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Building-bridge impact behavior induced by overturning collapse of RC frame structure under mega earthquake

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ABSTRACT

In high-density urban environments, earthquake-induced collapse of buildings impacting adjacent elevated bridges generates an increasing chain-disaster risk. This paper presents an experimental study that reflected the inclined collapse of a reinforced concrete (RC) frame following the impact onto an adjacent elevated bridge. The impact process was recorded using high-frequency accelerometers, photogrammetry and high-speed cameras. A multi-scale finite element model was then developed using LS-DYNA to simulate the collapse and impact behaviors with the validation against the experimental pictures. The test demonstrated that collapsed RC frame could exert multi-stage impacts on the adjacent elevated bridge. This study offers new insights for the urban seismic resilience.

1. INTRODUCTION

In densely built urban environments, elevated bridges are occasionally constructed adjacent to high-rise buildings. In the event of strong earthquakes, structures may collapse and impact the nearby elevated bridges, potentially causing structural damage and traffic disruption. Although the seismic performance of buildings and bridges has been extensively studied (Lu et al. 2011; Shi et al. 2021), understanding on the building-to-bridge impact are quite limited so far.

This study presents a scaled reinforced concrete (RC) frame structure collapsed and impacted onto an elevated bridge in an earthquake scenario. The collapse of the RC frame was triggered by suddenly removing one side of its columns. The model then obliquely impacted the scaled single-span RC elevated bridge. The impact process was recorded using measurement equipment and simulated using the finite element (FE) method. The impact behavior and structural responses were analyzed to provide insights for urban seismic resilience.

2. EXPERIMENTAL PROGRAM

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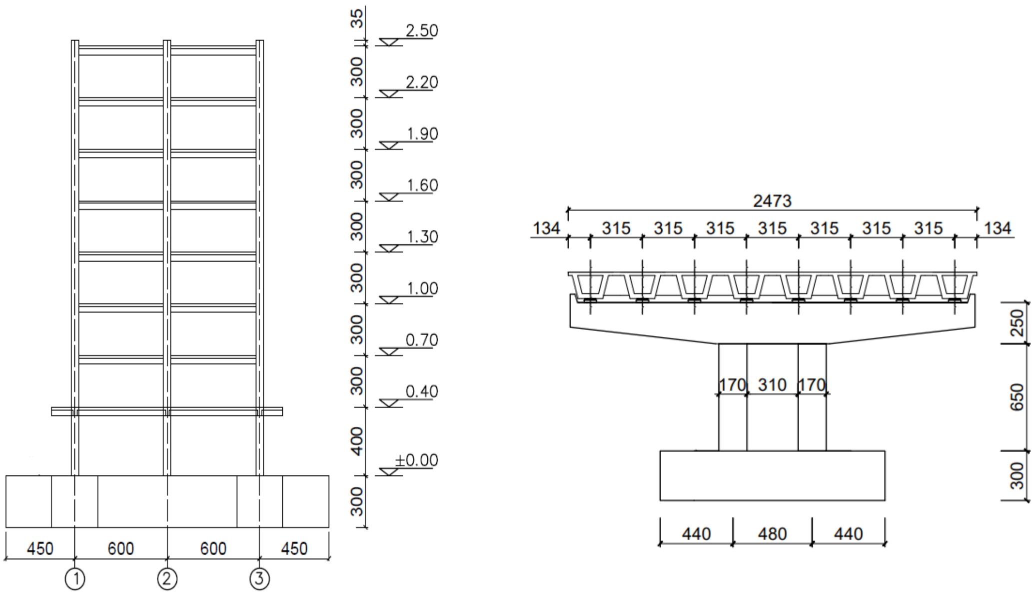
The test contained two specimens, i.e., a 1:10 scale RC frame and a 1:10 scale single-span RC box-girder elevated bridge. The frame specimen had 8 stories of 1x2 spans. Fig. 1 illustrate the dimensions of the two specimens. The frame specimen was constructed using mortar and galvanized wires. The bridge specimen had been previously subjected to shake table excitation to generate seismic damage and was not presented in this paper for brevity (Chen 2024). Additional mass blocks were placed on the frame floors with the information listed in Table 1, and also on the bridge specimen. Collapse of the frame specimen was triggered by removing one side of three columns. Material properties of the mortar and wire were obtained via tests.

The distance between the two specimens was set to 0.51 m to reflect typical urban spacings in the reality. Temporary supports and an automatic release device were installed to trigger side-sway collapse of the frame specimen under gravity. Fig. 2 illustrates the four accelerometers arranged on the bridge deck at midspan and cap beam. Fig. 3 illustrates the photogrammetric markers arranged on both models, and high-speed cameras were used to record the collapse process from multiple angles.

Fig. 4 animated the collapse and impact process. The frame specimen inclined and impacted the bridge specimen with its 4th, 5th, 6th, 7th and 8th floors sequentially. The total impact time lasted about 2 seconds. The bridge deck suffered perforations and local sagging. Accelerometers recorded the peak accelerations of 1335 m/s² in the *x*-direction, 1395 m/s² in the *y*-direction, and 1077 m/s² in the *z*-direction near the impact region.



