DAMPING OF AN OFFSHORE PLATFORM MODEL BY RANDOM DEC METHOD

by

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ABSTRACT

The purpose of this investigation is to examine the feasibility of using a new analysis technique called Random Decrement to accurately extract frequencies, and damping coefficients for an offshore platform structure supported by different foundation conditions.

The structure tested was a model of an oil drilling platform. It was a welded-steel space frame with four primary legs supported on a steel plate, and braced with horizontal and diagonal members. A special air cushion supported base was constructed and was connected to a Calidyne 5000 lb. shaker.

Three different foundation cases were investigated: (1) fixed (bolted) base, (2) free base, (3) embedded about 2 inches in soil.

In all cases tests were ran to measure the damping of the structure. Sinusoidal and random input excitation was applied in a single horizontal direction. The response of the structure was monitored with accelerometers placed at different positions on the structure.

The damping coefficient was first calculated from the frequency response curve (half power point) and the logarithmic decrement of the free response curve. Then the damping coefficient was calculated from the random decrement analysis of the response of a random input excitation and it was compared with the coefficients calculated from the first two classical analysis techniques.

INTRODUCTION

It is generally accepted that in the design of structures to safely withstand ground motions from earthquakes, more precise methods of analysis are needed. This is especially crit[illegible] for the design of

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important structures such as multi-story buildings, nuclear power plants, offshore platforms, etc. Sophisticated analytical techniques such as the finite-element method are being developed to satisfy these needs. The results of analyses using these techniques clearly show that there is a strong interaction between structures and their soil foundations, and accurate analysis of structural response during earthquakes are strongly dependent on the damping values used in the analysis (1,2,3,4,5,6,7).

Various attempts have been made to provide means for obtaining structural damping information used in the design of structures with foundations and used in the monitoring of the response to the applied forces. However, most of these techniques are only suitable for use under controlled laboratory conditions and are of little use for structures in service.

A simple, direct, and precise method is needed for translating the response time history into a form meaningful to the observer. Spectral power density has been considered, with damping measured by the half-power bandwidth method, but this was found to have a large measurement variance, especially when the bandwidth was small. In addition, when two modes are close this method cannot be applied.

A new technique called "Random Decrement" has been developed and explored initially by H. Cole (8) and continued by J. C. S. Yang (9) which advanced the state-of-the-art in the measurement of damping in structures subjected to random excitation when only response data is available. The method was originally developed as a technique for determining damping characteristics of models being tested in wind tunnels (8). The method is currently used in the aerospace industry to measure damping in tunnel models and aircraft in flight (10,11). Subsequently the method is used to measure damping in plates, beams, mobile homes, piping systems, etc. (9,12), and to detect structural failure in piping systems, offshore platforms, etc. (13,14).

The basic concept of the "random decrement signature" is based on the fact that a random response of a structure due to a random input is composed of two parts: a) a deterministic part (impulse and/or step function), and b) a random part. By averaging enough samples of the same random response, the random part will average out, leaving the deterministic part. It can be shown that by proper digital processing, the deterministic part that remains is the free decay response; from which the damping can be measured. Hence the Randomdec technique uses the free decay responses of a structure under random load to identify its vibration parameters, namely frequencies, damping and modal vectors. This method offers the obvious advantage that the input function can be any type of random loading which occurs during its service life, such as seismic, wind, ocean waves, traffic, etc. and the random decrement signal is independent of the input to the structure and represents that particular structure tested.

A brief, rather intuitive explanation of the principles of Random Decrement Technique is given in Appendix A.

EXPERIMENTAL SET-UP

Test Model

A model oil platform was constructed. It is a welded-steel space frame with four primary legs and an upper and a lower plate, braced with horizontal and diagonal members. The primary legs of the model had a diameter of 25 mm (0.984 inch), and the horizontal and diagonal members had diameter of 15 mm (0.591 inch). The structure, its design and the dimensions of all the components are shown in Figure 1.

