18th World Conference on Earthquake Engineering
Technical Session IDD-7

Friction-based force-limiting connections

Materials, designs, hybrid manufacturing, numerical simulations, and experiments

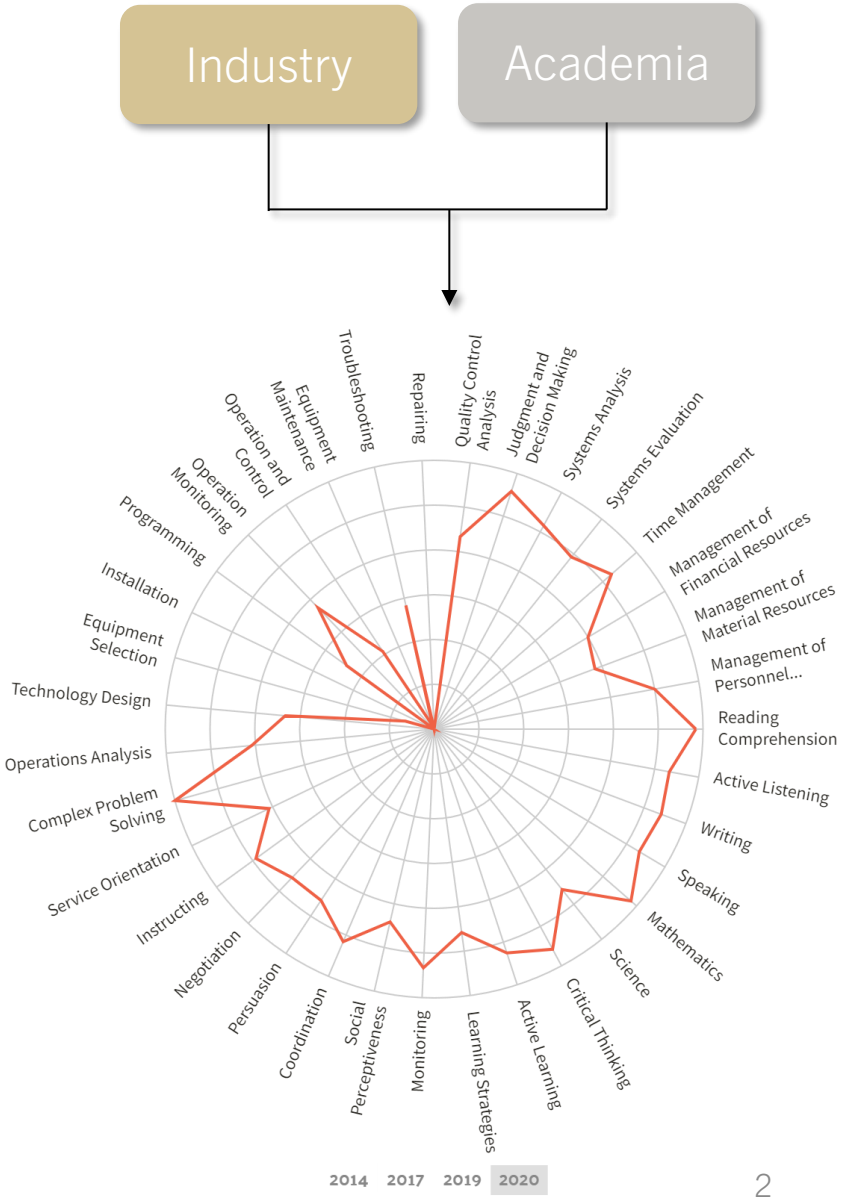
Georgios Tsampras, Ph.D.
Assistant Professor of Structural Engineering
Jacobs School of Engineering
UC San Diego

July 3, 2024
Milan, Italy

http://tsampras.ucsd.edu

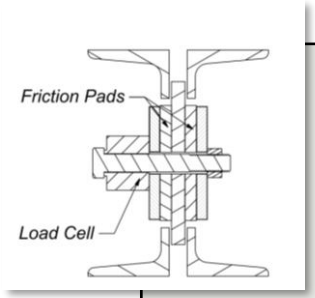
Future Structural Engineers

- Problem Solving
- Critical Thinking
- Analytical and Technical skills
- Time Management
- Collaboration
- Hands-on Experience
- Judgment and Decision Making
- Active & Continuous Learning
- Communication
- Mentorship
- Creativity

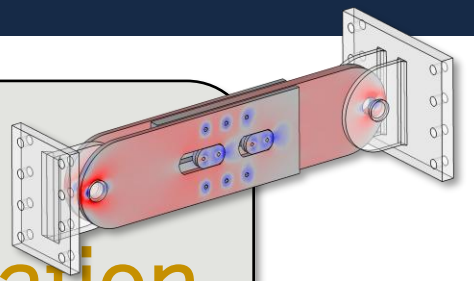


- Data, Bureau of Labor Statistics, 2021
- Georgios Tsampras, (2021), Careers in Structural Engineering, Invited Lecture, EERI at Lehigh University

Future Structural Engineers



Design



Analysis & Simulation

Practical structural solutions

Experimentation



Manufacturing



Design, Analysis & Simulations,
Hybrid Manufacturing, and Experiments

Education Research

Democratize the use of practical friction-based connections

Challenges
Advantages
Examples





ACKNOWLEDGMENTS

Inertial Force-limiting Floor Anchorage Systems For Seismic Resistant Building Structures (2011-2016)

Robert Fleischman, Jose Restrepo, Richard Sause, Joe Maffei, David Mar, Dichuan Zhang, Zhi Zhang, Ulina Shakya, Arpit Nema, Gabriele Guerrini

Alternative designs of friction-based connections (2020-Present)

Kaixin Chen, Dominic Tran, Anne-Sophie Roobol, Anthony Li

Steel buildings with sliding floors and elastic frames (2022-Present)

Chung-Che Chou, Shih-Ho Chao, Chia-Ming Uang, Li-Yu Huang, Chi-Jeng Wu, Alvaro Cordova, Huang-Zuo Lin, Shu-Hsien Chao, Nicholas Tedjasukmana, Ming-Yen Xie, Wei-Xuan Chen, Hao Wei Jian

Friction-based components in structural engineering

- Clark et al. 1973 – Limit forces due to differential settlement in foundations
- Bridge structures
- Precast concrete structures
- Steel braced frames
- Moment resisting frames
- Self-Centering Moment Resisting Frames
- Rocking Walls (Reinforced concrete and timber)
- Friction dampers
- Self-centering friction-based braces

Literature review available in:
Tsampras et al. (2018), Chen et al. (2023)

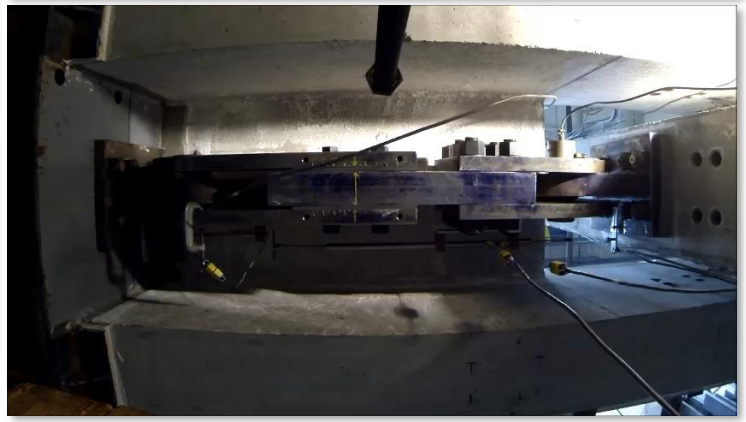
Some examples from our past and ongoing research projects:











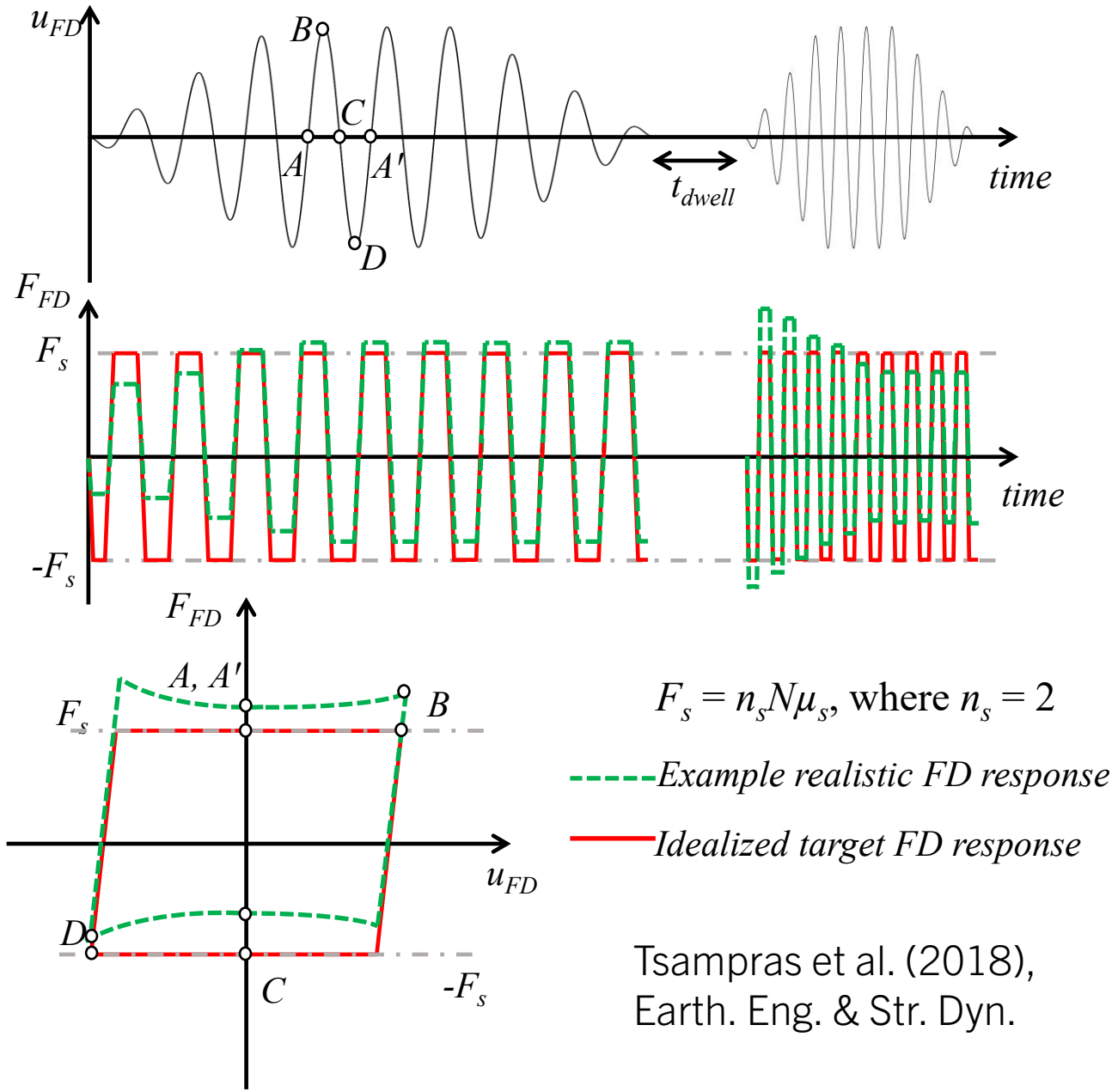
Challenges

Challenges with friction-based structural connections

Friction-sliding behavior of a bi-material interfaces is affected by:

- Sliding velocity
- Dwell time
- Galvanic corrosion in friction interface
- Creep of composite materials
- Break-in and cumulative sliding effects
- Geometric tolerances

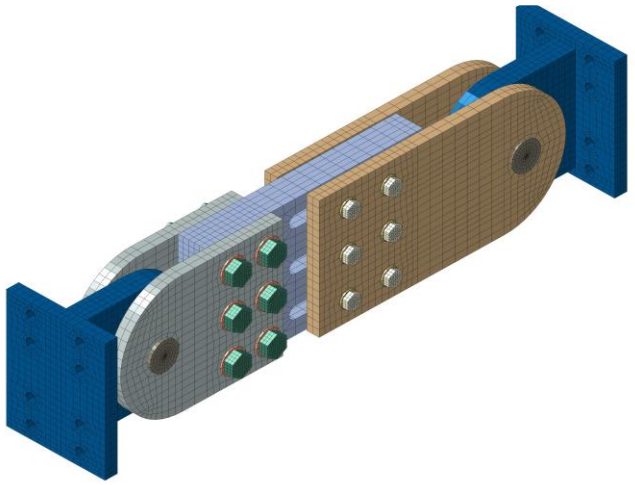
Limited large scale experimental data on mechanical and tribological properties of composite materials for friction-based structural connections

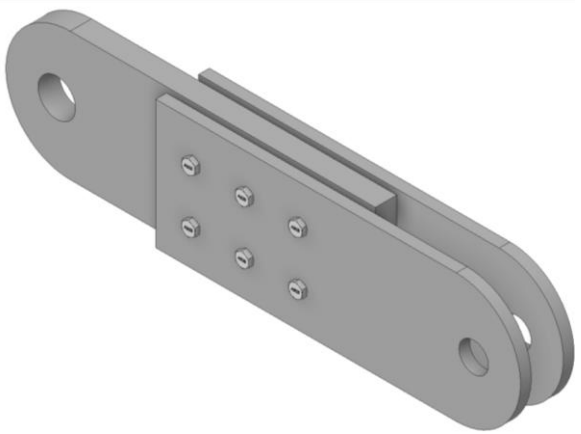


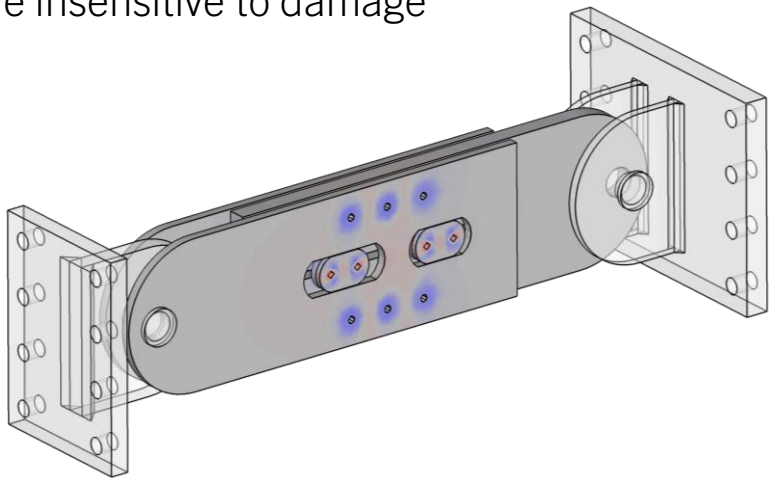
Tsampras et al. (2018), Earth. Eng. & Str. Dyn.

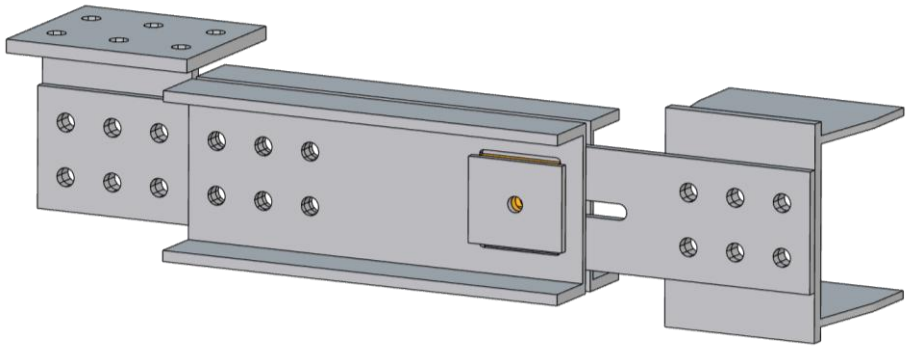
Why friction-based force-limiting connections?

