NEAR REAL-TIME GROUND MOTION PARAMETERS AND LOSS ESTIMATES SYSTEM FOR MEXICO CITY

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Abstract

We present and describe a near real-time Ground Motion Parameters and Loss Estimates Map Generation system for Mexico City. The system delivers physics-based estimates of engineering ground motion parameters (EGMP), macroseismic intensity, building damage, and water leak maps after any earthquake affecting Mexico's capital. The system is self-contained and can automatically or manually perform all calculations required for estimating EGMP and maps.

The initial data processing stage consists of baseline correcting and removing records containing glitches or low signal-to-noise ratio in regional and local stations. Then, required information on the source characteristics is estimated using a preliminary hypocentral location, magnitud and moment tensor, followed by a quick source time function estimate, obtained using a pre-calculated Receiver Green's Tensors (RGT) database for a realistic 3D model of Mexico and Mexico City. Spectral acceleration at different periods and peak ground motion values are obtained for more than 45 stations within the city and combined with values derived from synthetic seismograms using a Kriging algorithm. The hybrid synthetic generation approach relies on empirical Green's functions and numerical simulations performed in near real-time, using the RGT database. The resulting EGMP maps serve as input for fast estimates of collapsed structures and water leaks using six building classes and a damaged pipeline function based on peak ground velocity and acceleration. The maps are available to the public and the institutions in charge of civil protection and prevention approximately 10 minutes after the earthquake started.

Keywords: Mexico City; Risk assessment; Ground Motion and Intensity Maps

1. Introduction

Mexico City's seismic motion is primarily the result of interplate and deep intraslab earthquakes. The interplate seismicity, mostly observed near the Pacific's coastline, includes more than 50 earthquakes with M7 which caused minor to severe damage. Intraslab earthquake, not as frequent as the former type, have a complex spatial distribution and highly variable depth. Even though the hazard posed by interplate seismicity in Mexico City is high, compared to intraslab events, the latter have been widely felt and have caused severe damaged, such as the most recent M7.1 September 19, 2017, Puebla Morelos quake (Melgar et al., 2018).

The worst natural disaster faced by the population of Mexico's capital in recent history is the interplate M8.1 September 19, 1985 Michoacan event. Together with its aftershocks, it killed 5000 people and damaged 20000 structures (Reinoso, 2002). The effects of the earthquake attracted several research groups, motivated others to continue the study of the soil motion amplifications and extended duration in the lake-bed zone compared to rock and triggered the development of several institutions and systems to respond and manage the potential risk in the aftermath of any event.

As part of the systems developed to provide prompt and accessible information, a High-Resolution Early Earthquake Damage Assessment (HREEDA) System was implemented in 2005 (Ordaz et al., 2017). The former system computes ground motion parameters based on response spectral values using a reference site station. Additionally, the HREEDA toolchain delivers estimates of collapsed buildings and leaks in the primary water systems of the city.

Advances in ground motion modeling and the availability of information in the growing seismic instrumentation in Mexico City, pushed for a major upgrade of the system, mainly to reduce the uncertainty on the ground motion parameters estimates and the databases of the lifelines and built environment. Therefore, the Secretary of Science and Technology of the city funded the Seismic Instrumentation Unit (SIU) for the development of the Integrated Seismic Monitoring System (ISMS) presented here. Among the new features of the ISMS, we highlight the inclusion of more than 45 stations spread out in the region and the use of numerical models to provide better estimates of the soil motion, which feed the damage assessment engines with updated databases.

2. Methodology

The ISMS implementation is orchestrated in an end-to-end toolchain, whose main elements are displayed in Figure 1. Two conditions trigger the system: 1) The detection of an earthquake with magnitude M, provided by the National Seismological Service (SSN, for its acronym in Spanish), greater than a trigger magnitude M_t; and 2) A peak ground acceleration (pga) recorded in any of the station located in Mexico City, received at the UIS, greater than a threshold value pga_t.

