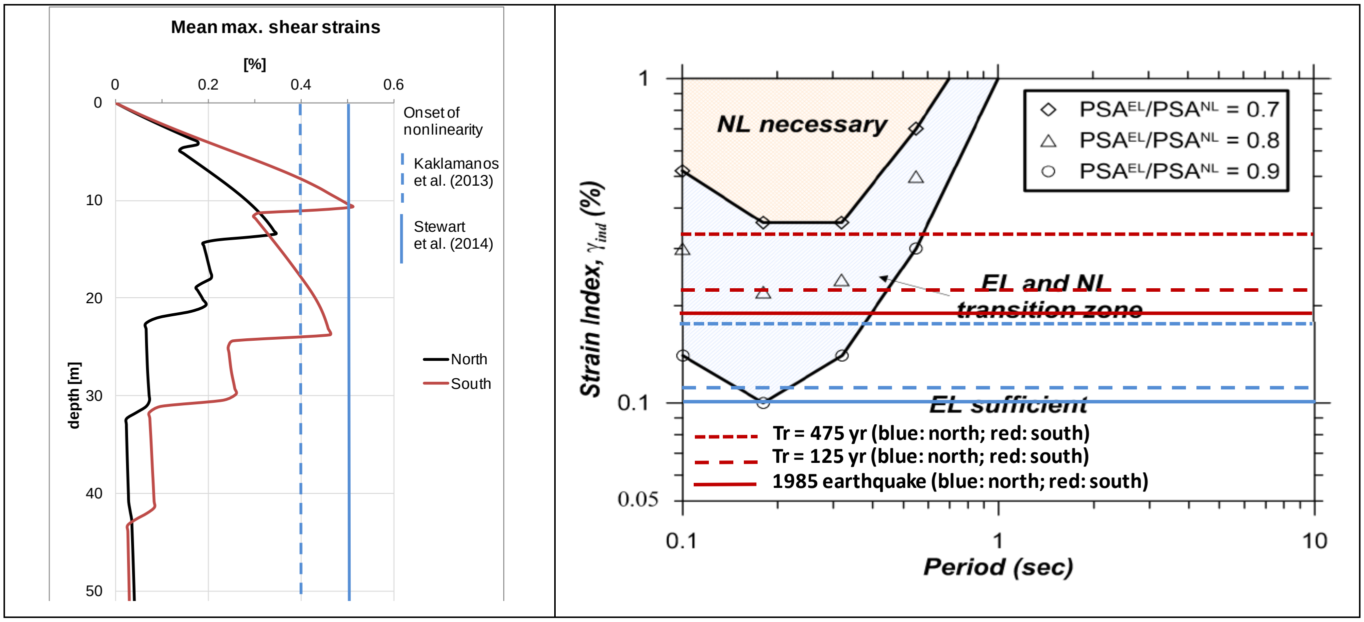

Fig. 6 – Left: Maximum shear strains from E-L models from north and south points in relation to proposed onsets of nonlinearity. Right: Strain index (γ,ind) for the north and south points at different seismic scenarios. The variation from this index indicates where PSA from E-L are biased low relative to PSA from nonlinear analysis (after [38])

To extend the review from the E-L ground response throughout the whole NAICM site, mean peak spectral amplification ratios with respect to the reference station, CU01, at the natural periods. These ratios were estimated for all the points of the grid and are plotted in **Fig. 7** together with the measurements from [2], as well as the interpretations from [3]. The velocity contrasts at NAICM range between 3.3 and 6, therefore the expected amplitudes will vary as well. The variation found from the 1D E-L at the NAICM is higher than the 1D models from [3] and shows agreement with the mean interpretation from [3] on the measurements from [2]. The measurements from [2] are clearly larger towards the longer periods. 1D E-L appears to have a relatively constant amplification for the covered period range (T=1.6-2.9 s). There are no higher periods at the NAICM site, therefore it is unknown the performance from the 1D E-L at that range. From the actual trend of relatively constant amplification on the E-L responses (**Fig. 7**), together with the response spectrum (**Fig. 5**) it can be expected that 1D E-L represents well the site response for periods up to 2.3 seconds. The response spectrum gets saturated above that period. Such range 1D E-L appears to handle is in agreement to the proposed period of 2 seconds [15], above which basin effects become important on the site response.

In time domain, the modelled response from individual input horizontal components of CU01 showed reasonable agreement to the measured amplitudes at TXSO station (**Fig. 8**). The register from TXSO does not seem to show the longer duration observed at other particular sites of the Mexican valley that cannot be reproduced by 1D models, addressed by [1],[3],[20], among others. It is plausible that at TXSO site the effect of surface waves is lesser than at other sites of the valley.

