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GROUND VIBRATION AND ITS EFFECTS ON BUILDING HABITABILITY

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SUMMARY

A study has been carried out to develop a method of predicting the vibration levels in domestic dwellings from a previous knowledge of the measured ground vibration on a proposed building site.

Measurements have been made on nine green field sites adjacent to railway lines (as this provides a convenient vibration source) and in houses subsequently erected upon five of these sites.

From these measurements, amplification spectra have been developed to predict the vibration on the ground and first and second floors of houses subsequently erected upon a green field site whose vibration level has been measured.

The spectra are developed in 1/3 octave bands over the frequency range 1 Hz to 80 Hz (to coincide with the range covered by BS 6472 : 1984) "Evaluation of Human Response to Vibration in Buildings (1 Hz to 80 Hz)" and should, therefore, be applicable to other sources of vibration where the input spectrum is known.

It is suggested, however, that the results in the 63 Hz and 80 Hz 1/3 octave band frequencies and below 4 Hz are less reliable than over the rest of the range.

THE PROBLEM

Over the years the problem has frequently arisen of assessing the possibility of complaints arising in planned new domestic buildings, which are to be erected on ground which is affected to some degree by existing powerful vibration sources. Whilst it is quite easy to measure the levels of vibration which exist on the ground in question before the building is erected, at present it is difficult to predict the levels of vibration which would be felt by the occupiers of a building subsequently erected on the site.

The financial incentives to build on sites affected by vibration are high because of the shortage of building land, and developers often have to satisfy the local authority that complaints of vibration are unlikely to occur.

The object of the study was to develop a method of predicting the response of new buildings, erected on green field sites, to ground borne vibration from existing vibration sources.

During the study it proved convenient to carry out field tests in the vicinity of railway lines as these were the most readily available sources of vibrations although it is intended that the results be applicable to any other vibration source.

The study was confined to residential buildings of brick/block construction.

APPROACH

At the outset of the project, it was intended to take measurements on eight green field sites with follow-up measurements in the houses subsequently erected upon the sites.

A method was devised after the first series of measurements for normalising the measured vibration levels to a constant 1/3 octave band spectrum as measured at a monitor position close to the railway track. This is described below in the 'Analysis Method' section. In all cases, several train pass-bys were recorded and the normalised vibration spectra at a particular measuring position were averaged over the total number of trains.

Thus, the difference between a vibration spectrum measured in-house and a vibration spectrum measured earlier on the green field site represents the amplification spectrum dependant upon the response of the house structure, which will be applicable whatever the source of ground vibration.

It was hoped that such amplification spectra measured for eight sites would prove consistent enough to form the basis for an empirical prediction method to be applied in future.

LIMITATIONS

Sites

In the event it only proved possible to take both green field and developed site measurements on five sites. Green field values were obtained for several other sites but for one reason or another developed site measurements proved impossible to make.

In some cases the ground floor was measured but not the second floor and in other cases vertical measurements were made and not horizontal.

No detailed information about ground conditions was obtained.

Human Response

BS 6472 (1984) "Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz)" [1] was published during this study.

This means that there is a standard with which the predicted building response may be compared, and no consideration was given to the relation between predicted building vibration and human reaction to it in this study.

No consideration is given in this paper to the acceptability of the vibration levels which were measured. Methods for evaluating human response are given in British Standard BS 6472.

TESTS

Houses

All houses tested were of standard brick/block construction.

Three houses tested at Site A were single storey on raft and spread footings.

Two Site B houses were three-storey terraced, while the Site C house was two storey detached. Two houses on Site D and two on Site E were also two storey detached houses. All had spread concrete bases on standard footings.

Parameters

Measurements were made at ground floor level in all five sites, and at first floor level at Sites B, C and D.

Second floor measurements were made at two houses on Site B.

Vertical measurements were made in all cases and horizontal measurements at Sites A and E. The horizontal measurements were all in a direction normal to the railway line.