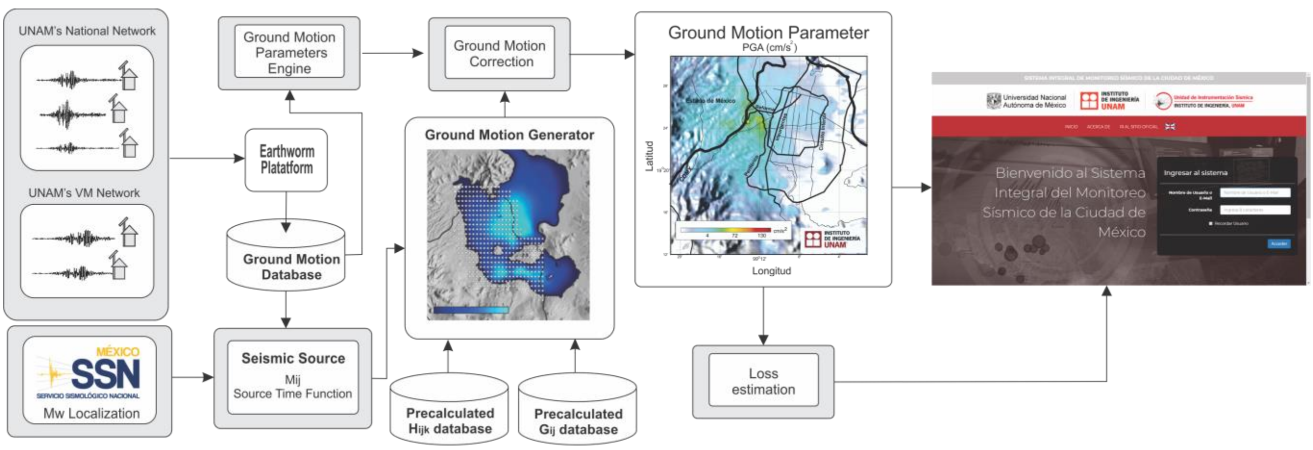

Fig. 1 – End-to-end Ground Motion Parameters and Loss Estimates System

As soon as any of the conditions is achieved, the system looks for the token and files associated to the quake, which include a preliminary magnitude and an initial time. All regional stations are extracted with initial time equal to the reported origin time minus 30 seconds and a duration of 3 minutes. Signals in the near field are used to obtain a quick estimate of the slip-rate function. In parallel, all stations within Mexico City are used to estimate ground motion parameters. Once a slip-rate function is available, an estimate of the ground motion is computed using a coarse grid of virtual stations, together with the same ground motion parameters obtained for the observations. Information from the simulations is combined with the observations to obtain maps of pga, peak ground velocity (pgv) and spectral acceleration (SA) used by the risk and damage engines.

3. Available Instrumentation, Data Processing and Acquisition

The instrumentation in Mexico includes several stations, among which more than 200 are operated by UNAM. Figure 2 only illustrates all stations installed (and reported) in and around Mexico City and those used automatically by the ISMS. The domain considered in the system encompasses mostly the urban areas around the capital, including regions of the neighboring State of Mexico.

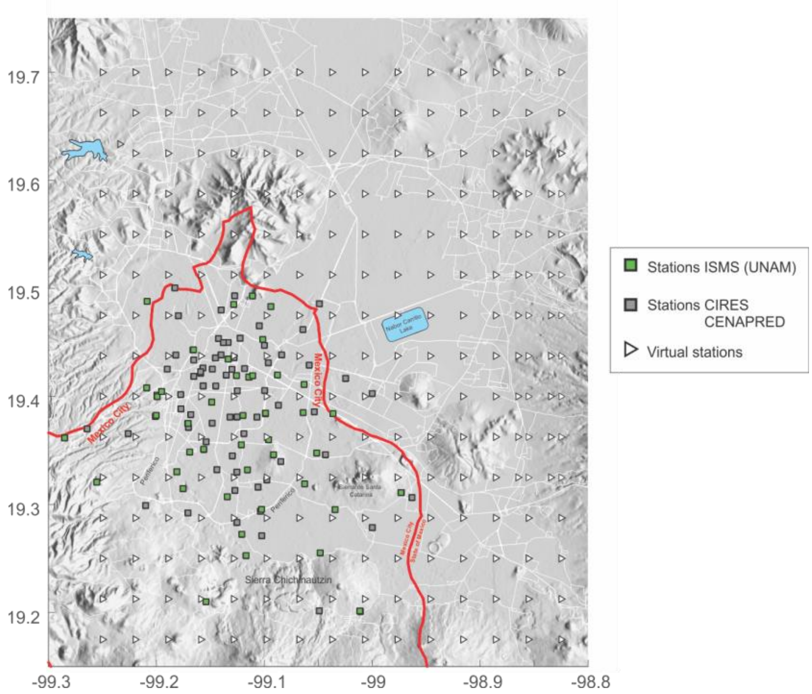

Fig. 2 – Strong Ground Motion Stations in Mexico City. Stations used by the ISMS are depicted with green squares. Stations operated by different institutions are displayed with gray squares. White triangles are the location of virtual stations, where synthetic ground motions are computed.

Once the system has detected an earthquake (using the SSN report or an intensity level associated to a quake), all signals received are processed by: 1) Applying a band-pass filter (0.025-25Hz), and 2) a computation of pga, pgv and SA for T=1, 2, and 3 s. Fig. 3 displays stations recorded and processed for M5.3 the January 30, 2020 earthquake near Coyuca de Benitez, Guerrero.

