2021-2024 QuakeCoRE Research Programme Contract Detail

Instructions [Delete these instructions before submission]

- **Where applicable please transfer information from the Research Programme Overview previously provided**
- All text in this proposal must be Calibri 11pt.
- These projects are for the period from 1 July 2021 to 31 December 2024
- Applications must include this form and the budget as an Excel spreadsheet using the template provided.
- Please return this form together with the completed budget to Ruth (ruth.hartshorn@canterbury.ac.nz) as soon as possible, but by no later than **Friday 25th June**. We appreciate that this is a tight deadline, please get in touch, if you are unable to meet this deadline. Note that any delays in returning this form will likely lead to further contracting delays.

Title of proposed coordinated project: DT2: Whole-of-Building Seismic Performance

Project Leader: Rick Henry

Project Co-Leader(s): Santiago Pujol

Project code:

Project Investigators

Project Leader Name (Organisation)	**Quake CoRE PI/AI**	**Quake CoRE Industry Affiliate**	**New for 2021 - 2024**	**Diversity**			
				Female Engineer	**Māori**	**Pasifika**	**New / Emerging**
Rick Henry (UA)	☒	☐	☐	☐	☐	☐	☐
Santiago Pujol (UC)	☒	☐	☒	☐	☐	☐	☐
Investigator Name (Organisation)							
Reagan Chandramohan (UC)	☒	☐	☐	☐	☐	☐	☒
Charles Clifton (UA)	☒	☐	☐	☐	☐	☐	☐
David Carradine (BRANZ)	☒	☐	☒	☐	☐	☐	☐
Rajesh Dhakal (UC)	☒	☐	☐	☐	☐	☐	☐
Ken Elwood (UA)	☒	☐	☐	☐	☐	☐	☐
Ashkan Hashemi (UA)	☐	☐	☒	☐	☐	☐	☒
Lucas Hogan (UA)	☒	☐	☐	☐	☐	☐	☒
Jason Ingham (UA)	☒	☐	☐	☐	☐	☐	☐
Chin-Long Lee (UC)	☐	☐	☒	☐	☐	☐	☐
Minghao Li (UC)	☒	☐	☐	☐	☐	☐	☐
Angela Liu (BRANZ)	☐	☐	☒	☒	☐	☐	☐
Quincy Ma (UA)	☒	☐	☐	☐	☐	☐	☐
Greg MacRae (UC)	☒	☐	☐	☐	☐	☐	☐
Pierre Quenneville (UA)	☒	☐	☐	☐	☐	☐	☐
Shahab Ramhormozian (AUT)	☒	☐	☒	☐	☐	☐	☒
Max Stephens (UA)	☒	☐	☐	☐	☐	☐	☒
Timothy Sullivan (UC)	☒	☐	☐	☐	☐	☐	☐
Charlotte Toma (UA)	☒	☐	☒	☒	☐	☐	☒
Anqi Gu (UC)	☒	☐	☒	☒	☐	☐	☒
Jared Keen (Beca)	☐	☒	☐	☐	☐	☐	☐
Stu Oliver (Holmes)	☐	☒	☐	☐	☐	☐	☐
Des Bull (Holmes)	☐	☒	☐	☐	☐	☐	☐

Project Proposal

1. Project Abstract

The goal of this programme is to develop fundamental understanding, and methods and models for the quantification, of whole-of-building seismic performance through direct consideration of interactions between structural and non-structural components, as well as advances in seismic design and assessment considering a whole-of-life approach. Idealization of building systems during design often leads to components being considered in isolation without fully accounting for the performance of the building as a whole. As society increasingly demands safe, resilient, and repairable buildings there is a greater need to consider buildings as a ‘holistic’ system in order to ensure continued functionality after a range of earthquake scenarios. Key thrusts of this research will include interactions between structural components, floor diaphragm assessment and design, non-structural component demands and interactions, and implication of design decisions and methods. The mechanics of component interactions will be investigated using a combination large-scale structural testing, data from international collaborative building tests (past and new),

and field observations of the performance of building in earthquakes. These data sources will be used to develop and vet methods of modelling component interactions using state-of-art numerical simulations. Synthesis and translation of these models to design methods will result in immediate improvements in building resilience.

2. Detailed outline of project:

Project Outline

Research Context:

Simplification of building systems during design often leads to components being considered in isolation without fully accounting for the performance of the building as a whole. Examples of observed damage due to interaction between structural and non-structural components during recent earthquakes highlighted the weakness of this approach: (i) Widespread damage to precast concrete floors during the 2016 Kaikōura earthquake caused by deformation demands imposed by adjacent structural frames and walls (Henry et al. 2017); (ii) Failure of concrete walls during the 2010 Chile earthquake attributed to increased axial loads from structural interactions (Jünemann et al. 2016); (iii) Decisions to demolish buildings following the Canterbury and Kaikōura earthquakes heavily influenced by the cost of repair of damaged non-structural components (Filiatrault and Sullivan 2014). Although unexpected behaviour of buildings during earthquakes is often attributed to simplification in design, researchers have only recently acquired the advanced tools and coordinated resources necessary to address this topic. Recognising the need to understand system-level response, a number of earthquake simulation laboratories have been explicitly established in order to test full-scale buildings and bridges (e.g. E-Defense in Japan, ILEE in Tongji). As society increasingly demands resilient and repairable buildings there is a greater need to consider buildings as a 'holistic' system in order to ensure continued functionality after a range of earthquake scenarios.

