2018 QuakeCoRE Annual Meeting
Theme: Flagship 4

Planning Shake-Table Testing of a Three-Storey Low-Damage Steel Frame Building

K Rangwani, G MacRae, C Clifton, R Dhakal, A Hashemi, G Beattie, G Rodgers, H Bagheri, K Elwood, L.J. Jia, M Rashid, P Quenneville, P. Xiang, P Zarnani, S Ramhormozian, T Sullivan, X. Zhao, Z Yan

INTRODUCTION

As part of QuakeCoRE research into the reparability of structures, the ROBUST (**RO**bust **BU**ilding **S**ys**T**em) BUILDING SYSTEM TESTING programme is a collaborative NZ-Chinese project involving the 2-D shaking table testing of a full scale multistorey resilient and reparable building system (i.e. with friction connections and non-structural elements (see Fig. 1).

The testing will be conducted at the International Joint Research Laboratory on Earthquake Engineering (ILEE) facilities, Shanghai, China. The test specimen will be representative of a realistic New Zealand building with structural elements, floor diaphragms, as well as non-structural elements (NSE) including ceilings, partitions, cladding and other details. Earthquake energy will be dissipated using a range of frictional systems, many of which have been developed in New Zealand. This poster describes the objectives of the testing, reports on developments that have taken place to date, and presents preliminary plans and drawings of the test specimen.

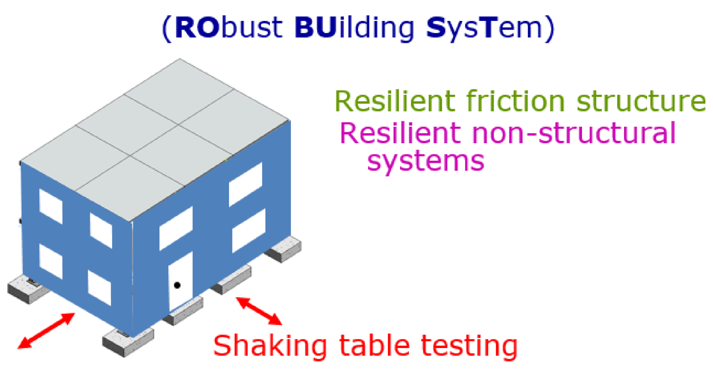

Figure 1. Testing of a ROBUST building system

NEED

Recent severe earthquakes worldwide have emphasised the need for building resilience. Some design procedures developed minimize the undesirable effects of the earthquakes by using friction for energy dissipation. Detailed experimental testing moment resisting frames and friction connections at component level has been undertaken, but no experimental testing has been undertaken on complete building systems using friction. Hence, there is a need to develop a full-scale steel structural building system, comprising both structural and non-structural components, that can withstand strong earthquake shaking without significant damage.

SCOPE

- This study is referred to as the RoBuSt (**RO**bust **BU**ilding **S**ys**T**ems) project. The structure tested (see Fig. 2) uses friction type energy dissipaters in the form of asymmetric friction connections (AFCs), symmetric friction connections (SFCs), and resilient sliding friction joints (RSFJs). The structural forms used include moment frames, braced frames, and rocking frames. New concepts, such as the GripNGrab (GnG) system, will be implemented.
- Whole building performance is evaluated with a range of non-structural elements (NSEs) including the building envelope, partitions, ceilings, and contents.
- Testing will be realistic, large scale, in 2 horizontal directions, and dynamic to define levels of scaled earthquake intensity.
- Repair, will be easily inspected and undertaken if required.
- The testing will be of a complete building system with both structural and non-structural (NS) elements.

Thus, this test is likely to develop new science regarding structural (friction connections) and non-structural elements by investigating the seismic performance of a complete building system (i.e. including the interactions between the structural and NS components). This may will provide an exemplar of how economic resilient technology can protect the whole building.

OBJECTIVES

1) Demonstrate the effectiveness of a variety of realistic scale structural friction technology solutions for resilient large scale structures under dynamic load conditions
2) Develop and evaluate the performance of non-structural technology for use in resilient buildings
3) Test economical methods for inspecting, and repairing damage, and for straightening such building systems .