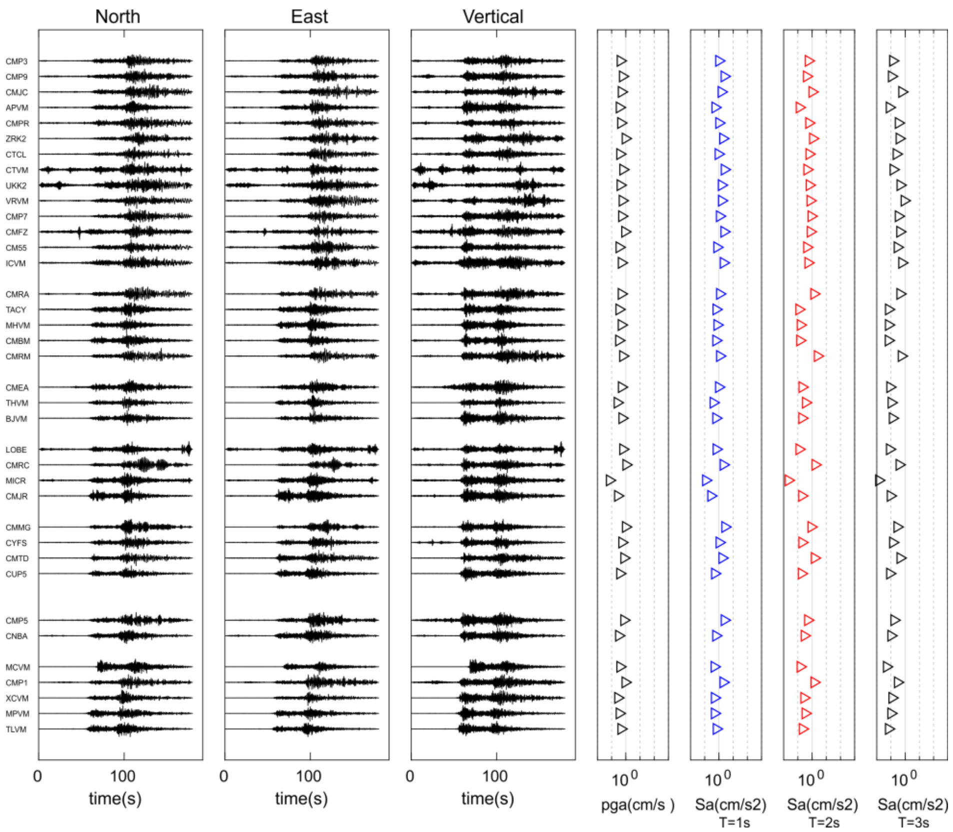

Fig. 3 – Accelerations recorded and processed by the ISMS for the M5.3 the January 30, 2020 earthquake near Coyuca de Benitez, Guerrero.

4. Ground Motion Parameter Estimates

We estimate low frequency displacement responses due to dislocations at observation points per potential faults, by computing strains at source locations due to three orthogonal forces located at stations sites and using reciprocity together with the source representation theorem for the computation of the displacement at a station due to different sources (see *e.g.* Zhao *et al.*, 2006; Lee *et al.*, 2011), *i.e.*

$$u_n\left(\bar{\mathbf{r}}_{\mathrm{r}},t,\bar{\mathbf{r}}_{\mathrm{s}}\right)=H_{ijn}(\bar{\mathbf{r}}_{\mathrm{s}},t,\bar{\mathbf{r}}_{\mathrm{r}})M_{ij}(\phi,\varphi,\theta,t) \quad (1)$$

where, $\bar{\mathbf{r}}_{\mathrm{s}}$ is the source location, $\bar{\mathbf{r}}_{\mathrm{r}}$ is the station location, $M_{ij}(\phi,\varphi,\theta,t)$ is the moment tensor defined in terms term with fixed strike $=\phi$, dip $dip=\varphi$ and rake $=\theta$, varying time and a third-order tensor, the Strain or Receiver Green's Tensor

$$H_{ijn}(\bar{\mathbf{r}}_{\mathrm{s}},t,\bar{\mathbf{r}}_{\mathrm{r}})=\frac{1}{2}\left[\frac{\partial G_{jn}\left(\bar{\mathbf{r}}_{\mathrm{s}},t,\bar{\mathbf{r}}_{\mathrm{r}}\right)}{\partial x_i}+\frac{\partial G_{in}\left(\bar{\mathbf{r}}_{\mathrm{s}},t,\bar{\mathbf{r}}_{\mathrm{r}}\right)}{\partial x_j}\right] \quad (2)$$

where $G_{pn}\left(\bar{\mathbf{r}}_{\mathrm{s}},t,\bar{\mathbf{r}}_{\mathrm{r}}\right)$ is the Green's function or displacement in direction $p=j,i$ due to an impulsive force acting along the n direction.