Prior research within QuakeCoRE (2016-2021) led to a number of large-scale tests of building systems that have provided valuable datasets that will be leveraged during the DT2 research programme, including:

- QuakeCoRE-ILEE low-damage concrete building test (Henry et al. 2019).
- Seven-storey torsional building test (Suzuki et al. 2021).
- Collaboration on several E-defense building tests.
- Robust steel building test [*in-progress*] (MacRae et al. 2020).

The holistic assessment of whole-of-building seismic response requires a detailed understanding of the interactions between structural components, quantification of demands on non-structural components, and consideration of performance across a range of earthquake scenarios. These themes will form the basis of the research conducted with DT2, with a series of projects aimed at advancing state-of-art knowledge in individual topic areas. Mature research and solutions will be tested and validated by conducting large-scale tests of building models representing state-of-art structural systems and design methods. Underlying simulation models and design methods will be refined and validated, providing a connection between individual projects when considering the response of entire buildings.

Key Objective(s):

Key research thrusts within DT2 and associated objectives include:

1. Implication of design and assessment methods:
    a. Quantify the impact of reducing drift limits on seismic design and post-EQ outcomes
    b. Investigate the design of nominally ductile structures for lower-drift buildings
    c. Comparison of performance of structural systems across all limit states
    d. Reimagining %NBS for seismic assessment of existing buildings

2. Interactions between structural components:
    a. Investigate the interaction between lateral load resisting systems and floors
    b. Investigate the interaction between different lateral load resisting systems
    c. Investigate the interaction between connected buildings
3. Diaphragm assessment and design:
    a. Refine seismic assessment methods for precast floor diaphragms in existing buildings
    b. Quantify the response of irregular floor diaphragms
    c. Investigate the design of emerging alternative floor systems
4. Non-structural component demands:
    a. Investigate the interaction between different NSE and between structural systems and NSE.
    b. Quantify the acceleration and drift demands on NSE.

Research Methodology:

1 – Implication of design and assessment methods

Current structural design standards target a life-safety performance objective at a design level earthquake intensity (typically 500-year return period shaking) with existing inter-storey drift limits leading to flexible high ductility structural systems that are damaged and uneconomical to repair following major earthquakes. The impact of changes to this typical design approach will be investigated, with a focus on assessing the impacts of designing to lower drift limits and the level of seismic detailing required to maintain robust and repairable designs.

Earthquake-prone legislation in New Zealand requires determining the level of earthquake shaking a building can withstand, expressed as a fraction of the earthquake shaking required for new buildings. This is known as % New Building Standard, or %NBS and an earthquake prone building is defined as a building with %NBS≤33%. The property market in New Zealand, and particularly Wellington, has recognised the importance of earthquake safety with many commercial tenant contracts requiring their buildings to be above 70-80 %NBS and some buildings are being closed when an assessment leads to a low %NBS (e.g. Wellington Central Library). While the introduction of %NBS has enabled seismic safety to be valued in property market decisions, there remain several shortcomings with the assessment procedures requiring further research and no prior calibration of the outcomes.

1a. – Impact of reducing drift limits

Field evidence following major earthquakes (e.g. Chile and Japan) suggests that robust lateral-load resisting systems leading to smaller drifts are more likely to produce buildings that can survive strong ground motion with minimal damage allowing for nearly immediate reoccupancy. This hypothesis will be tested by comparing the seismic response of a stiffer wall building with that of a more flexible structural system allowing for larger drifts. Such a comparison will be investigated through simulation and potentially included in a large-scale building test. The proposed research will investigate if similar (reduced) limits are feasible for New Zealand. A key aspect of this initiative is going to be the projection of costs and benefits over the entire life of the structure, which of course include much more than initial construction costs. It is expected that initial construction extra costs will be offset by life-cycle benefits. [This project is aligned to aspects of IP1 and will be integrated with related projects].

1b. – Nominally ductile structures

As building drift demands are reduced the designs will likely lead to the increased use of structural systems designed for nominally ductile actions and detailing. This may lead to perverse outcomes for seismic resilience due to the more relaxed design procedures allowed for nominally ductile systems (e.g. no capacity design) and the lack of ductile detailing that provides increased robustness to uncertain earthquake demands. The performance of different nominally ductile structural systems will be conducted to assess performance across a range of limit states. Such systems may include precast concrete walls and steel braced frames in both low-rise and multi-storey buildings. Improvements to the design methods and details for such systems will be proposed. Such solutions will target simple standardised details that can ensure both robustness and repairability when buildings are subjected to a range of earthquake intensities.

