- Technical Paper -

LONG-TERM DEFLECTIONS OF REINFORCED CONCRETE BEAMS WITH RECYCLED AGGREGATES FROM DEMOLISHED CONCRETE

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ABSTRACT

This paper presents test-results on long-term behaviors and recovery characteristics of reinforced concrete beams with recycled aggregates. Three beams with different replaced one condition of aggregates were subjected to the sustained flexural load ($0.5M_n$) for one year. The results shows that the performance of reinforced concrete beams with recycled aggregates are satisfied with the serviceability criteria in term of deflection. The beams of recycled aggregate are comparable to that of normal aggregate. The long-term deflection by the modified ACI shows good agreement with test results more than by the ACI.

Keywords: recycled aggregate, long-term behavior, deflection, reinforced concrete beam

1. INTRODUCTION

Infrastructure built during the middle twentieth century has become, or is becoming obsolete and in need of replacement or repair. As the government tear up roads and tear down buildings, they generate large quantities of demolition wastes. Therefore, there is a continuous shortage of landfill space. Also, a large volume of aggregates will be required to rebuild this infrastructure and support new construction. At the same time, there is a shortage of natural aggregate in urban areas. This circumstance has created a real and urgent need to consider using less satisfactory materials, which are of good quality.

The concept of recycling aggregate from demolition wastes and utilizing in another form has gained some momentum. The concept of using recycled aggregates not only saves landfill space but also reduces the demand for extraction of natural aggregate for new construction activity. Various investigations mainly engaged in the recycled aggregate concrete [1-3]. It is shown that strength properties of recycled aggregate concrete may be generally lower than those of natural concrete; however, they are sufficient for practical applications in architectural and civil engineering.

Regarding the popularization of recycled aggregate concrete, the structural behavior of recycled concrete should to be investigated. In fact, some studies concerning structural behavior (behavior under flexure conditions, shear, bond, torsion, etc.)[4-6] of recycled aggregate concrete were reported in the literature. Time dependent behaviors are the most important requirements of concrete constructions for satisfactory performance while the constructions use. However, there are only few investigations engaged in research on the time dependent behaviors of reinforced recycled aggregate concrete beams.

This study discusses the experimental results of the long-term behavior under sustained loads for a period of one year and the recovery behavior of the concrete beams with recycled aggregates. Also, the predictions of long-term deflection by the ACI Code and the modified ACI approach were compared with the experimental results.

2. EXPEMENTAL PROGRAM

2.1 Specimens details

In the experiment, three specimens were made with different replacement conditions of aggregates (natural aggregate 100%: C-30ω, recycled coarse aggregate 100%: RL-30ω, and recycled fine aggregate 50%: RH-30ω). The configuration of the beam is shown in Fig. 1. The sizes of beams were 170 × 200mm in cross-section and 2,300mm in total length (2,000mm in net span). The beams contained two tensile reinforcements (deformed bar 10mm in diameter)

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and two compressive reinforcements (deformed bar 6mm in diameter). Six millimeter deformed bars as shear reinforcements were placed a spacing of 100mm throughout the entire length of the beams. Characteristics of the tested specimens are summarized in Table 1.

2.2 Materials

(1) Aggregates

The recycled aggregates used in this study were the coarse aggregate and the fine aggregate from demolished concrete waste. The water absorption of recycled aggregates (1.86~3.64%) is higher but the density of recycled aggregates is lower than those of natural aggregates. The physical properties of the natural and recycled aggregates are given in Table 2. The shapes of aggregates are shown in Fig. 2.

(2) Reinforcements and Concrete

The characteristics of used reinforcements are listed in Table 3. The specified strength of the concretes was targeted as 30MPa. The strength properties of concrete are shown in Table 4, and the proportions of the mixture of the concrete are shown in Table 5.

