STRUCTURAL MONITORING TECHNIQUES AND INSTRUMENTATION FOR NUCLEAR POWER PLANTS

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SYNOPSIS

The ambient vibrations of the ground can be used as an excitation source to empirically determine the shape and frequency of the natural modes of vibration of a nuclear reactor power plant structure. If the mathematical model of the structure is upgraded to agree with these observations, it can provide more reliable extrapolations to the entire structure from strong-motion accelerograms observed in the free field and near the containment vessel. A system is available for recording in multiplexed FM format on magnetic tape up to 18 channels of accelerations, strains, meteorological, or other data. This system operates in a triggered mode so that only data of interest are recorded. The magnetic tape recordings can be digitized for computer processing in both the time and frequency domains. The time history of the acceleration, velocity, and displacement and their Fourier spectra can be used for evaluation of the structural integrity after a strong-motion event.

TEXT

Techniques and instrumentation are available that can aid in verifying structural design dynamic models of nuclear power plants. Similar techniques and less sensitive instrumentation can aid in a quick assessment of plant structural integrity and of the potential environmental risk resulting from an accident or from a large natural disturbance, such as an earthquake. This paper briefly describes some of these techniques and this instrumentation.

As a part of the structural design of a nuclear power plant, a mathematical model is created to simulate the actual structure. The mathematical model is used to predict the response of the unbuilt structure to the inputs from the ground during an earthquake of specified maximum acceleration and pseudo relative velocity. In addition to approximations made in assuming that the mass is concentrated at a limited number of points and in estimating spring rates and damping, the model contains simplified approximations to dynamic considerations such as 1) the interactions between separate structural buildings; 2) the effect of active

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machines; 3) the assumption of symmetry; and 4) the method of combining the motion from the various modes into a total maximum motion at the desired points. The validity of the model and the approximations can be verified by empirical measurements made on the actual structure. The Ambient Vibration Survey[1] (AVS) technique uses the ambient vibrations of the ground as an input excitation to the structure. The effect of these continuous vibrations are measured simultaneously at several points within the structure. Careful analysis of these data provide linear and torsional mode shapes and frequencies and an estimate of the damping at low vibration levels. The empirical measurements made at many locations in the structure can be used to improve the mathematical model. They also can be used to predict relative motion between the critical points in the structure and the specific points where permanently installed monitoring accelerometers are to be located.

Recording of the acceleration history of a nuclear power reactor near the epicenter of a great earthquake will give important data on the success of reactor engineering for earthquake survival. Recording of the acceleration history in the free field and at several points near the containment vessel will provide input and output time series that can be used with the mathematical model to analyze the extent of stress applied to the structural members. The extrapolation to the entire structure of the time history recorded at only a few points is dependent on the accuracy of the mathematical model and of the assumptions that went into its derivation. If this model has been improved to agree with empirical mode shapes and frequencies determined by an AVS, much greater confidence can be placed in this extrapolation.

New nuclear power reactor facilities in the USA are committed to install a strong-motion instrumentation system to record the acceleration time history in the free field and at least two points in the structure. A system designed for this application is shown in figure 1. The system normally is operated in a standby mode with only its automatic triggering circuitry energized. When the surface on which the trigger is located experiences motion above a preset threshold, the trigger is actuated and the system achieves full operational status within 0.1 second. The system continues to operate for up to 60 seconds after the motion from the event falls below the trigger threshold level. The use of the triggered mode of recording reduces the amount of data to be considered and simplifies the environmental risk considerations of the operator. The system utilizes triaxial force-balance accelerometers as sensors. These units measure acceleration directly over the frequency range from dc to 40 Hz. The direct measurement eliminates the necessity for electronic conversion of damped spring-mass electromagnetic transducer outputs to provide acceleration information. The recorder has a continuous loop magnetic tape cartridge with a recording capacity ranging up to 60 minutes. Four recording tracks are provided: one is used for internally generated timing information and speed compensation and the other three are data tracks. Each track can accommodate up to six channels of multiplexed FM data, providing capability for recording up to 18 channels of data. Meteorological data, dynamic strain data, and other parameters of interest can be recorded simultaneously with the strong-motion acceleration data. Multiplexing of data on a single tape cartridge allows accurate time and phase correlation of all data channels. The magnetic tape recording medium is ideal for use in a radiation environment such as that encountered in nuclear reactor installations because the recording medium suffers no deleterious effects. The advantages of analog magnetic tape recording over photographic film strong-motion recorders are: 1) minimum loss of data due to accidental exposure of film to light or erroneous developing process; 2) visual data immediately available with playback system; 3) data directly compatible with machine processing without degradation from visual digitization processes; 4) machine processing techniques can be used to enhance the analog data; 5) higher frequency components of the signal can be played back on a chart recorder with an expanded time base for easier analysis; and 6) equipment that is simpler to operate and maintain. This system is powered by internal rechargeable batteries which provide power in sufficient reserve to afford reliable operation in the event of ac power failure. The batteries are floated across a battery charger. Simultaneous with the magnetic-tape recording, visual recordings, and ancillarly level detectors are provided to indicate accelerations experienced at key locations for quick comparison to the Operating Basis Earthquake values so that the plant operator can assess the potential dangers.

