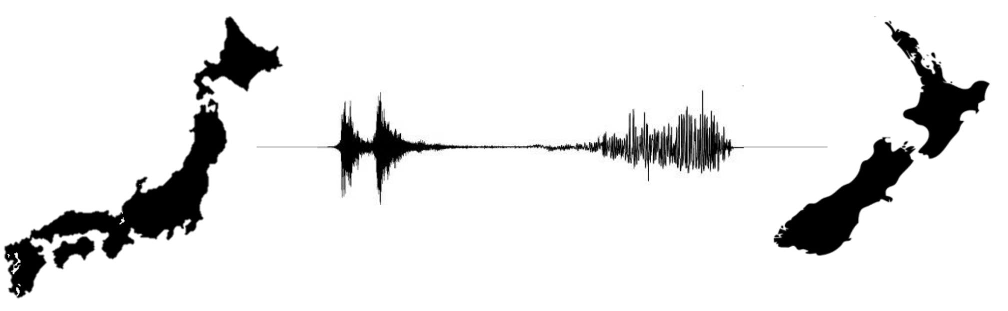
International Workshop for

“DPRI-QuakeCORE Student Forum in Earthquake Engineering”

February 26-27, 2016

DPRI, Kyoto University



Sponsor:

Disaster Prevention Research Institute, Kyoto University

DPRI-QuakeCoRE Student Forum
26-27 February 2016
Kyoto, Japan

Dear Participants,

I would like to extend my personal welcome to DPRI, Kyoto University and to the International Workshop for “DPRI-QuakeCoRE Student Forum in Earthquake Engineering”. I am very excited for intellectual challenges we will explore together. The agenda of the symposium are prepared by the four student leaders affiliated with DPRI and QuakeCoRE. In that sense, the collaboration between two institutions have already started approximately in half a year ago. I strongly believe this agenda is well designed to provide excellent opportunities for sharing the underlying issues and concerns related to Earthquake Engineering in New Zealand and Japan. Certainly, the borderless exchanges of ideas will result in the creation of an empowered research community engaged in the mitigation of seismic hazards.

Our success during this workshop will depend on the ideas and enthusiasm brought by the participants. The participants are encouraged to actively participate in discussions and in the process of developing a resolution.

To the end, I would like to express my sincere appreciation to our New Zealand friends, the DPRI administrative assistants, and DPRI for the generous financial support in making this opportunity possible.

Sincerely yours,

Masahiro Kurata, Ph.D.

Associate Professor and Program Coordinator
Division of Earthquake Research
Disaster Prevention Research Institute (DPRI),
Kyoto University
masahiro.kurata.5c@kyoto-u.ac.jp

Initiative of this workshop is taken by,

DPRI
- Hiroyuki Inamasu
- Yu Otsuki

QuakeCORE
- Claudio Cappellaro
- Kai Marder

The schedule of preliminary video conferences is as follows.

1st: 23rd October, 2015
2nd: 11th November, 2015
3rd: 25th November, 2015
4th: 21st December, 2015
5th: 15th January, 2016
6th: 9th February, 2016
7th: 22nd February, 2016

INTERNATIONAL WORKSHOP FOR
"DPRI-QuakeCORE Student Forum in Earthquake Engineering"

Day 1, Friday, February 26th (Room S-519), Chair: Yu Otsuki			
8:50–9:00	***Registration***	***Session 2 (14:00-15:30) : Chairman (Brandon McHaffie)***	
9:00–9:30	***Opening Remarks*: (Prof Nakashima/Kurata) from DPRI @ Kyoto University**	**14:00–14:30**	Shahab Ramhormozian, University of Auckland **"Enhancing the Seismic Performance of the Sliding Hinge Joint Using Belleville Springs"**
9:30–10:10	***Presentation of DPRI/current research needs in disaster mitigation in Japan*** **:** Prof Kurata from DPRI @ Kyoto University	**14:30–15:00**	Claudio Cappellaro, University of Canterbury **"Undrained cyclic response of sandy soils in simple shear tests"**
10:10–11:00	***Presentation of QuakeCoRE/current research needs in disaster mitigation in NZ*** **:** (Prof Elwood/Ma/Palermo) from QuakeCore @ UC or UA	**15:00–15:30**	Francesca Barbagallo and Ikumi Hamashima, Kyoto Univ. **"Investigation of the dynamic behaviour of free-standing structure with graphite lubrication"**
11:00–11:30	***Coffee Break***	**15:30–16:00**	***Coffee Break***
Session 1 (11:30-13:00) : Chairman (Hiroyuki Inamasu)		***Session 3 (16:00-17:30) : Chairman (Kai Marder)***	
11:30–12:00	Tadahisa Takeda and Lei Zhang, Kyoto Univ. **"Minimal-Disturbance Seismic Rehabilitation Technique Using Light-Weight Steel Elements"**	**16:00–16:30**	Thomas Matarazzo and Hiromichi Nishino, Kyoto Univ. **"Structural Health Monitoring: Extracting Infrastructure Information from Sensor Data"**
12:00–12:30	Kai Marder, University of Auckland **"Post-Earthquake Residual Capacity of Reinforced Concrete Buildings"**	**16:30–17:00**	Akiko Suzuki and Shota Shinmoto, Kyoto Univ. **"Seismic Fragility and State-Dependent Aftershock Risk Assessments of Japanese Steel Frames"**
12:30–13:00	Skalomenos Konstantinos and Hironari Shimada, Kyoto Univ. **"A new Steel Brace: Brace with Intentional Eccentricity (BIE)"**	**17:00–17:30**	Brandon McHaffie, University of Canterbury **"Numerical Investigation of Pier-Foundation Connections For Accelerated Bridge Construction"**
13:00–14:00	***Lunch break*** (Lunch box)	**19:00-**	Get-together party (@ Toriiebisu near Kyoto station)

Notes: Each presentation shall include 10 min for question and answer.

Day 2, Saturday, February 27th (Room S-519) , Chair: Claudio Cappellaro			
8:50–9:00	***Registration***	**10:00–10:30**	***Presentation of student forum*****:** Kai Marder from QuakeCore @ UA
9:00–9:10	***Summary of presentations from the 1st day - introduction to discussion for the 2nd day*****:** Claudio Cappellaro	**10:30–12:00**	***Discussion for establishment of "DPRI-QuakeCORE student forum" and resolution making***
9:10–09:25	***Brief presentations of Japanese academic system; organization of courses, laboratories and offer at DPRI*** **:** Hiroyuki Inamasu and Yu Otsuki from DPRI @ Kyoto University	**12:00–12:30**	***Closing Remarks*** **:** (Prof Nakashima / Kurata) from DPRI @ Kyoto University
09:25–09:40	***Brief presentations of NZ academic system; organization of courses, laboratories and offer at QuakeCORE*** **:** Brandon and Shahab from QuakeCore @ UC or UA	**12:30–13:30**	***Lunch Break*** (Cafeteria)
09:40–10:00	***Presentation on potential internship programs*****:** (Prof Elwood/ Ma/Palermo) from QuakeCore @ UC or UA		

Biographies and Abstracts

Masayoshi Nakashima
Professor
Kyoto University, Kyoto, Japan

Masayoshi Nakashima is Professor at Kyoto University, Japan. His fields of research include seismic analysis and design of steel building structures and large-scale experimental techniques for the simulation of earthquake responses. Nakashima and his students have published about four hundred technical papers, over one hundred and eighty of them in archived journals. He has earned various awards including the ASCE Moisseiff Award (2000), the Special Achievement Award of AISC (2009), the ASCE Ernest E. Howard Award (2013), and the EERI George W. Housner Medal (2014), among others. He is Member of the Engineering Academy of Japan and most recently inducted to Foreign Member of the National Academy of Engineering (NAE) of the United States. Currently, Nakashima serves as President of the Architectural Institute of Japan (AIJ) and Executive Vice-President of International Association for Earthquake Engineering (IAEE). He is also Editor of International Journal of Earthquake Engineering and Structural Dynamics (EESD).

What makes Japan different from the rest of the world in design and construction of buildings – a few examples?

Masayoshi Nakashima
Disaster Prevention Research Institute (DPRI), Kyoto University – Japan

Abstract

In the construction of Japan, wood has been the primary material for centuries. It is also notable that Japan and Japanese traditionally show significant appreciation to “handcraft” and “manufacturing”. Another nature of Japan is such that Japan suffers seriously from various natural disasters including earthquakes; hence how to protect our houses and infrastructural systems against such disasters has been and will be the most critical societal need. With such historical and topographical background in mind, this speaker wishes to touch upon the following issues, which are deemed to characterize the Japanese design and construction of buildings.

First, the Japanese fondness of steel structures is discussed in light of the similarities between wood and steel. Wood has been used for centuries for both individual houses and large structures such as temples and shrines. Both wood and steel commonly adopt framing systems that consist of columns and beams, and how to connect these members is the key for the assurance of structural integration. Making the best use of the centuries’ experience on wood design and construction, Japan has been very eager to develop technologies associated with steel construction.

Second, Japanese loves detailing, which indeed characterizes the architecture of Japanese buildings, houses, and other structures. Complicated roofing details, exquisitely crafted eaves, complex connections using interlocking, among others, have been appreciated particularly in temples and shrines. This spirit of “love for details” is inherited in the contemporary Japanese design and construction.

Third, Japanese eagerness to “new development” is worthy to note. It has been embedded in Japanese heart that handcraft and manufacturing and those engaged in them are the objects to respect. For this reason, new development, new invention, and sophisticated engineering are always the targets to challenge, and eventually very many new products have been developed in Japan. A few examples along this line, particularly those related to steel structures, include high-toughness steel, high-strength steel, fire-resisting steel, ultra-high-strength bolts, low-yield steel, buckling restrained braces, and concrete filled steel stubs. In not a few of those developments, however, the attitude of “technology-driven” (relative to “business-driven”) makes the products over-qualified, whose tendency of Japan is often called “Galapagosization”.

Last, Japan has a tradition of good collaboration between design and construction (manufacturing). In some countries, the relationship between design and construction is vertical, i.e., design is placed above construction in the order of chain as well as the social recognition. Unlike those, Japan traditionally exercises equal partnership between design and construction, which has been believed to be the key for the ultimate quality control of construction products.

Masahiro Kurata
Associate Professor
Disaster Prevention Research Institute, Kyoto University,
Kyoto, Japan

Dr. Masahiro Kurata is an Associate Professor of the Division of Earthquake Hazards, the Disaster Prevention Research Institute at Kyoto University. Dr. Kurata completed his graduate studies at the Georgia Institute of Technology where he received his Ph.D. in Civil and Environmental Engineering in 2009 and conducted two-year post-doctoral research at University of Michigan. Dr. Kurata focuses in the areas of post-disaster structural damage screening, self-diagnosable earthquake resistant system and sustainable seismic rehabilitation approaches for building structures. His work includes numerical simulations, large-scale testing using shake tables and development of autonomous structural monitoring system using advanced sensing technologies.

Unique Evolution and Globalization in Earthquake Engineering

M. Kurata[1]
[1]Disaster Prevention Research Institute, Kyoto University - Japan

Building and planning regulations in Japan have uniquely evolved based on the assessment of the past earthquake disasters and other factors. After the 2011 off the Pacific coast of Tohoku Earthquake, the Law Concerning the Promotion of Seismic Retrofit of Buildings was revised in 2013 to obligate the owners of large-scale buildings such as hotels and other institutions to undertake seismic inspections. This revision also applies to buildings alongside designated major roads that work as access for emergency service vehicles. The other factors impacted on regulations include defect and falsification, which raised suspicion on the quality of constructed buildings. The introduction of a performance code, the opening of construction confirmation and inspections to private enterprise and the introduction of interim inspection systems were made to the Building Standard Law.

A topic of conversation does not end just with it. As with many other countries, "Interdisciplinary" and "International" are the common keywords in Japanese university education and research in response to worldwide competition in the era of globalization. Earthquake Engineering is not exceptional. Needs on improving disaster management in collaboration with Social Science, Computer Science, etc. are highly encouraged. The aged society with a low birth rate, depression after 2020 Tokyo Olympic Game, etc. are some gently related pessimistic subjects. All in all, new challenges have surfaced one after another. Interaction of young and fresh brains is considered as the best way for tackling strange and curious problems. Of course, it is not to be done in a day, thus I expect this workshop to yield sustainable "connectors" of those affiliated with two leading countries in Earthquake Engineering.

Ken Elwood
Director, QuakeCoRE
Professor and MBIE Chair in Earthquake Engineering
University of Auckland, New Zealand

Ken joined the University of Auckland in July 2014 after 11 years on faculty at the University of British Columbia, Canada. Ken was drawn to New Zealand to pursue the numerous opportunities for research and implementation in earthquake risk reduction. He is actively involved in research related to the seismic response of existing concrete and masonry buildings.

Ken received his PhD in Civil Engineering from the University of California, Berkeley in 2002, M.S. from the University of Illinois at Urbana-Champaign in 1995, and BASc from the University of British Columbia in 1993.

Ken is a member of several national and international code committees including the seismic provisions of the American Concrete Instititute Building Code (ACI 318). He is also Chair of the EERI Learning from Earthquakes program.

Quincy Ma
Senior Lecturer
University of Auckland

Quincy Ma is a senior lecturer at the University of Auckland where he lectures in structural dynamics and structural analysis. He is experienced in the numerical simulations of seismic loads on structures, as well as static and dynamic structural experimentation. He currently leads a number of projects on a wide range of earthquake engineering topics, including risk-based cost benefit analysis, seismic structural monitoring, mechanics of rocking structures and hybrid testing. Quincy was the convenor of the 2011 Pacific Conference on Earthquake Engineering and he was also the 2010 recipient of the EQC-NZSEE Ivan Skinner award. He is the current President of the New Zealand Society for Earthquake Engineering.

Alessandro Palermo
Associate Professor / Reader
University of Canterbury, Christchurch

Since June 2009 Alessandro is faculty member at the University of Canterbury, as Associate Professor/Reader. Alessandro's research areas of interest are mainly focused on structural bridge engineering, where he is currently course coordinator of a post-graduate course. His expertise is particularly focused on implementation of seismic low-damage technologies for precast concrete bridges and post-tensioned timber buildings. Within the last two earthquakes he has been heavily involved in reconnaissance of Canterbury bridges. He launched and currently coordinates the Canterbury Bridge Group. Alessandro is author of more than 200 international and national conference and journal papers, 3 patents and reviewer of several international scientific journals. He is council member of the New Zealand Concrete Society, SEI-ASCE Technical Council on Life-Cycle Performance, Safety, Reliability and Risk of Structural Systems, and Australian Bridge design standards. He has been recently nominated fib New Zealand Head Delegate.

Alessandro has also a broad consulting experience ranging from bridges to post-tensioned low damage timber buildings and is currently principle of a University spin-off company. In 2013, he was 2013 recipient of the prestigious Ivan Skinner Award for recent advances in earthquake engineering. He has also been co-awarded with other colleagues the University of Canterbury Innovation Medal in 2013 for his research and real practice implementation of post-tensioned timber technology.

