DESIGN OF FOUNDATIONS IN SEISMIC AREAS: PRINCIPLES AND APPLICATIONS

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Front Cover Photograph: The Port and Customs Office building at Kandla Port leaned sideways, after the 2001 Bhuj Earthquake. Photo Courtesy: IIT Kanpur

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NICEE's Preface

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Many Indian earthquakes in historical times have clearly demonstrated the important role that geotechnical conditions play under strong earthquake shaking. For example, about two hundred years back, documentation on the 1819 Kutch earthquake clearly outlined that the buildings situated on soil sites suffered much greater damage than those on the rock sites (*site effect*). In the Bihar earthquakes of 1833, 1934 and 1988, it has repeatedly been seen that Munger town and Kathmandu valley, located away from the epicenter suffer much higher damage than the neighboring areas due to peculiar local geology. However, studies on site effect received a big impetus after the strong motion recordings of the 1985 Mexico earthquake, which showed substantial amplification in certain geotechnical conditions. This was again demonstrated through strong motion records obtained during the 1989 Loma Prieta (California) earthquake.

Another major challenge of earthquake geotechnical engineering is the soil liquefaction under seismic ground motion. Wide spread liquefaction phenomenon was displayed by the 1869 Cachar (north-east India), and the 1897 Assam earthquakes. During the 1934 Bihar earthquake, an entire area of about 12,200 sq. km (about 300km length with irregular width exceeding 65km at places) in north Bihar sustained large-scale liquefaction such that buildings underwent tilting and slumped bodily into the ground; this area was at that time termed as the *slump belt*. The liquefaction-caused damage to built infrastructure in the 1964 Niigata (Japan) and the 1964 Anchorage (USA) earthquakes gave a great deal of impetus to research in this area.

Clearly, the subject of earthquake geotechnical engineering is rather new and evolving. There are not yet enough books available on this subject, particularly those bridging the gap between state-of-the-art and state-of-the-practice. As a result, much of the research in this area does not get translated into the design practice even for major projects, particularly so in the developing countries.

Considering the huge seismic risk India faces and the need for trained manpower in this area, Ministry of Human Resource Development (Government of India) has launched the National Programme on Earthquake Engineering Education (NPEEE; www.nicee.org/npeee). This programme aims at building capacity in our technical education system through a variety of means, including training of faculty of engineering and architectural colleges and universities, development and dissemination of technical literature, etc. The National Information Centre of Earthquake Engineering (NICEE; www.nicee.org), established at IIT Kanpur in 1999, aims to disseminate information resources on earthquake engineering with a view to mitigate earthquake disasters. It brings out a range of publications and products and distributes these widely.

Currently, India is undergoing huge infrastructural development and therefore it is very important to implement the best earthquake engineering practices in such projects. This workshop at BESU Shibpur in January 2007 brought together academics and practising engineers from around the world to deliver lectures on design of foundations in seismic areas. When Dr Subhamoy Bhattacharya proposed to NPEEE and to

NICEE that the lectures of this workshop be collated and published in a single volume, it was immediately agreed to. It is hoped that this volume will be of value to both professionals and academics, and will be an important reference volume for the years ahead.

I wish to place on record our deep appreciation for Dr Bhattacharya's enthusiasm and efforts, and to the contributions of different authors and reviewers for this volume. This publication would not have been possible without the financial support from NPEEE and the contributions of numerous supporters of NICEE.

March 2007 Sudhir K Jain

Editor's Preface

Dr. Subhamoy Bhattacharya

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The subject "*Earthquake Geotechnical Engineering*" developed rapidly following the 1964 Niigata (Japan) earthquake. The understanding of the subject enhanced following every devastating earthquake. For example, the widespread destruction of 1964 Niigata earthquake showed the deadly effects of liquefaction (i.e. behaviour of loose saturated sandy soil under the effect of strong shaking), the 1985 Mexico earthquake showed the effects of site amplification (behaviour of some form of clay under a particular excitation frequency) and the 1995 Kobe earthquake showed the deadly effects of large ground displacements (lateral spreading). The subject has been continuously evolving in the last four decades. This reminds me the lecture of Professor Malcolm Bolton on "*Pile capacity in sand*". He says, quoting Mr Donald Rumsfeld:

> "*There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know*".

The above statement is quite applicable to earthquake geotechnical engineering. We are still discovering the physical processes, phenomena, principles, mechanisms that cause the damage to the infrastructure during earthquakes.

Text books on this subject written in English are particularly rare. The most often cited books related to this subject are Kenji Ishihara's text book on "*Soil behaviour in earthquake geotechnics*" and Steve L. Kramer's book on "*Geotechnical Earthquake Engineering*". The text book by Professor Kenji Ishihara concentrates on the basics of soil behaviour under cyclic loading with emphasis on element testing of soil. The book by Professor Steve Kramer covers the fundamentals on engineering seismology, soil behaviour, basics of liquefaction, engineering approaches to assess site specific earthquake motions, assessment of slope stability and retaining wall performance. Although these two books are well worth reading today for their excellent description of seismology, development of the subject and grasping the basics, there is a need for a text book on foundation design in seismic areas. This intended purpose of this proposed book will be to facilitate translating the research findings into practice – the ultimate goal being designing and construction of safe foundations for structures. The behaviour of soil under cyclic loading is quite complex and foundation/ structural engineers find it difficult to get the necessary parameters for designing of the foundations for the structures.

Following the widespread devastation of 1995 Kobe earthquake, research on seismic soil structure interaction has intensified. Majority of this research has been carried out in Japan, USA, Greece and the UK.

