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FLEXURAL STRENGTH OF ASR AFFECTED BEAMS UNDER SUSTAINED LOADING

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Abstract

Alkali silica reaction is the reaction between alkali in cement or other sources and certain forms of silica in aggregates. The reaction produces gel which expands resulting in cracking and disintegration of concrete.
A laboratory study was carried out to investigate the effect of deleterious ASR expansion on the structural behavior of reinforced concrete beams and on mechanical properties of concrete cylinders made with the same concrete mixture. The specimens were made with reactive or non-reactive aggregates.. The beams were standard cured and then to simulate in-service conditions, fourteen beams were held under load that caused flexural cracking. The strain of concrete beams was measured along the compression and tension zones. It was quite clear that the beams containing reactive aggregate showed a significant increasing measured strain. Increase in compression steel with constant tension steel showed a significant effect on tension expansion. On the contrary, an increase in tension steel with constant compression steel showed an insignificant effect on compression expansion. The effect of ASR on mechanical properties and expansion of concrete cylinders was more significant than on expansion of reinforced concrete beams. Ultimate loads are reduced in ASR-affected beams due to large irreversible steel strains.

Keywords: Alkali silica reaction (ASR); Expansion; Cracking; Reinforced concrete beams

1 INTRODUCTION

Many structures, such as dams, bridges and hydraulic structures, are suffering from deterioration induced by alkali silica reaction that impairs durability and might also affect the safety of installations. Some researchers investigated beams affected by ASR [1, 2, 3, 4, 5, 6, 9]. In all researches, ASR created large irreversible concrete and steel strains. But there are contradictory results of ASR effects on the overall serviceability, strength and stability of concrete structural members. In an investigation, ASR- affected beams under load exhibited considerable losses of flexural strength [1]. Other researches indicated that even though the reactive reinforced beams experienced visible cracking due to ASR, their flexural loading capacity was nearly the same as that of the non-reactive aggregate beams [2, 5]. However few researches showed that ASR increased the shear capacity of reinforced concrete beams [3]. This paper focuses on the new results obtained from the effects of ASR on flexural behavior of reinforced concrete beams under sustained loading.

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2 EXPERIMENTAL PROGRAM

2.1 Materials

Type II Portland cement in accordance with ASTM standard was used. Aggregates used in Ostoor dam were selected as reactive aggregates.

This aggregate has been confirmed to be reactive by the accelerated mortar-bar ASTM C1260 test method. Figure 1 shows that the expansion in both fine and coarse aggregate has exceeded the maximum allowable value of 0.2 percent. For comparison purposes, a non-reactive aggregate was selected. The result of mortar-bar test is shown in Figure 2.

Type III steel bars were used for reinforcing the beams. The yield strength of the bar was about 370 MPa.

2.2 Test specimens

Two concrete mixtures were produced. The first was with the reactive aggregate and the other with non-reactive one.

Test specimens are listed in Table.1. Fourteen 1100mm long reinforced concrete beams were made, seven with the reactive aggregates concrete indicated by R, and seven with non-reactive aggregates concrete indicated by N. All beams had a 100×150mm rectangular cross section. Stirrups were placed in the shear span and other parts of all beams. Details of the beams are shown in Figure 3.

In addition, 100×100mm and 150×300mm concrete cylinders representive of concrete in the beams were also cast. The average strengths of the reactive and non-reactive aggregates concrete at 28 days were 25.6 and 26.2 MPa respectively. The test specimens were kept in the casting forms for 1 day. After demolding, the specimens were moist cured. For length expansion measurements, studs were glued to the specimens as shown in Figure 4. A strain gauge mounted on the middle of each bar for monitoring steel strains.

2.3 Loading conditions

To investigate the ASR expansion of beams while under simulated service loads seven of each series of identical beams, the reactive aggregate beams and non-reactive aggregate beams were loaded. Two steel blocks with dimensions of 40×40×150mm were placed about 333mm apart in the center between the beams. The loading was gradually increased by tightly fastening the screws on steel rods until cracks having a width of about 0.2mm on the tension face of the beams were observed. Details of loading are shown in Figure 5.

