Bells situated in church towers can also produce high levels in the building structure. Sustained sources of vibration may produce resonances in buildings or parts of buildings. However, this is less likely to cause problems if the vibrations are transient. The natural frequency of a building will depend mainly on its height and base dimensions, typical values ranging from 10 Hz for a low building to 0.1 Hz for a very tall building. The natural frequency is of interest since this type of vibration may be excited by wind loading of the building. Floors, ceilings and windows also have their own natural frequencies. Typical values for floors are in the range 10-30 Hz depending on size and type of construction. People in buildings are more aware of vibrations transmitted via the floor than from any other part of the structure. It is important therefore that the natural frequency of the floor does not coincide with the range of maximum sensitivity (4-8 Hz) for vertical vibrations of the human body at which whole-body resonance occurs. The maximum amplitude usually occurs in the centre of the floor. Modern long-span floors are likely to cause an increase in floor vibration amplitudes. Natural frequencies of windows range from 10 to 100 Hz depending on the size and thickness of the glass, and for plaster ceilings typical values range from 10 to 20 Hz.

Many investigations have been carried out in an attempt to define threshold limits for the occurrence of vibration induced damage to buildings. The evidence from these investigation has been fully reported and discussed in a Building Research Establishment Report by R. Steffens entitled 'Structural Vibration and Damage', first published in 1974, and recently re-issued. In one investigation on the effects of blasting on buildings it was shown that buildings can withstand peak amplitudes of about 400 m. In contrast, typical levels produced in buildings by nearby road traffic often lie in the range 5-25 m. (10-30 Hz). It is often found that internal sources of vibration in a building, such as footsteps, door slamming, furniture moving, washing machines and vacuum cleaners, will produce levels comparable with or even greater than the external source which is the subject of complaint (road traffic, compressor, pile driver, etc.) Typical vibration levels produced by footsteps and by door slamming can be in the region of 50-150 m.

Other investigations have suggested that limits for damage are best expressed in terms of peak vibration velocity, and various values have been suggested ranging from 50 to 230 $mm.s^{-1}$ depending on the type of building and the degree of damage. For comparison it is interesting to note that a level of 75 $mm.s^{-1}$ corresponds to a Dieckmann K-value of 60, which would be extremely unpleasant, and is well into the painful zone of the Reiher-Meister scale (assuming frequencies in the range 5-40 Hz)

Yet another method for rating vibration, based on energy considerations and developed by Zeller in Germany, has been used for assessing possihle damage to buildings. This involves the acceleration and the frequency of the vibration, the Zeller power being given by the acceleration squared divided by the frequency, and measured in mm^2/Hz^3 .

<u>BS7385 Evaluation and Measurement for Vibration in Buildinqs Part 1. Guide for measurement of vibrations and evaluation of their effects on buildings</u>

This standard, which is identical to IS0 4866 :1990, discusses some of the principles involved in the measurement and evaluation of building vibration, and gives guidance on information to be recorded.The following factors are considered :

-the characteristics of vibration (type of signal, range of magnitudes and frequencies)

produced by different types of source, such as traffic, blasting, pile driving, and machinery

-type of building. Buildings are grouped into fourteen different classes, taking into account the different types of construction, types soil and foundations, and a political importance factor.

-selection of measurement parameters, equipment, transducers, measurement positions, data collection and analysis.

Most ground-borne vibration entering buildings from man-made sources is in the frequency range from 1Hz to 150 Hz. Natural sources such wind, and earthquakes produce significant amounts of vibrational energy lower frequencies, down to 0.1Hz. Vibration induced damage to buildings is classified into categories : cosmetic, minor and major.

Part 2 : 1993 Guide to damage levels from ground-borne vibration

The preferred method of measurement is to simultaneously record unfiltered time-histories of the three different orthogonal components (eg x, y, and z) of particle velocity. The (total) particle velocity may then be found, by taking the root mean square value of the three components, andd its peak value obtained. The peak values of the individual components should also be measured, since it is this type of data which has usually been presented in the various case histories used to develop the limits in the standard.

The case history data suggests that the probability of damage tends towards zero at levels below 12.5 $mm.s^{-1}$ peak component particle velocity. The limit for cosmetic damage varies from 15 $mm.s^{-1}$ at 4 Hz to 50 $mm.s^{-1}$ at 40Hz and above, for measurements taken at the base of the building. Different low frequency limits (below 40 Hz) are given for two different types of buildings. The limits for cosmetic damage should be doubled for minor damage, and doubled again for major damage.

BRE Digest 353, 1990 Damage to structures from ground-borne vibration

This Digest reviews various methods for measuring and assessing building damage caused by vibration, including German, Swiss and Swedish standards. The German standard, DIN 4150 Part 3 1986, which has been widely used, adopts a similar approach to B57385 Part 2. Guideline values of peak component particle velocity, in $mm.s^{-1}$, are given for three different types of building structure. Different limits are given for the frequency ranges : less than 10 Hz, 10 to 50 Hz, and 50 to 100 Hz.

SOURCES OF VIBRATION IN BUILDINGS

Road Traffic.

It is the variability of the interaction between tyres and the road which is the main source of vibration produced by traffic. 'Out of balance' forces produced by the operation of the vehicle also cause vibration, but with modern vehicles these are of less importance than the effects of variability in the road surface caused either by random surface roughness or by