Environmental Soil Physics

Contributors

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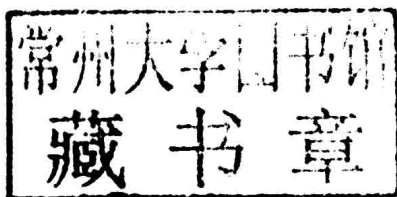
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Published by Koros Press Limited
www.korospress.com

United Kingdom

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Preface

Most of the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). It is well recognized that the dynamic characteristics of a foundation system (including its stiffness and capacity) influence the magnitude of the dynamic response and hence the earthquake load demands on the bridge structure. For pile or drilled shaft foundations, there are several conventionally used analytical procedures to account for the soil-foundation-structure interaction effects. Soil-Foundation-Structure Interaction describes the analytical models used to account for the soil foundation-structure interaction effects. The text is organized into nine chapters. Influence of the soil-structure interaction in the behavior of mat foundation have been reviewed in chapter two. An experimental study on the effect of foundation depth, size and shape on subgrade reaction of cohesion less soil is discussed in chapter third. The objective of chapter four is to provide a methodology to conduct seismic evaluations of bridge embankments in order to identify, rank, and prioritize the embankments that are susceptible to seismic failure and are in need of detailed analysis. This chapter addresses the technical component of embankment prioritization and is well-suited to a reliability-based model for seismic risk assessment. Bridge embankments – seismic risk assessment and ranking is presented in chapter five. Seismic stability analysis and retrofit of earth embankments, including site remediation, has been, to date primarily, focused on embankment dams and earth retaining structures. Finite element analysis of cable-stayed bridges with appropriate initial shapes under seismic excitations focusing on deck-stay interaction is reviewed in chapter six. Seven chapter aims to compare the responses of the bridge for seismic actions representative of the seismic hazard at the bridge location with those used in the design. The primary objective of chapter eight is to investigate the effects of default hinge properties based onFEMA-356 and user-defined hinge properties on the time-dependent seismic performance levels of corroded RC buildings. An assumed corrosion rate is used to predict the capacity curve of the buildings by using default and user-defined plastic hinge properties as a function of time. The ninth chapter is devoted to discuss an experimental scheme used to characterize mechanical behavior and subsequently develop a mathematical model representing the characteristic behavior of the bearings.

Contents

Chapter 1

MECHANICAL CHARACTERIZATION OF LAMINATED RUBBER BEARINGS AND THEIR MODELING APPROACH

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INTRODUCTION

Base isolation, also known as seismic base isolation, is one of the most popular means of protecting a structure against earthquake forces. It is a collection of structural elements which should substantially decouple a superstructure from its substructure resting on a shaking ground thus protecting building and bridge structure's integrity. Base isolation is the most powerful tool of earthquake engineering pertaining to the passive structural vibration control technologies. It is meant to enable building and bridge structure to survive a potentially devastating seismic impact through a proper initial design or subsequent modifications. In some cases, application of base isolation can raise both a structure's seismic performance and its seismic sustainability considerably.

An isolation system is believed to be able to support a structure while providing additional horizontal flexibility and energy dissipation. Until the 80th decade of the last century many systems have been put forward involving features such as rollers or rockers bearings, sliding on sand or talc, or complaint first story column, but these have usually not employed in the practice of isolation of engineering structures [1, 2]. The study on the mechanical behavior of the isolation system dates back to 1886, when Professor Milne from Tokyo University, Japan attempted to observe isolation behavior of a structure supported by balls.He conducted an experiment by making an isolated building supported on balls *"cast-iron plates with saucer-like edges on heads of piles. Above the balls and attached to the buildings are cast-iron plates slightly concave but otherwise similar to those below"* [3]. However, another guy J.A. Calantarients in 1909, a medical doctor of the northern English City of Scarborough, was claimed to be the first man who conducted the experiment of isolation behavior of a structure supported by balls [3]. What both guys wanted to get information from their experiments is the global isolation behavior of the structure. The philosophy given by them regarding seismic isolation of a structure is stillin practice. Several mechanisms of investigating the mechanical behavior of isolation systems are developed based on this philosophy which is readily used.

