Synthetic ground motion system (SGMS) for structural design and evaluation in Mexico City

Leonardo Ramirez-Guzman, Miguel Angel Jaimes Téllez, Jorge Aguirre González and Joaquín Sánchez Sánchez
Objective of the System

Provide a documented and validated web-based platform that will allow structural and geotechnical engineers to obtain ground motions, either synthetic or observed, in the 3 geotechnical zones of Mexico City for design and evaluation purposes.

Ongoing Project funded by the Institute for Structural Safety of Mexico City
Need for Synthetic Seismograms

- Recent construction boom of tall buildings
- New Seismic Provision

Tall Building Corridor
*Crossing the city from the Lake to the Hill zone*

Geotechnical Zones
- **Hills (rock)**
- **Transition**
- **Lake**
Outline

• Introduction
  • Site Effects
  • MCTNSD* (Current and Proposed Seismic Provisions in Mexico City)
• Ground motion generation methods used
• System Overview
• Conclusion

*MCTNSD – Mexico City Technical Norms for Seismic Design
Introduction

Valley of Mexico and Mexico City

- Close to one fourth of Mexico’s population is concentrated in the valley
- More than one-third of the GDP is generated there
- The city has more than 1.5 million structures
- Part of the city is built in the former Lake of Texcoco

![Map showing the location of Mexico City and its surroundings.](image)
Introduction

Unusual site effects

Amplification

Acceleration records for the Mw 8.0 September 19th Michoacan Earthquake. After Singh et al. (1988, BSSA). Instrumentation and data maintained by the Seismic Analysis and Instrumentation Team (II-UNAM)
Introduction

Unusual site effects

Long duration

- **Hills (rock)**
- **Transition**
- **Lake**
Unusual site effects

**Long duration**

- **Ground motions should at least consider**
  - Large amplification (Lake/Hill)
  - Duration in the Lake
The building code provision for synthetic ground motions for Mexico City

- Allows the use of synthetics
- More than four ground motions (independent or combinations)
- Non-linear effects and uncertainty should be considered
- Intensity levels should be compatible with the code

MCTNSD

“If a step-by-step analysis is performed due to specific earthquakes, recorded accelerograms, simulated ground motions, or combinations of the aforementioned can be used, always considering more than four representative ground motions independently, whose intensity levels are compatible with those described in this provision, and considering the nonlinear behaviour of buildings and the uncertainty in their parameters.”

NTCS

“Si se emplea el método de cálculo paso a paso de respuestas a temblores específicos, podrá acudirse a acelerogramas de temblores reales o de movimientos simulados, o a combinaciones de éstos, siempre que se usen no menos de cuatro movimientos representativos, independientes entre sí, cuyas intensidades sean compatibles con los demás criterios que consignan estas Normas, y que se tenga en cuenta el comportamiento no lineal de la estructura y las incertidumbres que haya en cuanto a sus parámetros.”
The building code provision for synthetic ground motions for Mexico City

- Pairs of simulated or recorded accelerations or combinations are allowed.
- 6 Pairs are required for analysis
- The ground motion intensity, duration and frequency content must be similar to the observed records in the site of interest, considering Uniform Hazard Spectra with 5% damping and a return period of 250 yrs.
- Disaggregation, choose M and R.
The building code provision for synthetic ground motions for Mexico City

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- Disaggregation, choose M and R.

What about validation? How do we guarantee that the signals are appropriate in terms of intensity, duration, and frequency content?
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# Ground motion generation methods used

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*Most commonly used*
Ground motion generation methods used

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- Building Design
- Dams
- Ground Motion Parameter Maps Scenarios

\[ A_e(\omega) = \xi A_s(\omega) \sum_{j=1}^{N} e^{-i\omega t_j} \]

\[ \xi = \left( \frac{M_{0e}}{M_{0s}} \right)^{-1/3} \left( \frac{\Delta \sigma_e}{\Delta \sigma_s} \right)^{4/3}, \]

\[ |P(\omega)| = \frac{\sqrt{1 + \alpha(\omega/\omega_{ce})^2}}{1 + (\omega/\omega_{ce})^2}, \]