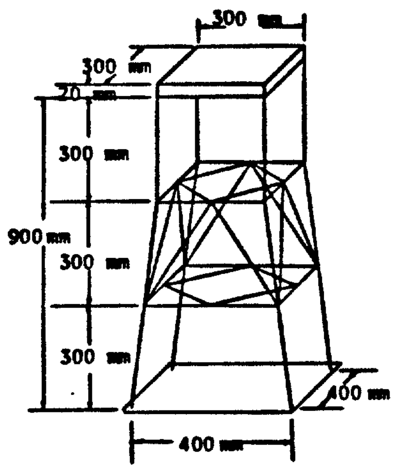

Fig.1 Offshore Platform Model

Shake Table

The platform model was placed on a special air cushion supported base connected at either ends to a Calidyne 5000 lb. shaker, or an MB Electronic, PM 50, 30 lb. shaker. The shake table consisted of a 4'x6' sheet of 3/4" plywood with 1"x8" pine wood sides supported on a cast iron grating. The grating is sitting on two rubber inner tubes. The two shakers are attached to the wooden sides of the table with their axis of motion in the longitudinal direction. An accelerometer is placed on the base of the platform in the direction of motion. A picture of the shake Table with the Test Model is given in Figure 2.

Soil Used

A fine sand was used to represent the foundation for the platform. Results from sieve tests shown in Fig. 3 performed according to ASTM Standard C-136 indicated that the sand to be fine and poorly graded and can be classified as SP according to the Unified Soil Classification System. Oven Dry Unit weight of the sand was 97.5 lb/ft^3.

From ASTM Standard C-128, the Bulk Specific Gravity of the sand was 2.633. The relative density of the sand in the loose state, determined according to ASTM Standard D-2049, was 0.895, and in the dense state it was 0.574. The average thickness of the soil in the shake table was 5 inch.

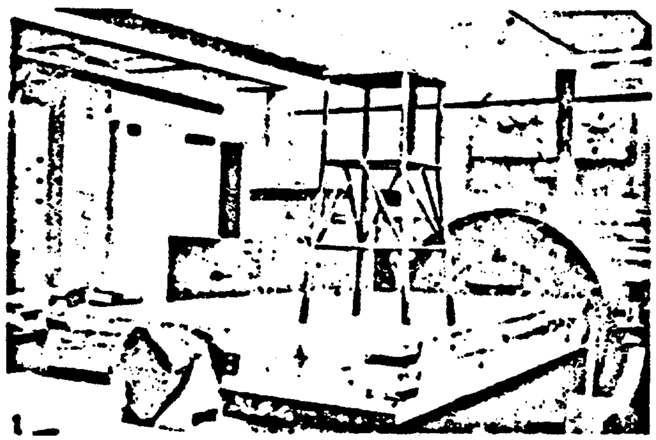

Fig. 2 Shake Table and Test Model

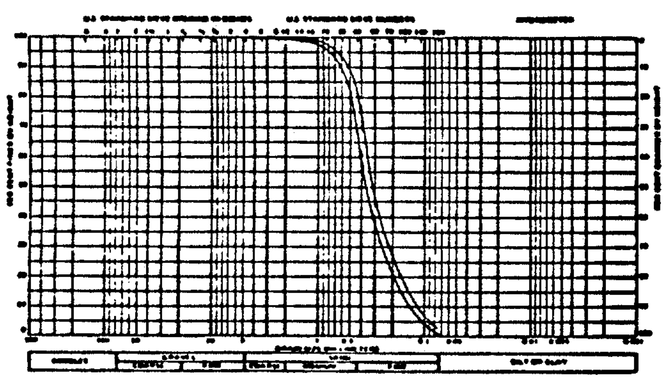

Fig. 3 Limits of Sieve Tests on Soil Used

DAMPING DETERMINATION

A laboratory experiment was conducted to measure the damping of the structure with three different foundation conditions: (1) fixed (bolted) base; (2) free base; and (3) embedded (2 inches) in soil. Sinusoidal and random input excitation was applied in a single horizontal direction. The response of the structure was monitored with accelerometers placed at different positions on the structure.

Sine Sweep

With the 30 lb. shaker bolted to the end of the shake table, sinusoidal vibration was inputted into the shake table. The output of the accelerometer was monitored on a Tektronix SA18N Trace Amplifier Oscilloscope and the signal strength, peak-to-peak, was recorded along with the frequency of the accelerometer signal at that signal strength: the frequency was found by using a 10 second count off, a Tektronix DC 504 Counter/timer and dividing the output by 10.