In practice of seismic base isolation of bridge structures, laminated rubber bearings have been popular since the last century. Among many types of laminated rubber bearings, natural rubber bearing (RB) which is formed by alternate layers of unfilled rubbers and steel shims has less flexibility and small damping. It has been used to sustain the thermal movement, the effect of pre-stressing, creep and shrinkage of the superstructures of the bridge or has been used for base isolation practices with additional damping devices [1, 2 and 4]. On the other hand, other two types of bearings possessing high damping were developed and have widely used in the seismic isolation practices [1, 3]. One is the lead rubber bearing (LRB), which additionally inserts lead plugs down the center of RB to enhance the hysteretic damping, and the other is high damping rubber bearing (HDRB), whose rubber material possesses high damping in order to supply more dissipating energy.

Following the same principle as Professor Milne used in his experiments, several authors conducted experimental studies on different bridge structures mounted on laminated rubber bearings. Kelly et al. [5] studied quarter-scale models of straight and skewed bridge decks mounted on plain and lead-filled elastomeric bearings subjected to earthquake ground motion using the shaking table. The deck response was compared to determine the effectiveness of mechanical energy dissipaters in base isolation systems and the mode of failure of base-isolated bridges. Igarashi and Iemura [6] evaluated the effects of implementing the lead-rubber bearing as seismic isolator on a highway bridge structure under seismic loads using the substructure hybrid loading (pseudo-dynamic) test method. The seismic response of the isolated bridge structure was successfully obtained. The effectiveness of isolation is examined based on acceleration and displacement amplifications using earthquake response results.All of their studies were related to observation of the isolation effects on the bridge structures.Very few works were undertaken in the past regarding the mechanical behavior of isolation bearings.

Mori et al. [7, 8] studied the behavior of laminated bearings with and without lead plug under shear and axial loads. They evaluated hysteretic parameters of the bearings: horizontal stiffness; vertical stiffness; and equivalent damping ratio. The similar study was conducted by Burstscher et al. [9]; Fujita et al. [10]; Mazda et al. [11] and Ohtori et al. [12] on lead, natural and high damping rubber bearings. They concluded from the experimental results that the hysteretic parameters have low loading rate-dependence. Furthermore, Robinson[13], a pioneer of developing and introducing the lead rubber bearing (LRB) as an excellent isolation system to be used in seismic design of civil engineering structures, conducted an elaborate experimental tests on LRB in order to describe the hysteretic behavior. From the experiments he concluded that the hysteretic behavior of the LRB can be expressed well by using a bilinear relationship of the force-displacements. In addition, he conducted some tests regarding fatigue and temperature performance of the LRB.

Several authors conducted different loading experiments on laminated rubber bearings (RB, LRB, and HDRB) in order to acquire deep understanding of the mechanical properties. In this case the

works of Abe et al. [14]; Aiken et al. [15]; Kikuchi and Aiken [16]; Sano and D Pasquale [17] can be noted. They have applied uni-directional and bi-directional horizontal shear deformations with constant vertical compressive stress. Several types of laminated rubber bearings were used in their experimental scheme. In their investigationsthey identified some aspects of the bearings such as hardening features and dependence of the restoring forces on the maximum displacement amplitude experienced in the past. Moreover, some of them also identified coupling effects on the restoring forces of the bearings due to deformation in the two horizontal directions. Motivated by the experimental results of the bearings different forms of analytical models of the bearings were proposed by them. However, their studies were mostly related to illustrating the strain-rate independent mechanical behavior of the bearings.

Very few works are reported in literature regarding the strain-rate dependent behavior of the bearings. In this regard, the works of Dall'Asta and Ragni[18]; Hwang et al. [19] and Tsai et al. [20] can be reported. They studied the mechanical behavior of high damping rubber dissipating devices by conducting different experiments such as sinusoidal loading tests at different frequencies, simple cyclic shear tests at different strain-rates along with relaxation tests. From the experiments they have identified the strain-rate dependence of the restoring forces and subsequently developed rate-dependent analytical models of the bearings. Strain-rate dependent Mullin's softening was also identified in the experiments [18]. However, separation of the rate-dependent behavior from other mechanical behavior of the bearings was not elaborately addressed in their studies.

A number of experimental and numerical works on different rubber materials (HDR: high damping rubber and NR: natural rubber) have been performed in the past [21-27]. These works show that the mechanical properties of rubber materials (especially HDR) are dominated by the nonlinear rate-dependence including other inelastic behavior. Moreover, the different viscosity behavior in loading and unloading has been identified [21, 23, 28 and 29].

It is well known that since seismic response of base isolated structures greatly depends on mechanical properties of the bearings, deep understanding of the characteristics of the bearings under the