Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 12, December -2017

AN EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOUR OF R C C TWO WAY SLABS

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Abstract: *Concrete is the most commonly used material in various types of constructions. The demand of aggregate and cement used in concrete is increasing worldwide every year due to rapid industrialization and urban development. The excessive utilization of aggregate for concrete production leads to excessive exploitation of natural aggregate and environmental degradation from quarrying activities. This has resulted in renewed interest in Recycled Aggregate (RA) as a viable source of concrete ingredient. Study carries casting and testing of two way slab specimens by using natural coarse aggregate and 50% replacement with recycled aggregate. The concrete grade considered for study is M25. In the experimental study the concrete mix has been designed as per the guidelines given in IS: 10262-2009 published by Bureau of Indian Standards. In slab specimens, the steel reinforcement varies from 0.3%, 0.4%, 0.5% in both the cases (natural and recycled) by using 6mm and 8mm diameter rebars. The size of two way slab is 600mm × 800mm × 90mm. The value of modulus of elasticity (E) is evaluated from the load vs. deflection curve of slab specimens. The modulus of elasticity of concrete is a very important parameter reflecting the ability of concrete to deform elastically. Deflections and crack widths are the parameters that gives us warning that the structure is about to fail so that there will be time to counter act. The aim of study is to verify the influence of steel reinforcement on the modulus of elasticity of reinforced concrete members.*

Key Words: *Concrete, Recycled aggregate, Steel reinforcement, Modulus of elasticity, Crack width, Deflection, Strain.*

I.INTRODUCTION

Concrete is the most commonly used material in various types of constructions. A huge quantity of concrete is consumed by construction industry all over the world. The demand of aggregate and cement used in concrete is increasing worldwide every year due to rapid industrialization and urban development. On the other hand, vast amounts of construction and demolition (C&D) wastes are generated due to increased construction activities and demolition of existing structures which create landfill problems worldwide.The excessive utilization of aggregate for concrete production leads to excessive exploitation of natural aggregates and environmental degradation from quarrying activities. This has resulted in renewed interest in Recycled Aggregates (RA) as a viable source of structural material.

Slabs are constructed to provide flat surfaces, usually horizontal, in building floors, roofs, bridges, and other types of structures. The slab may be supported by walls, by reinforced concrete beams usually cast monolithically with the slab, by structural steel beams, by columns, or by the ground.

Slabs are classified into two types:

1. One Way Slab
2. Two Way Slab

One way slab is a slab which is supported by beams on the two opposite sides to carry the load along one direction. The ratio of longer span (l) to shorter span (b) is equal or greater than 2. Two way slab is a slab supported by beams on all the four sides and the loads are distributed to the supports along both directions. In two way slab, the ratio of longer span (l) to shorter span (b) is less than 2.

Cracks in a building are of common occurrence. Any structural component develops cracks whenever stress in the component exceeds its strength. Cracks are classified in to structural and non structural categories. Depending on width of crack, these are classified in to thin (< 1mm), medium (1mm to 2mm) and wide (> 2mm wide). Internally induced stresses in building components lead to dimensional changes and whenever there is a restraint to movement as is generally the case cracking occurs.

Strain gauges work on the principle that the resistance of a conductor or a semiconductor changes when strained. This property can be used for measurement of displacement, force and pressure. The resistivity of materials also changes with change of temperature thus causing a change of resistance. The Wheatstone bridge is an electric circuit suitable for detection of minute resistance changes. It is therefore used to measure resistance changes of a strain gage. The bridge is configured by combining four resistors as shown in figure.

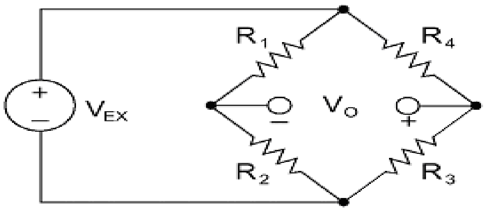


Figure.1 Wheatstone Bridge

II. MATERIALS AND EXPERIMENTAL METHODS

2.1 Cement: Ordinary Portland cement (Zuari cement), 43Grade conforming to **IS: 8112 – 1989** was used for casting all the specimens. The properties were obtained in accordance with Indian standard specifications.
2.2 Aggregate: The coarse aggregate of size 20 mm and 12.5 mm sieve is used and the recycled aggregate is obtained by crushing the hardened concrete cubes. The desired 20mm sample of required quantity is obtained by sieving the crushed concrete. The fine aggregate obtained from river bed, clear from all sorts of organic impurities is used in this experimental program. The sample pertained to zone-II as per IS classification of fine aggregate.
2.3 Water: Casting and curing of specimens were done with water available at local premises which was confirming to Indian Standards. Quality of water used for construction was determined in the laboratory as per clause 3.1.1 of **IS 3025**. The respective properties of the water sample were tabulated below.

