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Strength, Deflection and Cracking Behavior of Concrete Slab Using Demolished Concrete as Coarse Aggregates

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Abstract

Making use of demolished waste of reinforced concrete structures is one of the possibilities of reducing waste management and saving natural aggregates. In this experimental work strength, deflection and cracking behavior of reinforced concrete slabs made with recycled aggregate from demolished concrete waste as partial replacement of natural coarse aggregate is evaluated. The replacement of natural coarse aggregates is done in 50%, 60%, 70% and 80% proportion. To compare the results one batch of slab is cost with 100% natural aggregate. Maximum size of aggregates used is 1". For all batches of concrete 1:2:4 mix with 0.45-0.55 water cement ratio is used. All slabs are tested by applying central point load. Average reduction in load carrying capacity is recorded as 7.1% for 50% replacement of natural aggregates. Maximum deflection recorded is 4.4 mm which is with in allowable limits of ACI 318. Cracking behavior of all slabs is also observed and it is found that cracking pattern remained almost same for all models however reduction in cracking load with increased percentages of recycled aggregate is recorded. Based on result it is concluded that coarse aggregates from demolished concrete can effectively be used in reinforced concrete slabs with 50% replacement of natural aggregate with recycled aggregate from demolished concrete.

Keywords: Demolished concrete, Deflection, Cracking, Reinforced Concrete Slabs..

Introductions

Concrete has been proved to be leading construction materials since more than a century. With time existing structures deteriorates; growing population need more structures thus new construction becomes unavoidable. Space problem in city center force the construction industry to erect high-rise buildings. Thus the rate of consumption of natural aggregate in concrete is increasing day by day and if such, situation remained continued; the limited natural quarries of aggregates would be consumed very soon. On the other hand construction of new buildings by demolishing old structures results in potential quantum of the construction waste. Although type and quantity of this waste differ from region to region, approximately one billion tons of construction and demolition waste is generated every year worldwide and has posed serious problem everywhere. In recent year more and more attention is given to this problem and its associated ecological impacts that have direct effect on human life. The developed countries put more emphasis on waste recycling. The management of this waste is one of the priorities of every community and it has become evident that good waste management can enhance the quality of life. The main principal of a quality waste management is in lowering, production, finding ways of recycling and reusing existing material and safe and ecological acceptable depositing of unused waste. Both of the problems can be addressed by making sustainable use of this waste.

Attempts have been made to make use of various ingredient of construction waste by screening or detailed reprocessing. Recycling or re-using of bricks, glass, wood concrete, etc. has been done and observed that utilization of this concrete waste as an aggregate in new building construction has a positive effect on economy also. In normal concrete roughly 70% to 80% of concrete volume is of aggregate and was generally believed that aggregates are filler in concrete having little effect on finished product. But research reports have proved that this component contributes much in determining stability, workability, durability and strength of the concrete. Two main issues with conventional concrete remained hot since long. First is the finding of

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alternative ingredient or material to enrich the strength and second is the use of waste obtained from demolishing of existing concrete structure. Earlier, recycled aggregates were used mainly in low utility application such as general fill. Recently, these aggregate started to be used for intermediate utility application such as foundations for building, roads etc.

Acceptability of recycled material is hampered due to a poor image associated with recycling activity, and lack of confidence in a finished product made from recycled material. Cost of disposal of waste from construction industry to land fill have a direct bearing on recycling operation low dumping costs in developing countries also is a barrier to recycling activities. Imposition of charge on sanitary landfill can induce builder and owners to divert the waste for recycling. Some of these issue act as barrier in promoting more widespread of recycled aggregate and concrete made with recycled aggregate. Transporting waste over large distance makes the proposition of using construction and demolition waste uneconomical, lack of such plants is major barrier for new comers in the field of construction and demolition waste management. Lack of awareness towards recycling possibilities and environment implication of using only fresh aggregate are the main barrier due to which construction and demolition waste disposal goes only in landfills. Creating awareness and dissemination of information is thus essential to mobilize public opinion and create confidence in favor of the recycling option.

Keeping in view above mentioned problems with natural aggregate and advantages of secondary aggregate this research work undertaken study of compressive strength of reinforced concrete slab panels using coarse aggregate from demolished concrete. Natural aggregates are partially replaced in percentages of 50%, 60%, 70%, & 80%. Demolished waste of reinforced concrete structure is collected from Nawabshah city. After casting slab panels, curing for 28 days is done followed by testing & comparing results with slab panel made with 100% natural aggregates. It is hoped that the outcome of this research work will improve the understanding of re-using demolished concrete as coarse aggregate in reinforced concrete panels.

