Three-storey configurable steel framed building incorporating friction based energy dissipaters: structural configuration and instrumentation

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ABSTRACT

A 9 m high, full-scale three-storey configurable steel frame composite floor building incorporating friction based connections is being tested using two linked bi-directional shake tables at the International joint research Laboratory of Earthquake Engineering (ILEE) facilities, Shanghai, China. This RObust BUilding SysTem (ROBUST) project includes the testing of 9 different structural configurations, all of which incorporate friction-based energy dissipaters. Typical non-skeletal elements (NSEs) including precast-concrete panel (PCP), glass curtain walling (GCW), internal partition wall (IPW), suspended ceilings, fire sprinkler piping as well as some other common contents (desks/ tables/ bookshelves) are also being adopted in the last phase of the testing program, to determine the influence of these elements on the response.

One of the key challenges has been to accommodate different seismic resisting systems (moment resisting frames, braced frames and rocking frames) into one testing frame, which has significantly complicated the design and detailing procedure. This paper presents a summary of considered structural configurations and instrumentation plan.

1 INTRODUCTION

The concept of designing for controlled damage in a severe earthquake has been well developed and implemented for four to five decades (MacRae and Clifton, 2013). The 2010-2011 Canterbury earthquake sequence shows that the performance of controlled damage designed steel structures is very good, especially considering the intensity of shaking which was more than twice that considered in design (MacRae and Clifton, 2015). As a result, structural steel has been the construction material of choice in the Christchurch rebuild. However, for many building owners and occupiers, they will need to leave their damaged (or worse not functional) building following the earthquake for assessment and repair. It is obviously beneficial to make buildings operational rapidly or preferably immediately following a severe earthquake.

A 9 m three-storey steel frame composite floor building with configurable structural systems is to be tested at the International joint research Laboratory of Earthquake Engineering (ILEE) facilities, Shanghai, China. The purpose is to develop and/or examine damage avoidance design of steel structures based on a complete building system. This will embrace typical NSEs including PCP, GCW, IPW, suspended ceilings, fire sprinkler piping as well as many other common building contents (desks/ tables/ bookshelves) through shake table testing. The isometric view of proposed structural configurations and instrumentation plan are presented in this paper. The general instrumentation plan is also discussed.

2 STRUCTURAL SYSTEMS CONSIDERED

The building considered in this project is a 3-storey steel frame building with plan dimensions of 7250 mm by 4750 mm (from centre to centre of the corner columns) and an inter-storey height of 3 m. The structure is configurable on the tables to test 9 different structural as follows:

- Moment resisting frame (MRF) incorporating sliding hinge joint (SHJ) configuration: MRF-SHJ
- MRF incorporating optimised sliding hinge joint (OSHJ) configuration: MRF-OSHJ
- Concentrically braced frame (CBF) with diagonal brace incorporating symmetric friction connection (SFC) configuration: CBF-D-SFC
- CBF V-braced frame incorporating SFC configuration: CBF-V-SFC
- Resilient slip friction joint (RSFJ) MRF configuration: RSFJ-MRF
- RSFJ tension-compression braced configuration: RSFJ-CTB
- RSFJ tension-only braced configuration: RSFJ-TOB
- Rocking CBF incorporating GripNGrab (GnG) configuration: RF-GnG
- Multiple rocking column steel structural system configuration: MRC

Design and detailing has been reported by Yan et al. (2019 and 2020), Bagheri et al. (2020), Rangwani et al. (2020) and Jia et al. (2020). The aim of this section is to visually display the proposed structural configurations in detail.

2.1 Asymmetric friction connection (AFC)

2.1.1 MRF-SHJ

The 3 D view of MRF-SHJ configuration (adopted in the longitudinal direction) sitting on top of the linked shake tables is shown in Figure 1. There are two bays in the longitudinal direction on each side. The SHJ is only applied at one bay on each side, while the other bay is pinned at all three levels.

