SEISMIC ENGINEERING WORKSHOP:

ISSUES IN DISPLACEMENT BASED DESIGN AND ASSESSMENT

Instructors:

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Dates:

Monday September 18, 2017 13:30-18:00 and

Tuesday September 19, 2017 08:00-17:30

Location:

The Westin Bayshore Hotel & Conference Center

1601 Bayshore Drive, Vancouver, BC

Detailed Outline:

Lecture No.	Date and time	Lecturer	Topic
DAY 1: Monday September 18, 2017			
1	13.30 – 15.15	GMC	Motivations and fundamentals of displacement-based design
Coffee Break	15:15 – 15:45		
2	15.45 – 17.30	AF	Design of structures with supplemental damping and seismic isolation systems
	17.30 – 18.00	AF/GMC	*Presentation of practical application assignments*
DAY 2: Tuesday September 19, 2017			
3	08.00 – 09.45	GMC	Displacement-based assessment of buildings
Coffee Break	09:45 – 10:15		
4	10.15 – 12.00	AF	Seismic performance, design and assessment of non-structural components
Lunch	12:00 – 13:00		
5	13.00 – 14.45	GMC	Design and assessment of bridges
Coffee Break	14:45 – 15:15		
6	15.15 – 16.15	AF/GMC	*Considerations on the assignments and general discussion*
	16.15 – 18.00	GMC	Presentation of practical case-studies

** Draft schedule. All times and topics subject to change*

Lecture 1: Motivations and fundamentals of displacement-based design

An overview of damage in recent earthquakes is given, with particular emphasis on establishing the design errors leading to unsatisfactory performance. This is discussed with reference to the basis of conventional force-based design, and the inherent problems resulting from assumptions made. These errors include, amongst others, the assumption that stiffness of a given section is independent of the strength, that a force-reduction factor can be identified for a given structural system regardless of geometry, that strength should be distributed in proportion to elastic stiffness, and that displacement demand of a structure responding inelastically can be accurately estimated from the elastic stiffness.

An introduction to Direct Displacement-Based Design (DDBD) is made.

It is pointed out that damage limit states can be related to material strains, and hence displacements, or to interstorey drift (and again to displacements). DDBD principles for single-degree-of-freedom systems governed by material strains and by drift limits are presented, and then expanded to multi-degree of-freedom systems, in a general sense independent of structural type or configuration. Equivalent viscous damping for different structural systems are identified.

Characteristics of seismic accelerograms and response spectra are discussed with particular emphasis on displacement records and displacement response spectra. The influence of different levels of elastic damping is discussed, and differences between “normal” records and near-field records with forward directivity are presented.

Suggested reading:

- Chapters 1, 2 and 3 of the reference book.

Lecture 2: Design of structures with supplemental damping and seismic isolation systems

Over the last 30 years, a large amount of research has been conducted into developing innovative earthquake-resistant systems in order to raise the safety level of building and bridges while keeping construction costs reasonable. Most of these systems are intended to dissipate the seismic energy introduced into the structure by supplemental damping mechanisms and/or to isolate the main structural elements from receiving this energy through isolation systems.

Isolated structures, or structures with supplemental damping systems cannot be designed in accordance with conventional force-reduction procedures; the lecture will discuss how DDBD is directly applicable to both classes of structures, thereby simplifying and rationalizing the seismic design process. The mechanical behaviour of various types of of supplemental damping and isolation systems will be discussed, focusing on fluid viscous dampers and rubber and friction pendulum isolation systems. DDBD concepts appropriate for design will be presented with an emphasis of the strength and weaknesses of specific types of systems in various design situations. Some design examples of seismic isolated structures, or structures with supplemental damping systems will be discussed, to emphasize the simplicity of the design approach, and the significance of isolation and supplemental damping to structural performance. The adoption of DDBD procedure in current code seismic provisions will be highlighted.

Suggested reading:

- Chapter 11 of the reference book.
- Christopoulos, C., and Filiatrault, A. 2006. *Principles of Supplemental Damping and Seismic Isolation*, IUSS Press, Pavia, Italy

Lecture 3: Displacement-based assessment of buildings

Displacement based design approaches have been first developed with reference to new constructions, but it can be shown that their application to assessment of existing structures and comparison of alternative strengthening choices is equally effective and possibly the only viable solution.

Similar to new design, many of the DDBD principles have been extended to include the assessment of existing structures. Preliminary proposals for Direct Displacement-based Assessment (DBA) aimed to develop simplified assessment techniques that would identify the likely collapse mechanism (i.e.: beam sway or soft-story in frame structures) and system displacement capacity. Further, the risk associated with a structure reaching a certain limit state is deterministically calculated as the expected probability of occurrence for a critical seismic event based on the regional hazard of the building site.

Perhaps the most basic description of the DBA procedure is that it essentially applies the principles of Direct Displacement-Based Design in reverse. In the case of assessment, the process begins with the determination of how the structure is expected to respond through the investigation of existing structural properties in order to identify the likely inelastic mechanism. In the case of a simple frame structure this is determined by examining the relative beam and column strengths to determine what type of mechanism (e.g. soft-story mechanism) is likely to occur. A displaced shape is assumed as a function of the anticipated mechanism and used with local deformation limits to identify a system displacement limit, Δ_{cap}, similar to the design process. The expected base shear, V_{base}, and yield displacement, Δ_y, is calculated and used in order to determine the effective stiffness, K_e, and ductility demand, μ, which, in turn, allows for the effective period, T_e, and equivalent elastic spectral displacement, $S_{d,el}$, to be estimated. The equivalent elastic spectral displacement is used in order to determine the likely intensity level corresponding to an assumed limit state as generally site hazard is expressed in terms of an assumed initial elastic damping value (i.e. 5% of critical). Finally, based on the building site hazard, the seismic intensity corresponding to the development of the assumed limit state is realized and the corresponding risk can be estimated.