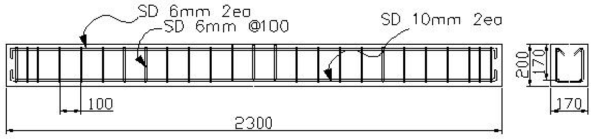


Fig. 1 Configuration of beams

(a) Natural coarse (b) Recycled coarse

(c) Natural fine (d) Recycled fine

Fig. 2 Shapes of aggregate

2.3 Test setup and instrumentation

All specimens were laboratory-cured specimens until completion test. The three beams were simply supported and subjected to the

Table 1 Properties of specimens

Specimen	b × d (㎜)	Net span (㎜)	Reinforcement A_s, ρ (㎟, %)
C30-0.5ω* RL30-0.5ω RH0-0.5ω	170 × 170	2,000	D10 2ea (142.2, 0.49)

* C 30-0.5ω
C: natural coarse + natural fine aggregate
RL: recycled coarse + natural fine aggregate
RH: natural coarse + natural fine aggregate (50%) + recycled fine aggregate (50%)
30: specified strength (f_{ck}=30N/㎟)
0.5ω: 50% of nominal moment capacity (M_n)

Table 2 Physical properties of aggregates

Aggregate	Density (g/㎤)	Water Absorption (%)	Fineness modulus
Natural coarse	2.56	1.39	6.02
Recycled coarse	2.54	1.86	6.72
Natural fine	2.56	1.42	2.84
Recycled fine	2.47	3.64	2.89

Table 3 Characteristics of reinforcements

Type	Yielding strength f_y(N/㎟)	Yielding strain ε_y($\times 10^{-6}$)	Tensile strength f_t(N/㎟)	Elastic modulus E_s(kN/㎟)
D6	291.19	1900	375.01	182.76
D10	413.56	2400	600.74	203.07

Table 4 Properties of concrete

Specimen	Compressive strength f_{cu}(N/㎟)	Elastic modulus E_c(kN/㎟)	Maximum strain ε_{cu}($\times 10^{-6}$)
C30-0.5ω	31.61	26.25	2460
RL30-0.5ω	39.66	28.48	3140
RH30-0.5ω	36.10	27.53	2510

Table 5 Mix proportions of concrete

Specimen	W/C	Unit weight (kg/㎥)						Slump	Fly-ash replacement	s/a
	(%)	C	FA	NF	RF	NC	RC	(mm)	percentage (%)	(%)
C30-0.5ω	45	331	58	763	0	927	0	230±20	15	46
RL30-0.5ω	45	331	58	763	0	0	888	230±20	15	46
RH30-0.5ω	50	298	53	409	402	979	0	150±20	15	47

FA: fine aggregate, NF: natural fine aggregate, RF: recycled fine aggregate,
NC: natural coarse aggregate, RC: recycled coarse aggregate

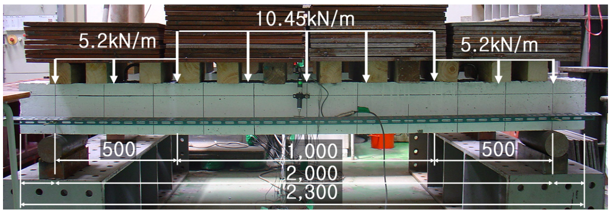


Fig. 3 Test setup for sustained loading (㎜)

sustained load 0.5ω equal to 50% of the nominal moment M_n (9.13kN.m) for a period of one year as shown in Fig. 3. The deflection at midspan was monitored by the LVDTs (Linear variable different transducers). Strains of steel reinforcements and concrete were measured using strain gauges. Monitoring deflection and strains were carried out through a data logger (TDS601A) which is an automatic data acquisition system every day. The crack was recorded at the same time. Recovery deflection and strains measured by a data logger during 3 days from the sustained load removed.

3. TEST RESULTS

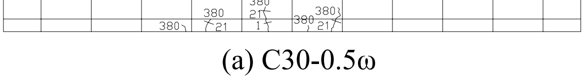
3.1 Long-term behaviors

(1) Cracking pattern

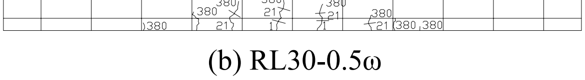
The cracking patterns of concrete beams under sustained loading on 1st day, 21st day, and 380th day are compared in Fig. 4. One crack appeared immediately after loading in the beam C30-0.5ω with natural aggregate while two cracks appeared in the beams RL30-0.5ω and RH30-0.5ω respectively. As the loading time increasing, some cracks were formed at the bottom of beams, and these cracks propagated to the upper compression zone. The number of cracks in the beam with natural aggregate is less than those in the beams with recycled aggregates. Especially, the crack-height of the beam RL30-0.5ω (with recycled coarse aggregate 100%) is higher than that of the beams C30-0.5ω and RH30-0.5ω.