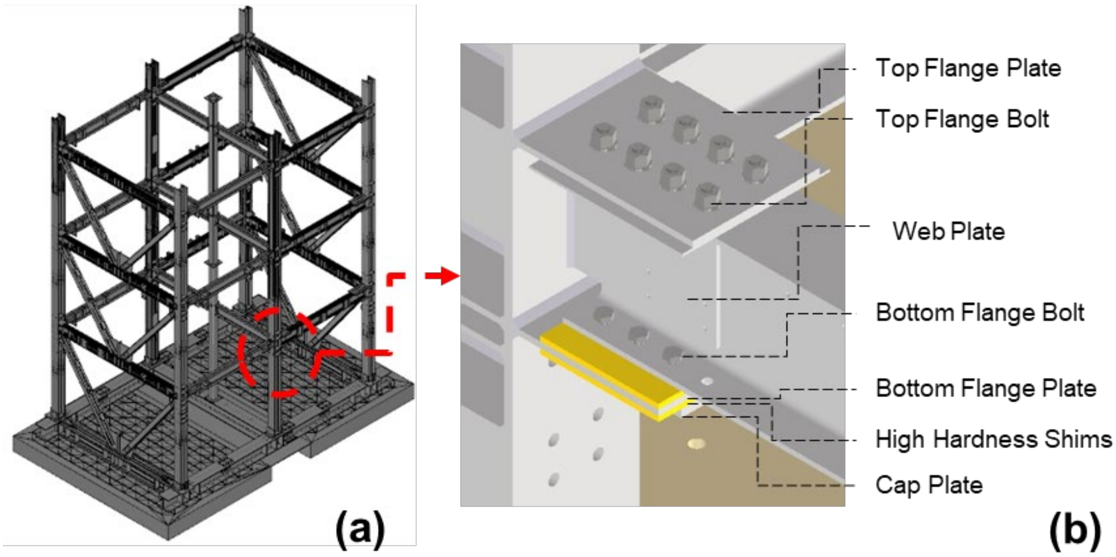

Figure 1: MRF-SHJ (a) Isometric View and (b) SHJ Detail

2.1.2 MRF-OSHJ

The structural general layout for the MRF-OSHJ is almost the same as for the MRF-SHJ configuration shown in Figure 1, except that two Belleville Springs (shown in red in Figure 2) are adopted, one at the bolt head and one at the nut in each bolt, with the one under the component being turned replacing the hardened washer. There is no need to use hardened washers when the Belleville Springs are used, as the BeS doubles as a hardened washer. With the use of these Belleville springs, the post-sliding AFC plies wearing can be potentially reduced through the wider distributed clamping force along the edges of the Belleville Springs as well as reducing the AFC bolts additional internal actions during stable sliding, minimizing the AFC bolt tension variations during bolt tightening and sliding, and greatly reducing the in-service AFC bolt tension loss (Ramhormozian et al. 2014, 2015 & 2017).

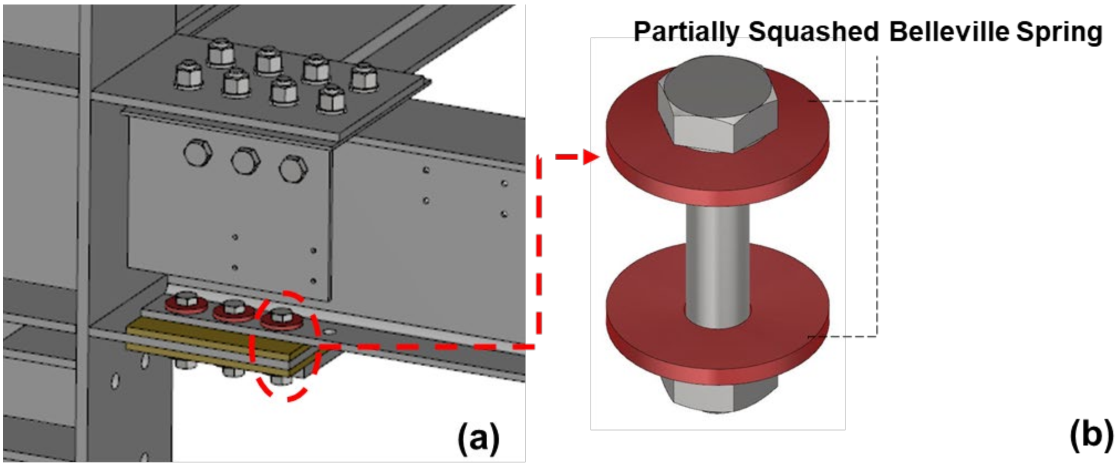

Figure 2: Close up View of (a) OSHJ and (b) Belleville Springs Assembly

2.2 SFC

2.2.1 CBF-D-SFC

In traditional CBF systems, the bracing elements are subjected to axial forces responding to the seismic action. The system, in nature, is stable in tension but unfavourable under compression, therefore the braces should always be in pairs. However, the SFC at brace to gusset plate connection can provide effectively identical response under both tension and compression and the seismic load C_s coefficient is not considered to be required due to the predictable/ stable sliding shear resistance. A single diagonally braced frame (in the longitudinal direction) is proposed, as shown in Figure 3. The system will also be tested for the case with and without Bellville Springs. The influence of using Belleville Springs on SFC at complete structure level can also be understood.