*As: Green’s function (seed)*

\( t_j \): starting time at “cell” j with PDF p(t)

\( \omega_{ce} \): corner frequency target event

\( \omega_{cs} \): corner frequency of the event that produced the Green’s function

**Key point:**
Modify (far-field approx.) the seed (Green’s function) by:

\[ F_c(\omega) = \frac{R_R}{R_M} \left[ \exp\left(\frac{-\omega \cdot (k_M - k_R)}{2}\right) \cdot \exp\left(\frac{-\omega \cdot (R_M - R_R)}{2Q\beta} \right) + \frac{\omega \cdot (R_M - R_R) \cdot \ln(\omega/\omega_{Nq})}{Q\beta \pi} \right] \]
The fundamental difference from the previous methods is the deterministic character of the rupture velocity and the hypocentral location.

One of the key features of the approach is the “accurate” modeling of directivity effects.

Some variants of the approach include fractal distributions of the slip distribution.
Validation
April 25th earthquake using May 5th 1989
Simulation
April 25th 1989
earthquake using May 5th 1989

Ground motion generation methods used

- Jaimes, Reinos and Ordaz (2009) JEE
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Ground motion generation methods used

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- Irikura (1986).
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- Building Design
Ground motion generation methods used

COPL ew displacement

COPL ew velocity

COPL ew acceleration

COPL ns displacement

COPL ns velocity

COPL ns acceleration

Observed

Synthetic
Hybrid Methods

| Ramirez-Guzman | Liu et al., (2006), BSSA | Tu et al. (2006), Proceedings SC Hercules code | Ground Motion Parameter Maps |

3D Velocity Model
Xyoli Perez-Campos and Arturo Iglesias (IG-UNAM) provided data to better constrain the model.
Mexico City Model

Processing Building Inventory and LiDAR

$V_s$ is assigned assuming that each building behaves like a shear beam and the fundamental period is $\#\text{stories}/10$

Tallest building (225m)
Simulations and Results

- Intraslab Earthquake (regional effect minimized)
- June 16th Mw=5.9 Huitzuco, Mexico
- Maximum Frequency=1Hz
- 85 seconds simulation
- ~215 K elements
- Minimum element size=2m

Simulated at DGTIC-UNAM cluster
Duration = time to reach from 0.05 to 0.9 the acceleration energy
Simulations and Results

- Intraslab Earthquake (regional effect minimized)
- June 16th Mw=5.9 Huitzuco, Mexico
- Maximum Frequency=0.75 Hz
- 105 seconds simulation
- ~100 K elements
- Minimum Vsmin=500 m/s (no basin), no buildings
- Bigger domain

Goodness of Fit (GOF). The overall grade for the model under the excitation of the 2013 Huitzuco earthquake was fair, following Olsen and Mayhew (2010).
Simulations and Results

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System Overview

User request
Mw, station, hyp.

Velocity Model
Fault and/or Mw Definition
Strong Ground Motion (UNAM)

Source Generation
Point Source (Orda et al., 1995)
Kinematic (Liu et al., 2006)
Kinematic (Irikura, 1986)

EGF (Irikura, 1986)
FEM+BB (Tu et al., 2006)
EGF (Irikura, 1986)

Ground Motion Generation

Synthetic Seismograms
Analysis
Use (Building Provisions)

Analysis
GOF-Olsen, K.B., and J.E. Mayhew (2010). Historic
2 Subduction and 1 intraslab

GMPMs for Hill and Lake-Bed Zones of Mexico City
Jaimes et al. (2015)
We have a stand-alone version of the system (for the EGF1 method)
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Validation

2014 Mw 7.3 Papanoa.

- Earthquake and aftershocks recordings available at most accelerographic stations (EGF methods)
- Source Inversion available (EGF2 and Hybrid Simulations)

Mendoza and Martinez (2016, in press)
Conclusions

• Quick overview of the importance of site effect in synthetic seismograms in Mexico City
• Mentioned some of the commonly used techniques
• The general overview of the Project (in progress)
Thank you!