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Development of an integrated "source process-to-city response" earthquake simulation for Metro Manila

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Abstract

This study aims to develop of an integrated, source process-to-city response earthquake simulation for Metro Manila. The procedure follows the Integrated Earthquake Simulation framework with tools developed for input ground motion modeling, building dynamic analysis, and postprocessing. The required inputs are parameters that influence the dynamic response of soil and building structures. The main outputs are displacements and story drifts that can be used to analyze the variability of response of the different buildings in a city. As application example, low to mid-rise building models of a city in Metro Manila were analyzed for a scenario earthquake with different location of epicenters. The results showed that C1-M type buildings obtained about twice the average and standard deviation of peak inter story drifts of the C1-L type. The visualization of spatial distribution of buildings with varying story drifts allowed for verifying the derived statistical information, as well as for studying the effect of spatial parameters, such as epicentral distance to story drift.

I. Introduction

In the Philippines many identified active faults are located close to urban areas with dense residential and commercial buildings. Some of these areas are situated in soil types which may increase the severity of ground shaking in the event of an earthquake. In aid of disaster mitigation planning and preparation, tools that can provide quantitative estimates of needed parameters for decision-making are indispensable. The knowledge on the design, updated configuration, and vulnerability of the target buildings can expedite the process of determining the level of safety for occupancy of the structures for multiple earthquake events. When vulnerability information from all buildings in the target city are combined, the obtained overall response of the city can be used in specific actions, such as in planning for resource allocation, strategic positioning of emergency equipment, and emergency evacuation routes and sites. However, determining the overall response of a city remains a challenge because of the wide variability in material composition, vintage, and structural design of existing buildings.

A collaborative study by DOST-PHIVOLCS and Geoscience Australia applied an area-based procedure to Greater Metro Manila Area to analyze the response of cities to earthquake hazards (Allen et al., 2014). The area-based procedure combines the hazard information, exposure data, and vulnerability curves to map high risk areas. The reliability of this approach depends on the quality of historical data of damage and experimental data. The procedure outputs quantitative values, such as total damaged floor area and number of affected population per city for a given damage state. However, its use of representative building models for a city places a limitation on spatial resolution of the outputs. As an example, for a given building type and damage state, a single range of values of floor area, is assigned to an area of the city that is defined by a political boundary.

An alternative approach that aims to output parameters related to building damage (such as story drift and displacements) is the simulation-based approach (Hori and Ichimura, 2008; Homma et al., 2014; Fujita, et al. 2015; Quinay and Ichimura, 2016; Quinay, et al. 2018; Quinay and Grutas, 2019). Because time-varying characteristics of these parameters are modeled at pre-defined points in a building, the simulation-based approach naturally outputs data in high spatial resolution. The Integrated Earthquake Simulation (IES) is one of the tools that uses this approach for source-to-city seismic analysis. Recently, Hori et al., (2018), identified two main problems in application of IES for structure response analysis: (1) requirement of large computation; (2) requirement of numerous analysis models for structures. The increasing availability of moderate class computers with multi-core processors and high memory allows for validation of crust, soil, and structure models. Thus, it is expected that many risk analysis studies will employ the simulation-based approach in the future.

This study aims to develop an integrated, "source process-to-city response" earthquake simulation for Metro Manila. This paper describes the tools that were developed for generation of input ground motion, building dynamic analysis, and postprocessing, and the implementation of parallel computing techniques.

II. Methodology

Figure 1 shows the general procedure of source process-to-city response seismic analysis, following the framework of IES (Hori and Ichimura, 2008). The IES framework includes all the parameters that influence the input ground motion to structure and the structure response. The framework is designed to be computationally-efficient and not limited to run in single workstations. The framework also allows for integration with other disaster mitigation studies, such as evacuation simulations and lifeline analysis.

Input ground motion generation

The input ground motion generation step requires information on scenario earthquake parameters (such as type, geometry, rupture process of the fault, magnitude), crust and soil data, and location of buildings. Here, the long-period and short-period components are estimated, using any, or a combination of: numerical modeling, stochastic modeling, and use of past earthquake records. In numerical modeling, a discretized model is constructed from the 3-D model, wherein discretization elements are selected to suit the geometry, physical properties, and the target unknowns of the problem. In this study, a tool is developed to generate the time-varying input data for each building. The tool accounts for each setting of building model and fault, and generates the input ground motion dataset. The tool includes waveform processing, such as for converting displacement results to the required acceleration inputs, and extracting the frequency components of the waveforms using fourier analysis.