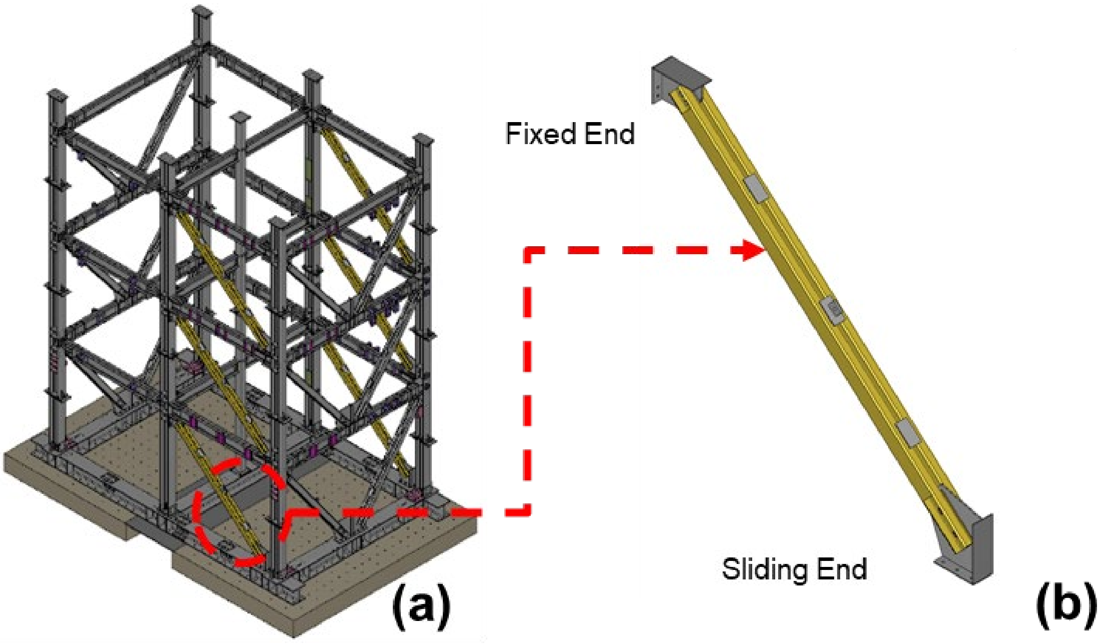

Figure 3: CBF Diagonally Braced Frame Incorporating SFC (a) Isometric View and (b) SFC Brace

2.2.2 CBF-V-SFC

The 3D view of the CBF V-braced frame incorporating SFCs is shown in Figure 4. The braces with SFCs are located in the transverse direction.