QuakeCoRE and NZ Research in Earthquake Engineering

Ken Elwood[1], Quincy Ma[1], Alessandro Palermo[2]
[1]Department of Civil and Environmental Engineering, University of Auckland - New Zealand
[2] Department of Civil and Natural Resources Engineering, University of Canterbury - New Zealand

New Zealand has a long history of research in earthquake engineering and associated fields. Research innovations such as “base isolation” and “capacity-design principles”, originating from NZ, have been implemented worldwide, resulting in a step-change in the seismic resilience of adopting societies. However, the estimated $40 Billion in direct losses (~20% GDP) associated with the 2010-2011 Canterbury Earthquakes provide a sobering reminder that significant research and implementation advances are still needed to achieve an acceptable level of economic and societal resilience against earthquake hazards in NZ.

Recognising this need, in 2016, the NZ government funded a Centre of Research Excellence on Earthquake Resilience, QuakeCoRE, hosted at the University of Canterbury, with seven other partners from across New Zealand. The mission of QuakeCoRE is to place NZ at the worldwide forefront of earthquake disaster resilience by utilizing NZ as a natural earthquake laboratory, producing new knowledge on the seismic response of the built environment, developing fundamental models to understand vulnerabilities within this environment, and designing innovative technologies and decision-support tools enabling rapid recovery of NZ communities.

The overarching goal of QuakeCoRE is to provide the fundamental research and education of future professional leaders to underpin a paradigm shift in the design and operation of infrastructure components toward system-level optimisation for earthquake resilience. QuakeCoRE will achieve this goal through the creation of new knowledge, models, technologies and implementation pathways. The research across QuakeCoRE is underpinned and facilitated by four Technology Platforms which provide the underpinning experimental (lab and field), computational, and data infrastructure which are necessary for realizing QuakeCoREs vision and mission and involve cross-institutional and industry collaborations. Flagship Projects are QuakeCoRE-funded projects involving multi-institution and multi-disciplinary research collaboration, engagement with end-users, and co-funding. The initial Flagship projects include: Ground motion simulation, Liquefaction impacts on infrastructure, Earthquake-prone buildings, Next-generation infrastructure, Spatially-distributed infrastructure, and Pathways to resilience.

A key priority in the QuakeCoRE plan includes *Growing international linkages*. Through leveraging on existing linkages at an investigator level, QuakeCoRE will provide a focal point for international research excellence in earthquake resilience, improving the international visibility of NZ-based researchers, and attracting internationally leading researchers to NZ.

Mary C Comerio
Professor
University of California, Berkeley
Member of the QuakeCoRE Governing Board

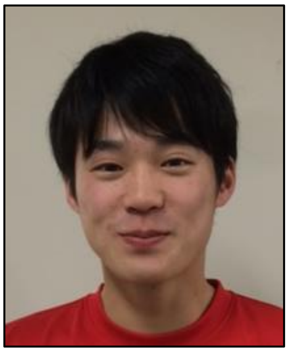
Mary Comerio is an internationally recognized expert on disaster recovery. She has been at the Department of Architecture at U. C. Berkeley since 1978 and served as Chair from 2006-2009. Her current research focuses on post-disaster recovery, resilience, and loss modelling. She is the author of hundreds of scholarly articles and research reports, including the book: Disaster Hits Home: New Policy for Urban Housing Recovery. In 2011, she received the Green Star Award from the United Nations for her work in post-disaster reconstruction. In 2013, she received the U. C. Berkeley Chancellor's Award for Public Service for Research in the Public Interest and the Earthquake Engineering Research Institute's Distinguished Lecturer Award. She is currently President of EERI.

Earthquake Loss Estimates and Policy Implications for Nonductile Concrete Buildings in Los Angeles

Thalia Anagnos[1], Mary C. Comerio[2], Jonathan P. Stewart[3]
1) San Jose State University, 2) University of California Berkeley, 3) University of California, Los Angeles

Research Paper Forthcoming: *Earthquake Spectra*

Collapse potential of nonductile concrete buildings represents a substantial life safety hazard globally that can be mitigated through carefully crafted policy. Mitigation policy should be approached incrementally by (1) understanding problem scale, (2) screening for low and high risk buildings, (3) engineering analysis for potentially vulnerable buildings, and (4) retrofit or replacement of high-risk structures. This research addresses initial stages of this sequence for Los Angeles, California. The intent was to investigate approaches for informing mitigation priorities by: characterizing the inventory of approximately 1500 pre-1976 concrete buildings; estimating risk, including identification of building types that contribute most substantially to the risk; and investigating the impact of retrofit policy alternatives. Loss estimates for scenario events are based on the HAZUSTM Advanced Engineering Building Module. Depending on model assumptions, losses range from $1.8 to $28.5 billion and <50 to 8,300 fatalities. We investigate proposals targeting vulnerable buildings for retrofit as compared to retrofitting all buildings in the inventory. Awareness raised by this research contributed to formation of the Los Angeles Mayoral Seismic Safety Task Force, which developed policy proposals.



Tadahisa Takeda
Undergraduate student
Disaster Prevention Research Institute, Kyoto University, Japan

Tadahisa Takeda (born 1993) is an undergraduate student in the school of architecture at Kyoto University, Kyoto, Japan. His current research is about the application of the developed system to low-rise steel frames and examining the effectiveness in enhancing seismic performance. He will study at University of Canterbury on this September for 2 months.

Zhang Lei
Doctoral Student
Disaster Prevention Research Institute, Kyoto University, Japan

Zhang Lei is a doctoral student of the Division of Earthquake Hazards, the Disaster Prevention Research Institute at Kyoto University. Mr. Zhang graduated from the Zhejiang University where he received his B.S. in Civil Engineering in 2009 and M.S. in Road and Railway Engineering in 2012. His current research interests are in the areas of seismic rehabilitation system for building structures and the investigation of the sliding behavior for free standing structure. His work includes test using shake tables, numerical simulations, and seismic analysis of structure.

Miho Sato
Graduate Student
Master of Architectural System, Kyoto University, Japan

Miho Sato is a 2nd year Master student at the department of architectural systems in Kyoto University. She obtained her Bachelor of Architectural Engineering at Kyoto University in 2014. Now she is working for the development of local deformation-based design method for the Minimal-Disturbance Arm Damper, which will be presented below.

Minimal-Disturbance Seismic Rehabilitation Technique Using Light-Weight Steel Elements

Lei Zhang[1], Tadahisa Takeda[1], Miho Sato[1], Masahiro Kurata[2], Masayoshi Nakashima[2]
[1]Architecture and Architectural Engineering, Kyoto University, Kyoto, Japan
[2]Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan

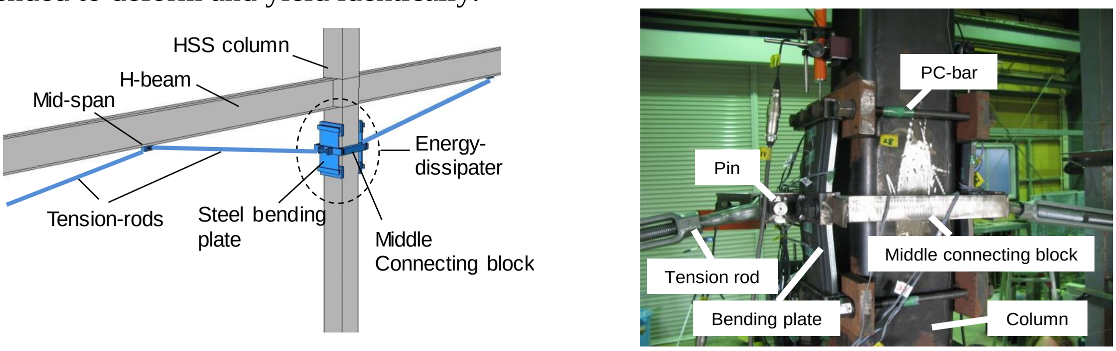
Introduction

Experience shows that large tensile strains at the bottom of flanges in composite steel beam and concrete slab sections are the weak point in steel frame structures. In view of this, some rehabilitation techniques have been developed to improve the seismic resistant capacity of existing steel moment resisting frames (FEMA547, 2006). Nonetheless, these techniques involve the use of heavy equipment and arduous work (welding / cutting), often interrupt sight of users, and cost and downtime associated with construction is a major obstruction to building owners.

Based on the consideration above, a rehabilitation technique within the design scheme of minimal disturbance, named MDAD (minimal disturbance arm damper), is developed. It pursues the seismic enhancement of frame by restraining local deformation of beams to utilize the reserve capacity of frame and by a stable energy dissipation. Besides, to achieve the design scheme of minimal disturbance to building users during or after rehabilitation, the MDAD is designed to consist of light weight steel members bolted only at the upper part of the column. In the study, the performance of MDAD is verified by a series of quasi-static cyclic loading tests and numerical analysis. The effectiveness of MDAD on the rehabilitation of frame is examined numerically in application to a low-rise steel-moment resisting frame.

Minimal disturbance arm damper (MDAD)

Figure 1(a) illustrates a MDAD applied to a beam-column connection of a HSS column and H-shape beams. The MDAD is comprised primarily of a set of tension-rods and an energy dissipater resisting against the deformation of the connection under lateral loading. The tension-rods connect the mid-span of the beam and the energy dissipater. In the energy dissipater, two steel bending plates connected each other by the middle connecting block are attached to the column at their ends using pre-tension bars [Figure 1(b)]. The two plates are intended to deform and yield identically.

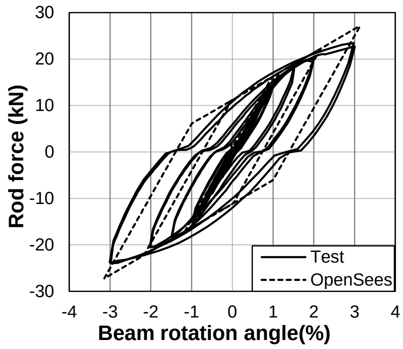


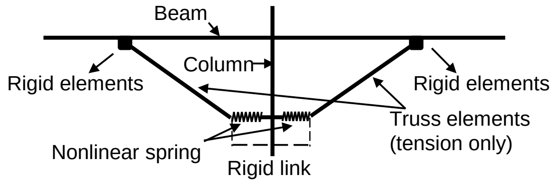
(a) Schematic illustration of the MDAD *(b) Component-level testing*

Figure 1: Schematic of rehabilitation technique.

Component-level tests and simplified model of MDAD

The performance of the MDAD was verified by a series of quasi-static cyclic loading tests. Two main parameters were considered: the rigidity of the middle connecting block between two plates and the yield strength of steel bending plates. Specimen 1 was regarded as the baseline model. Specimen 2 used relatively flexible elements to replace the middle connecting block between two plates. In Specimen 3, low-yield-point (LYP) steel that is characterized by low yielding stress and significant isotropic strain hardening was used for the bending plates to achieve yielding and energy dissipation at small levels of deformation. In Specimen 4, two plates made of high-strength steel (HSS) and LYP were stacked and jointed by bolts at the middle and both ends. The test result of baseline model is shown in Figure 2(a).





(a) Model of the MDAD *(b)Hysteretic behavior*

Figure 2: Modelling and hysteretic behaviour of MDAD

Figure 2(b) describes a simplified model of MDAD constructed in OpenSees for a baseline model, where the bending plates are modelled by using zero length spring elements that have nonlinear material behaviour. The numerical result is presented in Figure 3(a) using the dotted line and it can trace the test result with high accuracy.

Rehabilitation of four-story frame

The effectiveness of MDAD on the rehabilitation was examined through earthquake response analysis for LA 10% in 50 years ground motions in the SAC steel project[2)]. The target frame and rehabilitation plan are shown in Figure 3. Table 1 presents the 84th percentile response quantities for both the bare and rehabilitated frames. The inter-story drifts of the 1st-stories and the positive plastic rotations are reduced by 13% and 43%, respectively. The MDADs effectively reduced the positive plastic hinge rotations at beam ends compared with the roof drift and protect the bottom flange of beam from fracture accordingly.

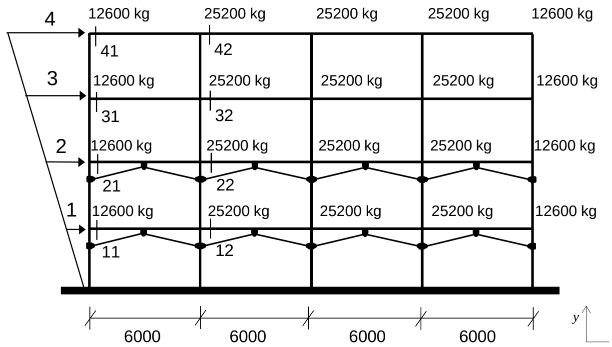


Figure 3: Application of MDAD in steel frame.

Table 1 Effect of MDAD on frame under LA10-50

	Peak roof drift [%]	Peak 1st story drift [%]	Peak 1st + 2nd story drift [%]	Peak hinge positive plastic rotation [rad]
Bare frame	1.99	2.53	2.58	0.021
Rehabilitated	1.84	2.20	2.12	0.012

Conclusions

The performance of MDAD was first verified by a series of quasi-static cyclic loading tests and numerical analysis. The results obtained from the tests showed a stable hysteretic behaviour. Then, the effectiveness of MDAD on rehabilitation was evaluated through application to a four-story steel moment-resisting frame. The MDADs contributed to reduce the positive plastic rotations of the beams that indicated a possibility to design the MDAD based the reduction of plastic rotation.

References

1) Federal Emergency Management Agency (2006): Techniques for the Seismic Rehabilitation of Existing Buildings, FEMA 547.
2) Somerville P, Smith N, Punyamurthula S, Sun J (1997): Development of ground motion time histories for Phase-2 of the FEMA/SAC Steel Project. Report no. SAC/BD-97-04. Sacramento (CA, USA).

DPRI-QuakeCoRE Student Forum
26-27 February 2016
Kyoto, Japan

Kai Marder
PhD Student
University of Auckland, Auckland, New Zealand

Kai Marder (born 1990) is a PhD candidate in Structural and Earthquake Engineering at the University of Auckland (UA). He graduated in 2014 with a Bachelor of Applied Science in Civil Engineering from the University of British Columbia (UBC), Canada. He then worked as a research assistant at UBC prior to commencing his doctoral studies at UA in February 2015. His area of research interest is the seismic performance of reinforced concrete structures, with his PhD research focusing specifically on post-earthquake assessment.

Post-Earthquake Residual Capacity of Reinforced Concrete Buildings

K.J. Marder[1], K.J. Elwood[1]
[1]Department of Civil and Environmental Engineering, University of Auckland - New Zealand

Introduction

The majority of modern reinforced concrete (RC) buildings are designed to withstand seismic loads by forming plastic hinges in pre-determined locations. This design philosophy permits RC buildings to dissipate a significant amount of energy and achieve a large ductility, but does not necessarily prevent damage or ensure reparability. The Canterbury earthquakes of 2010-2011 resulted in the demolition of approximately 60% of multi-storey RC buildings in Christchurch, New Zealand (Marquis et al., 2015). In some cases, the buildings were so heavily damaged that the need for demolition was immediately apparent, but in other cases there was only a moderate, and potentially repairable, amount of damage. However, engineers tasked with conducting detailed assessments on these moderately damaged buildings were left with limited resources on which to base their evaluation.