Literature review

Continuously increasing demand of accommodating peoples in urban areas have created serious problem particularly in region where space is already a problem. There, best solution of problem is to construct building with more height in place of short height buildings. This practice generates huge quantum of demolishing waste, which for large times gone to landfills. On other hand it also require additional cost for management and transportation, also areas for dumping this waste is reducing which give rise to another problem. Keeping in view, scholars have studied possibilities of reusing this waste in construction. Mas et al[13] performed research to evaluate use of recycled aggregates in non-structural members and found that at 90 day curing concrete with recycled aggregates observe less than 15% reduction in strength as compared to reference concrete thus has good potential to be used as the aggregate in new concrete construction particularly for non-structural members. Kearsley[27] also studied possibilities of reuse of demolished concrete as coarse aggregates and concluded its suitability as partially replaced coarse aggregate. Marinkovic et al[32] also studied the possibility of reuse of demolished concrete as coarse aggregates in new concrete with particular reference to environmental reference and concluded recycled aggregates as environmental friendly material. Olorunsogo[2], Kawano[21] and Noguchi[31] studied the possibilities of reuse of demolished concrete as coarse aggregates with reference to Japan government plans of recycling debris material. He-gon and jing[15] evaluated demolished concrete as coarse aggregates with reference to durability and concluded to be used as coarse aggregates in low load bearing members.

Gilpin et al[20] studies the possibilities of re-use of demolished concrete as coarse aggregate in new concrete. Based on his research author concluded that only 14% of debris material is utilized by recycling center, where as rest of the material goes to landfills. In another attempt Saeed[23] reported that debris from road, airport are utilized for recycling and consumed there in the new construction. Which can be extended to other modes of construction for better utilization of the same.

Defects and irregular voids are few problems associated with recycled aggregates. To this end Nagataki[34] presented technique of using jaw or impact crusher twice to process the demolished waste. Using this technique he got 50% betterment in defects and irregular voids. Zaharieva[12] also reported that recycled aggregate is highly heterogeneous and porous, with a large amount of impurities. Old mortar attached with demolished concrete possess serious issue regarding determination of final strength of concrete mix. Dosho[8] developed special technique to deal with this issue. His technique produces only 20-30% coarse aggregate as compared to current system which produces 60-70% coarse aggregates.

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Rao et al[10] in their research work studied properties of recycled aggregates and summarized the effect of use of recycled aggregates on the properties of fresh and hardened concrete. The authors also discussed the major obstacles, including lack of awareness, lack of administration support, non-existence of provisions/codes which can provide help for reusing these aggregates in new concrete. Wu and Feng[5] in their research work observed that properties of concrete are directly related to the properties of old concrete aggregates hence improving properties of aggregates will result in improved properties of concrete. Ksenija Jankovic et al [30] compared the existing experimental data of compressive strength of normal and recycled aggregates concrete and for technical regulation presented an equation. The accuracies of calculation by experimental data in laboratory as well as by EN1992.01.01, ACI 209 and SRPS U.MI.048 are compared on the basis of the co-efficient of determination. Abrasion resistance is one of the measures of quality of coarse aggregates. This is studied by Sagoe-Crentsil[6]. They found that the abrasion resistance of recycled aggregates was about 12% lower than natural aggregates. Authors also highlighted that removal of some of the adherent mortar helps to improve the properties of RCA containing concrete. The properties of the original concrete have a significant influence on the properties of the RCA containing concrete (compressive strength, tensile strength, bond stress at failure). Abou Zoid[1] also studied effect of abrasion resistance of recycled aggregates on strength of concrete with full and partial replacement. They found that this parameter has no effect on tuning of percentages of replacement of the aggregates.

Poon et al[16], Ajdukiewicz and Kliszewicz[3] found that concrete with recycling aggregates has relatively low flexural and splitting strength. They found 10-15% reduction in strength compared to ACI recommendation.

Li[18] mitigated successfully alkali-silica reactivity of coarse aggregates from demolished concrete to acceptable level by using 25% fly ash, Gull[19] used admixtures to improve the performance of the concrete with recycled concrete as aggregates. Taha and Nounu[17] used waste recycled glass as sand replacement.