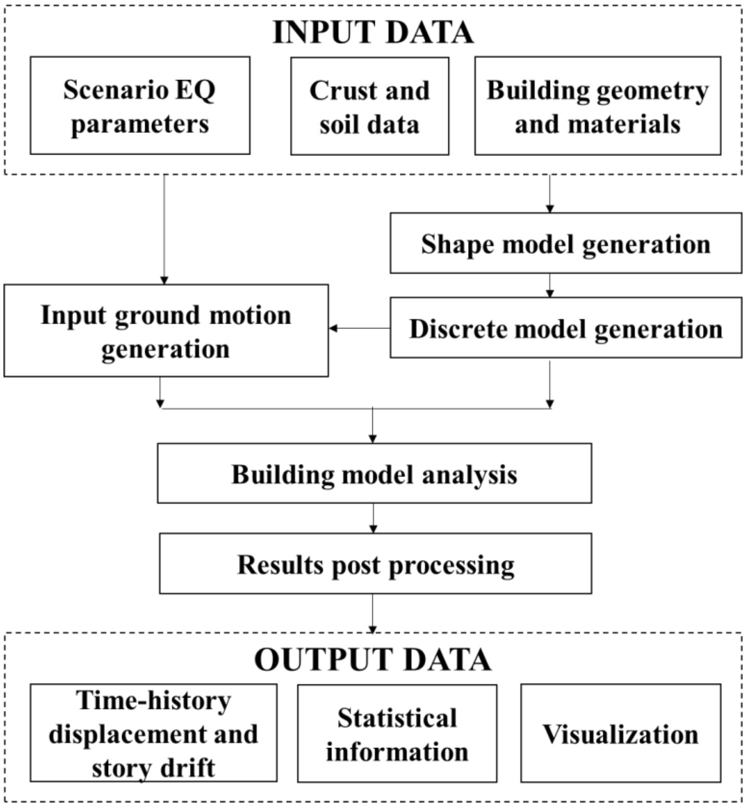

Figure 1. The general procedure of source process-to-city response seismic analysis

Building model generation and dynamic analysis

In the building model generation step, features in GIS data, that are given as polygons, are used to define the building footprints. Using the features, an envelope of a building is created by extruding the polygon to the height of the building. Then a 3D model is derived from the envelope by approximating the locations of the floor levels according to available data or by using typical floor-to-ceiling distance.

In the building dynamic analysis step, the discretized model is derived with the mass and stiffness computed at discrete points in the model. Examples of discretized models are multi-degree-of-freedom (MDOF) models, and finite element models. The Structural Response Analysis (SRA) module of IES generates MDOF model of each building. In IES-SRA, the dynamic properties (period, mass, stiffness, damping) can be set individually for each building model. The input ground motions computed in the ground motion modeling step are then used to analyze the response of the building model. The outputs of running the module are time-varying floor displacements and story drifts.

Postprocessing of results

In the postprocessing step, the peak values are extracted from the results for each building (floor displacements and story drifts). Buildings may be classified according to number of floors or pre-defined types (such as C1-L, C1-M; from Pacheco, et al., 2013 for building types for Greater Metro Manila Area) in outputting the peak, average, and standard deviations of displacements or story drifts.

City-level and building-level visualizations are also generated at this step. These visualizations aid in validations and communicating the results to non-technical analysts.

Computation

The number of features in the GIS data of a single city in Metro Manila ranges from ten thousand to hundred thousand. A dynamic analysis for the generated DOFs of models derived from these features requires large computing memory and runtime. Thus, all tools in the study were developed to use available distributed memory allocations and compute nodes. To divide these parameters across available compute nodes, a distributed-memory programming approach using Message Passing Interface (MPI) was implemented. The feature dataset is partitioned to a specified number of smaller datasets, and all the steps use this partitioning. Data partitioning allows for faster input/output operations and data management. The implemented partitioning circumvents the need for interprocessor communications which can increase the total runtime.

