INVESTIGATION ON STRESS WAVE PROPAGATION AND DISTANCE ATTENUATION CHARACTERISTICS IN REINFORCED CONCRETE STRUCTURES SUBJECTED TO PROJECTILE IMPACT

28 October 2026

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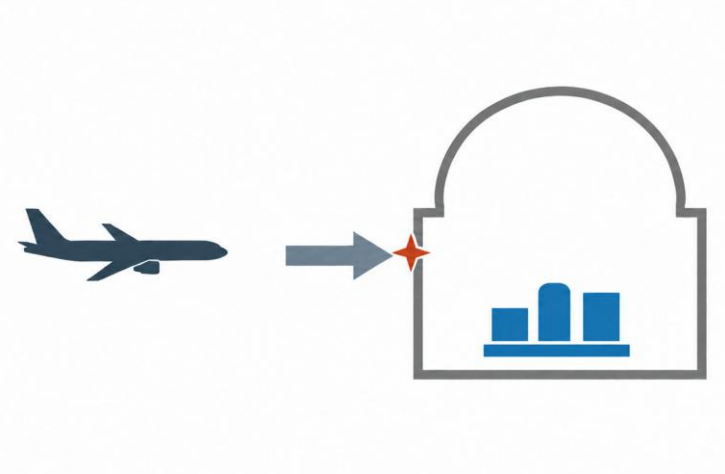
Note: These slides are an English translation of the slides presented at the JSME Computational Mechanics Division Conference (CMD2026), Presentation No.: OS14-1.

Projectile Impact and Equipment Shock Assessment



➢ **External Events Affecting Nuclear Facilities**

- It is critical to address impacts from projectiles, such as tornado debris and aircraft.
- At nuclear facilities, it is necessary not only to ensure the structural integrity of the buildings but also to maintain the functionality of safety-critical equipment.

➢ **Previous Research and Challenges**

- Previous studies have focused primarily on local damage and penetration of building exterior walls.
- On the other hand, knowledge regarding stress wave propagation and response distribution inside the buildings is limited.

➢ **Assessment of Equipment Functionality**

- The maximum response acceleration at the equipment installation location is a key evaluation metric
- It is necessary to quantitatively understand the relationship between the distance from the impact point and the response acceleration

⇒ It is important to understand the response distribution of stress waves propagating within the building and to reduce the input acceleration to the equipment.

Research Background

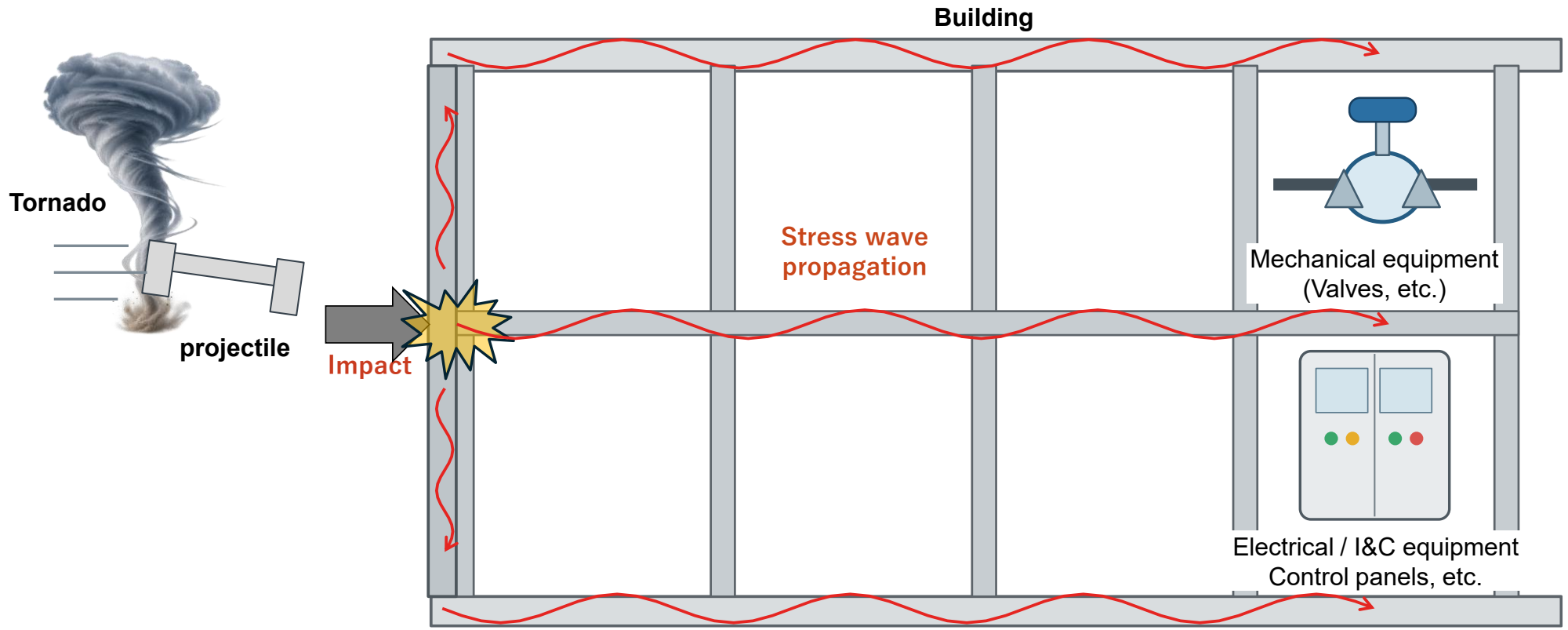
From projectile impact to shock vibration input to equipment