- Structural engineers have freedom in detailing
- Easy adjustments to achieve target force levels
- Decoupled stiffness and sliding friction force
- Possible designs with easy manufacturing and assembly
- Increase of displacement capacity by including longer slots in the design – no strain limitations
- Designs that allow low-damage and easy reparability
- Some designs are insensitive to damage







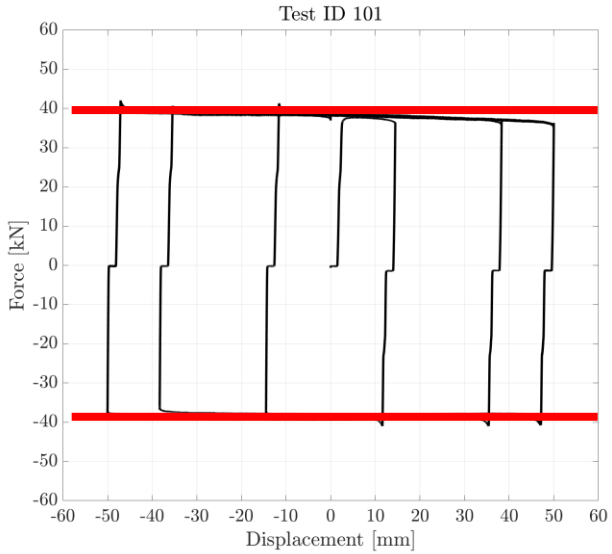


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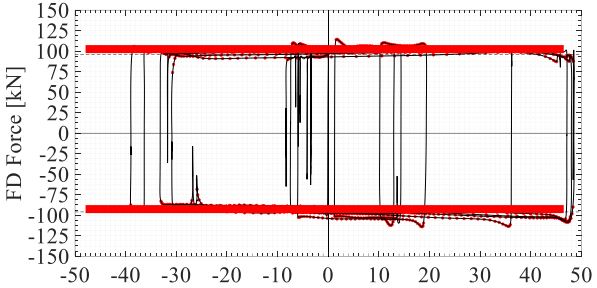
~40 kN





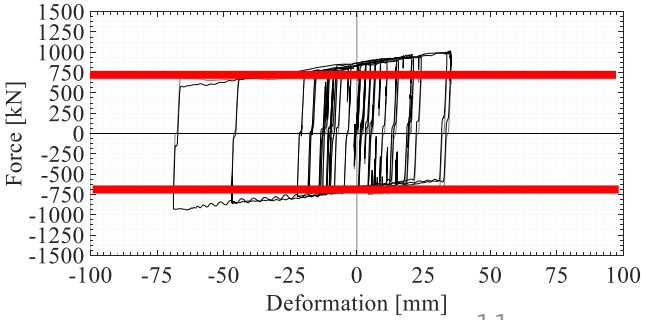
~100 kN



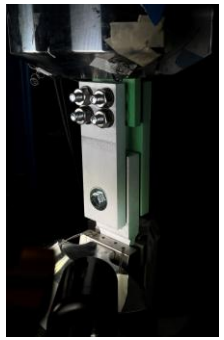


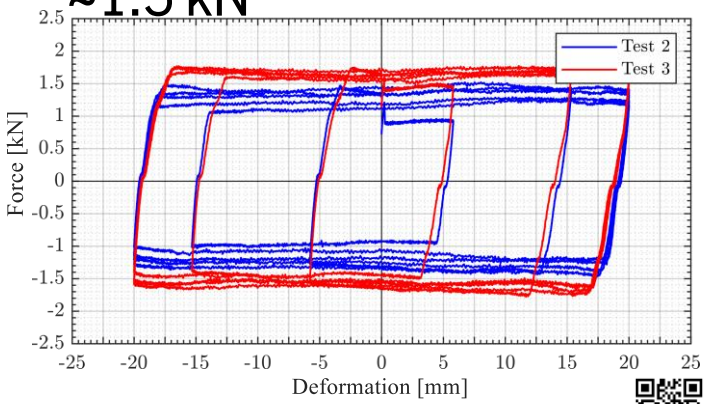
~750 kN





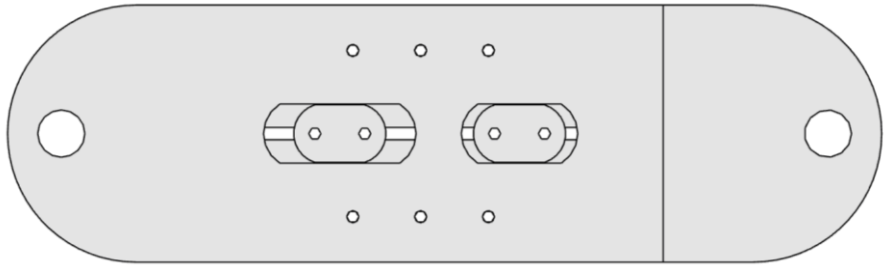
~1.5 kN

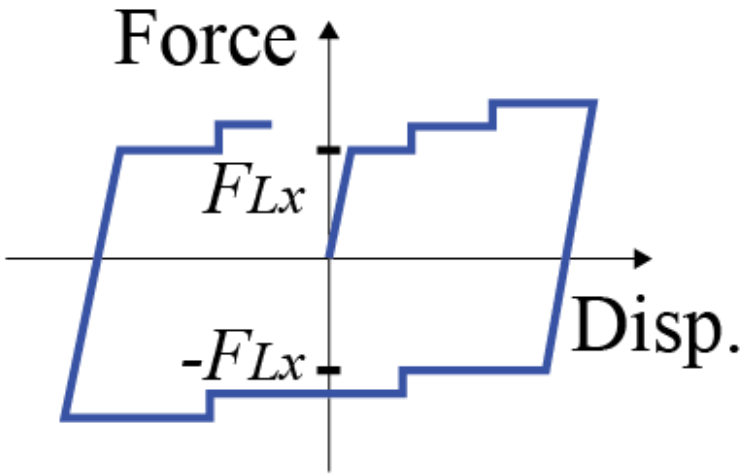




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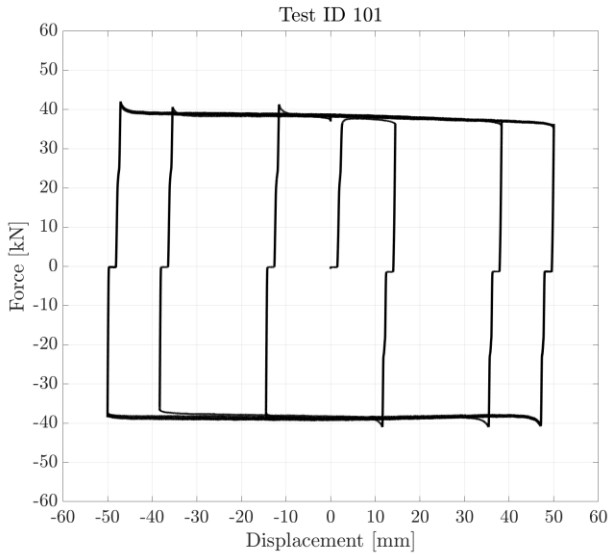


Chen et al. (2023) RCS Journal
Chen et al. (2024) WCEE Session IDD - 4

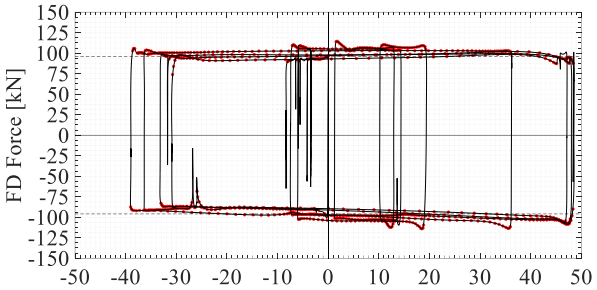
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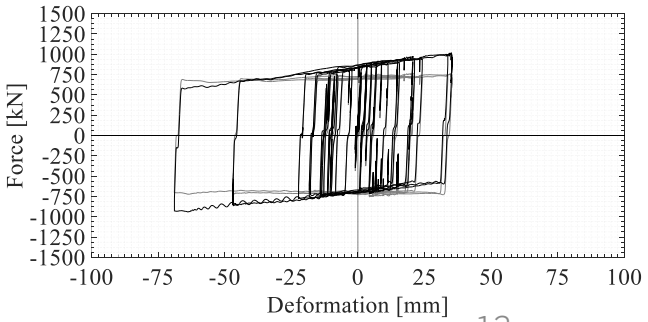












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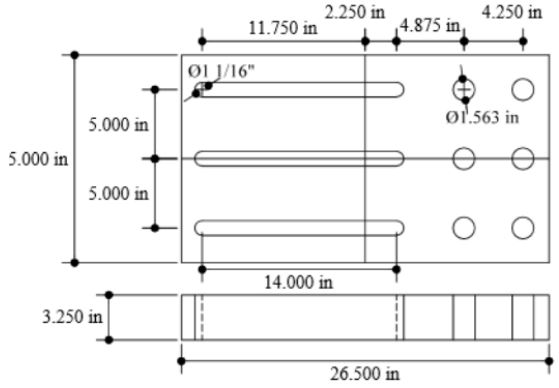