Analysis Method

An inherent problem in the analysis of these results lies in the fact that each train produces a different input due to variations in geometry, weight and speed. The first part of the analysis was, therefore, to normalise all measurements to a standard input.

To do this, the recordings were analaysed in 1/3 octave bands over the frequency range 1 Hz to 80 Hz. This range was selected to coincide with the frequency range of interest in BS 6472 (1984) "Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz)".

The spectra measured at the monitor position, both during the green field measurements and during the house measurements were enveloped to produce the maximum value of any of the train vibration inputs in each 1/3 octave band. The monitor spectrum for each train was subtracted from this envelope to produce correction spectra for application to the other measurements of each train.

Each set of normalised spectra for a particular measurement position and direction from a number of train pass-bys were then averaged logarithmically.

The differences between normalised averaged spectra at a given position and in a given direction for house measurement and green field measurement give the amplification spectra.

RESULTS

Nine amplification spectra were obtained for the ground floor vertical case, six for the upper floor vertical case and five for the ground floor horizontal case.

The arithmetic average of the nine ground floor vertical spectra is presented in Figure 1, for the six upper floor vertical spectra in Figure 2 and for the five ground floor horizontal spectra in Figure 3.

DISCUSSION OF RESULTS

Ground Floor - Vertical (Figure 1)
The sample of spectra for this configuration is nine, and arithmetic averages, together with the standard deviations, have been calculated in each 1/3 octave band.

Scatter is quite high over the nine samples, but the mean spectrum does display expected characteristics.

Below 4 Hz vertical acceleration on the ground floor is attenuated relative to the green field levels. This is probably due to a simple increase in mass impedance at such low frequencies.

The main area of amplification in this configuration occurs over the frequency range 4 hHz to 12.5 Hz where the whole body natural frequency of the house on the springy ground is expected to occur. This is followed at frequencies above 12.5 Hz of an attenuation, again suggesting that the house is acting, as far as the ground floor vertical vibration is concerned, like a mass on a spring.

It is not possible to draw conclusions about the 63 Hz and 80 Hz 1/3 octave bands as there is a distinct possibility that in some of the measurements the transducers were responding to airborne noise as well as to seismic vibration.

First and Second Floors - Vertical (Figure 2)
The sample of spectra for this configuration is six, and arithmetic averages, together with the standard deviations, have again been calculated in each 1/3 octave band.

Scatter is similar over the six samples to the Ground Floor case but, again the mean spectrum does display some expected characteristics.

The amplification between 4 Hz and 12.5 Hz is remarkably similar to that at Ground Floor level, which is to be expected if the above explanation of the house moving as a whole body mass on a spring is correct.

The 1/3 octave frequency bands centred on 20 Hz and 25 Hz are where the natural frequencies of the individual floor are to be expected and a consequent amplification at these frequencies is clearly demonstrated, together with even greater amplifications at 40 Hz and 50 Hz which may represent harmonics of the fundamental vibrations. Reference [1] suggests that these frequencies are typical of whole body response and floor response.

Again, the high levels in the 63 Hz and 80 Hz 1/3 octave bands should be considered with caution due to the possibility of the seismic response of the transducers being overwhelmed by the acoustic response in some tests.

Below 4 Hz, it would be expected that the mean amplification spectrum in this configuration would be similar to the Ground Floor vertical spectrum. In fact, in this frequency range, it demonstrates a considerable amplification and this element must be viewed with suspicion.

Ground Floor - Horizontal (Figure 3)
The sample of spectra for this configuration is five, and arithmetic averages, together with the standard deviations have again been calculated in each 1/3 octave band.

Scatter is similar to the two previous cases. The shape of the spectrum, however, is similar to the vertical spectrum with amplification between 4 Hz and 12.5 Hz and attenuation over the frequencies above and below this range. Both the amplifications and the attenuations, however, are larger than those in the vertical case.

Assessment of the Amplification Spectra
In order to assess these amplification spectra, it was decided to apply them to arbitrary green field vibration data to predict the vibration levels if houses were to be erected there and to assess the resulting overall amplifications.