The research discussed in this paper aims to address this area of need by numerically and experimentally evaluating the residual capacity of RC plastic hinges. 'Residual capacity' here refers to the ability of an earthquake-damaged member to resist future seismic loading, including any changes in stiffness, strength, energy dissipation, or fatigue life. Reduced fatigue life of the longitudinal reinforcing bars due to low-cycle fatigue effects (Mander et al., 1994) was a particular area of concern following the Canterbury earthquakes.

Background and Proposed Assessment Methodology

Previous guidelines for detailed post-earthquake assessments of RC buildings have been published in the United States (ATC, 1998) and Japan (as described in Nakano, 2004). These guidelines correlate visual damage indicators with reduction factors that modify the properties of the damaged member. While these guidelines provide a relatively consistent and efficient method of assessing residual capacity, there are several limitations:

- Much is left to the subjectivity of the building inspector
- No consideration is given to the number of loading cycles and residual fatigue life
- Reduction factors and damage indicators are calibrated off of static cyclic experimental tests which may not be representative of reality
- There is significant variability in the relationship between visual damage and peak demand

Due to these limitations, an alternate assessment methodology is adopted in this study, albeit with its own shortcomings and research needs. A flowchart showing this alternate methodology is presented in Figure 1. The principal difference is the focus on estimating the peak demands incurred during the damaging earthquake, and using these peak demands as a basis for assessing residual capacity. The visual damage is used to refine the estimates of peak demands rather than as the basis for the entire assessment.

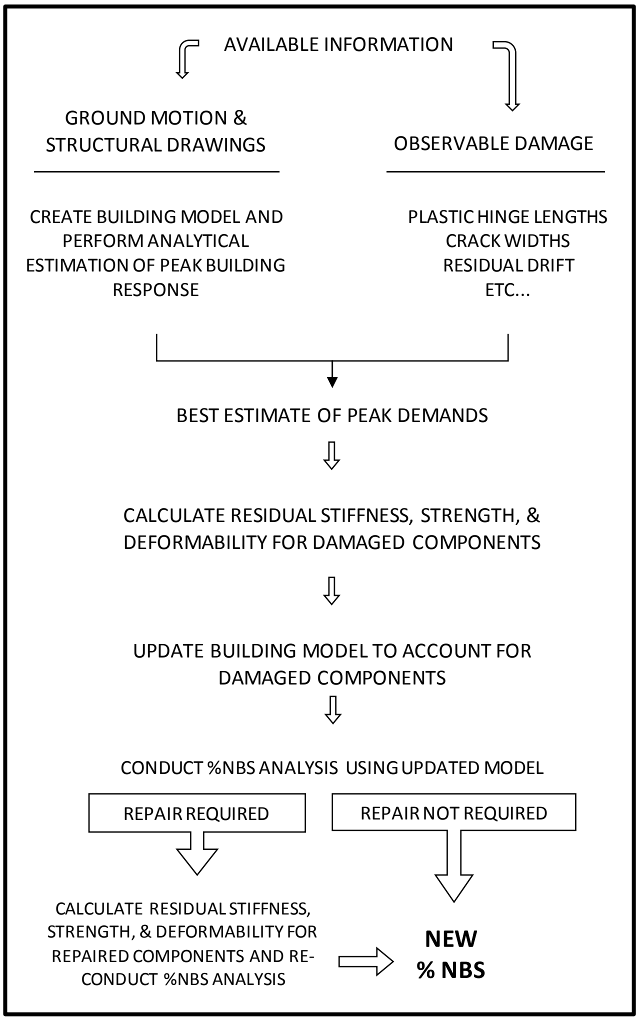


Figure 1: Proposed post-earthquake assessment methodology

As moderately damaged RC buildings that are not demolished will ultimately be repaired to some degree. This study also investigates the residual capacity of members repaired by epoxy injection. While many other repair methods are possible, epoxy injection was chosen as it is relatively consistent regardless of member type or detailing, and its effects can therefore be quantified for general use.

Experimental program

A substantial amount of research is required to make the proposed methodology practically applicable. As part of this required research, the author is conducting an experimental study that aims to increase knowledge on a number of relevant topics:

- Residual stiffness, strength, and deformability of flexural-controlled RC beams at various damage levels
- Whether or not tests with standard static cyclic loading protocols are able to accurately represent residual capacity
- The effects of variable cyclic loadings and low-cycle fatigue on the deformation capacity of plastic hinges
- The performance of epoxy injection-repaired specimens

The test program will consist of 14 identical large-scale cantilever RC beams tested under a wide variety of complex loading protocols, including monotonic, standard cyclic, pulse-type earthquake loading, and long duration earthquake loading. Five of the specimens will be repaired by epoxy injection after being subjected to a moderate damage level. Each repaired beam will have a control beam that is subject to the same initial damage level, but left unrepaired. This will allow any effects of epoxy injection on deformation capacity to be evaluated. A rendering of the test setup is shown in Figure 2.

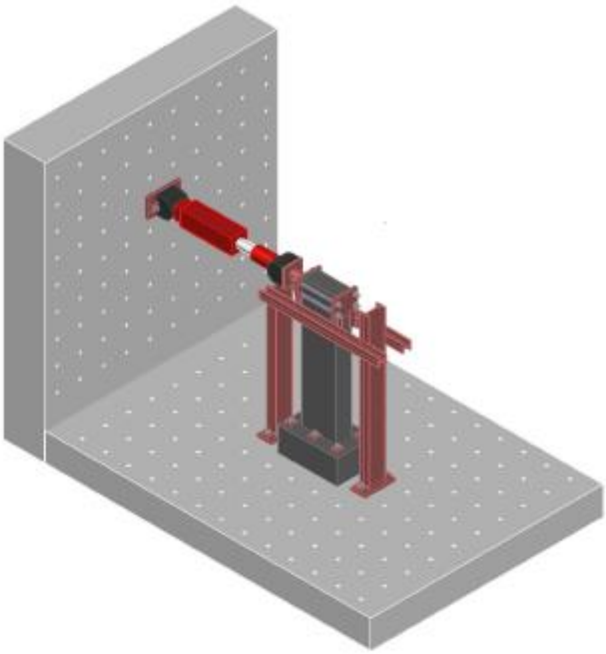


Figure 2: Rendering of test setup

Conclusions

Simple to implement methods of evaluating the residual seismic capacity of damaged RC buildings would help alleviate delays and reduce uncertainty in post-earthquake situations, allowing building owners and stakeholders to make informed decisions in a timely manner. This study aims to establish a new methodology for post-earthquake assessment and to improve understanding regarding the residual capacity of ductile reinforced concrete members.

References

Applied Technology Countil (ATC) (1998). "FEMA 306: Evaluation of earthquake damaged concrete and masonry wall buildings – Basic Procedures Manual.

Mander, J., Panthaki, F., & Kasalanati, A. (1994). "Low-cycle fatigue behavior of reinforcing steel." *Journal of Materials in Civil Engineering*, 6(4), 453-468.

Marquis, F., Kim, J.J., Elwood, K.J., & Chang, S.E. (2015). "Understanding post-earthquake decisions on multi-storey concrete buildings in Christchurch, New Zealand." *Bulletin of Earthquake Engineering*, 1-28.

Nakano, Y., Maeda, M., Kuramoto, H., & Murakami, M. (2004). "Guideline for post-earthquake damage evaluation and rehabilitation of RC buildings in Japan." *13th World Conference on Earthquake Engineering*.

Hironari Shimada
Undergraduate Student
DPRI, Kyoto University, Japan

Hironari Shimada (born 1994) is a bachelor student (B4) in Disaster Prevention Research Institute at Kyoto University and has already been admitted to the Master's degree program. Mr. Shimada graduated from the Kyoto Prefectural Sagano High School and entered Kyoto University in 2012. His research subject is development of new steel brace system called "Brace with Intentional Eccentricity". Now he is writing his graduation thesis.

Konstantinos Skalomenos
JSPS Postdoctoral Fellow
DPRI, Kyoto University, Japan

Dr Konstantinos Skalomenos is JSPS postdoctoral fellow in DPRI at Kyoto University. He graduated in 2007 from the Department of Civil Engineering, University of Patras, Greece. He received his M.Sc. in 2009 and Ph.D. in 2014 from the same University, working on the seismic design and analysis of steel and composite steel/concrete structures. In parallel, he worked in a large real-estate company as construction quality engineer of large projects. His current research interests focus in the area of earthquake engineering (development of new and innovative steel braces with high resiliency, analytical and experimental study on steel and composite steel/concrete structures, seismic assessment and rehabilitation of existing rc buildings, and damage-controlled seismic design).

A new Steel Brace: Brace with Intentional Eccentricity (BIE)

Konstantinos A. Skalomenos[1]; Hiroyuki Inamasu[1]; Hironari Shimada[1];
and Masayoshi Nakashima[1]
[1]Disaster Prevention Research Institute, Kyoto University - Japan

Introduction

The most common steel braces are the conventional buckling braces (CBBs) (Tremblay 2002). However, CBBs provide both a very large strength and stiffness which increases the base shear in the structure and leaves the foundation susceptible to overturning. Moreover, CBBs are characterized by intense local buckling in the mid-length which leads the braces to unstable energy dissipation and finally to fracture, decreasing the ductility of the system. To overcome these weaknesses, the present study proposes a new and prototype design of CBBs aimed to improve their seismic performance. The aforementioned design quantities (stiffness, strength and ductility) are naturally and simply formed by introducing along the brace length "eccentricity", *e*, as shown in Figure 1. Here, the experimental work on this new steel brace, named Brace with Intentional Eccentricity (BIE), is presented.

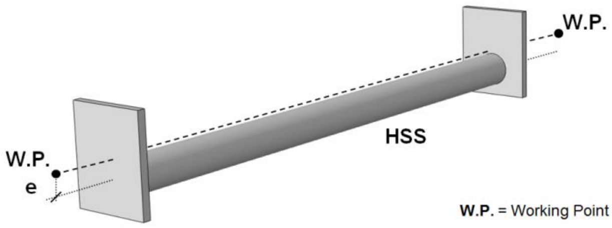


Figure 1: Configuration of the proposed steel brace (BIE)

Physical Mechanism

BIEs appear overall buckling from a small story drift. The inherent action moment caused from eccentricity affects their response and the braces sustain tri-liner behavior under tension, while under compression smoothly moving to the post-buckling behavior, as shown in Fig. 2. Furthermore, due to early overall buckling stresses and strains are uniformly distributed along the brace length, delaying the local buckling concentration in the middle cross-section, and the member's life is extended significantly, offering ductility and durability.

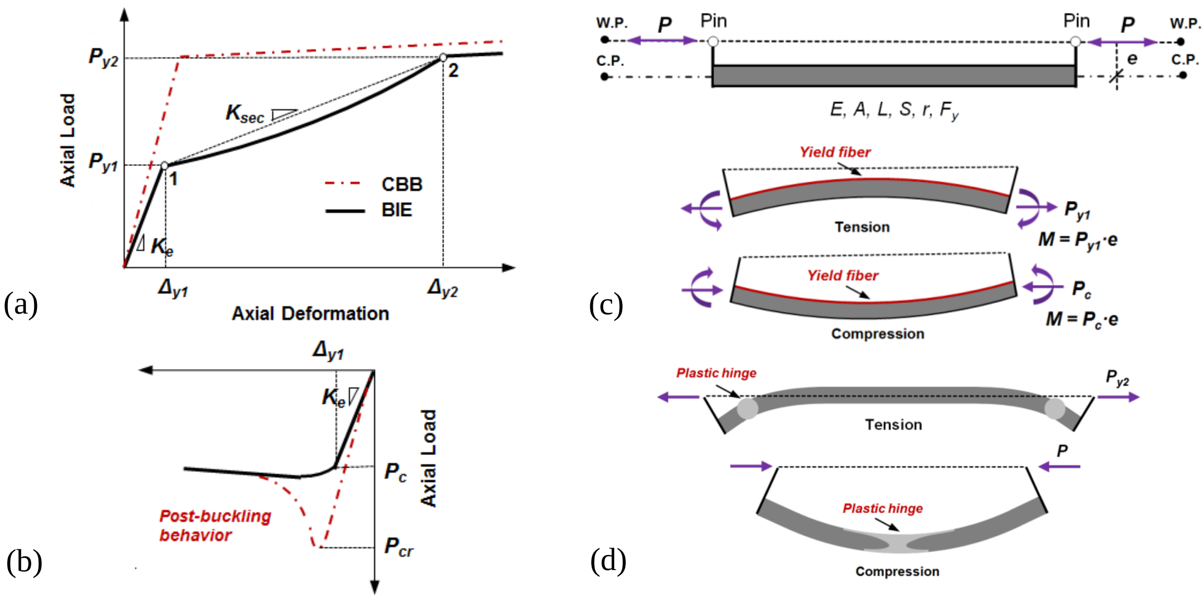


Figure 2: Backbone curve of BIE and CBB: (a) under tension; and (b) under compression. Deformed shape of brace under: (c) small; and (d) large tensile and compressive load

Experimental results

A circular hollow steel section (HSS) of 114.3mm diameter and 3.5mm thickness was adopted for the specimens made of conventional Japanese STK400 steel. The steel tube had a length 1,575 m and slenderness ratio λ = 54.40. Two specimens were tested, one conventional (CBB) and one with 60mm eccentricity *e* (BIE) using gusset plate connections (AISC 2010). The lateral loading history consisted of several drift levels (0.1~4%) with two cycles imposed at each level. Hysteresis curves are shown in Figs 3(a) and (b). The test results showed that compared with the CBB, the BIE offered 43.7% smaller stiffness and begun to dissipate energy at a force two times smaller. Due to the earlier yielding, the BIE provided very large post-yielding stiffness close to 14% of the initial stiffness, giving to the system advanced tri-

linear behavior. The brace finally achieved identical ultimate strength with the CBB at a higher story drift (3% instead of 0.4%).
Regarding the failure modes, local buckling and fracture occurred in the BIE at a drift level two times larger than CBB (2% instead of 1% and 4% instead of 2%, respectively). Figures 3(c) and (d) also shows photos with the deformation of the CBB and BIE specimens near to the middle cross-section at the 1.0% story drift angle under compression. Local buckling was occurred in CBB at this drift level combined with intense overall out-of-plane buckling, while no local buckling was occurred in BIE which had lighter and more uniform overall buckling.

