QuakeCoRE DT2 Workshop:

Connecting current projects with broad scope and collaborative efforts

University of Auckland, NZ

18 April 2023

Workshop Report

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I. Background

QuakeCoRE is a Centre of Research Excellence (CoRE) funded by the New Zealand Tertiary Education Commission. QuakeCoRE aims to transform the earthquake resilience of communities and society through research education, and collaboration, using New Zealand as a natural earthquake laboratory. QuakeCoRE Disciplinary Theme 2 – *Whole-of-building seismic performance* – Consists of several goals and specific thrusts regarding assessment, design objectives, diaphragm, and interactions of structural and non-structural elements of buildings. There are currently over a dozen active projects supported or aligned to DT2. These projects cover a wide scope of topics and are all in various stages of completion. The DT2 programme grew out of research initiated during the prior phase of QuakeCoRE and a 2019 workshop that that assessed research needs for whole-of-building response with a focus on the role of large-scale testing to address key questions.

II. Summary

0. Purpose

The purpose of this workshop was to provide updates to the various DT2 projects, to improve the interconnectivity between projects and students, and to discuss future large-scale testing and ongoing projects that could feed into such tests.

1. General Outcomes

The general outcomes expected from this workshop is improved contact between researchers, dissemination of research progress to the QuakeCoRE DT2 members, and production of an itemized list of topics of interest, design considerations, and alternative ideas for a proposed large-scale test from discussion and feedback from workshop attendees.

III. Workshop programme

Time	Title	Theme	Presenter
9:30	**Introduction, and workshop format**		
9:36	Seismic Assessment of RC Buildings based on Casualty Risk	1. Implication of design decisions	Faraz Zaidi
9:48	Improving the seismic performance of buildings by increasing stiffness	1. Implication of design decisions	Liam Pledger
10:00	Staggered Lap Splices in Slender RC Walls	1. Implication of design decisions	Charles Kerby
10:12	*Discussion*		
10:18	Seismic behaviour of low-rise precast wall-to-foundation connection	2. Interactions between structural components	Vinu Sivakumar
10:30	Interaction in coupling beams and coupled walls	2. Interactions between structural components	Ren-Jie Tsai
10:42	Seismic performance of recently constructed concrete wall-steel frame hybrid buildings	2. Interactions between structural components	Claire Pascua
10:54	ILEE-QuakeCoRE Low-Damage Concrete Building Test: Modeling and Design	2. Interactions between structural components	Anqi Gu
11:06	Low Damage Wall to Floor Connections for Seismic Resilient Timber Structures	2. Interactions between structural components	Soheil Assadi
11:18	ILEE ROBUST Project - Steel	2. Interactions between structural components	Zhenduo Yan
11:30	Recent testing at BRANZ		David Carradine, Angela Liu
11:42	*Discussion*		
12:00	**Lunch Break**		
12:45	~~System Level Seismic Performance Assessment Of Precast Hollow-core Floors~~	~~3. Diaphragm assessment and design~~	~~Mohamed Mostafa~~
12:57	FRP use in Diaphragm Strengthing	3. Diaphragm assessment and design	Junrui Zhang
13:09	Floor Response Spectra in buildings with controlled rocking braced frames	4. Non-structural component demands	Kieran Haymes **(online)**
13:21	Testing of a drift-sensitive sub-assembly of non-structural elements with low-damage characteristics	4. Non-structural component demands	Robert Clement
13:33	*Discussion*		
13:40	Previous identified research priorities for large-scale testing	Large-scale testing and ROBUST project	Rick Henry
13:50	ROBUST: What worked, lessons learned, and current research needs		Greg MacRae
14:10	*Discussion*		
14:30	**Coffee Break**		
14:45	Design of a large scale test structure for whole-of-building seismic performance	Future large-scale testing	Will Pollalis
15:00	Integration of research into large-scale tests - Structural systems		Break out groups
15:30	Integration of research into large-scale tests - NSE		Break out groups
16:00	General discussion - Identify priorities		
16:30	**Meeting Wrap-up**		

The workshop programme was structured to align with the four DT2 research themes, giving presenters approximately 10 minutes to present and then allowing a few minutes of questions after each presentation. After current research projects were covered, previous and future large-scale testing was presented and discussed.