1. Projectile impact
A projectile strikes the external building wall.

2. Impact load
A large impact load acts on the wall for a short time.

3. Stress wave propagation
Impact-induced stress waves propagate through the building.

4. Shock vibration input to equipment
Shock vibrations are transmitted to equipment inside the building.



Research Objectives

- Research topic

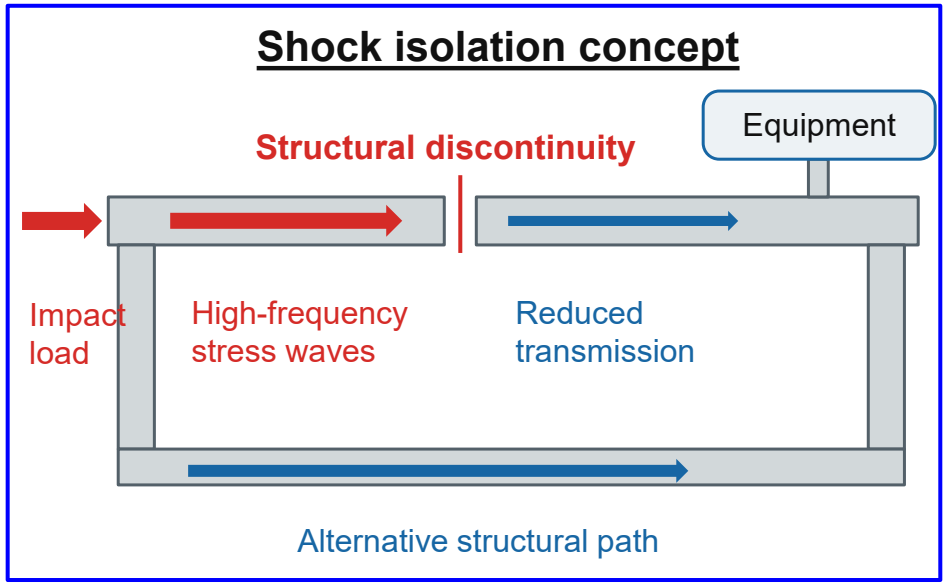
  Impact-induced high-frequency stress waves propagate through building structures.

  Understanding their propagation and attenuation is essential for assessing equipment response.

- Objectives of this study

  ① To characterize the attenuation of stress waves with propagation distance within building structures.

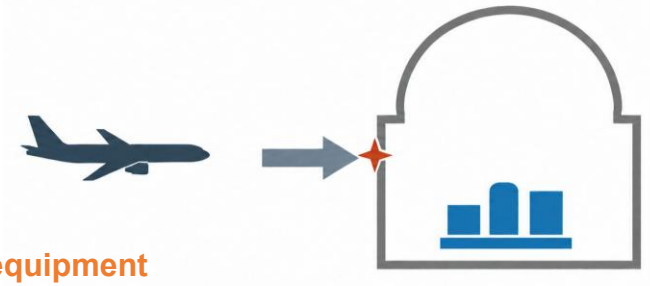
  ② To evaluate the effectiveness of shock isolation in suppressing the transmission of high-frequency longitudinal waves and reducing equipment response.



