STRUCTURAL CONTROL OF BUILDING FRAMES USING HYBRID PASSIVE DEVICE BASED ON ENERGY PRINCIPLES

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by

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Dedicated to my parents, my wife and my kid . . .

Certificate

This is to certify that the thesis entitled "**Structural Control of Building Frames using Hybrid Passive Device Based on Energy Principles**" being submitted by **Mr. Mahesh Babu Addala** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** in Civil Engineering is a record of original bonafide research work carried out by him under our supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirements for the degree of Doctor of Philosophy.

The results 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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Mahesh Babu Addala

Abstract

In this thesis, a novel hybrid device developed by combining friction and viscoelastic dampers is evaluated for performance based design criteria for multistory buildings. This device exhibits enhanced performance for structural vibration control under multi-hazard excitation by combining the benefits of individual elements and their drawbacks, namely viscoelastic and friction dampers. The relative movement of each element is trailed in a pre-designed manner such that independent hysteretic characteristics under small and large deformations will be facilitated, which enhances multi-level vibration control. This thesis aims to develop an improved design methodology for structures installed with the new hybrid device, which can work for both wind and seismic (minor and major earthquakes) events. The thesis is divided into two parts. The first part focuses on the formulation of a simplified and powerful design tool for designing the structure equipped with the hybrid device, which is similar to that of the current prescriptive seismic design. The numerical force-deformation characteristic of the hybrid passive device is validated using experimental results. The theoretical development of the structure with the hybrid device is validated using nonlinear dynamic analysis of the single degree of freedom (SDOF) and multi-degree of freedom system (MDOF) systems. The influence of hybrid devices is explicitly considered in terms of the response reduction factor, similar to traditional seismic design. The proposed design is examined using a six-storey building. Detailed seismic evaluation is carried out using nonlinear time-history analysis. The structural

performance is obtained for a two-level intensity level (i.e., a design based earthquake and a maximum considered earthquake event).

In the second part of the thesis, the design of the structure equipped with the hybrid device is implemented into a performance-based earthquake engineering framework using an energy-balance concept. A large number of nonlinear time-domain simulations for near-field and far-field ground motion are used to predict the preselected target drift and the yield mechanism assumed in the design of six- and twelve- storeyed buildings equipped with a hybrid device. A twenty-story building is also used to demonstrate an integrated design approach for wind and seismic loads. When subjected to wind and earthquake-induced excitations, the numerical response of the structure equipped with the hybrid device shows significantly improved performance. In addition, a comparative study of low to high-rise buildings designed using current design practice, performance-based design, and a hybrid device is also presented. It demonstrates the effectiveness of the hybrid device in controlling multi-hazard excitation. In a nutshell, the theoretical development of this thesis will assist structural designers in improving the performance-based design of low to high-rise structures by incorporating hybrid devices.

सामान्य सारांश

इस थीसिस में, बहुमंजिला इमारतों केप्रदर्शन आधारित डिजाइन मानदंड के लिए घर्षण और विस्कोलेस्टिकडैम्पर्स के संयोजन से विकसित एक नया हाइब्रिड डिवाइसका मूल्यांकनकिया गया है।यह उपकरण,वैयक्तिक तत्वों जैसे विस्कोलेस्टिक और घर्षण डैम्पर्सके लाभों और कमियांको मिलाकर बहु-खतरा उत्तेजनाके अंतर्गत संरचनात्मक कंपन नियंत्रण के लिए उन्नत प्रदर्शन प्रदर्शित करता है।प्रत्येक तत्वके सापेक्ष गति कोपूर्व-डिज़ाइन तरीके में इस तरह से फंसाया जाता हैकिछोटे और बड़े विकृतियों के तहतस्वतंत्र हिस्टेरेटिक विशेषताएँको सुविधा होगी, जो बहुस्तरीय कंपन नियंत्रणको बढ़ाता है।इस थीसिस का उद्देश्य,नए हाइब्रिड डिवाइस के साथ स्थापित संरचनाओं के लिएएक बेहतर डिजाइन पद्धति विकसित करना है,जो दोनों हवा और भूकंपीय (मामूली और बड़े भूकंप) घटनाएंके लिए काम कर सकता है।