We created a database of RGTs for 15x15 virtual stations (see white triangles in Fig. 2) and 30 stations of UNAMs regional network. The horizontal and vertical grid spacing for the potential source location is approximately 10 km and 5 km. All computations were performed using the Carnegie Mellon Finite Element toolchain, Hercules (Tu *et al.*, 2006; Bielak *et al.*, 2010). The methodology is applied to obtain low frequency seismograms which are combined with ground motions computed using an empirical Green's function approach (Ordaz *et al*., 1995, Jaimes *et al.*, 2008).

5. Ground Motion Parameter Maps and Loss estimates

Quick source estimates are based on point sources with known focal mechanism. A slip function is obtained using a subset of stations of the national UNAM's network. An example of the peak ground motion maps for the M7.1 Puebla Morelos earthquake is shown in figure 4, together with the estimates of the damage and waterleaks, computed following Ordaz et al. (2017), with the newest available information on the structures and pipe information.

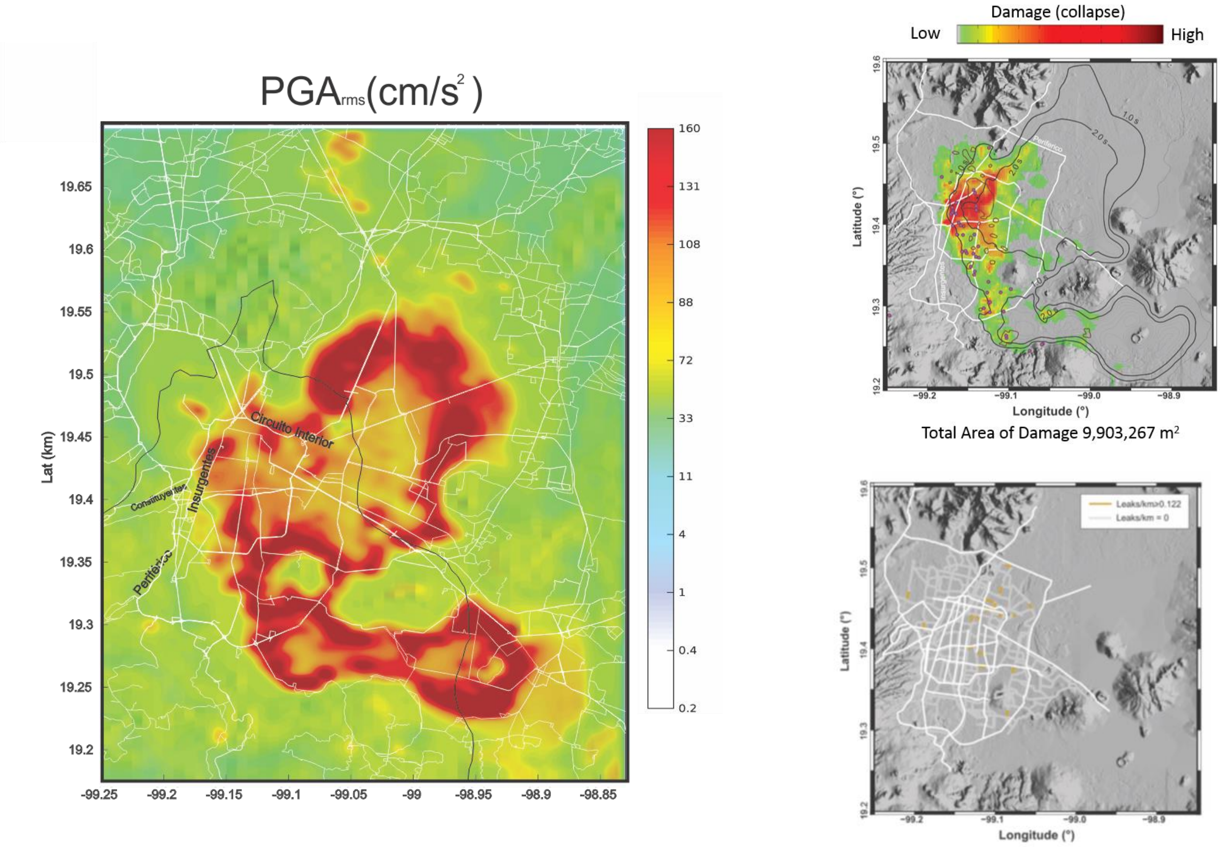

Fig. 4 – PGArms (left), building damage (upper right) and waterleak (lower right) estimates

6. Conclusions

We presented the new system Integrated Seismic Monitoring System (ISMS) for Mexico. The new system is a major update of the implementations prevously maintained by the UIS. The use of all observations available in the ground motion parameters calculations allows a reduction on the uncertainty of the estimates that feed the waterleaks and building damge computations.

4. Acknowledgements

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6. References

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