1c. – Comparison of structural systems across all limit states
Research into structural systems is often conducted in silos without direct comparison between systems or across multiple earthquake hazard levels or design limit states. Previously developed case study building archetypes will be used to encourage comparison of the performance of different structural systems and design approaches to assess performance across a range of limit states. Performance measures will consider both life-safety (e.g. collapse risk) as well as post-earthquake re-occupancy or repair targets. The DT2 programme will act as a coordinating mechanism to enable and support these comparisons.

1c. – Reimagining %NBS
While %NBS is intended to represent the life-safety risk posed by a building in an earthquake, it effectively only assesses the vulnerability of the building for one hazard level (typically 500-year return period). Three key pieces are missing from this assessment to be able to truly capture life-safety risk: population exposure in the building, relationship between "ultimate limit state" and injuries or fatalities, and consideration of a range of hazard levels beyond a 500 year shaking level. Recently a framework for determining seismic design forces for new buildings to achieve a selected risk target (eg fatality rate) has been proposed for New Zealand (Horspool et al 2021). This research seeks to extend this framework to the assessment of existing buildings, thus enabling %NBS to better represent the life-safety risk posed by an existing building. The outcome of this research will be that decisions by property owners and tenants can be better informed by the likely life-safety risks posed by a building in a context familiar to many in risk management. [Aligned funding from University of Auckland Doctoral Scholarship for Faraz Zaidi].

2 – Structural interactions
Interactions between different structural components can alter the seismic response of buildings when compared to simplified assumptions used when analysing lateral load resisting systems in design. In addition, structural interactions have been shown to result in unintended damage due to deformation compatibilities (e.g. precast floor unit damage). Three key types of structural interactions will be investigated, including the interaction between lateral load resisting systems (e.g. walls, frames) with connected floors, interaction between different lateral load resisting systems in dual system buildings, and interactions between connected buildings (e.g. URM row buildings).

2a. – Interaction between lateral load resisting systems and floors
Interaction between lateral load resisting systems and floors can result in unexpected seismic response, including altering the strength hierarchy, increasing structural actions on lateral load resulting systems, and damaging floor systems. Such structural interactions need to be quantified in design or minimised using novel connection detailing. Interactions in critical structural systems will be investigated, including the effect of floor axial restraint on coupled and core wall systems, wall-to-floor interaction in low-damage buildings, and floor effects on the performance of braced frames. Research will include testing of key connection details and refining modelling techniques to capture such structural interactions. Recommendations will be made regarding suitable connection detailing in new buildings and the seismic action and overstrength demands that may be induced in both existing and new buildings. [Aligned funding from Qun Yang CSC doctoral scholarship and post-doc funding for Anqi Gu].

2b. – Interaction between different lateral load resisting systems

New construction in New Zealand is increasingly combining multiple different structural systems to achieve project objectives. These mixed or structures may combine structural systems from different material-based design standards (e.g. concrete walls with steel or timber frames, timber frames with steel braces, etc.). The compatibility of such mixed systems is not well understood, and research is required to assess if current construction practice and design standards are adequate. In particular, the design assumptions will be assessed, and critical connection detailing examined to ensure they are sufficiently robust when considering the actions induced due to the interaction of the different systems. Such dual systems are also more likely to result in stiffness or strength irregularities in buildings and so investigation of the torsional response and design procedures will also be conducted. A mixed material structural system representing current design practice for new buildings will also be considered for inclusion in future large-scale building tests. [Aligned funding from University of Auckland Doctoral Scholarship for Claire Pascue].

2c. – Connected buildings

Some existing buildings may be interconnected, for example rows of unreinforced masonry (URM) buildings in main streets and town centres. The seismic assessment of these buildings as standalone structures may not represent the reality where they act as one structure with shared boundary walls. Investigation of the interaction between these buildings will allow for improved seismic assessment methods that may alter the outcome or strengthening strategies. This research will extend prior work on the seismic assessment of URM buildings and is intended to result in recommendations to improve the seismic assessment guidelines.

3 – Diaphragm assessment and design

The design of floor diaphragms has long been a neglected aspect of building design and significant vulnerabilities have been identified in existing buildings due to the use of non-ductile precast floor units and lack of robust load paths. While some of these issues have been resolved there is a general lack of research and understanding about diaphragm assessment and design, particularly considering the system level response when interactions with the lateral load resisting systems occur. Research will build on existing projects to further the seismic assessment and design provisions for floor and roof diaphragms in buildings to ensure that they adequately tie the building components together and enable reliable and predictable building response.

3a. – Assessment and retrofit of precast diaphragms

Floor diaphragms play a critical role is transferring forces within buildings but have historically been neglected in design. Research into the seismic performance of precast concrete floors commonly used in New Zealand has highlighted a number of vulnerabilities for which seismic assessment and retrofit methods have been developed to address. However, the diaphragm response of existing precast floors with an insitu topping is still poorly understood. The lack of robust load paths due to the use of non-ductile mesh reinforcing and a lack of collector elements creates difficulties in assessing the diaphragm seismic capacity. Modelling will be conducted on case-study floor diaphragms to investigate macro load paths that can be used to improve current assessment methods. The outcome of this research will result in revision to the seismic assessment guidelines and provide a platform to further research strengthening methods. [Aligned funding from Recast project and associated doctoral scholarships].

