A New Testing Arrangement for Damping of Concrete

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Abstract-The energy absorbing characteristics of a vibrating system is termed as damping. The phenomena is very important for structures subjected to earthquake and other dynamic loading conditions where small duration are involved. Damping characteristics of a material play an important role in overall stability of a structure. The higher is the damping value, the shorter will be the time to disappear the vibrations. However, damping requirement at the cost of strength of a given material is not justified in any case. This paper describes that the damping of material can be calculated from the time history curve as well as resonance frequency curve. Both these curves are available in new testing arrangements of Impulse Load Test (I. L.T.) and therefore were utilized for damping evaluation of concrete [i]. In this paper, the author is describing the I. L.T test either on cement concrete or asphalt concrete by considering relevant ASTM specifications. There are certainly different variables taken into account with respect to cement concrete or asphalt concrete. After the experiment, the conclusions are drawn in different ways depending upon either the specimen is of cement concrete or asphalt and by considering their relevant variables.

Keywords-Damping of Concrete, Earthquake, Impulse Load Test, Time History Curve, Resonance Frequency Curve

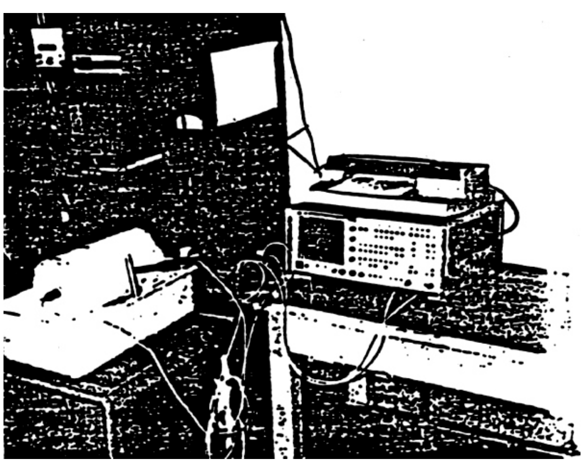

Fig. 1. Arrangement for Impulse Load Test

I. INTRODUCTION

The energy absorbing characteristics of a system is termed as damping. When a system of any material is set into a state of free vibration, the vibration will decrease in amplitude and eventually disappear. This phenomenon is very important for structures subjected to the earthquake and dynamic loading conditions. The damping of material can be calculated from the time history curve as well as resonance frequency curve. Fortunately both these curves are available in I. L.T (Impulse Load Test), which were utilized for damping evaluation of concrete. Impulse Load Testing arrangement is comprised of (a) Hammer (b) Accelerometer and (c) Fast Fourier Transform (F. F. T.) Analyzer [i]. In this testing arrangement a concrete sample is hit by the hammer and its response, through Accelerometer is received and analyzed by F. F. T Analyzer which gives both time history curve as well as resonance frequency curve. All these curves were analyzed for damping calculations and results are presented in this paper.

II. BACKGROUND

Damping consists of geometric damping, a measure of energy radiated away from the immediate region, and the material damping, a measure of energy loss due to imperfect elasticity [ii]. In order to obtain the total damping ratio of a system the geometric and material damping may be added directly.

Material damping is generally calculated from the hysteresis loop which represents the stress-strain relationship for one cycle of loading and unloading [ii].

The shape of the hysteresis loop depends on the type of material subjected to the cyclic loading. It was shown by Krizek and Franklin (5, 6) that or perfectly viscous materials a circular hysteresis loop is generated. For an elastic material the resulting graph is a straight line with a 1:1 slope, and with no area inside, indicating the absence of damping.

When a rod of any material is set into a state of free vibration. The vibration will decrease in amplitude and eventually disappear. This reduction in amplitude of vibration is caused by internal damping within the mass of the material. To predict or analyse such a response in a vibratory system, in many cases it is satisfactory to reduce the system to an idealized system of lumped parameters. The simplest system is the classical single degree of freedom (SDOF) consisting of a mass, spring, and dash pot, representing viscous damping [i].