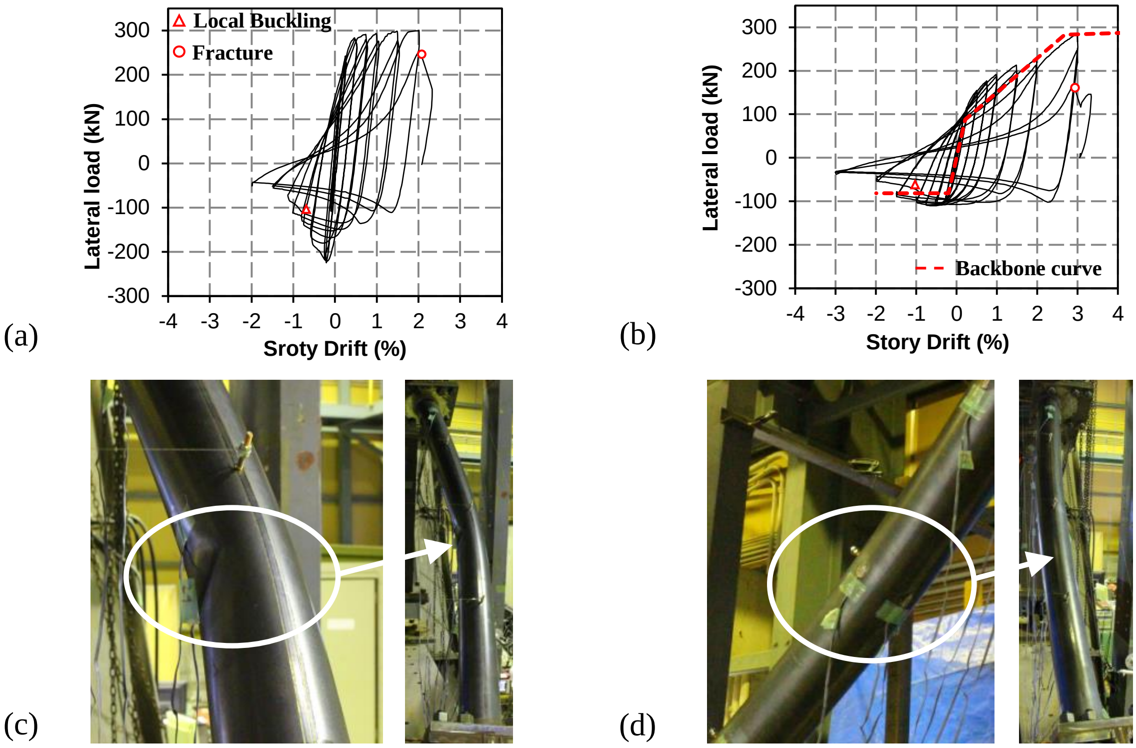


Figure 3. Hysteretic curves of (a) CBB; and (b) BIE. Under compression - drift level of 1.0%: (c) CBB; and (d) BIE.

Conclusions

An experimental study to investigate the seismic behavior of a new steel brace, named BIE, was conducted. The test results showed that the proposed steel braces overcome the negative traits of conventional steel braces and are a handy alternative for high-performance steel bracing system. A tri-linear behavior characterizes the BIE response. The BIE could achieve early yielding and therefore large post-yielding stiffness is provided, stably dissipate energy up to high drift levels delaying local buckling and fracture, and reach identical maximum strength with a CBB of same cross-section offering reduced initial stiffness.

References

Tremblay, R. (2002). "Inelastic seismic response of steel bracing members. " *Journal of Constructional Steel Research*, 8(5-8), 665–701.
AISC (American Institute of Steel Construction). (2010). Specification of structural steel. ANSI/AISC Standard 360-10, Chicago.
Bio and abstract of Shahab

Shahab Ramhormozian
PhD Student
University of Auckland, Auckland, New Zealand

Shahab Ramhormozian is a PhD student in Structural/Earthquake Engineering at the University of Auckland (UoA), Auckland, New Zealand. He earned his Bachelor in Civil Engineering, followed by his Master in Structural Engineering from Sharif University of Technology, Iran. His research topic, under the supervision of Associate Professor Charles Clifton, is the Sliding Hinge Joint Connection with Belleville Springs. His research activities are focused on analytical, experimental, and numerical investigations on the Sliding Hinge Joint, aimed at improving its post earthquake strength and stiffness and ability to dynamically self centre the structure.

Enhancing the Seismic Performance of the Sliding Hinge Joint Using Belleville Springs

S. Ramhormozian[1], G.C. Clifton[1]
[1]Department of Civil and Environmental Engineering, University of Auckland, Auckland – New Zealand

Introduction

The Sliding Hinge Joint connection (SHJ) is a low damage alternative to the traditional beam-column welded connections of the seismic Moment Resisting Steel Frames (MRSFs). The SHJ was initially proposed and developed from 1998 to 2005 by Clifton (2005) and has been further developed at the Universities of Auckland and Canterbury. The SHJ is intended to behave as a rigid beam-column connection under the serviceability limit state (SLS) condition. Under the ultimate limit state (ULS) condition, the SHJ is expected to allow large beam to column inelastic relative rotation through stable sliding in its key energy dissipating components i.e. the Asymmetric Friction Connections (AFCs). Figure 1 shows the SHJ layout.

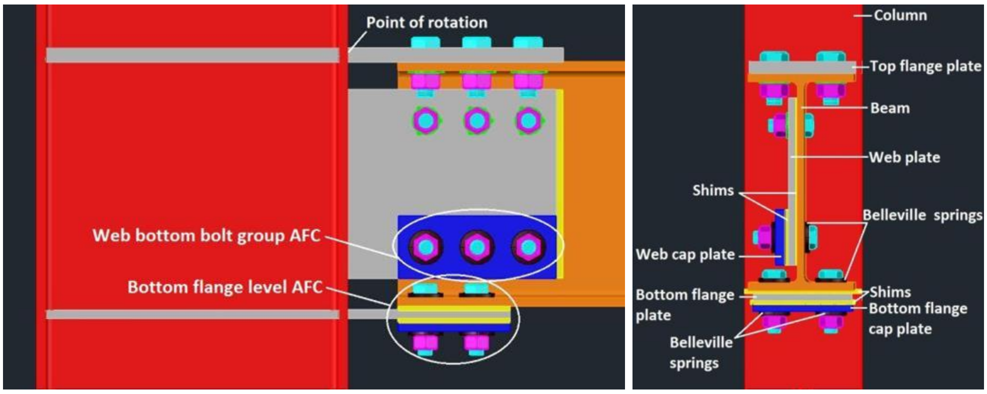


Figure 1. The SHJ layout: lateral view (left) and cross sectional view (right)

The AFCs are located in the bottom web and bottom flange bolt groups. A top flange plate is bolted to the beam top flange, and the SHJ point of rotation is where this top flange plate is pinned to the column. The main benefits of the SHJ are; isolating the floor slab to limit additional demands to the beam, column, and slab under inelastic rotations; decoupling joint strength and stiffness to limit inelastic demands in the beams and columns; and confining yielding to the bolts. However, the latter is being researched to ideally be avoided, thus eliminating the need to retighten or replace bolts following a severe earthquake.

This paper reports the results of the past research and presents a future plan of the ongoing research to improve the seismic behaviour of the SHJ.

Using Belleville springs in the SHJ

Experimental testing has shown that during sliding, the AFC bolts lose part of their installed tension when stable sliding is reached (Khoo, Clifton et al. 2012), causing the AFC to commence sliding in a less intense subsequent excitation. This is principally because the bending moment combines with the bolt installed tension to partially plasticize the bolt. The prying of the cleat can also over stretch and plasticize the bolts during sliding. Finally, the abrasion of the sliding surfaces makes the post sliding grip length slightly shorter, causing the bolt tension to drop.

To reduce this post sliding AFC bolt tension loss, the use of Belleville springs (BeSs) was proposed along with installing the bolts in their elastic range (Ramhormozian, Clifton et al. 2014). Belleville springs are very high strength, truncated conical washers which have a defined elastic stiffness when loaded and a defined squash load when fully compressed. They are a standard component in many mechanical engineering applications to maintain installed bolt tension. When the AFC bolt is subject to stress relaxation due to creep in service, or, more significantly, stress reduction during sliding due to being plastically stretched and/or becoming shorter due to the cumulative thickness of the plates and shims decreasing, the BeS pushes out to maintain most of the installed level of tension.

The optimum level of bolt tension as well as the optimum configuration of the BeSs has been being determined in this research. It has been also shown that the use of BeSs can improve the self-centring capability of the SHJ by increasing the self-centring ratio (Ramhormozian, Clifton et al. 2015). These concepts have been being experimentally, analytically, and numerically developed and established by the authors (Ramhormozian, Clifton et al. 2015; Ramhormozian, Clifton et al. 2015).

SHJ Dynamic Component Tests with and without Belleville Springs with the Bolts Installed in the Elastic Range

A test rig (Figure 2) has been used to test the sliding characteristics of the SHJ bottom flange AFC assemblage. It consists of a reaction arm hinged to a strong wall at A, a ±300 kN actuator applying the dynamic displacement controlled load at B, and the test specimen mounted at C. The test setup is actually an inverted configuration of the SHJ, with the point of rotation at bearing A, and C is representing the bottom flange plate. The motion of the reaction arm and the specimen simulates the rotational characteristics of the SHJ.

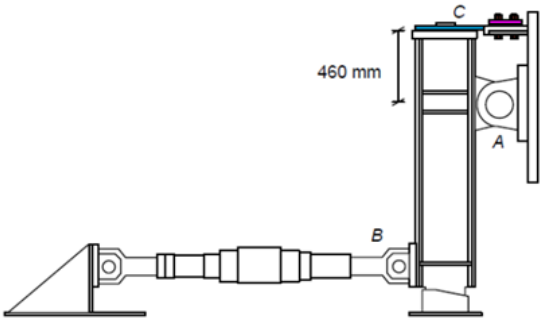


Figure 2. The AFC test rig

50% of the HSFG property class 8.8 M20 bolt proof load was considered as the installed bolt tension. Five different configurations were designed for the BeSs i.e. NS, S1, S2, S3, and S4 representing having no BeS, and having one, two, three, and four BeSs in series. Nine tests were carried out including three tests on NS, one test for each one of S1, S2, and S3, and three tests on S4 configurations. The specimens were tested with a displacement controlled quasi-static/dynamic load regime.

It was shown that BeSs can significantly reduce the bolt tension loss if they are used in the most effective way. The greater the squash load deflection of the BeS stack, the lower the loss of installed bolt tension, however the greater the cost and complexity of installation, so an optimum point where these two factors intersect needed to be found.

Figure 3 demonstrates the AFC system coefficient of friction, μ, calculated for the cases with no BeSs "NS" and with four BeSs "S4" respectively plotted with the same scale, each one for three test repeats. These show the higher coefficient of friction and the considerable improvement in the joint self-centring capability introduced by the BeSs. This effect is expected to be much more helpful for the joint self-centring capability while the BeSs are used in a whole SHJ including two AFCs with BeSs and more sources of restoring elastic energy such as floor slab out of plane strength and stiffness, continuous elastic columns, and elastic column bases.

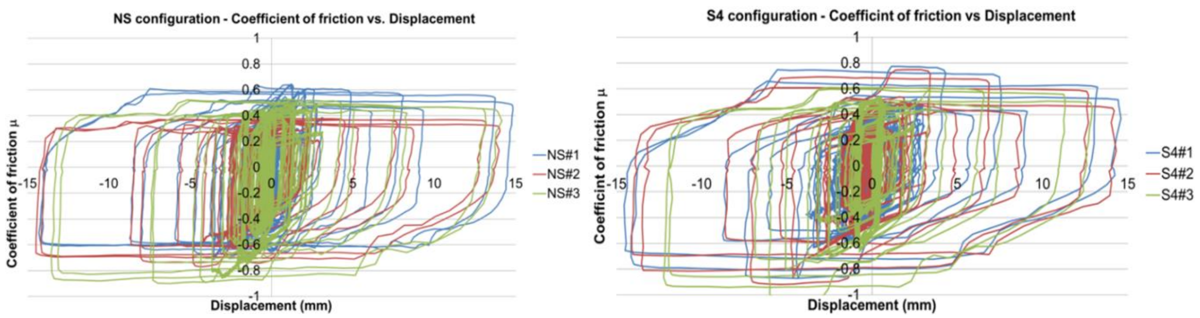


Figure 2. AFC sliding surfaces coefficient of friction, μ left) without BeSs "NS", right) with BeSs "S4"

An AFC test setup was also designed to be used on a 500kN MTS machine and an associated research investigated the correlation between the surface preparation levels and roughness values as well as the effect that surface preparation has on the sliding behaviour of the AFC in the SHJ (Figure 3). This was carried out through 27 AFC component tests on the MTS.

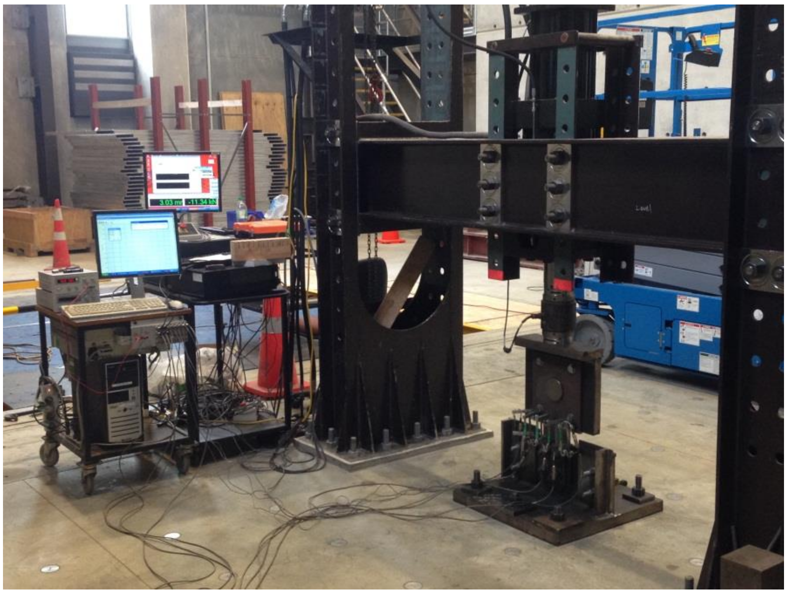


Figure 3. The AFC on MTS test setup

Conclusions and ongoing research

This paper provided a brief review of the SHJ, AFC, and their ongoing developments. The SHJ is a low-damage beam-column connection that confines inelastic demand to the AFCs' bolts. The aim of the current research is to minimize this inelastic demand.

It is shown that BeSs can considerably reduce the post sliding bolt tension loss in the AFC. Using BeSs reduces the sensitivity of the AFC bolts to the factors of the bolt tension loss, meaning that the post sliding bolt tension variability between bolts in a given AFC incorporating the BeSs will be much less than the variability in an AFC with no BeS. This will provide the SHJ with much more consistent and predictable seismic behaviour. Installing the BeSs in not flattened state provides a degree of flexibility under the bolt head and or nut causing to considerably reduce the possibility of the bolt to be plastically stretched. It is also beneficial from the SHJ self-centring point of view.

A set of experiments have been carried out to investigate the effects of the surface roughness, on the AFC sliding behaviour. A set of bolt tightening tests have also been carried out to establish the method of bolt tightening with BeSs. The following areas of research are currently being carried out by the authors:

- A finite element model of the AFC has been being developed using the ABAQUS software with the aim of redesigning the current SHJ component test rig.
- The AFC component tests on the MTS machine to establish the optimum level of installed bolt tension.
- The SHJAFC component tests using customized BeSs designed by the authors to be fit for purpose. This is to establish the optimum way of using BeS in the SHJAFC.
- The SHJAFC component tests using three rows of bolts instead of the current two rows of bolts being implemented in practice.
- The analytical and numerical research on the use of linear springs such as Lurethane spring to establish the design of the linear springs to make the SFC as well as AFC

statically and dynamically self centre. This will result in designing the required block of the Lurethane spring to develop the self-centring Sliding Hinge Joint (SCSHJ).

