STRUCTURAL STABILITY AND NONLINEAR BEHAVIOR

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Contents

Summary

Structural stability and nonlinear behavior of structures are briefly explained in this chapter. Due to strong earthquake ground motion, the structural response goes over the linear elastic limit. If structures have large deformation capability, earthquake energy is absorbed by nonlinear and inelastic behavior. However, for structures with small deformation capability, structural failure may be triggered due to strong ground motion.

1. Introduction

When structures are subjected to strong earthquake ground motion, it is inevitable that dynamic response of structures goes over linear and elastic limit and goes into inelastic range. To assure safety of structures in the inelastic range, structural stability and nonlinear behavior have to be carefully examined. Recently, many loading tests on materials and structures, and numerical analyses on inelastic earthquake response have been conducted. In this chapter, the related technical words are explained briefly for understanding of recent inelastic earthquake resistant design methods.

2. Nonlinear Materials and Members

When strain of materials and deformation of members grow up due to increasing deformation of structures, the corresponding stress and restoring force are no longer proportional to the strain or deformation. This is called nonlinearity of materials and members; in other words, the relation between stress and strain or force and deformation does not show linear curves.

Usually, relations between stress and strain or force and deformation show softening type nonlinearity, which is favorable for seismic design of structures, because proportionally high stress and force will not be generated when the structures show large displacement due to large earthquake motion.

Exceptionally, hardening type nonlinearity is found in high strain range of rubber material which is used in seismic isolation bearings. The hardening nonlinearity can be used to prevent large deformation which occurs due to large earthquake, if large deformation has to be limited for some reasons like pounding with adjacent structures, etc.

3. Structural Limit States

For structural design against external loads, resistance of structures is represented by various structural limit states. Elastic limit state is a point below which elastic structural behavior is guaranteed. Ultimate limit state is a point up to which restoring force keeps increasing either elastically or inelastically. Deformation limit state is a point below which structural failure can be avoided. Fatigue limit state is a point below which structures do not fail due to high cycles of repeated loading. To assure function of structures, serviceability limit state is defined. Definition of it may differ depending on types of structures and external load.

4. Structural Failures

4.1. Buckling Failures

When the axial force in flexible columns (height is large compared to their section depth or diameter, slender columns) reaches a certain value, the columns will show unstable behavior which is called buckling. The instability is attributed to the fact that flexible columns cannot prevent the increase of lateral deformation once it is generated by any source (i.e., asymmetric section, non straight columns, eccentric axial load, small lateral force, etc).

Buckling failure occurs not only in columns along their full height, but also in thin structural plates under compressive stress. The latter case was found in many steel bridge piers due to the Kobe (Japan) Earthquake in 1995.

4.2. Impact Failures

When structural materials receive very fast (sudden) loading, they will show brittle failure. In usual structural design, fast loading may be defined as impact, if its stress loading rate is higher than 1.0 per second. Most cases of impact failure are due to collision of vehicles and structures. However, in Kobe (Japan) Earthquake in 1995, impact type failures were found in steel column sections, bridge girder connections, bridge bearings, connecting bolts etc., due to shock type earthquake loading in addition to the low temperature.

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Biographical Sketch

Hirokazu Iemura was born on July 21, 1945. He is now Professor of Structural Dynamics Laboratory, Graduate School of Civil Engineering, Kyoto University, Yoshida Hon-machi, Sakyo-ku, Kyoto 606-8501, Japan. He received B. Eng. in civil Engineering, M.Eng. in Earthquake Engineering and Dr. Eng. in Earthquake Engineering (Structural Vibration Control) from in 1968, 1970 and 1977 respectively, all from Kyoto University. He held various positions at his *alma mater*: 1974 – 1977   Research Associate, 1977 – 1979   Lecturer, 1979 – 1994 Associate Professor at Kyoto University, and 2002-2003 Chairman of the Faculty of Engineering and since1994 he is a Professor.

He is a member of many Committees and Teams: Committee of Japan Highway Design Specification, Committee for New Seismic Design Codes of Japan Railways, JSCE Committee for the Kobe Earthquake Disaster Investigation (Secretary), JSCE Sub-Committee for Seismic Isolation and Response Control (Chairman), The Priority Research Project of the Ministry of Education for Urban Earthquake Disaster (Secretary), The Investigation Team of the Ministry of Education for the 921 Ji-Ji Earthquake (Principal Investigator), and International Association of Earthquake Engineering (Secretary General)

His major contributions to earthquake engineering include: Field investigation of domestic earthquake damages and overseas earthquake damages, Establishment of real time substructure hybrid loading systems for testing of structural elements, Innovation of dynamic loading test equipment for a real-size vibrator-controlling damper (Japanese and US Patents), Innovation of unbonded reinforced concrete

structures (being applied for Japanese and US Patents), Innovation of pseudo-negative stiffness dampers (being applied for Japanese Patent), and over 150 research papers.