Impact-resistant design assessment flow for RC buildings and equipment subjected to projectile impact

Projectile and impact conditions
Mass, velocity, stiffness, shape, impact angle

Impact load on the building
Load time history, location, direction



Local damage assessment

Local damage assessment
Penetration, scabbing, perforation

Comparison with local damage limits
Considering projectile stiffness and impact angle

Assessment of building structural integrity
Local damage within allowable limits

Functionality of equipment inside the building

Analysis of impact-induced vibration propagation
V&V of the RC building model and analysis method

Evaluation of input at equipment locations
Acceleration time histories, peak acceleration, frequency characteristics

Floor response spectra for equipment assessment
Considering equipment natural frequencies and damping ratios

Response assessment of equipment
Response reduction based on frequency ratio; peak response acceleration

Equipment functionality check
Response ≤ verified functional limit

NG

OK

Today's Topic

Application of shock isolation
response reduction through shock isolation

Confirmation of overall building structural integrity and equipment functionality

Analysis Model

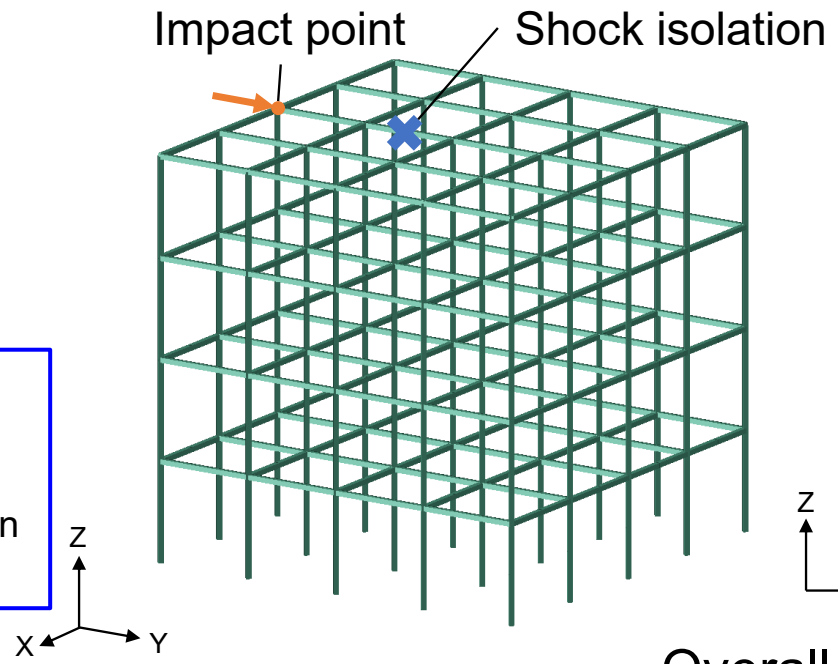
Overview of the analysis model

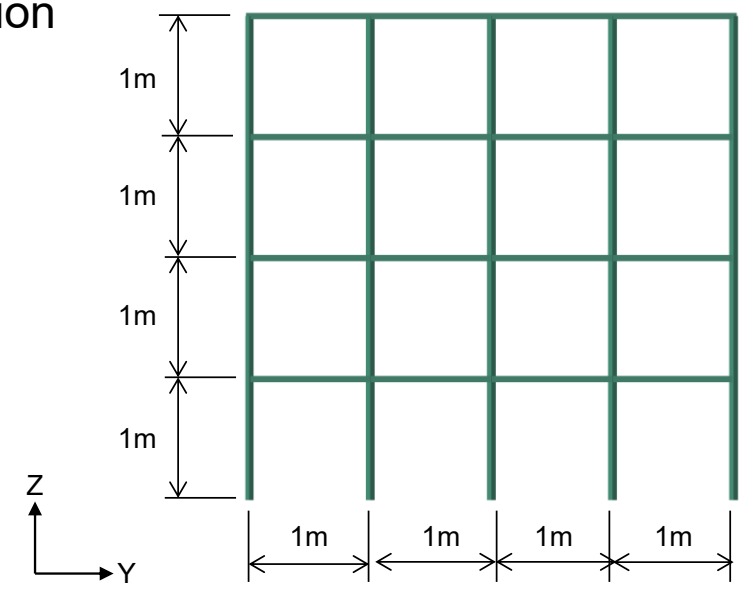
- Analysis code: ASIFEM(1)
- 3D RC frame: 4 stories, 4 × 4 bays
- 385 nodes and 520 elements
- Timoshenko beam elements
- Fully fixed base
- Linear elastic RC members

Note:
Nuclear buildings typically have RC wall structures. This study uses a simplified RC frame model for a fundamental investigation of stress wave propagation and response reduction through shock isolation.