The points were then plotted on an arithmetic scale graph and damping calculated using the half-power point technique.

Free Response

The Free Response of the system was arrived at by exciting the table at the system resonant frequency and suddenly removing the electrical cable running from the shaker amplifier to the vibrator, allowing the system to lose energy through damping. The signal of the accelerometer during the loss of energy was stored on the oscilloscope screen and transferred onto tracing paper. The logarithmic decrement of the signal was then calculated.

Frequency Spectrum

The frequency spectrum of the system was found through computer analysis of a recorded signal from an accelerometer (Columbia 504-3) on the platform while the Shake Table was undergoing random excitation.

The random input is produced by a Random Noise Generator (General Radio Company 1390-B), connected to a power amplifier (Electrochyne, N-100) whose signal was the input into the 30 lb shaker (MB Electronics, PM 50).

The platform response is picked up by the accelerometer glued to a support near the top of the platform. The output signal is amplified by a charge amplifier (Kistler, 504) and then recorded on magnetic tape with an AC/DC tape recorder (B & K, 7003).

The recorded response signal is first passed through a signal amplifier then through a band pass filter (I claco, P.11) before it is fed into a programmable amplifier, which is tied to a minicomputer (Cromenco, 32-K bit memory).

The computer program is set up such that it automatically amplifies the input signal to the full range capacity of ±8 volts of the following analog-to-digital converter (8 bits). The digitized signal is then stored into the memory of the computer and the power spectral density function is evaluated. The execution of the analysis is controlled by a terminal (TEKTRONIX, 4066-1) which can also be used to display the resulting power spectral density. If a hard copy is desired it can be obtained from a digital plotter. (HOUSTON INSTRUMENTS, HIPLOT TM) A schematic diagram of the computer set-up is shown in Figure 4.

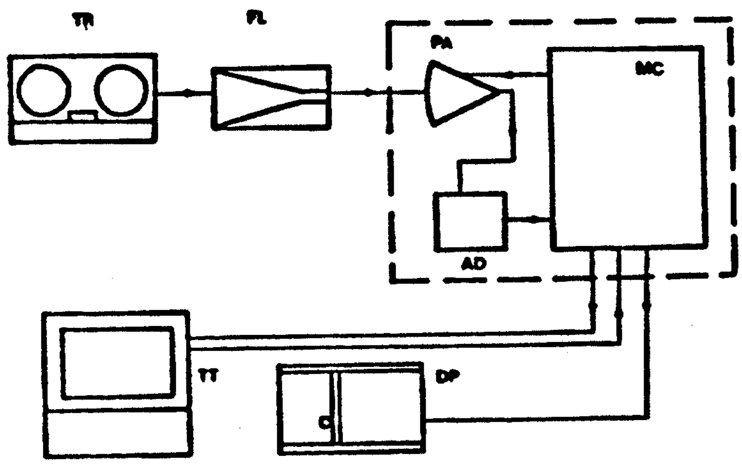

Fig.4 Analysis of the recorded response signal, with TR: tape recorder, FL: filter, PA: programmable amplifier, AD: digitizer, MC: minicomputer, TT: tektronix terminal, DP: digital plotter

Random Decrement Technique

For the Random Decrement Technique the same procedure as was used for the power spectrum was used. However, for the fixed and free conditions the signal was first passed through a 3rd Octave filter (B & K 2112 Audio-Frequency Spectrometer) and then into the minicomputer. Center frequencies of the filter were chosen after analyzing the power spectrum. When smaller bandwidths were needed for close spaced modes, a resonant filter contained within the minicomputer was used. The signal was then analyzed by the Random Decrement computer program within the minicomputer. For the platform in the sand condition the signal was passed through the signal amplifier then into the minicomputer. After the signals were analyzed the output in all cases was recorded using the digital plotter.

Numerical Model

A finite element space frame model of the structure was developed using the GIFTS and the NASTRAN computer programs. The horizontal and the diagonal braces were modeled by beam elements, the top plate was modeled by plate elements which allow bending and membrane flexibility. From the computer model program, the frequency of the first natural mode of oscillation of the model platform was found to be 59.8 cycles/sec.

RESULTS

The computer generated power spectral density curves of the response for the different cases tested are shown in Figure 5.

