Understanding the interactions between people and structures

Dr Tianjian Ji, Senior Lecturer in Structural Engineering at Manchester Centre for Civil and Construction Engineering, UMIST, and a member of the Institution's Research Panel discusses work on the human response to structural vibration

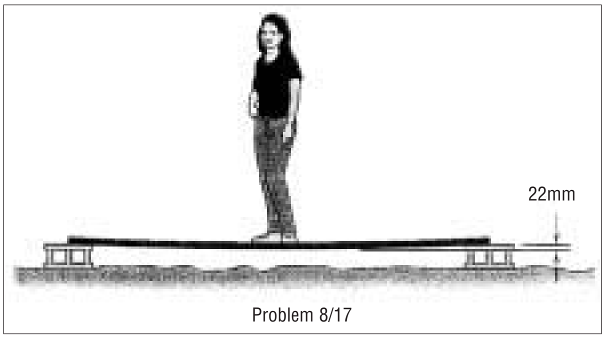


Fig 1a. (above) A woman standing on a beam[1] ***(Reprinted by permission of John Wiley & Sons, Inc)***

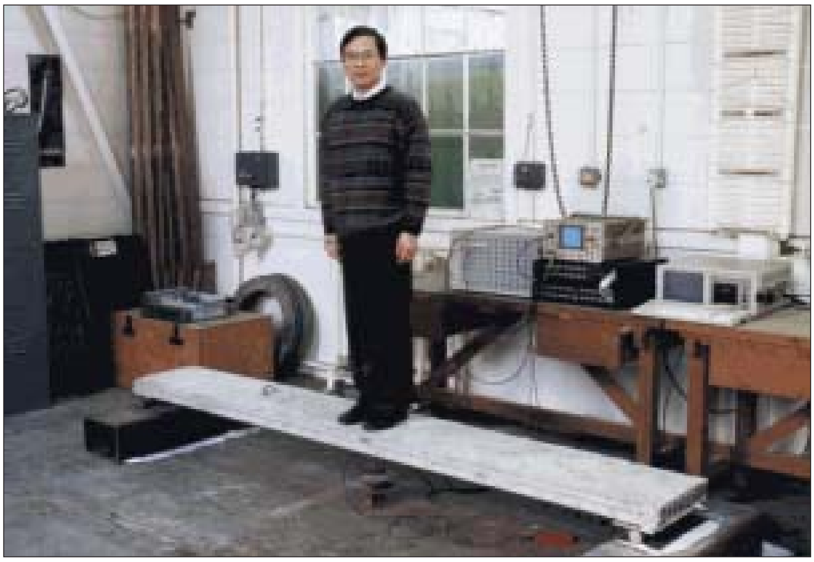


Fig 1b. (left) A man standing on a beam[2]

How people interact with their environment is a topical issue and one of increasing importance. One form of physical interaction which is understood poorly, even by professionals, is concerned with human response to structural vibration. This is important for instance when determining how dance floors, footbridges and grandstands respond to moving crowds and when determining how stationary people are affected by vibration in their working environment. Human-structure interaction provides a new topic that describes the independent human system and structural system working as a whole and studies the structural vibration where people are involved and human body response to structural movements.

When a structure is built on soft soil, the interaction between soil and structure may be considered; when a structure is in water, such as an offshore platform, the interaction between the structure and the surrounding fluid may be considered. Similarly when a structure is loaded with people, the interaction between people and structure may need to be considered. An interesting question is why this was not considered before? There are two reasons:

1. The human body is traditionally considered as an inert mass in structural vibration. For example, Fig.1a is a question taken from a well-known textbook on Engineering Mechanics[1] where the girl is modelled as an inert mass in the calculation of the frequency of the human-beam system.

2. The human mass is small in comparison with the masses of many structures and in this situation its effect is negligible. Thus there were no requirements from practice for considering such effects as human interaction.

Dynamic measurements were taken on the North Stand at Twickenham when it was empty and when it was full of spectators[2]. The observations on the stand suggested a new concept that the human whole-body acts as a mass-spring-damper rather than an inert mass. The phenomenon was reproduced in the laboratory. We conducted the same test as shown in Fig.1a where the frequencies of the bare beam and the human occupied beam (Fig.1b) were measured. It was confirmed that the human whole-body did not act as an inert mass but at least a mass-spring-damper system in structural vibrations.

Nowadays many structures are lighter and have longer spans than former similar types of construction and as a consequence the effect of human bodies becomes important. The newly emerged problems are the human induced vibrations of grandstands and footbridges, where crowds of people are involved, and human perception of floor vibration induced by individuals' walking.