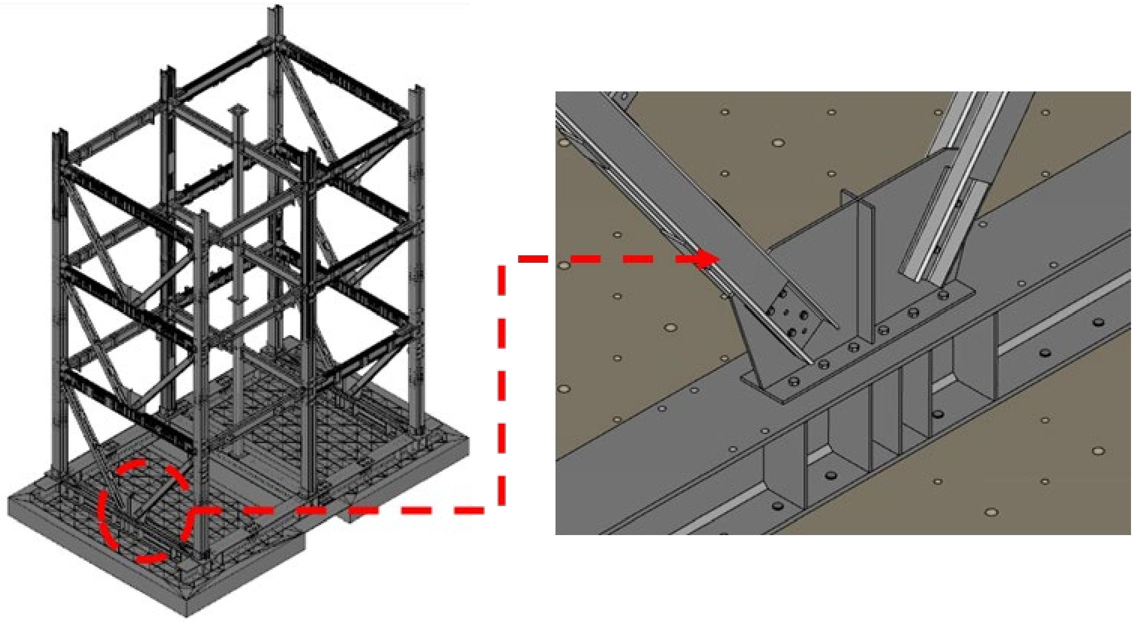

Figure 4: CBF V-Braced Frame Incorporating SFC

2.3 RSFJ

2.3.1 RSFJ-MRF

Figure 5 shows the isometric view of moment resisting frame incorporating RSFJ and key design features. The RSFJ is placed at the bottom flange of the beam and in conjunction with the pin can provide positive and negative moment capacity through joint axial tension and compression in the RSF.

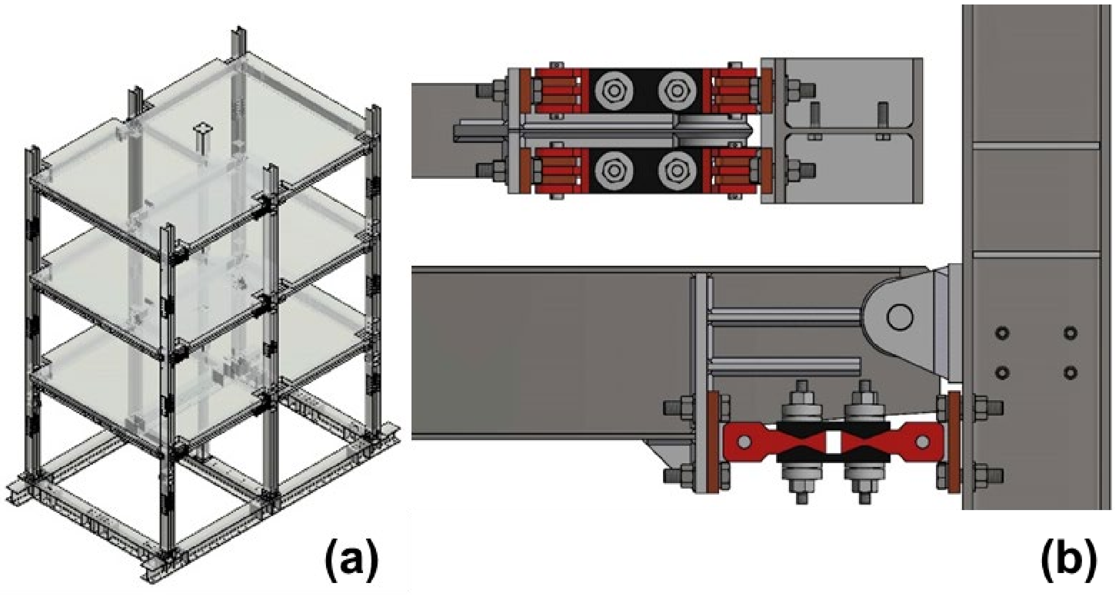

Figure 5: Moment Resisting Frame Incorporating RSFJ (a) 3D View and (b) Beam to Column Connection

2.3.2 RSFJ-CTB

Isometric view of CBF with RSFJ compression and tension brace and key design features are shown in Figure 6. The RSFJ and the brace body will undergo compression forces. In order to prevent brace buckling, an anti-buckling tube mechanism is used as shown in Figure 6 (b). The braces are placed only at the bottom two levels.

