SPRINGER BRIEFS IN GEOTECHNICAL AND EARTHQUAKE ENGINEERING

Florin Pavel
Viorel Popa
Radu Vacareanu

Impact of Long-Period Ground Motions on Structural Design: A Case Study for Bucharest, Romania

Springer

SpringerBriefs in Geotechnical and Earthquake Engineering

Series editor

The Aims of This New Series

Springer Briefs in Geotechnical and Earthquake Engineering is to establish an authoritative set of publications covering the most recent findings and design procedures in these engineering fields. Volumes are presented in an easy accessible and compact form to researchers and practitioners to advance the state-of-the-art and state-of-the-practice. The volumes will be peer-reviewed and be overviewed by a respected editorial board.

Typical topics might include: *Topical overviews, case studies and applications in the fields of soil mechanics, foundation engineering, geotechnical earthquake engineering, earthquake engineering, earthquake hazard and other related subjects.*

More information about this series at http://www.springer.com/series/15951

Florin Pavel · Viorel Popa
Radu Vacareanu

Impact of Long-Period Ground Motions on Structural Design: A Case Study for Bucharest, Romania

Springer

Florin Pavel
Seismic Risk Assessment Research Center
Technical University of Civil Engineering Bucharest (UTCB)
Bucharest
Romania

Radu Vacareanu
Seismic Risk Assessment Research Center
Technical University of Civil Engineering Bucharest (UTCB)
Bucharest
Romania

Viorel Popa
Seismic Risk Assessment Research Center
Technical University of Civil Engineering Bucharest (UTCB)
Bucharest
Romania

ISSN 2522-8781 ISSN 2522-8803 (electronic)
SpringerBriefs in Geotechnical and Earthquake Engineering
ISBN 978-3-319-73401-9 ISBN 978-3-319-73402-6 (eBook)
https://doi.org/10.1007/978-3-319-73402-6

Library of Congress Control Number: 2017963291

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The issue of long-period strong ground motions arose for the first time in the second half of the twentieth century in Japan. Since then, compelling evidence of long-period seismic waves has occurred in many strong ground motion recordings obtained throughout the world. The only strong ground motion recorded in Bucharest during the 4 March 1977 Vrancea intermediate-depth earthquake revealed, for the first time in Romania, low-frequency (long-period) spectral components of ground motion, which were responsible for the heavy damage or complete collapse of tall, flexible and vulnerable residential buildings in Bucharest. Since then, the earthquake of 30 August 1986, which was also generated by the Vrancea intermediate-depth seismic source, produced strong ground motions with low-frequency content in some sites in Bucharest. It should be noted that the Michoacan earthquake of 19 September 1985 produced in Mexico City the narrowest and lowest frequency content strong ground motion recorded until then. Later on, Munich Re. who compiled “The World Map of Natural Hazards” named Bucharest a “large city with Mexico-City effects”.

The issue of long-period ground motions was from the beginning at the focus of engineering seismology, and later came to the attention of earthquake engineering specialists. The challenges raised to structural engineering by the very high seismic displacement demands are daunting, and the technical solutions to tackle these challenges are, sometimes, very costly. Nevertheless, it is at the very core of the structural engineering to find solutions to such complicated problems.

In Bucharest, the compelling evidences of the issue of long-period ground motions are provided by actual records. As a consequence, the design acceleration response spectrum has a very long control period T_C of 1.6 s (among the largest values in the world). The design peak ground acceleration with 20% exceedance probability in 50 years is 0.3 g, and it is envisaged that this will be raised by another 20–25% in the next revision of the Romanian earthquake-resistant design code (to codify design values with 10% exceedance probability in 50 years). The issue of the control period T_C increasing along with magnitude increasing is a hot topic, as well. Consequently, the seismic demands in terms of displacements, that are quite high at present, will further increase, thus exacerbating the challenges encountered by the structural engineers. Nevertheless, the need for a larger and safer building stock in Bucharest must be properly addressed both by designers and contractors, as well. The code drafters cannot argue with nature, so the issue of long-period high-spectral acceleration design spectra is clearly stated in the documents issued and enforced by the building officials.

To the best of the authors' knowledge, the combination of long-period and high-acceleration design spectrum is not common in seismic codes and regulations, so there is limited experimental experience or practical expertise in the design of flexible or high-rise buildings for this kind of challenging seismic demand. Up to now, the Romanian design practice has found some solutions to meet the concurrent demands for very high strength, deformability and ductility. Nevertheless, it seems that the boundaries of structural earthquake engineering are pushed by the current solutions: very high density of shear walls, very heavy RC cores, very heavily reinforced structural elements and very thick foundation mats. Of course, it is legitimate to ask about the employment of seismic isolation devices and energy dissipation solutions. The former is limited by the very high displacement demands. Certainly, dampers and friction pendulums might reduce these displacement demands (albeit, the strength demand is increased), but the cost is an important criterion on a very competitive real-estate market, as it is the case in Bucharest. Moreover, when applying base isolation, one has to consider that the horizontal-to-vertical spectral ratio method applied on ambient vibrations in Bucharest revealed spectral peaks for periods of five to six seconds. There is limited opportunity for the employment of energy dissipation devices because of the associated cost and limitation of functionality and usage class of the buildings.