Saleem[7] studied water absorption of demolished concrete aggregates and found that it is about 4-12% lower than natural aggregates. This difference is mainly due to higher absorption of the old mortar contained in the recycled concrete aggregates. Naik[4] studied that creation of high quality RCA produces a large amount of fines that can be problematic to deal. This residual can be mixed with a clay soil to improve its properties. In his work author found that addition of this residual material to soil improves its properties from clay to silty sand.

Compressive strength of concrete with demolished concrete as coarse aggregates has been studied by different scholars under different conditions. To this end Mirjana Malesev et al[28] used 50% and 100% replacement of natural coarse concrete aggregates in concrete and observed 25% reduction in strength. Oad[35] and Bhatti[36] used several percentage replacements of natural aggregates with demolished concrete aggregates from 10% to 80% and found reduction in compressive strength as low as 7% for lower replacement and 25% for higher replacement of natural aggregates with demolished concrete aggregates. Bazaz and Khayati[22] also based on their research work reported lower compressive strength of concrete with recycled aggregates in comparison to reference concrete. Kumutha and Vijai[9] used different replacement of natural aggregates from 0% to 100% with increment of 20% to evaluate compressive strength and concluded its suitability in new concrete as low grade structural concrete. Pual and Van Zijl[26] observed brittle effect on stress-strain diagram of concrete with recycled aggregates and concluded its suitability as low grade concrete. Buller[25] also observed reduction in compressive strength of concrete with recycled aggregates. In addition he also observed that no significant change in compressive strength is recorded with higher water-cement ratios. Chinwuba Arum[29] used 24 cubes to check compressive strength and found that concrete with recycled aggregates observed about 27% reduction in strength as compared to reference concrete.

From the above summary it may be concluded that although good quantum of research work is available regarding the reuse of demolished concrete as coarse aggregate in new concrete yet a wide scatter of results may be observed. This motivated the present research work to evaluate the properties of reinforced concrete slabs using coarse aggregates from demolished concrete.

Research methodology

The demolished concrete in the shape of large blocks is collected from different locations of Nawabshah city. These large blocks are then hammered down to average size of 1 inch. As believed and reported in literature contamination can affect the final strength of concrete made with recycled aggregates therefore aggregates were washed and dried before further processing. To keep similarity in size of aggregates natural aggregates are also sieved to maximum of 1” size, washed and dried. Details of the ingredients are given in table 1. Basic properties of aggregates, i.e. water absorption and specific gravity are then evaluated using standard procedures. Details of the same will be presented in relevant section.

Table 1: Ingredient details

Sr. No:	Ingredient	Source
1	Cement	Pak land
2	Fine aggregate	Bolhari
3	Coarse aggregate Natural aggregate size = 1” Recycled aggregate size =1”	Nawabshah city

For laboratory testing five batches of concrete with 0%, 50%, 60%, 70% & 80% replacement of natural aggregates with coarse aggregates from demolished concrete are prepared using 0.45 – 0.55 water cement ratio. Adjustment in water cement ratio is done to accommodate higher replacement of recycled aggregates as it is observed that as percentage of recycled aggregates is increased water demand of the concrete mix is also increased to maintain the workability. In each batch 4 specimen of slab of dimension 36”x 6”x 4” (figure 1) are prepared. All models are reinforced with 2#4 bars in bottom zone. The steel used is deformed bars of grade 60.

Figure 1: Specimen dimensions

Mixing of concrete ingredient is done by using concrete mixer and compaction in molds is achieved by rodding. To check and ensure the workability of concrete slump is checked by slump cone test in standard fashion. After 24 hours of pouring concrete in molds, molds are opened and models are cured for 28 days by standard water curing procedure.

Experimental work

As mentioned earlier basic properties of aggregates are evaluated and compared with those of the natural aggregates. Obtained results are tabulated in table 2.

Table 4.1: Basic properties of aggregates

Material	Water absorption %	Specific gravity
1.Natural aggregate	1.52	2.64
2.Recycled aggregate	5.54	2.36

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After elapse of curing time, specimen are taken out of water pond and prepared for testing. The same testing procedure is adopted for all the specimen. Which include application of central point load and measurement of the deflection by dial gauges in universal load testing machine. Figure 2 shows load arrangement of the model. Load is applied gradually. Periodically load and deflection are recorded along with visual observation of cracks in the model till failure. Twenty two readings of load and deflection are recorded for each speciman.