Table.1 Properties of Water

Water Parameters	As per Environmental Laboratory	As per Specifications
PH	6.8	≥6.0 (IS 456: 2000)
Chlorides	250 mg/l	500 mg/l (RCC)
Sulphates	150 mg/l	400 mg/l
Organic matter	50 mg/l	200 mg/l
Inorganic matter	1150 mg/l	3000 mg/l
Suspended matter	500 mg/l	2000 mg/l

2.4 Steel: The steel reinforcement used for this investigation is confirmed to IS specifications. In this study, bar sizes of 6 mm diameter and 8mm diameter used.

Table.2 Properties of HYSD steel reinforcement bars

Diameter of bars (mm)	Yield strength (N/mm^2)	Ultimate tension strength (N/mm^2)
6	420	455
8	445	530

2.5 Experimental Methods:
In the present investigation, slab specimens were casted with varying percentages of reinforcement from 0.3%, 0.4%, 0.5%. Slab specimens are prepared one with natural coarse aggregate and 50% of natural coarse aggregates replaced by recycled coarse aggregate.
2.6 Concrete Mix Proportion: The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required workability, strength, durability as economically as possible, is termed as the concrete mix design.

Table.3 Stipulations for proportioning of M25 grade concrete

Type of Cement	OPC 43 Grade
Maximum Nominal size of Aggregate	20 mm
Minimum content of Cement	300 kg/m^3
Maximum Water Cement ratio	0.45
Specific Gravity of Cement	3.13
Specific Gravity of Fine aggregate	2.56
Specific Gravity of Coarse aggregate	2.57
Gradation of fine aggregate	Zone II

After designing as per code IS 10262:2009 the concrete mix design obtained as follows

C: W: F.A: C.A = 1: 0.48: 1.94: 3.4

2.7 Cube Test Specimens: The experimental investigation is carried out to obtain the compressive strength of cubes to decide the percentage of recycled aggregate to be replaced with natural coarse aggregate.

Table.4 Results of Compressive strength

Type of Concrete Mix(M25)	Compressive Strength (MPa)		
	3 Days	7 Days	28 Days
Control mix	15.8	23.4	33.8
RCA-50%	14.5	22.3	32.3

2.8 Casting of Test Specimens: For slabs, level platform is prepared and wooden sides of required length and width and they were arranged. The level platform is cleaned of dust particles and applied with mineral oil on all sides before concrete is poured. The reinforcement cage is placed in the level platform with cover blocks of thickness 15mm. Then well mixed concrete is poured and compacted thoroughly by vibrator. After the casting of slabs the specimens were kept at room temperature for one day, then the specimens were demoulded. Markings were made on the specimens for identification. To maintain the constant moisture on the surface of the specimens, they were covered with wet gunny bags till the age of testing.

Slabs are designed as per IS 456 -2000 and the ultimate moment Mu and the respective ultimate load Wu for different percentage of steel is obtained as follows:

Table.5 Design of Two Way Slab with Different Flexural Reinforcement

Specimen	Size (mm*mm)	Thickness (mm)	P_t req (%)	Spacing		M_u (kN-m)	W_u (kN)
				Shorter Span	Longer span		
8mm Ø bars were used as both main and distribution reinforcement							
Slab 0.3%	800*600	90	0.3	@190mm	@210mm	6.36	50.88
Slab 0.4%	800*600	90	0.4	@160mm	@150mm	7.92	63.32
Slab 0.5%	800*600	90	0.5	@130mm	@110mm	10.1	80.8
Slab 0.3% + 50%RCA	800*600	90	0.3	@190mm	@210mm	6.36	50.88
Slab 0.4% + 50% RCA	800*600	90	0.4	@160mm	@150mm	7.92	63.32
Slab0.6% + 50% RCA	800*600	90	0.5	@130mm	@110mm	10.1	80.8
6mm Ø bars were used as both main and distribution reinforcement							
Slab 0.3%	800*600	90	0.3	@130mm	@110mm	6.29	50.28
Slab 0.4%	800*600	90	0.4	@90mm	@90mm	7.57	60.56
Slab 0.5%	800*600	90	0.5	@70mm	@70mm	9.5	76.02
Slab 0.3% + 50%RCA	800*600	90	0.3	@130mm	@110mm	6.29	50.28