Hysteretic proportional damping is the type of damping used for Steady State Analysis in SAP2000. Steady State Analysis computes the steady state dynamic response to a two of harmonically varying loads (a sine and cosine term) at specified frequency increments and was used for analytical predictions of accelerance FRFs to compare to vibrating floor measurements. For any frequency of interest, the analysis seeks the peak value of the steady state response after any transient response has damped out [v]

For the purposes of selecting a damping ratio for the steel beams in the finite element model, a damping ratio of 0.2% seems appropriate. Although measures were taken to reduce the amount of damping provided by the supports in the footbridges, some amount of the global damping should be expected to come from the supports. A damping ratio of 0.2% is within the reported values for bare steel structures and steel footbridges which include connections and supports [vi]. It is clear that both the Concre Damp, latex and rubber mixtures are cost prohibitive. Additionally, the concrete supplier would not allow a latex based concrete mixture to be put into a redi-mix truck. Therefore, a mixture containing only CRM ground rubber with a 15% replacement of FA by volume was chosen [vii]. Next, multiple adjustments were made to the base mix in an attempt to control the air content. Although the exact cause of the air entrainment from the rubber is not known, the effects that the aggregates and cement have on air content can be found in literature [viii].

It is an interesting approach where they pre-coated coarse aggregate with an acrylic ester and styrene latex in an attempt to improve post cracking toughness. The purpose was to investigate more efficient methods for distributing the latex in the transition zone between the aggregates and the cement paste. The researchers premixed the latex with the coarse aggregate (in concentrations of 0.5%, 1% and 2% weight of latex solids to coarse aggregate weight) and let the mixture dry for 2 to 3 minutes before adding it to the concrete. The researchers found that this premixing method was an effective means for creating a latex coating around the aggregate and that post cracking toughness was improved. However, it was concluded that accompanying reductions in compressive strength and modulus were of enough significance that the benefit of the method was not justified [ix]. Fine aggregate replaced by mass in percentages of 5, 10, 20, and 30 percent using waste tire rubber in gradations of 0-1 mm, 1-2 mm, and 2-3 mm [x].

A. Types of Damping Forces

The damping of real system is a complex phenomenon. It involves several kinds of damping forces that are assumed to act in opposition to the motion, doing negative work and dissipating the energy of the system. Reference [ii] investigated different kinds of damping forces that are encountered in real materials and presented them in a detailed study.

When the damping forces are proportional to the velocity of the vibration, it is referred to as viscous damping. In a physical sense, viscous damping is attainable from a fluid dashpot. The viscous damping is equal to

$$F_{DE} = cZ \qquad 2.1$$

Where

$c =$ Viscous damping coefficient
$Z =$ Velocity of vibration

Another type of damping force is Coulomb damping, which occurs when two dry surfaces slides upon each other. This force is of a constant magnitude and can be represented by

$$F_{DE} = \mu F_N \qquad 2.2$$

Where

$F_N =$ Normal force
$\mu =$ Coefficient of friction

A third type of damping force is hysteric damping. The damping property can be described by a viscous dashpot for which the viscous damping coefficient "*c*" varies inversely with the frequency of vibration ($c = h/\omega$, where h is the hysteretic coefficient). This force can be represented by

$$F_{DE} = h/\omega\, Z \qquad 2.3$$

Where

$\omega =$ Circular frequency

Because of the difficulty of predicting the magnitude of different damping forces, according to [xi] introduced the concept of equivalent viscous damping. This concept consists of replacing all the damping terms of the original differential equation of motion with a single equivalent damping term, proportional to the first power of velocity of motion. According to this concept, viscous forces that produce the same rate of energy dissipation as the actual damping forces are applied to the system [xi].

III. Damping Evaluation

There are several methods of determining the damping capacity of a material; the two most common methods for concrete are discussed below [xii]:

A. Band-Width of a Resonance Curve Method

In this method the damping was calculated using the following equation [vii]

$$D = \Delta w / 2 f_n \text{ x } 100\% \qquad 3.1$$

The unknown in the above equation was obtained from the resonance curve of a function of I.L.T. shown in Fig. 1 (a) in which Δw is the frequency range taken at 0.707 times maximum amplitude and f_n is the resonance frequency [viii].