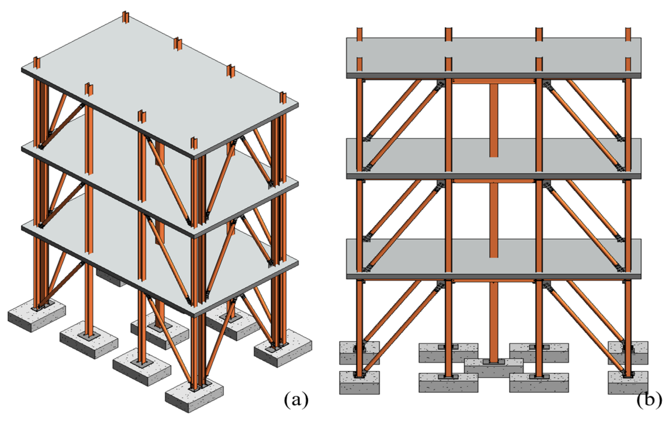

Figure 2. (a) 3D view and (b) front view of the structure to be tested.

TYPE OF FRAMES

Depending upon different types of frames system various changeable configurations will be considered in structure for the test. They are: (see Fig. 3)

- Moment resisting frame (MRF)
- Braced frame (BF) system
- Rocking frames

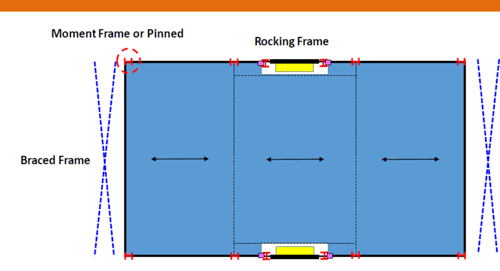

Figure 3. Test frame plan

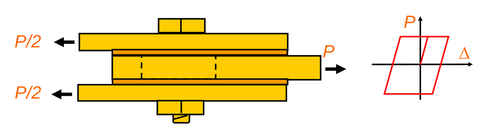

Figure 4. Symmetric friction connection (SFC)

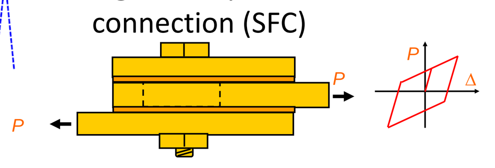

Figure 5. Asymmetric friction connection (AFC)

TYPE OF CONNECTIONS

Significant development of a number of connection types have been developed in NZ since 1995. The basic friction connection types are:

- *Symmetric Friction Connections (SFCs)* (Fig. 4)
- *Asymmetric Friction Connections (AFCs)* (Fig. 5)
- *Resilient Slip Friction Joint (RSFJ)* (Fig. 6)

The friction connections are held together with high strength bolts. These connections remain rigid during low levels of earthquake shaking but slide and dissipate energy through friction during severe earthquake shaking.

Friction connections are frames at different locations such as at the beam ends, column bases, at the brace ends, rocking wall base, and rocking wall sides (see Fig. 7).

Friction connection configurations:

- *Sliding Hinge Joint (i.e. beam end AFC)*

The SHJ is a low damage alternative for traditional seismic MRFs (see Fig 8). Belleville springs (BS) may be used with the bolts. Connections are initially rigid then rotate at higher moments. They can sustain high rotations with minimal degradation. Placing them on the beam bottom flange minimises slab damage.

- *Rotational link at brace end* (Fig. 9)
- *Rocking frame dissipater* (Fig. 10)
- *Rocking wall tension only dissipater such as GripNGrab device* at rock wall base (Fig. 11)

Figure 6. Resilient Slip Friction Joint (RSFJ)

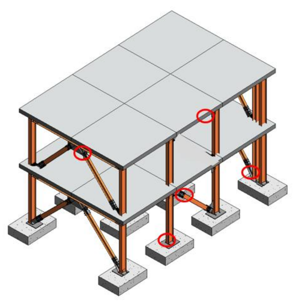

Figure 7. Friction connection locations

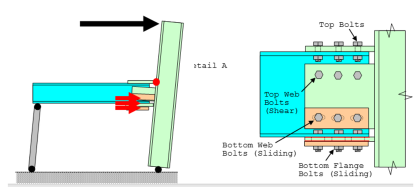

Figure 8. Sliding Hinge Joint (SHJ)