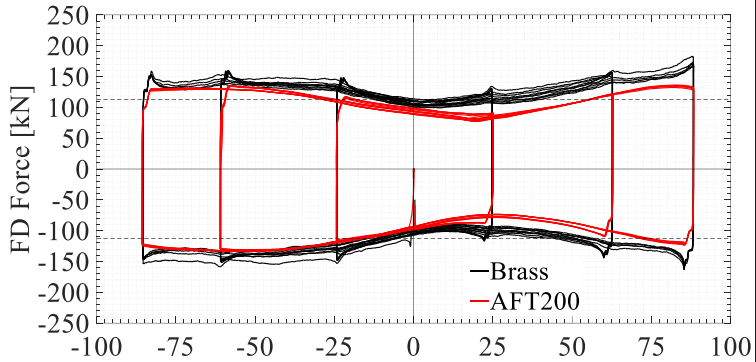


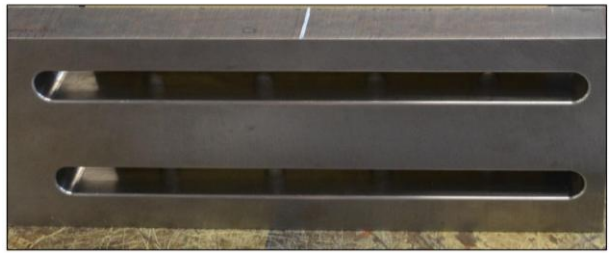


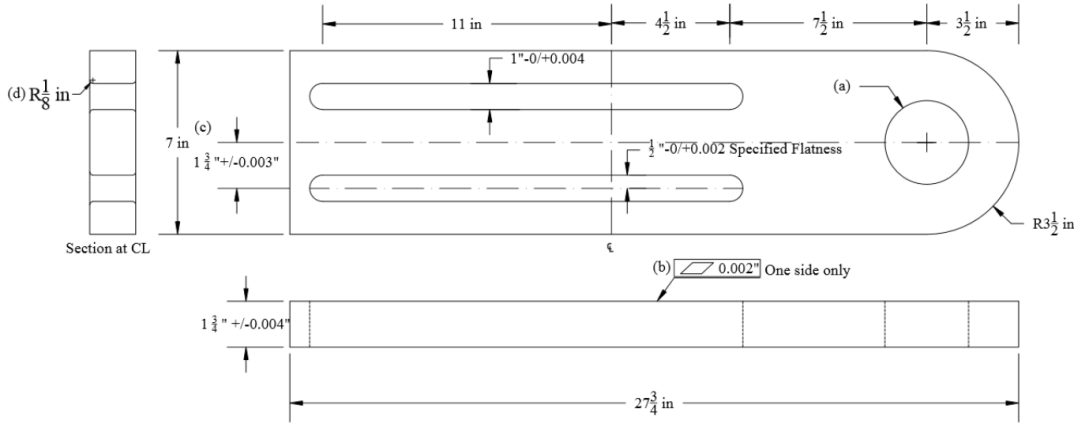
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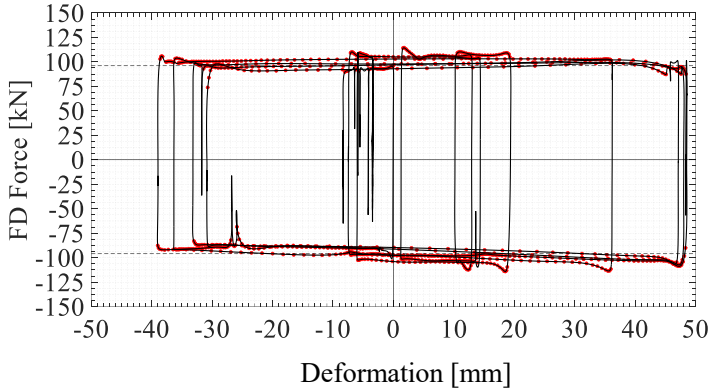








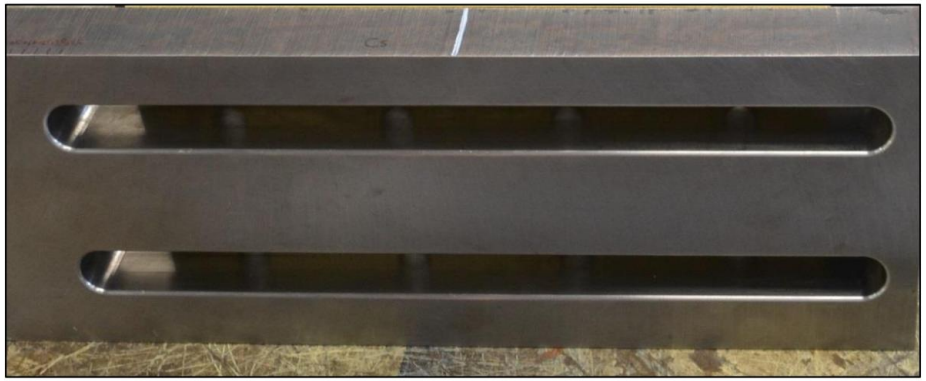




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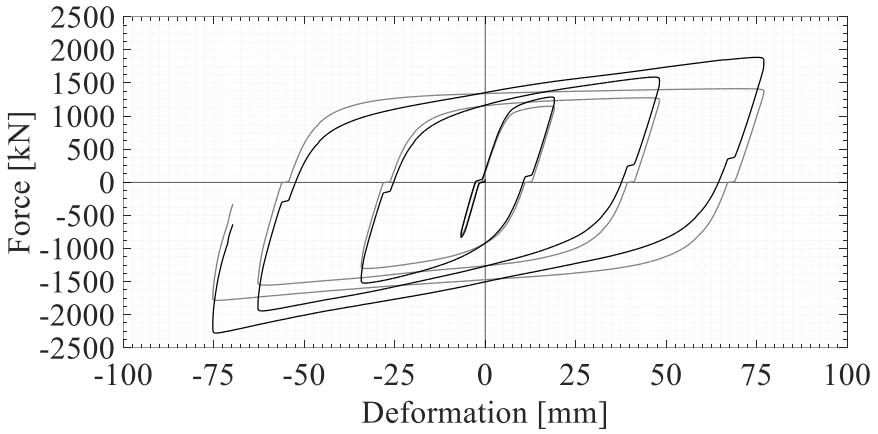
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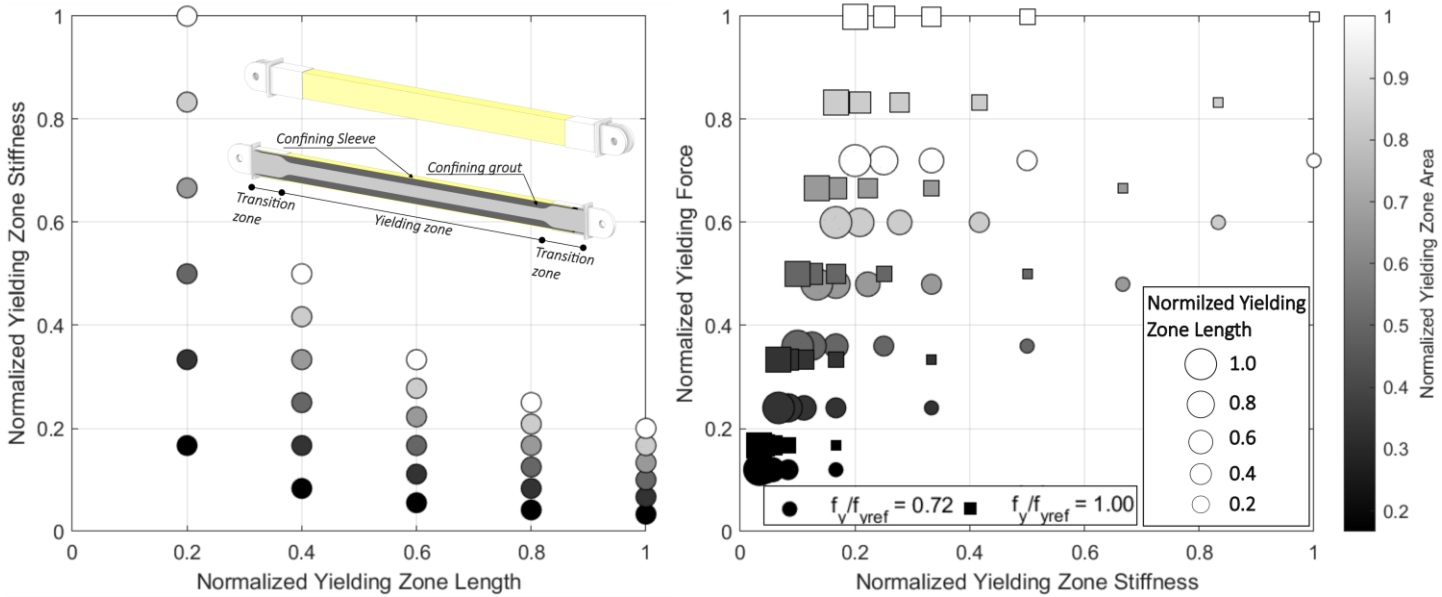




