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Effects of concrete shrinkage and temperature on the dynamic characteristic of reinforced concrete beams

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ABSTRACT: In this paper, the effects of concrete shrinkage and temperature on the dynamic characteristics of reinforced concrete beams are studied. The study comprised manufacturing and testing 10 reinforced concrete beams. Concrete strength, reinforcement ratio and temperature varied in different specimens. The specimens were lifted up and suspended by elastic cables and tested using a modal test setup. Frequency changes and damping ratios of beams were measured at different ages of specimens. Test results show that the frequencies of all specimens decreased with the age of specimens. The frequencies of the specimen kept outdoors in dry and hot conditions decreased significantly. The average values of the frequencies of specimens with 40 MPa concrete strength were approximately 18 percent larger than those of the specimens with 21 MPa concrete strength. The frequencies of the specimens with the larger tensile reinforcement ratio were larger than those of the specimens with the smaller one. No meaningful trend is seen in the relationship between the damping values and the age of the specimens. The damping values of the specimen kept outdoors in hot and dry conditions are larger than those of other specimens.

1 INTRODUCTION

Vibration monitoring is a useful and elaborate tool for damage assessment and can be used as a basis of any decision to repair, rehabilitate or replace a structure. For critical structural systems an accurate and reliable monitoring of the structure is essential. If damage is not detected and repaired, it may lead to catastrophic structural failure. Modal tests performed by Goush and Karbhari (2007) on slab sections cut from a bridge deck prior to demolition were used to match the analytical modal parameters for assessing the response of the test specimens. The most appealing feature associated with using frequencies is that natural frequencies are relatively simple to measure. However, variations in the mass of the structure or measurement temperature may introduce uncertainties in the measured frequencies (Kim et al. 2003). Many researchers have reported that the natural frequencies varied significantly in a single day due to temperature change (Xia et al. 2006). Researchers at Los Alamos National Laboratory (Farrar et al. 1997) found that the first three natural frequencies of the Alamosa Canyon Bridge varied about 4.7%, 6.6% and 5% during a 24h period as temperature of the bridge deck changed by approximately 22 ^{oC}. Peeters and De Roeck (2000) conducted another study for monitoring the effect of changing environmental conditions on structural properties. They monitored the Z24 Bridge in Switzerland continuously for nearly a year and reported that the vibration frequencies decreased with the temperature increase. Askegard and Mossing (1998), Rohmann and Rucker (1994), Rucker et al. (1995), Khahil et al. (1998), Rohmann et al. (1997) and Cawley (1997) have also concluded that vibration frequencies decrease with temperature increase. The damping ratios are not reliable indication of damage in structures. Williams and Salawu (1997) have shown that the

use of damping factors is still in the experimental phase. Tests conducted by Salawu and Williams (1995) on a reinforced concrete bridge before and after repair indicated that no clear trend can be identified from damping values. Ibarra et al. (2001) and Bonfiglioli et al. (2004) considered the basic modal parameters (damping factors and frequencies) for identification purposes. This paper deals with the dynamic identification methods to study the effects of temperature and concrete shrinkage on the basic modal parameters of reinforced concrete beams.

2 TEST SPECIMENS

Ten RC beams, in 6 groups, with the dimensions of 150 mm width, 200 mm height and 2200 mm long were manufactured and tested. Two compressive strengths of 21 MPa and 40 MPa for concrete were considered for different specimens. For each series of casting, the specified compressive strength was measured by compression test of five concrete standard cubes. Reinforcing bars, with 12 and 18 mm diameters for longitudinal reinforcement and 8 mm diameter for transverse reinforcement were used in specimens. For each size of bars, three samples were tested under tension. The yield strength of the bars was 370 MPa. The reinforcing bar ratio, ρ calculated according to ACI 318-05 (2005) was less than ρ_{max}. Fig.1 and Table 1 show the details of the test specimens. Specimen B1 in Group 1 was considered to study the effect of temperature change and dry condition on modal parameters. This specimen was similar to the specimens B2 and B3 in Group 2. Specimens B2 and B3 were kept always in the laboratory with the average temperature and humidity of 27^{oC} and 45% respectively, while Specimen B1 was moved to outdoors after 11 days of casting and kept under dry condition and sunlight in summer with the maximum temperature of 40^{oC} degrees. Then it was brought back to the laboratory after 28 days at the age of 39 days. Specimen B4 in Group 3 was also similar to the specimens B2 and B3 except that its compressive reinforcement was the same as its tensile reinforcement. Group 4 comprised four similar specimens (B5 to B8) with smaller tensile reinforcement compared to the specimens in Group 2. Specimens B9 and B10 in Groups 5 and 6 were made with 40 MPa concrete strength which is larger than that in other specimens. Other specimens (B1 to B8) were made with 21 MPa concrete strength. Specimen B10 had larger amount of tensile reinforcement compared to the specimen B9. As seen in Table 1, some specimens have the same design details and configuration. It was the intension to test more samples and report the most accurate results.