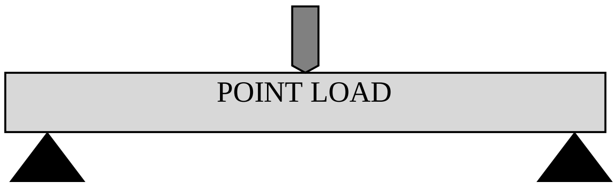

Figure 2: Load arrangement

Result and discussion

Both basic properties of coarse aggregates from demolished concrete i.e. water absorption and specific gravity shows different results than those of natural aggregates. Higher values of both parameters are obtained. It is mainly due to old mortar attached with the recycled aggregates. To maintain the workability of concrete mix, slump test is done which showed increased water demand of concrete mix as percentages of recycled aggregates is increased, therefore water-cement ratio is kept in range of 0.45-0.55.

Total of 20 reinforced concrete slabs (36"x 4"x 6") reinforced with 2#4 bars in tension zone are casted and tested with 0%, 50%, 60%, 70% & 80% replacement of natural coarse aggregates with coarse aggregates from demolished concrete. Deflection in all models is recorded to a value of 4.4 being the maximum deflection. Average of maximum load sustained by the reinforced concrete panels is tabulated in table 3. The average maximum load of slabs with 0% recycled aggregates (100% natural aggregates) is recorded as 37.14 KN and deflection equal to 4.4 mm. Load-deflection behavior of these slabs in plotted in figure 3. The pattern of the graph confirm with theoretical idea of increasing deflection with increase in load.

Average of maximum load and deflection for slabs with 50%, 60%, 70% & 80% replacement of natural aggregates are given in tables 3. For 50%, 60%, 70% & 80% average maximum load sustained by slab is 34.48 KN, 31.893KN, 30.287KN and 28.253KN respectively. For all percentages of recycled aggregates average maximum displacement recorded is 4.4 mm. For above mentioned percentages of recycled aggregate load versus deflection behavior is shown in figure 4 to figure 7. Almost same pattern of all graphs is recorded with different maximum load.

Table 3: Average maximum load in all slabs

#	**Average maximum load (KN) for different percentage replacement of NA**				
	0%	**50%**	**60%**	**70%**	**80%**
1	37.233	34.31	32.007	30.100	28.300
2	37.209	34.47	31.810	30.21	28.200
3	36.499	34.19	31.855	30.26	28.003
4	37.630	35.20	31.900	30.58	28.510
Average	**37.140**	**34.48**	**31.893**	**30.287**	**28.253**

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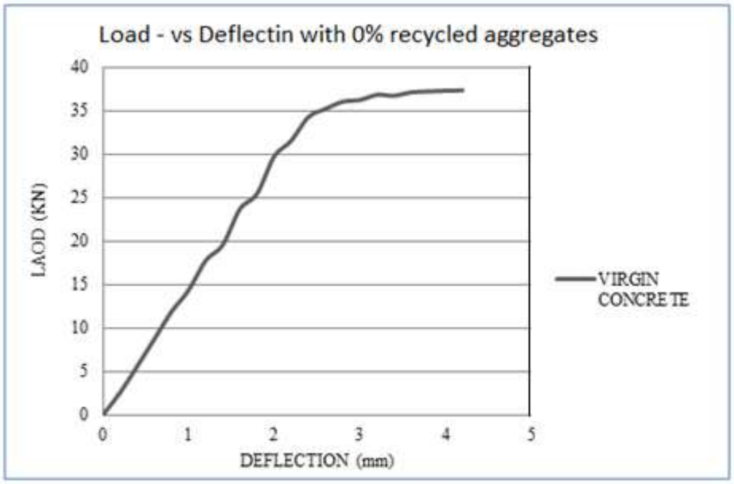