IV. Workshop Report

0. 9:34 - Welcome and Introduction

   Rick Henry gave a short presentation on the structure of QuakeCoRE, DT2 research objectives, past large-scale testing efforts, and the general objectives and structure of the day's workshop.

1. Session 1: Implication of design and assessment methods

   a. 9:40 – Faraz Zaidi -Seismic Assessment of Reinforced Concrete Buildings based on Fatality Risk
      Faraz provided perspective on the use of percent New Building Standard (%NBS) as a measure of life safety, and how current assessment measures are relatively subjective. He also highlighted the need to balance the risk of fatality and the consequences of closing buildings. He provided a way to use the Mean Annual Frequency of collapse as an alternative to %NBS provided a web-based app to assist in decision making.

   b. 9:54 – Liam Pledger - Investigating the effect of stiffness on the Seismic performance of Buildings
      Liam highlighted the difference between "stiff" and "flexible" building systems and how they respond to seismic events. He also questioned the claim that certain non-structural elements (NSE) are "acceleration sensitive" and noted a shortcoming in testing methods, where NSE are tested using ground motion instead of story motions. Finally, Liam presented his proposed experimental program for testing NSE using story motions representative of stiff and flexible buildings. He identified that large-scale system tests would allow for the structure-NSE interactions to be investigated, and to provide valuable data to validate numerical models and loss assessment methods.

   c. 10:08 – Charles Kerby – Staggered Lap Splices in RC Walls
      Charles presented on field observations of a RC wall that appeared to fail at the non-staggered boundary element lap splice due to the recent earthquake in Turkey. He also provided updates on his testing of staggered lap splices in RC walls. His first wall test lost 20% of its lateral capacity between 1.5-2% drift; about half of the drift expected of a wall without splices.

2. Session 2: Interactions between structural components

   a. 10:22 – Vinu Sivakumar - Seismic Behavior of low-rise Precast Concrete Wall to foundation Connection
      Vinu identified vulnerabilities in the connection of precast wall to foundation connections. She explained how shallow inserts create potential cracking planes when precast connections are loaded out-of-plane, especially when there is little axial load and the foundation isn't rigid. She explored other connection details

like Drossback and cranked bar connections, and discussed testing needed to determine an appropriate force reduction factor.

b. 10:34 – Ren-Jie Tsai - System response of coupled wall systems
Ren-Jie discussed coupled wall systems, their benefits and drawbacks, and issues created by the axial restraint induced by elongation in coupling beams. He described the current database of tests for coupling beams and detailed a method for computer modelling of diagonally reinforced coupling beams. He identified interesting findings on the restraint effect, and proposed a series of coupling beam tests where axial restraint is varied. Coupled walls are a complex system and would benefit from large-scale testing, particularly when included within a building and accounting for system interactions (e.g. floor restraint).

c. 10:58 – Claire Pascua - Seismic performance of recently constructed concrete wall-steel frame hybrid buildings.
Claire identified that Hybrid or mixed-material structural systems are often chosen for their economy and efficiency. But there are few tests of hybrid structural configurations and several discrepancies between material structural design standards which allow for "compliance" that may not be acceptable. She conducted a study of NZ buildings and discovered much "creativity" in hybrid connection details. She also conducted experimental tests of steel beam to concrete wall connections and identified typical failure modes, the importance of slotted hole detailing, and the need for representative gravity load during testing. Given the common use of such structural configurations and lack of prior tests, a large-scale test of concrete wall and steel frame building would potentially highlight critical issues for future research.