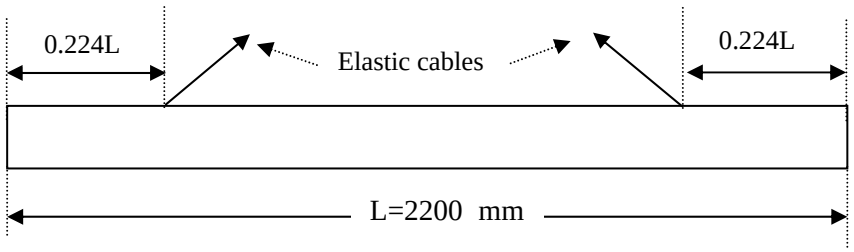

Fig. 1 Details of specimens

3 DYNAMIC TEST SET-UP

The dynamic response of the beams was recorded using one accelerometer. Each beam was treated as a 1D element and the accelerometer was placed at the longitudinal center line of the top surface at the degree of freedom No.8. The impact excitation forces were applied to the beam axis at different degrees of freedom with spacing 100 mm (Fig.2). A digital low-pass filter was imposed to both input and output signals. Data were collected in 0-1600 Hz range with a

sampling frequency of 4096 Hz. To eliminate the problem of support effects on dynamic test results, the specimens were suspended by elastic cables (Fig.1). Lifting up the specimens for dynamic tests is a common practice in laboratory based experiments (Maeck 2003; Ndambi et al. 2000; Ndambi 2002). It must be noted that uncontrolled changes in the support conditions may affect the vibration characteristics of the specimens (Garaygordobil, 2003). In the dynamic tests, the impact hammer provided the excitation input at every degree of freedom, and the frequency response functions (FRF) were derived by measuring the input force (of impact hammer) and response (of the stationary accelerometer) at each measurement point. For each point, test procedure was repeated ten times and the average of FRFs was finally stored as the input-output transfer function for that particular point.

Table 1. Details of specimens

Group	Specimen	f_{cu} (MPa)	Tensile reinforcement (mm^2)	Compressive reinforcment (mm^2)	Spacing of stirrups (mm^2)
1	B1	21	509	100	80
2	B2	21	509	100	80
	B3	21	509	100	80
3	B4	21	509	509	80
4	B5	21	226	100	80
	B6	21	226	100	80
	B7	21	226	100	80
	B8	21	226	100	80
5	B9	40	226	100	80
6	B10	40	509	100	80

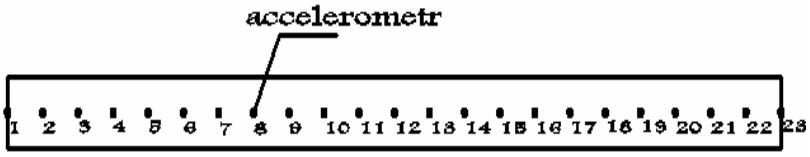

Fig 2. Different degrees of freedom of beams

4 RESULTS AND DISCUSSION

4.1 Frequency changes

The factors affecting natural frequencies include concrete aging, shrinkage, bearing and environmental conditions. In practice, these factors affect the frequencies of concrete structures in a more complicated manner. In some cases, the effect of changing environmental conditions on structural vibration properties is larger than or comparable to the effect of damage. Xia et al. (2006) showed that the frequencies decrease with an increase in temperature and humidity. Tables 2 and 3 present the frequency changes of different specimens in groups 1-6. All frequencies decrease with the age of the specimens. Fig.3 compares the results of the Specimen B1 in Group 1 with the average of the results of the specimens B2 and B3 in Group 2. As mentioned earlier, the details of all these specimens were similar. Fig. 3 shows that the frequencies of modes 1 and 2 of the Specimen B1 decreased significantly when it was kept in outdoors under hot and dry conditions (during 11-39 days after casting). However, when it was

