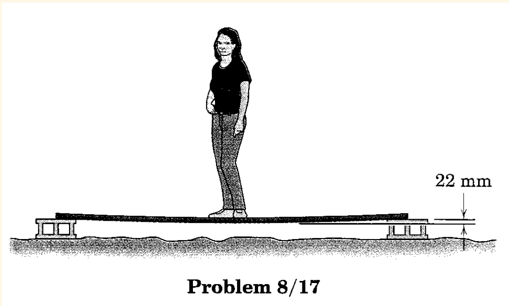
Human-Structure Interaction

What is Human-Structure Interaction?

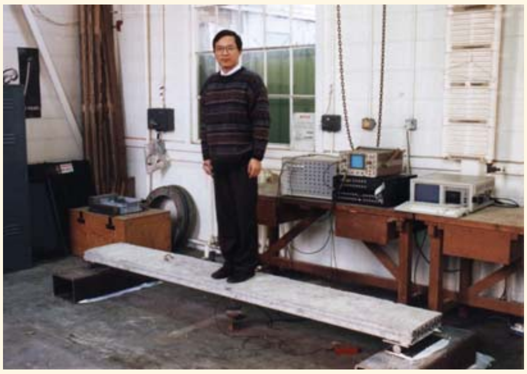
A structure in water	==>	fluid-structure interaction	yes
A structure on soft soil	==>	soil-structure interaction	yes
A crowd on a structure	==>	human-structure interaction	?

Human-structure interaction has not been considered before. One reason is that the human body is traditionally considered as an inert mass in structural vibration.

The figure on the right is a question from a well-known textbook where a girl is treated as an inert mass.



A girl standing on a beam

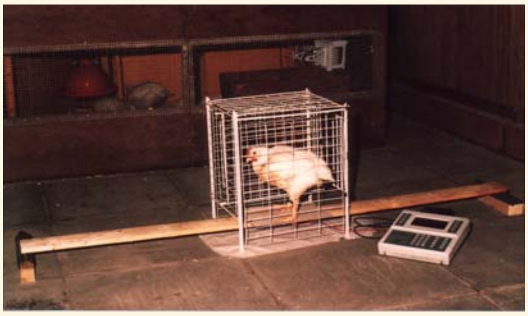


T Ji standing on a beam

A similar test was conducted shown in the figure on the left.

It was found that the human body did not act as an inert mass but as a mass-spring-damper system.

This finding, together with many site measurements, forms a basis of a new topic, human-structure interaction and leads to new applications. One of them is the indirect measurement of the frequency of a chicken.



A chicken perched on a beam

Human-structure interaction *describes the independent human system and structure system working as a whole and studies the structural vibration where people are involved and human body response to structural vibration*

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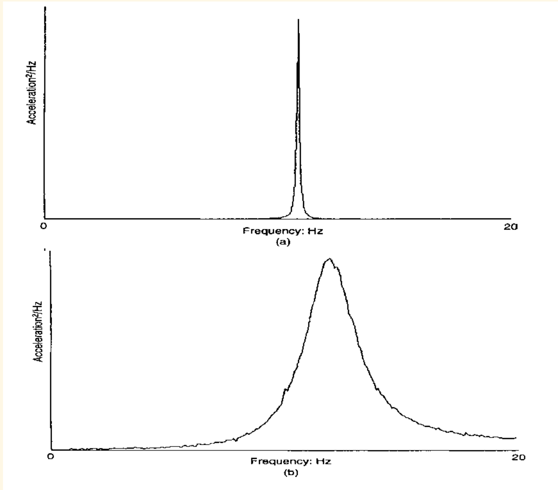
Human-Structure Interaction

Evidence of Human-Structure Interaction

The figure on the right shows the frequency spectra when a test beam is empty and when it is occupied by a standing person.

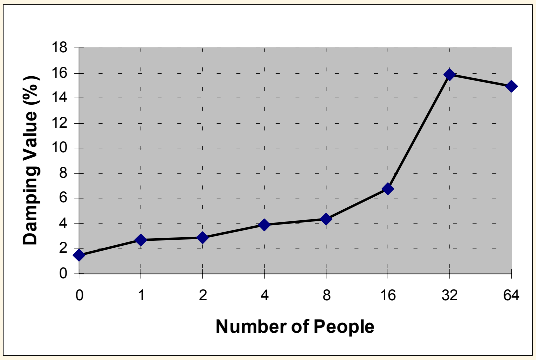
If the human body acted as an inert mass the frequency of the human occupied beam would be smaller rather than bigger.