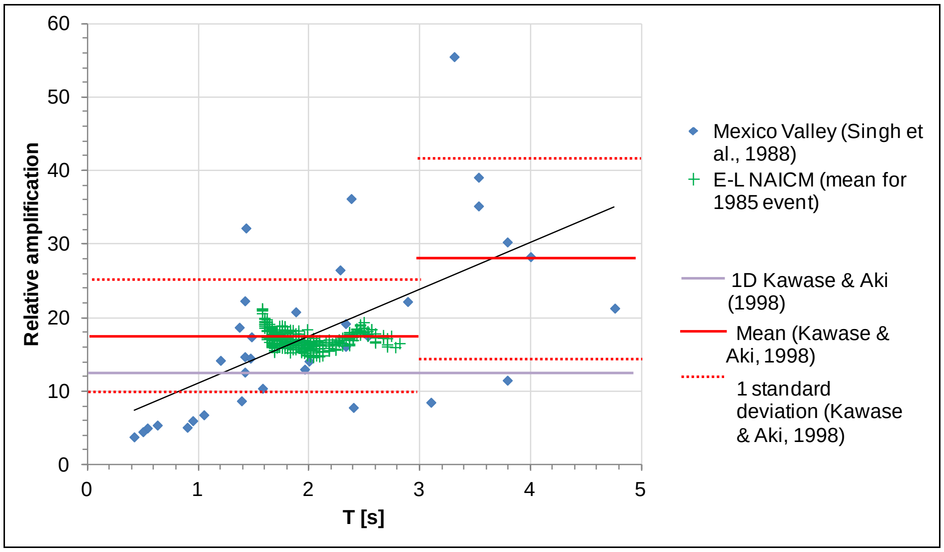

Fig. 7 – Comparison among 1985 earthquake spectral amplification ratios measured by [2] with respect to CU01 station at the natural periods (blue); 1D models and interpretation from [3]; 1D E-L models (mean) from this article (green). Black line corresponds to the linear trend from the observed ratios from [2]

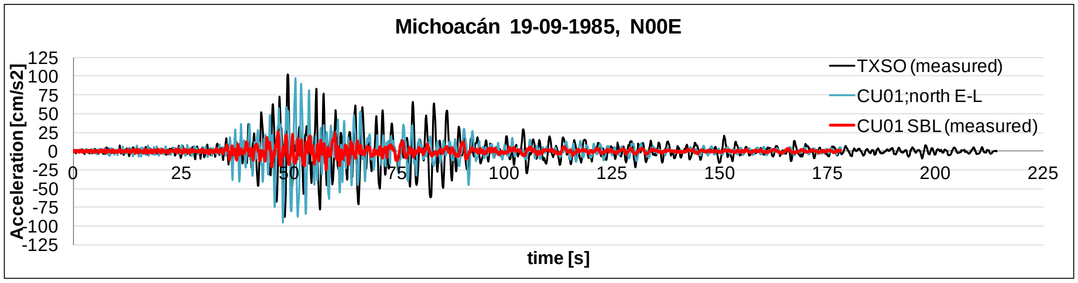

Fig. 8 – Comparison of surface measurement (TXSO) with 1D E-L ground response from north point

6. Conclusions

The 1D E-L models from the NAICM site show agreement, within some extend, to the measured response at station TXSO, near 3 km to the north-west, during the 1985 Michoacán earthquake. The peak ground accelerations and response spectrum are in agreement up to a period of 2.3 seconds. The common limitation from E-L approach at high frequencies is not found in the response from this site at this seismic load, but on the longer periods the modeled and measured responses diverge. The best match found among the measured response to the modelled 1D E-L corresponds to a site from the north-western corner of the NAICM site. In particular, the best match is found from an individual signal response from CU01 station, rather than a mean response from the different horizontal components assessed. In the response spectrum, it is noticed a larger spectral amplitude of the E-L peak response towards the natural period of the soil. This is related to resonance, the E-L method is known to amplify more near the resonant site frequency. For the northern part of NAICM, the amplitude of the time history is reasonably captured as well. The point measured at the south of the site, showed different spectral response, expected given its different soil profile.

The response from the NAICM site is compared as well to the measurements throughout the whole Mexican Valley provided by [2], and analyzed by [3]. The NAICM 1D E-L site response falls in agreement to the measurements of the 1985 earthquake for the natural periods of the site (T=1.6-2.9 s, **Fig. 7**). However, the trend of the E-L response is relatively constant, meaning that the increase in the amplification towards the larger periods observed during that earthquake will not be captured by the 1D E-L method.