Table 6 Total deflection at midspan (㎜)

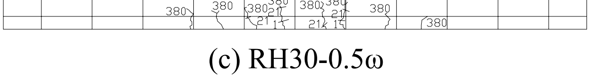
Specimen	1st day	380th day	Permissible deflection by ACI	EXP /ACI
C30-0.5ω	1.012	2.103	8.333	0.252
RL30-0.5ω	0.908	1.802		0.216
RH30-0.5ω	1.175	2.286		0.274



(a) C30-0.5ω



(b) RL30-0.5ω



(c) RH30-0.5ω

Fig. 4 Cracking patterns (1st day, 21st day, 380th day)

(2) Long-term deflection

Fig. 5 shows the total deflections at the midspan for all beams. The amount of instantaneous deflections are in the order of the beams RH30-0.5ω, C30-0.5ω and RL30-0.5. As the loading time increases, the deflection at the midspan increases continuously and it results 2.103, 1.802 and 2.286 ㎜ for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively at an age of 380 days. The experimental results of total deflections are satisfied with maximum permissible computed deflections (8.333mm) by the ACI 318 Building Code. The total deflections of the beams are compared with permissible

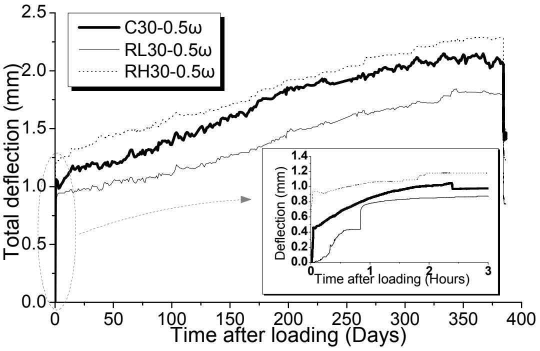


Fig. 5 Total deflection

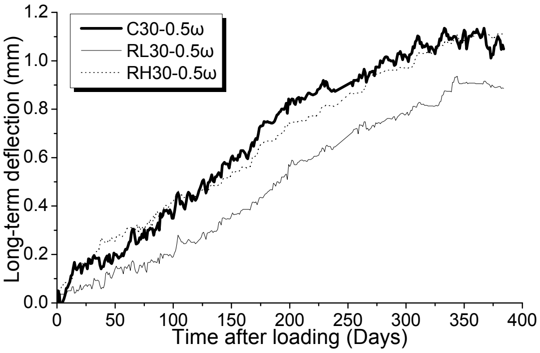


Fig. 6 Long-term deflection

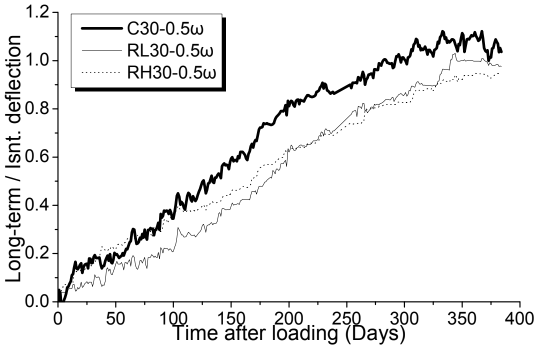
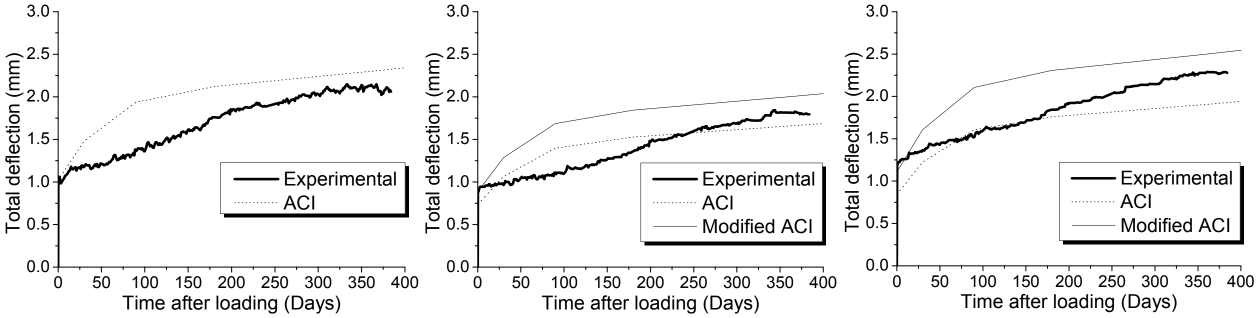


