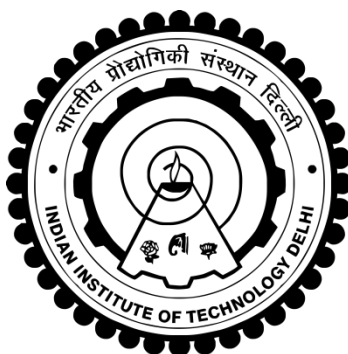


# **SITE DEPENDENT SEISMIC EVALUATION OF BUILDINGS IN DELHI REGION**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI  
SEPTEMBER 2018**

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*by*

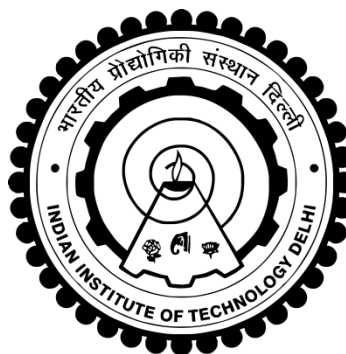
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*Submitted*

*in fulfilment of the requirements of the degree of Doctor of Philosophy*

*to the*



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**SEPTEMBER 2018**

*Dedicated to*  
*maa Sharda and*  
*my mother Smt. Suman Shrivastava*

## **CERTIFICATE**

This is to certify that the thesis entitled, “**Site Dependent Seismic Evaluation of Buildings in Delhi Region**” being submitted by **Mr. Hemant Shrivastava** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a bonafide record of research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard fulfilling the requirement 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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**Hemant Shrivastava**

## ABSTRACT

Many strong earthquakes (Mexico city 1985; Northridge 1994; Kobe 1995; Kocaeli 1999; Bhuj 2001) demonstrated that damage of buildings depends strongly on the effect of local site amplification. Response spectra of seismic codes incorporate the site effects either in the form of soil categories (IS1893 (Part I): 2016) or site amplification factors (IBC 2000). Generally for important structures and in situations where damage is expected to be high, it is recommended that in addition to the codal provision, detailed site-dependent analysis which includes generation of strong ground motion at bedrock level, propagating it through soil layers, arriving at the design ground motions and response spectra at surface should also be carried out.

In this study, first, simulation of far-field earthquake from the Himalayan region at bedrock level in Delhi region has been carried out using specific barrier model. The parameters (global stress drop and local stress drop) of specific barrier model are estimated from the observed data of Uttarkashi and Chamoli earthquakes in the Himalayan region. The simulated  $S_a$  and  $PGA$  values have shown a similar trend as observed in the Himalayan region. This calibrated specific barrier model for far field earthquakes is then used to simulate in Delhi region earthquakes at four sites at which earthquake records of Chamoli earthquake are available. It is seen that specific barrier model predicts better  $PGA$  values than the stochastic finite-fault method at two out of four sites. Next for near-fault earthquakes, using specific barrier model, high frequency ground motion at bedrock level in Delhi region is obtained. The parameters of specific barrier model are estimated by comparing the simulated earthquake records with the observed records of Delhi earthquake ( $M_w$  4.1, 2007). In order to incorporate forward directivity effect (Somerville et al. 1997), the hybrid methodology (Halldorsson et al. 2011) that superimposes high-frequency ground motion and long period velocity pulse has been used.

The above specific barrier models then used to simulate the scenario far-field earthquakes ( $M_w$  7.5, 8.0 and 8.5) and near-fault earthquakes without and with long period velocity pulse ( $M_w$  5.0, 5.5 and 6.0) at bedrock level in Delhi region.

Subsequently, ground motions have been generated at three sites with different geotechnical characteristics in Delhi region for the scenario far-field earthquakes ( $M_w$  7.5, 8.0 and 8.5) and near-fault earthquakes ( $M_w$  5.0, 5.5 and 6.0) without and with long period velocity pulse at  $R = 10$  km and 20 km. The  $S_a$  at the three sites are quite different for the far-field earthquakes and near-fault earthquakes and cause different degree of damages. The Park-Ang damage index is used to compute overall damage ( $DI_{overall}$ ) of buildings.  $DI_{overall}$  is computed for three-story (B1) and ten-story (B2) building frames at three sites. It is observed that  $DI_{overall}$  at three sites varies significantly for far-field and near-fault earthquakes. It is observed that  $DI_{overall}$  for near-fault earthquakes with long period velocity pulse is higher than for near-fault earthquakes without long period velocity pulse. It is further observed that near-fault earthquake without and with long period velocity pulse may cause damages higher than far-field earthquakes. Comparison between damages of the buildings for scenario far-field and near-fault earthquakes with damage resulting from IS1893 compatible time history has also been carried out. Although, all the three sites fall in the Type II soil sites as per IS1893 (Part I): 2016, it is observed that damage for buildings at three different sites varies significantly. While, damage of buildings for IS1893 compatible time history for Type II soil site is constant. Therefore, a methodology is required for everyday design for rapid estimation of damage of buildings for scenario earthquakes at different sites.