थीसिस दोभागों में विभाजित है। पहला भाग हाइब्रिड डिवाइस से लैस संरचना को डिजाइन करने के लिएसरलीकृत और शक्तिशाली डिजाइनसाधन के निर्माण पर केंद्रित है, जो वर्तमान अनुवांशिक भूकंपीय डिजाइन समान है।हाइब्रिड निष्क्रिय डिवाइस की संख्यात्मक बल-विरूपण विशेषताकी पुष्टि,प्रायोगिक परिणामों द्वारा की गयी है।हाइब्रिड डिवाइस के साथ संरचना के सैद्धांतिक विकास का सत्यापन,सिंगल डिग्री ऑफ फ्रीडम (एसडीओएफ) और मल्टी डिग्री ऑफ फ्रीडम (एमडीओएफ़) का नॉन-लीनीयर डाइनैमिक विश्लेषणद्वारा किया गया है। हाइब्रिड उपकरणों का प्रभाव स्पष्ट रूप से पारंपरिक भूकंपीय के समान रेस्पोंस रिडक्शन फेक्टरमें किया गया है। छह मंजिला इमारत का उपयोग करके प्रस्तावित डिजाइन की जांच की गयी है।नॉन-लीनीयर समय-इतिहास विश्लेषण का उपयोग करके विस्तृत भूकंपीय का मूल्यांकन किया गया है। दो-स्तरीय तीव्रता(यानी, डिजाइन आधारित भूकंप और अधिकतम मानी जाने वाली भूकंप घटना) के स्तर के लिए संरचनात्मकवीप्रदर्शन प्राप्त किया गया है ।

थीसिस के दूसरे भाग में ऊर्जा-संतुलन अवधारणा का उपयोगकरते हुए हाइब्रिड डिवाइस से सुसज्जित संरचना का प्रदर्शन-आधारित भूकंप इंजीनियरिंग ढांचे में लागू किया गया है।बड़ी संख्या में निकट-क्षेत्र और दूर-क्षेत्र की जमीनी गति के लिए नॉन-लीनीयर समय-डोमेनसिमुलेशका उपयोगहाइब्रिड डिवाइस से लैस छह और बारह मंजिला इमारतों में पूर्व-चयनितलक्षित बहाव और उपज तंत्र को प्रेडिक्ट करने के लिए किया गया है। पवन और भूकंपीय भारके लिए एक एकीकृत डिजाइन दृष्टिकोण का प्रदर्शन करने के लिए एक बीस मंजिला इमारत का भी उपयोग किया गया है।हवा और भूकंप से प्रेरित उत्तेजनाओं के अधीन,

हाइब्रिड डिवाइस से लैस संरचना का संख्यात्मक प्रतिक्रियाकाफी बेहतर प्रदर्शन दिखाता है।इसके अलावा, वर्तमान डिज़ाइन अभ्यास द्वारा निम्न से ऊंची इमारतों का डिजाइन, प्रदर्शन-आधारित डिज़ाइन और एक हाइब्रिड डिवाइस का तुलनात्मक अध्ययनपेश कियागया है । यह बहु-खतरे उत्तेजनाको नियंत्रित करने में हाइब्रिड डिवाइस की प्रभावशीलता को प्रदर्शित करता है। संक्षेप में, इस थीसिस के सैद्धांतिक विकास द्वारा संरचनात्मक डिजाइनर को लो टू हाइ राइस संरचनाओं के प्रदर्शन-आधारित डिजाइन में हाइब्रिड उपकरणों को शामिल करके सुधार करने में सहायता मिलेगी।

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List of Acronyms

APD	Average period and damping
ASE	Average stiffness and energy
DBD	Displacement based design
DBE	Design based earthquake
EL-SDOF	Equivalent linear SDOF system
EP-SDOF	Elastic-perfectly-plastic SDOF system
FD	Friction damper
FF	Far-field ground motions
IIT	Indian Institute of Technology
MCE	Maximum considered earthquake
MDOF	Multi-degree of freedom system
MRF	Moment resisting frame
MRFFD	Moment resisting frame system with
MRFHD	Moment resisting frame system with
MRHDF	Moment resisting frame with the hy
MRI	Mean Return Interval
NF	Near-field ground motions
PBD	Performance-based design
PBPD	Performance-based plastic design
PBSD	Performance-based seismic design
PED	Passive energy dissipation
PBEE	Performance-based earthquake engineering
PEER	Pacific Earthquake Engineering Res
R	Response reduction factor
RC	Reinforced concrete
RPI	Relative performance index

SC	Self-centering device
SDOF	Single degree of freedom
SMA	Shape memory alloys
VE	Viscoelastic damper