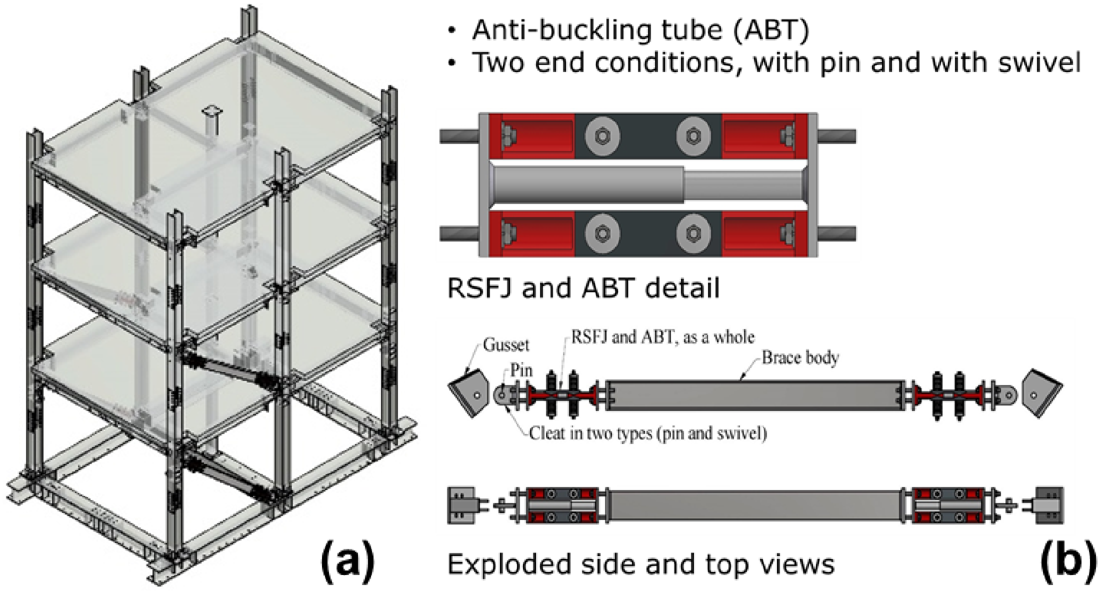

Figure 6: CBF with RSFJ Compression and Tension Brace (a) 3D View and (b) Design Features

2.3.3 RSFJ-TOB

A 3D view of the CBF with RSFJ tension only braces is shown in Figure 7 along with key design aspects of the brace. The RSFJ is combined with the DONOBrace, a tension only bracing system, adopted in the bottom two stories.

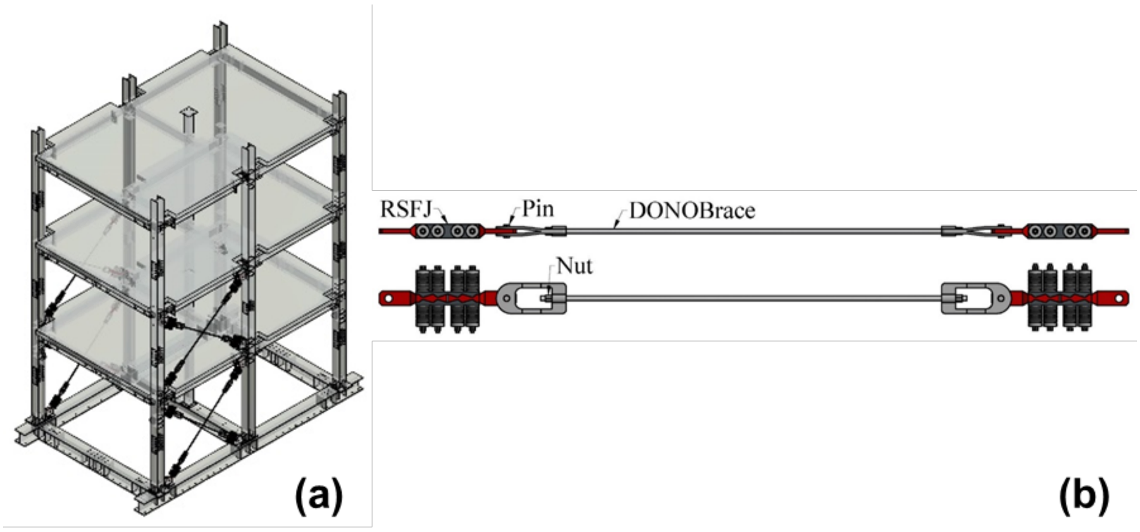

Figure 7: CBF with RSFJ Tension Only Brace

2.4 Rocking systems

2.4.1 RF-GnG

The Rocking CBF with GnG is as shown in Figure 8. The tension-only GnG device is installed at the inner side of the corner columns on the bottom level. A total of 4 devices are applied. The GnG is comprised of two components: a ratcheting component and an SFC component. When the GnG is in tension, energy is dissipated though sliding of SFC. When in compression, it carries almost no force but accommodates in-plane rod displacements due to ratchetting. The GnG has a strong potential to provide large displacement capability without obvious damage.