Upper: The bare beam, f=18.68 Hz
Lower: The occupied beam f=20.02Hz
Left: A test beam

The figure on the right shows the damping value measured from a floor when different numbers of stationary people are involved.

If people acted as an inert mass, they would not change the damping of the floor



Damping value contributed from people in standing

64 students on a test floor

These phenomena were first observed when the North Stand at Twickenham was tested when it was empty and when it was full of spectators. They were then reproduced in laboratories and explained by the concept of human-structure interaction.

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Human-Structure Interaction

Human Actions on Structures

• Stationary -- sitting and standing
• Moving in the time domain -- jumping and stamping
• Moving in both space and time domains -- walking and running

Human Body Models in Structural Vibration

• Solely as a load when a person is moving
• As a mass-spring-damper system when a person is stationary

Modelling of Moving Human Loads

Both jumping and walking loads can be modelled using the equation:

Static **Dynamic**

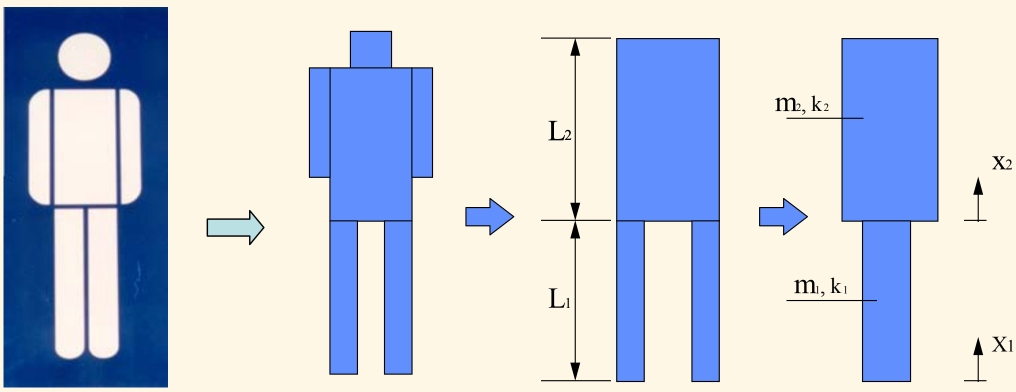
$$F(x,y,t) = G(x,y)\left[1 + C_f \sum_{n=1}^{I} C_n^{np} r_n \sin(2n\pi ft + \theta_n)\right]$$

Density Distribution

Load factors and phase lags
Types of activity
Frequency range
Dynamic crowd effect

Modelling of a Standing Person

The usual sign for a man provides a basic representation of a standing man. This has been evolved into a structural model consisting of two uniform bars. The model bridges the gap between a standing man and a mass-spring-damper model in the study of human-structure interaction in the vertical direction.



Sign for a man

Model of a standing person

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Human-Structure Interaction

Applications

In Structural Engineering:

- Predict human body response to structural vibration
- Evaluate structural vibration where people are involved
- Identify some dynamic characteristics of the human body
- Reduce human induced structural vibrations

Above: Moving spectators
Left: Stationary spectators

In Other Areas:

- Improve human comfort in a working environment
- Improve animal welfare and meat quality

The Structures Concerned

- Long-span floors used for offices, airport terminals and shopping centres
- Grandstands used for sports events and pop concerts
- Light-weight footbridges

Demonstration

The human body model of a stationary person in structural vibration can be easily and quickly demonstrated. A single degree of freedom test rig has been built for the demonstration. The test procedure is:

- Measure the frequency of the test rig
- Add a metal plate on the test rig
- Measure the new frequency of the rig. (A *decreased* frequency will be observed due to the added mass)
- Remove the plate and replaced by a standing person
- Measure the frequency of the human occupied rig (An *increased* frequency with *significantly increased* damping will be observed)

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