

**EFFECT OF FOUNDATION COMPLIANCE AND OF
ROTATIONAL COMPONENTS OF EARTHQUAKE ON
SEISMIC RESPONSE OF TORSIONALLY COUPLED
MULTISTOREY BUILDINGS**

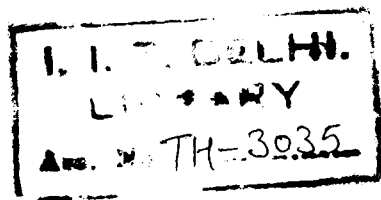
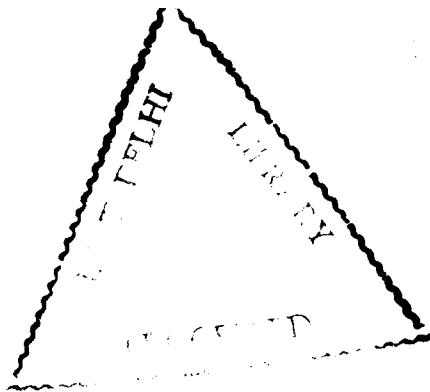
By
M.K.MAHESH

Submitted
in fulfilment of the requirements
for the award of the degree of
DOCTOR OF PHILOSOPHY



to the
Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
New Delhi-110016, INDIA
AUGUST - 2000

-2429



TM

624.042.7:69.032.2

MAH-E

Earthquake hazard analysis;
Tall building

Dedicated to

***Lord Madhur
Shri Ganapathy:***

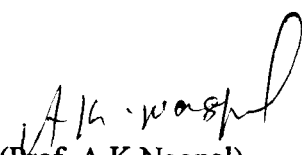
Parents and

S. Chatterjee

CERTIFICATE

This is to certify that the thesis entitled, “**Effect of Foundation Compliance and of Rotational Components of Earthquake on Seismic Response of Torsionally Coupled Multistorey Buildings**”, being submitted by Mr. M. K. Mahesh to 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. Mr. M. K. Mahesh has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to the best of my knowledge has reached the requisite standard.

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


(Prof. A.K. Nagpal)
Dept. of Civil Engineering
Indian Institute of Technology
Hauz Khas, New Delhi-110016
India

ACKNOWLEDGEMENTS

It gives the author a great pleasure in expressing his regards and profound sense of gratitude to Dr. A. K. Nagpal, Professor of Civil Engineering Department, Indian Institute of Technology, New Delhi, for his perspective supervision, invaluable guidance and constant encouragement throughout the period of the Doctoral Programme.

The author is grateful to the Head and faculty of Civil Engineering Department and also the staffs of Computational Laboratory for their co-operation and providing computer facilities round –the- clock in the Department.

The author acknowledges his sincere thanks to the authorities of the K.V.G. College of Engineering, Sullia, Karnataka for sponsoring him for the Ph.D. programme.

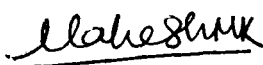
The work of this dimension could not have been possible without the encouragement and cooperation of Mr. N. Santhosh Rao, Prof. V.Seshadri, Mrs. Seshadri, Miss. Smitha, Prof. S.S. Murthy, Mrs. Murthy, Mrs. Rashmi, Prof. B. Chandra, Prof. Girija Jayaraman, Prof. C. P. Ravi Kumar, Dr. M. R. Shenoy, Dr. P.V. Madhusudan Rao, Dr. ShriRam Hegde, Dr. Jayadeva and Prof. S.N. Singh.

The author is grateful to Dr. A.K. Jain, Prof. V. B. Deshpande, Dr. Bhattacharjee, Dr. G. V. Ramana, Dr.K.C. Iyer, Dr. Ashok Gupta, Prof. A. Varadarajan and Prof. Y. Nath for their kind help and encouragement.

The author acknowledges sincere thanks to Mr.M. Nagesh, Mr.D. Madhu, Mr. K.M. RamKrishna, Mr. B.G. Prasad, Mr. R.V. Mahendra Gowda, Mr. Ravi Sharma, Mr. Javed Ahamed Bhat, Miss. Savita, Mr. Amit Kumar Agarwal, Mr. Shivanagendra, Ms. Gayathri, V., and Mrs. Sheela Evangeline for their help and encouragement.

The author is highly grateful to Dr. K. Rama Mohan Rao, Dr. N. Tanwani, Dr. Y. Singh, Dr. Mak, and Dr. Ashok Gupta.

Finally, the author acknowledges sincere thanks to his family members for their encouragement and moral support.


(M.K.Mahesh)

ABSTRACT

Multistorey buildings are often supported on raft foundation with piles. The usual assumption that the base motion of a structure is the same as the ground motion is valid for the structures supported on rigid foundations. For a structure having compliant foundation, the motion of the footing is different from that of the soil and also has a rocking component. For symmetric buildings resting on elastic halfspace the effect of foundation compliance has been reported to result in reduced response. Limited research work on the seismic response of torsionally coupled multistorey buildings resting on compliant foundation has been reported in the literature. However, most of the work is confined to a single storey framed building or a multistorey framed building idealised as a single storey framed building resting on elastic halfspace. Recently, some studies have been carried out on the seismic analysis of torsionally coupled multistorey building resting on layered soil stratum. No work has been reported in the literature on the seismic analysis of torsionally coupled multistorey buildings comprising of frames and shearwalls supported on raft foundation with piles passing through homogeneous or layered soil stratum. The present study, in part, is an effort in this direction.

Soil-Pile behaviour based on the plane strain idealisation has been used to determine impedance functions of the raft-pile system. For rigid raft five degrees of freedom (d.o.f), a translation and a rotation about each of the horizontal axes and a rotation about the vertical axis, are considered.

