CONTROL OF SEISMIC RESPONSE OF TALL STRUCTURES

by

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1. Tall Structures
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CERTIFICATE

This is to certify that the thesis entitled, **"Control of Seismic Response of Tall Structures"**, being submitted by **Rajeev Dua** to the **Indian Institute of Technology, Delhi** for the award of the degree of **Doctor of Philosophy** in **Civil Engineering** is a record of the bona fide research work carried out by him under my supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of my knowledge has reached the requisite standard.

The materials contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The response of a structure to a seismic activity depends on the characteristics of the structural system and the seismic activity. There are a number of techniques to control/improve the seismic response of structures. These control-techniques are categorized as (i) active, (ii) semi-active and (iii) passive, and are used for improving the seismic response of (i) low-rise, (ii) medium-rise and (iii) high-rise or tall structures. The present study focuses on the passive control of seismic response of tall structures. Most of the present seismic response control techniques are based on isolation and are effective for low-rise building structures only. The need for developing an effective technique for controlling/improving the seismic response of tall structures led to the present study.

The primary objective of the present study is to develop an effective and a simple technique for controlling the seismic response of tall building structures. The study presents a technique, called seismic bifurcation (SB) (Dua and Jain, 2004), to control/improve the seismic response of tall building structures by way of (i) shifting the natural periods of the structural system to zones of low seismic input energy, and (ii) absorption/dissipation of a substantial part of seismic input energy by non-structural elements leading to minimal structural distress.

In SB, a conventional structural system is bifurcated into "flexible" and "stiff" subsystems. The flexible subsystem carries the major part of the system's mass, and its stiffness is kept at a minimum level required for its stability. The stiff subsystem possesses the major part of the lateral stiffness of the system. It is proposed to have the primary function/occupancy of the system, e.g. office/commercial/residential units, within the flexible subsystem and to have the major services of the system, e.g. lifts, staircases

etc., accommodated in the stiff subsystem. The two subsystems are connected to each other by links at various floor levels, and are also interconnected at each floor level with horizontal passages having suitable connection details to accommodate the relative displacements between the two subsystems during a seismic activity.

The strength of the SB technique lies in shifting the natural periods of the system to zones of low seismic force and energy, and in separating the natural periods of the two subsystems. The low stiffness associated with high mass in the flexible subsystem results in shifting the natural periods of the system to zones of low seismic force and energy. A well-defined separation between the periods of the two subsystems leads to relative movement between the two during a seismic activity, and provision of interconnecting links with appropriate damping results in absorption of substantial part of the seismic input energy to the system.

The study is carried out for a conventional building system (CBS), a seismically bifurcated system with identical horizontal rigid links (SBS-IHRL), a seismically bifurcated system with identical horizontal damping links (SBS-IHDL), six seismically bifurcated systems (SBSs) with different number of horizontal damping links across the height, and a seismically bifurcated system with optimized horizontal damping links (SBS-OHDL). These studies are done for nine different earthquake horizontal-acceleration records which represent a wide spectrum of earthquake characteristics. A number of parameters are analyzed to study the usefulness of the SB technique. These are: (i) total input energy to the system, (ii) energy absorbed by the structural components of the system i.e. structural distress energy, (iii) maximum inter-story drift, (iv) maximum displacement-at-top, (v) root–mean-square (RMS) displacement-at-top, (vi) maximum acceleration-at-top, (vii) RMS acceleration-at-top, (viii) maximum base shear, and (ix) maximum base moment. The results show a marked improvement in the response of seismically bifurcated systems (SBSs) over the CBS. The SBS-IHDL gives better results than the SBS-IHRL. The response further improves with SBS-OHDL. The response of an SBS improves with increase in the number of damping links across the height. Linear viscous dampers, which are commercially available, are proposed as the damping links.

All the studies are carried out with the time history analysis (THA) for the duration of the earthquake record. Nine earthquake records are chosen for the study covering a wide spectrum of earthquake characteristics, e.g. near-field or far-field, with or without velocity/displacement pulses, on-rock or on-soft-soil, ratio of the peak spectral acceleration and the peak ground acceleration (PGA) etc. The nine earthquake records chosen for the study are: (i) El Centro NS 1940, (ii) Northridge Santa Monica 1994, (iii) Imperial Valley 1979, (iv) Uttarkashi 1991, (v) Kobe 1995, (vi) San Fernando 1971, (vii) Mexico City 1985, (viii) Chile 1985 and (ix) Parkfield 2004. The single-degree-of-freedom analyses are carried out for all the nine earthquake records to obtain various response spectra for various damping values. The response spectra obtained and plotted are: (a) displacement response spectra, (b) pseudo-velocity response spectra, (c) pseudo-acceleration response spectra, (d) normalized (vis-à-vis PGA) pseudo-acceleration response spectra, and (e) input energy per unit mass spectra. These spectra are used to qualitatively explain the results obtained from the detailed THA. Quantitative studies are also carried out using response spectrum analysis (RSA). The results obtained by the THA and the RSA are then compared and explained. Three different methods of combination of modal responses are used. The results obtained by THA and RSA compare reasonably well.

The effect of the vertical component, along with the horizontal component, of an earthquake on the structural systems is studied for the CBS and the SBS-IHDL. The study is carried out for all the nine earthquake acceleration records. The results show that the additional energy getting into the system due to the vertical component of an earthquake results in higher structural distress energy, i.e. the horizontal damping links do not absorb/dissipate the additional input energy due to the vertical component of an earthquake, though these are very effective in absorbing/dissipating the input energy due to the horizontal component of an earthquake. To efficiently minimize the structural distress energy due to vertical component of an earthquake, a new SBS with horizontal and slanting damping links (SBS-HSDL) is proposed. The results show that the SBS-HSDL controls/improves the response of the structural system to an earthquake with horizontal and vertical components considerably.

To explore the usefulness of SB technique in seismic retrofitting, the same 30-storey CBS is chosen for study. A stiffer system is added and the two systems, the "existing" and the "added" one, are interconnected with damping links at all floor levels. Identical linear viscous dampers are chosen as damping links at all the floor levels between the existing and the added systems. Various parameters are studied to ascertain the usefulness of the SB in seismic retrofitting. A comparison of results shows that the seismic performance of the conventionally designed existing system improves considerably after retrofitting using SB technique. All the parameters point towards a marked improvement in the seismic response of the system after retrofitting using SB technique. The usefulness of SB technique is further studied for strengthening of a 30-storey seismically weak building system (WBS). A stiffer system than the WBS is added and the two are interconnected at the floor levels with damping links. The results obtained are promising.

The results of the studies show that the response of a tall building structure to a seismic activity improves when it is seismically bifurcated into flexible and stiff subsystems interconnected by links across the height. The improvement in response is achieved due to lengthening of the natural period of the structure corresponding to a lower seismic input energy zone, improvement in damping characteristics of the system and dissipation of a part of the input energy by interconnecting links. With SB, not only the total input energy to the system reduces, the fraction of it causing structural distress also reduces considerably. SBS-IHDL/OHDL show better results than SBS-IHRL, because the relative movement between the interconnected nodes of the two subsystems of SBS-IHDL/OHDL is favourably utilized by damping links in absorbing/dissipating a substantial part of the total input energy. The results of the studies further show that the SB technique can be useful in rehabilitating existing structures which are regarded as seismically weak, and in improving the seismic performance/response of conventionally-designed existing structures by way of seismic retrofitting.

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