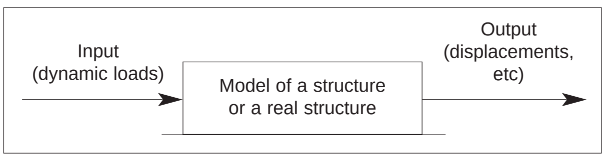
The study of human-structure interaction is concerned with both structural dynamics and body biodynamics[3]. The former belongs to engineering while the latter is part of science. Fig 2 describes the study of structural dynamics. The structure may range from a simple beam to a complex building, from a car to an aeroplane. The relationships between input, output and the model of a structure can normally be described by governing equations and the solution of the equations is the output. In the diagram the input, output and the structure are quantified, or at least quantified statistically.

If a similar diagram to Fig.2 is required to describe the basic studies in biodynamics of human body, it may be represented as in Fig 3.

The objective of the study of human response to vibration is to establish relationships between cause and effect[4]. However, there are no governing equations available to describe the relationships between causes, people and effects. This might be because one cause generates a range of effects and different causes induce the same effect. In addition, the effects, relating to comfort, interference, perception of vibration, may be descriptive and difficult to quantify.

There are four significant factors in the study of human-structure interaction:

Fig 2. Basic studies in structural dynamics



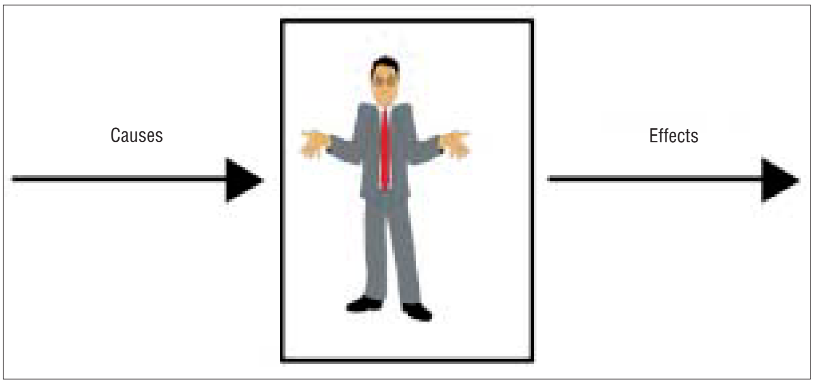


Fig 3. Basic studies in biodynamics of the human body

1. *The high damping of human body (30-50% critical)*. This may indicate that the traditional eigenvalue analysis where damping is ignored is not valid and damping matrix cannot be expressed as a linear combination of mass and stiffness matrices.
2. *The basic data for human body obtained from the study of biodynamics of human body may not be applicable to small amplitude vibrations of structures*. This is because the dynamic properties of the human body are amplitude-dependent. The vibration of a civil engineering structure is usually much smaller than the movement of a shaking table where the basic data have been measured. Also the concept of modal (or effective) mass is not used in biodynamics of human body.
3. *Large variations on measurements*. This is due to the fact that individuals have different weights, and frequency and damping characteristics. Even for the same individual changes in posture will alter the dynamic properties.
4. *Dynamic measurements may be incomplete.* As the transducers are only placed on the structure where people are involved, some human dominated vibration modes may not be measurable from the structure.

As human-structure interaction is a new topic and the problems in practice have only recently emerged, there are not many publications available. The understanding of the dynamic properties of the human whole-body subject to low amplitude vibration is the key item in the development of this new topic. Recently, a literature review on human-structure interaction has provided some useful information[5].

In the future it is probable that structures will be longer and lighter, and the human expectation of the quality of life and their working environment will be greater. Therefore, engineers will need an improved understanding of human-structures interaction to tackle these problems where structural safety and/or human comfort are concerned.

Acknowledgement
I am grateful to the Leverhulme Trust for making a grant to the research project: human-structure interaction: applying body biodynamics into structural dynamics. se

REFERENCES

1. Meriam, J. L. and Kraige, L. G.: *Engineering Mechanics*, **V**2: *Dynamics*, Fourth Edition, John Wiley & Sons, ISBN 0 471 24167, 1998
2. Ellis, B. R. and Ji, T.: 'Human-structure interaction in vertical vibrations', *Structures and Buildings, Proc. Civil Engineers*, **V**122/1, p1-9, 1997
3. Ji, T.: 'On the combination of structural dynamics and biodynamics methods in the study of human-structure interaction', 35th United Kingdom Group Meeting on *Human response to vibration*, Southampton, 13-15 September 2000
4. Griffin, M. J.: *Handbook of human vibration,* Academic Press Limited, ISBN 0 12-303040 4, 1990
5. Sachse, R, Pavic, A. and Reynolds, P., 'Human-structure interaction in civil engineering dynamics: a literature review', *The Shock and Vibration Digest*, **V**35, No.1, p 3-18, 2003