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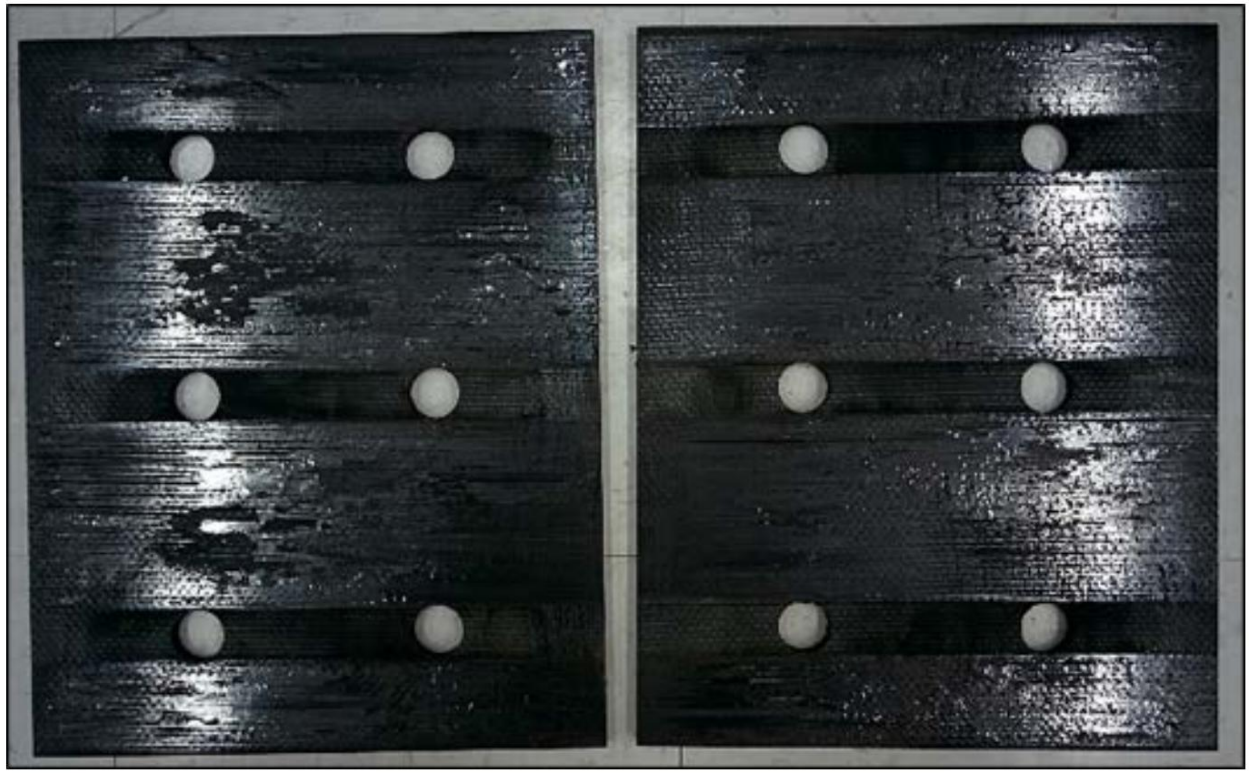
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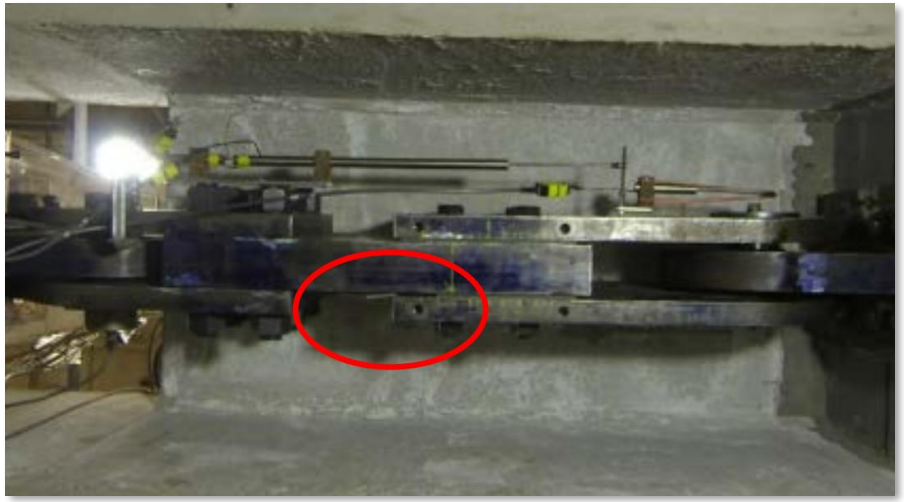
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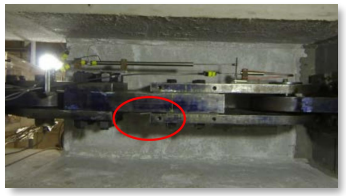




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Acknowledgments: NTU – UTA - UCSD Collaboration

Chung-Che Chou, Director General, NCREE, Professor, NTU

Shih-Ho Chao, Professor, University of Texas, Arlington, USA

Chia-Ming Uang, Professor, UCSD, USA

Li-Yu Huang, Chi-Jeng Wu, Master Students, NTU

Alvaro Cordova, Ph.D. Candidate, NTU

Huang-Zuo Lin, Shu-Hsien Chao Research Fellows, NCREE

Nicholas Tedjasukmana, Ming-Yen Xie, Wei-Xuan Chen,

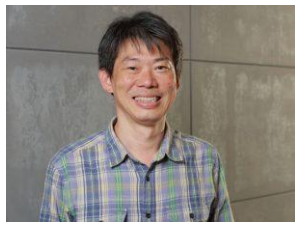
Hao Wei Jian, MS students, NTU











Chung-Che Chou
National Taiwan University



Shi-Ho Chao
UT Arlington



Chia-Ming Uang
UCSD



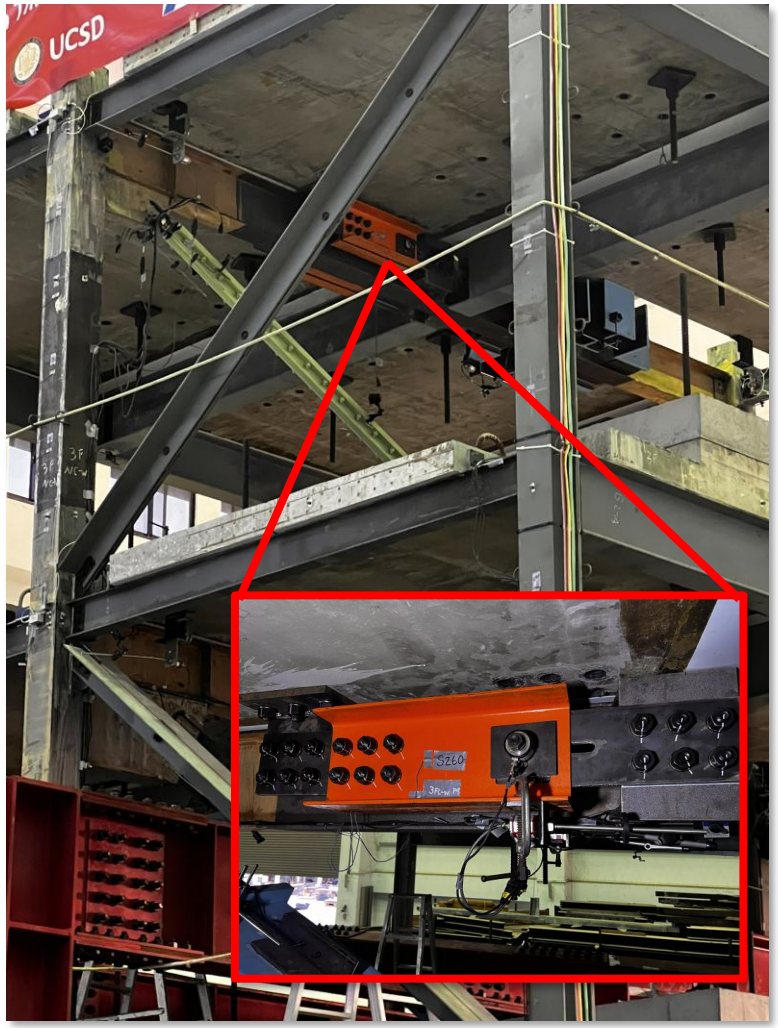
Georgios Tsampras
UCSD

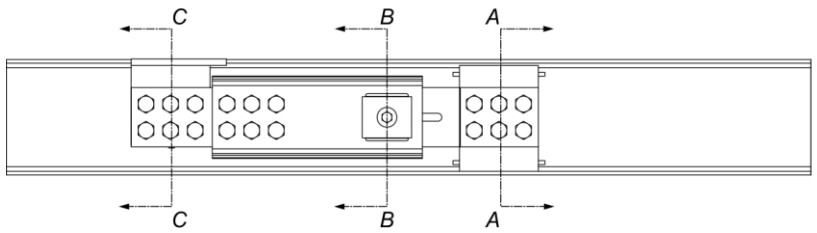
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JACOBS SCHOOL OF ENGINEERING
Structural Engineering