RC material properties

Material	Member cross section	Young's modulus [MPa]	Poisson's ratio [-]	Density [kg/m^3]
RC	50 × 50 mm	25100	0.2	2450





Overall model

(1) ASIFEM: Finite element code for frame structures using the ASI-Gauss method, University of Tsukuba

Analysis Conditions

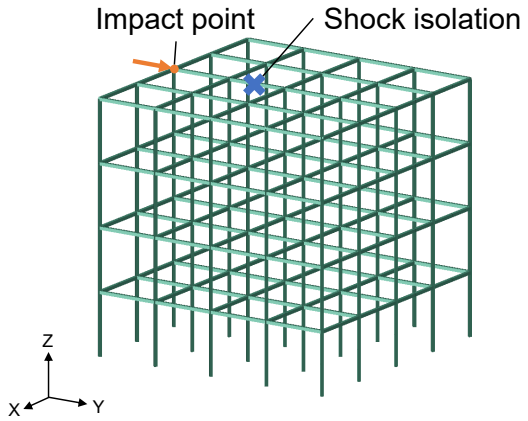
Input conditions (impact load)

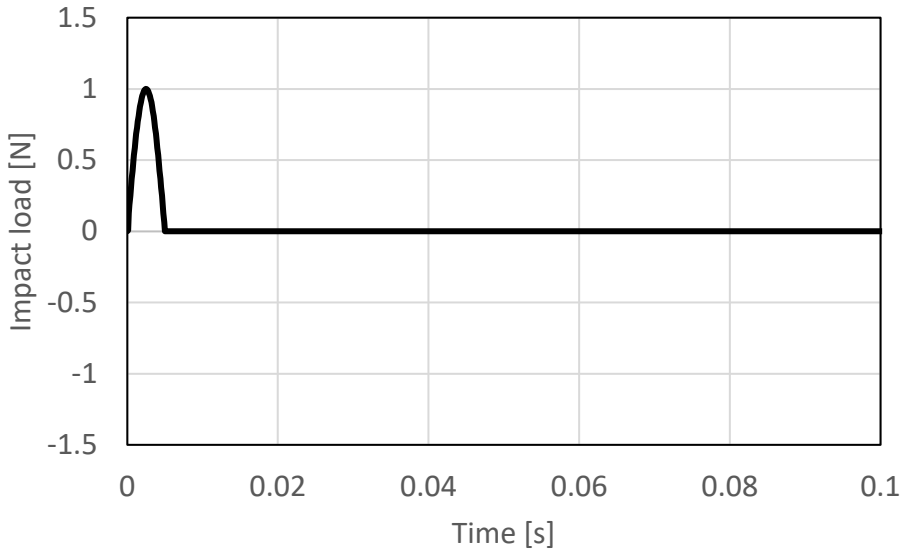
- Load applied in the Y direction at the top of the building
- Peak impact load: 1 N
- 100 Hz half-sine pulse (shown on the right)
- Fundamental frequency: 4.1 Hz

Analysis cases

① Reference case: without shock isolation

② Shock isolation case: nodes disconnected at a distance of 1.5 m from the impact point



