Title of dissertation			
Seismic Building Assessment using Integrated Soil-Structure Applied Element Modelling of the Detailed Area Plan of Dhaka City, Bangladesh			
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Surface ground motions are influenced by several factors, including the seismic source, the path through which the seismic waves travel, and the specific local site conditions. Free field motion, unaffected by structures, is typically used as input at the base of structures, assuming a very stiff foundation. However, the base of structure motion can differ in soft soil areas. As a result, seismic assessments now consider soil-structure interaction (SSI), where the soil affects the structure's motion, and the structure affects the soil's motion.

Modified building response due to SSI could be detrimental or beneficial, which depends mainly on the ground motion characteristics, building dynamic properties, and subsurface soil. Subsurface soil is considered an essential condition as it may amplify the vibration of buildings and consequently increase the likelihood of damage. Usually, practitioners and engineers neglect SSI in building design because of its complex procedure and conservative structural response estimation. Accurate estimating of structural response and behavior is vital for buildings; therefore, neglecting SSI is not acceptable.

The analysis of SSI commonly employs numerical methods like Finite Element Method (FEM) and coupled Finite Element Method–Boundary Element Method (FEM-BEM). Emerging approaches like the coupled Finite and Discrete Element Method (FDEM) and Applied Element Method (AEM) are gaining traction for SSI analysis. These methods help address two crucial questions in structural dynamic analysis: 1) Will the structure fail? 2) If it does, how will it fail? FEM accurately addresses the first question by treating materials as a continuum. On the other hand, the discrete element method focuses on the second question. AEM, introduced by Hatem Sayed Tagel-Din in 1998, combines the advantages of both FEM and DEM. AEM can comprehensively analyze structural behavior from initial loading to complete collapse, providing reliable accuracy and efficiency with simple material models. However, AEM research is predominantly centered on structures, with limited exploration in the context of SSI.

Dhaka City, Bangladesh's administrative, political, and economic capital, plays a pivotal role in its economy, contributing to a significant portion of its GDP. However, the city faces several challenges, including high population density, rapid urbanization, and poor construction practices, making it highly vulnerable to earthquakes. In the event of a magnitude 7.0 earthquake, over 72,000 buildings are estimated to be damaged. To mitigate these risks and create a more habitable city, the Government of Bangladesh has initiated a Detailed Area Plan (DAP) that involves comprehensive urban planning, considering various geotechnical and environmental factors. This planning follows the Sendai Framework for Disaster Risk Reduction (2015-2030), which emphasizes understanding and reducing disaster risks. Given the increasing height and soft soil foundations of buildings in Dhaka, it is crucial to study their dynamic behavior to assess seismic risks accurately and reduce them. Unexpectedly, previous studies have not explored the impact of geomorphic units on typical DAP structures in Dhaka.

Therefore, the objective of this research is:

i) To conduct simplified engineering geomorphologic unit-based seismic site characterization for identifying the prominent soil type and properties for SSI.

ii) To upgrade and verify the Integrated Soil-Structure 2D Applied Element Modeling for investigating soil-structure interactions.

iii) To examine the effect of geomorphic units on 3 to 10-story Reinforced Concrete (RC) residential buildings in the DAP area.

For engineering geomorphic seismic site characterization of the DAP area of Dhaka, a simplified engineering geomorphic unit map of the DAP of Dhaka City was prepared and verified with the boreholes and surface geological data. The region has been divided into three major simplified geomorphic units. They are the Holocene deposit (HA: Holocene Alluvium), Pleistocene deposit (OC: Over-consolidated Clay), and Landfill (LAN). Nearly 50% of the area comprises Holocene deposits, and OC, LAN, and water bodies cover the remaining 33% and 17%, respectively. Further, major geomorphic units are subdivided into seven sub-geomorphic units considering the subsurface soil profile. Among the seven types of geomorphic sub-units, two types are included in HA, two types in LAN, and three classes in OC. Engineering properties of the seven sub-geomorphic units of three major geomorphic units are identified and summarized. Nine earthquake time histories, including seven historical and two synthetic ground motions, were utilized alongside seven identified subsurface soil profiles for nonlinear site response analysis. The analysis incorporated the Bangladesh National Building Code (BNBC) 2020 uniform hazard spectrum (UHS) as the target spectrum to select the ground motion. The findings revealed an increase in response acceleration over long periods, near the natural frequency of the soil, to the chosen earthquake ground motions.