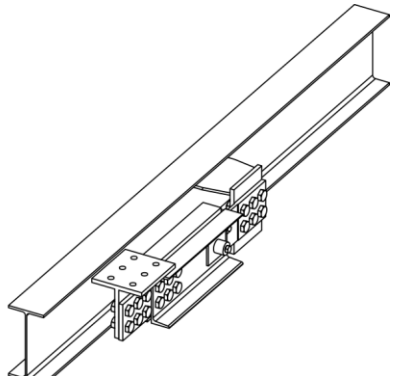
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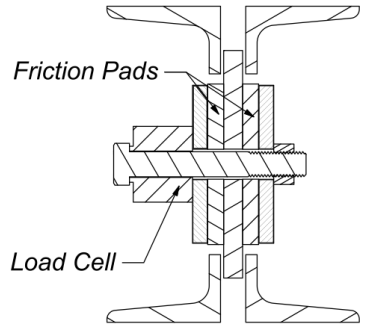
Chung-Che Chou, Huang-Zuo Lin, Alvaro Córdova, Jian-Ming Chen, Daniel Yen-Hsun Chou, Shu-Hsien Chao, Shih-Ho Chao, Georgios Tsampras, Chia-Ming Uang, Hsin-Yang Chung, Chin-Hsiung Loh, Hsuan-Teh Hu, "Earthquake simulator testing of a three-story steel building for evaluating built-up box column performance and effect of sliding slab". Earthquake Engng Struct Dyn. 2024; 1-19. https://doi.org/10.1002/eqe.4130

