Course: Disaster Management

Project Report
Simulating an Earthquake : Exploring Building Vulnerabilities using Blender

Submitted to :

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1. Introduction

Building performance assessments during earthquakes have traditionally relied on physical shake table tests. These tests involve constructing scale models or full-size structures and subjecting them to simulated ground motions generated by powerful hydraulic actuators. While shake table tests offer realistic and accurate results, they are expensive, time-consuming, and limited in their ability to explore various scenarios due to the need to construct and destroy structures physically.

This project aims to investigate the impact of earthquakes on various building structures by leveraging computer simulations. Using the open-source 3D modeling software Blender and its Bullet Constraints Builder (BCB) plugin, different building typologies, materials, and configurations were modeled and subjected to simulated earthquake conditions. The simulations enabled a comprehensive analysis of these structures' vulnerabilities and failure modes under seismic loads. The findings from this project provide valuable insights for designing earthquake-resistant buildings and enhancing structural safety.

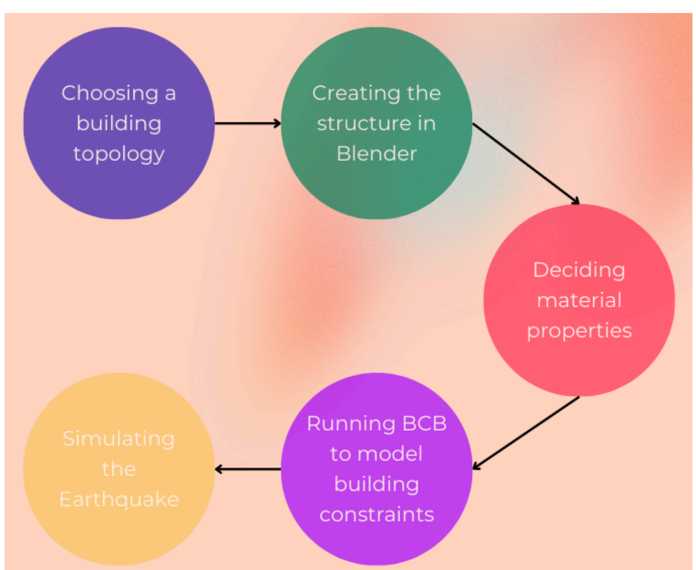
2. Objectives

The primary objectives of this project include

1. To identify vulnerabilities and potential failure modes in various building structures and designs under seismic loads.
2. To understand their impact on structural performance, experiment with different parameters such as building shape, size, column distribution, materials (e.g., concrete, steel, masonry), and vertical layout.
3. Leverage Blender's Bullet Constraints Builder (BCB) plugin is used to accurately model building constraints, material properties, and structural dependencies.
4. To provide insights and recommendations for improving the design of earthquake-resistant structures based on the simulation results while comparing the performance of the various designs being tested.

3. Methodology

The methodology followed in this project involved a systematic approach to simulating earthquakes and analyzing their effects on various building structures. The process can be summarized by the flowchart shown in the figure below. First, a building topology was chosen based on size, horizontal layout, vertical layout, and column distribution. Next, the selected structure was modeled in Blender, with distinct layers for the foundation, bedrock, and structural components. Material properties were then assigned, and constraints were set up using the Bullet Constraints Builder (BCB) plugin to



model realistic structural dependencies. Finally, the earthquake simulations were conducted within the Blender environment, incorporating the chosen parameters and configurations. This allowed for a comprehensive analysis of the structural behaviour and potential failure modes under seismic loads.

a. Choosing building topologies

The ability of a building to resist earthquakes is significantly influenced by its architectural features, such as shape, size, and geometry, as well as its structural design and load transfer mechanisms. In this project, the following planning aspects were taken into account when selecting building topologies for simulation:

i. **Size of buildings**: The recommended length-to-width ratio for buildings is less than 4 to ensure better seismic performance. Tall buildings with a sizeable height-to-base ratio and short but very long buildings are more prone to poor earthquake resistance due to excessive horizontal movement and seismic forces.