Sine sweep test results are shown on Figure 6. Damping values were obtained, for the different cases tested, from half power point measurements.

From the power spectral density curves appropriate narrow band filters were selected to isolate individual modes for random decrement analysis. Typical random decrement free vibration decay curves are given in Fig. 7 for each case tested. Damping coefficients are calculated from the logarithmic decrement of the random decrement free response curve.

A summary of the damping measurements from all the techniques are given in Table 1.

TABLE 1: Summary of Results

Test Condition	Conventional Techniques				Random Decrement	
	Sine Sweep		Free Response			
	Freq.	Damping	Freq.	Damping	Freq.	Damping
Fixed	15.1 66.0	.045 -.060 .0025-.0045	15.1 66.0	.024 .0046	14.2 63.8	.015 .0030
Free	64.9	.004 -.006	64.9	.0045	62.8	.0030
Platform Embedded 2 inches in Sand	6.9 59.5	.065 -.085 .02 -.04	6.9 59.5	.070 .029	8.1 60.5	.065 .017

DISCUSSION AND CONCLUSIONS

The limitations imposed by the digital filter characteristics at low frequencies considerably affected the calculation of damping ratio. However the results from Table 1 show that for the comparisons which were made, the damping ratios differed by less than a factor of 1.4 except for the case where the structure is fixed to the support.

