Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

Experimental Study on the Dynamic Characteristics of a Vibration-Controlled Concrete Beam

Young-Soo Chung[1], Yong-Goo Park[2], Sung-Ho Cho[1] and Kwang-Myong Lee[3]

1) Chung Ang University, Korea
2) Samsung Engineering Co., Ltd., Korea
3) Sung-Kyun-Kwan University, Korea

ABSTRACT

Recent construction activities have given rise to civil petitions associated with vibration-induced damages or nuisances. Therefore, it is strongly needed to develop a remedial technique to mitigate unfavorable effects of construction activities. The objective of this research is to investigate dynamic material and structural characteristics of vibration-controlled concretes which have been mixed with various vibration-reducing materials, such as latex, rubber powder, plastic resin, polystyrofoam. Normal and high strength concrete specimens are also prepared. As a part of the research to study recycling obsolete aged tires and plastic materials, 32 concrete bars and 8 concrete beams have been made for investigating their dynamic properties. From the results of resonance tests on concrete bars, it can be concluded that a vibration-controlled concrete has relatively larger material damping ratio than a normal or high strength concrete. Styrofoam was determined to be the most effective vibration-reducing mixtures. Also, the flexural vibration tests on 8 concrete beams revealed that material damping ratio is much smaller than structural damping ratio for all the cases.

1. INTRODUCTION

With the acceleration of infrastructure construction to keep up with the economic growth in Korea before the IMF bailout, construction activities have often given rise to civil petitions associated with vibration-induced damages or nuisances. The objective of this experimental study is to develop a vibration-controlled concrete with a vibration-mitigation material, which can be recycled from obsolete materials, such as aged tires, plastics, styrofoams and etc. Albeit a possible disadvantage of low compressive strength of the concrete with these mixtures, it is important to develop a useful vibration-mitigation material which can be contributed not only to reduce vibration-induced damages or nuisances at construction sites, but also to recycle obsolete materials as a part of the environmental protection movement. This study includes the investigation of dynamic material characteristics and dynamic structural characteristics of a vibration-controlled concrete, and the dynamic characteristics of the concrete can be effectively used to assess the possible damage of cracked RC structures. This study is categorized into two tasks : 1) the investigation of dynamic material properties of 32 round and square concrete bars, and 2) the investigation of dynamic structural properties of uncracked and cracked RC flexural beams. For comparison, normal and high strength concretes were also included in this experiment. Free-free resonant column tests have been performed to investigate dynamic material damping ratios, resonant frequencies, elastic and shear moduli, poisson's ratio in accordance with KS F2437. Further investigation was performed on resonant frequencies and structural damping ratio of 15×10×240cm RC beams by the half-power bandwidth method. In addition, damage assessment has been made on the basis of resonant frequencies of uncracked and cracked RC beams in five stepwise loads.

2. TEST SPECIMENS

Type I Portland cement has been used in vibration-controlled concrete specimens with various vibration-mitigation materials. In the concrete, 19mm coarse aggregates and standard fine aggregates, of which gradation is 2.6 and unit weight is 1.53 t/m3, were mixed together. In addition, high strength concrete specimens have been prepared by using an appropriate mix proportion. For the measurements of dynamic material characteristics based on the code of relevant KS, ASTM and JIS, test specimens have been made in four different types of concrete bars, and the dimensions are 10×20cm and 10×40cm for cylinders, and 10×10×20cm and 10×10×40cm for rectangular bars, as shown in Table 2.1. Dynamic structural properties have been also investigated for flexural RC beams with the dimension of 15×10×240cm.

As shown in Table 2.2, polystyrofoam, plastic resin, rubble powder and latex have been mixed in vibration-controlled concrete by 1%, 1%, 2% and 4% of the cement weight, respectively.

3. WAVE PROPAGATION TEST

3.1 Dynamic Material Properties

Dynamic material properties of concrete specimens have been evaluated by free-free resonant column method of KS F2437, which is similar to ASTM C215, JIS A1127-1976. Wave velocity, elastic and shear moduli have been evaluated using the first resonant frequencies of longitudinal and torsional waves on RC bars with free-free boundary conditions. Then, material damping ratios and Poisson's ratios were computed from the wave velocity measurements.

