Structural Collapse Visualization Using Blender and BCB

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Abstract: Over the past few years, a range of adverse factors including excess applied structural loads, unequal settlement of the ground beneath foundations, significant deflection, flooding, landslides, material degradation, inadequate maintenance, gaps in the original builder's structural understanding, seismic and earthquake activity, and the force of explosions have all contributed to the failure of buildings and the unfortunate loss of human lives. It has often been reported that theseevents do not kill people but rather the affected structures do. Hence, the collapseof engineering structures is a contemporary and critical topic all over the world. However, to simulate these phenomena, a great number of input data and failurecriterion definitions are required which have an elaborated form owing to the interaction between several elements of engineering structure. Also, the computational cost is relatively high and time-consuming. Hence the justification for an alternative simplified method using Blender software and Bullet Constraints Builder (BCB). Blender software and BCB add-on work in harmony to simulate collapse scenarios. Blender and BCB averaged a multitude of structural attributes using streamlined engineering equations. Consequently, this leads to substantially reduced executable simulation model development time with approximately equal accuracy and debris formation outcomes. The debris formulation of the simplified method could be used to trace victims in the event of a collapsein reality. This study aims to review the alternative simplified method that couldbe used for visualizing collapse. The review is supported by masonry structure as a case study.

Keywords: Blender, BCB, Collapse, Masonry, Visual simulation.

1 Introduction

Structures are designed for safety with a precise comprehension of their collapse states. The concept of ductility plays a pivotal role in modern structural design, serving as an indicator of potential collapse. Moreover, when faced with excessive loads, ductility becomes instrumental in absorbing energy. This approach empowers engineers to confidently develop and assess the structural integrity of reinforced concrete and steel buildings, considering failure mechanisms with assurance. While structural collapse may stem from factors like excess applied structural loads, unequal settlement of the ground beneath foundations, significant deflection, material degradation, inadequate maintenance, and gaps in the original builder's structural understanding, there are notable instances that underscore these risks. The Mexico City Cathedral and Tower of Pisa serve as well-known examples of masonry structures vulnerable to soil settlements, while the Cathedral of Florence and the Cathedral of Pavia highlight the risk associated with insufficient structural design in masonry monuments [1]. Predominantly, the leading cause of structural collapse remains earthquakes. Surprisingly, many structures that continue to operate today are built with little or no regard for earthquake action. This was evident about 20 years after the Erzurum Earthquake, the 7.6 magnitude Izmit

Earthquake (otherwise known as the Kocaeli earthquake) shocked Turkey again. The aftermath of this earthquake was staggering, with more than 300,000 homes documented as either damaged, partially collapsed, or completely levelled, leading to a tragic loss of over 17,480 lives [2].

As a direct consequence of this fact, the problem of designed constructions collapsing is one that is of the utmost significance in the modern world. Several scholarshave greatly done great work regarding this contemporary subject. The collapse mechanism of masonry structures when subjected to seismic actions was studied by Tamaam Bakeer [3]. The research entails the creation of numerical tools to recreate thereal behaviour of masonry from the point of linear elasticity to the progression of damage till the collapse. The numerical models were created with an open-source programme called LsDyna. Dolatshahi and Aref [4] proposed a constitutive material model that is compatible with widely used available finite element (FE) software such as LS-DYNA, TNO DIANA, and ABAQUS. This model is established on a combination of implicit and explicit formulations. Seyedrezai [5] utilized the commercially available FE programme LS-DYNA to simulate the collapse behaviour of unreinforced, one-way arching walls under blast stress. Oliveira [6] made it a point to clarify the responses of masonry buildings to cyclic loads. A constitutive model was suggested and implemented in a prototype version of the DIANA FE code. Unfortunately, because of the intricate nature of the interactions between the numerous engineering structures, the simulationof such events requires a huge quantity of input data as well as failure criterion definitions. The amount of time it takes to accomplish the work in addition to the expense of the computations is considerable. However, the use of Blender and BCB eliminates difficulties relating to high computational requirements. Also, it requires a little description of the structures making it user-friendly as well as less time consuming