Fig. 7 Long-term / Inst. deflection



(a) C30-0.5 (b) RL30-0.5 (c) RH30-0.5

Fig. 7 Comparison of test results with theatrical predictions

Table 7 Deflection of test results with theoretical predictions

Specimen	Instantaneous					380th day				
	EXP	ACI	EXP /ACI	Modified ACI	EXP / Modified ACI	EXP	ACI	EXP /ACI	Modified ACI	EXP / Modified ACI
C30-0.5ω	1.01	1.02	0.99	-	-	2.10	2.32	0.91	-	-
RL30-0.5ω	0.91	0.73	1.25	0.87	1.04	1.80	1.69	1.07	2.01	0.89
RH30-0.5ω	1.18	0.84	1.41	1.16	1.01	2.29	1.93	1.19	2.63	0.87

deflections in Table 6. Fig. 6 shows the long-term deflections at the midspan. The long-term deflections are obtained by subtracting the instantaneous deflections from the total deflection. As the loading time increases, the long-term RL30-0.5ω (recycled coarse aggregate 100%) is smaller than those of the beams C30-0.5ω and RH30-0.5ω. The beams C30-0.5ω and RH30-0.5ω show similar increases in the long-term deflection. Fig. 7 shows the ratios of long-term to instantaneous deflection. On 380th day, the ratios of long-term to instantaneous deflection are 1.07, 0.98, and 0.95 for the beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. Therefore, the ratios of long-term to instantaneous deflection in beams with recycled aggregates (RL30-0.5ω, RH30-0.5ω) are smaller than those in beam with natural aggregate.

(3) Comparison with theoretical predictions

Deflection calculations for beams with cracked sections are rather complicated. In design specifications (ACI 318) [6], the long-term deflections increment is simply calculated by multiplying a factor λ_Δ to the initial deflections due to bending

$$\Delta_{(cr+sh)} = \lambda_\Delta(\Delta_i) \qquad (1)$$

where,

$\Delta_{(cr+sh)}$: long-term deflection

Δ_i : instantaneous deflection

The instantaneous deflection Δ_i is calculated with an effective moment of inertia. The coefficient λ_Δ, which depends on the duration on sustained load, is given by

$$\lambda_\Delta = \frac{\xi}{1+50\rho'} \qquad (2)$$

where,

ξ : time dependent factor

ρ' : compressive reinforcement ratio

The modified ACI approach considers the recycled aggregates concrete. The modulus of rupture concrete (f_r) is multiplied by the factor (RL30-0.5ω: 0.92, RH 30-0.5ω: 0.86).

The comparison between the theoretical predictions and the test results is shown in Fig. 7 and Table 7. In the instantaneous deflection, the ACI value of the beam C30-0.5ω shows good agreement with the observed result. However, the experimental values of the beams with recycled aggregates (RL30-0.5ω, RH30-0.5ω) are above the ACI values, while the modified ACI approach shows good agreement with the experimental value. In the ACI approach, the multiplier of long-term deflection was taken to remain constant for periods of 380 days under sustained loading. The ratios of observed values to prediction values are 0.91, 1.07 and 1.19 for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. The predicted value of the beam with natural aggregate is above the experimental values; however, that of beams with recycled aggregates are smaller than the experimental values after approximately on 200th day. In the modified ACI approach, the ratios of observed to predicted values are 0.89, 0.87 for beams RL30-0.5ω, RH30-0.5ω respectively. Therefore, the modified ACI approach predicts slightly overestimates.

(4) Strains

Fig. 8 shows the time-dependent total strain of reinforcement observed at the midspan for the beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω. The instantaneous strain of reinforcement in the beam RH30-0.5ω (with recycled fine aggregate 50%) is higher than the others. As the loading time increases, the strain of reinforcement increases continuously and it results 1683, 1772, and 1828 ($\times 10^{-6}$) for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively, on 380th day. In general, the strain of reinforcement in the beam with natural aggregate is smaller than that in the beams with recycled aggregates during 380 days.