3.2 Structural Damping Ratio and Damage

As shown on Fig 3.2, both ends of flexural RC beams have been bounded so as to have free flexural motions in a minimized constraints, and their structural damping ratios have been measured by the wave excited by the impact hammer. An accelerometer has been placed underneath the midpoint of flexural RC beams, which have been impacted at the midpoint to induce flexural vibrations. A rubber tip has been attached at the impact hammer so as to minimize the components of high frequency. Using the FFT analyzer, the time histories of acceleration have been transformed into the transfer function, which can be used to compute the damping ratio by the half-power bandwidth method.

Furthermore, five incremental loads, such as 250kgf, 500kgf, 750kgf and 1,000kgf, have been applied to incur cracks underneath the midpoint of flexural RC beams. Flexural vibration tests have been performed on uncracked and cracked RC beams to determine the first resonant frequency and the damping ratio. Five incremental loads have been chosen to be equally spaced between the crack-initiated load and the failure load for a normal flexural RC beam. Possible damage of cracked RC beams have been assessed by deflection and crack width which have been measured by a LVDT and a clip gauge, respectively.

It is well understood that the first resonant frequency of a flexural RC beam is dependent on support conditions, material properties, sectional shapes and so on. Stiffness of a cracked RC beam is also one of very important factors for the determination of the first resonant frequency. In the flexural RC beam test, the determined structural damage is from the first resonant frequency which should be variable with the crack levels. Damage index, which is an indicator of structural safety, can be generally expressed as Eq. (1). Equation (1) is a function of the first resonant frequencies of undamaged and failed structures.

$$D_I = 1 - \frac{W_D^2}{W_N^2} \tag{1}$$

where W_N is the 1st resonant frequency of undamaged structure, and W_D is the 1st resonant frequency of damaged structure.

4. TEST RESULTS

4.1 Wave Analysis for Concrete Bars

4.1.1 Longitudinal and Torsional Wave

The velocity of stress waves propagating through a concrete specimen is completely dependent on the water content of a concrete, specimen, and, therefore, all test specimens have been dried in the laboratory. An impact hammer has been applied at the end of free-free RC beams. Longitudinal waves, which have been initiated at the one end of a free-free RC beam, are reflected at the other end of a RC beam. The first resonant frequency of the longitudinal wave is used to calculate dynamic elastic modulus and wave velocity. As shown in Fig. 4.1, the velocity of a longitudinal wave increases with the compressive strength of concrete specimens.

As shown in Fig. 4.2, torsional wave has been generated using the aluminum bar attached at the one end of a test bar. Two accelerometers have been attached at the other end of a test bar. When an impact hammer is applied at the aluminum bar, torsional wave is propagated in a circular motion and, simultaneously, a flexural wave is also propagated in vertical motion. Torsional and flexural waves are generated at the same time. However, the torsional wave alone can be extruded by removing the component of a flexural wave. Figure 4.3 shows the spectrum curves of a torsional wave and a flexural wave. Figure 4.3 and Fig. 4.4 show the spectrum curves of the waves obtained by one accelerometer and two accelerometers, respectively. Figure 4.5 shows the spectrum curve of a torsional wave alone which have been computed by the half of the difference between magnitudes of Fig. 4.3 and Fig. 4.4. The wave velocity increases with the compressive strength as shown in Fig. 4.6

4.1.2 Dynamic Material Properties

Elastic modulus, shear modulus and poisson's ratio can be obtained by the first resonant frequencies of longitudinal and torsional waves. Dynamic elastic and shear moduli increase with the compressive strength of concrete, as shown in Fig. 4.7. However, dynamic Poisson's ratio is not proportional to the magnitude of compressive strength of concrete, as tabulated in Table 4.1.

Concrete material properties can be nondestructively obtained by the wave analysis, but they are more or less affected by water content, air temperature, humidity and etc. Thus, it is necessary to establish the relationship between wave velocity and concrete strength through testing a large number of concrete specimens to obtain more reliable results.

Figure 4.8 shows the relationship between the damping ratio and compressive strength of concrete. As shown in Fig 4.9 for bar specimens, a bigger damping ratio was obtained by adding vibration-reduced materials, such as polystyrofoam, plastic resins, rubber powder, latex and etc, compared with those with normal and high strength. Similar results have been obtained for other test specimens, too. The increase of damping ratio due to the addition of the vibration-reduced material can be attributed to the fact that various voids generated by vibration-reduced mixtures decrease the concrete density and, as a result, decrease compressive strength of concrete.

4.2 Flexural Vibration Test for RC Beams

8 flexural RC beams have been made as shown in Table 2.1 and Table 2.2, and their structural damping ratios have been obtained on the damage level in five stepwise cracking loads.