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2 Blender and BCB

The BCB serves as a simulation add-on tool rooted in the broader concept of the Discrete Element Method (DEM). It facilitates the simulation of collapse scenarios by utilizing the freely accessible Bullet Physics engine and Blender software. This software bundle comprises three interconnected program modules, each functioning in synergy. Every component of the software is distributed under an open-source license, granting external programmers the ability to use and modify the source code [7]. This collaborative approach ensures a continuous process of quality validation and maintains a consistent trajectory of software improvements. The key constituents of the program encompass:

✓ Bullet Physics Engine [8]
✓ Blender [9]
✓ The BCB script [10]

DEM predicts how deformable and/or rigid moving objects interact. Newton's motion theories specify object trajectories and routes. DEM may be employed when several objects interact and frictional, electromagnetic, and cohesive forces can be used. DEM simulates building collapse by automatically creating a model and reducing simulation time. DEM is used to design agricultural machinery capable of managing bulk materials like seeds and grains. Additionally, it's employed to analyze the viscosity and geomechanics of materials like gravel and sand within soil processing contexts [11,12,13]. DEMs are used as methods in "Interactive Rigid Body Dynamics". It allows easy user-simulation interaction and "real-time" outcomes. Speedis more important than accuracy [14].

2.1 The Benefits and Drawbacks in Terms of Collapse Simulations

The Rigid Body Dynamic (RBD) simulation approach offers several advantages over continuum approaches, which estimate each element's material behaviour. As the focus is solely on rigid bodies, predominantly interacting through Newton's equations, there is a notable reduction in the numerical workload required for problem definition and analysis. Therefore, RBD presents a rapid real-time viable approach.

Numerous structural attributes are averaged in engineering computations, with geometry roughly approximated. Consequently, the creation of a functional simulation model is expedited. However, this advantage is balanced by the limitation that continuous deformations within objects are perceivable solely as relative distance alterations. Along with a coarsely discretized structure, this lowers accuracy. Not paying attention to structure is undesirable. The governing equations are tailored to capture the physics of dynamic structural behaviour in discrete entities exclusively, making them inapplicable to the continuum during collapse scenarios. Bakeer [5] has described successful efforts to utilize RBD to model and simulate masonry construction collapse.

The RBD is a good choice for brick constructions, which have a grid of regular blocks and fail at the mortar joints. Mortar characteristics can be used in force modelling. The same is true for reinforced concrete constructions when numerical and structural parts lose their link. All approaches of this type require to modify the main algorithm. In the utilized application, the physics engine's existing capabilities were explored. So, the limitations between dissolved items are evaluated after a certain level. They are used in addition to physical threshold knowledge.

2.2 Bullet Physics Engine

Physics Engine (commercial or open-source) implements DEM and RBD. It solves the discrete-time model. It simulates physical and mechanical processes to deliver realistic game experiences. Physics engines employ a variety of ways to simulate physical processes in games, such as stiff bodies (like rocks and dirt), soft bodies (like clothes), fluids (like water), and their interactions. PhysX can simulate realistic particles [15]. It's used to produce physics-based visual effects and animations in movies. NASA's tensegrity robotics simulator [16] and BBZ medical technologies' robotic surgical simulation [17] use its application.