Figure 3: Load-deflection behavior of slabs with 0% recycled aggregates

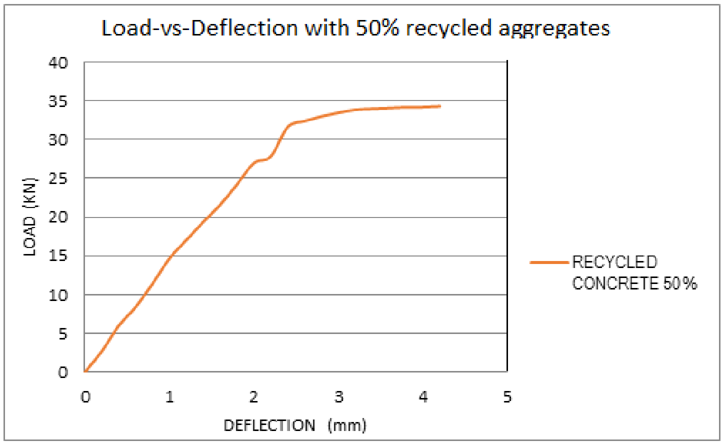

Figure 4: Load-deflection behavior of slabs with 50% recycled aggregates

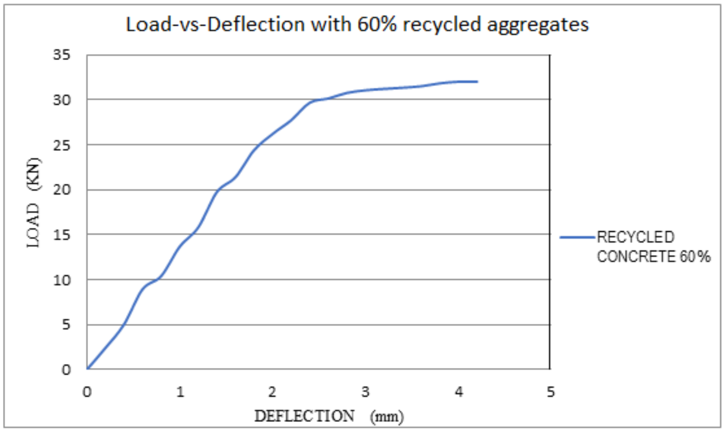

Figure 5: Load-deflection behavior of slabs with 60% recycled aggregates

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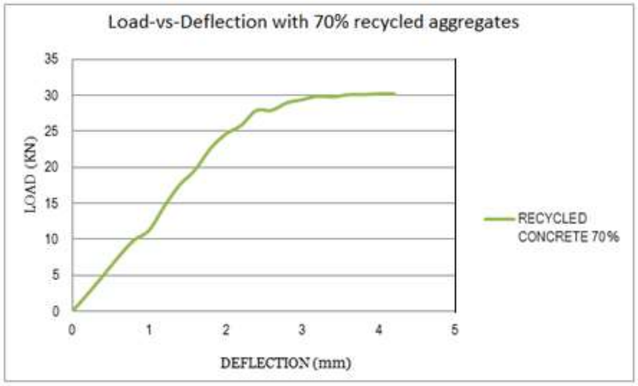

Figure 6: Load-deflection behavior of slabs with 70% recycled aggregates

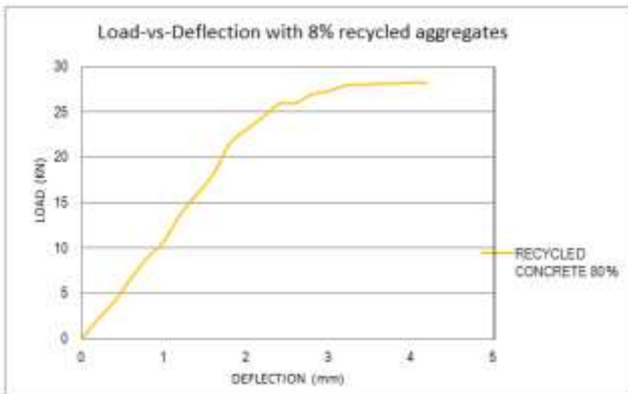

Figure 7: Load-deflection behavior of slabs with 80% recycled aggregates

Table 4 give comparison of average maximum load of all batches of reinforced concrete slabs made with recycled aggregates with slabs made from 100% natural aggregates. This table also gives details of percentage reduction of the load. It is observed that minimum reduction in load is 7.1% for 50% replacement of natural aggregates by recycled aggregates. Maximum reduction in load is recorded as 23.93% for replacement of natural aggregates with recycled aggregates. Intermediate values are recoded between 7% and 23.93% for other two percentages of replacement.

Table 4: Comparison of average maximum load.