4.2.1 Structural Damping Ratio

As shown in Fig. 4.10, crack widths are steadily increased by the 500kgf cracking load, but are rapidly increased above the 750kgf cracking load. The Vibration-controlled concrete shows a steeper curve than normal and high strength concretes. It is explained by the fact that the bonding strength of vibration-controlled concretes is smaller than those for normal and high strength concretes due to a probable bigger void ratio for the vibration-controlled concrete. Similar results have been obtained in flexural deflection measurements. Table 4.2. shows damping ratios and the first resonant frequencies of RC beams, which were increased and decreased by the bigger damage level as per five stepwise load steps. In general, the first resonant frequency of RC beam is known to be dependent on support conditions, material properties, sectional shapes and so on. In the case of this simple RC beam test, it is observed that the first resonant frequency is strongly dependent on the sectional modulus which is an important factor for structural stiffness. Damping ratio could be increased by the possible friction at the interface of concrete crack. However, similar results to Fig 4.9 show the larger material damping ratio for vibration-controlled concrete. This can be explained by the fact that only a smaller material damping ratio could contribute to the structural damping ratio for this test.

4.2.2 Structural Damage Assessment

In the previous researches, it is widely noted that structural damage can be assessed by using the damage index, as Eq. (1). Damage indices are increased by the damage level which can be generally computed by resonant frequencies of cracked RC beams. Figure 4.11 shows that damage indices are increased by the increment of stepwise cracking loads. Vibration-controlled concretes show steeper gradient curves than those for normal and high compressive strength of concrete. It is, in particular, noted in Fig. 4.11 which the slopes for vibration-controlled concretes become steeper above 750kgf cracking loads. As expected, these test results show that wave measurements could be widely used for the integrity assessment of RC structures.

5. CONCLUSIONS

For the development of vibration-controlled concrete to mitigate vibration-induced damages or nuisances at various construction sites, wave measurements have bean carried out for 32 concrete bars and eight flexural RC beams. Dynamic Material and structural properties of vibration-controlled concretes have been investigated together with those for normal and high strength concrete. It can be concluded as :

1) Material damping ratio is increased by adding more vibration-mitigation material to concrete. Larger damping ratio for vibration-controlled concretes is obtained compared with those for normal and high strength concrete. This can be explained by more and larger voids generated by adding vibration-mitigation materials into concrete.
2) Structural damping ratio is increased by the possible friction at the interface of concrete cracks for cracked concretes. However, we could not get larger material damping ratio for vibration-controlled concretes than for normal and high strength concretes.
3) Pertinent wave measurements can be widely used for the integrity assessment of RC structures in a nondestructive way.

ACKNOWLEDGEMENTS

This study was partially supported by the KOSEF under Grant NO. 981-1202-005-1. The support is gratefully acknowledged. Also, the authors give much thanks to colleagues in KHCO.

REFERENCES

1. Baek, Y.S., Sim, J.S., Chung, Y.S., "Research of Prediction and Protection Technology for Vibration Pollution, Specific Research Assignment 2nd Middle Term Report," *Korea Science and Engineering Foundation*, 1996.
2. Chung, Y.S., Choi, W.S., Lee, D.H., "Experimental Study on Dynamic Characteristics of Vibration-Controlled Concrete Beam," *Journal of KCI*, Vol. 9, No.9, 1997. 12.
3. Korea Industrial Standard, "Resonance Vibration Testing for Dynamic Moduli, Shear Moduli and Poisson's Ratio of Concrete," *Korea Industry Promotion Government Office*

Table 2.1 Test Specimen Table

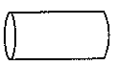
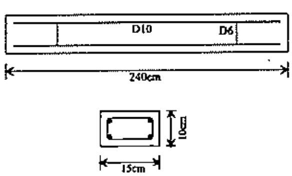
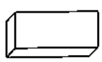
Material Dynamic Properties		Structural Dynamic Properties	
Resonance Test (KSF 2437)		Free Vibration Test	
A-Type	ø10× 20 cm Cylinder	Length	240 cm
B-Type	ø10× 40 cm Cylinder	Width	15 cm
C-Type	10× 10× 20 cm Prism	Height	10 cm
D-Type	10× 10× 40 cm Prism	Longitudinal : D10	Stirrup : D6
(Cylinder) 			
(Prism) 			