B. Logrithmic Decrement Method

Logarithmic decrement (δ) is defined as the natural logarithm of the ratio between the amplitudes of successive oscillation in the damped sine wave produced by the decay of free vibrations of a sample, and it is given by the following

$$\delta = l_n Z_1 / Z_2 \qquad 3.2$$

Where

$$Z_1/Z_2 = exp\{(2\pi D)/(\sqrt{1-D^2})\} \qquad 3.3$$

Therefore

$$l_n Z_1/Z_2 = \{(2\pi D)/(\sqrt{1-D^2})\}$$

Where Z_1, Z_2 are the two successive amplitudes of output spectrum in time domain of I. L. T. showing Fig. 1 (b) .If Z_1, and Z_1 are known, the damping (D) can be determined with the above equation [viii].

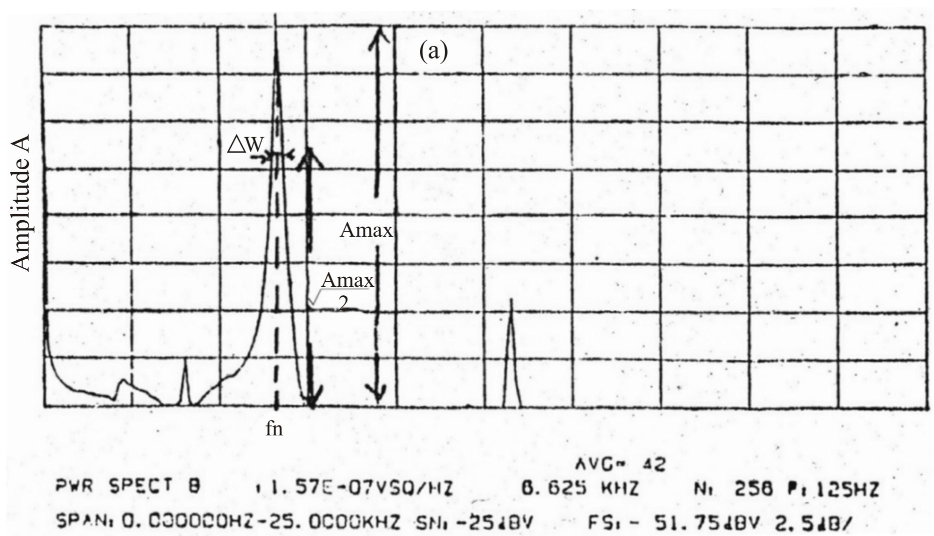

Fig. 2(a). Band width of resonance curve method

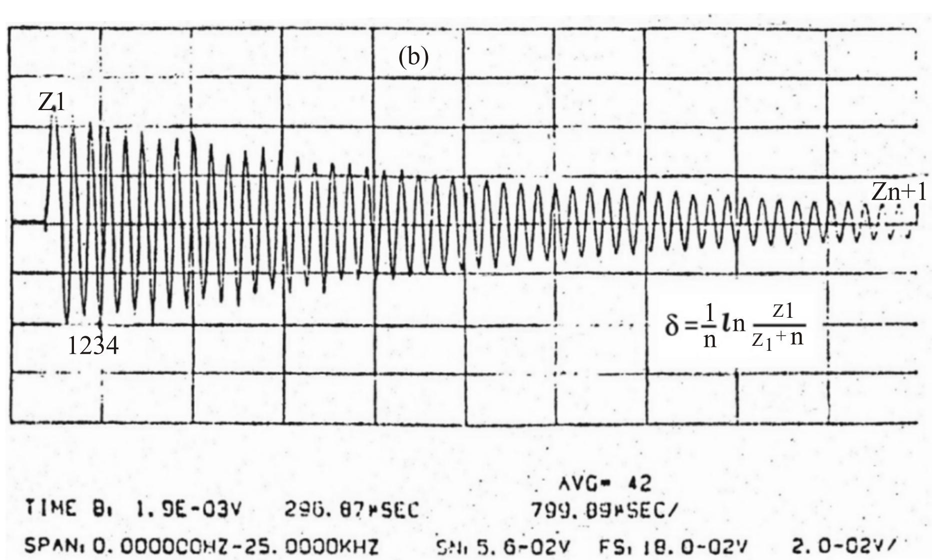

Fig. 2(b). Logarithmic decrement method

C. Comparison between two methods

It is possible to determine the damping values from the output spectrum in time domain, but analysis in the frequency domain seemed to be more convenient [xiii]. Thus the damping values for all samples were calculated by the second method. However for comparison purposes few samples were tested by the first method also.