Fig. 9 shows the time-dependent total strain of compressive concrete observed at 20 ㎜ from the top fiber at the midspan for the beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω. The instantaneous strain of compressive concrete in the beam RL30-0.5ω is smaller than the others. As the loading time increases, the strain of compressive concrete increases continuously and it reached 1481, 1576, and 1424 ($\times 10^{-6}$) for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively, on 380th day. In general, the strain of compressive concrete in all beams shows similar during 380 days.

3.2 Behavior of recovery

(1) Deflection of recovered

Fig. 10 shows the recovered deflections observed at the midspan for the beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω when the sustained load removed. The recovered deflections of each specimens are 0.662, 0.948 and 1.056 ㎜ for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. Therefore, recovered deflections of the beams with recycled aggregates (RL30-0.5ω, RH30-0.5ω) show higher than those of the beam with natural aggregate (C30-0.5ω).

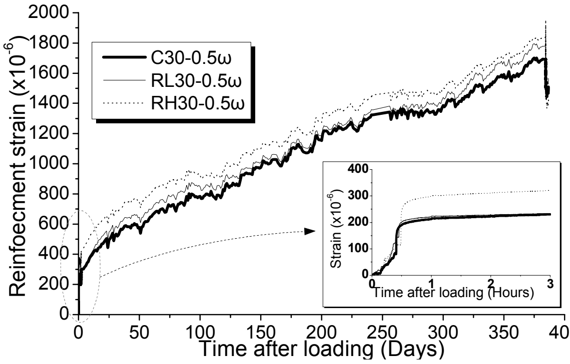


Fig. 8 Reinforcement strain

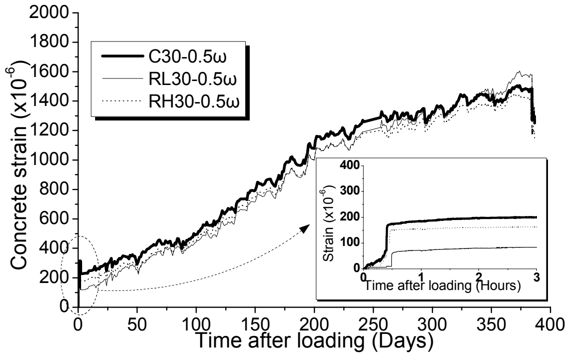


Fig. 9 Compressive concrete strain

(2) Strain of recovered

Fig. 11 shows the recovered strain of reinforcement observed at the midspan for the beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω when the sustained load removed. The recovered strains of reinforcement are 245, 269, and 470 ($\times 10^{-6}$) for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. The recovered strain of the beams with recycled aggregates show higher (RL30-0.5ω: 10%, RH30-0.5ω: 91%) than that of