The three-component accelerograms recorded on the magnetic tape can be automatically digitized for computer analysis. Time histories of acceleration, velocity, and displacement can be established for the accelerometer locations. Transfer functions between these several points can be calculated and compared to the predictions of the mathematical model. The Fourier amplitude and phase spectra can be used to estimate the extent of excitation of the several natural modes of oscillation of the structure. The Fourier spectra can be compared to the design criteria for pseudo relative velocity. Narrow band-pass filtering can be used to determine the maximum amplitude, duration, and frequency content of the acceleration, velocity, and displacement. These amplitudes and durations can be used to analyze the potential damage to the structure from the strong-motion excitation.

BIBLIOGRAPHY

1. Stubbs, Ian R. and Vernon R. McLamore, 1973, The ambient vibration survey, Proc. Fifth World Conference on Earthquake Engineering

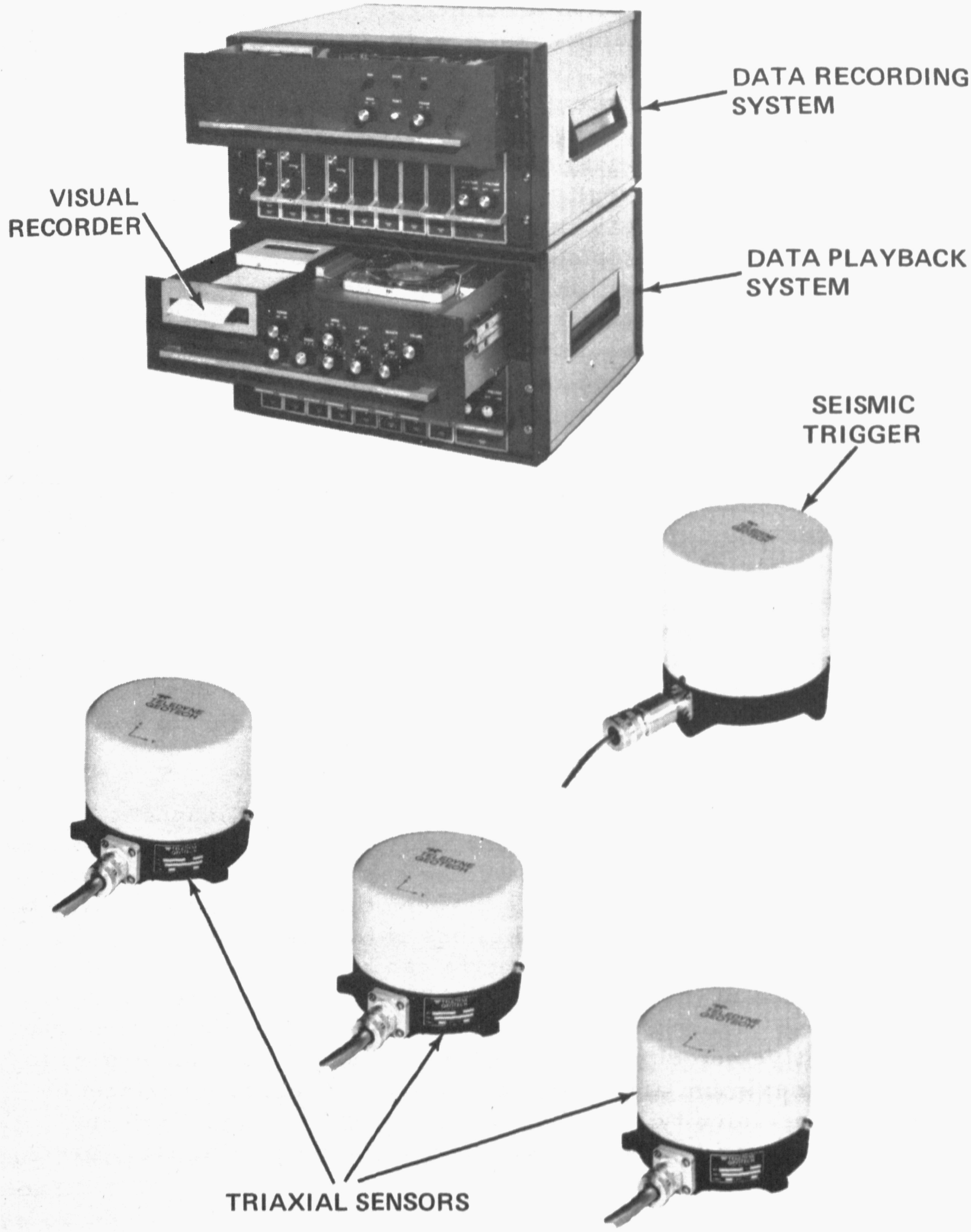

FIGURE 1. NUCLEAR POWER PLANT, STRONG-MOTION RECORDING SYSTEM