d. 11:18 – Anqi Gu - ILEE-QuakeCoRE Low-Damage Concrete Building Test: Modelling and Design
Anqi provided an overview of tests conducted at ILEE of a 2-story building with concrete walls and beams using different energy dissipation connections (High force-to-volume dissipators and nonlinear viscous dampers). Her work focused on various modelling techniques and addressed the complexities of floor interaction. Conventional planar models tended to underestimate the base moment by around 30%, which was reduced to around 15% by including the additional strength from the floor and the flexibility in energy dissipator connections. Finally, she detailed a direct displacement-based design (DDBD) procedure for the studied structural system. This research highlighted the importance of large-scale tests, where even when component interactions are carefully considered in design, tests can identify new phenomena (unknown-unknowns) that are critically to understanding the system response of structures.

e. 11:31 – Soheil Assadi - Low Damage Wall To Floor Connections For Seismic Resilient Timber Structures
Soheil highlighted the advantages of timber construction but also identified undesirable characteristics of conventional detailing (specifically in balloon-type designs). Conventional details can lead to irreparable failures at low drifts with

little ductility, either through failure of the connection plate or fasteners, or through tear out or crushing of the timber. He proposed a novel system with slotted hole shear keys, flag-shaped friction spring hold downs, and friction dampers at floors. Numerical analyses of this system were completed and show potential to reduce story drifts, accelerations, and residual drifts.

f. 11:50 – Zhenduo Yan - RObust BUilding SysTem (ROBUST) Project with emphasis on the Optimised Sliding Hinge Joint
Zhenduo presented updates on the ROBUST project, focusing on the Optimized Sliding Hinge System. The ROBUST group proposed a 3-story building with interchangeable seismic resisting systems (variations on Slip Friction Joints, Sliding Hinge Joints, Grip N Grab, etc) to be tested at ILEE. Due to COVID shutdowns, research has been limited to component-level tests and large-scale test design refinement. Zhenduo provided details on the component test of Sliding Hinge Joints and Optimized sliding hinge joints and identified an originally unintended but potentially beneficial limit state of the design: bolt bearing at the slotted hole of the SHJ. He also provided refined details for the use of BeSs at column bases and in brace to gusset connections.

3. Session 3: Diaphragm assessment and design

    a. 1:05 – David Carradine - BRANZ – Large-Scale Testing and New Structures Laboratory
    David provided the motivation and details behind the new facilities at BRANZ, including a new structures lab (with 8.5m tall strong wall) and a new fire lab. He also covered various testing that was completed by BRANZ, including SIP seismic testing, diaphragm tests for low- and mid-rise hybrid residential buildings, and subfloor design for houses on sloping sites.

    b. 1:27 – Junrui Zhang - Behaviour of Large FRP Ties Externally Bonded on RC Members with and without FRP Anchors
    Junrui identified weak tensile capacity of concrete diaphragms as motivation for studies to strengthen diaphragms using unidirectional FRP sheet. His tests helped fill gaps identified in the database of FRP anchor tests, varying stiffness, tie length, diameter of dowel, and anchor arrangement. His analysis of the current database showed that the equation provided by ACI-440 is unreliable for predicting debonding force, and proposed alternatives for prediction and design equations. Finally, he provided some recent test results, highlighting DIC imaging of FRP sheets debonding from concrete and ultimately failing at the anchor. This research will be extended to look at system level response, starting with sub-assembly floor tests.

4. Session 4: Non-Structural component demands.

    Please note that Robert Clement presented before Session 3 due to prior commitments.

    a. 12:48 – Robert Clement - Quasi-static cyclic testing of a low-damage, drift-sensitive, non-structural components sub-assembly

Robert highlighted the importance of Non-Structural Elements to building performance, emphasizing the large economic losses and potential risks posed to emergency services from NSE damage. He also identified the lack of NSE testing, particularly tests combining NSE systems. He is in the process of testing low damage rocking precast concrete panels and Seismic Frame Glazing, which are susceptible to loss of watertightness at low drifts. These tests will help quantify interactions between NSE, which could be extended to large-scale system tests to include structure-NSE interactions.

b. 1:41 – Kieran Haymes – Floor Response Spectra in buildings with controlled rocking braced frames
Kieran provided updates on work he completed as part of his PhD and current work as a post-doc. His work focused on modelling the response of rocking braced frames with flag-shaped responses. He noted that traditional modelling techniques needed to be updated to account for the nonlinear behaviour, where 1st mode response was effectively capped while higher modes were largely unaffected.