- A large scale test setup of the SHJ is being planned to be designed to investigate the SHJ behaviour with BeSs, Lurethane springs, and contribution of the floor slab.

References

Clifton, G. C. (2005). Semi-rigid joints for moment-resisting steel framed seismic-resisting systems. PhD, University of Auckland.

Khoo, H. H., C. Clifton, et al. (2012). "Development of the self-centering Sliding Hinge Joint with friction ring springs." Journal of Constructional Steel Research 78: 201-211.

Ramhormozian, S., G. Clifton, et al. (2014). The Asymmetric Friction Connection with Belleville springs in the Sliding Hinge Joint. NZSEE, Auckland, New Zealand.

Ramhormozian, S., G. C. Clifton, et al. (2015). Improving the seismic behaviour of the Sliding Hinge Joint using Belleville Springs. 8th Conference on Behaviour of Steel Structures in Seismic Areas (STESSA). Shanghai, China.

Ramhormozian, S., G. C. Clifton, et al. (2015). The optimum use of Belleville Springs in the Asymmetric Friction Connection. 8th Conference on Behaviour of Steel Structures in Seismic Areas (STESSA). Shanghai, China.

Claudio Cappellaro
PhD Student
University of Canterbury, Christchurch, New Zealand

Claudio Cappellaro (born 1989) is a PhD candidate (D2) in Earthquake Geotechnical Engineering at the University of Canterbury (UC), Christchurch, New Zealand. He earned both his Bachelor in Civil Engineering and his Master in Environmental Engineering from the University of Udine, Italy. In 2015, as a part of his PhD study, he was a Visiting Student Researcher at the University of California at Berkeley, USA. His main research interest is soil liquefaction and related problems, and currently his experimental research work is about investigating the undrained cyclic behaviour of fines-containing sandy soils.

Undrained Cyclic Response of Sandy Soils from Simple Shear Tests

C. Cappellaro[1], M. Cubrinovski[1], G. Chiaro[1], J.D. Bray[2], M.F. Riemer[2]
[1]Department of Civil and Natural Resources Engineering, University of Canterbury - New Zealand
[2]Department of Civil and Environmental Engineering, University of California, Berkeley - US

Introduction

Earthquake-induced liquefaction damage is one of major seismic hazards in New Zealand, and it is responsible for significant socio-economic costs. For instance, soil liquefaction can be accounted for some of 50% of the NZ$ 40 billion of direct losses caused by the 2010-2011 Canterbury Earthquake Sequence in Christchurch city and its surroundings, where severe damage to road and bridge infrastructures, residential houses, commercial buildings, lifeline facilities and levees was widely observed (Cubrinovski et al., 2014). Due to the severe impact on people, built and natural environments, a key requirement in the immediate future in NZ is to gain a better understanding of the susceptibility to liquefaction of natural silty sand deposits.

On this purpose, an experimental research program is currently undertaken at UC, by which the cyclic undrained response of silty sands retrieved from Christchurch will be evaluated by means of direct simple shear tests while focusing on the effects of fines content, fabric and structure. The study makes use of a state-of-the-art direct simple shear device, whose performance is currently being assessed before proceeding with the liquefaction testing program.

Theoretical background

The term *liquefaction* refers to a partial or complete loss of stiffness and strength following the development of excess pore water pressure induced by monotonic or repeated (cyclic) shear loading.

Early research on soil liquefaction essentially focused on loose clean sands (i.e. fines content less than 5%) as the first well-documented case histories reported on this type of soils (Seed, 1979). Nowadays most of the data available for lateral spreading and flow failure involve sands with fines rather than clean sands (Cubrinovski and Ishihara, 2000), but the mechanics of liquefaction triggering and its consequences for fines-containing soils remains much less understood than that of clean sands.

Usually, laboratory studies on soil liquefaction have been performed using the triaxial apparatus because of its widespread availability. Subsequently, a method for converting triaxial test results to simple shear conditions has been introduced. However, it accounts only for the difference in the stresses applied to a typical soil element and does not reflect the actual soil deformation mode when subjected to horizontal earthquake shaking (Figure 1):

$$\left(\frac{\tau_{cyc}}{\sigma_v'}\right)_{field} = \frac{1+2K_0}{3}\left(\frac{|\sigma_c' - \sigma_a'|}{2\sigma_c'}\right)_{TX} \tag{1}$$

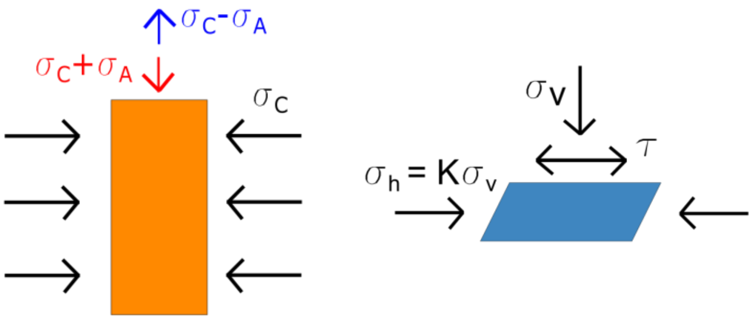


Figure 1: Loading conditions in triaxial (left) and simple shear (right) conditions.

Although it has been shown that this procedure tends to be conservative (Tatsuoka et al., 1986), triaxial testing conditions are very far from the actual stress conditions found in the field during an earthquake. Calibration of advanced constitutive models for numerical modelling of soil response during earthquakes should therefore be based on other more appropriate laboratory tests, namely simple shear tests.

Most of the current knowledge on soil liquefaction derives from tests on reconstituted specimens prepared with the techniques of moist tamping or dry pluviation. However, measures of liquefaction resistance are sensitive to the mutual arrangements of particles (*soil fabric*), which in laboratory tests depends on the employed method of specimen preparation. The water sedimentation technique produces a fabric closer to that of fluvial soil deposits like those found in Christchurch (Vaid and Sivathalayan, 2000). Moreover, it enables one to obtain a layered structure analogous to that resulting from segregation in natural depositional processes, which affects the stress-strain response of soils as well (Verdugo et al., 1995).

Experimental program and preliminary tests

In this study, cyclic simple shear tests will be performed on silty sandy soils from Christchurch using a direct simple shear device, namely UCB 1D-DSS, which is capable of testing saturated specimens in effectively undrained conditions. This is a major feature of the employed device, as most of the direct simple shear tests described in the literature are of the "constant volume" type and are carried out in drained conditions (e.g. Vaid and Sivathalayan, 2000). The response of undisturbed specimens collected with the Gel-Push and Dames &

Moore samplers will be compared with that of specimens reconstituted by water sedimentation, in order to investigate the effects of fines content, fabric and structure. Moreover, comparisons made against cyclic triaxial tests will provide an indication on the influence of different modes of loading. The results of this experimental campaign will be used for the subsequent modelling of the numerical response of these soils within an effective stress analysis framework.

The UCB 1D-DSS has been recently subject to upgrades, most noticeably the installation of a closed-loop control software for running automated monotonic and cyclic stress and strain-controlled tests. For this reason, an assessment of the capabilities of the automated control system is currently being undertaken. This will be followed by a preliminary series of cyclic simple shear tests on the idealised Monterey 0/30 sand (e_{max}=0.885, e_{min}=0.541; G_s=2.64 – Kammerer, 2002). In these tests, simple shear conditions will be achieved either by imposing a constant specimen height or by varying the confining pressure while keeping a constant vertical stress. Medium dense specimens (D_R=60%) of 61.5 mm in diameter, 15 mm in height will be used, and suitability of plain latex membranes and wire-reinforced membranes will be checked. These trial tests are necessary to evaluate the best experimental setup for subsequent tests on natural silty sands retrieved from Christchurch.

Conclusions

Improvement of current knowledge on soil liquefaction behaviour requires a better understanding of how the response to seismically-induced loadings of sandy soils is influenced by content of fines, soil fabric and structure. This is pursued in the present study by means of laboratory tests using the state-of-the-art UCB 1D-DSS device. Evaluation of equipment capabilities and of experimental procedures is currently being performed, and they will be followed by a comprehensive series of liquefaction tests on native soils from Christchurch.

References

Cubrinovski, M., Taylor, M., Robinson, K., Winkley, A., Hughes, M., Haskell, J., Bradley, B., Bray, J. D., O'Rourke, T. D., and Wotherspoon, L. "Key Factors in the Liquefaction-Induced Damage to Buildings and Infrastructure in Christchurch: Preliminary Findings " *Proc., 2014 NZSEE.*

Cubrinovski, M., and Ishihara, K. (2000). "Flow Potential of Sandy Soils with Different Grain Compositions." *Soils and Foundations*, 40(4), 103-119.

Kammerer, A. M. (2002). "Undrained Response of Monterey 0/30 Sand under Multidirectional Cyclic Simple Shear Loading Conditions."PhD Thesis, University of California, Berkeley, CA, USA.

Seed, H. B. (1979). "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground during Earthquakes." *Journal of the Geotechnical Engineering Division*, 105(2), 201-2055.

Tatsuoka, F., Ochi, K., Fujii, S., and Okamoto, M. (1986). "Cyclic Undrained Triaxial and Torsional Shear Strength of Sands for Different Sample Preparation Methods." *Soils and Foundations*, 26(3), 23-41.

Vaid, Y. P., Sivathayalan, S. (2000). "Fundamental Factors Affecting Liquefaction Susceptibility of Sands." *Canadian Geotechnical Journal*, 37, 592-606.

Verdugo, R., Castillo, P., and Briceño, L. (1995). "Initial Soil Structure and Steady State Strength." *1st International Conference on Earthquake Geotechnical Engineering*, K. Ishihara, ed.Tokyo, Japan, 209-214.

Francesca Barbagallo
PhD Student
University of Catania, Catania, Italy

Francesca Barbagallo (1989) is a second year Ph.D candidate in "Assessment and mitigation of urban and territorial risks" at the Department of Civil engineering and Architecture of University of Catania. She took her Master degree in Building Engineering and Architecture at University of Catania in 2013, with the degree thesis titled "Design of Buckling Restrained Braces for the seismic retrofitting of r.c. frames". Her current research topic deals with the assessment of the seismic behaviour of existing structures by nonlinear static methods of analysis. Since May 2015, as a part of her Ph.D studies, she is a visiting student researcher at DPRI (Kyoto University, Japan) where she works on the experimental and numerical investigation of the lubricated free-standing structure.

Ikumi Hamashima
M1 student
Kyoto University, Kyoto, Japan

Ikumi Hamashima (1992) is a first grade student of Master course at the department of architecture and architectural engineering in Kyoto University. She has belonged to Nakashima-Kurata Lab. and studied about Free Standing Structure (FSS), which can decrease the damage of structure by slipping against the foundation under huge earthquake since 2014. In 2015, she obtained her Bachelor of Architectural Engineering at Kyoto University under the guidance of Professor Nakashima and Professor Kurata. After she entered into Master course, she continues to research about FSS. This September she is supposed to research in Catania University, Italy. Her heart is filled with expectation and she cannot wait for this September.

Investigation of the dynamic behaviour of free-standing structure with graphite lubrication

F. Barbagallo[1], I. Hamashima[1], H. Hu[1]
[1]Disaster Prevention Research Institute, University of Kyoto, Kyoto, Japan

Introduction

Strong earthquakes generally cause the most severe damage to the columns of the first floor. Base-isolation is recognized as one of the most effective means to prevent the seismic damage of the superstructure. However, it requires the use of isolating devices installed at the isolation floor, which need more construction work and additional costs. An alternative and promising technique is represented by the Free-Standing Structure (FSS). In this system the columns are detached from the foundation and can slide on their supports in case of strong earthquakes. The slippage of the structure reduces the shear forces applied to the superstructure, which are controlled by the friction coefficient of the sliding surface. A proper and stable value of the friction coefficient has to be ensured to prevent both the damage in the superstructure and the untimely slippage. For this reason it is proposed and investigated an innovative and handy method which uses a steel base to slide on a mortar surface covered by graphite powder.

Two sets of shaking table tests were conducted (i) to examine the dynamic behaviour of the free-standing structure, (ii) to investigate the properties of the carbon powder lubrication and (iii) to verify the efficiency of the FSS applied to frames with realistic features.

Theoretical background and basic behaviour

The superstructure and the lower structure of the FSS (Figure 1 a) can be modelled by two masses, m_t and m_b respectively, connected by two springs of stiffness $k/2$ and a dashpot of damping c (Figure 1 b). The friction force develops between the sliding base and the rigid horizontal base, and the static friction force F_μ is equal to μN, where μ is the friction coefficient of the sliding surface and N is the total normal force ($N=g(m_t + m_b)$).

The basic dynamic behaviour of the FSS distinguishes two main states: the *stick phase* and the *sliding phase*. If the sliding friction force f does not overcome the static friction force F_μ the sliding does not occur. The system is in the *stick phase* and behaves as a fixed base structure with natural frequency ω_n and damping ratio ξ. Thus, the non-sliding condition can be expressed as follows:

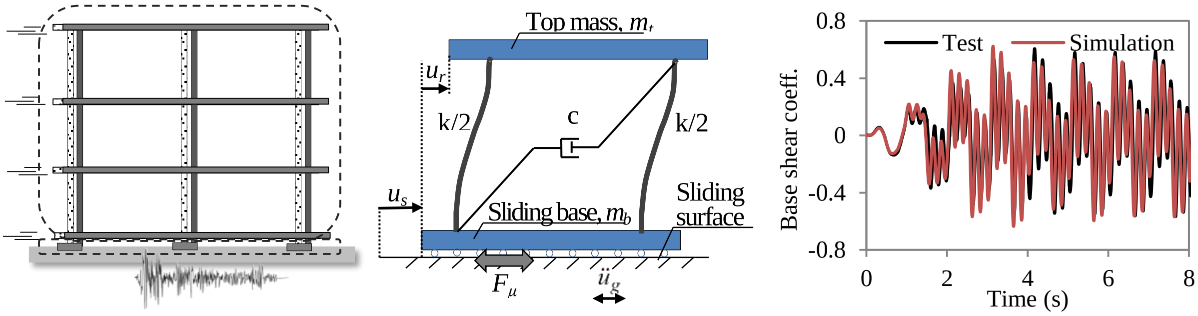
$$f \le (m_t + m_b)\mu g \tag{1}$$

When the previous condition is no longer satisfied, the sliding occurs and the FSS falls into the *sliding phase*. In such case, the base mass m_b experiences a constant friction force of magnitude equal to μN, and the response characteristics of the FSS change compared to those of the fixed base structure. Due to the slippage, the structure experiences a new "internal" sliding frequency ω'. This is larger than ω_n and causes the smaller oscillations shown in the base shear coefficient time history. Furthermore, the structure shows a new damping ratio ξ' larger than ξ. Both the quantities are related to those of the *stick* by means of the mass ratio α as follows:

$$\omega' = \frac{\omega_n}{\sqrt{1-\alpha}} \quad \xi' = \frac{\xi}{\sqrt{1-\alpha}} \quad \alpha = \frac{m_1}{m_1 + m_2} \tag{2}$$

Experimental test

Two types of superstructures were designed for the shaking table tests. The first type is referred to as short specimens. It consisted of two horizontal steel frames connected by ten rubber bearings (Figure 1 (a)) and three mass ratios were simulated: 0.49, 0.65 and 0.79. The second type of superstructure is referred to as tall specimens, which are one-storey one-bay



a) b) c)

Figure 3. Model of the free-standing structure and base shear coefficient time history

a) b) c)

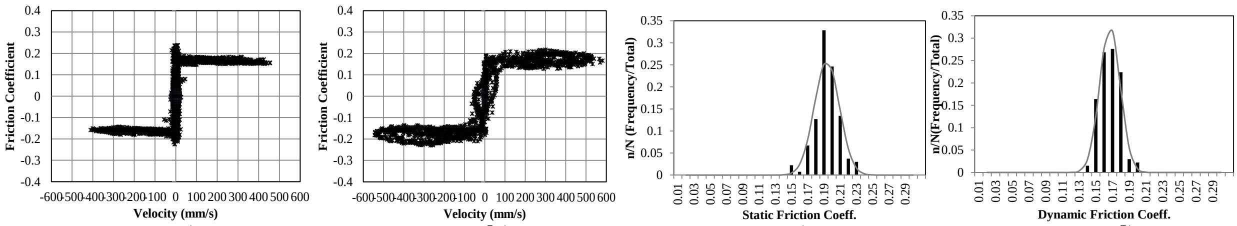
Figure 4. Pictures of the shaking table test: (a) Test 1: short specimen (b,c) Test 2: tall specimen

three-dimensional steel frames. Two geometric configurations (TBB in Figure 1(b) and TTB in Figure 1(c)) with an emphasis on the locations of horizontal beams were considered. The mass ratio α achieved for both the tall frames is close to 0.9. Beneath each corner of every superstructure there was a steel element sliding on the mortar surface lubricated with graphite powder. The loading protocol of each specimen included four sinusoidal input motions with different frequencies and three natural accelerograms (ElCentro, JMA Kobe NS and JMA Kobe EW), applied with increasing magnitudes.