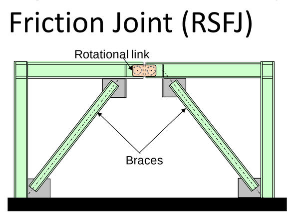

Figure 9. Rotational link at brace end

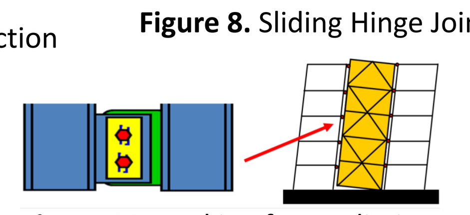

Figure 10. Rocking frame dissipater

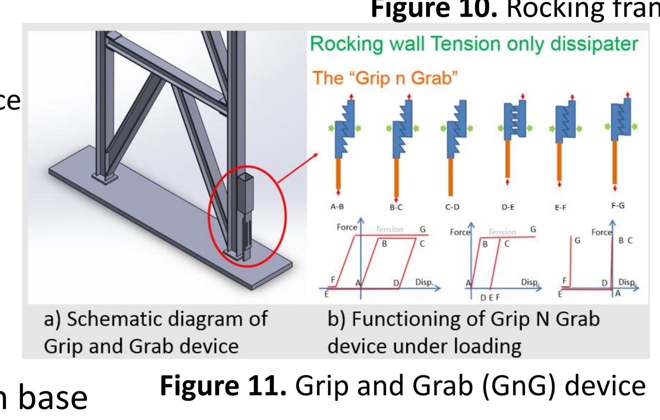

Figure 11. Grip and Grab (GnG) device

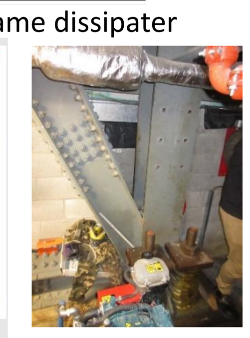

Figure 12. Ring spring at base

- Column base connections may use the following options (Figs 12 and 13).

a. *Traditional AFC*
b. *BS AFC*
c. *Crocodile type (RSFJ)*
d. *Flexible Plate*
e. *Ring Spring*

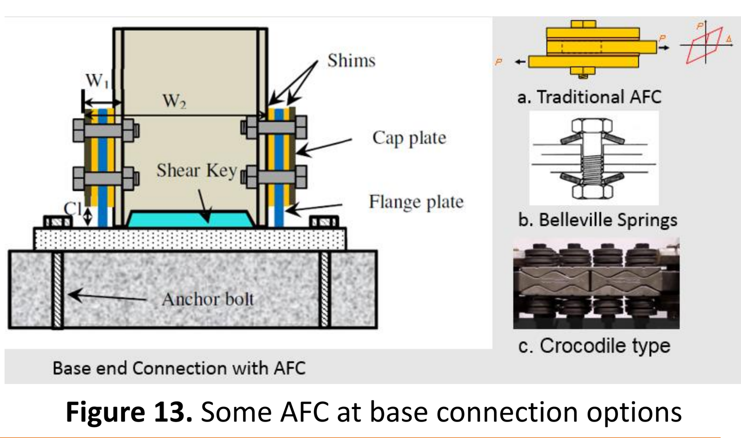

Figure 13. Some AFC at base connection options

NON STRUCTURAL ELEMENTS (NSE)

This aspect is of great interest to NZ sponsors who wish to ensure a robust system. NSEs include a variety of components (partitions, chimneys, parapets, ceilings, claddings, facades, doors/windows, HVAC (heating, ventilation and air conditioning systems), plumbing and electrical equipment, piping etc. In this test, the 3-storey structure (building) (see Figs. 2 and 4) to be tested is to be equipped with:

1. Suspended Ceilings comprising of composite tiles and aluminium grids with two different support systems (perimeter fixed and fully floating with damping layer around the perimeter).
2. Sprinkler systems comprising of rigid and flexible dropper pipes with different bracing configurations.
3. Partition drywalls with linear, right angle and T shaped configurations with traditional and low damage details.
4. Precast masonry claddings and glass glazing using traditional and low-damage connections to the structure.

This may be the first test of a multi-storey building structural system at this scale including multiple drift and acceleration sensitive NSEs.

Objectives of Testing NSEs

- Assess the seismic performance and deficiencies of traditional way of installing NSEs
- Prove the seismic resilience of new innovative NS systems
- Compare seismic performance of traditional and new (low-damage) NS systems.

PRELIMINARY PLAN AND SPECFICATIONS

PLAN LAYOUT

The structure is a 3 storey building with a storey height of 4 m with dimensions as 8.455 x 4.75 x 12 m. There are three bays in longitudinal direction (only the central bay is rigid) with a span of 2800 mm, 2855 mm and 2800 mm and one bay in transversal direction (rigid) with a span of 3920 mm. One gravity column (C2) located at the center of the structure which is continuous from bottom to the top (see Fig. 14). **Floor system:** Floor area at each level is 4.6 m * 8.15 m. An 80 mm ComFlor with 150 mm deep slab is used at each floor (107.42 kN) .