5. Session 5: Large-Scale testing

a. 1:57 – Rick Henry - Past Workshop: Large-scale structural testing
Rick provided a recap of a 2021 workshop that identified areas of interest for large-scale testing. Key topics identified by the previous workshop included Buckling restrained braces (BRB), Column base detailing and effects, Interactions between LLRS/LLRS+floors, Diaphragms, Irregular Diaphragms, Interactions between NSE/NSE+Structure, Lower drift limits, and the development/validation of models. Some of these topics were covered by DT2 projects, but some are still unexplored.

Key points raised during discussion of topics identified from prior workshop:

- Should the focus of future tests be on assessment of existing structures or new design? *[Most tests have focused on the later]*
- It is practical to test realistic diaphragms? Eve for full-scale building tests the diaphragms are small and regular.
- Advantages of modular test buildings where multiple systems can be included is valuable.
- Consideration of sustainable design objectives in future tests?
- Are hybrid (or mixed material systems) common in buildings internationally? If so, this seems like a critical gap in prior tests.
- BRBs and viscous dampers remain common and system level building test is still needed.

b. 2:09 – Greg MacRae - Robust Building System (RoBuSt) Project: Lessons from a Test Programme in Progress
Greg summarized work conducted by the ROBUST group, detailing tests (completed and in progress), difficulties the group encountered and overcame,

and the current state of their projects (and the need for funding of their current projects). From experience with international collaboration, he highlighted the need for peer review, steady communication, building trust between groups, and finding solutions that can benefit all groups supporting the research. He also stressed the importance of planning and consideration for technical aspects, like specimen transportation, contractor sourcing, scheduling of lab time, and backup plans if something doesn't go according to plan. Finally, he provided his input on what might be needed for consideration of future projects. His main focuses were identifying a worthwhile need (don't just test for the sake of testing something), building upon projects already in the DT2 wheelhouse, considering the scope of work required and the personnel needed to complete the work, and to not forget the current commitments of ongoing DT2 projects.

Key points raised during discussion on Robust:

- Tests need to be motivated by interests of each collaborator.
- Robust includes testing of low-damage NSE solutions in high drift structural configuration. NSE interactions considered but detailed to minimise and achieve low-damage.
- Need to have post-docs and PhD students who can analysis the tests results and extract the key findings and lessons. This is an opportunity of DT2 to ensure maximum benefit is extracted from the Robust test.

c. 2:40 – Will Pollalis - Design of a large-scale test structure for whole-of-building seismic performance

Will summarized the focal points of the previous presenters, consolidated the several objectives of DT2 into a single actionable goal, and then provided a concept for a potential large-scale test that could act as a platform for researching many of the objectives covered in the workshop. He identified NCREE as a potential international collaborator since NCREE and QuakeCoRE have a history of collaboration. The main concept presented was a hybrid system with steel MRF and concrete core wall, with a link which would allow the two systems to be coupled or decoupled quickly. This would allow for a specimen with identical floorplan to have multiple building responses and would serve as a testing platform for non-structural (or, non-skeletal) elements (NSE).

Key points raised during the general discussion included:

- Ken suggested a need to step back and consider the key objective of future tests. For shake-table tests these typically fall into several categories: 1) Validate models and design methods; 2) Proof of concept or demonstration of new designs; 3) Comparison of design options; 4) Demonstration of issues (i.e. show what doesn't work).
- Should testing continue to focus on multi-storey buildings or are their research needs in low-rise design that need to be considered as well.
- Prior tests have focused on low-damage systems – Perhaps future tests should focus on more conventional systems which are more common.

- Need to balance the desire to include multiple configurations/systems in test building (i.e. maximise objectives) with ensuring that the building is representative (i.e. not a Frankenstein trying to do too many things).

