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ギャップブレースを取り付けた鉄骨架構の力学的挙動の検討
その 7 A comparative study: Gapped braced frame, conventional braced frame and non-braced frame

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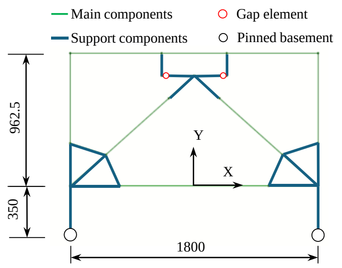
鉄骨架構 耐震設計 変形制御機構
有限要素モデル 曲げモーメント分布

1. Introduction

In response to the need for mitigating displacement of frame structures during major seismic events, a novel seismic device called “Gap Brace” has emerged from collaborative efforts between the Institute of Science Tokyo (Sato Lab and Kasai Lab) and Takenaka Corporation. A 1/4 reduced-scale test specimens were designed and manufactured for static cyclic load test[1)-3)] (Figure 1 (a)). The test confirmed that the Gap Brace can enhance the system’s lateral stiffness only during large frame displacement[2)-3)]. In addition, the finite element simulation conducted by software ABAQUS/Standard provides more information about effect of Gap Brace in frame[4-5)].

However, it is unclear how the impact in frame of Gap Brace differs from that of conventional brace or non-brace. To clarify this difference and provide a basis for subsequent design method, this paper carries out three simplified models by Software OpenSees for comparison: Gap braced frame (GBF), conventional braced frame (CBF) and non-braced frame (NBF). Firstly, the GBF is validated by the results obtained from test and ABAQUS. Then, the drift ratio - lateral force relationship (*Q*-*R*) and stress distribution are compared among GBF, CBF and NBF.

(a) Test photo



(b) GBF

Figure 1 Test specimen and simplified model of GBF

2. The simplified GBF model and validation

To faithfully replicate the reduced-scale GBF test, the finite element model in OpenSees has been meticulously constructed (Figure 1 (b)), encompassing the following key aspects:

- **Components**: The main components (beams, columns and braces) adopt the fiber section and “forceBeamColumn”; while support components use “elasticBeamColumn”.
- **Gap element**: the “zeroLengthImpact3D” is used to simulate the gap, with the gap value set as 7.5 mm and friction coefficient set as 0.15.
- **Material Properties**: “Steel02” material is employed, with the Young’s modulus and yield stress set as the test.
- **Load Application:** A static cyclic load (peak value = 800 kN) was used.
- **Boundary condition**: The basement is pinned.

The *Q*-*R* relationships are shown in Figure 2, where Q_C means the lateral force in columns, Q_B means the lateral force in braces, and Q_S means the lateral force in system. In addition, the moment and axial force distribution when pressure force is 800 kN (from left side) are shown in Figure 3. These results show the simplified GBF can match the test and ABAQUS model well, in the aspect of *Q*-*R* relationship and stress distribution. Thus, this indicates that the simplified model in OpenSees is used for future research.

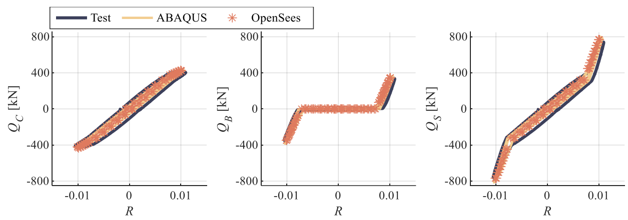
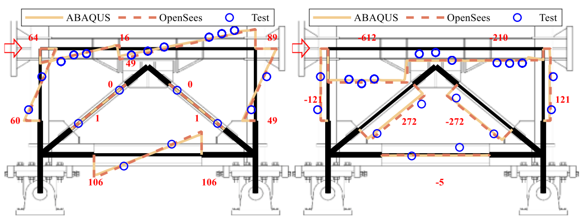


Figure 2 *Q*-*R* relationship of GBF



(a) Moment (unit, 10^3 kN・mm) (b) Axial force (unit, kN)