STRUCTURAL SYSTEMS CONSIDERED

There are two main structural systems considered, namely Moment resisting frames (MRF) and braced frames (BF) system.

1) For MRF-1 (MRF-1 is designed to apply SHJ), the external bays in the longitudinal direction and the bay in transverse direction are MRFs.
2) For MRF-2 (MRF-2 is designed to apply RSFJ), only the central bay in the longitudinal direction and the bay in transverse direction are MRFs.
3) For BF system, it is the same as MRF model except that beam to column connection is pinned and Inverted V braces used in transversal direction and single brace in longitudinal direction (see Fig.2). The frame in transverse direction is to be rocking frame.

❖ *This Structural System (Fig. 2 and Fig. 4) with and without NSE will further be divided for shake table testing in various matrices using the below frame systems and friction connections along the different directions and locations mentioned below:*

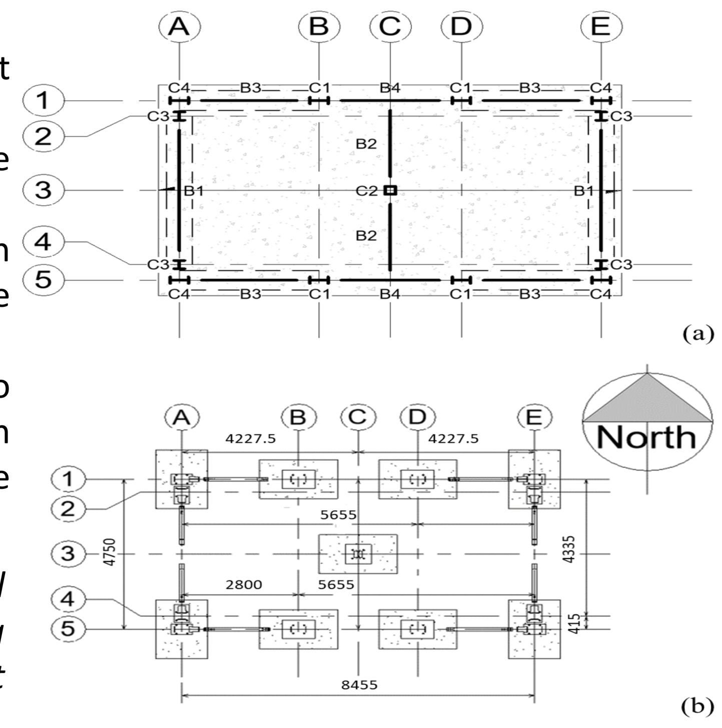

Figure 14. Plan layout on each level for both MRF and BF systems (a) frame section and (b) dimension.

Directions:

***Longitudinal Direction*:**

- Moment Resisting Frame (MRF) – *Friction Type*
- Concentrically Braced Frame (CBF) – *Friction Type*
- Dual System

(Combination of MRF and CBF)

***Transverse Direction*:**

BF – *Friction type and conventional*
Rocking frame (RKF)
GripNGrab (GnG)

Locations: (see Fig. 4)

Column base
Beam to column connection (MRF)
Brace

Types of friction connection:

Asymmetric friction connection (AFC)
Symmetric friction connection (SFC)
Resilient slip friction joint (RSFJ)

TYPE OF ANALYSES

Analysis

The analysis will be done using SAP2000

- Equivalent static method (ESM)
- Push-over analysis
- Numerical integration time history analysis

DESIGN CONSIDERATIONS

Design considerations

This is based on the design for

- Wellington Soil Class C
- Important Level IL = 2
- Ductility Factor μ = 3
- Structural Performance Factor, S_p = 0.7
- Natural Period (see Table 1)
- Interstorey drift: Along longitudinal direction is taken as under the load combination G+0.3Q+EQX and in transverse direction is taken as G+0.3Q+EQY. The values are shown in Table 2.
- Mass = 126.5 tons

The mass of column and beam is taken based on MRF model which is very close to BF model.

- Base connections

Column base stiffness is best represented using rotational springs. The formulae for rotational springs are as follows:

k=1.67 EI/L (ideally fixed)

For gravity column (ideally pinned), k=0.1 EI/L

For the support condition, the column base are restrained at U_1, U_2, U_3 and R_3 with rotational springs applied at R_1 and R_2. U_1, U_2, U_3 indicate the translation about X, Y and Z directions and R_1, R_2 and R_3 represent the rotation about X, Y and Z directions. Z axis is the column longitudinal axis.