6. Breakout Discussion

   Following presentations on large-scale testing, workshop participants were encouraged to break out into 4-5 larger groups to brainstorm items of interest for a potential large-scale test. These ideas may build upon ideas shared in previous presentations or provide novel solutions and setups. The goal of these brainstorming teams is to produce ways to incorporate as many DT2 topics of interest as possible into a large-scale test. After groups met for 20-25 minutes, the groups were called together to share their ideas with the rest of the workshop. The outcomes of these brainstorming sessions are detailed in the Minutes and actionable items section of this report.

7. Workshop Closing

   The workshop ended around 5pm after final comments were shared with the group and salient points and opinions were recorded.

V. Minutes and actionable items

Breakout groups were separated approximately by research theme. Several comments, additions, changes, and ideas were produced regarding a potential large-scale test. Breakout groups met for approximately 20 minutes, and many points were brought up during the following discussions. The main discussion points brought up are as follows, organized by breakout group theme:

1. Design implications
   a. Make it simple!
   b. Focus on stiff vs flexible -> Goal to lower drift limits in NZ, move away from force-based design.
   c. Is simple representative, or can it be made representative of current practice?
   d. Take something that doesn't work normally and retrofit to make it work (precast)
   e. Unknowns addressed by large scale that can't be addressed by component tests.
   f. "Slim" frame vs stiff hybrid (MRF design for 30% or 100% of lateral load capacity)
   g. Link compromises interaction between floor and wall. Good for NSE, less good for Structural
2. Interactions
   a. Test beam to wall connection – make sure it works on a component level first.
   b. 2 tests: Hybrid that doesn't work (assessment lessons) and then Hybrid that does work (also considering nominally ductile vs. ductile detailing)

c. Coupling beam: accept damage? Epoxy and test again?

d. Current design not representative. If made representative will international collaborators benefit? Precast Rectangular RC section is common in NZ.

e. Directional testing – x direction nominally ductile, y direction ductile->demonstrate that ductility is needed.

f. Sliding hinge joint can produce gravity frame.

3. Diaphragms (plus other topics)

    a. Floor types – Timber CLT Precast Cold-form steel or conventional. Show that systems can be made to work?

    b. Beam-slab connection: change MRF to pinned connection.

    c. Details of floor around column. Does gap lead to twisting?

    d. Diaphragm to CW – choice to make. “Link” or conventional connection

    e. T-shaped (Asymmetric) Core wall

    f. Replaceable ED coupling beams.

    g. Potential for BRB in frame

    h. Single, 5 story test, or multiple 2-3 story tests.

    i. Make a test that “works” and then can be changed to not work.

    j. 5-story: put openings on different floors

    k. What is needed to put out practice advisory to not connect steel beams directly to concrete walls?

    l. Shear forces in core wall

    m. Biaxial bending in core wall

4. NSE

    a. Conventional gib-board partition on one floor and low-damage system on another floor

    b. Partition performance at higher velocities

    c. Make sure system is representative of what would be seen in a building.

        i. Include HVAC and desks/shelves etc?