2.4 ASR accelerated conditioning

The natural Na_2O_{eq} content was increased to 1.75% of the cement weight for reactive aggregate beams by adding sodium hydroxide solution into the mixing water.

A tank having dimensions of 600×600×3600mm was used for ASR accelerated conditioning.

All specimens except R7 and N7 were placed in the tank. In order to obtain 100 percent relative humidity, 60 mm depth of water was used at the bottom of tank. The water was heated to 38^oC by a temperature-controlled heater.

2.5 Creep strain measurement

For creep strain measurements, two R7and N7 beams were loaded and placed in a laboratory environment. The concrete strain and steel strain of N7 beam were regularly monitored with time. Difference between N5 and N7 strains is due to the increase in temperature and moisture absorption in N5. In order to calculating creep strain in non-reactive aggregate beams, this difference was subtracted from the strains of N1 to N6.

3 TEST RESULTS AND DISCUSSION

The measured strains are divided into the following three major parts:

1) Service load strain: This strain is approximately similar for both reactive aggregate beams and non-reactive aggregate beams.
2) Creep strain: This strain causes the increase in both tension and compression strains, regardless of whether in reactive aggregate beams or non-reactive aggregate beams.
3) ASR strain: This strain appears after 100 days just in reactive aggregate beams. It causes the increase in tension strain but the reduction in compression strain.

There is also minor increase in strains at initial days due to the increase in temperature and moisture absorption.

A schematic model of strain distribution is shown in Figure 6. The total measured strain is a combination of the elastic strain caused by the bending load, creep strain and tensile strain due to ASR. It is found from this figure that the neutral axis of the ASR affected beams has shifted towards the tension face at earlier ages due to creep and compression face at longer ages due to alkali- silica reaction. This is a very important structural implication indicating that the strain in the tension steel had also increased due to expansive gel formation.

3.1 ASR strain

In order to obtain ASR Strain, the strains of non-reactive aggregate beams were subtracted from the strains of reactive aggregate beams. Concrete ASR strains are shown in Figures 7 and 8. It is clear that the ASR strain in compression zone is higher than tension zone because of higher restraint of the tension reinforcement.

Effect of increase in tension steel on ASR strain

Effect of increase in tension steel on ASR strain is shown in Figure 7. When the tension steel is increased, (with constant compression steel) it causes the reduction in ASR strain in tension zone of concrete. In R2 and R3 beams, there are 12.5% and 30.9% reduction in strain respectively when compared with R1 beam. Large differences in concrete strains between the tension and compression zone of beams can be developed due to ASR expansion. This difference shows that the increase in tension steel with constant compression steel has insignificant influence on ASR strain in Compression zone. There are 3.5% and 6.8% reduction when compared with R1 beam in R2 and R3 beams respectively.

Effect of increase in compression steel on ASR strain

Figure 9 shows the effect of increase in compression steel on ASR strain. When the compression steel is increased (with constant tension steel) ASR strain in compression zone is reduced.

In R5 and R6 beams, there are 43.7% and 53.8% reduction in strain respectively when compared with R3 beam. There is significant influence on ASR strain at tension zone, while compression steel (with constant tension steel) is increased. There are 16.3% and 35.3% reduction in R5 and R6 respectively when compared with R3 beam due to the increase in compression steel.

3.2 Mechanical tests of concrete cylinders

Expansion of reactive and non-reactive aggregate concrete cylinders is shown in Figure 10.After 240 days the strain in reactive aggregate concrete cylinder has reached about 1050 microstrain. Compressive strength and nondestructive dynamic modulus tests in accordance with ASTM C215-91 [7] were carried out in the laboratory. The variations of compressive strength ratio to the 28 day value and variations of the dynamic modulus ratio to the 28 day value are shown in Figure 11. It was found that the change in the mechanical properties was closely related to ASR expansion. The compressive strength and dynamic modulus were not affected significantly up to 100days.At an age of 240 days, the losses of the compressive strength and dynamic modulus of the concrete cylinders were 28 and 34 percent respectively compared with the corresponding 28 day values.