DESIGN

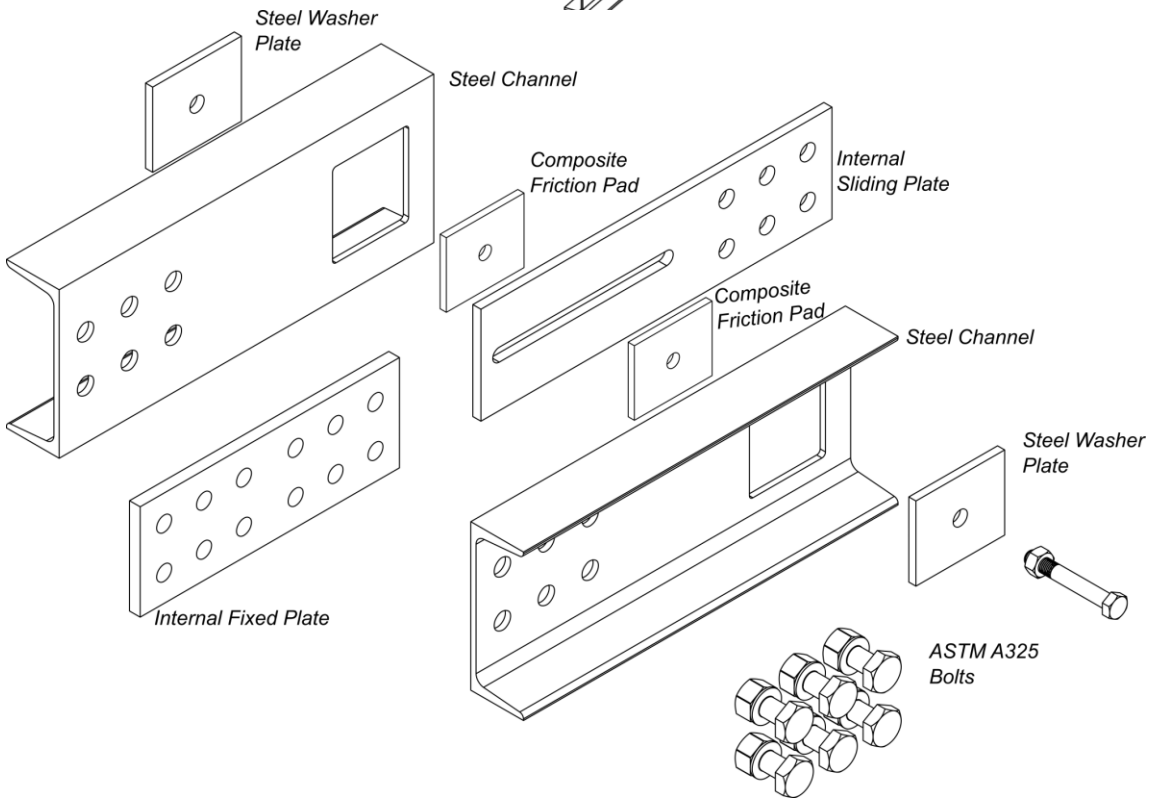




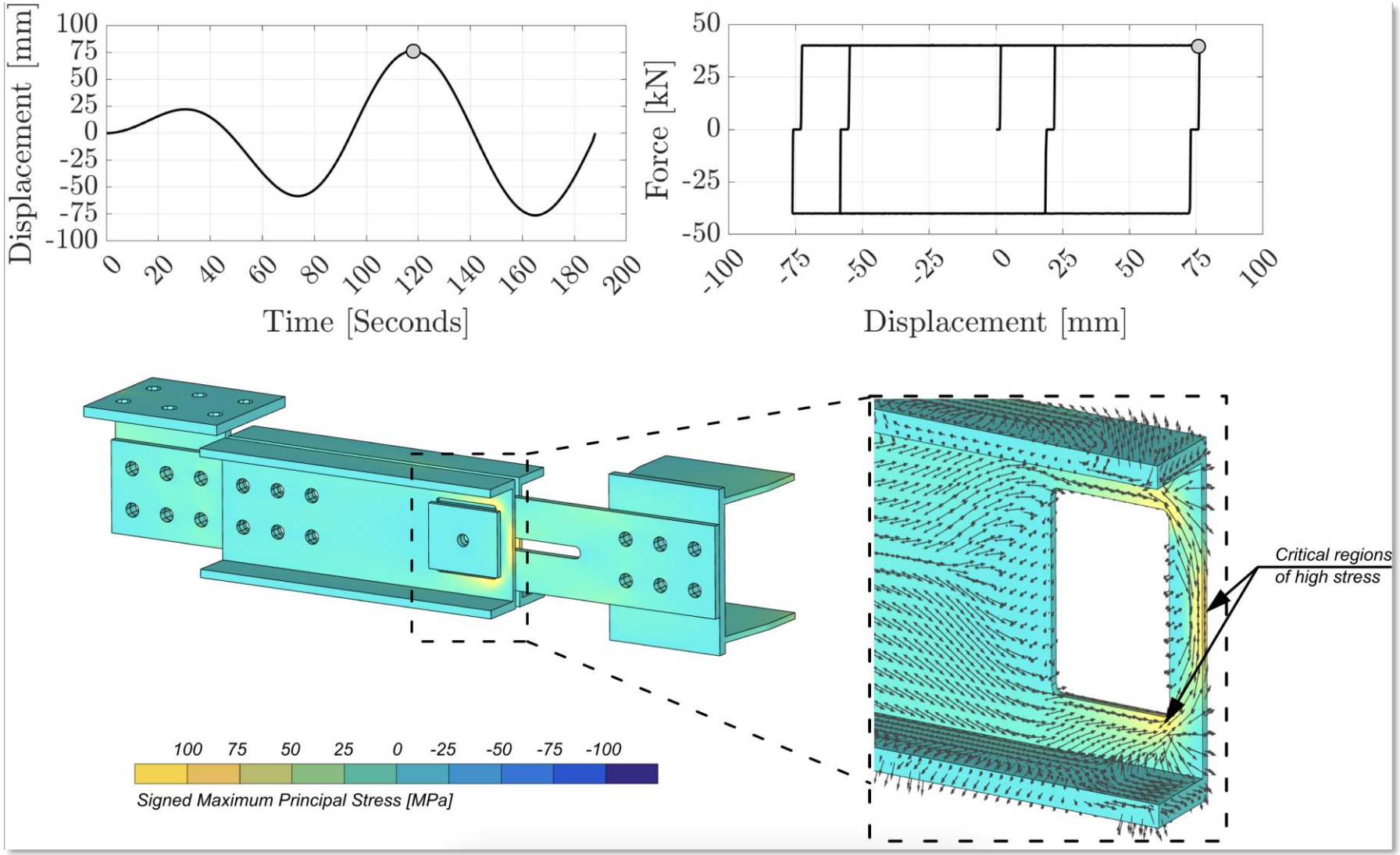




Section B-B



SIMULATIONS

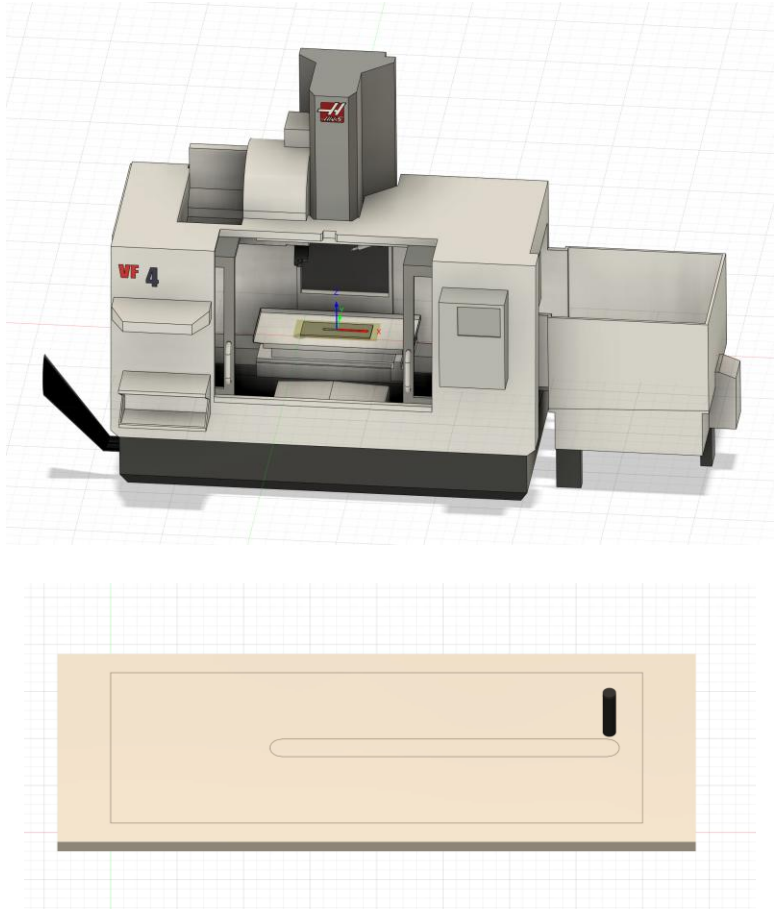


MANUFACTURING - PROGRAMMING

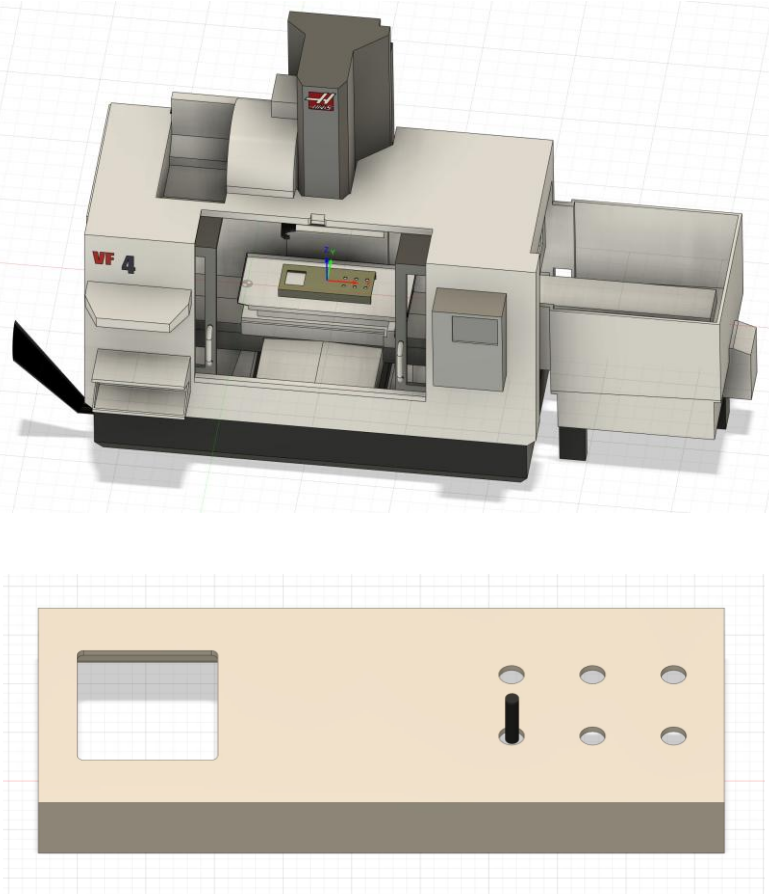
Internal fixed plate



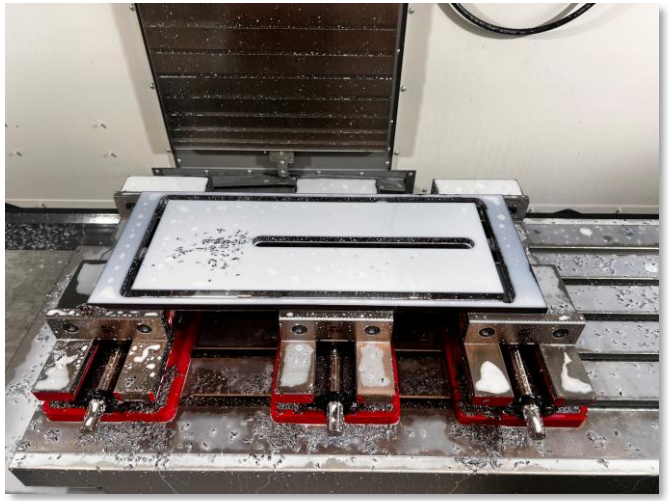
Internal sliding plate



Channels

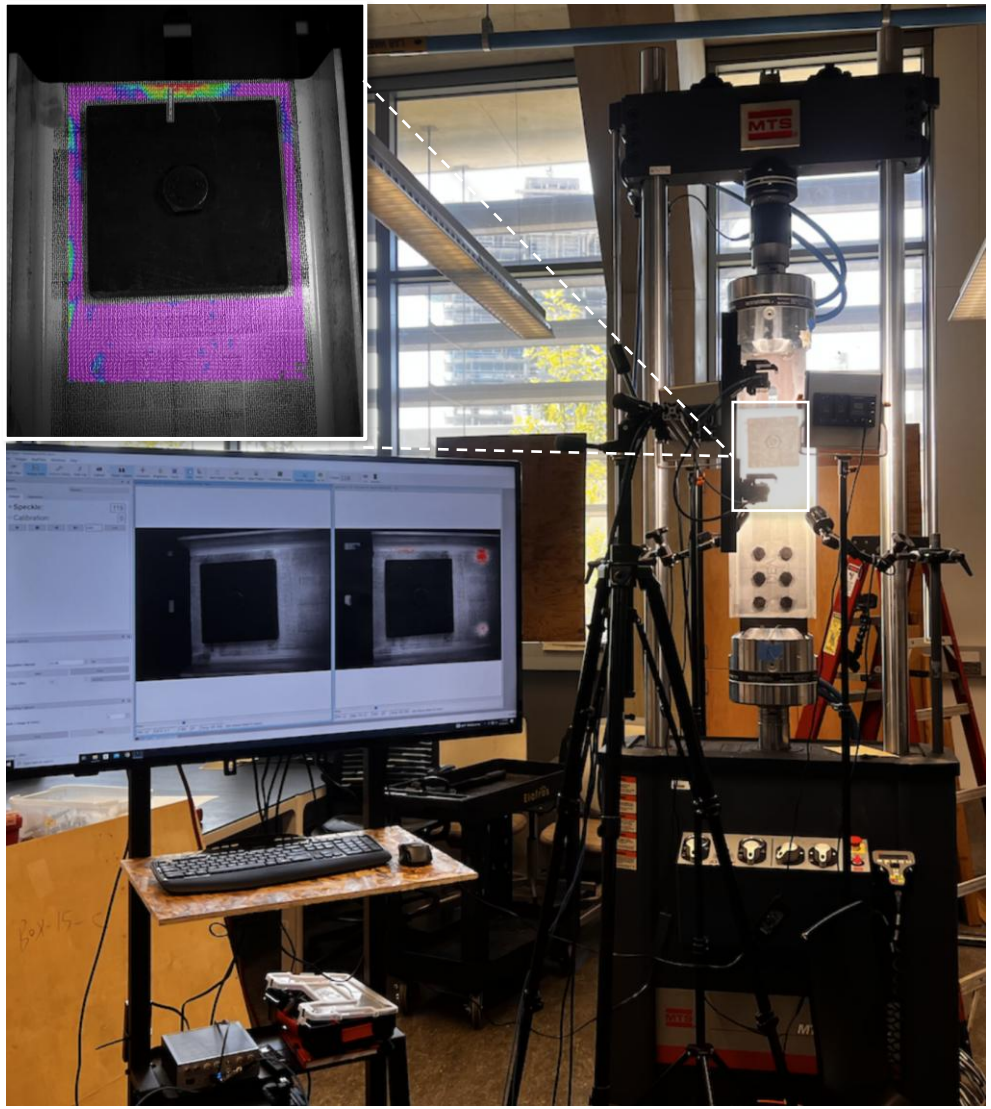


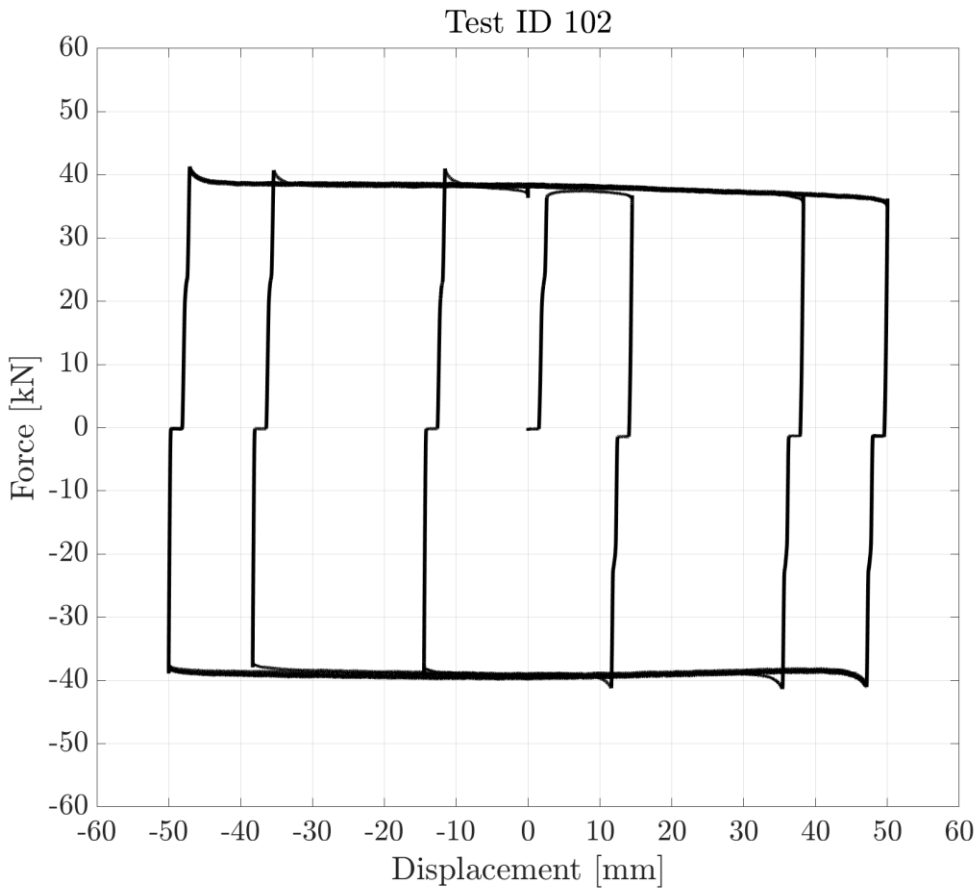
Automated Manufacturing



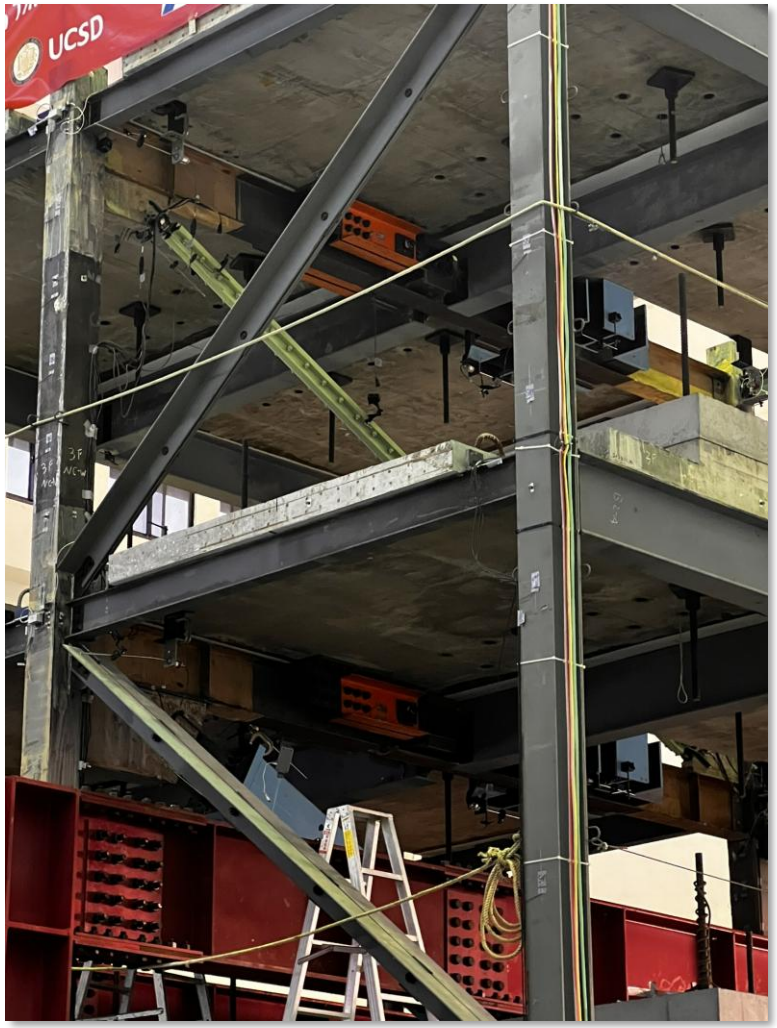


Component Level Testing





2023 NCREE Shake Table Testing







Demonstration of repairability – If needed



UC San Diego

Please consider joining us at:

18TH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING WCEE2024 MILAN

Day	Room	Time	Session	Title
MONDAY	SPACE 3	11:36 - 11:45	IDD11	EFFECT OF UNCERTAINTY IN RC WALLS ON SEISMIC RESPONSES OF BUILDINGS WITH FORCE-LIMITING CONNECTIONS