Summarizing, the response spectrum and relative amplitudes point to a good match among the 1D E-L response to the actual measurements of the 1985 Michoacán earthquake for periods up to 2.3 seconds (after the response spectrum). The response at higher periods is over-damped. At those periods the basin effects influence more the ground response, when the slower surface waves lead to larger amplitudes and durations that simple E-L models cannot reproduce. On this regard, at other places it has been suggested that basin effects start playing a role at periods larger than 2 s [15] or even as low as 0.7 s [8]. For practical purposes in engineering design, special attention is recommended within the Mexican codes for that long-period range. A factor might be necessary to implement to design spectrum or ground motion prediction equations at periods T>2.3 s approximately, as already pointed by others (e.g. [3],[11]). More clear guidelines are still needed on the need and use of such factors on seismic-resistant design on those particular seismo-tectonic environments.

The findings from this study should be taken with care since the whole response is site-dependent, variations on basin shape and seismic hazard will all have an influence on the overall seismic response. The findings from this study are applicable to the assessed site.

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8. References

[1] Seed, H.B., Romo, H.M., Sun, J.I., Jaime, A., Lysmer, J. (1988): The Mexico earthquake of September 19, 1985 - Relationship between soil conditions and earthquake ground motions. *Earthquake Spectra*, **4** (4), 687-729.

[2] Singh. S.K., Lermo, J., Dominguez, T., Ordaz, M., Espinoza, M., Mena, E., Quaas, R. (1988): The Mexico earthquake of September 19, 1985 - A study of amplification of seismic waves in the Valley of Mexico with respect to a hill zone. *Earthquake Spectra*, **4** (4), 653-673.

[3] Kawase, H, Aki, K (1989): A study on the response of a soft basin for incident S, P, and Rayleigh waves with special reference to the long duration observed in Mexico City. *Bulletin of the Seismological Society of America*, **79** (5), 1361-1382.

[4] TASANA. (2015a): Ground Interpretation Report (GIR). *Design Studies, Second Phase,* Ciudad de México: TASANA.

[5] TASANA. (2015b): Ground Response Analysis Final Study. *Design Studies, Second Phase*, Ciudad de México: TASANA.

[6] Bard, PY, Bouchon, M (1980a): The seismic response of sediment filled valleys. Part I. The case of incident SH waves. *Bulletin of the Seismological Society of America,* **70**, 1263-1286.

[7] Bard, PY, Bouchon, M (1980b): The seismic response of sediment filled valleys. Part II. The case of incident SV waves. *Bulletin of the Seismological Society of America,* **70**, 1921-1941.

[8] Stewart, JP (2011): Southern California seismic site response: effects of basin geometry and shallow geometry. *Lecture presentation*, Los Angeles, Univ. of California.

[9] Kramer, SL, Stewart, JP (2004): Geotechnical aspects of seismic hazards. In: *Earthquake Engineering: From Engineering Seismology to Performance-Based Engineering*, Y Bozorgnia and VV Bertero (eds.), CRC Press.

[10] Bormann, P, Engdahl, B, Kind, R (2012): Seismic wave propagation and Earth models. In: *New Manual of Seismological Observatory Practice 2 (NMSOP2),* P Bormann (ed.), Potsdam Deutsches GeoForschungsZentrum GFZ.

[11] Chávez-García, FJ, Faccioli, E (2000): Complex site effects and building codes: making the leap. *Journal of Seismology*, **4**, 34-40.

[12] Joyner, WB (2000): Strong motion from surface waves in deep sedimentary basins. *Bulletin of the Seismological Society of America*, **90** (6B), S95-S112.

[13] Semblat, JF (2002): Seismic site effects for shallow and deep alluvial basins: In-depth motion and focusing effect. *Soil Dynamics and Earthquake Engineering*, **22** (9-12), 849-854.

[14] NIST (2011): Selecting and scaling earthquake ground motions for performing response-history analyses. *NIST GCR 11-917-15*, USA.

[15] Day, SM, Graves, R, Bielak, J, Dreger, D, Larsen, S, Olsen, KB, Pitarka, A, Ramirez-Guzman, L (2008): Model for basin effects on long-period response spectra in Southern California. *Earthquake Spectra*, **24** (1), 257-277.

[16] Somerville, PG, Collins, N, Graves, R, Pitarka, A (2004): An engineering ground motion model of basin generated surface waves. *Proceedings from 14th World Conference on Earthquake Engineering*, Paper No. 515, Vancouver, Canada.

[17] Narayan, JP (2004): 3D simulation of basin-edge effects on the ground motion characteristics. *Proceedings from 13th World Conference on Earthquake Engineering*, Paper No. 3333, Vancouver, Canada.

[18] Chávez-García, FJ (2007): Site effects: From observation and modeling to accouting for them in building codes. In: *Earthquake Geotechnical Engineering*, KD Pitilakis (ed.), Springer.