#	% of RCA	LOAD (KN)	% REDUCTION
1	0	37.145	………
2	50	34.486	7.1%
3	60	31.893	15.24%
4	70	30.287	18.45%
5	80	28.253	23.93%

Comparison of average load of slab with 100% natural aggregates with average load of slabs with 50% replacement of natural aggregates with recycled aggregates recorded for same deflection values is figure 8(a). Trend of both graphs is same. Figures 8(b), 8(c) and 8(d) shows similar values for 60%, 70% and 80% replacement of natural aggregates with recycled aggregates. Table 5 and figure 9 gives comparison of load recorded for same deflection for all batches of concrete.

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With increased load crack has to form in concrete, same remained the situation of all slabs tested. Formation of cracks and load at which cracks formed are recorded for all slabs. It should be noted that only first three cracks are recorded. Load and deflection values along with cracks number are tabulated in table 6 to 10 for 0%, 50%, 60%, 70% and 80% replacement of natural aggregates with recycled aggregates. Figure 10 shows graphical view of cracking in slabs for selected slabs.

It is observed with pattern of crack formation for all slabs are same with difference in cracking load. In comparison to slabs made with 100% natural aggregate all slabs containing recycled aggregates gave lesser cracking load. With increased percentage of recycled aggregates cracking load was lesser.

Conclusion

Fast pace construction of reinforced concrete buildings including world record holding sky scrapers are to meet the need of present day to accommodate increasing population. This new construction in most of places result in mega bulk of demolished concrete waste. Which need good management and space to dump, on the other hand new construction make excessive use of natural aggregate. Resulting in faster decrease in the natural sources of these aggregates. A solution to both of the issues to make use of this demolishing waste in new concrete. Therefore this experimental work under taken evaluation of strength of reinforced concrete slabs using demolished concrete of Nawabshah as partial replacement of the natural coarse aggregates. In this work 50%, 60%, 70% and 80% replacement is used. Basic properties of aggregates are studied. Based on the results of water absorption and specific gravity, it is concluded that concrete mix with recycled aggregates need more water to maintain workability and it is mainly due to the old mortar attached with recycled aggregates.

Four slabs of each batch of concrete are prepared along with 04 slabs with 100% natural aggregates. All models are tested for load carrying capacity, deflection and cracking pattern. The results presented in tabular and graphical format shows good agreement with models of natural aggregates with reference to load-deflection pattern. However in comparison to models made with 100% natural aggregate all models failed at lower load. Minimum reduction in load was 7.1% for 50% replacement of natural aggregates with recycled aggregates. Maximum deflection is 4.4 mm which is within allowable limits.

Cracks also appeared at lower load than that of slabs with natural aggregates. However the cracking behavior remained same to that of slabs made with 100% recycled aggregates. Based on the results it is concluded that coarse aggregates from demolished concrete shows good scope to be used in reinforced concrete slabs in 50% proportion to natural aggregates. Slabs made with 50% replacement of natural aggregates can effectively be used as reduction in load carrying capacity is only 7.1%.

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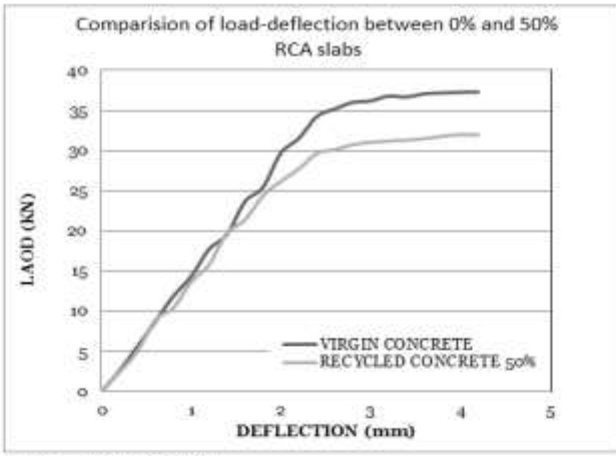
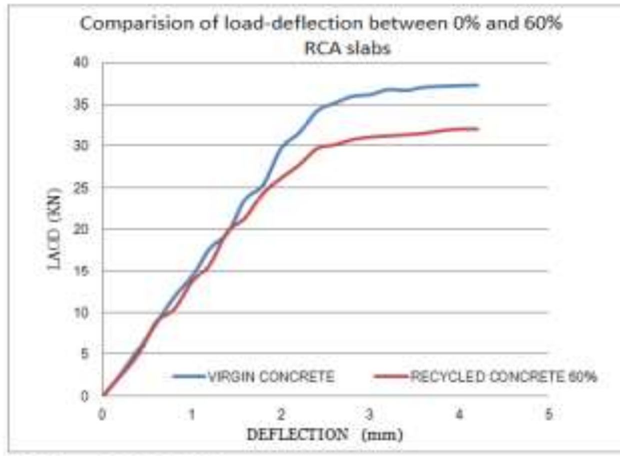
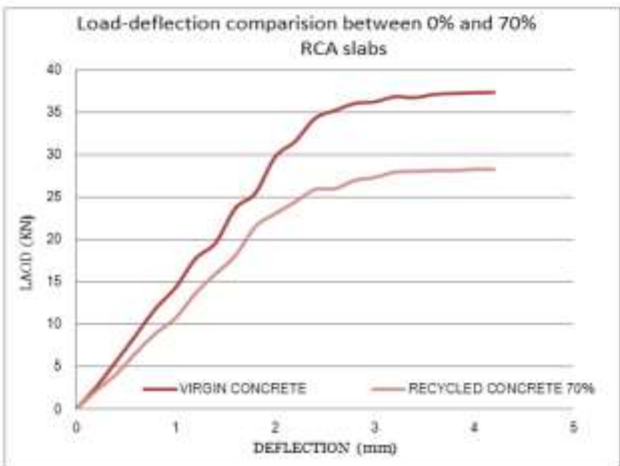