Table 1 Natural Period (s)

(s)	Longitudinal Direction	Transverse Direction
MRF-BF	0.544	0.268
BF-BF	0.20	0.28

Table 2 Inter-storey drift

	Longitudinal Direction	Transverse Direction
MRF-BF		
Level 3	1.93%	0.82%
Level 2	2.41%	0.90%
Level 1	2.29%	0.79%
BF-BF		
Level 3	0.40%	0.86%
Level 2	0.45%	1.00%
Level 1	0.42%	0.79%

TESTING EQUIPMENT

Plan Layout of the Shake table

The structural systems in different matrices will be tested for its performance in Jiading campus, Tongji University, Shanghai, China. The plan lay out of the shake table used in this project is shown in Fig. 15.

Two multi-functional shake tables, Tables B and C, each 6 m x 4 m will be used for this project. These two shake tables will work together (see Fig 16). Each table has 2 horizontal translational degrees of freedom with a capacity of 70 tons. The frequency is between 0.1 Hz to 50Hz. The maximum acceleration is 1.5g in both horizontal directions (longitudinal and transverse). There is a 1.5 m gap between two shake tables which is covered by a steel plate (for safety). In total, the usable area is 9.5 m x 6 m.

M 24 and M 36 screw holes are available on the shake table. The base moment that can be resisted is 400 ton.m per shake table.

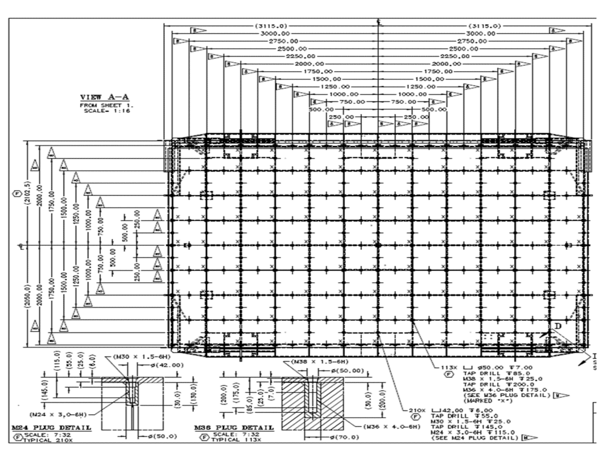

Figure 15. Plan layout of the shake table

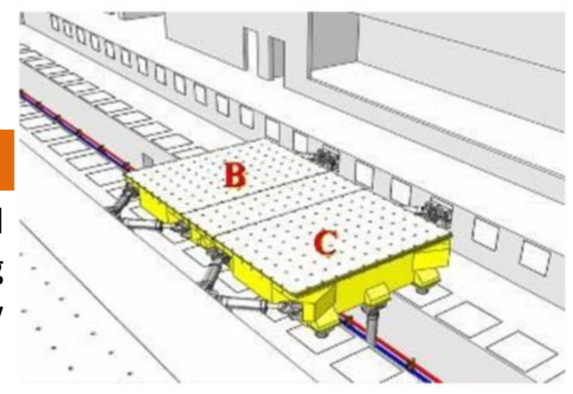

Figure 16. Two shake tables working together

ORGANIZATIONS INVOLVED

The project has gained support from a number of groups in New Zealand and promises to provide interesting insight into the performance of emerging technologies and design strategies. The primary investigators are from New Zealand and China (ILEE).

Participants and sponsors currently include QuakeCoRE (ILEE partner), Building Research Association of NZ (BRANZ) under Building Research Levy, Composite Flooring System (ComFlor), the Heavy Engineering Research Association (HERA), STELTECH, University of Auckland (UA), University of Canterbury (UC), Auckland University of Technology (AUT), the Earthquake Commission (EQC), and the QuakeCentre as well as NZ consultants.

References: ILEE ROBUST Project: A Progress Report June 2018 by Zhenduo Yan
Robust meeting presentation by MacRae March 22, 2018 and August 13, 2018
Meeting minutes
(PDF) Available from:
https://www.researchgate.net/publication/300045551_Influence_of_the_Asymmetric_Friction_Connection_AFC_ply_configuration_surface_condition_and_material_on_the_AFC_sliding_behaviour [accessed Aug 21 2018].