Table 4.1 Dynamic Poisson's Ratio

Specimen Designation	A-Type	B-Type	C-Type	D-Type
NR	0.33	0.26	0.22	0.24
ST	0.25	0.29	0.22	0.24
PR	0.29	0.28	0.23	0.25
RP	0.29	0.27	0.23	0.26
LT	0.24	0.26	0.24	0.26
H35	0.21	0.26	0.22	0.26
H45	0.24	0.29	0.24	0.26
H70	0.23	0.25	0.22	0.24

Table 2.2 Mix Proportions and Compressive Strength of Specimen

Specimen		Designation	Comp. Strength (kg f/㎠)	Slump (cm)	Mix Proportion (kg f/㎥)							
					Fine Agg.	Coarse Agg.	Cement	Water	V-R*	Super Plasticizer	A.E.	Silica Fume
Normal		NR	289	8	1144	717	350	168	-	-	1.12	-
Vibration Reduced Material	Poly Styrofoam	ST	253	8.7	943.3	742.8	368.58	175	3.72 (1%)	-	1.12	-
	Plastic Resin	PR	261	9.5	943.3	742.8	364.86	175	7.41 (2%)	-	1.12	-
	Rubber Powder	RP	268	8.5	943.3	742.8	368.58	175	3.72 (1%)	-	1.12	-
	Latex	LT	275	8	943.3	742.8	372.30	161	14.00 (4%)	-	1.12	-
High Strength	350kgf/㎠	H35	398	3.5	1,052	766	389	175	-	-	-	-
	450kgf/㎠	H45	499	7.5	1,065.9	741.3	462.80	166.6	-	3.70	-	-
	700kgf/㎠	H70	497	-	1,037	668	552	160	-	13.8	-	82.6

※ V-R : Vibration-Reduced Materials

Table 4.2 1st Resonance Frequency and Structural Damping Ratio for Stepwise Load

Specimen		NR	ST	PR	RP	LT	H35	H45	H70
Mat. Damping Ratio / Load Steps		0.69%	0.74%	0.76%	0.74%	0.76%	0.69%	0.51%	0.55%
1st Resonance Frequency (Hz) / Damping (%)	0kgf	40.49 / 3.05	31.63 / 2.15	37.51 / 1.62	40.89 / 1.39	43.42 / 1.85	42.67 / 1.54	48.66 / 1.08	47.78 / 1.17
	250kgf	38.61 / 3.15	31.41 / 2.28	37.04 / 1.69	37.52 / 1.60	41.38 / 1.93	40.69 / 1.56	44.16 / 1.78	47.15 / 1.32
	500kgf	38.61 / 3.66	30.88 / 2.43	36.53 / 1.74	36.32 / 1.95	40.26 / 1.99	39.05 / 1.57	42.57 / 2.15	42.48 / 1.71
	750kgf	38.61 / 3.79	29.83 / 2.89	36.17 / 1.89	35.35 / 1.95	39.45 / 2.03	38.13 / 1.71	41.01 / 2.36	42.01 / 1.69
	1,000kgf	38.09 / 3.79	28.85 / 2.90	35.81 / 1.95	32.54 / 2.03	39.02 / 2.25	37.80 / 1.79	40.63 / 2.37	41.49 / 1.74
	1,250kgf	37.17 / 4.23	23.50 / 3.54	32.36 / 2.22	27.11 / 2.05	38.20 / 2.29	35.44 / 1.92	40.21 / 4.47	41.19 / 1.85