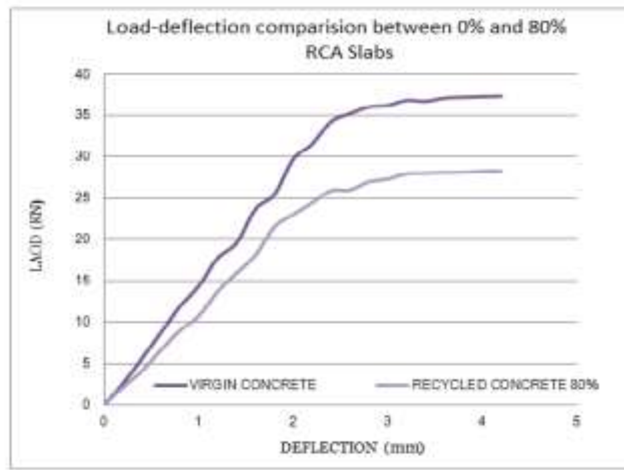
(a) 0% and 50% RCA Slabs



(b) 0% and 60% RCA Slabs



(c) 0% and 70% RCA Slabs



(d) 0% and 80% RCA Slabs

Figure 8: Comparison of load and deflection

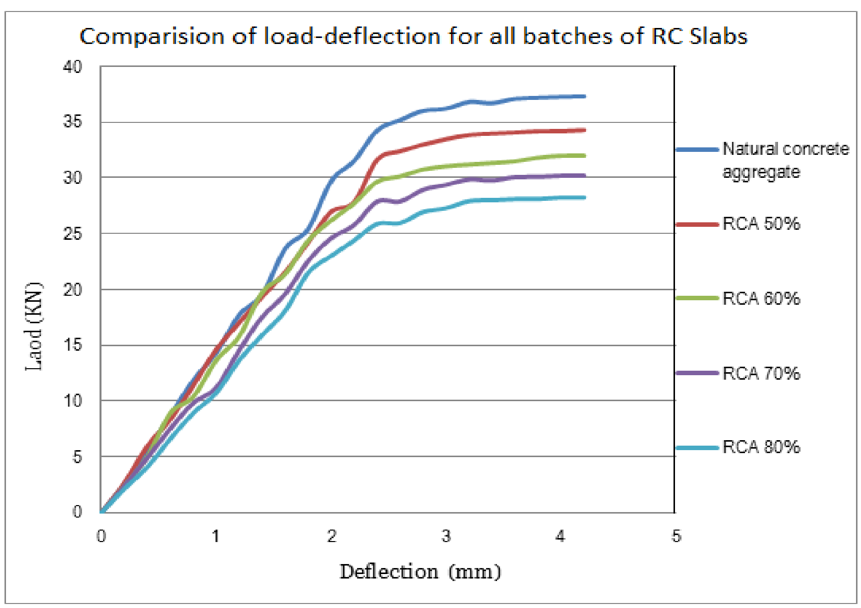


Figure 9: Comparison of load and Deflection for all batches of RCA with NCA

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Table 5: Load vs Deflection for all batches of concrete

