On the Performance of Base-Isolated Buildings: A Generic Model

A dissertation submitted to the University of Cambridge
for the degree of Doctor of Philosophy

by

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To Mum, Dad

& Kathy
Just as in this age of mechanisation we welcome the advent of any mechanical process which makes a demand on craftsmanship and manual skill, so some of us at any rate may feel grateful that, in problems relating to vibrations, nature has provided us with a range of mysteries which for their elucidation require the exercise of a certain amount of mathematical dexterity. In many directions of engineering practice, that vague commodity known as common sense will carry one a long way, but no ordinary mortal is endowed with an inborn instinct for vibrations; mechanical vibrations in general are too rapid for the utilization of our sense of sight, and common sense applied to these phenomena is too common to be other than a source of danger.

Professor C E Inglis, OBE, MA, LLD, FRS

James Forrest Lecture, 1944
PREFACE

The work described in this dissertation was carried out at Cambridge University Engineering Department between November 1998 and October 2001. The project was suggested by Dr Hugh Hunt, who also acted as my research supervisor. I have been very fortunate in having such an enthusiastic and knowledgeable supervisor and I would like to thank him for all his help. I would also like to thank Professor David Newland, who acted as my supervisor for part of my final year and has maintained a keen interest in my work.

I am very grateful to Professor Jim Woodhouse, without whose initial encouragement I would not have returned to the Department, and to Professor Robin Langley for some helpful teatime discussions.

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Finally, I would like to thank Peterhouse, for providing such a pleasant, supportive and rewarding environment in which to be a student.

I declare that, except for commonly understood and accepted ideas, or where specific reference has been made to the work of others, this dissertation is the result of my own work and includes nothing that is the outcome of collaborative work. This dissertation is approximately 56,400 words in length and contains 98 figures.

James Talbot
Cambridge, November 2001
SUMMARY

Ground-borne vibration has existed ever since the development of urban road and rail networks. Vibration generated by the moving traffic propagates through the ground and into buildings, resulting in unacceptable levels of internal noise and vibration. A common solution to this increasingly significant problem is the base-isolation of buildings by incorporating vibration isolation bearings between the buildings and their foundations. This technique has been employed for over forty years but the exact performance of base isolation remains uncertain.

This dissertation is concerned with the development of a generic computational model; generic in that it accounts for the essential dynamic behaviour of a typical base-isolated building in order to make predictions of isolation performance. The model is a linear one, formulated in the frequency domain, and consists of a two-dimensional portal-frame model of a building coupled to a three-dimensional boundary-element model of a piled-foundation. Both components of the model achieve computational efficiency by assuming they are infinitely long and using periodic structure theory.

The development of the model is described systematically, from the modelling of a building and its isolation bearings to that of its foundation. The majority of the work is concerned with the piled-foundation model, which is comprehensive in that it accounts for the vertical, horizontal and rotational motion of the pile heads due to both direct pile-head loading and interaction through wave propagation in the surrounding soil. It is shown that this level of detail is important in the prediction of base isolation efficiency.

A key question facing designers is not only how but on what basis base isolation should be assessed, since fundamental problems exist with the existing measures of isolation performance. Power flow analysis is explored and the concept of power flow insertion gain, based on the total mean vibrational power flow entering a building, is introduced as a useful measure of isolation performance. This is shown to offer clear benefits by providing a single measure of performance that is suitable for design purposes.

Finally, the development of a prototype force-sensitive vibration isolation bearing is described as a contribution to verifying base-isolation theory with experiments.
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