A Balance between Strength, Stability, and Ductility in Contemporary Seismic Design for Steel Structures

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Lecturer:
Masayoshi Nakashima
Professor Emeritus of Kyoto University
President of Kobori Research Complex Inc.
Chief Technical Counselor of Kajima Corporation

Abstract:

Steel is one of the most popular materials for building construction. Members and frames made of steel are generally strong; hence, buckling of members subjected to compressive forces has been the primary concern when forming a frame structure. For the past three centuries, numerous studies have been carried out to quantify buckling behavior and avoid premature buckling in steel building frames. Design codes and specifications have also been developed to cope with such buckling.

For the past half a century, seismic design has been fond of the term ductility, i.e., the ability not to lose strength earlier and to dissipate energy exerted into the structure by seismic action. To achieve this ability, steel members tend to become stockier and thicker, and such treatment makes steel building frames less and less vulnerable to buckling mentioned above. In seismic design, little has been discussed lately on buckling and the associated instability of steel building frames.

Recently, a new paradigm, represented by "functional recovery" and "damage minimization," has received attention in seismic analysis and design. Here, "ductility" has been accused in that it is nothing but severe structural damage. In tune with the new paradigm, there is a notable revival of slender steel members and frames as they tend to possess larger elastic capacity, i.e., the ability to maintain the no-damage status until more significant deformations. Those slender members are commonly combined with various dampers to dissipate the energy exerted onto the structure by seismic actions.

This lecture considers these conceptual revolutions in the design of steel building frames and consists of four parts. First and in Part 1, the fundamentals of buckling of steel members are revisited and epitomized using classical buckling theories and equations. Second and in Part 2, the essence of plastic analysis and limit analysis using concentric plastic hinges are presented, followed by the mechanism of frame instability of steel buildings using the slope-deflection method in which stability functions are included to allow for the effect of compressive forces on the member stiffness. In Part 3, ductility and deformability

of various steel elements, members, and frames are examined, including the cyclic behavior of brace members and the damage of nonstructural components. This part also discusses a good balance and trade-off between steel building frames' strength, stability, and ductility. Last and in Part 4, seismic design of a typical Japanese steel tall building is presented, and its performance is evaluated through the comparison of the corresponding seismic design exercised in the United States.

Topics covered:

The following 20 sessions are considered in this course. One session is planned for 90 minutes (including a "short quiz" and a five-minute "short break"); four sessions are to be covered for one day; and five working days are to spend to the completion of this course.

Day	Session	Topics
1	1	Introduction of Lecturer Fundamentals of buckling I (elastic compression members)
	2	Fundamentals of buckling II (initial imperfections, and residual stresses) Fundamentals of buckling III (inelastic compression members)
	3	Fundamentals of buckling IV (buckling of members subjected to torsion)
	4	Fundamentals of buckling V (lateral torsional buckling for members subjected to bending)
2	5	Fundamentals of buckling VI (plate buckling and local buckling) Fundamentals of buckling VII (elastic and inelastic local buckling)
	6	Plastic analysis I (plastic hinges with and without axial force)
	7	Plastic analysis II (limit analysis)
	8	Plastic analysis III (upper and lower bound theorems)
3	9	Plastic analysis IV (floor moment methods)
	10	Frame instability I (slope-deflection method with stability functions)
	11	Frame instability II (instability with and without lateral translation)
	12	Frame instability III (P-δ versus P-Δ)
4	13	Behavior of braces I (cyclic behavior of long and short braces) Behavior of braces II (formulations of inelastic buckling under cyclic loading)

	14	Behavior of braces III (behavior of buckling-restrained braces (BRBs))
	15	Ductility consideration I (correlation between member ductility and frame ductility)
	16	Ductility consideration II (a trade-off between ductility and structural damage)
5	17	Diagnosis of structural and nonstructural damage
	18	Design of tall steel buildings I (a case study in Japan and comparison with those built in the United States)
	19	Design of tall steel buildings I (comparison for serviceability and collapse margin between the United States and Japan)
	20	Review and discussion of this course

Lecturer Profile (a longer version):

Masayoshi Nakashima is Professor Emeritus of Kyoto University, Japan. He earned his bachelor and master degrees from Kyoto University (1975, 1977) and Ph.D. from Lehigh University, the Unites States of America (1981). After the doctoral study, he started working for the Building Research Institute (BRI) of Japan between 1981 and 1988 and then for Kobe University between 1988 and 1992 before joining Disaster Prevention Research Institute (DPRI), Kyoto University in 1992. During 2004 to 2011, he also worked as Director of E-Defense, a research institution that manages the world largest shaking table, and led a large international project commonly called "NEES/E-Defense Joint Research".

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, nearly two hundred and fifty of them appearing in archived journals. He has earned various national and international awards, including the Best Paper Prize of AIJ (Architectural Institute of Japan), the Best Paper Prize of JSSC (Japanese Society for Steel Construction), the ASCE (American Society of Civil Engineers) Moisseiff Award (2000), the Special Achievement Award of AISC (American Institute for Steel Construction) (2009), the ASCE Ernest E. Howard Award (2013), and the EERI (Earthquake Engineering Research Institute) George W. Housner Medal (2014), among others.

Nakashima served as Director of DPRI, Kyoto University between 2011 and 2013, Program Director of Cabinet Office of Japan in charge of Cross-Ministerial Project on disaster resilience between 2014 to 2017, and President of the Architectural Institute of Japan (AIJ) between 2015 and 2017. He also served as Director of Earthquake Engineering Research Institute (EERI) between 2008 and 2011, and since 2018 he is President of International Association for Earthquake Engineering (IAEE). Furthermore, he continues to work as Editor and Executive Editor of International Journal of Earthquake Engineering and Structural Dynamics (EESD) since 2006.

He is Member of the Engineering Academy of Japan (2013) and also inducted to

Foreign Member of the National Academy of Engineering (NAE) of the United States (2015), Corresponding Member of the Mexican Academy of Engineering (2016), and Corresponding Member of the Slovenian Academy of Arts and Science (2020). He also holds the honorary positions that include Honorary Professor of Tsinghua University, China (2018), Honorary Professor of Institute of Engineering Mechanics (IEM) (2017), China Administration of Earthquakes, Honorary Member of IAEE (2017), Honorary Member of AIJ (2018), and Honorary Member of EERI (2019).

Nakashima retired from Kyoto University in March 2017, and since then, he works as President of Kobori Research Complex Inc. (KRC) and Chief Technical Counselor of Kajima Corporation.