III. Demonstrative Example

Problem setting

The developed simulation approach was applied to a seismic response analysis of a city in Metro Manila. The response of the city will be analyzed using the parameters of the Magnitude 7.2 West Valley Fault Earthquake, but with different locations of epicenter as case studies. From these cases we aim to study the variation in peak story drifts in the city as the distance between each building and the fault is varied. For each case, the variation of distances of the buildings to the epicenter are listed in Table 1. We used the Vs30 data by Grutas and Yamanaka, (2012) to set the site class of the city. To create the building models to analyze, we used the GIS features that were outputted by GMMA READY Project (2013). We considered low- to mid-rise concrete moment-resisting frame buildings: C1-L type with 1 to 2 stories, and C1-M type with 3-7 stories, which are assumed to comprise 78% and 21% of the total building models for the city, respectively. The total number of building models that was analyzed is 9,452. The stochastic modeling approach (Halldorsson et al., 2011) was used for input ground motion generation. Two horizontal components (east-west, north-south) of acceleration with time interval of about 0.007 second and total time steps of 2,048 were generated.

Table 1. Cases of epicenters and distance from buildings

Case	Latitude	Longitude	Depth (km)	Ave. distance (km)	St.dev of distance (km)
1	14.58337	121.07045	4.0	4.43	0.88
2	14.54687	121.06045		6.84	0.64
3	14.64798	121.08520		7.28	0.80
4	14.51787	121.05595		9.69	0.59
5	14.43287	121.04695		18.77	0.56

Results and Discussions

Figure 2 shows the visualization of distribution of peak interstory drifts (ISDs) in the city for the five cases. Case 1 resulted to the largest number of buildings with value of peak ISDs up to 0.02 radian. The visualization shows that these buildings are scattered throughout the city. As the epicenter is moved farther from the buildings, as set for Cases 2 to 5, the peak ISDs are reduced.

Figure 3 shows the statistical values computed in the postprocessing step. The values are derived from the peak ISDs for the different cases, and grouped according to building type, C1-L and C1-M. In terms of the average and standard deviation of the peak ISDs, the C1-M type obtained about twice that of the C1-L type, in all cases. The results show that for buildings designed as moment-resisting frames, building with larger number of floor levels are expected to exhibit larger ISDs than buildings with fewer number of floors. This suggests the use of effective lateral force resisting system for the target seismic load.