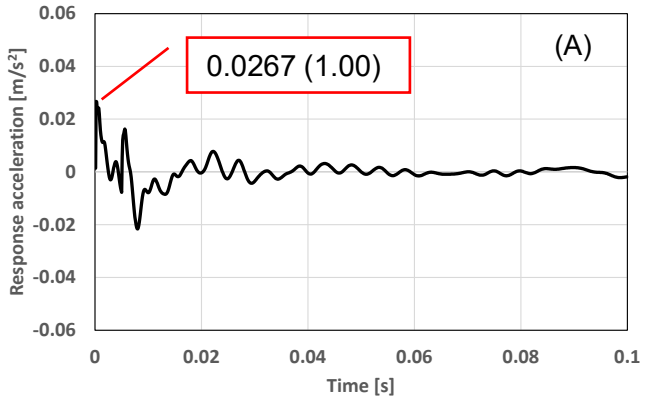


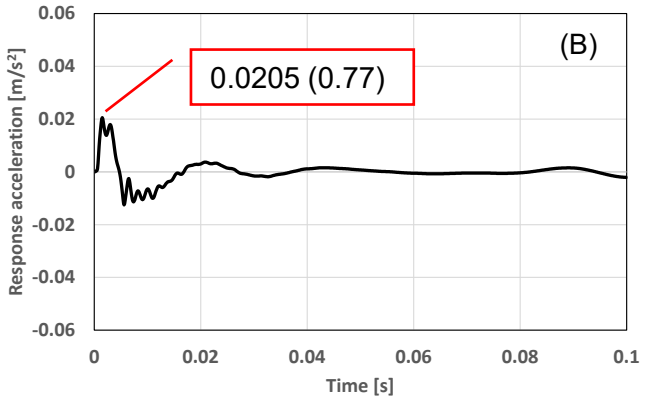
Impact load time history

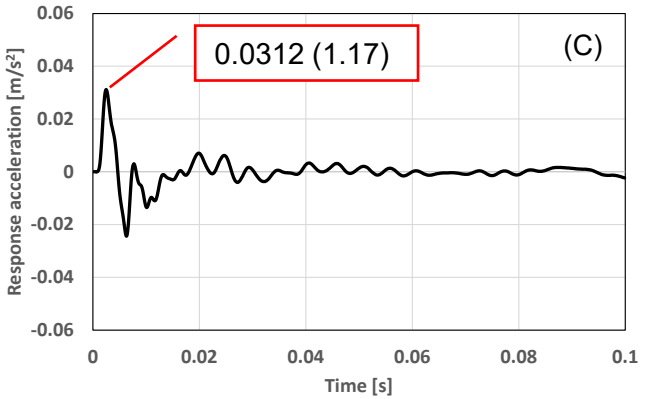
Results: Reference Case

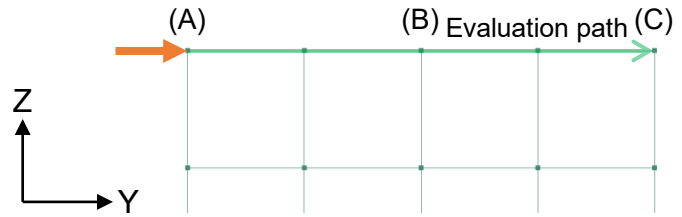
- Reference case

Values in parentheses: peak acceleration ratios normalized by the peak acceleration at point A in each case.







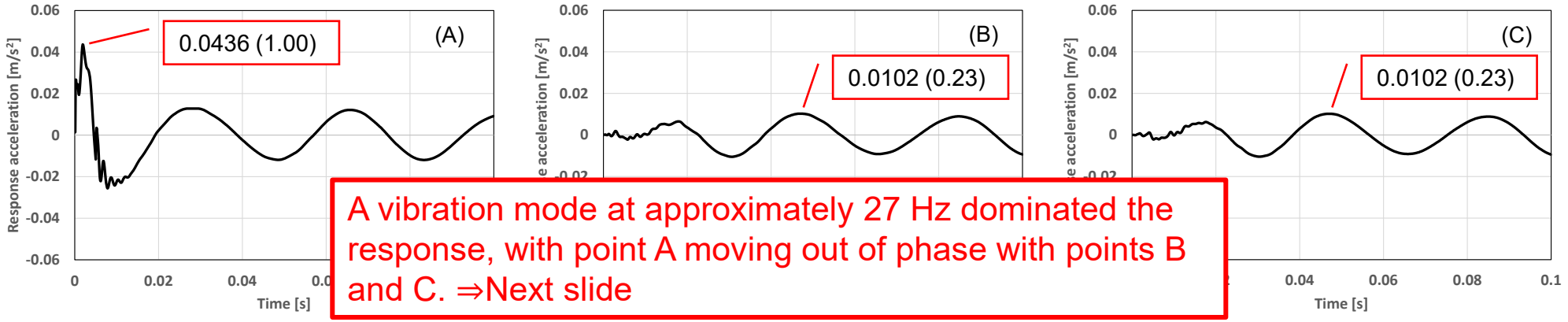


In the reference case, stress waves propagated through the RC members, and no significant attenuation with distance was observed along the evaluation path.