Slab 0.4% + 50% RCA	800*600	90	0.4	@90mm	@90mm	7.57	60.56
Slab0.6% + 50% RCA	800*600	90	0.5	@70mm	@70mm	9.5	76.02

2.9 Experimental Test Setup:

Place the cured specimen on the loading frame supported at all the edges. Place the data logger near to the specimen and preset the required settings. Attach the strain gauge at the centre of the slab specimen and connect it to the data logger. Place the LVDT at the centre of the slab specimen and connect it to the data logger. Place the hydraulic jack with load cell at required position. Apply the load gradually. Data logger gives the values of deflection and strain at different loads. Observe the first crack and calculate its width with the use of crack-scope. Record all the observations accordingly.

Figure.2 Test setup and application of load on the specimen

Figure.3 Observing the crack width of the specimen using crack scope

Figure.4 Crack propagation and ultimate failure of the specimen

Figure.5 Failure profile after reaching ultimate load

IV. RESULTS & DISCUSSIONS

The tests were conducted on the two-way slab specimens made with 100% natural coarse aggregate and 50% replaced recycled coarse aggregate to evaluate the flexural characteristics i.e., deflection, strain, crack-width, ultimate strength and modulus of elasticity.

3.1 Ultimate Load: From the test results, it is found that the ultimate load carrying capacity of the slab specimens is 2 to 20% more compared to the theoretical ultimate load for both natural coarse aggregate slab specimens and recycled coarse aggregate slab specimens. The load carrying capacity of the recycled aggregate slab specimen is less compared to the natural aggregate slab specimen.

Table.6 Results of Ultimate Load

Specimen no	Specimen	Experimental ultimate load(kN)	Theoretical ultimate load(kN)
S1	S0.3%(6Ø)+RA (50%)	**61.23**	**50.28**
S2	S0.3%(6 Ø)	**64.05**	**50.28**
S3	S0.4% (6Ø)+RA (50%)	**69.61**	**60.56**
S4	S0.4% (6 Ø)	**72.36**	**60.56**
S5	S0.5% (6Ø)+RA (50%)	**76.27**	**76.02**
S6	S0.5% (6 Ø)	**76.53**	**76.02**
S7	S0.3%(8Ø)+RA (50%)	**66.53**	**50.88**
S8	S0.3% (8 Ø)	**68.94**	**50.88**
S9	S0.4% (8Ø)+RA (50%)	**75.36**	**63.32**
S10	S0.4% (8Ø)	**78.62**	**63.32**
S11	S0.5% (8Ø)+RA (50%)	**81.2**	**80.1**
S12	S0.5% (8Ø)	**84.3**	**80.1**

Table.7 Experimental results of different slab specimens

Slab specimen no	First crack load Pcr (kN)	Ultimate load Wu (kN)	Mid-span Deflection @ Pcr (mm)	Maximum mid-span deflection (mm)	Strain @ Pcr (μm/m)	Ultimate strain (μm/m)	Crack width @ Pcr (mm)	Maximum crack width (mm)
S1	33	61.23	0.094	1.44	163	489	0.1	4.3
S2	36	64.05	0.086	1.36	171	520	0.1	5.6
S3	35	69.61	0.124	1.14	156	510	0.2	5.1
S4	38	72.36	0.097	1.22	163	451	0.2	5.2

S5	41	76.27	0.141	1.28	189	435	0.1	5.4
S6	42	76.53	0.113	1.56	151	497	0.1	4.2
S7	35	66.53	0.085	1.12	163	464	0.3	5.0
S8	37	68.94	0.092	1.18	155	463	0.2	5.3
S9	40	75.36	0.116	1.54	162	485	0.2	4.3
S10	45	78.62	0.108	1.54	182	492	0.2	5.0
S11	44	81.2	0.128	1.52	165	431	0.3	4.8
S12	49	84.3	0.109	1.74	187	511	0.1	5.6

3.2 Deflections of Slabs:

Deflections are measured at the centre of the specimen under the load application point with linear variable differential transformer (LVDT) and recorded and the deflection profile comparison is shown for each varying percentage of reinforcement with 6mm and 8mm separately. From the results, it is observed that the variation of deflection of natural aggregate slabs to recycled aggregate slabs up to first crack point is very small beyond that the variation increases. But for p_t= 0.5%, the variation of deflection beyond first crack load is less compared to the lesser percentage of reinforcements.