3b. – Response of irregular diaphragms

Recently constructed buildings are commonly irregular in both geometry and layout of structural systems. In addition, diaphragms in both new and existing buildings can have large penetrations that disrupt load paths and may contribute to poor load transfer between key components. Irregular floor diaphragms contain more complex load paths than the idealised regular floor plans typically investigated in research (esp. in large-scale building tests). The seismic response of realistic floor diaphragms will be investigated across a range of alternative floor systems. Comparisons of the floor diaphragm design, interactions with structural systems, and connection detailing will be examined. The use of an irregular floor diaphragm layout will also be considered for inclusion in future large-scale building tests.

3c. – Design of alternative floor diaphragm systems
Despite the widespread use of precast floor units in New Zealand from the 1980s-2000s, there is an increasing adoption of alternative floor systems such as composite steel tray floors and post-tensioned flat slab floors. Although these alternative systems overcome many of the challenges and vulnerabilities of precast floor units, their seismic performance is less well known and required a detailed investigation. In particular, the lessons from structural interactions and defamation compatibility in precast floors will be applied to these alternative floor systems to assess their expected response and failure modes. Improvements to seating details and incorporation of associated overstrength actions that develop into design methods will be investigated. This research is expected to result in recommendations for revised diaphragm provisions in New Zealand design standards.

4 – Non-structural component demands
Consideration of the seismic design and performance of non-structural elements (NSE) has become increasing critical to seismic resilience when considering a whole-of-building approach. Seismic demands on NSE can be generated by displacements (e.g. inter-storey drifts) or accelerations. These demands depend on the response of the structural system as well as potential interactions between the structural system and NSE and between different NSE. A new design for exterior precast concrete cladding panels has been developed in an ongoing research at the University of Canterbury. This design allows the panels to rock under seismic action, minimizing the damage to the concrete panels and resulting in only the silicone sealant between the panels needing repair. This design has been tested and validated as a low-damage rocking solution but has not yet been tested in combination with other building components, such as external plasterboard claddings, internal partition walls, and curtain wall glazing systems. Examining the interaction between these components and the precast panels will provide insight into the applicability of this new design in becoming a low-damage alternative for standard precast concrete panel design.

Research will be conducted to test a condensed section of a standard commercial building, to examine the panels interaction with other building components under seismic action. Various NSE will be included to provide a simulation of the context in which the precast concrete panels would be used. This experiment will also examine the serviceability of this simulated construction, by testing the weather-tightness of the sub-assembly following seismic actions. This is to ensure that not only will the system be structurally sound following an earthquake but also that the space is still usable, in order to reduce business-interruption following earthquake events. From these tests, recommendations will be provided on the use of rocking precast panel and partition walls are for commercial use. The validation of NSE designs requires proof of concept at a building system level and so NSE will be included as payload experiments in all future large-scale building tests. [Aligned funding for tests provided by Quake Centre Building Innovation Partnership funding for NSE].

Data collection
A number of existing data sources will be utilised to conduct the research:

- Databases of existing and recently constructed buildings (develop building archetypes, identify case-study buildings, observe design/construction trends).
- Field data on the performance of buildings in past earthquakes (both in New Zealand and overseas).
- Published data from previously conducted large-scale building tests (both from QuakeCoRE Phase 1 and other international tests).

Large-scale testing

Opportunities to conduct large-scale collaborative testing with affiliate organisations will identified. Large-sale testing opportunities can allow for entire buildings to be tested, where interactions between structural and non-structural systems can be evaluated at a system level and design and modelling methods can be validated and refined. The core research projects for the topics listed will provide the underlying basis for these large-scale tests and the need for such large-scale tests will be assessed as these projects progress. Building tests would aim to combine multiple objectives to maximise the outcomes and may include the following topics:

- Comparison of a robust lateral-load resisting element (e.g. an RC core wall) and a more flexible lateral-load resisting system (e.g. 'BRB' braces).
- Floor diaphragms with irregular plan geometries.
- Mixed or 'hybrid' lateral and gravity-load resisting systems.
- Critical non-structural elements (e.g. cladding, sprinklers, partitions, windows, HVAC)

Data from large-scale buildings tests will be collected and archived in such a way that allows for maximum reuse for future research projects.

Simulation and design methods

The development and validation of numerical models will underpin all of the research tasks. Existing modelling techniques will be compared to data for large-scale tests to identify aspects that are inadequately captured, such as interactions between structural components and the response of irregular diaphragms. Improvements ad validation of numerical modelling techniques will contribute to improved seismic design and assessment outcomes as well as providing a platform for further research into whole of building seismic response.

In addition to developing and validating numerical models, improvements to fundamental design methods and assumptions will also be explored as key outcomes of this research. The assessment of whole of building response can lead to increased complexity in design and efforts will focus on simplifying these once understood to develop design methods that are suitable for implementation in practice.