2.3 Blender Softwares

Blender is a free 3D modelling programme that allows user interactivity. It's related to the physics engine and allows modelling and simulation visualization. It was NeoGeo's 1995 proprietary application. This programme has gained animation, game logic, route tracing rendering, powerful texture mapping, real-time physics simulation, video editing, and sculpting capabilities. Blender's functionality is regularly improved by programmers and users. Blender allows interactive "walkthroughs" of simulation results with lighting, texturing, and realistic shading. It covers cavityidentification and victim tracing in a collapse situation. Custom extensions can be utilized using a Python script interface

2.4 BCB

RBD was created to imitate moving things. Rigid bodies must be linked to show building members. Because rigid bodies don't include material behaviour, components must be connected by constraints to define the material's strength. BCB enhances Blender's Bullet physics. It combines discrete rigid entities with advanced constraint arrangements to simulate complex collapses by considering the materials' mechanical characteristics. The BCB's fundamental principles are as follows: Multiple Constraints, Precise Placement of Constraints and Calculation of Admissible Forces

2.5 Fracture Modifier

The DEM approach aims to solve "real-time" simulation challenges quickly. Despite using RBD, which reduces computation time, Blender's current simulations fall short. The Northridge earthquake model with 625 simulation frames took 13,620 seconds to bake (actual simulation time) (almost four hours). Discretized models and their restrictions clutter Blender scenes, making them difficult to handle. Blender's object management performance diminishes as the scene's object count rises. Cameras, lighting, limitations, and rigid bodies are examples of Blender objects. Fracture Modifier (FM) is a custom-made Blender mode

3 Collapse Visualization and Conclusion

For this study, a half-scaled masonry structure was utilized. The half-scale masonry model is made from perforated engineering brick. Brick measures 102mm, 215mm, and 65mm. Figure 4.1 shows the masonry model with unit geometry. The Turkish Building Earthquake Code [18] requires that 23% of bricks be hollow. Construction usedstretcher bond with toothing texture. The mortar is 7.5mm thick and 1:3. (cement: sand).1800mm square and 1600mm height. The north and south masonry apertures have RCsupports. The South door measures 100mm x 45mm. From the first block, it's 65 mm above the notch. The north window is 55mm by 45mm. The opening supports are 650mm long, 75mm tall, and 8mm thick. Overhead was an 1800mm RC square slab. It's 100mm thick 25-grade concrete reinforced in both directions with 8mm steel. Masonry was built on RC squares. 35-grade concrete with 14mm rebar is used for the base. The base is 2100x200mm. Bricks at a building's base slip, shear, or bounce away.To avoid this, the base has a 100mm wide, 30mm deep slot for brickwork.

Fig 1. The masonry model utilized as a case study

The structural representation employed mesh cubes for modelling, with rigidity enabled in the model's preprocessing phase. However, BCB utilizes a "convex hull" as the standard collision shape for all elements, which doesn't accommodate concave forms like the notch in the base. Consequently, the base was subdivided into blocks to ensure each sub-element is convex, allowing for straightforward discretization. This modification in topology was necessary to circumvent collision issues. Additionally, object scaling (Ctrl+A) was implemented, as Boolean operations in the preprocessing phase function optimally with unity scaling. The ground motion was introduced through a ".csv" file during preprocessing. To enhance computational efficiency, the FM version of Blender was employed for the simulation [7, 10, 19].

Table 1. Parameters and Values Employed for Analysis

Parameter	Unit	Value
Discretization Size	*m*	0.3
Connection Type	-	15
Compressive	N/mm^2	10
Tensile	N/mm^2	0.1
Shear	N/mm^2	0.1 + abs (1.85-z) * 0.1
Bend	N/mm^2	0.1
Density	Kg/m^3	1800


Fig 2. An illustration of Visual Simulation in comparison to Experiment result - 1