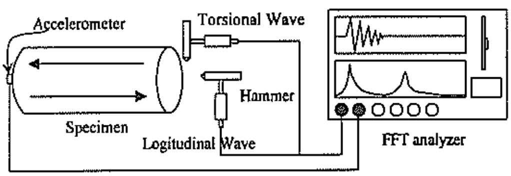


Fig 3.1 Resonance Test

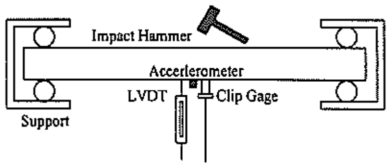


Fig 3.2 Schematic Diag. for Flex. Vib. Test

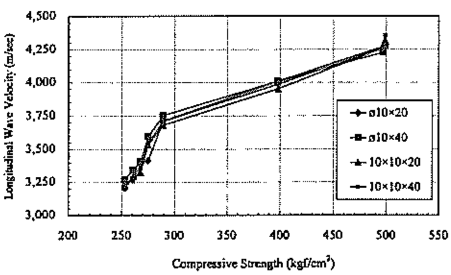


Fig 4.1 Longitudinal Wave Velocity

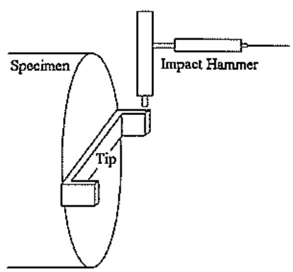


Fig 4.2 Excitation of Torsional Wave

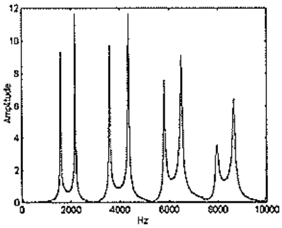


Fig 4.3 Spectrum of Torsional Wave

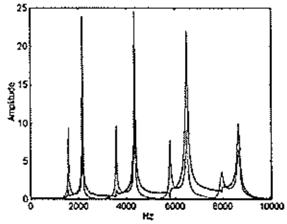


Fig 4.4 Spectrum of Torsional and Flexural Waves

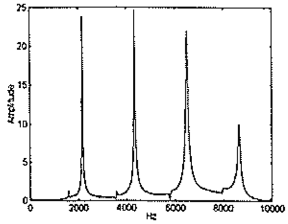


Fig 4.5 Spectrum of Torsional Wave only

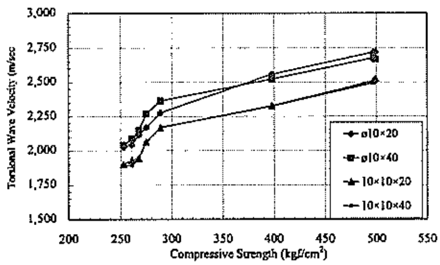


Fig 4.6 Torsional Wave Velocity and On Compressive Strength

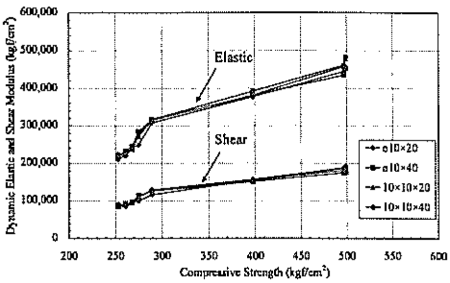


Fig 4.7 Dynamic Elastic and Shear Modulus On Compressive Strength

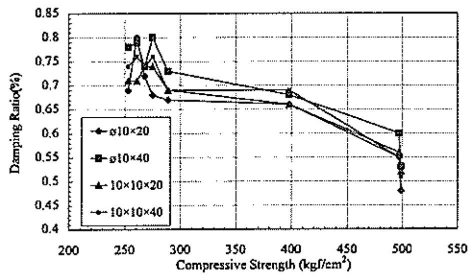


Fig 4.8 Damping Ratio On Comp. Strength

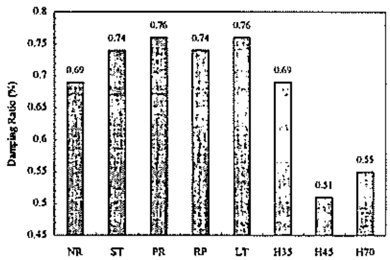


Fig 4.9 Mat. Damping Ratio for A-Ty. Bar

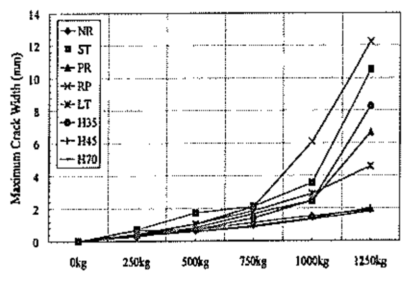


Fig 4.10 Maximum Crack Width of Middle Point on Beam Specimen for Load Steps

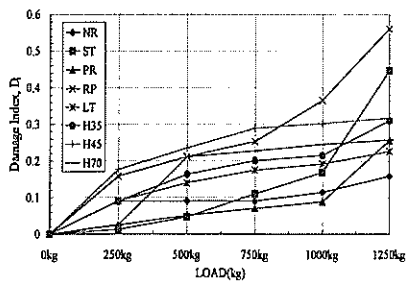


Fig 4.11 Damage Index(D_l) for 5 Stepwise Loads