4 STRUCTURAL ANALYSIS OF TEST RESULTS

4.1 Structural model

From Figure 6 it was shown that the time-dependent strain distribution in all beams remained linear under the combined action of sustained load, creep and the ASR strains. The effect of ASR can then be considered to be an "Equivalent axial tensile force" as shown in Figure 12.

4.2 Structural analysis

Using the measured values of concrete and steel strains from the test results in this study, a conventional RC structural analysis of the tested beams was carried out. The elastic modulus of the concrete was then calculated from the equilibrium of moments. Using the equilibrium of forces, and the calculated value of the concrete elastic modulus, the equivalent axial tensile force can then be evaluated.

Elastic modulus of concrete

Figure 13 shows the time-dependent variation of elastic modulus of concrete of the tested beams. The elastic modulus of the concrete for all reactive aggregate beams decreases at a faster rate up to about 100 days due to creep strains. After 100 days, reduction in elastic modulus of concrete is due to both creep and ASR actions.

Equivalent axial force

Figure 14 shows the calculated variations with time of the equivalent force shown in the structural model for ASR. There is an increase in equivalent axial force in reactive aggregate beams due to ASR strains which will have major structural implications on the performance of the beams. The highest value of this axial force for R2 and R4 beams are 40.6 KN and 31.2 KN respectively. Using compressive reinforcement in R4 beams causes this reduction in axial force. The highest value of this axial force for R3, R5 and R6 beams are 51.9 kN, 39.3 kN and 36.4 kN respectively. Reduction in axial force for R5 and R6 compared to R3 is due to using compressive reinforcement.

5 CONCRETE BEAMS FLEXURAL LOADING

After 270 days of ASR accelerated conditioning with sustained load , flexural loading tests were carried out to investigate the structural behavior of the reinforced concrete beams. Deflections at the first point of the beams were measured using Linear Variable Differential Transformer (LVDT).The beams were loaded symmetrically at two points spaced 1000 mm apart until concrete crushing occurred on the top face of the compression zone. Results of the tests are shown in Figures 15 to 20.All the data show that ASR reduces the stiffness of the beams. ASR affected beams do not appear to lose their ductility or capability to absorb large amounts of energy at failure. The first cracks loads, reinforcement yielding loads and the ultimate loads are reduced in ASR affected beams due to large irreversible steel strains too. Table 2 shows the first cracks loads, reinforcement yielding loads and the failure loads carried by the ASR-affected beams, and the percentage loss in these loads compared to the control beams. The important role of the compression steel is clear from the results. Increase in compression steel, induces the reduction in percentage loss in failure load.

6 CONCLUSIONS

From the results obtained in this investigation, the following conclusions can be drawn:

1. Expansion of ASR in tension zone of beams is less than compression zone due to the higher restraint from the tension reinforcement.
2. The neutral axis of the beams shifted towards the compression face due to ASR.
3. Due to large differences in concrete strains between the tension and compression zone of beams, influence of the increase in tension steel with constant compression steel is insignificant on compression zone.
4. Influence of increase in compression steel with constant tension steel on tension zone is significant.
5. Mechanical properties of concrete cylinders are closely related to ASR expansion. At an age of 8 months, the compressive strength and dynamic modulus of elasticity were reduced by 28 and 34 percent respectively when compared with the corresponding 28-day values.
6. ASR shows a much more detrimental effect on the mechanical properties and expansion of concrete cylinders than on expansion of reinforced concrete beams.
7. Under sustained load, ASR causes the reduction in initial elastic modulus of concrete.
8. Under sustained load, the structural effect of ASR expansion is shown as an equivalent axial tensile force applied to the beam. Increase in compression steel, resulted in reduction in this load.
9. Due to large irreversible steel strains, failure loads are reduced in ASR affected beams. Increase in compression steel, reduces percentage loss of failure load.