Finally, a neural network based methodology has been proposed to rapidly estimate the site-dependent damage index ( $DI_{SD}$ ) for qualitative assessment of buildings for far-field earthquakes and near-fault earthquakes without and with long period velocity pulse. The methodology is demonstrated for Delhi region. Detailed qualitative assessment serves the

purpose of determining if detailed site dependent analysis is required to be carried out. The modified Park-Ang damage index has been chosen for compute the damage. The sensitivity analysis is carried out to identify the probable seismic, soil and structural parameters that can influence the  $DI_{SD}$  and chosen as the input parameters. The closed-form expressions are obtained from the weights and biases of the developed neural networks. The proposed expressions predict  $DI_{SD}$ . The  $DI_{SD}$  obtained from the proposed expressions are compared with nonlinear analysis of RC building frame for different far-field and near-fault earthquakes at different sites. The proposed neural networks predict better qualitatively damage assessment of buildings than reported in the literature (Karbassin et al. 2012).

## सार

कई मजबूत भूकंप (मेक्सिको शहर 1985; नॉर्थ्रिज 1994; कोबे 1995; कोकाली 1999; भुज 2001) ने दर्शाया कि इमारतों का नुकसान स्थानीय साइट प्रवर्धन के प्रभाव पर निर्भर करता है। भूकंपीय संहिता के प्रतिक्रिया स्पेक्ट्रा साइट मिट्टी श्रेणियों (आईएस 18 9 3 (भाग I): 2016) या साइट एम्पलीफिकेशन कारकों (आईबीसी 2000) के रूप में साइट प्रभाव को शामिल करते हैं। आम तौर पर महत्वपूर्ण संरचनाओं और ऐसी परिस्थितियों में जहां क्षति उच्च होने की उम्मीद है, यह सिफारिश की जाती है कि संहिता प्रावधान के अतिरिक्त, विस्तृत साइट-निर्भर विश्लेषण जिसमें आधार स्तर पर मजबूत ग्राउंड गति की पीढ़ी, मिट्टी परतों के माध्यम से इसे प्रसारित करना, सतह पर डिजाइन ग्राउंड मोशन और प्रतिक्रिया स्पेक्ट्रा भी किया जाना चाहिए।

इस अध्ययन में, पहले, दिल्ली क्षेत्र में आधार स्तर पर हिमालयी क्षेत्र से दूर-क्षेत्र के भूकंप का सिमुलेशन विशिष्ट बाधा मॉडल का उपयोग करके किया गया है। विशिष्ट बाधा मॉडल के पैरामीटर (वैश्विक तनाव ड्रॉप और स्थानीय तनाव ड्रॉप) हिमालयी क्षेत्र में उत्तरकाशी और चमोली भूकंप के मनाए गए आंकड़ों से अनुमानित हैं। वर्णक्रमीय त्वरण और पीजीए मूल्यों ने हिमालयी क्षेत्र में देखी गई समान प्रवृत्ति दिखाई है। दूर-दराज के भूकंप के लिए यह कैलिब्रेटेड विशिष्ट बाधा मॉडल तब दिल्ली क्षेत्र के भूकंपों में चार साइटों पर अनुकरण करने के लिए प्रयोग किया जाता है, जहां चमोली भूकंप के भूकंप के रिकॉर्ड उपलब्ध हैं। यह देखा जाता है कि विशिष्ट बाधा मॉडल चार साइटों में से दो में स्टोकास्टिक परिमित-गलती विधि की तुलना में बेहतर पीजीए मानों की भविष्यवाणी करता है। निकट अवरोध भूकंप के लिए, विशिष्ट बाधा मॉडल का उपयोग करके, दिल्ली क्षेत्र में आधार स्तर पर उच्च आवृत्ति ग्राउंड गति प्राप्त की जाती है। विशिष्ट बाधा मॉडल के मानकों का अनुमान दिल्ली भूकंप ( $M_w 4.1$ , 2007) के मनाए गए रिकॉर्ड के साथ नकली भूकंप रिकॉर्ड की तुलना करके किया जाता है। आगे निर्देशकता प्रभाव (सोमरविले एट अल. 1997) को शामिल करने के लिए, हाइब्रिड पद्धति (हैल्डर्सन एट अल. 2011) जो उच्च आवृत्ति ग्राउंड गति और लंबी अवधि के वेग नाड़ी का अतिसंवेदनशील उपयोग किया गया है।