brought back to the laboratory after 39 days of casting, the frequencies changed mainly with the temperature of the specimen at the test time. Fig.4 compares the results of the specimens in Group 2 with those in Group 6. These specimens were similar to each other except that their concrete strengths were different (i.e. 21MPa in Group 2 and 40MPa in Group 6). As seen in Fig.4, the average values of the frequencies of specimens with 40MPa concrete strength were approximately 18 percent larger than those of the specimens with 21MPa concrete strength. Figs. 5 and 6 compare the results of different specimens in groups 2, 3 and 4. All these specimens were made with 21MPa concrete strength. However, the values of tensile and compressive reinforcement in these specimens were different. As seen in Figs. 5 and 6, the frequencies of most of these specimens are almost the same.

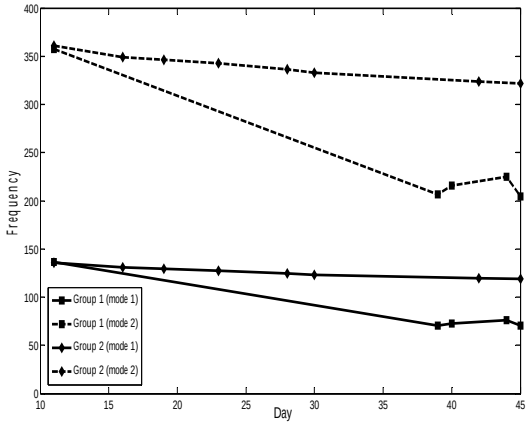

Fig.3 Comparison between the frequencies of the specimens in groups 1 and 2

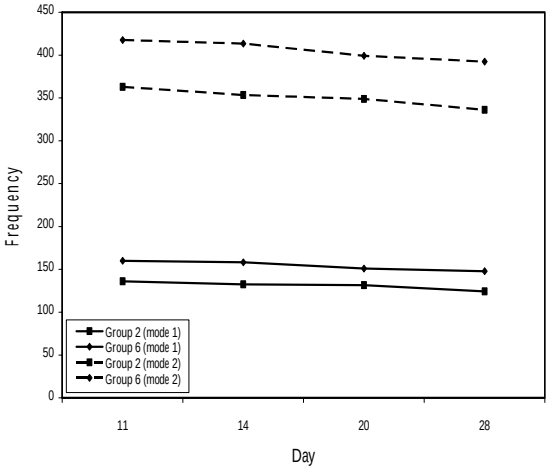

Fig.4 Comparison between the frequencies of the specimens in groups 2 and 6

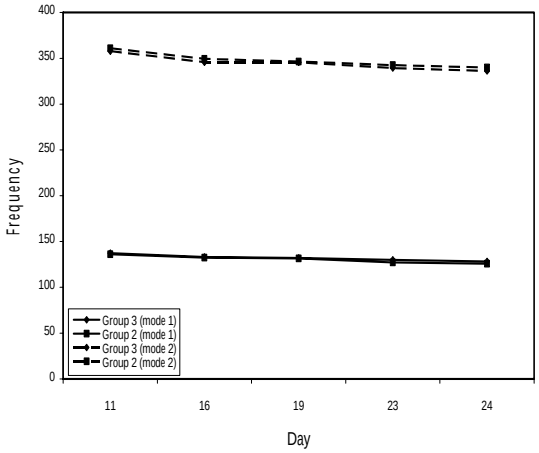

Fig. 5 Comparison between the frequencies of the specimens in groups 2 and 3

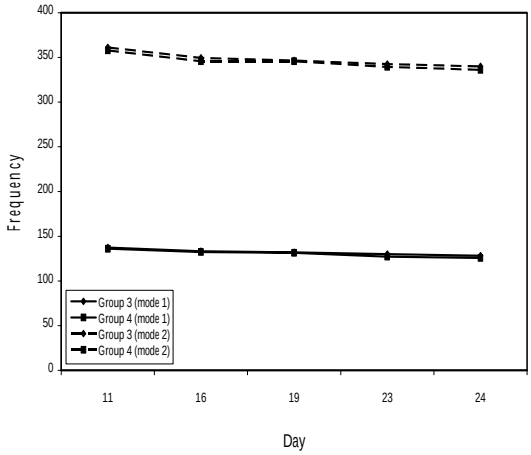

Fig. 6 Comparison between the frequencies of the specimens in groups 3 and 4

Fig.7 compares the results of the specimens 4 and 5. It shows that the increase of concrete strength from 21 to 40MPa increases the frequency values, considerably. Fig.8 shows that, unlike in the specimen with 21MPa concrete strength (Fig.6), the effect of tensile reinforcement on frequency values is not small in the specimens with 40MPa concrete strength.

Table 2. Frequency changes of Specimen B1 in different temperatures

Day	11	39	40	44	44	45
Temperature ^{oC}	31	40	30	30	20	30
Mode 1	136.6	70.7	72.8	74.0	76.4	70.3
Mode 2	357.6	206.7	215.6	218.1	225.2	204.4
Mode 3	660.8	408.4	419.5	424.2	435.5	401.5