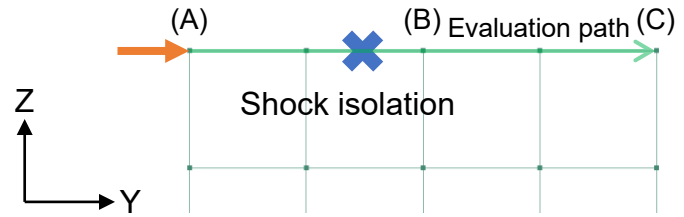
Results: Shock Isolation Case

- Shock isolation case

Values in parentheses: peak acceleration ratios normalized by the peak acceleration at point A in each case.



A vibration mode at approximately 27 Hz dominated the response, with point A moving out of phase with points B and C. ⇒Next slide

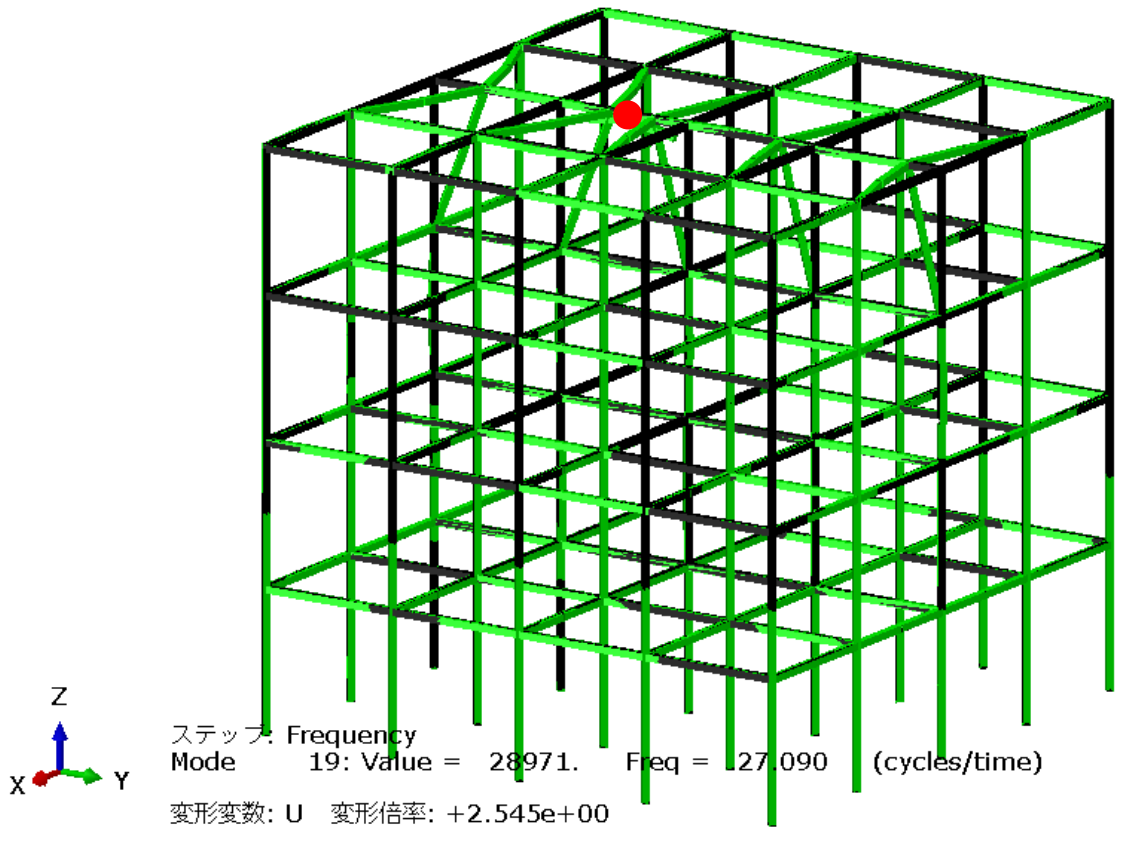