<u>Relationship to our Vision Mātauranga Strategy:</u>

WHAKAAROTAU: The research primarily addresses the seismic design and assessment of buildings, with a view of improving the resilience through a holistic understanding of the system response and incorporation of low-damage design principles. The project team will work with QuakeCoRE Associate Director - Māori, Professor Anthony Hoete to identification research areas with the programme where consideration of Mātauranga Māori can be incorporated.

WHAKARAKEI: The programme will engage with Māori researchers in QuakeCoRE to understand how the research outcomes can contribute to enhanced Māori and national built, social, economic, and environmental resilience to earthquakes.

WHAKATIPUORA: Efforts will be made to recruit Māori students through a pathway from undergraduate research projects to masters or PhD research. Undergraduate research projects can be developed that specifically address Mātauranga Māori approach to the seismic resilience of buildings and allow this to be weaved into the wide research programme.

Expected Impacts:

- Improvements to the design of new buildings through the implementation of research findings in design standards and guidelines.
- Improvements to the assessment and strengthening of existing buildings through the implementation of research findings into the seismic assessment guidelines.

References:

Henry, R. S., Dizhur, D., Elwood, K. J., Hare, J. & Brunsdon, D. (2017). Damage to concrete buildings with precast floors during the 2016 Kaikōura earthquake. Bulletin of the New Zealand Society for Earthquake Engineering 50, 174-186.

Henry, R. S., Lu, Y., Elwood, K. J., Rodgers, G., Zhou, Y., Gu, A., Yang T. Y. (2019). ILEE-QuakeCoRE collaboration: Low-damage concrete wall building test, Proceedings of the 2019 Pacific Conference on Earthquake Engineering, Auckland, April 4-6.

Filiatrault A, Sullivan T.J. (2014). Performance-based Seismic Design of Nonstructural Building Components: The Next Frontier of Earthquake Engineering. Earthquake Engineering and Engineering Vibration 13, 17-46.

Jünemann R, de la Llera JC, Hube MA et al. (2016). Study of the damage of reinforced concrete shear walls during the 2010 Chile earthquake. Earthquake Engineering & Structural Dynamics 45, 1621-1641.

MacRae, G. A., Dhakal, R., Zhao, Z., Jia, L.J., Xiang, P. Clifton, C., Ramhormozian S., Rodgers G. (2020). Robust friction building shaking table testing overview. Proceedings of the 2020 New Zealand Society for Earthquake Engineering Annual Technical Conference, (online).

Suzuki, T., Elwood, K., Puranam, A., Lee, H-J., Hsiao F-P., Hwang, S-J, (2021). Drift Demand Estimates for Inelastic Torsional Response of Half-scale Seven-storey RC Specimens. Proceedings of the 2021 New Zealand Society for Earthquake Engineering Annual Technical Conference, Christchurch.

3. Project Budget

See excel file: 2021 - 2024 Research Programme Budget_DT2.xlsx

- **Budget Justification:**

Roles:

Name	Role (e.g. Project Leader, Project Investigator, Student, Translation partner)	Responsibilities
Rick Henry (UA)	Project co-lead	Lead of objectives 2 & 3
Santiago Pujol (UC)	Project co-lead	Lead of objective 1
Reagan Chandramohan (UC)	Investigator	Project investigator objective 1 & 2
Charles Clifton (UA)	Investigator	Project investigator objective 1 & 2 & 3
David Carradine (BRANZ)	Investigator	Project investigator objective 2
Rajesh Dhakal (UC)	Investigator	Lead of objective 4
Ken Elwood (UA)	Investigator	Project investigator objective 1 & 3
Ashkan Hashemi (UA)	Investigator	Project investigator objective 2
Lucas Hogan (UA)	Investigator	Project investigator objective 1 & 3
Jason Ingham (UA)	Investigator	Project investigator objective 2
Chin-Long Lee (UC)	Investigator	Project investigator objective 1
Minghao Li (UC)	Investigator	Project investigator objective 2
Angela Liu (BRANZ)	Investigator	Project investigator objective 3
Quincy Ma (UA)	Investigator	Project investigator objective 1
Greg MacRae (UC)	Investigator	Project investigator objective 1 & 2 & 3
Pierre Quenneville (UA)	Investigator	Project investigator objective 2
Shahab Ramhormozian (AUT)	Investigator	Project investigator objective 1 & 2
Max Stephens (UA)	Investigator	Project investigator objective 1 & 2
Timothy Sullivan (UC)	Investigator	Project investigator objective 1 & 3 & 4
Charlotte Toma (UA)	Investigator	Project investigator objective 1 & 2
Des Bull (Holmes)	Industry partner	Partner objective 1-3
Jared Keen (Beca)	Industry partner	Partner objective 1-4
Stu Oliver (Holmes)	Industry partner	Partner objective 1-4
Anqi Gu (UC)	Research fellow	Post-doc objective 2
Faraz Zaidi	Student	Student objective 1d
Qun Yang	Student	Student objective 2a
Claire Pascue	Student	Student objective 2b
Mohamed Mostafa	Student	Student objective 3a
Frank Bueker	Student	Student objective 3a
Charles Kerby	Student	Student objective 1 & 2
Zhenduo Yan	Student	Student objective 2
Muhammad Rashid	Student	Student objective 4
Jitendra Bhatta	Student	Student objective 4
Hamed Bagheri	Student	Student objective 2
Tomomi Suzuki	Student	Student objective 1
Sunil Nataraj	Student	Student objective 1
Vishvendra Bhanu	Student	Student objective 1
Kiran Rangwani	Student	Student objective 2
Ren-Jie Tsai	Student	Student objective 2a
Robert Clement	Student	Student objective 4a
Vinu Sivakumar	Student	Student objective 1b

