

**GROUND RESPONSE ANALYSES AND LIQUEFACTION
STUDIES FOR DELHI**

By

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DEPARTMENT OF CIVIL ENGINEERING

Submitted

in fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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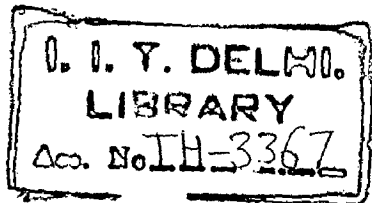


INDIAN INSTITUTE OF TECHNOLOGY, DELHI

INDIA

DECEMBER 2006

1. Seismic hazards
2. Earthquakes



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Dedicated

to

MY MOTHER

CERTIFICATE

This is to certify that the thesis entitled, “**Ground Response Analyses and Liquefaction Studies for Delhi**” being submitted by **Hanumantharao Ch** to the Indian Institute of Technology, Delhi for the award of degree of **Doctor of Philosophy** is a bonafide record of research work carried out by him under my supervision and guidance. The thesis work, in my 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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ACKNOWLEDGEMENTS

The time I had spent at IIT Delhi has been enriching both professionally and personally. I sincerely thank my research supervisor Dr. G. V. Ramana, Associate Professor, Department of Civil Engineering, Indian Institute of Technology Delhi for his valuable guidance, inspiration and motivation at every stage of the present work. The knowledge and experience that I have gained working with him will forever be valuable and appreciated. I gratefully acknowledge his valuable suggestions and generous support including comprehensive corrections on the draft versions of this thesis.

I wish to express my thanks to Prof. A. K. Nagpal, Head, Department of Civil Engineering for his valuable comments as Chairman of Student Research Committee. Thanks are due to the members of the Student Research Committee Prof. T. K. Datta and Dr. S. P. Singh for their comments and critical review of the work that helped me to a great extent in improving the quality of my work.

I am very thankful to Prof. G. V. Rao, Prof. K. G. Sharma, Prof. Manoj Datta, Prof. K. S. Rao, Prof. J. M. Kate, Dr. K. K. Gupta, Dr. J. T. Shahu and Dr. K. Ramachandra Rao for their constant moral support, technical advice and help provided at various stages of this work.

The help rendered by Prof. S. K. Singh, UNAM, Mexico and Prof. A. Papageorgiou, University of Patras, Greece in making me understand seismology and generation of strong ground motion is gratefully acknowledged. Thanks are also due to Prof. Ahmed Elgamal, UCSD, San Diego; Prof. Amir, NGI, Norway; Prof. T. Ramamurthy; Prof.

Chandan Ghosh, NIDM; Mr. Nakul Dev, CSMRS; for their valuable discussions regarding the test methodologies and parameters adopted at several stages of this work.

The cyclic triaxial system used in the current work was procured through the generous financial support provided by Seismology Division, Department of Science and Technology and is gratefully acknowledged. I am also thankful to Olson Instruments Co., USA, Wykeham Farrance International Ltd., UK, and Ultra Technologies Ltd, New Delhi for their support during the rough times I had with the equipments. I specially acknowledge Larry Olson, Fred Evans, Saif Mobin and Neeraj Chadda for their timely help in times of equipment breakdown.

The help and assistance provided by the laboratory and departmental staff Omprakash, Gosain, Biswas, Manoj, Jodhraj, Neeraj, Munnilal, Bikram, Agarwal, Bali, Ramkumar and Kaushik is greatly acknowledged.

My special thanks to all my friends and colleagues Mallikarjuna, Raveendra Babu, Ramana Reddy, Ravi Shankar, Arvind Jain, Maheedhar, Vittal, Vidya Sagar, Yoseph, Kamatchi, Varun, Amardeep, Sandeep, Shiva, Sridhar, Sudhakar, Sri Hari, Kiran, Raja Ramesh and to my fellow students.

Finally, my heartfelt gratitude to my family members for their unconditional love, constant inspiration and encouragement through out this work, I am sure without their support, this thesis could not be completed.