Reference [2] indicated that overall amplification values range as high as x 5 but the vast majority lie below 2.5 in the vertical direction. This coincides with the experience of ISVR Consultancy Services which indicates first and second floor overall amplification values of x 2.4 to x 2.7 in the vertical direction.

Application of the mean value of the amplification spectrum for a given condition (eg, ground floor vertical) may be expected to predict a vibration spectrum which would not be an under-prediction for 50% of cases. It is considered more cautious to apply a value of the amplification spectrum based upon the mean + $\sigma/2$ value which may be expected to produce a spectrum which would not be an under-prediction for about 75% of cases.

Consequently, it was decided that this would be assessed and the mean + $\sigma/2$ spectra are reproduced (to the nearest dB) in Figures 1, 2 and 3.

First and Second Floor - Vertical: Two measured green field vibration spectra (vertical) were selected:

1. Site F - This was due to a fast passenger train at 5-6 metres below the measurement point at a distance of about 20 metres.

2. Site G - This was due to a heavy goods train approximately level with the measurement point at a distance of about 30 metres.

When the Site F green field spectrum was amplified by the application of the mean + $\sigma/2$ amplification spectrum for First and Second Floor vertical, the overall amplification (ignoring 63 Hz and 80 Hz) was x 4.3.

When the Site G green field spectrum was amplified by the application of the mean + $\sigma/2$ amplification spectrum for First and Second Floor vertical, the overall amplification (ignoring 63 Hz and 80 Hz) was x 2.6.

Ground Floor Vertical: When the Site F green field spectrum was amplified by the application of the mean + σ/2 amplification spectrum for Ground Floor vertical, the overall amplification (ignoring 63 Hz and 80 Hz) was x 1.2.

A similar application on the Site G green field spectrum also produced an overall amplification of x 1.2.

The ground floor overall amplification factors are quite typical as is the overall amplification factor for Site G First and Second Floor. The overall amplification factor for Site F First and Second Floor is quite high but not unreasonably so.

It is clearly dominated by high input levels (green field spectrum) coinciding with the second harmonic frequency of the floors.

CONCLUSION

It is suggested that the brief assessment above indicates that the mean + σ/2 amplification spectra are reasonable and could form the basis of a more accurate prediction of the vibration response of proposed domestic dwellings on sites close to sources of vibration.

ACKNOWLEDGEMENT

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REFERENCES

[1] Harvey H. Hubbard: Noise Induced House Vibrations and Human Perception. Noise Control Engineering Journal, Vol 19, No 2, Sept/Oct 1982.

[2] M.E. House: Traffic Induced Vibrations in Buildings. The Highway Engineer. February 1973.

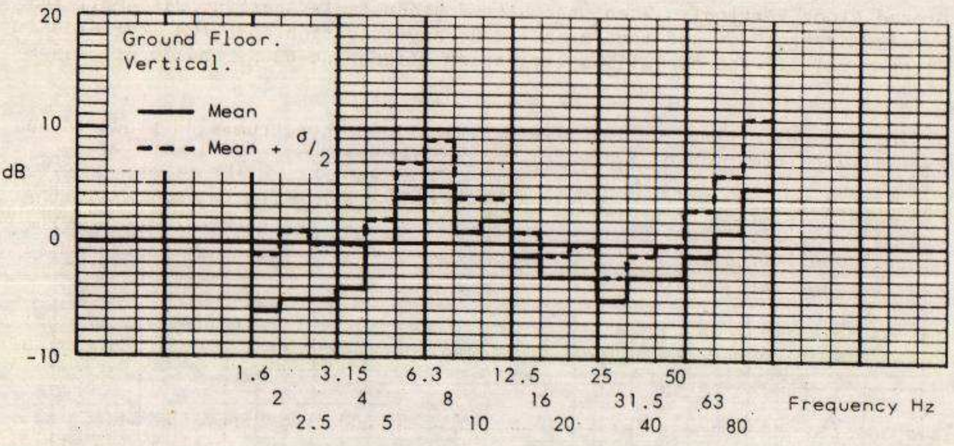

Figure 1: Amplification Spectrum - Ground Floor Vertical.