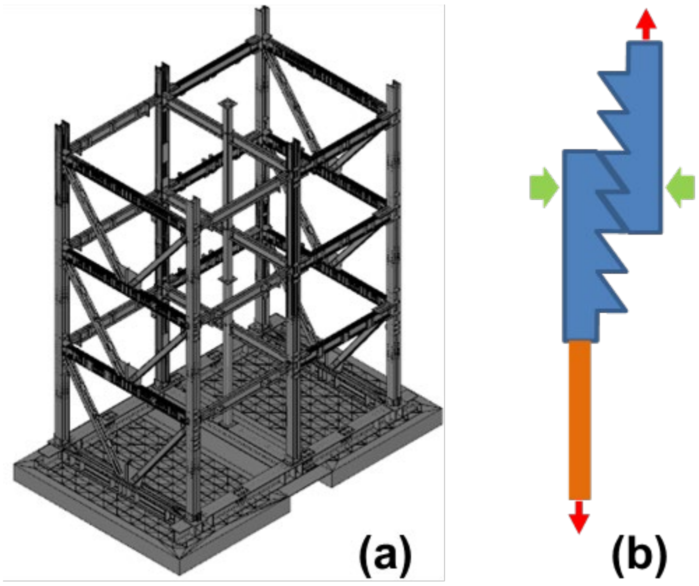

Figure 8: Rocking CBF with GnG (a) 3D View and (b) Tension-only Concept (MacRae and Clifton, 2015)

2.4.2 MRC

The isometric view of multiple rocking column steel structural system is shown in Figure 9. Comparing with the previous configurations, the V type braces in the transverse direction are now taken off and replaced by the rocking columns. This concept originates from Chinese ancient wooden pagodas, which have been shown to be highly earthquake resilient against many severe events. The vertical load on the rocking columns multiplied by the eccentricity of the rigid column pedestal is used for providing restoring force.

Figure 9 (a) shows the detail at column splice when the system is moment/ braced frame. The columns are separated as shown in Figure 9 (b) by removing the middle shim plate. This will provide enough tolerance allowing the rocking columns to rock freely.

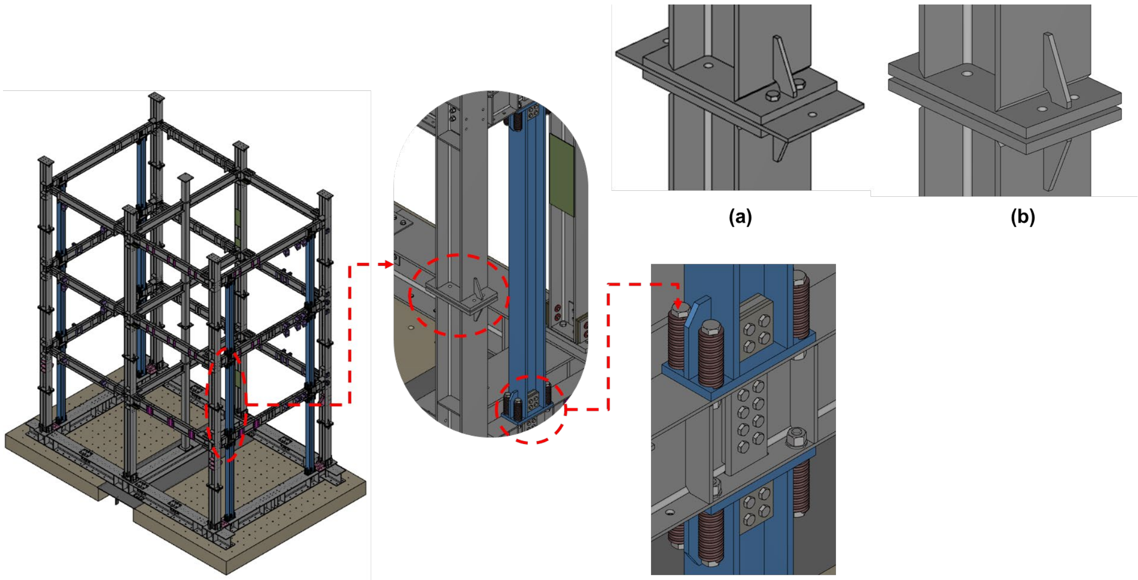

Figure 9: Rocking Column System (a) Prior to and (b) After Installation of Rocking Column

3 INSTRUMENTATION

The proposed structure will be tested on a shake table at the ILEE facilities, Shanghai, China. The linked shake table has a base dimension of 6.0 m x 9.5 m, maximum payload of 1400 kN, frequency range 0.1 – 50 Hz, peak acceleration of 1.5 g and displacement in the range ± 500 mm. The accelerometers, displacement transducers, strain gauges and load cells will be connected to NI SCXI-1520 Data Acquisition System. A total of 220 channels is provided.