        ii. Baffles

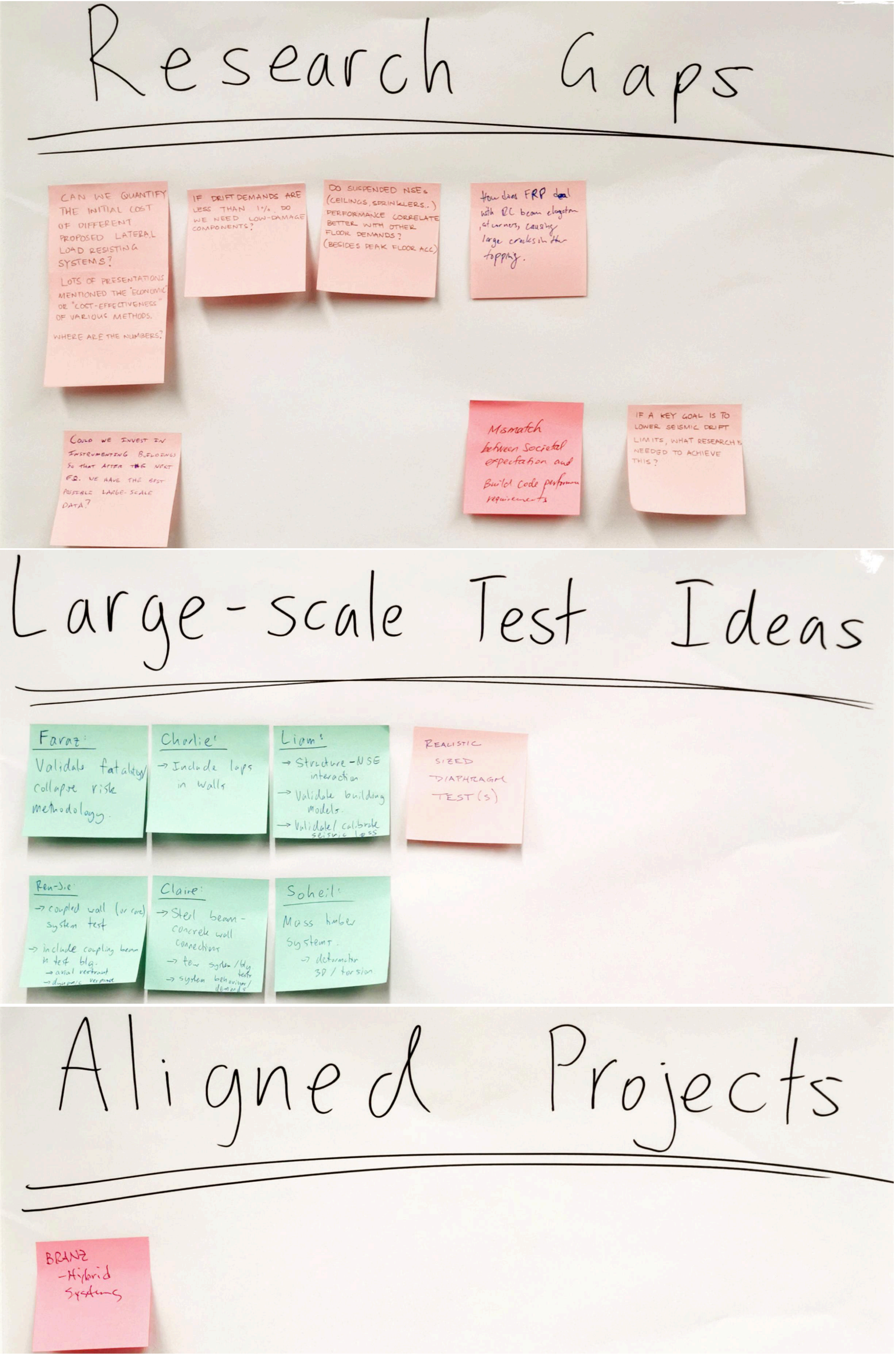
        iii. Penetrations

        iv. Fire protection

    d. Quantify/standardize “standard” practice.

    e. Serviceability issues -> not “failed” but leakages, etc. that need repaired.

Scans of questions and ideas formed during presentations and points of interest produced during the breakout groups are shared on the following pages.


Research Gaps
CAN WE QUANTIFY THE INITIAL COST OF DIFFERENT PROPOSED LATERAL LOAD RESISTING SYSTEMS?
LOTS OF PRESENTATIONS MENTIONED THE "ECONOMIC" OR "COST-EFFECTIVENESS" OF VARIOUS METHODS.
WHERE ARE THE NUMBERS?
IF DRIFT DEMANDS ARE LESS THAN 1%. DO WE NEED LOW-DAMAGE COMPONENTS?
DO SUSPENDED NSEs (CEILINGS, SPRINKLERS..) PERFORMANCE CORRELATE BETTER WITH OTHER FLOOR DEMANDS? (BESIDES PEAK FLOOR ACC)
How does FRP deal with RC beam elongation at corners, causing large cracks in the topping.
COULD WE INVEST IN INSTRUMENTING BUILDINGS SO THAT AFTER THE NEXT EQ. WE HAVE THE BEST POSSIBLE LARGE-SCALE DATA?
Mismatch between Societal expectation and Build code performance requirements
IF A KEY GOAL IS TO LOWER SEISMIC DRIFT LIMITS, WHAT RESEARCH IS NEEDED TO ACHIEVE THIS?
Large-scale Test Ideas
Faraz:
Validate fatality/collapse risk methodology.
Charlie:
→ Include laps in walls
Liam:
→ Structure-NSE interaction
→ Validate building models.
→ Validate/calibrate seismic loss
REALISTIC SIZED DIAPHRAGM TEST(S)
Ren-Jie:
→ coupled wall (or core) system test
→ include coupling beam in test blg.
→ axial restraint
→ dynamic response
Claire:
→ Steel beam - concrete wall connections
→ few system/blg tests
→ system behavior/demands
Soheil:
Mass timber systems.
→ deformation 3D / torsion
Aligned Projects
BRANZ
-Hybrid Systems