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TABLE 1: Test specimens

Concrete specimens		Specimens size	Aggregate	Tension reinforcement	Compression reinforcement	NO. of specimens
Beams	R1	100×150×1100 mm	Reactive	2 Φ 8	-	1
	N1		Non-reactive	2 Φ 8	-	1
	R2		Reactive	2 Φ 10	-	1
	N2		Non-reactive	2 Φ10	-	1
	R3		Reactive	2 Φ 12	-	1
	N3		Non-reactive	2 Φ 12	-	1
	R4		Reactive	2 Φ 10	2 Φ 8	1
	N4		Non-reactive	2 Φ 10	2 Φ 8	1
	R5		Reactive	2 Φ 12	2 Φ 8	1
	N5		Non-reactive	2 Φ 12	2 Φ 8	1
	R6		Reactive	2 Φ 12	2 Φ 10	1
	N6		Non-reactive	2 Φ 12	2 Φ 10	1
	R7		Reactive	2 Φ12	2 Φ 8	1
	N7		Non-reactive	2 Φ 12	2 Φ 8	1
concrete cylinders	R	100×100mm	Reactive	None	None	40
	N		Non-reactive	None	None	40
	R	150×300mm	Reactive	None	None	3
	N		Non-reactive	None	None	3

TABLE 2: First cracks loads, Reinforcement yielding loads and Failure loads for ASR affected beams compared to control beams

Beams No.	First cracks loads (kN)	percentage loss compared to control beams	Reinforcement yielding loads (kN)	percentage loss compared to control beams	Failure loads (kN)	percentage loss compared to control beams
R1	7	45.6	29.3	16.8	30	18.9
R2	7.5	53.1	39.4	12.6	42	15
R3	12	34	59.3	12.5	61.2	15
R4	10.5	37.5	40.9	9.9	42.5	9.5
R5	11	37.1	57.8	10.9	63	9
R6	13.3	32.8	56.8	6.3	63.1	6.2

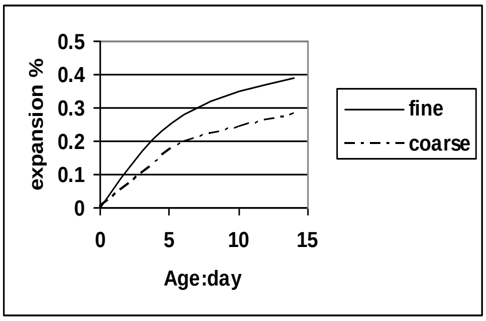


FIGURE 1: Accelerated mortar bar testing for reactive aggregate

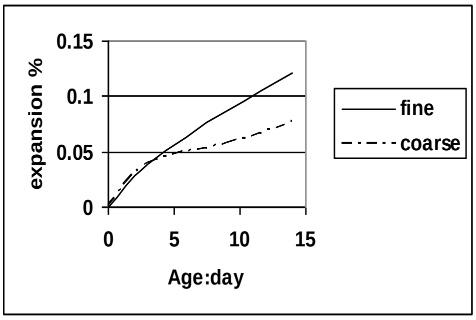


FIGURE 2: Accelerated mortar bar testing for non-reactive aggregate

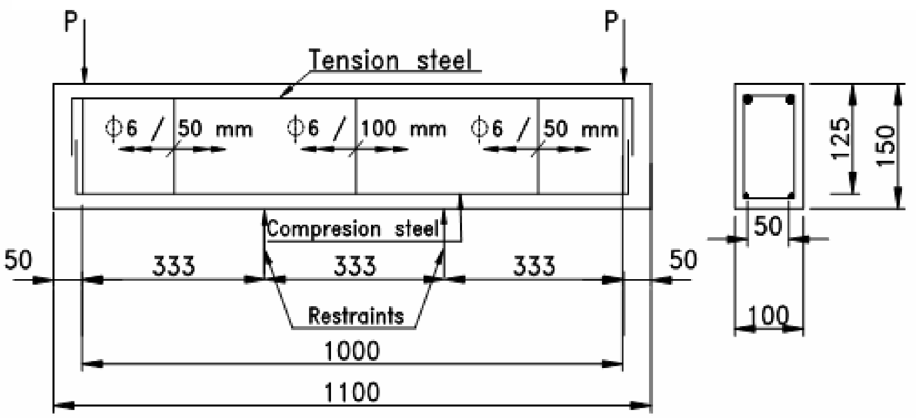
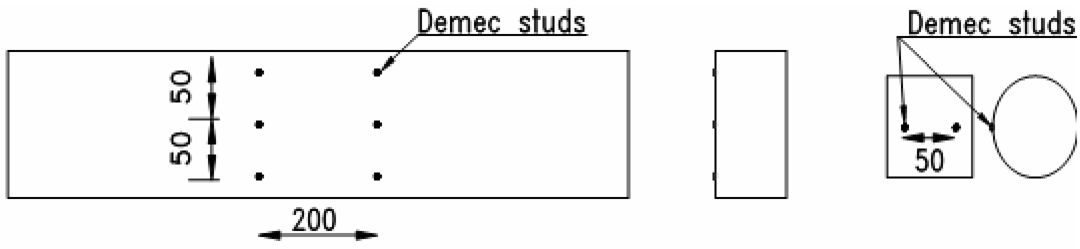