Test results

Figure 3 shows the friction coefficient vs. velocity relationship for one short specimen (a) and one tall specimen (b). For low values of velocity, the structure is in the *stick phase* and the friction coefficient is defined *static* friction coefficient μ_s. Thanks to the graphite lubrication, the maximum static friction coefficient between steel and mortar is reduced from 0.78 [1] to 0.2. When the structure falls in the *sliding phase* the friction coefficient decreases to the dynamic friction coefficient μ_d, which does not show a strong dependence on the velocity. Among all the 134 tested input cases, μ_s and μ_d showed a mean value of 0.188 and 0.162 respectively, with a corresponding standard deviation of 0.02 and 0.012. Thus, the graphite lubrication provided a stable behaviour and a great robustness, regardless of the number of sliding cycles, the features of the mortar surfaces and the characteristics of the superstructures.

From the experimental results, the FSS showed an efficient behaviour. Although the tall specimens experienced a larger overturning moment, the rocking did not occur since the axial force in columns never became lower than the gravity load. The main advantage provided by the FSS system is the limitation of the maximum base shear C_b transmitted to the superstructure. Differently from the fixed base structure, larger input magnitudes lead the base shear coefficient of the FSS towards an upper limit, whose value decreases for increasing



a) b) c) d)

Figure 3. Friction coeff. vs. sliding velocity for SF-3 (a) and TBB (b)specimens. Distribution of the static (c) and dynamic (d) friction coefficient

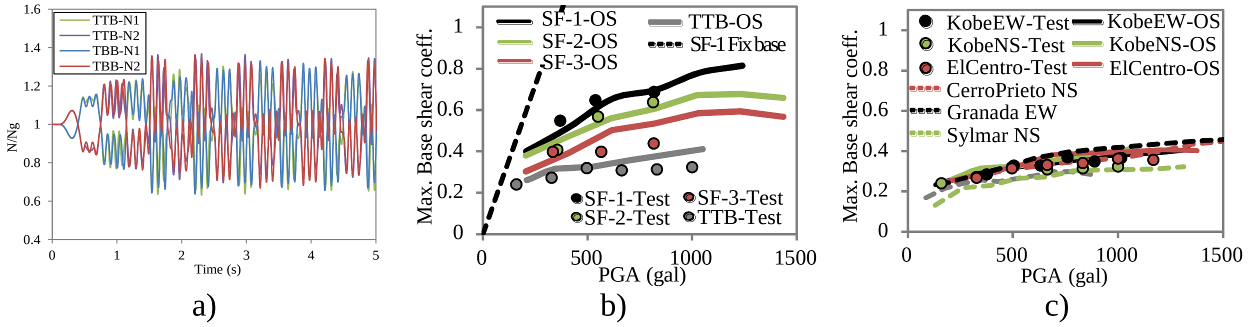


Figure 4. (a) Experimental axial force time history of two front columns of TBB and TTB. Max base shear coeff. vs. PGA for all specimens under KobeNS (b) and for TTB under different earthquake motions (c)

mass ratios. This may be explained referring to Eq. (2). There, larger mass ratios lead to larger damping ratios ξ', which reduce the level of the maximum acceleration response. Thanks to the upper limit of C_b, the rocking behaviour can be prevented ensuring that the aspect ratio *h/b* be lower than $1/(2C_{b,max})$. More realistic frames have a value of α close to 0.9 and the corresponding maximum base shear coefficient was found close to 0.4. This makes the FSS a suitable and promising technique for the seismic retrofitting of existing r.c. frames.

Conclusions

Experimental results showed an efficient behaviour of the FSS showed. Even if more than 1500 loading cycles were applied, the dynamic friction coefficient showed a stable value at an average of 0.16 with a maximum standard deviation of 0.048. The overturning moment did not show significant influence to the overall behaviour and thanks to the slippage, the base shear of the superstructure had an upper limit, which was lower than the base shear of the fixed base structure.

References

1. McCormick J, Nagae T, Ikenaga M, Zhang P, Katsuo M, Nakashima M. Investigation of the sliding behaviour between steel and mortar for seismic applications in structures. *Earthquake Engineering and Structural Dynamics* 2009; 38: 1401-1419
2. Enokida R, Inami M, Nakashima M, Nagae T, Ikenaga M, Development of Free-Standing Steel structure using kinematic friction of steel-mortar. Proceedings of 15 WCEE 2012
3. Mostaghel N, Hejazi M, Tanbakuchi J, Response of sliding structures to harmonic support motion. *Earthquake Engineering and Structural Dynamics* 1983; 11: 355-366

Hiromichi Nishino
Master 1st Student
Kyoto University, Kyoto, Japan

Hiromichi Nishino (born 1991) is a master student in Architectural Engineering at Kyoto University, Kyoto, Japan. He earned his Bachelor in Engineering at Kyoto University in 2015. His research topic is Structural Health Monitoring to detect and quantify the local damage and estimation of the residual capacity of the frame. For his graduate thesis, he designed and conducted a shake table test using a 3-story steel frame in 2014. Currently he works on verification of the accuracy of estimation for residual strength of damaged substructure.

Thomas Matarazzo
JSPS Postdoctoral Research Fellow
DPRI, Kyoto University, Kyoto Japan

Thomas Matarazzo was born in New Brunswick, New Jersey, USA in 1988. In 2010, he graduated Summa Cum Laude with a B.S. in Civil Engineering from Manhattan College in New York City. Later that year, he began graduate school at Lehigh University in Pennsylvania, where he did research under the supervision of Prof. Shamim Pakzad. At Lehigh, he received an M.S. degree in 2012 and a Ph.D. in 2015 for his work "A Framework for the Use of Mobile Sensors In System Identification". In the summer of 2015, he joined Nakashima-Kurata lab for the NSF EAPSI program, where he officially returned as a JSPS postdoc last October. He is interested in system identification, damage detection, mobile sensors, big data, and the intersection of data and information.

Structural Health Monitoring: Extracting Infrastructure Information from Sensor Data

H. Nishino[1], T.J. Matarazzo[2], M. Kurata[2]
[1]Department of Architecture and Architectural Engineering, Kyoto University, Kyoto, Japan
[2]Disaster Prevention Research Institute, Kyoto University, Kyoto Japan

Introduction to Structural Health Monitoring (SHM)

Structural systems are engineered to achieve particular criteria based on their function, location, and the design team. However, their true behavior is heavily influenced by the interaction of numerous random processes in the physical world. It is therefore desirable to measure and analyze responses of constructed infrastructure so that their intended performances may be verified. Structural health monitoring (SHM) encompasses sensing devices for data collection and targeted analysis methods. Modern SHM goals have focused on three broad areas: (i) system identification; (ii) damage detection and localization; and (iii) model updating. This paper briefly discusses the application of these disciplines to a three-story steel frame specimen (pictured in Figure 1) which was designed and assembled at DPRI.

Subsequent sections consider measurements collected from this specimen, using sensors such as strain gauges, displacement transducers, accelerometers, and polyvinylidene difluoride (PVDF) sensors (dynamic strain gauges) (Kurata et al. 2013) in various loading conditions.

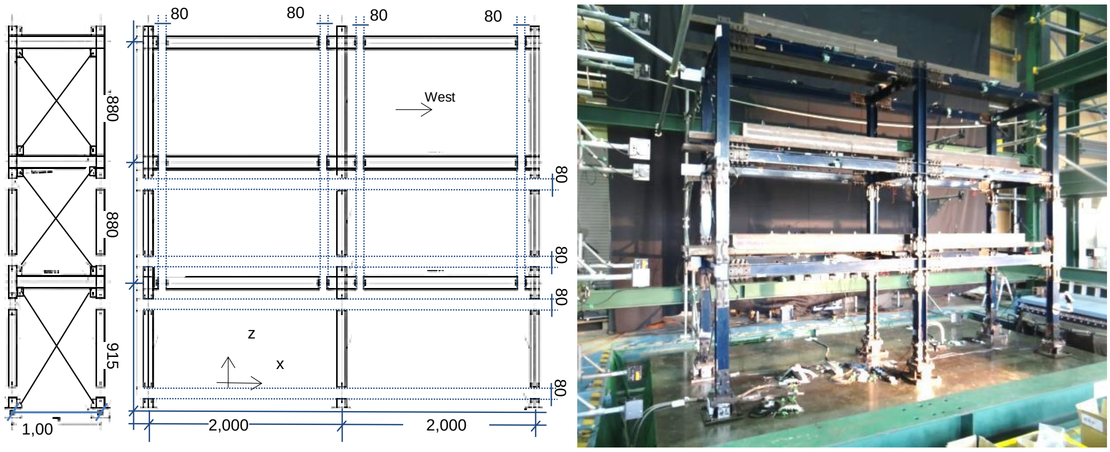


Figure 1. Schematic and photograph of the scaled three-story steel frame specimen at DPRI

System Identification

System identification (SID) is the process of estimating structural modal properties from measured response data. If dynamic loading is also measured, the SID is classified as an input-output method. More frequently, in operational conditions, the input force cannot be recorded; these SID methods are output-only. SID methods vary greatly in complexity, computational efforts, and accuracy. The simplest SID methods are “peak-picking” techniques such as *Frequency Domain Decomposition*, in which the frequency and damping properties are selected directly from a power spectral density estimate, e.g., a Fourier transform. More sophisticated SID methods are often embedded within a mathematical time-series model, e.g. autoregressive model or the state-space model. With model-based methods, structural mode shapes may also be estimated. Figure 2 provides output-only SID results for the three-story frame using the STRIDE method (Matarazzo & Pakzad 2016).

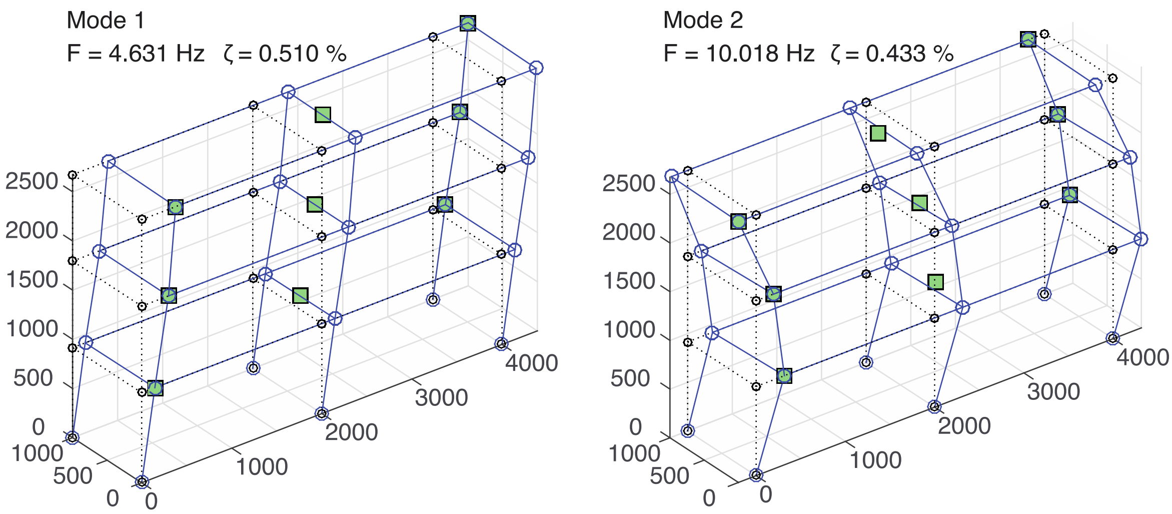


Figure 2. First two horizontal vibration modes identified from nine accelerometers; the structure was excited with white noise at the third story by a modal shaker

Damage detection

Damage detection methods have been developed to determine the presence of damage, quantify damage severity, and/or pinpoint the damage location. Some damage detection techniques embed statistical principles and incorporate time-series models while others do not. A prerequisite for all damage detections methods is the acquisition of data from an undamaged "healthy" structure. The Damage Index (DI) is a damage metric developed at DPRI (Li et al. 2015) which excels at quantifying beam-column damage from PVDF sensor measurements; its performance has been verified analytically and demonstrated experimentally. When a beam-end becomes damaged, the bending moment is decreased. The ratio of the undamaged and damaged bending moments is equivalent to DI, a ratio of corresponding dynamic strain root-mean-square (RMS) values, which can be determined from PVDF data. With one sensor near the fractured beam-end and another at an undamaged reference point, damage severity can be quantified. Figure 3 displays the relationship between DI and a reduction in the moment of inertia at the damaged section, caused by connection fracturing; DI is equal to 0% at the undamaged state and -100% at complete fracture.