ii. **Horizontal layout of buildings**: Buildings with simple, regular plans perform better during earthquakes than those with complex, irregular shapes. Complex shapes can introduce stress concentrations and lead to uneven load distribution, increasing the risk of damage.

iii. **The vertical layout of buildings**:

- Vertical setbacks: Buildings with vertical setbacks (abrupt changes in the plan area or floor size at different elevations) can experience a sudden increase in earthquake forces at the level of discontinuity, leading to potential failure.
- Weak or flexible stories: Buildings with an unusually tall story (commonly referred to as a weak or flexible story) are prone to damage or collapse starting from that story due to the concentration of seismic loads and excessive deformation.
- Floating columns or discontinuous walls: Buildings with floating columns (columns not supported by a continuous load path to the foundation) or discontinuous walls are more vulnerable to earthquakes due to interruptions in the load transfer path, leading to potential failure at those locations.

iv. **Column and wall distribution**: Appropriate distribution and placement of columns and walls within a building is crucial for ensuring balanced load transfer and overall stability during seismic events. Irregular or inadequate column and wall arrangements can lead to uneven load distribution and localized failures.

b. Creating structures in Blender

The building structures were modeled in Blender with three distinct layers:

- Foundation: The base layer represents the earth's surface, acting as the foundation for the structure.
- Bedrock: An indestructible layer beneath the foundation, simulating the bedrock or stable ground.
- Structural: The building contains columns, walls, ceilings, and other structural elements.

To explore the impact of various design parameters, the following hyperparameters were varied for the simulations:

1. **Building topology**: Different shapes and layouts were modeled, including regular, irregular, cross-shaped, T-shaped, and other configurations.

2. **Column length and distribution**: Column lengths and placement patterns were varied to study their influence on structural performance. Scenarios with hanging columns, irregular column lengths, and irregular column distributions were examined.

3. **Building material**: Different construction materials were simulated, including reinforced concrete, masonry walls (e.g., bricks, blocks), and steel structures.

4. **Building height**: The number of floors in the buildings was varied to investigate the impact of height on seismic vulnerability.

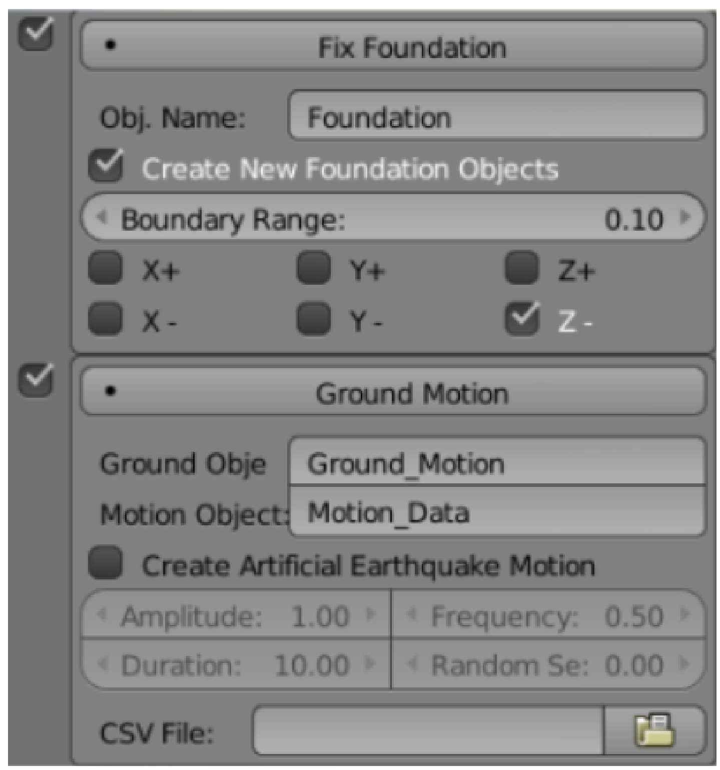
5. **Vertical building layout**: Tapered and different vertical layout configurations were explored to understand the effects of setbacks, irregular floor plans, and other vertical irregularities on structural behaviour.