Superstructure comprising of frames and shearwalls in random arrangement in floor plan is idealised as a discrete 3D model. Three global d.o.f at each floor level (two horizontal translations and a rotation about vertical axis) are considered. The lateral stiffness matrices of stiffening elements of size $(N \times N)$, are first obtained by condensation and are used to form a global stiffness matrix of size $(3N \times 3N)$, where N is the number of floors in building.

For analysis of foundation-superstructure system the substructure method has been used. Equations of motion of the system incorporating foundation impedance functions are written in time domain, converted into frequency domain and the response obtained. Using Inverse Fast Fourier Transform the seismic response is then determined.

Two seismic inputs, at the footing level and at the bedrock level are considered in the present investigation. When the seismic input is at the bedrock level, earthquake is assumed to propagate vertically upwards in shear mode. Time histories of earthquake are generated from the specified response spectra of IS Code in the case of input at the footing level and from the Kanai-Tejimi filter transfer spectral density function, in the case of input at bedrock level.

It is shown that the distribution of storey shears along the height in the building or in the stiffening elements obtained assuming the foundation to be compliant is not the same as that obtained assuming the foundation to be fixed.

Recently the effect of torsional component of earthquake has received attention. In these studies coherency loss in spatially varying ground motion is considered. The studies relate to a single storey framed building. Not much work is reported on the effect of rocking component of earthquakes. In the present work the effect of torsional and rocking component of earthquake on the response of torsionally coupled multistorey buildings comprising of frames and shearwalls is studied. The Superstructure is modelled as described above. The rotational and rocking component of ground motion are generated from the spectrum given by Buchholdt, H.A.

It is shown that the response due to rocking and torsional motions is significant. It is further shown that the variations of responses along the height due to translational and torsional motions are different but are similar for translational and rocking motions.

LIST OF CONTENTS

CHAPTER	DESCRIPTION	PAGE NO
	Abstract	i
	List of Contents	iii
	List of Figures	vii
	List of Tables	xix
CHAPTER-1	INTRODUCTION AND LITERATURE REVIEW	
1.1	Introduction	1
1.2	Literature Review	2
1.2.1	Impedance Functions	2
1.2.2	Dynamic Response of Building	4
1.2.3	Response of Buildings to Torsional and Rocking Components of Earthquake	6
1.2.4	Methods of Response Analysis	6
1.2.5	Superstructure-Foundation Interaction Effects	8
1.3	Objectives of the Present Work	9
CHAPTER-2	IMPEDANCE FUNCTIONS OF RAFT-PILE FOUNDATIONS	
2.1	Introduction	11
2.2	Soil Resistance to Pile Motion	11
2.2.1	Low Frequency Corrections	13
2.3	Impedance Function of Single Pile	14
2.3.1	Vertical Motion	14
2.3.2	Flexural Motion	16
2.4	Computer Program Verification	18
2.5	Impedance Function Matrix of Raft-Pile System	19

2.6	Computer Program Verification for Raft-Pile System	22
2.7	Free Field Motion of Soil Stratum	23
2.8	Fundamental Frequency of Soil Stratum	25
2.9	Conclusions	26
	Notations	54
	Appendix	56

CHAPTER-3

ANALYSIS OF FOUNDATION-TORSIONALLY COUPLED BUILDING SYSTEMS

3.1	Introduction	58
3.2	Modelling of Superstructure	58
3.2.1	Stiffness Matrix of a Stiffening Element in Local Coordinates	59
3.2.2	Global Stiffness Matrix of the Building	60
3.3	Interaction Equations for Foundation-Building Systems	61
3.3.1	Displacement of a Floor Slab in Global Coordinates	61
3.3.2	Mass Matrix	63
3.3.3	Equation of Motion for the Superstructure	66
3.3.4	Equation of Motion for the Footing	66
3.3.5	Equation of Motion in Frequency-Domain	70
3.3.6	Equilibrium Equations in Generalised Coordinates and Solutions	71
3.4	Computer Program	73
3.5	Verification of Results	74
3.6	Conclusions	75
	Notations	89

CHAPTER-4	FREQUENCY DOMAIN ANALYSIS OF FOUNDATION-BUILDING SYSTEM	
4.1	Introduction	92
4.2	Numerical Study	92
4.2.1	Input at Footing Level	93
4.2.2	Input at Bedrock Level	96
4.3	Conclusions	98
CHAPTER-5	EARTHQUAKE ANALYSIS OF FOUNDATION-SUPERSTRUCTURE SYSTEMS	
5.1	Introduction	144
5.2	Evaluation of Seismic Response	144
5.3	Input at Footing Level	145
5.4	Input at Bedrock Level	148
5.5	Codal Provisions	150
5.6	Computer Program	151
5.7	Numerical Study	151
5.7.1	Input at Footing Level	151
5.7.2	Input at Bedrock Level	156
5.8	Conclusions	157
	Notations	208
CHAPTER-6	EFFECTS OF ROTATIONAL COMPONENTS OF EARTHQUAKE	
6.1	Introduction	210
6.2	Modelling of Superstructure	210
6.3	Displacements of a Floor Slab in Global Coordinates	210
6.4	Equation of Motion for the Superstructure	212
6.5	Equation of Motion in Frequency-Domain	212

6.6	Equilibrium Equations in Generalised Coordinates and Solutions for Transfer Functions	213
6.7	Computer Program	215
6.8	Numerical Study (Frequency Domain)	216
6.9	Generation of Earthquake time history	218
6.10	Evaluation of Seismic Response	218
6.11	Numerical Study (Time Domain)	219
6.12	Conclusions	222
CHAPTER-7	CONCLUSIONS AND SCOPE FOR FUTURE WORK	
7.1	Conclusions	255
7.2	Recommendations for Future Work	258
	REFERENCES	259