(a) The RC Frame (b) The Bridge

Fig. 1 Frame and Bridge Specimens (facade view)

Tab. 1 Additional Mass Blocks of Frame Specimen

Floor	Calculated/kN	Actual/kN, (Blocks amount)
1st Floor	2.542	2.541 (70)

Floors 2-7	1.587	1.597 (44)
8th Floor	1.423	1.379 (38)

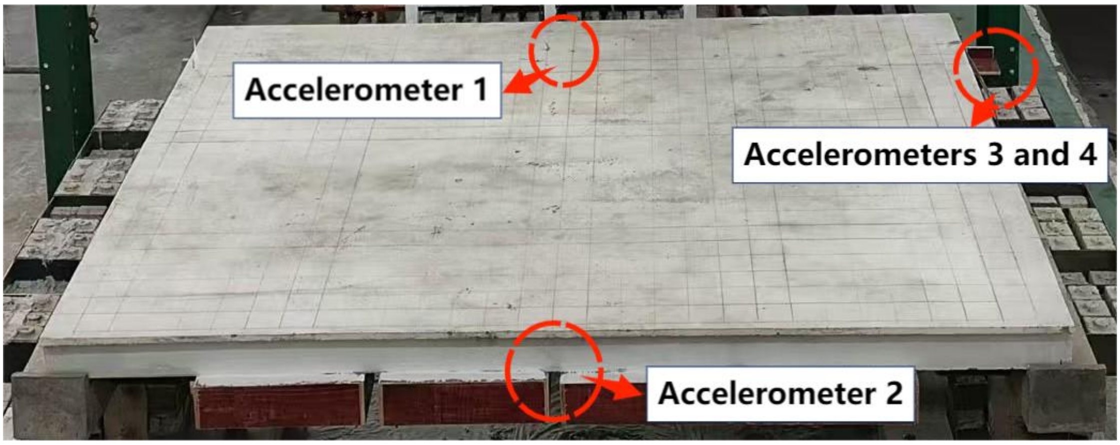


Fig. 2 Accelerometer Layout

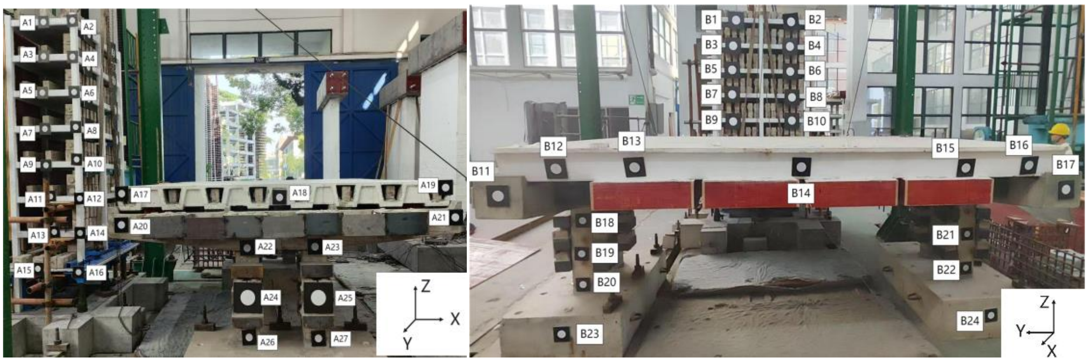


Fig. 3 Photogrammetry Marker Layout

(a) 0.0s (b) 0.6s (c) 0.8s

(d) 1.0s (e) 1.5s (f) 3.0s

Fig. 4 Frame Specimen Collapsed and Impacted Bridge Specimen

3. NUMERICAL SIMULATION

The collapse and impact behaviors were numerical simulated using the software LS-DYNA. A multi-scale finite element (FE) model was established. The lower portion of the frame specimen was modeled with the solid and beam elements, while the upper portion of the structure was simulated using the fiber beam and shell elements. The bridge specimen was modeled with the solid elements and beam elements to represent the embedded reinforcements. Contacts and friction were also appropriately defined in the model. The simulation well replicated the observed collapse and impact behaviors, as showed in Fig 5.

(a) 0.3s (b) 0.3s

(c) 1.0s (d) 1.0s

(e) 2.5s (f) 2.5s

Fig. 5 Comparison Between Simulation and Test

4. CONCLUSIONS

This study presented the impact behavior between a collapsed scaled RC frame and a scaled elevated bridge. Physical experiment and numerical simulation were performed to have a primary insight into the impact behavior. Following conclusions could be drawn based on the study:
(1) The RC frame specimen side-sway collapsed, producing strong and multi-stage impacts on the bridge specimen;
(2) The bridge specimen experienced perforation damage and high peak accelerations responses more than 1000 m/s² in all directions.

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