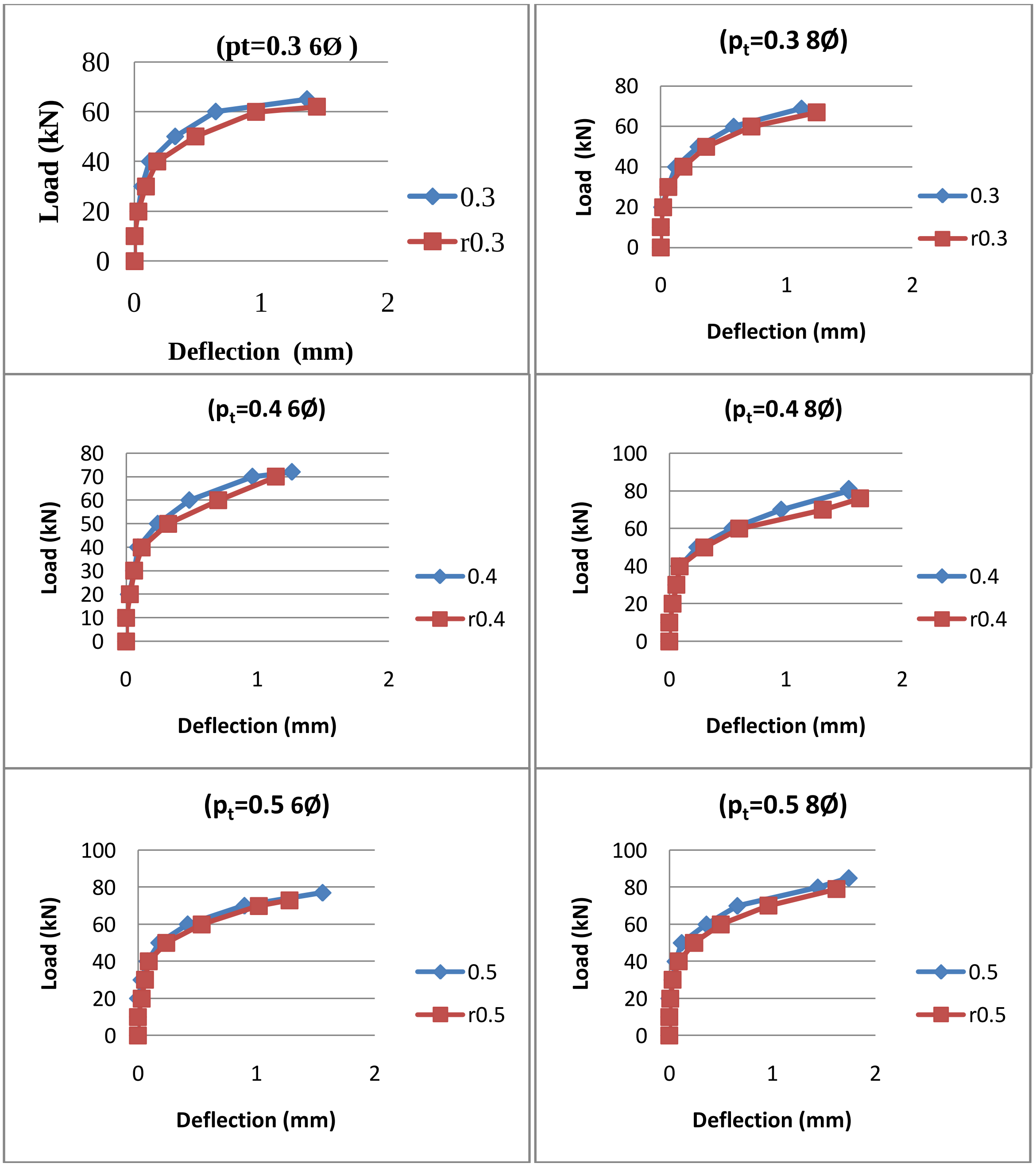


Figure.6 Deflection profile for each percentage of steel of slab specimens

3.3 Effect of Strains on Slabs:

The strains in the slab specimens are measured by using strain gauges placed at the mid span of the slab. The strains are small up to first crack load after that increases with the increase in load. Comparison of the strains between natural aggregate slabs and recycled coarse aggregate slabs is shown in the figure below.