Resources:

- 0.6FTE post-doc funding for both UA and UC (intended to be used for cofounded positions).
- RA support to assist with project admin and lab support at both UA and UC.
- Consumable costs for lab testing of $30,000 pa at both UA and UC.
- Funds set aside for future large-scale collaborative testing with international partners ($250,000).
- Student stipend and fees for 4 new PhD students as well as extension funding for aligned students previously funded in QC1.
- Annual Meeting travel of $1000 per active collaborator of IP1 is included.
- Additional travel costs for project meetings of $8000 pa.

4. Outline of aligned funding:

Description of aligned activities:

- ILEE concrete building: The test is completed and dataset is available for future use during DT2 projects. The current project team includes one post-doc and one PhD student who are funded from other sources and who will contribute to structural interaction and numerical modelling topics in DT2.
- Robust building test: Test is on track to be completed soon and will provide an additional dataset for use during DT2 projects. Several aligned PhD students.
- Recast project: Several PhD and ME students funded who are working on seismic assessment and retrofit of precast floor diaphragms, aligned to key DT2 topic areas.
- Quake Centre Building Innovation Partnership programme includes substantial funding to investigate the seismic performance of non-structural elements. Aligned projects to theme 4 (NSE) will include BIP funded students and experimental costs.
- Proposal for testing of lap splices in reinforced concrete walls has been submitted to EQC biennial round. Additional funding requests are being made to ACI. These proposals will fund the experimental costs of the testing which is aligned to the DT2 research programme.

Direct costs:

- ILEE concrete building project extension (~$110k)
- Robust building test (~$300k)
- Recast project – remaining aligned objectives (~$50)
- BIP funding for NSE testing (~$100k)

Travel: N/A

Personnel (salaries and student scholarships):

Name	Funding source	FTE	Cost (including overhead and salary related costs)
Faraz Zaidi (PhD)	UoA doctoral scholarship	1.0	$110k
Qun Yang (PhD)	CSC doctoral scholarship	1.0	$35k
Anqi Gu (post-doc)	Rutherford discovery fellowship (Geoff Rodgers)	0.5	$80k
Claire Pascue (PhD)	UoA doctoral scholarship	1.0	$45k

Mohamed Mostafa (PhD)	BRANZ/Recast doctoral scholarship	1.0	$70k
Frank Bueker (PhD)	Recast doctoral scholarship	1.0	$70k
Charles Kerby (PhD)	UC doctoral scholarship	1.0	$105k
Zhenduo Yan (PhD)	Doctoral scholarship	1.0	$35k
Muhammad Rashid (PhD)	Doctoral scholarship	1.0	$35k
Jitendra Bhatta (PhD)	Doctoral scholarship	1.0	$35k
Hamed Bagheri (PhD)	Doctoral scholarship	1.0	$35k
	Total:		$655k

Total aligned funding: $1,215,000

5. Project Deliverables:

Research Programme Deliverables		
Deliverables / Milestones		**Due Date**
1.1 - Objective 1: Review of current design and construction practices in NZ and oversees, and review of past earthquake performance.		31/12/2022
1.2 - Objective 1: Assessment of holistic impacts of reduced drift demands on building design.		31/12/2024
1.3 - Objective 1: Recommendations for improvements to seismic assessment procedures.		31/12/2024
2.1 - Objective 2: Recommendations on wall-to-floor interaction in low-damage buildings.		31/12/2022
2.1 - Objective 2: Identify potential gaps in current design procedures for buildings with hybrid structural systems.		31/12/2023
2.3 - Objective 2: Revised design provisions for coupled wall systems.		31/12/2024
3.1 - Objective 3: Recommendations for macro load paths to assess existing floor diaphragms.		31/12/2023
3.2 - Objective 3: Recommendations for design of diaphragms in new buildings.		31/12/2024
4.1 - Objective 4: Completion of precast cladding interaction tests.		31/12/2022
4.2 - Objective 4: Recommendations for non-structural element demands due to interactions.		31/12/2024
5 - Concept developed for a large-scale test building		31/12/2024
Publication and Data		**Due Date**
Publications	1. 2022 Peer Reviewed Journal Publications: At least 3 peer reviewed journal publications	31/12/2022
	2. 2023 Peer Reviewed Journal Publications: At least 3 peer reviewed journal publications	31/12/2023
	3. 2024 Peer Reviewed Journal Publications: At least 3 peer reviewed journal publications	31/12/2024
Data	1. Share all appropriate 2022 data on DesignSafe, DIVE or equivalent platform	31/12/2022
	2. Share all appropriate 2023 data on DesignSafe, DIVE or equivalent platform	31/12/2023
	3. Share all appropriate 2024 data on DesignSafe, DIVE or equivalent platform	31/12/2024