Mode 4	1117.4	662.8	680.4	680.7	706.0	653.0

Table 3. Frequency changes of different modes of the specimens in groups 2-6

Group	Specimen	Day	Mode1	Mode2	Mode3	Mode4
2	B2	11	135.49	361.1	654.52	1022
		16	130.92	349.46	635.13	991.64
		19	129.77	346.55	629.65	986.01
		23	127.49	342.6	620.12	971.48
		28	124.29	336.14	608.77	953.95
		30	122.98	332.91	602.81	944.8
		42	119.6	324.13	586.89	924.25
		45	118.68	322.11	586.45	916.62
	B3	11	136.61	364.71	670.95	1074
		16	133.9	357.26	653.06	998.9
		19	133.27	351.25	643.01	987.66
		23	127.21	342.79	633.53	961.13
		24	125.76	340.01	617.45	953.13
3	B4	11	137.34	357.84	659.08	1015
		16	133.14	345.74	640.78	990.4
		19	132.05	345.67	640.2	988.07
		23	129.99	339.32	632.04	974.64
		24	128.25	336.15	624.69	968.01
4	B5	12	136.63	359.23	654.63	1021
		16	134.35	354.48	645.89	1020
		20	132.86	350.91	643.52	1013
		28	129.32	343.08	633.98	985.79
	B6	13	130.89	350.41	641.4	990.84
		18	128.83	345.28	621.76	977.89
		20	127.14	342.04	620.25	970.28
		28	123.53	333.57	611.29	948.95
	B7	13	125.32	338.31	627.01	959.38
		18	123.43	335.05	619.34	947.9
		20	120.9	327.68	608.05	934.77
		28	116.27	320.91	593.16	911.72
	B8	13	129.88	354	647.21	1006
		18	125.98	344.62	630.7	986.46
		20	120.69	336.59	607.07	960.45
		28	114.79	325.67	597.84	927.85
5	B9	11	141.35	382.48	699.89	1086
		14	139.33	378.12	696.25	1084
		20	138.77	375.54	693.04	1080
		28	134	366.08	669.69	1051
6	B10	11	159.94	417.63	767.54	1172
		14	158.21	413.48	759.48	1170
		20	150.86	399.24	738.37	1137
		28	147.85	392.36	724.29	1121

4.2 Damping changes

Tables 4 and 5 show the damping changes of some of the specimens. In the tables, no meaningful trend is seen in the relationship between the damping values and the age of specimens. The damping values of the Specimen B1 (Table 4) kept outdoors in hot and dry conditions are considerably larger than those of other specimens. It may be concluded that the damping value increases with the increase of temperature and concrete shrinkage.