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ABSTRACT

Delhi and its surroundings are seismically active. Retrofitting of existing structures or design of new structures to mitigate the seismic hazard requires site specific ground response analysis and evaluation of liquefaction susceptibility of local soil deposits to begin with. Site specific ground response analysis requires dynamic soil properties such as shear wave velocity, modulus reduction and damping curves of local soil deposits even to conduct a simple equivalent linear analysis. In addition, either a measured or artificially generated ground motion is also required to be used as an input excitation. Evaluation of liquefaction susceptibility requires cyclic strength curves of local soil deposits. In this thesis, an effort has been made to generate a database of reliable input parameters like dynamic and cyclic properties of local soil deposits and provide useful correlations and curves for use by engineers. These parameters can be readily integrated for any other applications such as microzonation, soil structure interaction studies, assessment of seismic slope stability etc.

As there is very little or no recorded ground motion in Delhi, stochastic models are used to generate the strong ground motion due to postulated earthquake scenarios. A long distance earthquake of moment magnitude 8.5 from central seismic gap as reported in the literature and six earthquake scenarios from local sources are considered in the current study. Earthquake from local sources are of moment magnitude 6 and 6.5 occurring at distances of 25, 50 and 100 *km* respectively. After critically reviewing the literature, appropriate source models and seismological parameters are adopted to generate the strong ground motion. Seismological parameters to be used with two different source models are tabulated for further use by other researchers.

Shear wave velocity, the fundamental engineering property in any dynamic analyses is usually not measured in regular geotechnical investigations due to cost and expertise required. In the current study, the Spectral Analysis of Surface Waves (*SASW*) technique which is nondestructive and portable is used to evaluate shear wave velocity profile at different locations to a depth of 24 to 32 m depending on site conditions. Based on the measured shear wave velocities at several locations in Delhi, V_{s30} is estimated and is observed that the sites of Delhi belong to four site categories (*A*, *B*, *C*, and *D*) as per *IBC 2003*. In addition, useful empirical correlations between shear wave velocity and *N* values are developed for preliminary design purposes by engineers.

Since varying amounts of silt are found mixed with sand in different regions of Delhi, four combinations of sand-silt mixtures are selected to be representative of local soil deposits, for laboratory characterization of cyclic properties of local soil deposits. Strain controlled cyclic triaxial tests as per *ASTM D3999* were conducted to generate the modulus reduction and damping curves of local soil. It is observed that lower bound values for sand developed by Seed and Idriss (1970) can be used to represent local soil deposits.

Ground response analyses using the equivalent linear analysis technique implemented in the popular *SHAKE* program has been conducted at four representative sites wherein shear wave velocity has been measured to qualitatively assess the ground motion amplification. Stochastically generated ground motions are used as an input motion along with other engineering properties either measured in situ or in the laboratory. The resulting free field acceleration response spectra are compared with Indian standard codal provisions. The influence of depth to the bedrock is also qualitatively assessed. It is also

observed that the *SHAKE* program is not the best computational technique for estimating the free field ground response due to local sources.

Stress controlled cyclic triaxial tests as per *ASTM D5311* were conducted on loose Yamuna sand as well as loose Yamuna sand mixed with different percentages of nonplastic fines. Cyclic strength curves are generated for representative soil types. Influence of nonplastic fines on the liquefaction susceptibility of Yamuna sand is examined and is observed that fines content more than 15% decreases the liquefaction resistance. Influence of other parameters such as density, confining pressure, and frequency of load application on liquefaction susceptibility of Yamuna sand is also investigated. Based on the stress controlled cyclic triaxial tests, the rate of generation of excess pore water pressure with cyclic ratio is also characterized in accordance with the standard formulation available in literature and this can be used directly to represent the pore water pressure generation in any dynamic analysis.

Liquefaction susceptibility at two representative soil deposits (sand and sandy silt) is evaluated using simplified approach based on measured N values and shear wave velocity. In addition, cyclic strength curves developed are also used to estimate the zone of liquefaction. The zone of liquefaction from the three approaches is compared.

Finally conclusions from the current work are presented, limitations are highlighted and future research direction to overcome the deficiencies in the current work is suggested.

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