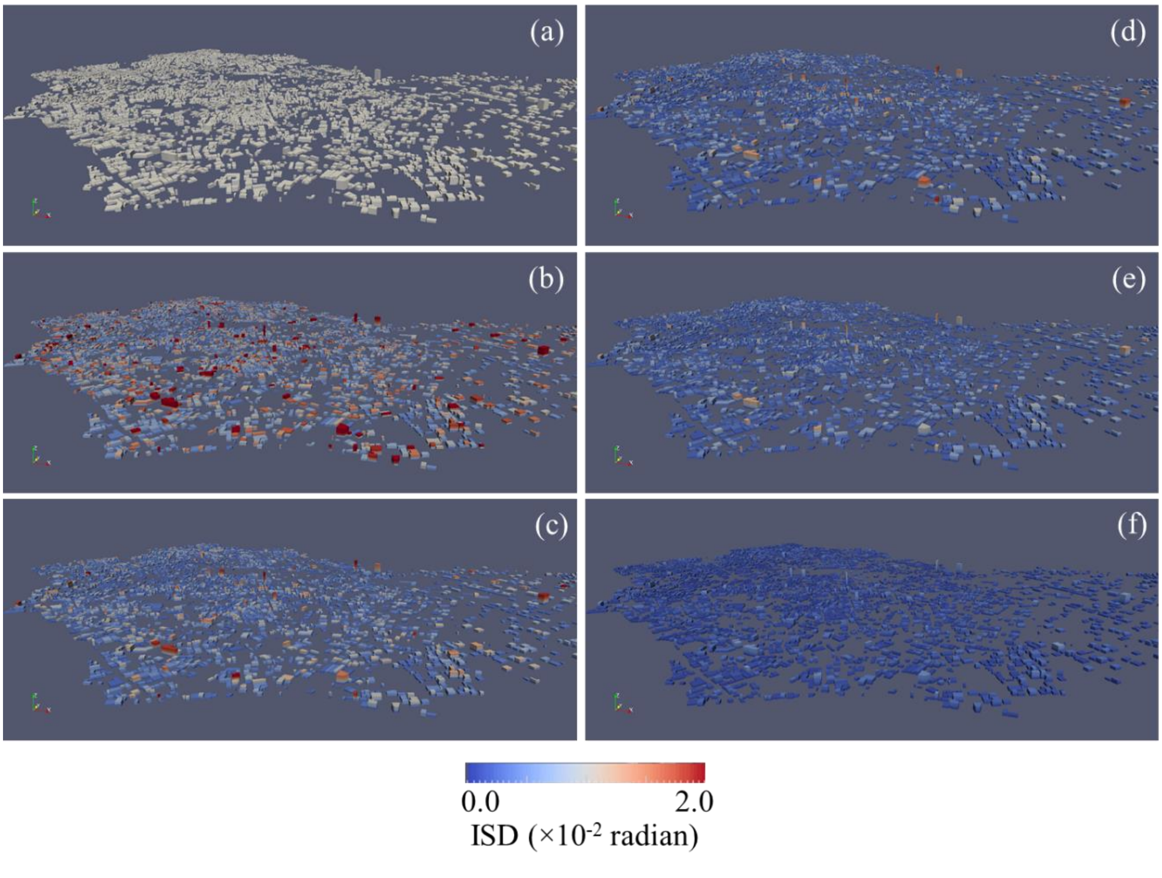

Figure 2. Distribution of peak interstory drifts (ISD) in the target city for multiple cases: (a) building locations; (b) Case 1; (c) Case 2; (d) Case 3; (e) Case 4; and (f) Case 5

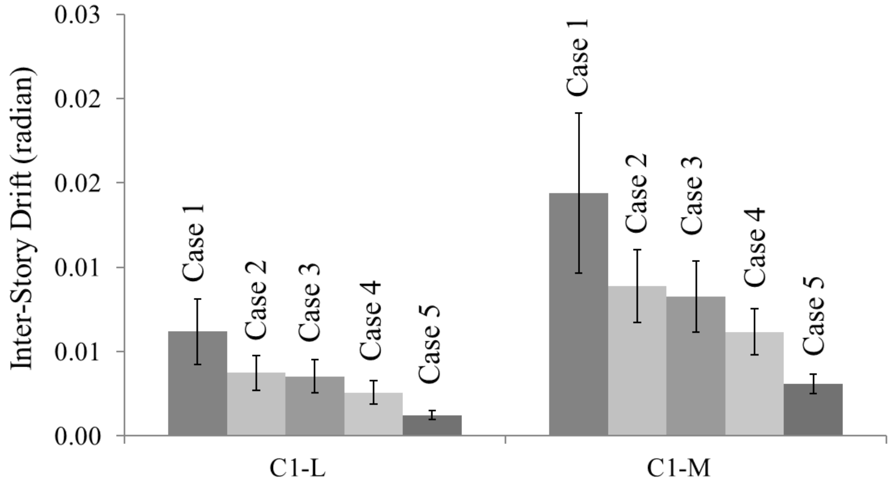

Figure 3. Average and standard deviation of inter-story drift for the two building types and the five cases.

Remarks on computation cost:

Table 2 shows the different tasks and the computation costs in running the application example. As shown, the analysis time for each task is relatively small, which is due to the use of MDOF models that have few discretization points. The generation of input ground motion takes the largest fraction of total computation time, which is due to the looping of computation per combination of building site and epicenter by the stochastic modeling tool. The output sizes are relatively large, especially the outputs of the postprocessing task. This is due to visualization files generated per time step.

Table 2 Analysis time and disk usage of Application Example

Task	Analysis time (sec)	Output size (MB)
Ground motion generation	146	226.7
Building model generation	60	0.5
Model MDOF analysis (8 procs)	20	122
Postprocessing	37	2,200

IV. Conclusion

This study aimed to develop an integrated, source process-to-city response earthquake simulation for Metro Manila. The procedure follows the Integrated Earthquake Simulation framework, with tools developed for input ground motion modeling, building dynamic analysis, and postprocessing. The required inputs are parameters that influence the dynamic response of soil and building structures. The main outputs are displacements and story drifts that are needed to analyze the variability of response of the different buildings in a city.