FIGURE 3: Reinforced concrete beams



Elevation of beams

Elevation of concrete cylinders

FIGURE 4: Arrangement of demec studs on specimens

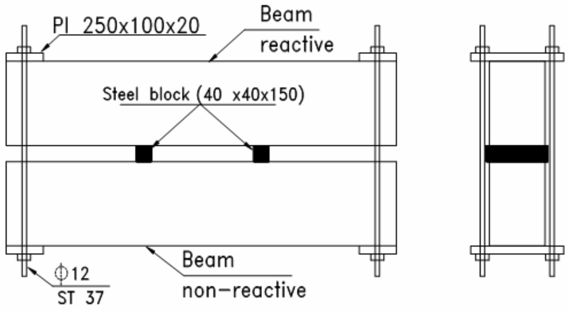


FIGURE 5: Details of loading

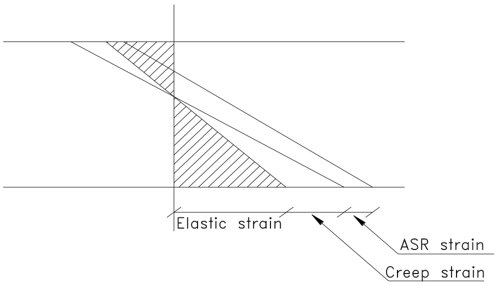


FIGURE 6: Strain distribution

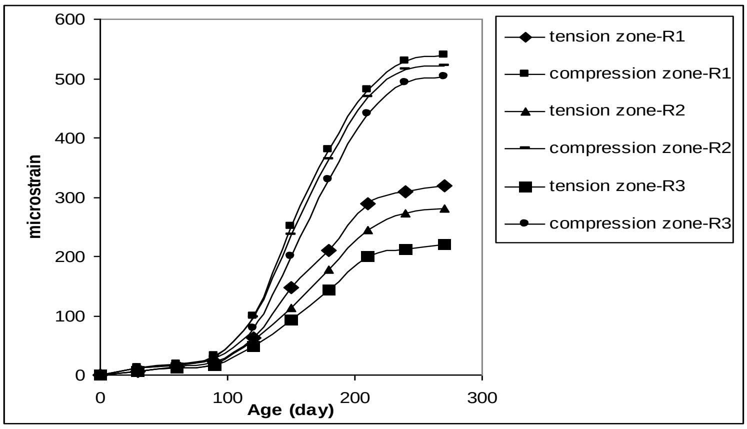


FIGURE 7: Variations of concrete strains due to ASR in R1, R2, and R3 beams

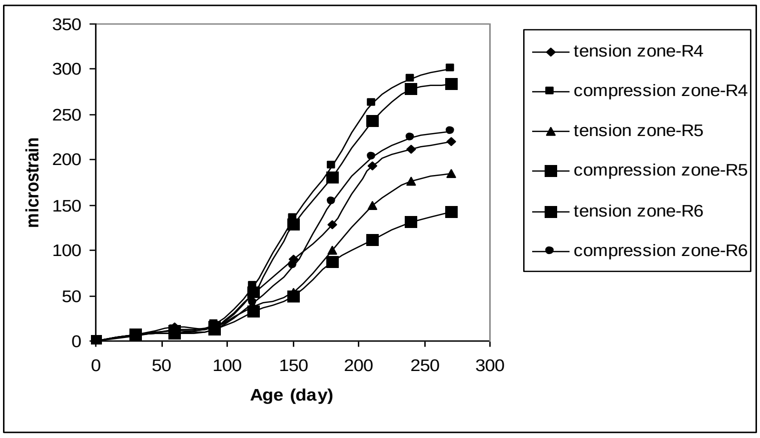


FIGURE 8: Variations of concrete strains due to ASR in R4, R5, and R6 beams

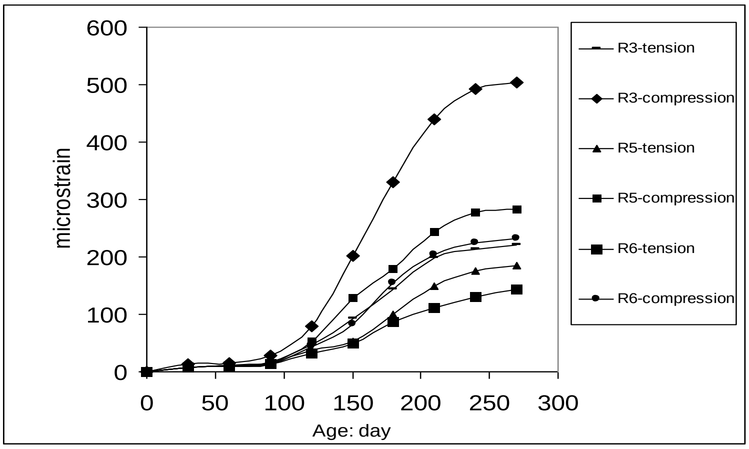
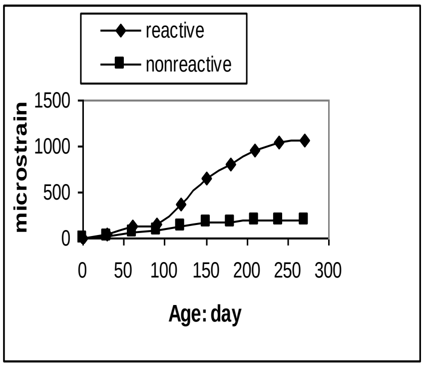