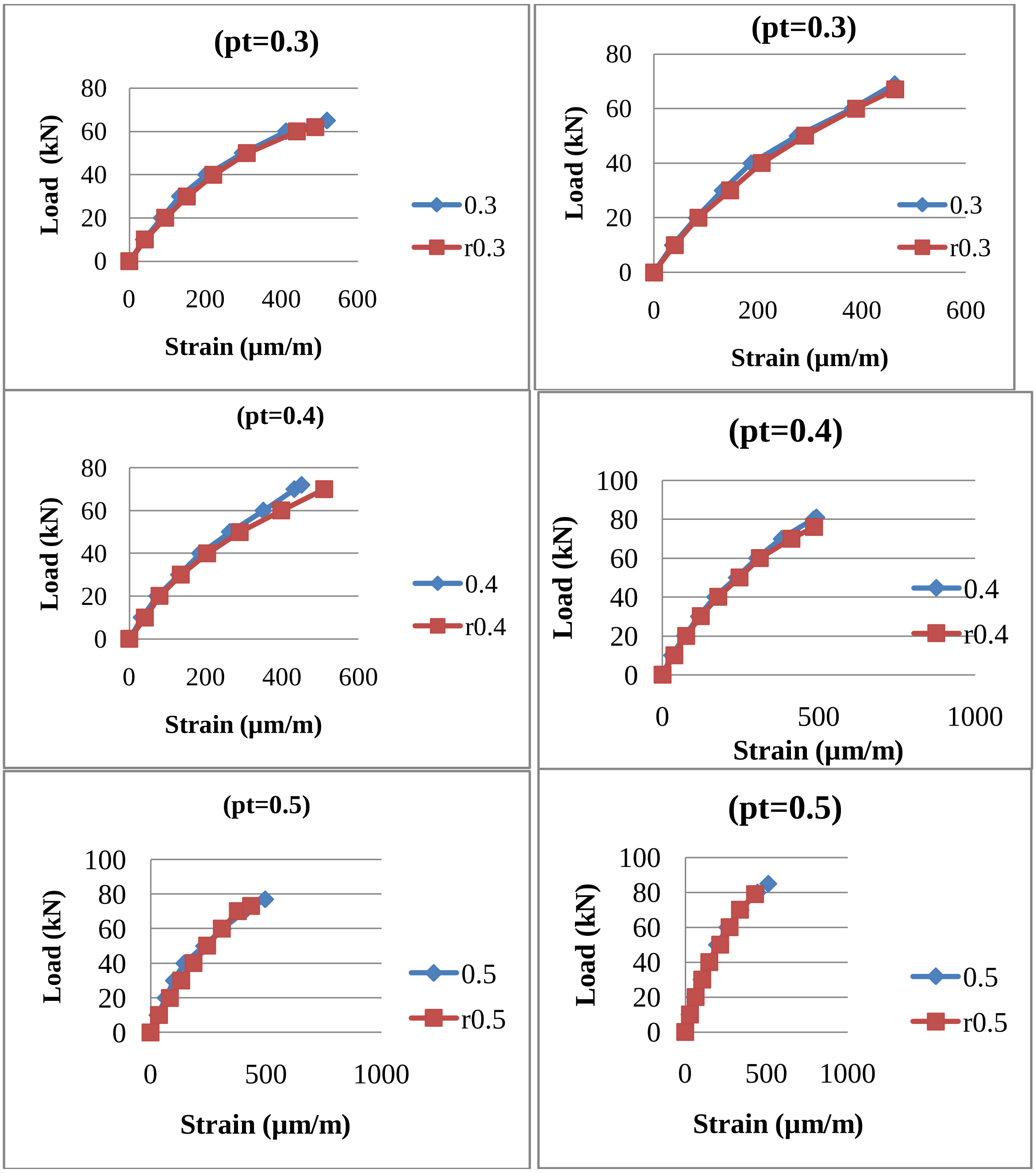


Figure.7 Strain profile for each percentage of steel of slab specimens

From the graphs, it shows at a particular load point i.e., up to first cracking load, the strain variation in slabs with natural aggregate and recycled aggregate was small beyond that the variation was increased. This phenomenon may be due to less bonding between the aggregate in recycled aggregate specimens compared to natural aggregate specimens.