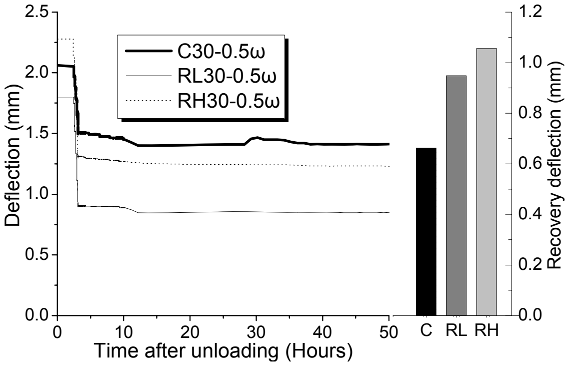


Fig. 10 Recovery of deflection

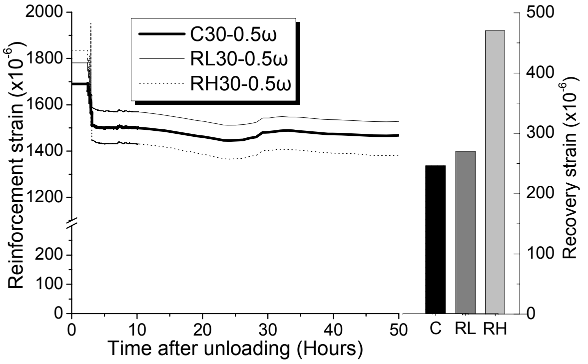


Fig. 11 Recovery of reinforcement strain

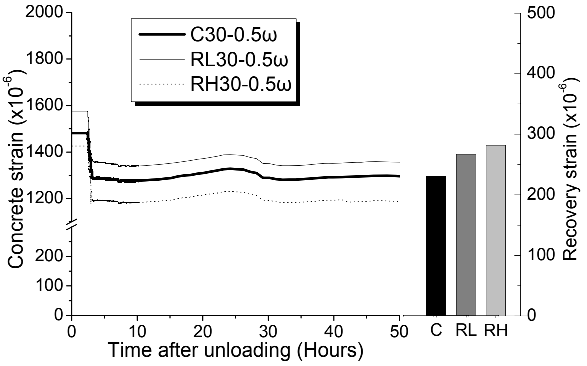


Fig. 12 Recovery of concrete strain

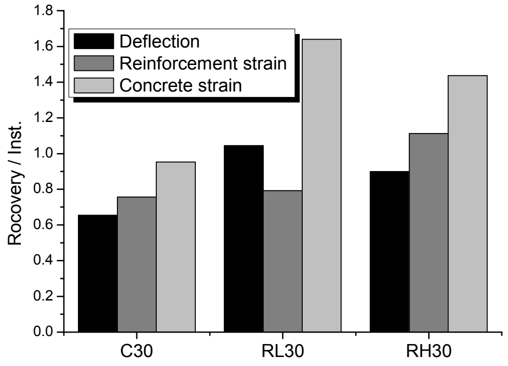


Fig. 13 Recovery / Instantaneous

the beam with natural aggregate (C30-0.5ω). Fig. 12 shows the recovered strains of compressive concrete observed at the midspan for the beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω when the sustained load removed. The recovered strains of compressive concrete are 229, 266, and 281 ($\times 10^{-6}$) for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. The recovered strains of the beams with recycled aggregates show higher (RL30-0.5ω: 16%, RH30-0.5ω: 23%) than those of the beam with natural aggregate (C30-0.5ω).

(3) Recovery / Instantaneous

Fig. 13 shows the ratio of recovery to instantaneous deflection, strains of reinforcement and concrete. The ratios of recovery to instantaneous deflection are 0.65, 1.04, and 0.89 for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. Therefore, the beams with recycled aggregates show higher (RL30-0.5ω: 60%, RH30-0.5ω: 37%) than the beam with natural aggregate (C30-0.5ω). The ratios of recovery to instantaneous strain of reinforcement are 0.75, 0.79, and 1.11 for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. Therefore, the beams with recycled aggregates show higher (RL30-0.5ω: 5%, RH30-0.5ω: 48%) than the beam with natural aggregate (C30-0.5ω). The ratios of recovery to instantaneous strain of compressive concrete are 0.95, 1.64, and 1.47 for beams C30-0.5ω, RL30-0.5ω, and RH30-0.5ω respectively. Therefore, the beams with recycled aggregates exhibited higher (RL30-0.5ω: 73%, RH30-0.5ω: 53%) than the beam with natural aggregate (C30-0.5ω).

4. CONCLUSIONS

(1) The crack in the beam with recycled aggregates formed and developed more than that in the beam with natural aggregate. But the beams are appeared in similar cracking patterns irrespective of usage of recycled aggregates.

(2) The instantaneous and total deflections of beam RL30-0.5ω (with recycled coarse aggregate) are smaller than those of beams C30-0.5ω, RH30-0.5ω. The ratios of long-term to instantaneous deflection of beams with recycled aggregates are smaller than those of the beam with natural aggregate.

(3) Total deflections of beams are satisfied irrespective of using recycled aggregates with maximum permissible by the ACI.

(4) The long-term deflection by the modified ACI approach shows good agreement with experimental results more than by the ACI.

(5) Recovered deflections and strains of the beams with recycled aggregates are higher than those of the beams with natural aggregate.

(6) The ratios of recovery to instantaneous deflection in the beams with recycled aggregates (RL30-0.5ω, RH30-0.5ω) are 60, 37% higher than those in the beam with natural aggregate. The ratios of recovery to instantaneous strain of the beams with recycled aggregates are higher than those of the beam with natural aggregate.

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