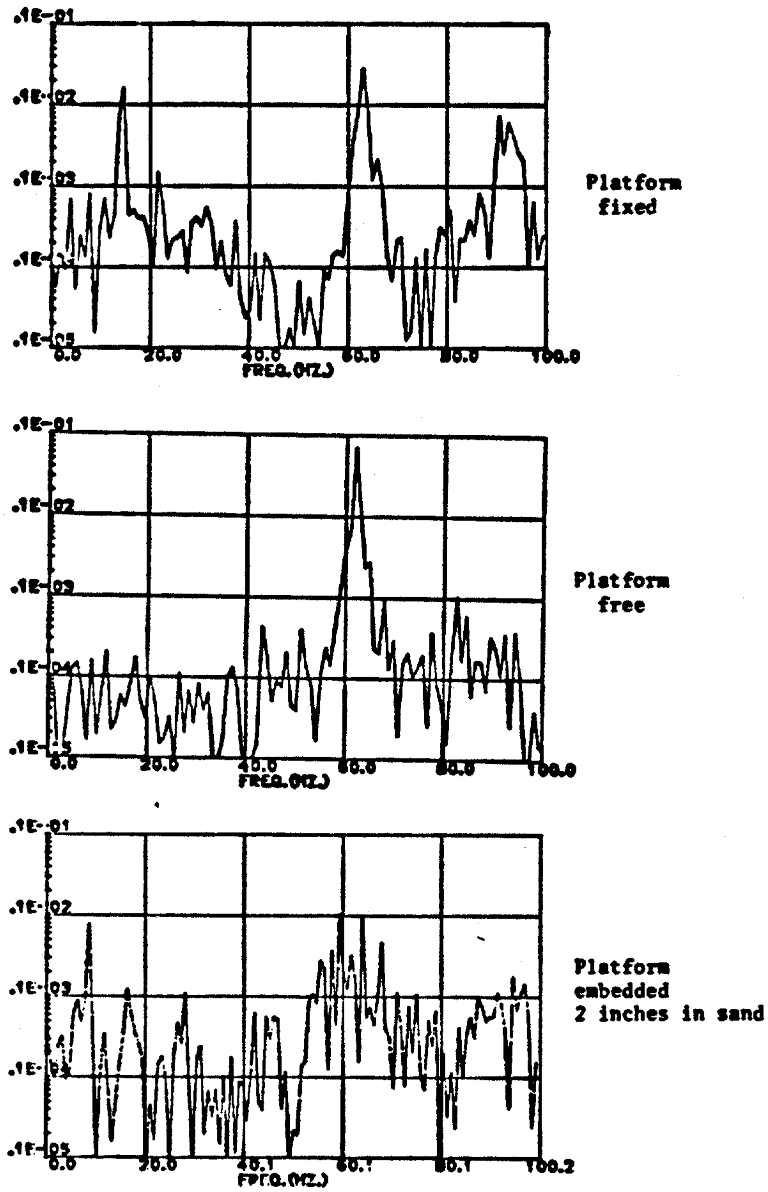

Fig. 5 Power Spectral Density Curves

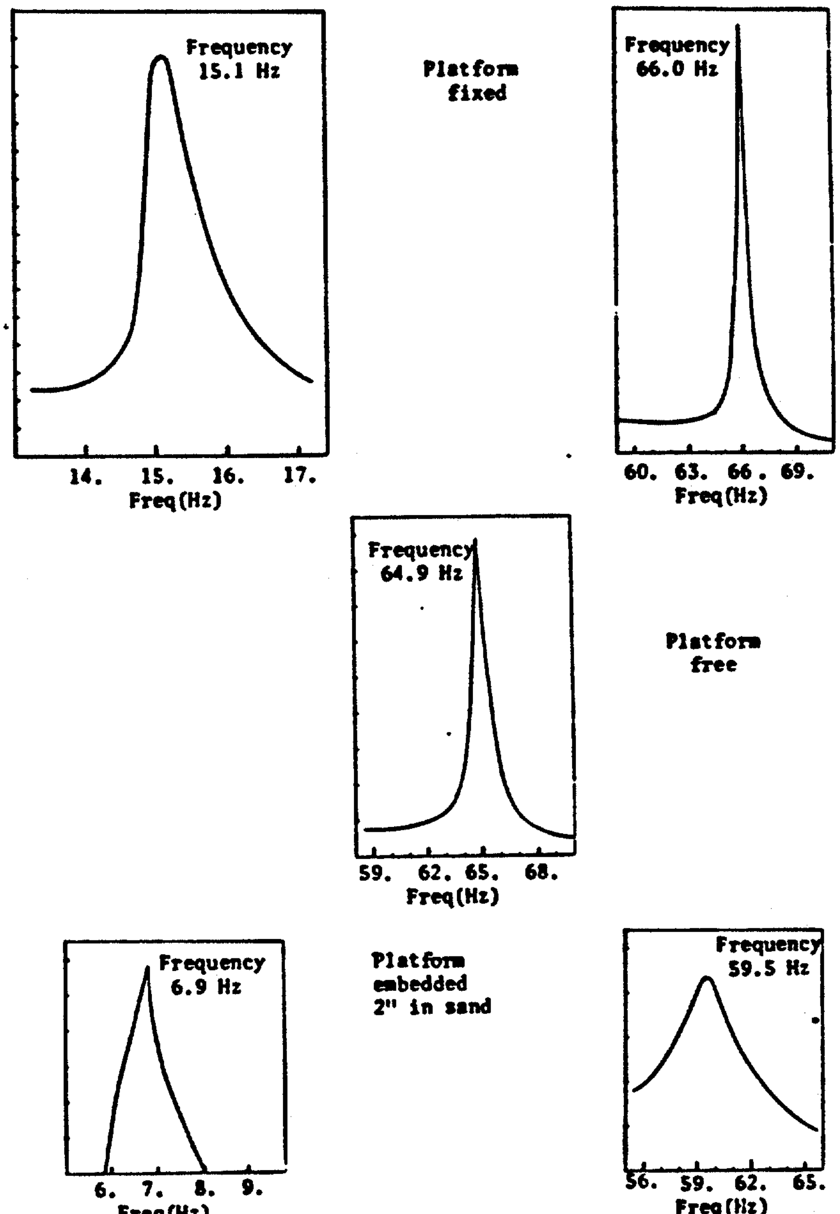

Fig. 6 Sine Sweep Results

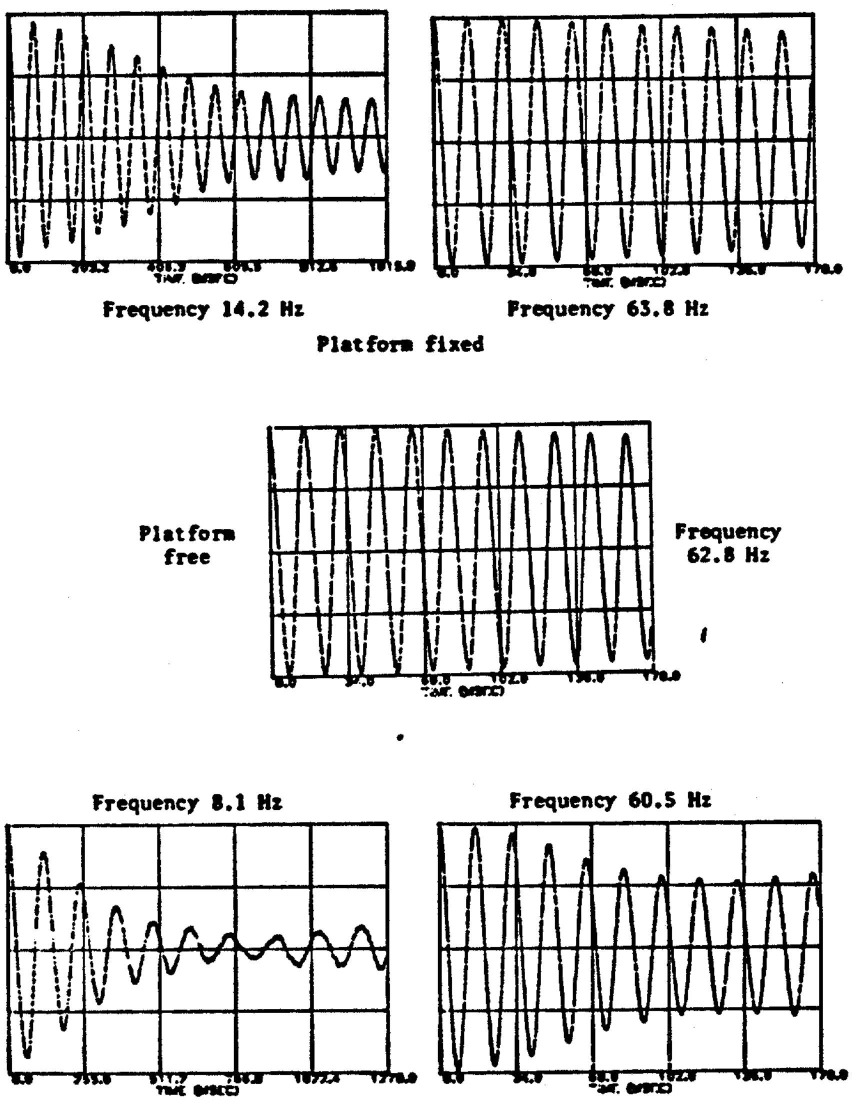

Fig. 7 Random Dec. Free Vibration Decay Curves

The damping ratio at the fundamental frequency differs by a factor of 3.

A comparison of values of the resonant frequencies obtained from the transfer function and sine sweep plots with those calculated from the periods of the random decrement signatures show that all differed by less than 6 percent, except for the fundamental mode of the structure embedded in soil. The difference is about 14%. Considering that the random decrement signatures were calculated from only response data while it was necessary to also use the excitation data for the calculation of the transfer function, these results are very good.

The satisfactory results obtained from the experimental comparisons indicate that the random decrement technique is a valid method of measuring damping ratios.

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APPENDIX A

RANDOM DECREMENT TECHNIQUE

The response x(t) of a linear system is governed by the following basic equation:

$$m\,\ddot{x}(t) + c\,\dot{x}(t) + k\,x(t) = f(t) \qquad (1)$$

The solution of this differential equation depends on its initial conditions and the excitation f(t). Since, for linear systems the superposition law applies, the response can be decomposed into three parts: response due to initial displacement $x_d(t)$, response due to initial velocity $x_v(t)$ and finally the response due to the forcing function $x_f(t)$.