Essential enhancements and considerations have been integrated to enhance accuracy and realism in analyzing SSI effects using the 2D Applied Element Method (AEM). These upgrades encompass boundary conditions, damping mechanisms, material models, and failure criteria, all essential for a comprehensive understanding of how structures interact with the surrounding soil. Boundary conditions, including Free-H (Horizontal) with viscous damping boundaries, are crucial to analyzing the SSI effect. Rayleigh damping is employed to capture the dynamic response of the structure-soil system. The choice of material model is pivotal; the Hardin-Drnevich (HD) model is used to characterize soil behavior. Mohr Column Failure criteria are integrated to predict soil failure conditions. After incorporating these improvements, a verification process is conducted, assessing the model's accuracy in representing real-world conditions by analyzing a fixed-based structure, modeling the soil's behavior, specifying boundary conditions, and integrating all these aspects into a single soil-structure model. The results of this verification process ensure the model's ability to simulate and analyze SSI effectively. The upgraded AEM is used to analyze the 3 to 10-storey RC residential buildings of the DAP area using the geomorphic unit property of that area. Selecting the typical structures for the DAP area involved discussion with experts, review of documents, and DAP 2016 project data. In addition, a questionnaire survey was conducted with the experts working on designing and supervising the buildings in the DAP area to finalize the data set. For this study, considering the geological and tectonic setting of the country and DAP area soil types, four earthquakes have been chosen; two are low frequency (Mexico 1985, Christchurch 2011), and one is selected considering the similar response spectra to the BNBC 2020 for maximum credible earthquake (MCE) and SB type soil condition (Vs. 360 to 800 m/s) and one high-frequency earthquake (Great East Japan 2011). Furthermore, this study strongly emphasizes the complex dynamics of SSI to facilitate a comprehensive investigation into large deformation with soil. In addition to investigating the SSI effects, this research provides valuable recommendations for policy implementation to reduce seismic risk.

In summary, this research includes seismic site characterization of Dhaka's DAP area, upgrading 2D AEM for SSI analysis, and examining the impact of geomorphic units on 3 to 10-storey RC residential structures. The study area is divided into three major geomorphic units and seven sub-geomorphic units based on subsurface soil profiles. Extensive nonlinear site response revealed acceleration amplification in the near-surface soil. The upgraded 2D AEM was verified to simulate SSI problems. Finally, the model assesses 3 to 10-storey reinforced concrete residential buildings in the DAP area.

The analysis of response acceleration highlighted significant amplification for the Mexico 1985 earthquake input, consistent with the proximity of the soil's natural period. Conversely, the Great East Japan 2011 earthquake ground motion induced amplification, and the Loma Prieta 1989 input showed varied responses for OC (stiff) and HA (soft) soils. Results from SSI analysis revealed that inter-storey drift ratios consistently followed a specific order across all SSI cases, overall observation, higher in low-frequency earthquakes (Mexico 1985 and Christchurch 2011) and lower in high-frequency earthquakes (The Great East Japan 2011), with noteworthy effects for 3 to 9-storey structures in both HA (soft) and OC (stiff) soils for the Mexico 1985 earthquake input and 6 to 10-storey in HA (soft) soil for the Christchurch 2011earthquake input. However, OC soil shows SSI effect on 3 and 4-storey structures for Loma Prieta 1989 earthquake input.

Groundwater effects increased inter-storey drift for OC (Stiff) and decreased HA (Soft) for the Mexico 1985 earthquake input. However, in the context of the 2011 Christchurch earthquake input, the 9-storey structure with a foundation on soft soil exhibits a minor decrease in inter-storey drift, while 10-story structures show a slight increase, suggesting that groundwater level fluctuations can induce changes in the natural frequencies and resonance characteristics of soil-structure systems. Considered simplified, poorly constructed, and height-violated structures exhibited significant detrimental SSI effects on HA soil for Christchurch 2011 earthquake input. Long-period structures (30-storey) demonstrated substantial SSI impact for Christchurch 2011 compared to the Mexico 1985 earthquake input on HA soil. Overall, low-frequency earthquake input (around 1-3 Hz) showed a substantial SSI effect on typical DAP structures. Therefore, it is recommended to incorporate Soil-Structure Interaction (SSI) considerations in the design and analysis, emphasizing seismic risk mitigation for DAP structures in Bangladesh.

Photos

Photo with my supervisors on graduation day

Photo with my lab mates after the farewell party