In this lecture most aspects of the DBA approach will be presented, with focus on some critical issues, such as:

- How to deal with difference performance levels and limit states, which ones are more effective and what are their relation with collapse prevention.
- What acceptance criteria can be reasonably considered for existing constructions? With new design a pass/fail mentality still prevails. This is inappropriate for assessment. Is it appropriate to conform to new-design standard or relaxed standards should be defined?
- How to deal with probabilistic risk assessment, certainly appropriate at least to define hazard. A probabilistic assessment of vulnerability can be difficult and will require sound simplifications.

Suggested reading:

- Chapter 13 of the reference book.
- Welch, D.P., Sullivan, T.J., Calvi, G.M. (2014). Developing direct displacement-based procedures for simplified loss assessment in performance-based earthquake engineering, *Journal of Earthquake Engineering*, 18:2, 290-322.

Lecture 4: Seismic performance, design and assessment of non-structural components

With the development and implementation of performance-based earthquake engineering, harmonization of performance levels between structural and nonstructural building components becomes vital. Even if the structural components of a building achieve a continuous or immediate occupancy performance level after a seismic event, failure of architectural, mechanical or electrical components can lower the performance level of the entire building system. This reduction in performance caused by the vulnerability of nonstructural building components has been observed during recent earthquakes worldwide. Moreover, nonstructural damage has limited the functionality of critical facilities, such as hospitals following major seismic events. The investment in nonstructural building components and building contents is far greater than that of structural components and framing. Therefore, it is not surprising that in many past earthquakes, losses from damage to nonstructural building components have exceeded losses from structural damage. Furthermore, the failure of nonstructural building components can become a safety hazard or can hamper the safe movement of occupants evacuating or of rescue workers entering buildings. In comparison to structural components and systems, there is relatively limited information on the seismic design of nonstructural building components. Basic research work in this area has been sparse, and the available codes and guidelines are mostly based on experiences, engineering judgment and intuition, rather than on objective experimental and analytical results. Often, design engineers are forced to start almost from square one after each earthquake event: to observe what went wrong and to try to prevent repetitions. This is a consequence of the empirical nature of current seismic regulations and guidelines for nonstructural building components.

The main objective of this lecture is to familiarize participants with current knowledge on the seismic performance, design and assessment of nonstructural building components focusing on those that are particularly sensitive to interstorey drifts in buildings. Specific topics discussed will include: the definition and classification of nonstructural building components; the importance of considering nonstructural building components in seismic design; the challenges associated with the seismic design of nonstructural building components; the causes of seismic damage to nonstructural building components; the performance of nonstructural building components in recent earthquakes; the practical seismic assessment and mitigation of nonstructural building components using the FEMA E-74 methodology; the direct and cascading analysis methods of nonstructural building components including the Floor Response Spectrum (FRS) method; the current seismic design requirements for nonstructural building components in the United States, Canada and Europe; the seismic performance of specific typologies of nonstructural components that are particularly sensitive to interstorey building drifts such as light and heavy partition walls and how DDBD can be applied to design these non-structural elements.

Suggested reading:

- Filiatrault, A. and Sullivan, T. (2014). Performance-based Seismic Design of Nonstructural Building Components: The Next Frontier of Earthquake Engineering, *Earthquake Engineering and Engineering Vibration*, **13(1)** Supplement, 17-46.

Lecture 5: Design and assessment of bridges

Bridges have always occupied a special place in the affection of structural designers, possibly because their structural form tends to be a simple expression of their functional requirements and a direct connection between structure and aesthetics is somehow of immediate perception.

Despite, or possibly because, their apparent structural simplicity, bridges have not performed well under seismic attack.

This unexpected poor performance can in general be attributed to the design philosophy adopted and to a lack of attention to design detail: earthquakes have the habit of identifying structural weaknesses and concentrating damage at these locations.

Typically, bridges have little structural redundancy, making them more sensitive to errors and local failures, are often sensitive to soil-structure interaction effects, and may have to be constructed in areas with problems of potential fault dislocation.

Typical problems that have caused extensive damage and collapse in previous earthquakes may be summarized as:

Underestimation of seismic deflection demands, with possible catastrophic consequences related to unseating of spans and insufficient rotation capacity in plastic hinges;

Underestimation of seismic forces and inappropriate application of capacity design principles, with possible consequent wrong location of points of contraflexure and brittle shear and joint failures.

Within this framework, the lecture will focus on the following aspects, considering first the case of bridges that could be modelled by single degree of freedom models and bridges to be best represented by multi-degree of freedom models:

- Estimate of some equivalent yield displacement
- Definition of appropriate design displacements
- Calculation of equivalent viscous damping
- Assessment of displacement shapes
- Estimate of effective displacement

Some specific attention will be devoted to cable stayed and isolated bridges.

Suggested reading:

- Chapter 10 of the reference book.
- Calvi, G.M., T.J. Sullivan and A. Villani (2010). Conceptual Seismic Design of Cable-Stayed Bridges, *Journal of Earthquake Engineering*, 14, ISS8, pp. 1139-1171

Lecture 6: Presentation of practical case-studies

A number or real case studies will be presented and discussed with reference to the subjects of the five lectures.

The cases will include design and assessment of large bridges, buildings, isolated structures.

Homework assignments

Two simple assignments will be prepared, presented and discussed, with the aim of allowing the participants to practice the approaches presented to simple cases.