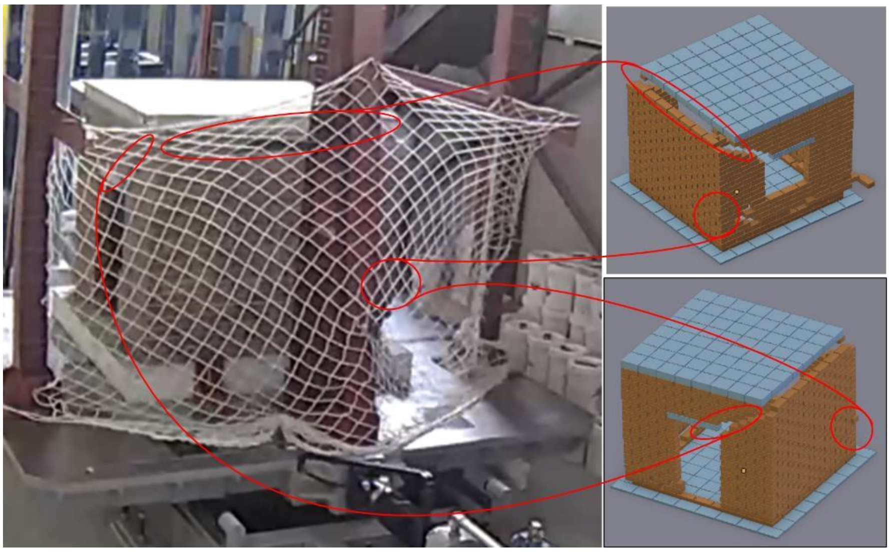
Fig 3. An illustration of Visual Simulation in comparison to Experiment result - 2

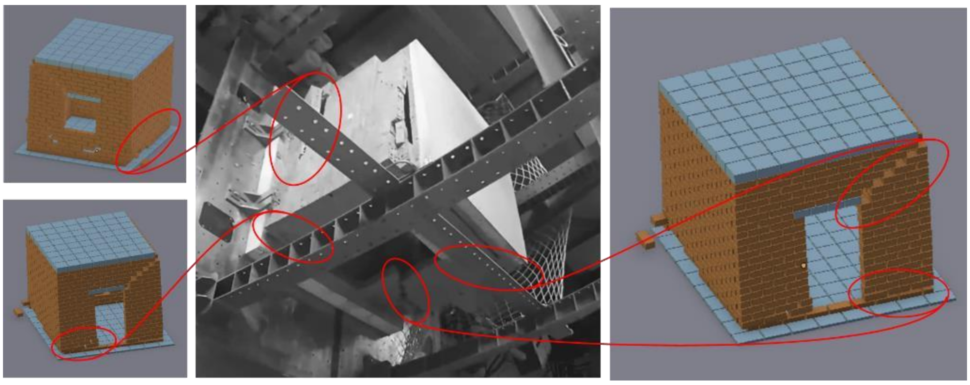
Fig 4. An illustration of Visual Simulation in comparison to Experiment result - 3

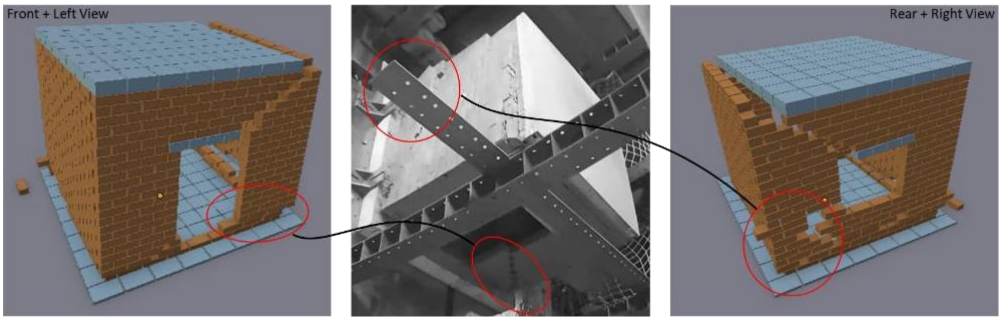

Fig 5. An illustration of Visual Simulation in comparison to Experiment result - 4

