THE AMBIENT VIBRATION SURVEY

Ian R. Stubbs[(I)] and Vernon R. McLamore[(II)]

Synopsis

The Ambient Vibration Survey is a practical method of determining the dynamic properties of a structure at any stage of construction or occupancy. The characteristic mode shapes, their associated frequencies, and the value of damping at low vibration levels are measured experimentally. The natural and cultural vibrations, which exist at all times, cause structures to respond selectively in their characteristic modes of vibration. By measuring the effect of these ambient vibrations on the structure with very sensitive sensors, and by carefully analyzing the data mathematically, the dynamic properties can be obtained without the use of large mechanical shakers. The technique can be used to verify mathematical models and to investigate changes in resonant frequencies before and after earthquakes.

TEXT

The Ambient Vibration Survey (AVS) is a direct and practical method of determining the dynamic properties of a structure. It is based upon measuring the response of structures to natural and cultural vibrations which exist at all times. Shakers or other potentially destructive methods of inducing forced vibrations are not required. The technique has a wide variety of applications. Typical surveys have included suspension bridges, rotating machinery supports, earth dams, urban areas, floors, nuclear power facilities, offshore platforms, high rise buildings, a monorail, and a hover craft.

(I) Manager, West Coast Office, Teledyne Geotech, Monrovia, California

(II) Project Manager, West Coast Office, Teledyne Geotech, Monrovia, California

Locations within the structure for recording the ambient vibrations are selected to identify the modal frequencies and to quantify the relative amplitude of each mode at different points in the structure. The instrumentation used for an AVS is illustrated in figure 1. The motion is detected with sensors which can measure vibrations in the range from 10^{-8}g to over 1 g. The frequency response of the instrumentation covers the range from 0.01 to 150 Hz which includes the frequencies expected in the analysis of any structure. Signal conditioners provide amplified output in terms of acceleration, velocity, or displacement as required by the objectives of the survey and the field conditions. The data are recorded in analog form on magnetic tape. A multi-track recorder is used which permits the ambient vibrations at several locations to be recorded simultaneously on a common time base with voice annotation to identify the data.

The data which have been recorded in analog form on magnetic tape are digitized and converted into a form suitable for processing by digital computer. The data may be filtered, decimated, despiked, truncated, and summed in order to enhance the signal. The analysis includes Fourier transforms, power spectral densities, cross spectra, auto correlations, and other processes associated with time series analyses. A plot of power spectral density is used to determine natural frequencies of vibration (figure 2a). Plots of relative amplitude (figure 2b) and relative phase (figure 2c) are used to derive mode shapes (figure 3). The velocity proportional damping can be estimated from the plot of power spectral density using the half power point method.

In the design stage, structures are normally analyzed for earthquake resistance using mathematical models. The dynamic properties are computed from the physical dimensions and the properties of the building materials. Once the structure is in service, it is advisable to compare the computed and actual dynamic characteristics. The AVS is an excellent tool for this purpose. In the cases of large structures where a failure would have a serious local impact, i.e., a nuclear reactor, any differences in "as designed" and "as constructed" properties can be evaluated and problem areas can be rectified. A comparison of typical relations between mathematically predicted natural frequencies and experimentally determined natural frequencies is given in table 1. Correlation of "as built" dynamic properties and mathematical models is also useful where analyses for earthquake resistance are being performed on structures that have been in service for considerable time. An example of this is the case of the early dams in California constructed using the hydraulic fill method. Currently, there is some concern that these structures may be subject to liquefaction in a strong earthquake. Excellent results in obtaining the dynamic properties of earth fill dams have been obtained using the AVS.

Another application is the stability of high rise structures. The natural frequencies of these structures are essentially a function of the mass and the stiffness. For most structures, once in service, the mass will vary only slightly. Therefore, a change in frequency will signify a change in stiffness. It is necessary to make an AVS as soon as possible after occupancy. From time to time the survey can be repeated to insure that no changes in frequency have occurred. After the structure experiences strong motion, an AVS could reveal a shift in the natural frequencies and could give a positive indication as to the post earthquake integrity of the structure. Ambient Vibration Surveys were performed on one structure in Los Angeles in 1968 and again in 1969. This structure experienced strong motion in the San Fernando earthquake and two post earthquake surveys were made. The frequencies of vibration measured each time are tabulated in table 2. It is obvious that a detailed study of this building was warranted.

There are several methods of determining the natural modes of vibration of structures as built. The AVS has a number of features which makes it particularly attractive over other methods. The instrumentation is lightweight and portable. This permits data to be recorded at a large number of locations with very little interference with the normal flow of activity. There is no requirement for attachment of equipment to the structure with the resulting patchwork which has to be done. The levels of vibration recorded are those that the structure is constantly being subjected to and owners have no fear of damage during testing. The instrumentation will cover a wide frequency range. Structures with natural periods of fractions of a second, such as equipment foundations and structures with natural periods of several seconds such as suspension bridges can be handled with equal ease. The range of vibration amplitudes which can be handled is also large. The recorded data contain all the resonances at a location. Thus, the analysis and determination of the natural modes can be done at the data center. The analog form of the data permits processing in several different ways and gives the analyst greater scope in interpretation.