FIGURE 9: Effect of increase in compression steel on ASR strain



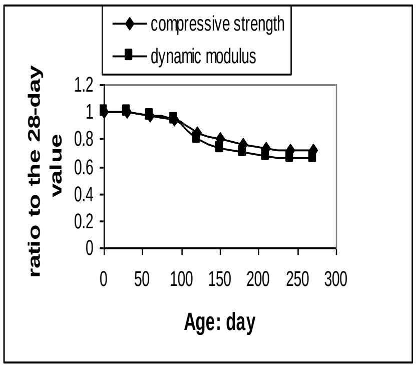


FIGURE 10: ASR strain of concrete Cylinders

FIGURE 11: Change in chemical properties of reactive concrete cylinders

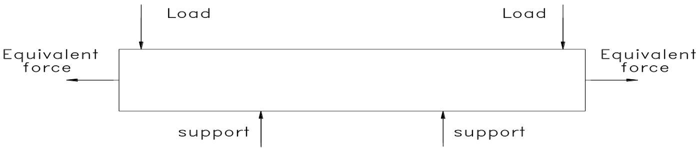


FIGURE 12: Structural Model for beams under ASR strain

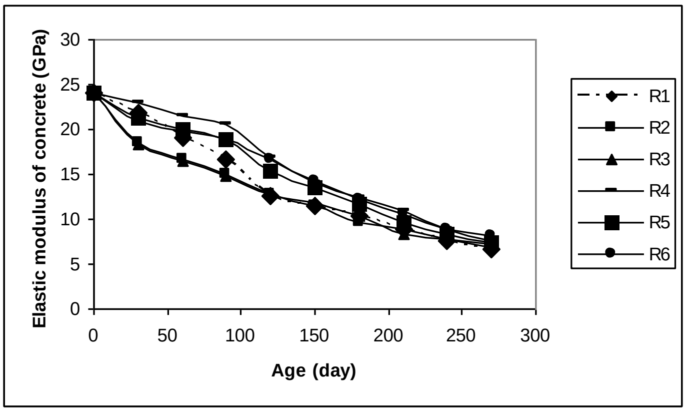


FIGURE 13: Time-dependent variation of elastic modulus of concrete for R1 to R6 beams

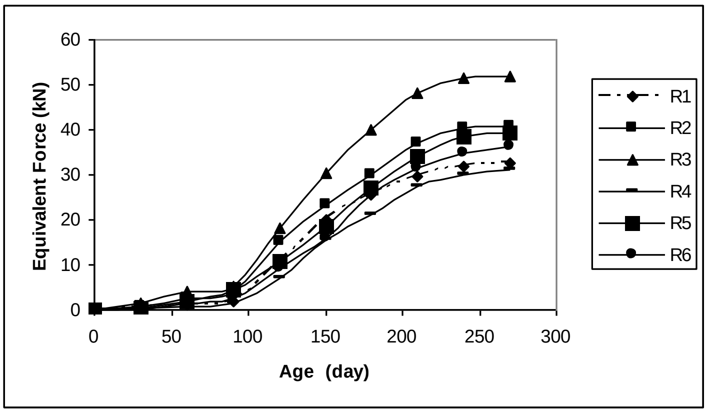
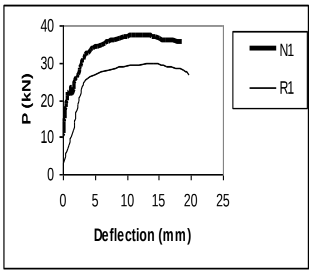
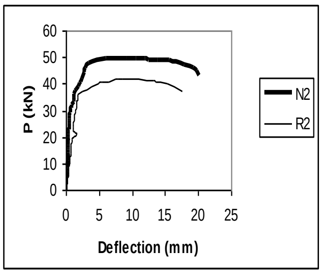