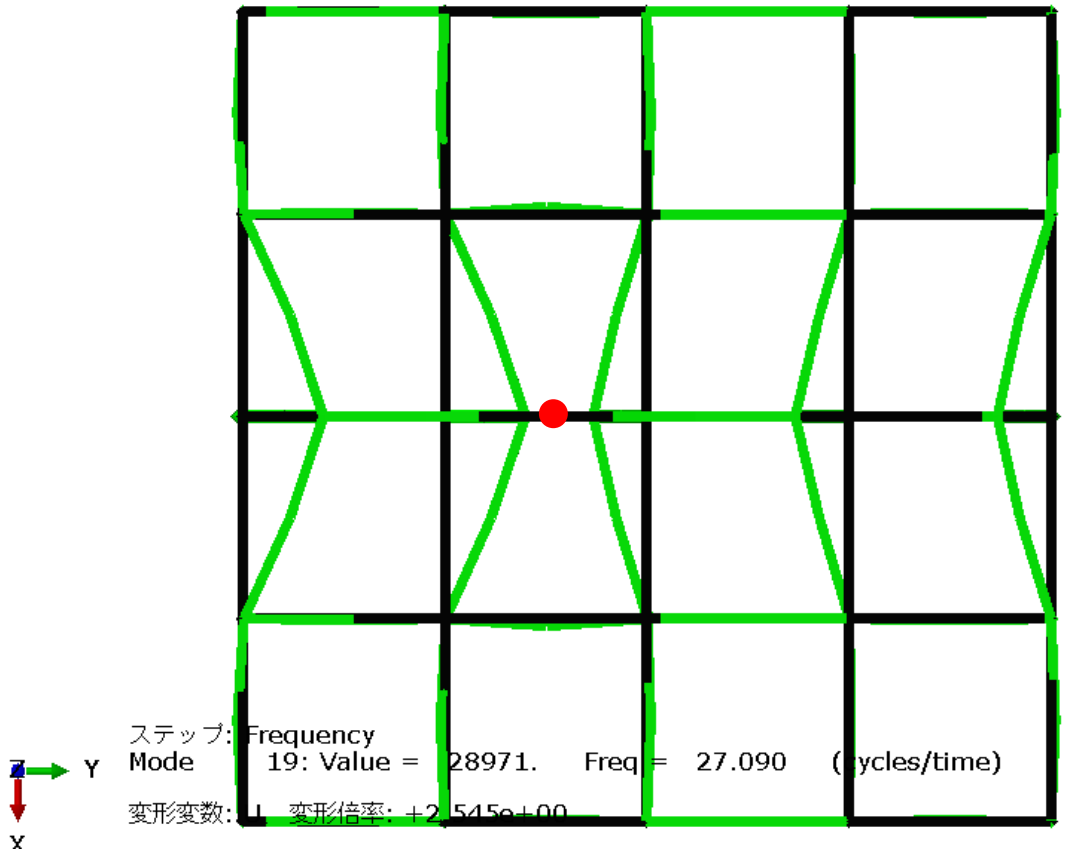
- Shock isolation suppressed the propagation of high-frequency stress waves, and low-frequency structural response dominated downstream of the isolation interface.
- In the shock isolation case, high-frequency components were substantially reduced by the isolation.

Mode 19: 27.1 Hz

- Eigenvalue analysis of the shock isolation case revealed a new vibration mode.