c. Implementing BCB for constraint modeling

The Bullet Constraints Builder (BCB) is an add-on for Blender that complements the built-in Bullet physics engine. It attributes realistic structural dependencies between various building elements, such as pillars, walls, beams, slabs, and foundations. The BCB script automatically calculated the breaking threshold values for each constraint based on the specified material properties, enabling the simulation of failing building structures under hazardous seismic impacts.

d. Earthquake simulation using BCB

After modeling the structures with the desired parameters and setting up the appropriate constraints using BCB, the earthquake simulations were conducted within the Blender environment. The simulations incorporated the chosen building topologies, materials, configurations, and constraint settings, allowing for a comprehensive analysis of the structural behaviour and potential failure modes under seismic loads.



4. Results and observations

The simulations provided valuable insights and observations regarding the performance of different building structures under earthquake conditions, which can be summarized as follows:

- **Regular shapes**: Buildings with regular, symmetrical shapes (e.g., rectangular, square) demonstrated greater resilience against seismic loads than those with irregular or complex geometries. Support structures like columns played a crucial role in maintaining stability, as evidenced by the superior performance of cross-shaped structures.
- **Impact of column configuration**: Hanging columns, irregular column lengths, and irregular column placement patterns significantly reduced the overall stability of the structures. In contrast, dense and evenly distributed column layouts provided exceptional support, minimizing the risk of collapse even in partial failures.
- **Material performance**: The choice of construction material significantly impacted the buildings' seismic performance. Steel structures demonstrated superior resilience compared to reinforced concrete structures, while masonry walls (e.g., bricks, blocks) exhibited the worst performance, being more susceptible to cracking and collapse.
- **Building height**: Taller buildings with more floors were more vulnerable to collapse during the simulated earthquakes. The increased height amplified the horizontal movements and seismic forces acting on the structure, making it more prone to failure.
- **Vertical layout irregularities**: Irregular vertical layouts, such as tapered buildings or structures with setbacks, posed additional risks to the stability of the structures. These irregularities can lead to stress concentrations and uneven load distribution, increasing the likelihood of localised failures or progressive collapse.

5. Conclusion

This project successfully simulated earthquakes and their effects on various building structures using Blender and the BCB plugin. The simulations allowed for the exploration of different building topologies, materials, and configurations, leading to the identification of potential vulnerabilities and failure modes under seismic loads.
The findings highlight the importance of building shape, column distribution, material selection, and vertical layout in ensuring structural integrity during

earthquakes. Regular, symmetrical shapes with evenly distributed columns and appropriate material choices (e.g., steel) demonstrated superior performance to irregular geometries, irregular column configurations, and weaker materials like masonry.
The project demonstrates the potential of using computer simulations as a cost-effective and repeatable method for understanding building vulnerabilities and designing safer, more earthquake-resistant structures. By leveraging simulations, architects, engineers, and researchers can explore various scenarios, identify potential weaknesses, and optimise building designs to mitigate the risks associated with seismic events.

6. Future Work

Future work can ensue using different parameters being simulated in the BCB plugin to recreate different seismic scenarios. Moreover, the structures can be made more realistic by incorporating real-life support structures like beams and concentric reinforcement rods in the pillars, which were absent in this project's scope.

7. Video Link for Simulations

Find the drive link shared below, which contains the video files for all the simulations.

https://iiitaphyd-my.sharepoint.com/:f:/g/personal/aditya_sehgal_research_iiit_ac_in/Ejec_Eb1cfBIh0zIDQEevcwBqThVdBiGZMV-K6AOWAgbGg?e=yra0W8