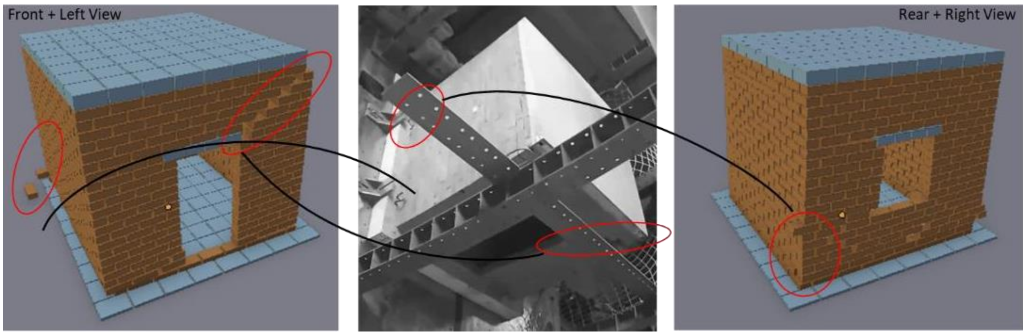

Fig 6. An illustration of Visual Simulation in comparison to Experiment result - 5

The proposed DEM system cannot visualize internal forces because Blender's Python API links add-ons such as BCB to the fundamental Blender functions and data. As a result, direct access to the simulation forces generated by the Bullet engine is not feasible. Conversely, it's feasible to inspect the displacements of adjacent rigid bodies caused by these forces by using a Python script. Blender's deformation visualizer v1.10 python script (written by Kai Kostack) generates element displacements relative to start frame coordinates. It is important to note that displacement values aren't accessible due to the aforementioned reasons, and hence could only be visualizedusing the deformation visualizer. Bodies with low relative displacements are represented with blue colours, whereas those with high displacements are represented in red. Figure 7 shows the model's relative displacement.

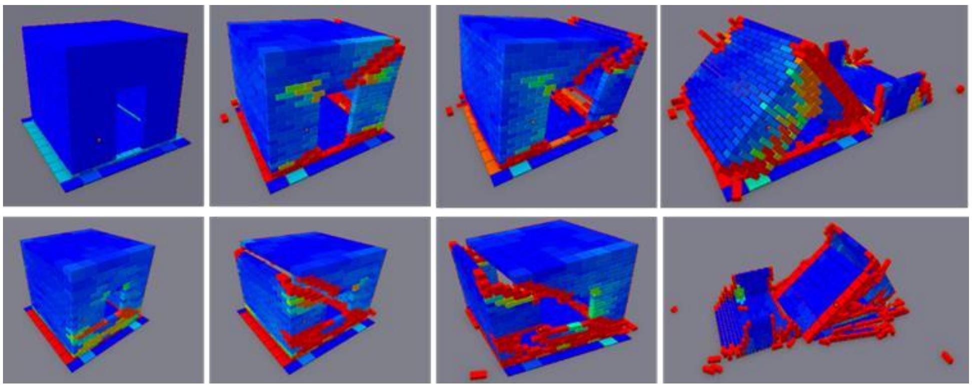

Fig 7. A visualization of the relative displacement

4. Conclusion

The primary goal of the method presented in this study is to provide a visual representation of the impacts ofthe EQ on the structure. This method not only enables the recreation of past EQs but also foresees the potentially devastating effects of EQs yet to come. Using the methods outlined in this study, one may visualize the structural behaviour in advance of seismic movements. The simulation was carried out by subjecting a half-scale model of the stone building to escalating seismic activity until it collapsed, and it was found to be bothrealistic and effective. The damage pattern seems to be a perfect match, although the debris formation slightly differs. For this reason, this method may help engineers make better decisions on reinforcement andretrofitting. This approach might potentially be expanded to landslide effects on engineering structures as well as the analysis of explosions to investigate diverse risk and threat scenarios (even though these aspects aren't explored within this paper's scope). Important factors like the Poisson ratio, Elasticity modulus, Shell object, etc. should be integrated into the streamlined programme to maximize its exploitation for advanced structural application. The relative displacement visualization Python script also needs an update to allow for the retrieval of displacement data. This functionality will subsequently be expanded to include force and stress value retrieval.

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