WEDNESDAY	SUITE 6	09:35 - 09:45	SDM5	PRACTICAL DESIGN OF FORCE-LIMITING CONNECTIONS FOR BUILDINGS WITH REDUCED HIGHER-MODE RESPONSES
WEDNESDAY	SPACE 3	09:50 - 10:00	IDD7	FRICTION-BASED CONNECTIONS: MATERIALS, DESIGNS, MANUFACTURING, SIMULATIONS, AND EXPERIMENTS
THURSDAY	AMBER 7	15:09 - 15:21	IDD4	EXPERIMENTAL CHARACTERIZATION OF COMPOSITE MATERIALS IN FRICTION-BASED FORCE-LIMITING CONNECTIONS
FRIDAY	MONITOR 20	09:24 - 09:36	IDD4	STRUCTURAL CONNECTION WITH PREDETERMINED DISCRETE VARIABLE FRICTION FORCES
FRIDAY	SPACE 3	09:36 - 09:48	CMS2	SHAKE TABLE TESTS OF A FULL-SCALE THREE-STORY STEEL BRBF WITH SLIDING SLABS IN CHIHSHANG EARTHQUAKE
FRIDAY	SUITE 9	09:38 - 09:47	EVO9	ASSESSMENT OF ALTERNATIVE SEISMIC DESIGN PROVISIONS FOR DIAPHRAGMS PER ASCE/SEI 7-22
FRIDAY	SUITE 8	10:54 - 11:06	IDD4	SEISMIC RESPONSE OF CORE WALL BUILDING WITH FRICTION-BASED FORCE-LIMITING CONNECTIONS

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