FIGURE 14: Time-dependent variation of equivalent force for R1 to R6 beams





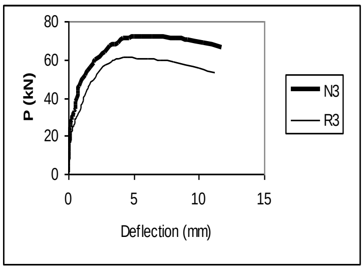
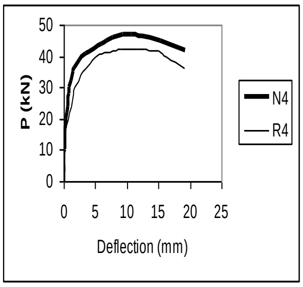
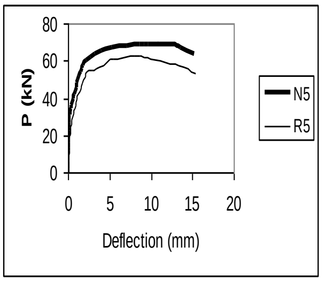


FIGURE 15: Load versus deflection for N1 and R1 beams

FIGURE 16: Load versus deflection for N2 and R2 beams

FIGURE 17: Load versus deflection for N3 and R3 beams





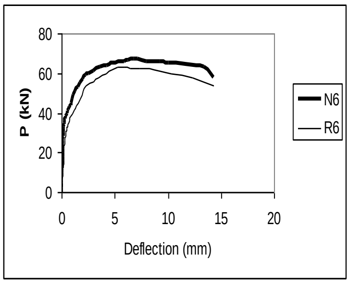


FIGURE 18: Load versus deflection for N4and R4 beams

FIGURE 19: Load versus deflection for N5 and R5 beams

FIGURE 20: Load versus deflection for N6 and R6 beams