3.1 Table instrumentation

Nine uni-axial Setra-141 accelerometers will be installed at the centre and two opposite corners to measure the table acceleration and the base shear. Ten displacement transducers will be installed at the corners to measure the table displacement. Positive-X, Y and Z of these accelerometers corresponded to the axes shown in Figure 10.

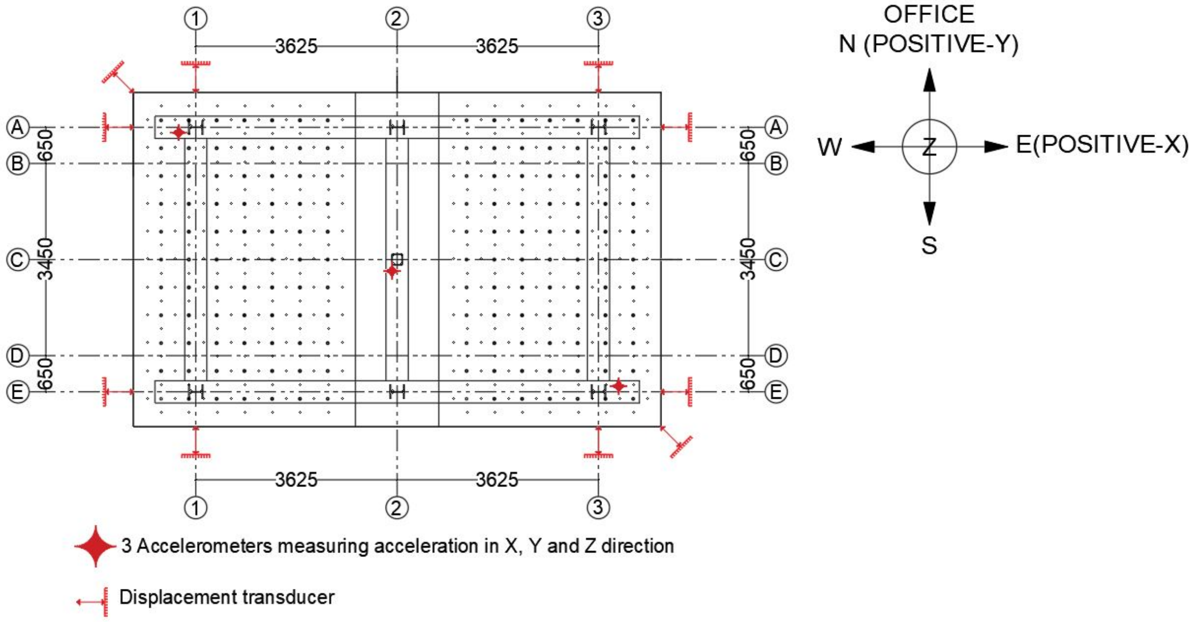

Figure 10: Instrumentation at Shake Table

3.2 Structure instrumentation

A total of 27 uni-axial Setra-141 accelerometers will be installed. The accelerometers will be placed at the centre and two opposite corners on each floor to measure the acceleration response and the storey shear in two directions (see Figure 11). Displacement transducers will be installed on each floor at two opposite corners to measure the storey drift response (see Figure 11). Strain gauges will also be used to monitor the strain and yielding of structural members, as well as the forces in the braces.