6. Communication and Engagement

Communication of findings and engagement with stakeholders and end-users will be done at regular intervals throughout the project. The following key activities are planned:

- Monthly videoconferences held for each thrust area to ensure that researchers are aware of potential interconnection in projects and stakeholders and end-users are engaged to help guide direction and co-create research ideas.
- Workshops held with the research community and industry aligning with QuakeCoRE Annual Meeting and NZSEE conferences.
- At least one QuakeCoRE seminar per year from DT2 investigators as part of the monthly seminar series to the broader QuakeCoRE community.
- Industry facing seminars organised near the conclusion of the programme to disseminate key findings to practicing structural engineers.
- Media releases and social media to promote large-scale collaborative tests.

7. Risks

- Delays to student scholarship start dates due to contracting delays (solution seems to be resolved at both UA and UC).
- Recruitment of PhD students may be delayed due to Covid-19 border restrictions and drop in international students and a lack of domestic PhD student applicants.
- The goal of the DT2 programme is to develop a series of research projects that cumulate in a large-scale collaborative test. Such tests are reliant on international partnerships and co-funding. The success of QC1 projects (ILEE, NCREE, e-defense) have developed strong relationships to enable such collaborative tests to proceed.
- The DT2 programme includes a wide range of investigators and projects. It is possible that research priorities and projects may shift throughout the duration of the programme and so variations to the scope, deliverables, and budget may need to be made.

8. Ethics or Regulatory Approvals:

Does this project require ethics and/or regulatory approval(s)?

☐ Yes ☒ No

If approvals are required please indicate if you have these approvals or how approvals may affect the project timelines.

This application is consistent with the QuakeCoRE collaboration agreement and has been read by both the applicant and employing organisation and it is acknowledged that if this proposal receives QuakeCoRE funding, the terms and conditions set out in the agreement must be adhered to. I confirm that all of the people named in this proposal are aware of their involvement in this project and are committed to supporting a successful project outcome.

SIGNATURE:

Date: 22/7/2021

International Review

International Advisor Review

For each of the criteria listed below, please indicate how well you feel the project meets this area.

1. **Research Excellence**

   As a centre of research excellence, we are committed to undertaking world class research. Our funders place an emphasis on measuring research excellence by peer reviewed publications.

   Please consider these criteria in your evaluation:

   - Quality of proposed research
   - Track Record & ability to deliver proposed research

   SELECT FROM:

   - **Excellent**
   - Well Above Average
   - Average
   - Below Average
   - Well Below Average

   Excellent

2. **Human Capacity Development**

   QuakeCoRE is committed to developing human capacity in our community.

   Please consider these criteria in your evaluation:

   - Involvement of postgraduate students and emerging researchers (both Postdoctoral fellows and researchers that are less than 7 years from conferment of their PhD)
   - Development & support for members of under-represented groups in particularly women in engineering, researchers that identify as Māori or Pasifika.

   SELECT FROM:

   - **Excellent**
   - Well Above Average
   - Average
   - Below Average
   - Well Below Average

   Excellent

3. **Fit with QuakeCoRE Mission**

   QuakeCoRE is funded by TEC to deliver on our mission of placing Aotearoa New Zealand at the worldwide forefront of earthquake disaster resilience by utilising Aotearoa New Zealand as a natural earthquake laboratory, producing new knowledge on the seismic response of the built environment, developing models to understand vulnerabilities within this environment, and designing innovative technologies and decision-support tools enabling rapid recovery of Aotearoa New Zealand communities.

   Please consider these criteria in your evaluation:

   - Alignment of the proposed research with the QuakeCoRE Mission
   - Value and additionality of proposed research relative to its cost. Opportunities, relevance and translation to practice including direct involvement of end-users and stakeholders.

   SELECT FROM:

   - **Excellent**
   - Well Above Average
   - Average
   - Below Average

- Well Below Average

Excellent

Briefly outline below how the research in this project proposal corresponds with international research priorities

Results from the proposed research will lead to more robust structures under earthquake attack. The research is aimed at filling existing gaps between research, design and construction as a consequence of a more demanding society in terms of expectations of building performance and serviceability after earthquakes.

Outcomes from this research will:

(a) Provide tools for cost-benefit estimations over the entire life of the structure, comparing flexible and stiff structures.
(b) Shed light into the behaviour of interconnected unreinforced masonry (URM). These buildings are common in main streets of cities in New Zealand and little information is available on the seismic behaviour of such structures.
(c) Help to better understand and quantify the effect of axial restrain imposed by the slab on the performance of coupled wall systems.
(d) Provide information to improve the %NBS to facilitate decision making processes for the society.
(e) Result into design recommendations for the seismic design of diaphragm, including composite steel deck systems and PT slabs.
(f) Lead to a better understanding of the interaction between structural and non-structural components under different levels of drift demands, and the cost involved in their repair and replacement.