The recent experience of the 14 November 2016 Kaikoura earthquake in New Zealand raised again the problem of seismic damage produced by long-period strong ground motions in Wellington. One has to put this problem in the context of the paradigm shift in seismic design towards resilience. This latter approach is further complicating the earthquake-resistant design of structural and non-structural elements for long-period ground motions. It is the belief of the authors that the international community of seismologists and engineers will tackle this issue properly and the need for development will be fuelled by their collective wisdom. The authors consider this publication as a golden opportunity to share the Romanian experience of long-period high-acceleration strong ground motions, both in engineering seismology and earthquake engineering.

This book in the Springer Brief series aims at discussing the impact of long-period ground motions on structural design using as case study the situation of Bucharest, the capital city of Romania. The first part of the Brief evaluates the soil conditions in the Bucharest area. The characteristics of ground motions for Bucharest in terms of amplitudes and frequency contents of both recorded and simulated motions are subsequently discussed. The causes of long-period ground motions related to both source and site features are then discussed in the light of a new ground motion model specifically derived for Bucharest using a ground motion database of both natural and simulated ground motion recordings. Next, a discussion regarding the current seismic design and detailing practice for buildings built in Bucharest is presented. The evolution of seismic design codes for Bucharest and the assessment of inelastic spectral displacements are also addressed in the same section. Moreover, the impact of long-period ground motions on the seismic design practice is analysed. Finally, several case studies of buildings in Bucharest are presented, and the major challenges encountered in their design are discussed. This Brief contains various numerical examples which will aid the reader to better understand the discussed topics. The book is addressed to both researchers in the field of seismic hazard and risk assessment and designers of multi-storey buildings located in moderate and high seismic areas.

In the opinion of the authors, out of the numerous national and international projects aiming at understanding the Romanian seismicity and at improving the codes and regulations for seismic design and evaluation of buildings, the most comprehensive one was the Japan International Cooperation Agency (JICA) Technical Cooperation Project for Seismic Risk Reduction, implemented in the period 2002–2008. Many outstanding scholars, researchers and engineers from Japan served as short-term and long-term experts in Romania during that period and became acquainted with the issues tackled in this book. Two of the experts, Dr. Toshihide Kashima, senior researcher at the International Institute for Seismology and Earthquake Engineering of Building Research Institute, Tsukuba, and Dr. Koichi Kusunoki, associate professor at the Earthquake Research Institute, University of Tokyo, gracefully accepted to review the manuscript of this Brief. The authors would like to extend their gratitude to the reviewers; their valuable comments and suggestions are very much appreciated as they have helped us to greatly improve the quality of the manuscript.

Some of the results shown in this Brief were obtained within the framework of three national research projects implemented at the Seismic Risk Assessment Research Center of Technical University of Civil Engineering of Bucharest in the period 2012–2017, namely BIGSEES, COBPEE and RO-RISK. The authors extend their gratitude to the Romanian taxpayers for financing these grants.

The authors would also like to thank Petra van Steenbergen and all the editorial staff from Springer International Publishing AG for their professional coordination and support in preparing this work in Springer Briefs in Geotechnical and Earthquake Engineering.

Bucharest, Romania
August 2017

Florin Pavel
Viorel Popa
Radu Vacareanu

Contents

Chapter 1
Introduction

Long-period ground motions and their effects on the built environment have come to the attention of the scientific community especially after the devastating Michoacan (Mexico) earthquake of September 1985. The losses caused by this earthquake, both in terms of structural damage and human casualties, were extensive in an area of Mexico City that overlays an old lake bed. However, long-period ground motions had already been identified in other parts of the world. For instance, Koketsu and Miyake (2008) note that long-period ground motions were identified for the first time during the 1968 Tokachi-Oki earthquake at Hachinohe station in Japan (the predominant period of soil vibration was around 2.5 s). The authors associate these types of far-field long-period ground motions to offshore earthquakes occurring in subduction zones. However, inland earthquakes can also generate long-period ground motions due to a combination of factors, such as: rupture directivity, basin effects and/or site effects can be responsible for this type of ground motions.

Romania, and specifically its southern part (including Bucharest), has been affected by numerous large-magnitude intermediate-depth earthquakes originating in the Vrancea intermediate-depth seismic source. The only free-field ground motion that was recorded in Romania during the March 4, 1977 Vrancea earthquake at a seismic station in the eastern part of Bucharest showed very large spectral amplifications for periods of vibration in the range 1.0–2.0 s. However, in the case of this ground motion recording, besides the site effects, another element that increased the level of damage, especially in the Bucharest area, was the velocity of the earthquake rupture propagation that was almost equal to that of the shear waves (Hartzell 1979).

In April 2015, the strong ground motions recorded during the Gorkha earthquake (Nepal) have shown that through a combination of basin effects and directivity, the predominant period of the acceleration response spectra can be in excess of 5 s for both horizontal components, leading to very large displacement demands for high-rise/flexible buildings/structures.

F. Pavel et al., *Impact of Long-Period Ground Motions on Structural Design: A Case Study for Bucharest, Romania*, SpringerBriefs in Geotechnical and Earthquake Engineering, https://doi.org/10.1007/978-3-319-73402-6_1