S. No	Slab with 0% RCA Load (KN)	Slab with 50% RCA Load (KN)	Slab 60% RCA Load (KN)	Slab with 70% RCA Load (KN)	Slab with 80% RCA Load (KN)	Deflection (mm)
0	0	0	0	0	0	0
1	2.580	2.675	2.340	2.393	2.070	0.2
2	5.601	5.970	5.022	4.920	4.045	0.4
3	8.730	8.733	8.930	7.544	6.380	0.6
4	11.870	11.399	10.402	9.833	8.512	0.8
5	14.350	14.644	13.672	11.3320	10.203	1.0
6	17.744	17.035	15.823	14.570	11.863	1.2
7	19.572	19.368	19.744	17.547	14.881	1.4
8	23.670	21.572	21.399	19.610	16.875	1.6
9	25.433	24.232	24.390	22.570	19.540	1.8
10	29.727	26.975	26.203	24.604	21.713	2.0
11	31.540	27.840	27.731	25.792	22.533	2.2
12	34.252	31.638	29.675	27.891	24.671	2.4
13	35.200	32.400	30.140	27.900	24.901	2.6
14	36.020	33.001	30.759	28.954	25.106	2.8
15	36.211	33.477	31.055	29.392	25.780	3.0
16	36.812	33855	31.204	29.874	26.541	3.2
17	36.705	33.890	13.340	29.999	27.443	3.4
18	37.100	34.075	31.501	30.080	27.535	3.6
19	37.199	34.195	31.811	30.008	27.872	3.8
20	37.244	34.202	32.007	30.100	28.003	4.0
21	37.233	34.310	32.007	30.100	28.003	4.2
22	37.233	34.310	32.007	30.100	28.003	4.4

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Table 6: Load-deflection for first three cracks in slabs with 0% RCA

Slab No:	Load (KN)	Deflection (mm)	Successive crack
1	29.727	2.0	One
	35.200	2.6	Two
	36.211	3.0	Three
2	28.855	2.0	One
	34.005	2.4	Two
	36.205	3.0	Three
3	29.452	2.2	One
	31.817	2.6	Two
	35.302	3.4	Three
4	28.498	2.0	One
	32.425	2.4	Two
	36.241	2.8	Three

Table 7: Load-deflection for first three cracks in slabs with 50% RCA

Slab No:	Load (KN)	Deflection (mm)	Successive crack
1	27.840	2.2	One
	32.400	2.6	Two
	33.477	3.0	Three
2	27.403	2.2	One
	32.960	2.8	Two
	33.622	3.2	Three
3	26.302	2.0	One
	31.205	2.4	Two
	32.545	2.8	Three
4	26.567	2.2	One
	29.855	2.6	Two
	32.450	3.0	Three

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Table 8: Load-deflection for first three cracks in slabs with 60% RCA

Slab No:	Load (KN)	Deflection (mm)	Successive crack
1	26.203	2.0	One
	29.675	2.4	Two
	30.759	2.8	Three
2	27.600	2.2	One
	29.492	2.4	Two
	30.511	2.8	Three
3	24.633	1.8	One
	26.711	2.2	Two
	30.299	2.8	Three
4	25.497	2.0	One
	28.739	2.4	Two
	29.841	2.6	Three

Table 9: Load-deflection for first three cracks in slabs with 70% RCA

Slab No:	Load (KN)	Deflection (mm)	Successive crack
1	27.891	2.4	One
	28.954	2.8	Two
	29.874	3.2	Three
2	24.983	2.2	One
	27.572	2.6	Two
	28745	3.0	Three
3	24.424	2.0	One
	25.907	2.4	Two
	28.472	3.0	Three
4	25.450	2.2	One
	28.910	2.8	Two
	29.410	3.0	Three

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Table 10: Load-deflection for first three cracks in slabs with 80% RCA

Slab No:	**Load (KN)**	**Deflection (mm)**	**Successive crack**
1	23.023	2.0	One
	25.892	2.4	Two
	26.953	2.8	Three
2	22.968	2.0	One
	25.345	2.4	Two
	25.913	2.6	Three
3	22.533	2.2	One
	24.901	2.6	Two
	26.541	3.2	Three
4	23.435	2.2	One
	24.511	2.4	Two
	26.589	2.8	Three

Figure 10: Cracking in slabs for selected models

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