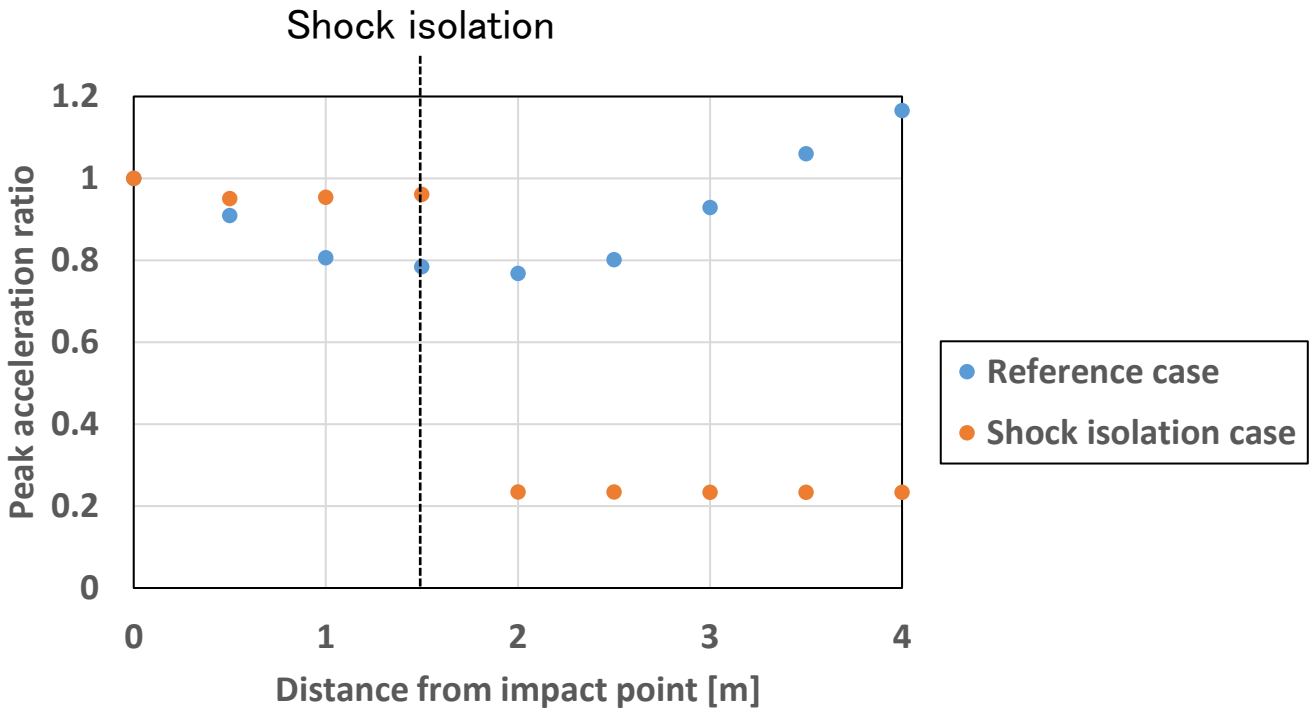
Undeformed configuration
Deformed configuration

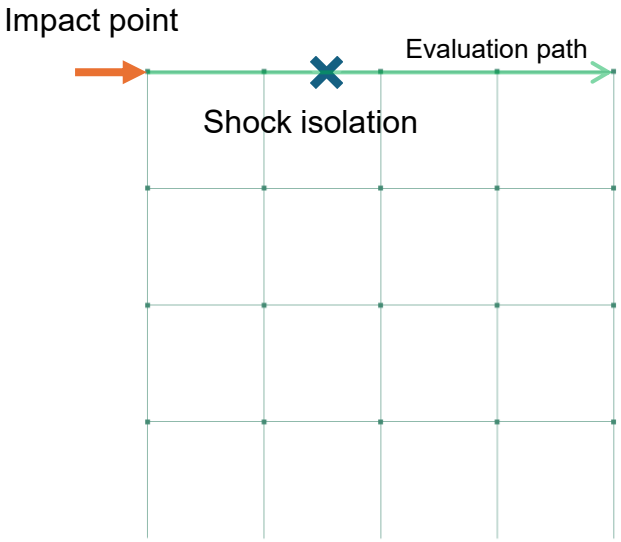




Comparison of Peak Acceleration Ratios

- Peak acceleration ratios





- In the reference case, the peak acceleration ratio ranged from approximately 0.77 to 1.17.
- In the shock isolation case, the peak acceleration ratio decreased from approximately 1.0 to 0.23.

Conclusions

This study examined the attenuation of stress waves with propagation distance within building structures and the response reduction achieved through shock isolation. The following findings were obtained.

- Attenuation with distance
  In the reference case, the peak acceleration ratio ranged from approximately 0.77 to 1.17.
  ⇒ No significant attenuation with distance was observed along the evaluation path.
- Shock isolation
  In the shock isolation case, the peak acceleration ratio decreased from approximately 1.0 to 0.23.
  ⇒ Shock isolation reduced the acceleration response of the downstream structure.
- Potential application to equipment
  ⇒ Shock isolation may reduce the peak acceleration transmitted to equipment inside buildings during projectile impact.

Future work

Further investigations will consider the impact loading direction, the location of shock isolation, and the nonlinear behavior of RC members.

Thank you for your attention