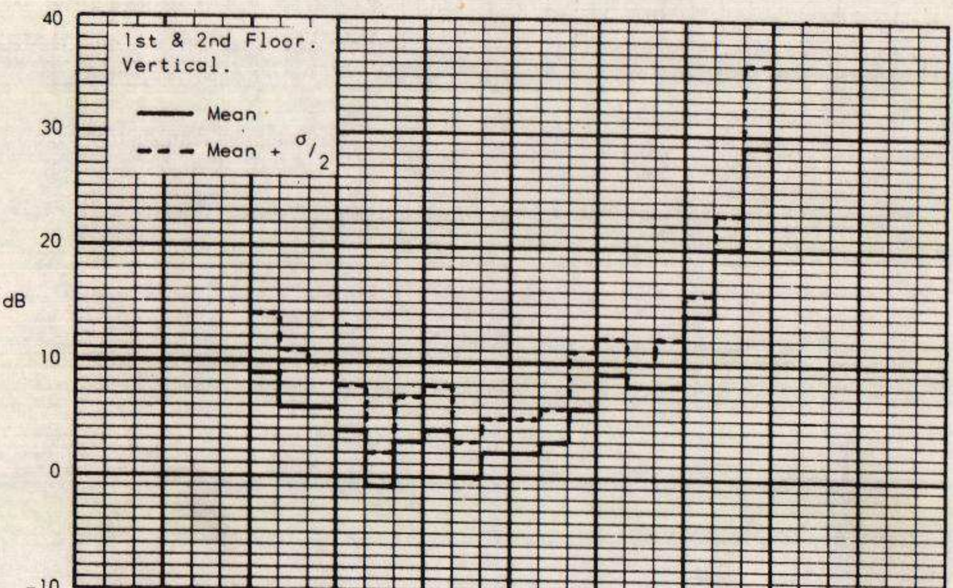

Figure 2: Amplification Spectrum - 1st and 2nd Floor Vertical.

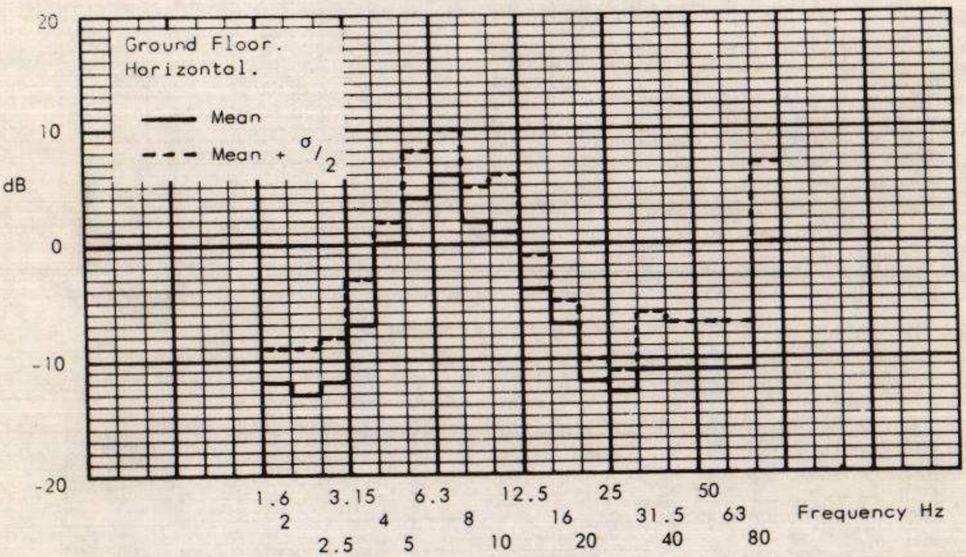

Figure 3: Amplification Spectrum - Ground Floor Horizontal.