The Randomdec analysis consists of averaging N segments of the length τ_1 of the system response in the following manner: the starting time t_i of each segment is selected such that $x_i(t_i)=x_s$=constant and the slope $\dot{x}_i(t_i)$ is alternating positive and negative. This process can be represented in mathematical fo—:

$$\delta(\tau) = \frac{1}{N}\sum_{i=1} x_i(t_i+\tau) \qquad (2)$$

where $x_i(t_i) = x_s \qquad i = 1, 2, 3 \ldots.$

$\dot{x}_i(t_i) = \geq 0 \qquad i = 1, 3, 5 \ldots.$

$\dot{x}_i(t_i) = \leq 0 \qquad i = 2, 4, 6 \ldots.$

The function $\delta(\tau)$ is called the Randomdec signature and is only defined in the time interval $0 \leq \tau \leq \tau_1$. The meaning of the Randomdec signature can now be determined. If the parts due to initial velocity are averaged together, they cancel out because alternately parts with positive and negative initial slopes are taken and their distribution is random. Furthermore, if the parts due to the excitation are averaged they also vanish because, by definition, the excitation is random. Finally only the parts due to initial displacement are left and their average is the Randomdec signature representing the free vibration decay curve of the system due to an initial displacement, which corresponds to the bias level x_s. (Fig 1)

In reality the Randomdec computer converts each segment into digital form and adds it to the previous segments (Fig 2); the average is then stored in the memory and can be displayed on a screen. The number of segments to be averaged for the Randomdec signature depends on the signal shape, usually 400 to 500 averages are sufficient to produce a repeatable signature.

One particularly interesting characteristic of Randomdec technique should be mentioned: it requires no knowledge of the excitation f(t) as long as it is random. Neither the type nor the intensity of the input affect the signature.

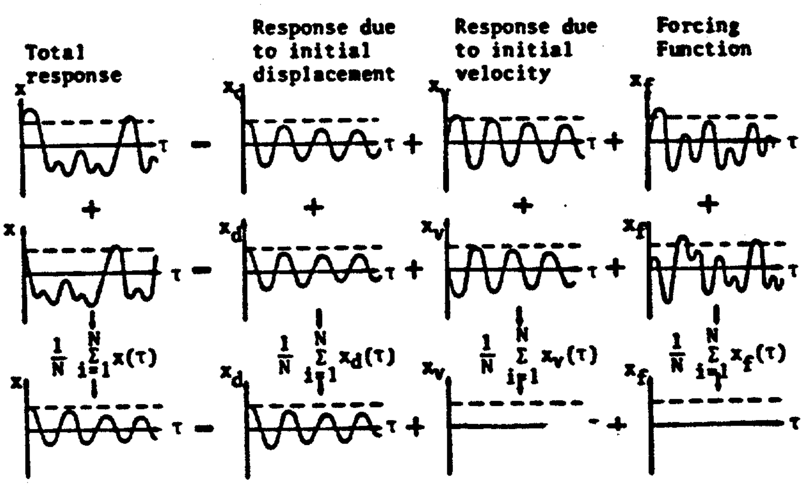

Fig. 1 Principles of Random Decrement Technique

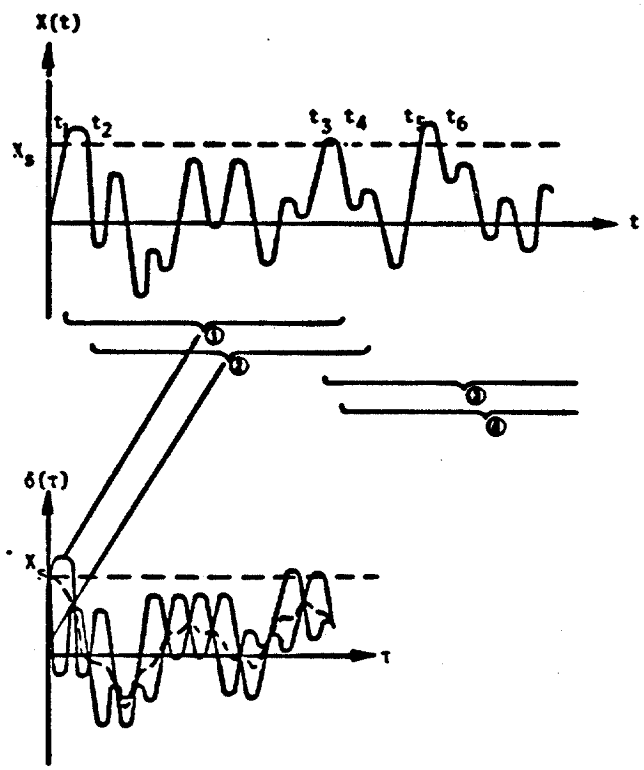

Fig. 2 Extraction of the Random Decrement Signature