DESIGN IMPLICATIONS

OF LARGE SCALE TEST

- SIMPLIFYING DESIGN PROCESS/VALIDATION.
- COMPARING "STIFF" and "FLEXIBLE" BUILDING (DESIGN DRIFT LIMIT).
  Lowering the drift limit.

~ MECHANICAL COUPLERS
IN-SITU SLABS
NEW DRIFT LIMIT

- INCORPORATE PRE-CAST FLOORS
  - REPRESENTATIVE OF CURRENT PRACTICE.

- USING TEST STRUCTURE TO TEST/VALIDATE. DIFFERENT RETROFIT METHODS

Non-Structural Elements

{ ○ What to Include
○ What details

○ Conventional GIB board partitions vs Low-Damage Partitions in the same structure.
○ Effect of Higher Speeds on these partitions

○ Ceilings contained within partitions

○ Piping..?
↳ Looking for leaks (Air pressure?)

○ Full system with sprinklers, partitions, penetrations, etc. (where sprinklers go through the walls)
↳ get as close to an interior (office, medical equipment, copier, etc.)
↳ TV/AV equipment

○ HVAC

○ Glazing Systems (Standard, Seismic, etc.)

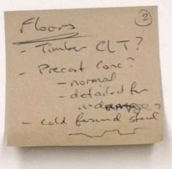
○ Deficiencies & Strengths of Existing Practice
↳ Technical Literature
↳ Construction Issues

○ How much is the serviceability affected?

OTHER:
○ CLT Floors & Diaphragms

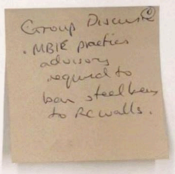
Diaphragm

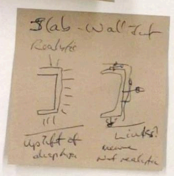
Types:

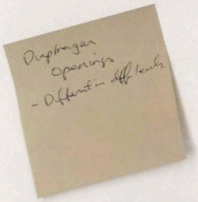


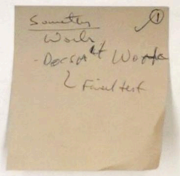
Beam end connection:

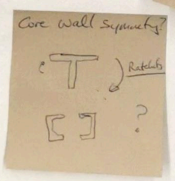
Connected to the columns and Core walls

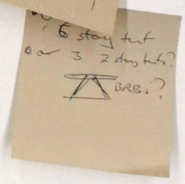












- Steel beam + concrete wall connection
  - → make it work at ~~system level~~ component level first before doing large-scale

- TESTING SCENARIO (IDEAL)
  - current hybrid system that will have issues vs. a hybrid system that will work
  - (similar to hollowcore testing principle

- COUPLING BEAM ⇒ design to be damaged
  - → does it need to be changed?
    - maybe let it be since it is not overly critical
    - try epoxy injection?

- current MRF+CW configuration may not be a reflection of reality
  - → but will collaborators benefit from testing

- test nominally ductile vs ductile system

- anchoring to concrete

- turn MRF into gravity frame
  - to reduce base shear capacity
    - ⇒ use sliding hinge joint and remove it

- exhibit evidence vs. nominally ductile design