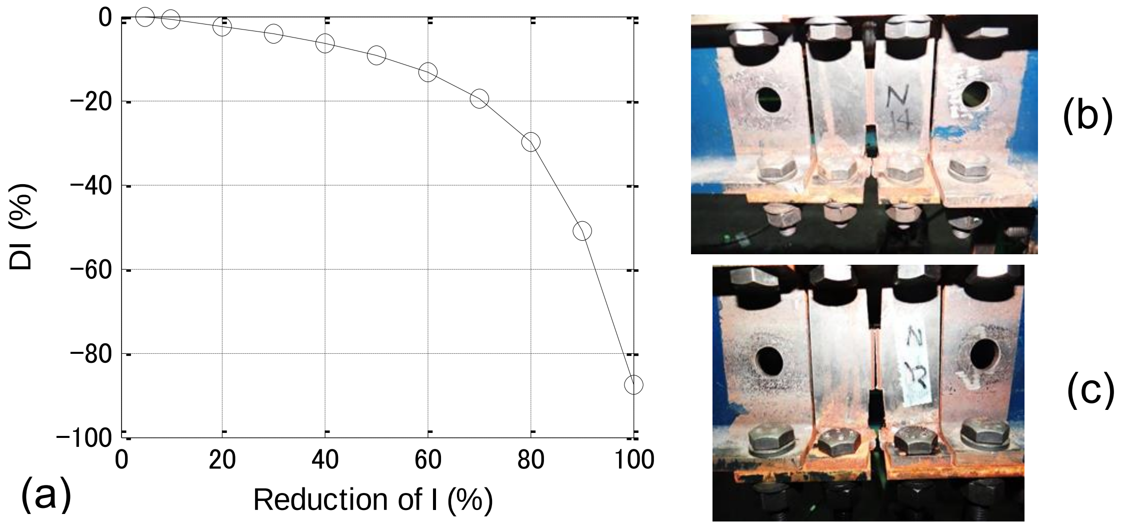


Figure 3. (a) Relationship between DI and moment of inertia; observed damage link fractures at the (b) bottom flange; and (c) web

Model updating and residual capacity estimation

Model updating is a technique to include new information from field measurements into a mathematical model, e.g., finite-element model, to better capture the true behavior of a real structural system. In this application, model updating is implemented to reflect observed damage information into an OpenSees model. With the updated model, the structure's residual strength can be estimated through a nonlinear pushover analysis. For the steel frame, the OpenSees model (Figure 4a) simulated damaged beam-ends using zero-length rotational springs and plastic hinges. The rotational springs targeted the stiffness reduction of the beam due to fracturing (Figure 4b) while the plastic hinges captured its strength reduction. In the model updating procedure, the rotational spring stiffness coefficients at each beam-end were modified based on the DI values computed from test measurements. For each damage case, the iterative procedure determined the reduced moment of inertia and section modulus from the final rotational spring stiffness value. Finally the yielding strength of the plastic hinge in the model could be calculated, thus quantifying the reduced moment capacity of the frame.

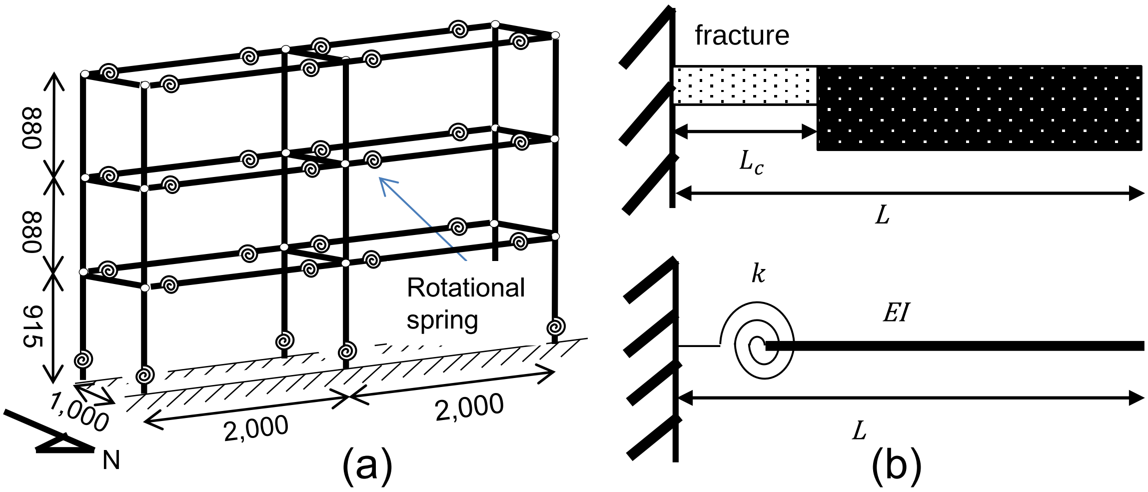


Figure 4. (a) Drawing of OpenSees model; (b) beam model with a rotational spring which represents a fractured beam-end connection

Shake table testing

For experimental validation of the proposed DI and model updating procedure, shake table tests were conducted using the three-story steel frame specimen (Figure 1). Damage progressed throughout the frame in response to a series of ground motions with increasing intensities. Links were used in-between all beam-column connections to ensure moment distributions that would be typical of a moment-resisting frame. The strain measurement system consisted of forty-eight PVDF sensors that communicated through a *Narada* wireless sensor network, developed at the University of Michigan. The PVDF sensors were attached near the end of each beam in the specimen and recorded dynamic strain responses during excitation. Additionally, to verify DI results, visual inspections of the beam-end conditions were documented after each ground motion.

Summary

Structural health monitoring (SHM) procedures have been developed to assess structural condition from sensor data. *System identification* estimates structural modal properties, *damage detection* estimates the severity and location of structural deficiencies, and *model updating* methods reflect true structural characteristics into an analytical model. Shake table tests were conducted at DPRI to demonstrate the information that can be delivered by SHM.

References

Kurata, M., Li, X., Fujita, K., and Yamaguchi, M. (2013). “Piezoelectric dynamic strain monitoring for detecting local seismic damage in steel buildings.” *Smart Materials and Structures*, 22.

Li, X., Kurata, M., and Nakashima, M. (2015). “Evaluating damage extent of fractured beams in steel moment-resisting frames using dynamic strain responses.” *Earthquake Engineering & Structural Dynamics*, 44, 563–581.

Matarazzo, T. J., and Pakzad, S. N. (2016). “STRIDE for Structural Identification using Expectation Maximization: Iterative Output-Only Method for Modal Identification.” *Journal of Engineering Mechanics*.

Shota Shimmoto
Graduate Student
Kyoto University, Japan

Shota Shimmoto is a graduate student (M1) of Department of Architectural Engineering at Kyoto University. He earned his bachelor at Faculty of Engineering Undergraduate School of Architecture in Kyoto University. His main research interest is seismic risk assessment and structural health monitoring.

Akiko Suzuki
Graduate Student
Kyoto University, Kyoto, Japan

Akiko Suzuki is a graduate student (M2) of Department of Architectural Engineering at Kyoto University. Ms. Suzuki completed her bachelor studies at Faculty of Engineering Undergraduate School of Architecture in Kyoto University. Her current research interests are in the areas of post-disaster structural damage screening and seismic risk assessment.

Seismic Fragility and State-Dependent Aftershock Risk Assessments of Japanese Steel Frames

S. Shimmoto[1], A. Suzuki[1], M. Kurata[2], and L. Xiaohua[2]
[1]Department of Architecture and Architectural Engineering, Kyoto University - Japan
[2]Disaster Prevention Research Institute, Kyoto University - Japan

Introduction

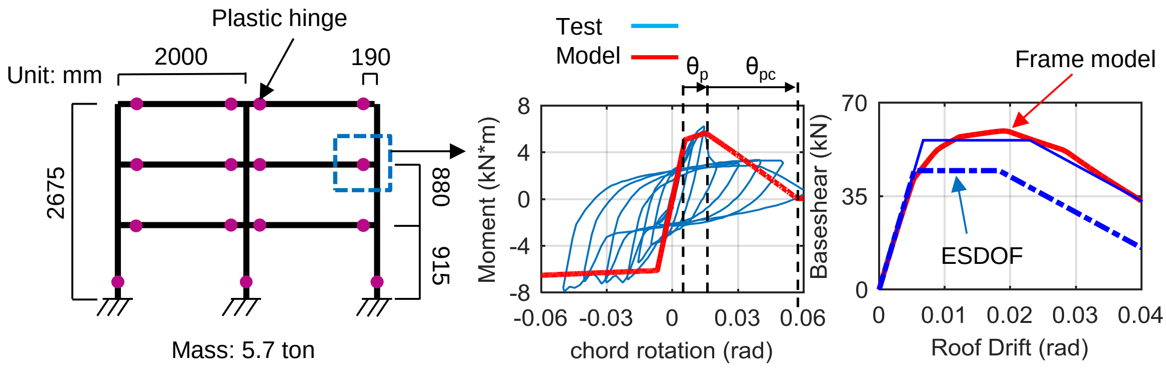
Post-earthquake decision making framework for infrastructures has been attracting a great deal of attention in Japan, especially after the recent mega-earthquakes in Tohoku with the long-lasting sequence of aftershocks. For severely damaged structures, frequent and strong aftershocks can be a threat, which may cause a difficulty for stakeholders to perform consistent decision making to warrant business continuity. Thus, it is essential to quantify the risk of the earthquake-affected structures by considering both the structural fragility and the aftershock hazard.

This research presents seismic fragility of a Japanese steel frame and the application for state-dependent aftershock risk assessment. To examine the seismic fragility of structures, a numerical model of a 3 story 2 bay steel frame was first constructed based on the experimental results, and further transferred to an Equivalent SDOF (ESDOF) model. Using this model, a state-dependent seismic reliability assessment was explored for an imminent earthquake scenario at Nankai trough subduction zone. The aftershock hazard and structural fragility were respectively characterized following the past earthquake records and time history response analysis of structures. To the end, time variant aftershock risk was quantified as the damage state transition probability via Markov chain.

Model construction

To properly assess the structural fragility, a structural model with strength deterioration was constructed for the target building of the 3 story 2 bay steel moment frame. Concentrated plasticity model was adopted; elastic material was assigned to beam-column elements while plastic hinges were assigned to beam-ends and column-bottoms, as shown in Fig. 1a. For the plastic hinge, the Ibarra Krawinkler model [1] was used to account for the deterioration behaviour due to damage accumulation. As shown in Fig. 1b, the back bone curve of plastic hinge model was determined by tuning parameters, such as pre-capping rotation θ_p and post-capping rotation θ_{pc} to the component test result of beam column connections.

Nonlinear static analysis of the frame model was carried out to derive the pushover curve. The first mode natural period of structure was 0.23 second while the base shear coefficient at the maximum value was approximately 1.0. The accuracy of the constructed model was verified through the shaking table test of the target frame. Furthermore, the ESDOF model [2] of the frame model was derived through the linearization and the introduction of the first mode contribution factor, as shown in Fig. 1c.



(a) frame model **(b)** plastic hinge model **(c)** capacity curves

Fig. 1 Conversion of frame model to ESDOF model;

Application of State-Dependent Aftershock Risk Assessment

The risk of damaging structures can be expressed as "damage states transition probability", that is, the probability of structures traveling from a damage state toward another damage state [3]. For earthquake-induced damage, the transition probabilities from *i* th to *j* th damage state within an unit time interval (t, $t+\Delta t$), is expressed in the form of the following matrix [4].

$$P_E(t, t+\Delta t) = \begin{bmatrix} 1-\sum_{j=2}^{n}\lambda(t)P_{1,j} & \lambda(t)P_{1,j} & \cdots & \lambda(t)P_{1,n} \\ 0 & 1-\sum_{j=2}^{n}\lambda(t)P_{2,j} & \cdots & \lambda(t)P_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} \quad \text{Eq. (1)}$$

where each row and column corresponds to the defined damage states, and the (i, j) element represents the transition probability from *i* th to *j* th damage states; each element involves both the earthquake occurrence $\lambda(t)$ and the transition probability P_{ij} given an earthquake.

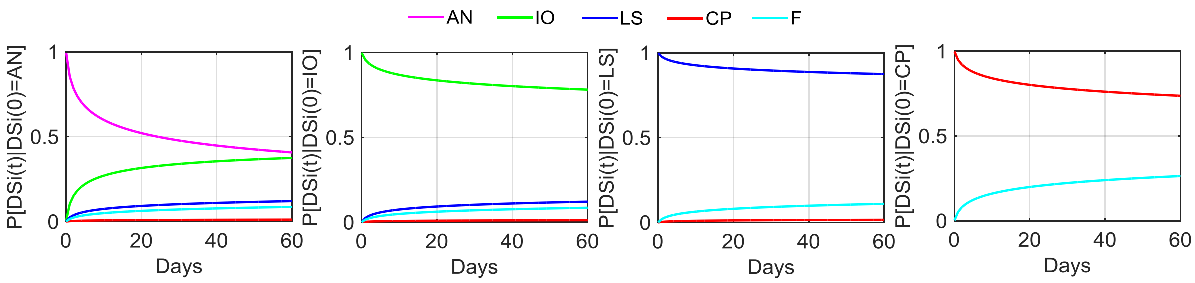
The introduction of Markov chain into Eq. (1) enables to compute the transition probability within a certain time interval, $P_E(t, t+m)$, given by the following equation.

$$P_E(t,t+m)=\prod_{i=1}^{m}[P_E(t+i-1,t+i)] \qquad \text{Eq. (2)}$$

This state-dependent reliability method was adopted for aftershock risk assessment of the target structure, assuming Osaka, the site of interest, subjected to a mainshock at Nankai trough subduction zone. Following the damage observation in the shake table test, the five damage states were defined in terms of roof drifts; As New (AN, 0-0.5%), Immediate Occupancy (OS, 0.5-1.2%), Life Safety (LS, 1.2-2.5%), Collapse Prevention (CP, 2.5-4.0%), and Failure (F, 4.0% -).

Using the constructed ESDOF model, time history response analysis was carried out with thirty ground motions recorded after Tohoku earthquake in 2011, at the sites with the soil class D (the same category as the site of interest). The analysis involved two successive ground motions' input to realize the damage transition between damage states, and the minimum ground motion intensity level to induce the target damage state was collected for all the combination of ground motion records. Fragility curves were derived in terms of the first mode spectrum acceleration $Sa(T_1)$ and further integrated with Aftershock Probabilistic Seismic Hazard Analysis. These results were reflected in the transition probability matrix given an earthquake in Eq. (1).

Time-variant transition probability as a function of time was computed using Eq. (1), (2). Fig. 2 shows the transition probability within 60 days after mainshock occurrence with the given mainshock-induced damage state. Transition probabilities to worse damage cases increases day-by-day due to aftershock damage accumulation. However, it converges to a constant probability because of the decreasing aftershock daily rate. A series of study showed that this probabilistic index can promote a rapid post-earthquake decision making.



(a) AN (b) IO (c) LS (d) CP

Fig. 2 Time-variant transition probability given the initial damage state

Conclusions

The seismic fragility of a Japanese steel frame was examined accounting for the deterioration behaviour due to damage accumulation. The numerical model of the target structure was experimentally verified and further applied for the state-dependent reliability assessment. The study represented the time-variant aftershock risk of the structure in Osaka, subjected to Nankai Trough mega-earthquake.

References

1) Fajfar P, A nonlinear analysis method for performance-based seismic design, *Earthquake spectra*, 2000: **16**(3), 573-592.
2) Ibarra LF, Krawinkler H, Global collapse of frame structures under seismic excitations, *Pacific Earthquake Engineering Research Center*, 2005.
3) Yeo, G. L., Cornell, C. A.: Stochastic Characterization and Decision Bases under Time-dependent Atershock Risk in Performance-Based Earthquake Engineering., *Pacific Earthquake Engineering Research Center*, 2005.
4) Iervolino I, Giorgio M, Chioccarelli E, Markovian modeling of seismic damage accumulation, *Earthquake Engineering & Structural Dynamics*, 2015.