IV. Testing Program

In order to find the damping values from I. L. T., many concrete samples made of either asphalt or cement concrete were prepared. The applicability of this technique was checked by changing either the mix design or the environmental conditions of these samples. Many variables were thus selected for both types of concrete samples. The variables selected for cement concrete were, water/cement ratio, percentage , use of admixtures, aggregate/cement ratio, compacting efforts, coarse/fine aggregate ratio, curing conditions, maximum nominal size of coarse aggregate, and quality of coarse aggregate. An average of six samples with a wide variation in a mix design was made for each variable. The bandwidth resonance curve method was used for damping calculations in these samples.

For Asphalt concrete, the maximum nominal size of asphalt, quantity of fines, and the temperature were the selected variables. Samples made for all these variables were tested in the same way as for the concrete samples.

V. Specimen Preparation

Two types of concrete samples were studied in the testing program. These concrete samples, made of either cement concrete or asphalt concrete were prepared according to ASTM procedures, briefly discussed as follows:

Cement Concrete: Cylindrical samples of 6 by 12 inches were selected and made accordance to ASTM C31 and ASTM C215-185. Single use mould fulfilling the requirements of ASTM C470-81 were used for these samples. The maximum size of coarse aggregate used in all these samples was according to ASTM C192, which describes that the diameter of the cylindrical sample shall be at least three times the maximum nominal size of the coarse aggregate. All the samples were made according to ASTM C192-81 procedure. Also, ASTM C-617 was followed for the capping of the cylindrical concrete samples.

Asphalt concrete: Asphalt concrete samples were made accordance to ASTM D3496-79 Cylindrical samples of 4 inch in diameter by 8 inch in height were selected for this study. A bituminous mixture of approximately 4000 grams was prepared for each sample, the temperature requirements of the bituminous mixture before and during compaction were according to the method ASTM D1561. This method was also used for the application of the static load during the compaction process as well as for removing the sample from the mould by a push-out device.

VI. Testing and Evaluation

In order to find the damping values from new testing arrangement of I. L. T. all the samples were tested and evaluated by Bandwidth of resonance curve obtained from transfer function of Resonance Frequency Method (R. F. M) [i]. The detail of these results is given below.

Cement Concrete: During this study it was found that damping ratio increases as the water/cement ratio increases. It shows that the damping ratio increases as the dynamic modulus decreases, which agrees with the results of reference [xiv]. It was also observed that damping ratio decreases by an increase in age, compacting efforts, course/fine aggregate ratio, curing conditions. However damping ratio increases by using air entrained admixtures and maximum nominal size of coarse aggregate thus can be justified on the facts that damping ratio is inversely proportional to the dynamic modulus value. These results are also tabulated in Table I.

TABLE I
Relationship Between Damping Ratio and Variables of Cement Concrete

S. No.	Variable	Relationship with Damping Ratio
1	Water cement ratio	Varies directly
2	Dynamic modulus	Varies inversely
3	Age	Varies Inversely
4	Compacting effort	Varies Inversely
5	Course/fine aggregate ratio	Varies Inversely
6	Maximum nominal size of coarse aggregate	Varies directly
7	Air entrained admixtures	Varies directly

Asphalt Concrete: ln this study damping of asphalt concrete was evaluated from new testing arrangement of I. L. T. Many asphalt concrete samples of different mix design variables were made and tested. Bandwidth of resonance curve method was used for damping evaluation. It was observed that damping ratio decreases with an increase in maximum size of coarse aggregate, and quantity of fines. However, damping ratio increases by an increase in temperature, which provides a good agreement with the study of reference [xv].

TABLE II
RELATIONSHIP BETWEEN DAMPING RATIO AND VARIABLES OF ASPHALT CONCRETE

S. No.	Variable	Relationship with Damping Ratio
1	Maximum size of coarse aggregates	Varies Inversely
2	Quantity of fines	Varies Inversely
3	Temperature	Varies Directly

CONCLUSIONS

The following are some detailed conclusions from the work performed.

Damping value for both types of concrete decreases as the dynamic modulus increases.

For cement concrete water/cement ratio has a major effect on its dynamic properties.

Dynamic Modulus of Asphalt Concrete decreases with increase in temperature.