Figure 3 Moment and axial force distribution of GBF

3 The simplified CBF, NBF model and comparison

To emphasize the different effects of GBF, another two simplified models of CBF and NBF are also conducted (Figure 4). In GBF, the frame connects to braces only when the displacement

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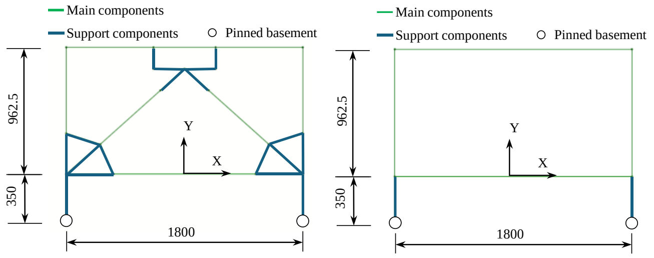
is large. Differently, the frame is always connected to braces in CBF during the whole loading, while that never happens in NBF.



(a) CBF (b) NBF

Figure 4 Simplified model of CBF and NBF

The *Q*-*R* relationship of half cycle is shown as Figure 5. GBF, CBF and NBF show different trends:

1) For GBF, only the frame bears load force at the beginning. When the frame is about to yield, the gap closes, and the brace begins to bear the main additional load force. As a result, the brace does not yield during 800 kN load.
2) For CBF, the brace operates from the beginning, and frame bears less load force than GBF and NBF. However, when Q_B is about 420 kN, the brace yield and then the system stiffness decreases a lot. After brace yielding, the frame behavior of CBF is close to NBF. As a result, the drift ratio of CBF is close to GBF.
3) For NBF, due to the lack of reinforcement from supporting components, stiffness is smaller than GBF. When Q_C is about 400 kN, the frame yield and the system stiffness decrease gradually.

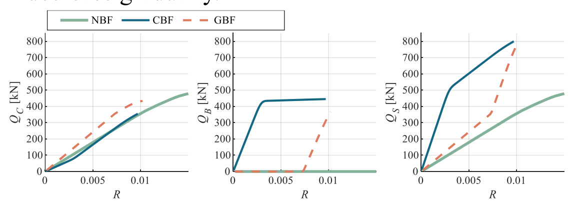
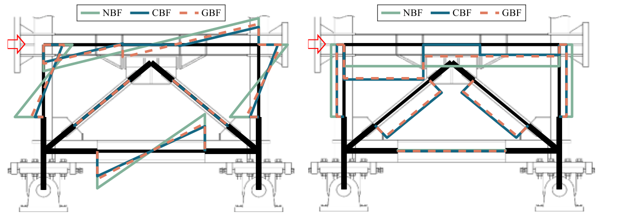


Figure 5 Q-R relationship comparison

The moment and axis force distribution when Q_S = 800 kN is shown as Figure 6. Based on these results, the key observations are summarized as follows:

1) For the GBF, the left gap close only when large frame displacement. The system fully utilizes the deformation capability of the frame.
2) For the CBF, the braces bear main load force at the beginning. However, when under 800 kN, the brace yields, and the moment and force in frame is close to GBF.
3) For the NBF, due to its smaller lateral stiffness and large deformation, the moment and axial force are much larger than GBF and CBF.



(a) Moment (b) Axial force

Figure 6 Moment and axial force distribution comparison

4. Conclusion

The study investigated the mechanical behavior of the test frame with different braces by comparing three models. Some conclusions can be marked as follows:

1) GBF initially relies on the frame to bear load forces, and the brace operates only when large displacement. As a result, the system fully utilizes the deformation capability of the frame. The brace does not yield under an 800 kN load.
2) CBF has the brace engaged from the start, reducing the force on the frame. However, when the brace force reaches approximately 420 kN, it yields, leading to a significant decrease in system stiffness.
3) NBF relies solely on the frame to resist external forces. When the lateral force reaches about 400 kN, the frame yields, causing a gradual reduction in stiffness.

GBF has a more balanced seismic performance between braces and frame. Designing Gap brace to increase the yield force of the system is a highly promising solution in seismic reinforcement.

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