The research will lead to improved design methods aligned with the interest of a society focused on resiliency and sustainability.

Please comment briefly on the quality of the research and provide a brief critique of the project proposal

The quality of the proposed researched is Excellent. No critiques but rather two recommendations.

(a) In Objective 2: *Identify potential gaps in current design procedures for buildings with hybrid structural systems*, it would be interesting to investigate the potential of using systems composed of steel beams and reinforced concrete columns, commonly known as RCS system in the United States.
(b) Instrument existing buildings in New Zealand to gather information about their dynamic properties, as part of the evidence used in the research program.

Based on your review of the project, would you recommend that QuakeCoRE fund this proposal as written?

☒ **Yes** ☐ **No**

Industry Reviewer Details

Name: Luis B. Fargier Gabaldon, PhD

Organisation: DCI America

Email Address: lfagier@dcintegrados.com

Industry / Stakeholder Review

Industry / Stakeholder Review

For each of the criteria listed below, please indicate how well you feel the project meets this area.

4. **Research Excellence**
   As a centre of research excellence, we are committed to undertaking world class research. Our funders place an emphasis on measuring research excellence by peer reviewed publications.
   Please consider these criteria in your evaluation:
   - Quality of proposed research
   - Track Record & ability to deliver proposed research

   SELECT FROM:
   - Excellent
   - Well Above Average
   - Average
   - Below Average
   - Well Below Average

   Excellent

5. **Human Capacity Development**
   QuakeCoRE is committed to developing human capacity in our community.
   Please consider these criteria in your evaluation:
   - Involvement of postgraduate students and emerging researchers (both Postdoctoral fellows and researchers that are less than 7 years from conferment of their PhD)
   - Development & support for members of under-represented groups in particularly women in engineering, researchers that identify as Māori or Pasifika.

   SELECT FROM:
   - Excellent
   - Well Above Average
   - Average
   - Below Average
   - Well Below Average

   Well Above Average

6. **Fit with QuakeCoRE Mission**
   QuakeCoRE is funded by TEC to deliver on our mission of placing Aotearoa New Zealand at the worldwide forefront of earthquake disaster resilience by utilising Aotearoa New Zealand as a natural earthquake laboratory, producing new knowledge on the seismic response of the built environment, developing models to understand vulnerabilities within this environment, and designing innovative technologies and decision-support tools enabling rapid recovery of Aotearoa New Zealand communities.
   Please consider these criteria in your evaluation:
   - Alignment of the proposed research with the QuakeCoRE Mission
   - Value and additionality of proposed research relative to its cost. Opportunities, relevance and translation to practice including direct involvement of end-users and stakeholders.

   SELECT FROM:
   - Excellent
   - Well Above Average
   - Average
   - Below Average
   - Well Below Average

Excellent

Briefly outline below how the research in this project proposal will support the benefit to industry and communities in Aotearoa New Zealand.

Jared Keen:

The research in this proposal is strongly aligned to address some of the most immediate and critical issues currently needing to be addressed in NZ structural and seismic engineering. Of particular importance is further into areas impacting seismic assessments.

Further comments are provided against specific research programme items.

Stu Oliver:

The project will greatly benefit the NZ construction industry and wider communities in that it will provide practicing engineers with additional knowledge in terms of being able to assess how new and existing buildings are likely to perform during earthquakes. This will enable us to better communicate with building owners, tenants, and users:

- life safety risks associated with existing buildings and how these could be mitigated or reduced.
- likely performance of new buildings in earthquakes and how building resilience can be improved using the outcomes associated with the project.

Please comment briefly on the quality of the research and provide a brief critique of the project proposal

Jared Keen:

The proposed project represents important research into numerous important areas, delivered by a very capable research team.

Specific critiques have been provided against individual research items.

Stu Oliver:

The quality of the research looks excellent. The research will directly address several keys areas of uncertainty that currently exists in the NZ construction industry:

- Benefits/disadvantages of designing stiffer, less ductile, buildings as a means to limit structural and non-structural building damage in moderate earthquakes.
- How significant the interactions between different structural components, and between structural and non-structural components, are and is there a need to more accurately account for this in building design. If so, how can this practically be done in a conventional design office?

Provide greater clarity on how we can more accurately assess and retrofit existing buildings containing precast floors with insitu floor toppings reinforced with cold drawn wire mesh.

Based on your review of the project, would you recommend that QuakeCoRE fund this proposal as written?

☒ **Yes** ☐ **No**

Industry Reviewer Details

Reviewer 1: Jared Keen

Organisation: Beca

Email Address: jared.keen@beca.com

Reviewer 2: Stu Oliver

Organisation: Holmes Consulting LP

Email Address: stuarto@holmesgroup.com