इसके बाद उपरोक्त विशिष्ट बाधा मॉडल दिल्ली क्षेत्र में आधार स्तर पर लंबी अवधि के वेग पल्स ( $M_w$  5.0, 5.5 और 6.0) के बिना और दूर-दराज के भूकंप ( $M_w$  7.5, 8.0 और 8.5) और निकट-गलती भूकंप के परिदृश्य को अनुकरण करने के लिए उपयोग किए जाते थे।

इसके बाद, दूरदराज के भूकंप ( $M_w$  7.5, 8.0 और 8.5) और निकट भूकंप ( $M_w$  5.0, 5.5 और 6.0) परिदृश्य के लिए दिल्ली क्षेत्र में अलग-अलग भू-तकनीकी विशेषताओं के साथ तीन साइटों पर जमीन की गति उत्पन्न की गई है और लंबी अवधि के साथ  $R = 10$  किमी और 20 किमी पर वेग पल्स। दूरदराज के भूकंप और निकट भूकंप के कारण तीन साइटों पर सा काफी अलग हैं और विभिन्न नुकसान के कारण हैं। पार्क-एंग क्षति सूचकांक भवनों के समग्र नुकसान ( $DI_{overall}$ ) की गणना करने के लिए प्रयोग किया जाता है।  $DI_{overall}$  की गणना तीन मंजिला (बी 1) और दस- मंजिला (बी 2) इमारत के फ्रेम के लिए तीन साइटों पर की जाती है। यह देखा गया है कि तीन साइटों पर  $DI_{overall}$  दूर-क्षेत्र और निकट भूकंप के लिए महत्वपूर्ण रूप से भिन्न होता है। यह देखा जाता है कि लंबी अवधि के वेग नाड़ी के साथ निकट भूकंप के लिए  $DI_{overall}$  लंबे समय तक वेग पल्स के बिना निकट भूकंप के मुकाबले ज्यादा है। यह आगे देखा गया है कि लंबी अवधि के वेग पल्स के बिना और दूर-दराज के भूकंप दूर-क्षेत्र के भूकंप से अधिक नुकसान का कारण बन सकते हैं। आईएस 18 9 3 संगत समय इतिहास के परिणामस्वरूप क्षति के साथ इमारतों के नुकसान और दूर-दराज के भूकंप के लिए भवनों के नुकसान के बीच तुलना भी की गई है। हालांकि, आईएस 1893 (भाग I): 2016 के अनुसार, सभी तीन साइटें टाइप II मिट्टी साइटों में आती हैं, यह देखा गया है कि तीन अलग-अलग साइटों पर भवनों के लिए नुकसान में काफी भिन्नता है। हालांकि, टाइप II मिट्टी साइट के लिए आईएस 1893 संगत समय इतिहास के लिए भवनों की क्षति स्थिर है। इसलिए, विभिन्न साइटों पर परिदृश्य भूकंप के लिए इमारतों के नुकसान के तेजी से आकलन के लिए रोजमर्रा के डिजाइन के लिए एक पद्धति की आवश्यकता है।

अंत में, लंबी अवधि के वेग पल्स के बिना और दूर-दराज के भूकंप और निकट भूकंप के लिए इमारतों के गुणात्मक मूल्यांकन के लिए साइट-निर्भर क्षति सूचकांक ( $DI_{SD}$ ) का तेजी से अनुमान लगाने के लिए एक तंत्रिका नेटवर्क आधारित पद्धति का प्रस्ताव दिया गया है। दिल्ली क्षेत्र के लिए पद्धति का प्रदर्शन किया जाता है। विस्तृत गुणात्मक मूल्यांकन यह निर्धारित करने के उद्देश्य से कार्य करता है कि विस्तृत साइट निर्भर विश्लेषण करने की आवश्यकता है या नहीं। संशोधित पार्क-एंग क्षति सूचकांक को क्षति की गणना के लिए चुना गया है। संवेदनशीलता विश्लेषण संभावित

भूकंपीय, मिट्टी और संरचनात्मक मानकों की पहचान के लिए किया जाता है जो  $DI_{SD}$  को प्रभावित कर सकते हैं और इनपुट पैरामीटर के रूप में चुने जा सकते हैं। बंद-स्वरूप अभिव्यक्ति विकसित तंत्रिका नेटवर्क के वजन और पूर्वाग्रहों से प्राप्त की जाती हैं। प्रस्तावित अभिव्यक्ति  $DI_{SD}$  की भविष्यवाणी करते हैं। प्रस्तावित अभिव्यक्तियों से प्राप्त  $DI_{SD}$  की तुलना अलग-अलग जगहों पर विभिन्न दूरदराज के इलाकों और निकट भूकंप के लिए प्रबलित कंक्रीट इमारत फ्रेम के गैर-लाइन विश्लेषण के साथ की जाती है। प्रस्तावित तंत्रिका नेटवर्क बेहतर गुणात्मक रूप से भविष्यवाणी करते हैं।

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