Brandon McHaffie
PhD Student
University of Canterbury, Christchurch, New Zealand

Brandon McHaffie (born 1992) is a PhD candidate in Earthquake Engineering at the University of Canterbury (UC), Christchurch, New Zealand. He earned his Bachelor in Civil Engineering with honours at the University of Canterbury. His main research interest is seismic design of bridges, and particularly the performance of pier – foundation connections.

Numerical Investigation of Pier-Foundation Connections For Accelerated Bridge Construction

B. McHaffie, A. Palermo
Department of Civil and Natural Resources Engineering, University of Canterbury - New Zealand

Introduction

In the recent Canterbury earthquake sequence the majority of bridges performed structurally well. However, some routes lost their functionality and some required costly repairs (NZTA, 2012). While life safety is still the primary design objective, new societal needs are moving the trend to post earthquake functionality and minimal vehicle disruption even after a Maximum Credible Earthquake (MCE) event. In addition, network owners and asset manages want to reduce maintenance costs and construction time. This will reduce the impact to users as bridge down time will be improved. With these societal needs in combination with high seismicity, Accelerated Bridge Construction (ABC) poses a promising solution to minimize vehicle disruption and provide improved seismic performance over traditional Cast In Place (CIP) construction methods (Palermo & Mashal, 2012). ABC is a construction technique that offers rapid construction due to the use of precast superstructure and substructure elements. The intent of this research is to develop upon previous experimental testing on ABC connections in order to improve performance based design parameters, optimize connection detailing and carry out a cost analysis on different connection types.

Background

Many connections have been developed for ABC in regions with low seismicity (Marsh et al., 2011). However, there was insignificant testing to prove their performance in seismic regions. Recently several connections developed for ABC have been designed and tested for use in earthquake prone areas. These can be categorized into three main types as shown in in Figure 1. All three arrangements have been tested and all perform well under seismic loading (Mashal & Palermo, 2014; White, 2014).

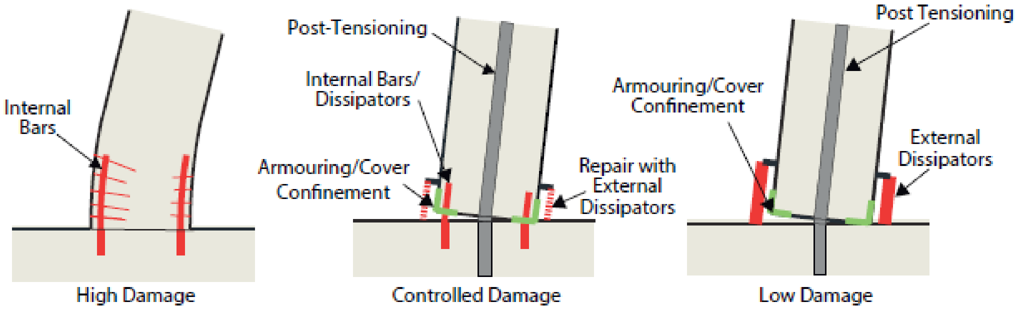


Figure 1: Retrieved from (White, 2014) shows typical High, Controlled and Low Damage solutions for ABC connections.

The High Damage (HD) solutions are designed to emulate the behaviour of Cast-In-Place structures and dissipate energy through the formation of a Plastic Hinge (PH) (Park & Paulay, 1975). This approach is chosen as it is efficient to accept some structural damage and reduce seismic demand rather than design the member to remain elastic. The problem with this approach is the significant damage after a seismic event. The repair is costly and if bars rupture replacement of the bridge is often necessary (Priestley, Seible, & Calvi, 1996). The Low Damage (LD) solution however, targets little to no damage in a design level event. This is achievable through the use of steel armouring, mild steel dissipaters and un-bonded post-tensioning. The mild steel is designed to yield as rebar does in traditional PH. However, the mild steel is placed on the outside of the member and detailed so that it can be easily replaced. The initial construction cost of this method is more expensive but can be repaired quickly with low costs after a seismic event. The Controlled Damage (CD) solution aims to limit and control damage. Damage is expected to occur but can be repaired at a much lower cost than HD connections. The controlled damage is achieved through the use of post-tensioning, steel armouring and the use of couplers. The couplers allow the replacement of sections of bar which is much cheaper than repairing a HD connection but more expensive than repairing a LD connection. Alternatively the CD pier can be designed to allow the addition of external dissipaters after an event rather than before which reduces initial costs.

Currently, the NZTA Bridge Manual mentions both pure rocking structures and low-damage post-tensioned design but leaves design at the complete discretion of the designer. This leaves a significant gap in design guidelines. Despite this gap the first low-damage post-tensioned rocking bridge design has been completed and is currently under construction in Christchurch. However, one example is not enough to increase the use of ABC technology to a level where it is considered “common practice” and development of design parameters is required.

Research

The research objective is a continuation of the ABCD project funded by the New Zealand Natural Hazards Research Platform (NZ- NHRP) and can be split in three main parts. Part one involves Finite Element Modelling of experimentally tested ABC connections. This will allow optimization of connection detailing including couplers, debonded length, minimum concrete confinement, and armouring thickness. In addition, performance based parameters such as ductility can be examined at a local level. Part two involves numerical modelling to find out the overall response of the bridge with ABC high, controlled and low damage connections. A comprehensive investigation will be carried out to examine the effects of boundary conditions, cross section profile, continuity, span length, superstructure type and abutment fixity. This will allow global parameters such as ductility, yield displacement and displacement profile to be examined. The third and final part is to look at the Wigram Magdala Bridge which has LD piers and is currently under construction. The intent is to quantify the increased initial cost associated with using a low damage solution compared to commonly used solutions.

Bibliography

Marsh, M. L., Wernli, M., Garrett, B. E., Stanton, J. F., Eberhard, M. O., & Weinert, M. D. (2011). *NCHRP Report 698: Application of accelerated bridge construction connections in moderate-to-high seismic regions.pdf*.

Mashal, M., & Palermo, A. (2014). EXPERIMENTAL TESTING OF EMULATIVE FULLY PRECAST CONCRETE BRIDGE BENT IN SEISMIC REGIONS.

NZTA. (2012). Performance of highway structures during the darfield and christchurch earthquakes of 4 september 2010 and 22 february 2011, (February).

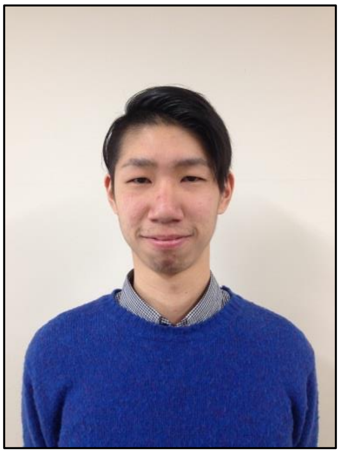
Palermo, A., & Mashal, M. (2012). Accelerated bridge construction (abc) and seismic damage resistant technology: A new zealand challenge. *Bulletin of the New Zealand Society for Earthquake Engineering*, *45*(3), 123–134. Retrieved from http://www.nzsee.org.nz/db/Bulletin/Archive/45(3)0123.pdf

Park, R., & Paulay, T. (1975). *Reinforced Concrete Structures*.

Priestley, M. J. N., Seible, F., & Calvi, G. (1996). *Seismic Design and Retrofit of Bridges*. http://doi.org/10.1002/9780470172858

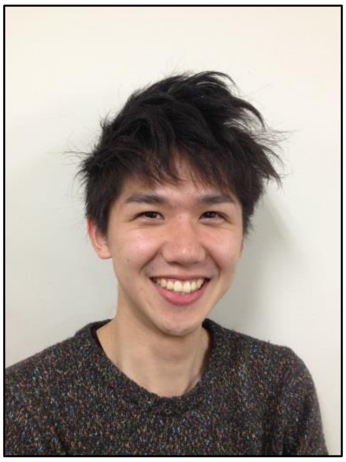
White, S. (2014). *Controlled damage rocking systems for accelerated bridge construction*.

Hiroyuki Inamasu
Master Student
Kyoto University, Kyoto, Japan



Hiroyuki Inamasu (born 1991) is a master student (M2) in Architectural Engineering at the Kyoto University, Kyoto, Japan. He earned his Bachelor in Architectural Engineering from the Kyoto University, Japan. His main research interest is earthquake resistant structures, especially steel structure and steel brace member, and currently his experimental research work is about developing new type of steel brace that combines two types of steel materials and has an intended initial eccentricity. His hobby is to play and watch football.

Yu Otsuki
Bachelor Student
Kyoto University, Kyoto, Japan



Yu Otsuki (born 1992) is an undergraduate student at the Department of Architecture of Kyoto University and he goes to the master course from next April in Nakashima & Kurata laboratory. His research subject is structural health monitoring, especially for applying monitoring information to supporting consensus-building after an earthquake. As a first step of his research, he did a shaking table test for a 3 story steel frame with braces on this November and he is now writing a graduation thesis. He likes basketball.

Japanese academic system; organization of courses, laboratories and offer at DPRI

H. Inamasu[1], Y. Otsuki[1]
[1] Department of Architecture and Architectural Engineering, Kyoto University - Japan

Academic system of Kyoto University

Kyoto University is a national university located in Kyoto, Japan. It is the second oldest Japanese university, one of the highest ranked universities in Asia and one of Japan's National Seven Universities. One of Asia’s leading research-oriented institutions, Kyoto University is famed for producing world-class researchers, including ten Nobel Prize laureates, two Fields medalists and one Gauss Prize. In Kyoto university, there are approximately 22,000 students and 2800 teachers. Out of those students, 17,000 are male, while 5000 are female. Kyoto University adopts two semesters system. 1st semester begins from April and ends at the beginning of August. After the summer vacation, 2nd semester starts from October and continues until the end of January. The period from February to April is spring vacation.

Kyoto is also famous for the old capital of Japan, therefore there are many historical places and buildings. In Kyoto, there are 17 world heritage sites. Kyoto University has three campuses. They are located in Yoshida, Katsura, and Uji, respectively. Yoshida campus is our main campus, located near the central of Kyoto city. All of the bachelor students except for the 4th year bachelor student take the classes there. In the 4th year, undergraduate student in faculty of Engineering moves either to Katsura campus or Uji campus to start working on the research.

Faculty of Engineering consists of 6 Departments (Architecture, Global engineering, Engineering science, Informatics and mathematical science, Electrical and electronic engineering, and Industrial chemistry). Out of them, Department of Architecture and that of Global engineering are closely related to so-called ‘civil engineering’. In the Department of Architecture, some students work on building structure and geotech, while in the department of global engineering, some students work on bridge, dam structure, soil and geotech.

Academic system of each course in Faculty of Engineering can be explained as follows; 1) Bachelor course: It takes 4 years (3 years for classes / 1 year for research). 60 credits for liberal arts / 70 credits for specialized subjects and bachelor thesis are required. After graduation, 90% go on to the master course, while 10% start working. 2) Master course: It takes 2 years (1 year for classes / 1 year for research). 20 credits for specialized subjects and master thesis are required. After graduation, 5% go on to doctoral course, while 95% start working. 3) Doctor course: It takes 3 years (Research). Dissertation and 3 papers publication are required.

Disaster Prevention Research Institution (DPRI)

Since its inception in 1951, Disaster Prevention Research Institute (DPRI) of Kyoto University has been pursuing principles of natural disaster reduction, establishing integrated methodologies for disaster prevention on the basis of natural and social sciences, and educating students in related fields. The research staff members of the Institute are also affiliated with the Graduate Schools of Science and Engineering of Kyoto University. Many graduate students come to the Institute to carry out their studies under supervision of its staff members.

DPRI is located in a tranquil suburban setting within the Uji Campus of Kyoto University. There are five research divisions, and six research centers with 15 state-of-the-art laboratories in Japan engaged in the development of cutting-edge science and technology. To facilitate integrated research, each division and center is nestled among one of the following four research groups: 1) Integrated Art and Sciences for Disaster Reduction, 2) Seismic and Volcanic Hazards Mitigation 3) Geohazards, and 4) Atmosphere-Hydrosphere.

In 2010, DPRI was certified as a national Joint Usage/Research Center in Japan for performing various integrated research on natural disaster reduction and disaster prevention at local and global scales. DPRI with its more than half-a-century of accumulated scientific achievements, knowledge, facilities and data collections, has been recognized as a Global Center of Excellence in the area of disaster risk reduction for its work on disaster prevention research and mitigation.

Our research field Civil Engineering is mainly related to 2) Seismic and Volcanic Hazards Mitigation 3) Geohazards gorup. Those groups have several experimental facilities such as one directional static-loading system, shaking table, full-scale 5 story steel frame, online hybrid load cell, geotechnical centrifuge and machines for consolidation, liquefaction, sliding, single shear, sarticle fracture, synamic deformation of soil etc (see fig. 1). (More detailed information: http://www.dpri.kyoto-u.ac.jp/collaborative_en/)

Nakashima and Kurata laboratory

Nakshima and Kurata laboratory is one of the research groups in Architectural engineering. The primary research interests are steel structures, structural health monitoring systems, seismic rehabilitation, and probabilistic research hazard. In this workshop, from DPRI side, the students and professors from this laboratory are the participants. Currently, Nakshima and

(a) Shaking table

(b) Liquefaction machine

Figure 1: Examples of experimental facilities.

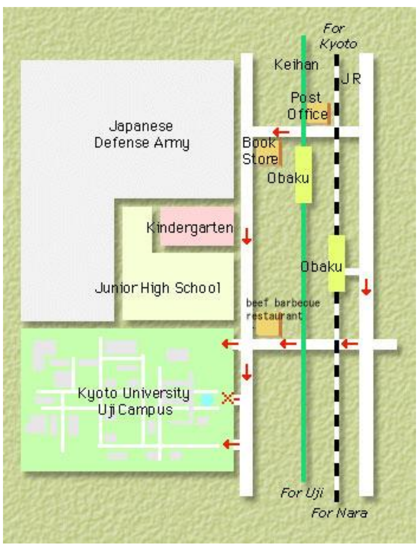
Kurata laboratory consists of prof. Nakashima and prof. Kurata, 3 postdoc researchers, and 11 students. It is also noted that 4 persons of them are foreigners. They work as a group and each group are comprising postdoc, doctor, master, and undergraduate student.

School life

From senior grade, students belong to a laboratory. For Nakashima & Kurata laboratory, senior students come to the lab twice a week to study programming and technical terms in English in the first semester, and prepare for the entrance examination of the graduation school in August. After that, they start their research and write a graduation thesis.

In the master course, first semester is dedicated to taking classes and the rest of two years are mainly for research. In our laboratory, there are 4 research groups and each member belongs to a group. Usually, the research group meeting is held once a week and we report our progress to the supervisors, Prof.Nakashima and Prof.Kurata. Also, there is another whole meeting once a week and assigned persons present in front of our all members. 2nd semester of M1 and 1st semester of M2 are used for job-hunting if the students don't continue research as a doctor.

Access to DPRI @ Uji Campus, Kyoto University



Direction to Uji Campus

Keihan line
「Keihan Oubaku」→Walking about 6 minutes

JR Nara line
「JR Oubaku」→ Walking about 6 minutes
(JR Kyoto → JR Oubaku about 20 minutes)