Dynamic Modulus of both types of concrete increase with increase in aggregate size.

Dynamic Modulus of both types of concrete increases with increase in unit weight.

For Asphalt concrete temperature has the major effect on its dynamic properties.

Both methods of clamping evaluation almost gave the same value for both types of concrete.

For hardened cement concrete damping was ranging from 1.13% to 3.40%.

For Asphalt concrete damping was ranging from 4.80% to 8.30%. However, Asphalt samples of low temperature gave smaller damping values.

TABLE III
EFFECT OF WATER CEMENT RATIO ON DAMPING OF CONCRETE

Water Cement Ratio	Damping
48	1.1
55	1.75
62	2.4
75	3.1

COMPARISON WITH LATEST RESEARCH

Besides the ILT another latest technique is forced harmonic test. In this test, the concrete cylinder specimens were tested under cyclic axial compression loading. By plotting the applied stress versus strain, a hysteresis loop was obtained. The area of hysteresis loop were then used to calculate and compare specific damping capacities of the different specimens. Whereas in case of ILT we obtained resonance curve or history curve.

REFERENCES

[i] A. A. Malik,"Nondestructive Testing Of Pavement", M.S Thesis University of Maryland, 1988.

[ii] Al-Sanad, H.A.A., "Effect of Random Loading on Shear Modulus and Damping of Sands", dissertation submitted to the Faculty of the Graduate School of The University of Maryland in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1982.

[iii] R. J. Krizek, A. G Franklin, "Energy Dissipation in Soft Cay", Proceedings of the Symposium on Wave Propagation and Dynamic Properties of Earth Materials, University of New Mexico Press Albuquerque, NM, Aug. 1967 pp. 797-807.

[iv] R. J. Krizek, A. G Franklin, "Nonlinear Dynamic Response of Soft Clay", Symposium on Vibration Effects of Earthquakes of Soils and Foundations, ASTM STP 450, American Society for Testing and Materials, 1968, pp.96-114.

[v] B. Davis,(2008). "Finite Element Modeling for Prediction of Low Frequency Floor Vibrations due to Walking." *VPI & SU. Civil Engineering. Ph. D. 2008.*, University Libraries, Virginia Polytechnic Institute and State University, Blacksburg, Va.

[vi] C. W. De-Silva, (2007). *Vibration Damping, Control, and Design*, CRC Press.

[vii] S. Jones, (2011). "Personal Communication: Dispatcher, Conrock", Blacksburg, VA.

[viii] S. H. Kosmatka, B. Kerkhoffand W. C. Panarese, (2008). "Design and Control of Concrete Mixtures, Portland Cement Association".

[ix] Morin et al. (2011), V. Morin, M. Morin, I. Doubois-Brugger and E. Gartner, (2011). "Effect of Polymer Modification of the Paste-Aggregate Interface on the Mechanical Properties of Concretes." Cement and Concrete Research, 41(5), 459-466.

[x] G. Skripkiūnas, A. Grinys and K. Miškinis, (2009). "Damping Properties of Concrete with Rubber Waste Additives." *Materials Science*, 15(3), 266-272.

[xi] B. O. Hardin, V. P. Drnevich, "Shear Modulus and Damping in Soils Measurements and Parameter Effects", J. of Soil Mech. And Found. Div. Proc. ASCE Vol 98 No, SM6, June 1972, pp.603-624.

[xii] V. M. Malhotra, "Testing Hardened Concrete: Nondestructive Methods", The lowa State University Press., Ames, and American

Concrete Institute, Detroit, Monograph No. 9, 1976, pp.74- 102

[xiii] M. R. Taha, "Effects of Loading Type on the Dynamic Properties of Soils", thesis submitted to the Faculty of the Graduate school of The University of Maryland in partial fulfillment of the requirements for the degree of master of Science, 1987.

[xiv] D. L. Allen and R. C. Deen, "Modulus and Damping of Asphalt Concrete Using the Resonant Column", Geotechnical Testing Journal, Vol 3, No. 4 Dec. 1980, pp. 167-171.

[xv] S. Jatinder, R. N. Stubstad, "Evaluation of Pavement in Florida by Using the Falling Weight Deflectometer", Transportation Research Board, No 755, 1980, pp. 42-49.