The Ambient Vibration Survey has been used on a wide variety of structures and the method has proven to be both an economical and practical way of determining the dynamic properties of these structures.

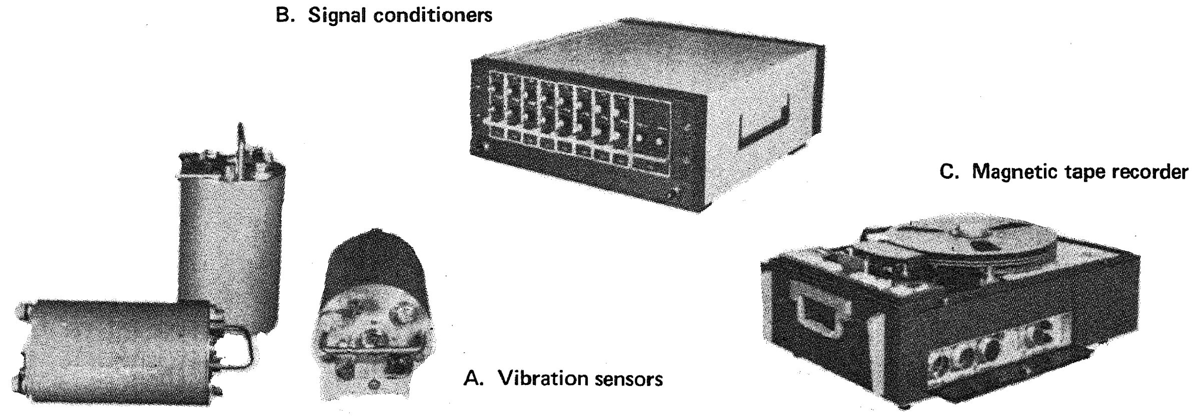
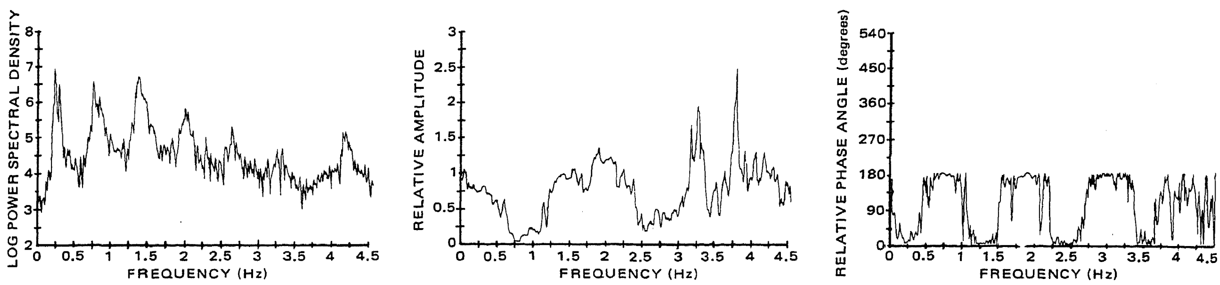


Figure 1. Instrumentation



A. Power spectral density B. Relative amplitude C. Relative phase

Figure 2. Examples of data processing

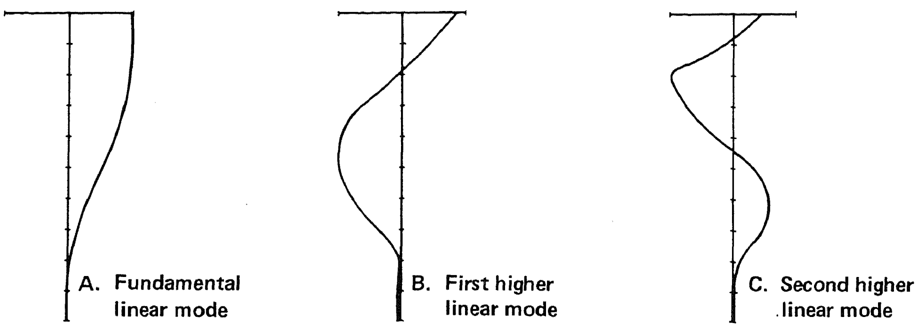


Figure 3. Typical mode shapes of a nine story building

	FREQUENCY (Hz)			
MATHEMATICAL	2.20	2.77	3.12	3.46
EXPERIMENTAL	2.08	2.63	2.97	3.20

Table 1. Typical comparison of mathematically predicted and experimentally observed natural frequencies

	FREQUENCY (Hz)			
MODE	1968	1969	Feb 1971	May 1971
1	0.283	0.28	0.245	0.25
2	0.858	0.84	0.745	0.77
3	1.579	1.52	1.35	1.38
4	2.251	2.21	1.91	1.99
5	2.972	–	2.49	2.62

Table 2. Variation of natural frequencies of a high rise building with time before and after an earthquake