As an application example, low to mid-rise building models of a city in Metro Manila were analyzed for a scenario earthquake with different location of epicenters. The results showed that C1-M type buildings obtained about twice the average and standard deviation of peak inter story drifts of the C1-L type. The visualization of spatial distribution of buildings with varying story drifts allowed for verifying the derived statistical information, as well as for studying the effect of different parameters, such as epicentral distance to story drift. The analysis of computation cost showed that the simulation-based approach leads to largest disk usage in the postprocessing of results.

Lastly, the integrated simulation may provide an opportunity for scientists and engineers, who have extensive knowledge and experience in seismology, geotechnical, structural engineering analysis, and computing, to collaborate in aid of improving the city disaster risk reduction efforts.

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References

1. Allen, T., Ryu, H., Bautista, B., Bautista M. L., Narag, I., Sevilla, W.I., Melosantos, M. L., Papiona, K., Bonita, J. (2014) Component 5 - Earthquake Risk Analysis, Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for Greater Metro Manila Area, Philippine Institute of Volcanology and Seismology and Geoscience Australia.

2. Fujita K, Ichimura T, Hori M, Maddegedara L, Tanaka S. (2015) Scalable multicase urban earthquake simulation method for stochastic earthquake disaster estimation. Procedia Computer Science, 14th International Conference on Computational Science 2015; 51: 1483-1493.

3. GMMA READY Project (2013) Hazards Mapping and Assessment for Effective Community Based Disaster Risk Management, Phase II. Project implemented by National Disaster Risk Reduction and Management Council-Office of Civil Defense – Collective Strengthening of Community Awareness on Natural Disasters Agencies (NDRRMC-CSCAND), administered by United Nations Development Programme (UNDP) and funded by Australian Government through the Australian Agency for International Development (AusAID).

4. Grutas R, Yamanaka H. (2012) Shallow shear-wave velocity profiles and site response characteristics from microtremor array measurements in Metro Manila, the Philippines. Exploration Geophysics; 43, 255-266.

5. Halldorsson B, Mavroeidis G P, Papageorgiou A. (2011) Near-fault and far-field strong ground-motion simulation for earthquake engineering applications using the Specific Barrier Model. Journal of Structural Engineering; 137 (3).

6. Homma S, Fujita K, Ichimura T, Hori M, Citak S, Hori T. (2014) A physics-based Monte Carlo earthquake disaster simulation accounting for uncertainty in building structure parameters. Procedia Computer Science, 14th International Conference on Computational Science 2014; 29: 855-865.

7. Hori M., Ichimura T (2008) Current state of integrated earthquake simulation for earthquake hazard and disaster. Journal of Seismology 2008, 12, 2, 307-321.

8. Hori M, Ichimura T, Wijerathne L, Ohtani H, Chen J, Fujita K, Motoyama, H (2018) Application of high performance computing to earthquake hazard and disaster estimation in urban area. Frontiers in Built Environment Ed. By Katsuichiro Goda, Vol. 4, Article 1, pp. 1-13.

9. Pacheco, B., Hernandez, J., Castro, PP., Tingatinga, EA., Suiza, R., Tan, LR., Longalong, RE., Veron, MC., Aquino, DH., Macuha, R., Mata, W., Villalba, IB., Pascua, MC., Ignacio, U., Germar, F., Diño, JR., Reyes, GP., Tirao, JL., Zarco, MA. (2013) Development of Vulnerability Curves of Key Building Types in the Greater Metro Manila Area, Philippines. UP Institute of Civil Engineering.

10. Quinay P E, Grutas, R. (2019) Development of building-specific approach to city seismic response analysis for Metro Manila, Philippine Engineering Journal, 40, (1), pp.41-50.

11. Quinay P E, Grutas, R, Ichimura T, Bautista B, Hori, M (2018) A two-step procedure for estimation of seismic response of urban areas in the Philippines. 11th U.S. National Conference on Earthquake Engineering, Los Angeles, California, June 25-29.

12. Quinay P E, Ichimura T (2016) An improved fault-to-site analysis tool towards fully HPC-enhanced physics-based urban area response estimation. Journal of Earthquake and Tsunami, 10, (5).