[19] Bard, PY (2007): Ground shaking site effects: fundamentals and modelling. *Presentation: 'Lectures on site effects'*, PYB, University of Granada, May 2007, http://www.ugr.es/~geomet/doc/lecture1_pyb.pdf

[20] Sánchez-Sesma, FJ, Chávez-Pérez, S, Suárez, M, Bravo, MA, Pérez-Rocha, LE (1988): On the seismic response of the Valley of Mexico. The Mexico earthquake of September 19, 1985. *Earthquake Spectra*, **4**, 569-589.

[21] Ordaz, M, Faccioli, E (1994): Site response analysis in the valley of Mexico: Selection of input motion and extent of non-linear soil behaviour. *Earthquake Engineering and Structural Dynamics*, **23**, 895-908.

[22] Flores-Estrella, H, Yussim, S, Lomnitz, C (2007): Seismic response of the Mexico CIty Basin: A review of twenty years of research. *Natural Hazards*, **40**, 357-372.

[23] Singh, SK, Ordaz, M (1993): On the origin of long coda observed in the lake-bed strong-motion records of Mexico City. *Bulletin of the Seismological Society of America*, **83** (3), 1298-1306.

[24] Chávez-García, FJ, Bard, PY (1994): Site effects in Mexico City eight years after the September 1985 Michoacan earthquakes. *Soil Dynamics and Earthquake Engineering*, **13**, 229-247.

[25] Chávez-García, FJ, Salazar, L (2002): Strong motion in central Mexico: A model based on data analysis and simple modeling. *Bulletin of the Seismological Society of America*, **92**(8), 3087-3101.

[26] Chávez-García, FJ, Ramos-Martínez, J, Romero-Jiménez, E (1995): Surface wave dispersion analysis in Mexico City. *Bulletin of the Seismological Society of America*, **85**(4), 1116-1126.

[27] Chávez-García, FJ, Quintana, L (2010): Velocity structure under the Trans-Mexican Volcanic Belrt: preliminary results using correlation of noise. *Geophysical Journal International*, **183**, 1077-1086.

[28] II-UNAM (2014a): Estudio de Estructuras. Para resolver la problemática del transporte aéreo en el centro del país. *Convenio de colaboración no. ASA-UNAM-13-001*. Tercer Informe Parcial y Final (Noviembre 2014).

[29] IIUNAM (2014b): Revisión y Evaluación en Geotecnia y Estructuras. Para resolver la problemática del transporte aéro en el centro del país. *Convenio de colaboración no. ASA-UNAM-13-002.* Informe Final (diciembre 2014).

[30] Ovando E, Romo MP (1990): Correlación entre la velocidad de propagación de ondas sísmicas y la resistencia a la penetración. In: *Memorias de la XV Reunión Nacional de Mecánica de Suelos*, SMMS, vol. 2, 1990.

[31] Mayoral JM, Romo MP, Osorio L (2008): Seismic parameters characterization at Texcoco lake, Mexico. *Soil Dynamic and Earthquake Engineering*, **28**, 507-521

[32] Mayne PW, Rix GJ (1995): Correlations between shear wave velocity and cone tip resistance in natural clays. *Soils and Foundations*, **35** (2), 107–110.

[33] Romo MP, González-Blandón, CM (2011): Estimación de propiedades de arcillas. *Ingeniería Sísmica*, **84**, 1-23.

[34] Vucetic M, Dobry R (1991): Effect of soil plasticity on cyclic response. Journal of the Geoechnical Engineering Division, ASCE, **117** (1), 89–107.

[35] Seed HB, Idriss IM (1970): Soil moduli and damping factors for dynamic response analyses. *Technical Report EERC 70-10*, Earthquake Engineering Research Center, University of California, Berkeley, CA.

[36] ASCE 7-10 (2010): Minimum Design Loads for Buildings and Other Structures. *ASCE Standard [ASCE/SEI 7-10]*, USA.

[37] Kottke AR, Wang X, Rathje EM (2013): *Technical Manual for STRATA*. Geotechnical Engineering Center, Dept. Of Civil, Architectural and Environmental Engineering, University of Texas.

[38] Stewart JP, Afshari K, Hashash YMA (2014): Guidelines for performing hazard-consistent one-dimensional ground response analysis for ground motion prediction. *Technical Report PEER 2014/16*, Pacific Earthquake Engineering Research, Berkeley, CA..

[39] Kim B, Hashash YMA, Stewart JP, Rathje EM, Harmon JA, Musgrove MI, Campbell KW, Silva WJ (2016): Relative differences between nonlinear and equivalent-linear 1D site response analyses. *Earthquake Spectra, in press*.

[40] Kaklamanos J, Baise LG, Thompson EM, Dorfmann L (2015): Comparison of 1D linear, equivalent-linear, and nonlinear site response models at six KiK-net validation sites. *Soil Dynamics and Earthquake Engineering*, **69**, 207-219.