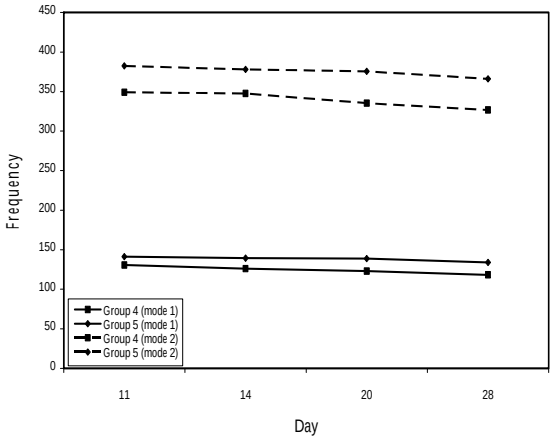

Fig. 7 Comparison between the frequencies of the specimens in groups 4 and 5

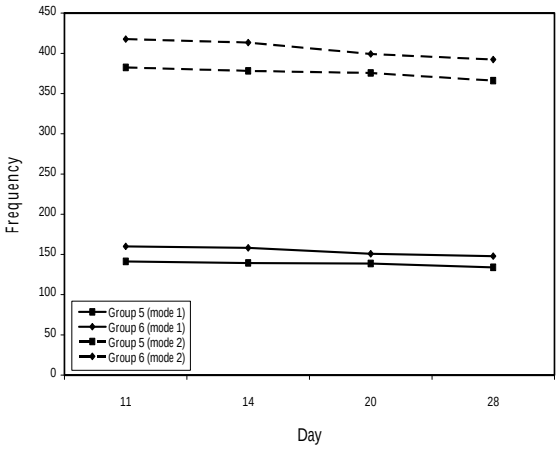

Fig. 8 Comparison between the frequencies of the specimens in groups 5 and 6

Table 4. Damping changes of different modes of specimen B1 (Group 1) in different temperatures

Day	39	40	44	44	45
Temperature ^{OC}	40	30	30	20	30
Mode 1	-	3.141	2.409	3.243	3.090
Mode 2	1.928	1.727	1.609	1.679	1.727
Mode 3	1.265	1.663	2.454	1.558	1.871
Mode 4	0.009	0.367	0.138	0.166	0.607

Table 5. Damping changes of different modes of the specimens in groups 2-6

Group	Specimen	Day	Mode1	Mode2	Mode3	Mode4
2	B3	16	1.548	0.9039	0.9816	0.3275
		19	1.609	0.3759	0.3759	0.0477
		24	1.621	0.8822	1.072	0.5961
3	B4	16	1.668	0.9877	0.5734	…
		19	1.591	0.9789	0.6461	0.1687
		24	1.845	0.9984	0.86	0.4121
4	B8	13	1.816	2.048	2.447	0.2869
		18	1.825	1.135	0.3328	0.0031
5	B9	14	1.617	0.7851	0.3145	0.1998
		20	1.611	0.8379	0.2061	0.6505
		28	1.492	0.7443	0.3457	…
6	B10	14	1.312	0.8412	0.7439	1.291
		28	1.369	0.7869	0.7888	0.5468

5 CONCLUSIONS

A modal test program comprised ten reinforced concrete beam specimens was conducted in the structural laboratory to study the correlation between the temperature change and concrete shrinkage with the variation of the dynamic characteristics of concrete beams. The compressive strengths of 21MPa and 40MPa for concrete were considered for different specimens. Tensile and compressive reinforcement ratios varied in different specimens. Frequencies and damping values of specimens were recorded in the model tests. From the test results, the following conclusions are drawn:

1. The frequencies of all specimens decreased with the age of specimens. The frequencies of the Specimen B1 decreased significantly when it was kept outdoors under hot and dry conditions (during 11-39 days after casting). However, when it was brought back to the laboratory after 39 days of casting, the frequencies changed mainly with the temperature of the specimen at the test time.

2. The average values of the frequencies of the specimens with 40MPa concrete strength were approximately 18 percent larger than those of the specimens with 21MPa concrete strength.

3. The frequencies of the specimens with the larger tensile reinforcement ratio were larger than those of the specimens with the smaller one.

4. No meaningful trend is seen in the relationship between the damping values and the age of specimens. The damping values of the specimen kept in hot and dry conditions are considerably larger than those of other specimens. It may be concluded that the damping value increases with the increase of temperature and concrete shrinkage.

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