Research work had been (are being) published in the proceedings of the international conferences, journals but there has not been a single text book written that adequately covers these research. This text book is a necessity for those seismic prone developing countries who on one hand cannot afford the cost for carrying out cutting-edge research but has to educate post graduate students who are going to fill the posts of designers in the industry. Under such circumstances, an international workshop on earthquake geotechnical engineering was organised as a humble attempt to satisfy the need. The workshop was organised as a part of the 150th year celebration of the Civil Engineering Department of Bengal Engineering and Science University (Shibpore, India). This workshop papers produced a proceeding covering most of the aspects of Earthquake Geotechnical Engineering such as seismic hazards, liquefaction, site response, dynamic soil-structure interaction and piled foundations. The papers are authored and presented by experts not only from academics but also from top-class industry such as Ove-Arup (London) and Shimizu Corporation (Tokyo). Fourteen papers were presented in the workshop. The workshop was attended by more than 100 delegates. Following the workshop it was decided to peer review the papers and publish this proceeding as a teaching resource material for post graduates. Based on the review, some papers are excluded and some papers are shortened. Additional papers covering some aspects of dynamic earth pressure and synthetic input motion are now included to make this proceedings more complete.

The subject is arguably the most complex multidisciplinary discipline in the civil engineering profession. The subject encompasses various disciplines, for example seismology, geology, geophysics, random vibrations, structural engineering and soil dynamics. It is quite impossible for a single individual to do justice to this subject by publishing a book. As a result, the chapters of this book have been authored by various researchers from many disciplines. In addition, there are tensions between the culture of industry and that of academia. In this workshop, an attempt has been made to bring closer the practicing engineers from world-class organisations and the academics actively involved in earthquake research since we have a common aim – designing safe structures.

A text book on a multidisciplinary subject can be structured in many different ways. In this case, I found it difficult to choose between organization of the book around the physical mechanisms, phenomenon, and processes that occur and are manifested during an earthquake or the principles necessary for design of foundations. Ultimately, I chose to divide it into two parts:

1. Principles and the theoretical concepts required during designing.

2. Applications of the principles discussed in the previous part through some practical examples.

An appendix is added collating various formulas, equations and tables which are useful in design.

I am grateful to NICEE (National Information Centre of Earthquake Engineering) for publishing this book. A special thank goes to Professor Sudhir K.Jain of IIT Kanpur, also national coordinator of NPEEE [National Program on earthquake Engineering Education] for his pragmatic advices and inspiration. I feel myself lucky to have worked closely with Professor Jain and I have learned so much through his association. Without his support, this book could not been published. He is truly the father of India's earthquake awareness program. The workshop would not have been possible without the generous financial support of TEQIP (Technical Education Quality Improvement Program, a wing of the World Bank), Bengal Engineering and Science University (BESU), India, and NPEEE (National Program on Earthquake Engineering Education).

I am grateful to the Vice Chancellor of BESU Dr. N.R.Banerjea, Professor Saibal Ghosh and Professor Gautam Bhattacharya of Civil Engineering Department of BESU for providing all infrastructural support and moral support to organise the workshop.

Many people have contributed in preparing this compilation either through reviewing the papers or by maintaining a website or by providing ideas. It is difficult to name all of them. In this context, this page would be incomplete if I don't mention the names of Mr. Suresh R Dash (my PhD student), Dr L Govindraju

(academic visitor of Oxford University), Dr. A. J. Brennan, Dr. Barnali Ghosh, Dr. Sondipon Adhikari, Dr. T Tazoh and Ms Alison May (secretary to the civil engineering research group at the University of Oxford).

While I am editing this book, I have been a beneficiary of Somerville College (University of Oxford) and the Department of Engineering Science (Oxford), which have allowed me to pursue many interesting topics. I would like to record my appreciation to these enlightened Institutions.

Oxford, March 2007 Subhamoy Bhattacharya

Foreword

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Earthquakes cause widespread destruction and often results in the loss of precious lives. India, like Japan is one of the seismic hazard prone countries in the world. The amount of destruction that earthquakes can cause has been experienced by India during the 2001 Bhuj, India, earthquake. The loss due to earthquake was more than 1 billion dollar and most importantly more than 20,000 people were killed. Indian universities have a great role to play to safeguard the country against such natural calamities. I was glad to see the initiatives taken by Bengal Engineering and Science University (BESU), NICEE (National Information Centre of Earthquake Engineering, IIT Kanpur), and NPEEE (National Programme on Earthquake Engineering Education) to enhance and disseminate knowledge to mitigate this disaster. It was a great pleasure to present a keynote paper on "Site response" at the International Workshop on "Earthquake Geotechnical Engineering" on 10th January 2007 on the 150th anniversary of the Civil Engineering Department of Bengal Engineering and Science University. The speakers of this workshop were industry leaders (e. g., Shimizu, Arups, and Halliburton) and top rated academics around the world in the field of earthquake geotechnical engineering. The topics and theme that was covered in the workshop reflected almost the entire gamut of earthquake geotechnical engineering.

Earthquake geotechnical engineering is very important research in order to reduce earthquake damage. Text book on this field are, however, very rare. The latest information is available only through academic journals and international conferences, but it may not be easily accessible to most practicing engineers. Therefore, I strongly supported the idea of publishing a text book by collating the papers in the workshop. I am glad that the book is finally being published after some additions and peer reviewing.

I hope this book can serve as a good teaching resource material and further the research advancement in the area.

March 2007 Nozomu Yoshida

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