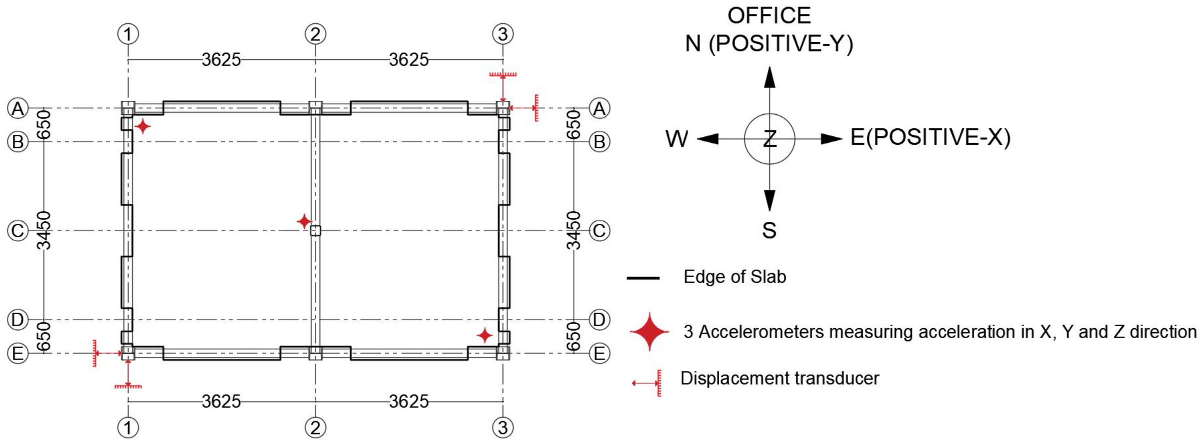

Figure 11: Global Acceleration and Displacement at All Levels

Besides the global measurement, measurement at connection level is also important but needs to be simplified due to the limited number of channels available in the data acquisition system (DAQ). An example of instrumentation that will be used at the beam to column connection when testing MRF-SHJ configuration is shown in Figure 12. A linear potentiometer will be installed near the beam bottom flange, this is to measure the joint rotation. Strain gauges will be placed at beam ends on top and bottom flange, this is to monitor the bending moment at critical section. The full moment-rotation curve can then be obtained.

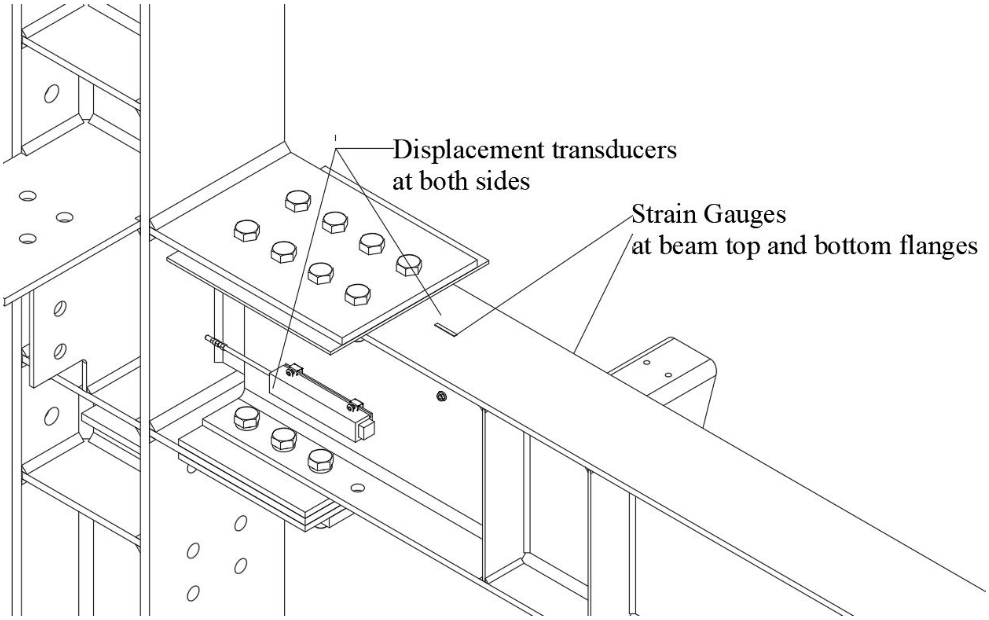

Figure 12: Instrumentation at Beam to Column Connection (SHJAFC and OSHJAFC)

3.3 Digital image correlation (DIC)

An optical measurement system will also be used as an alternative for measuring global and local displacement and accelerations. The DIC system uses infrared cameras to capture three-dimensional coordinates of each reflective sphere or target marker. This system is especially adopted to measure the response of glazing curtain wall (GCW) and precast concrete panel (PCP) as a supplement to the total 220 channels from the data acquisition system, thereby avoiding the need for two DAQs, which brings problems with data synchronisation.

4 CONCLUSIONS

This paper presents an overview of the ROBUST structure, with details of the 9 structural configurations to be tested, and describes the general instrumentation plan. The testing is expected to be conducted in June 2021 at ILEE facilities, Shanghai, China. All going to plan, this test will provide an exemplar of how economic resilient technology may protect the whole building against severe earthquakes.

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