3.4 Crack Width Behaviour of The Slabs:

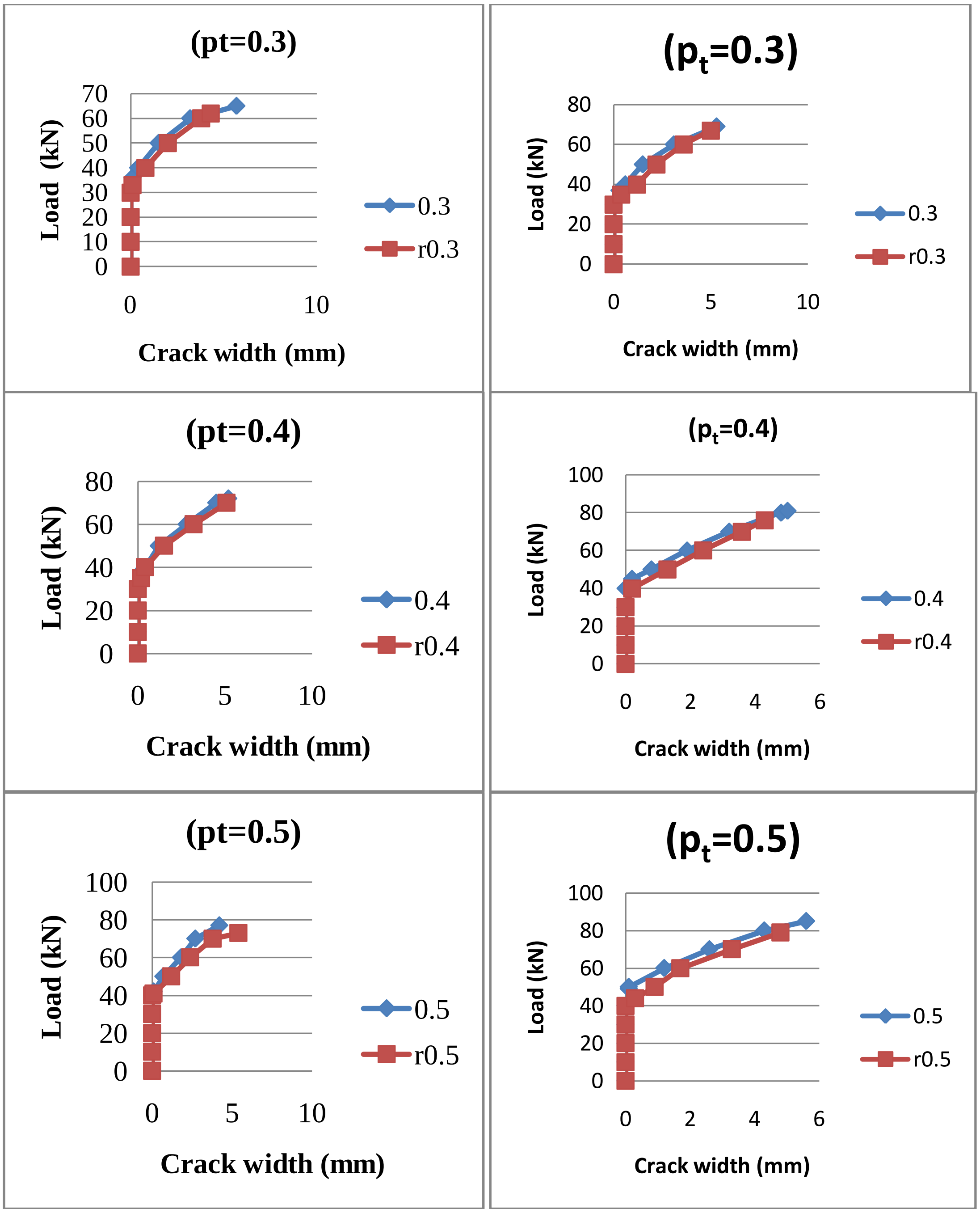


Figure.8 Crackwidth profile for each percentage of steel of slab specimens

From the graphs, it shows first cracking load occurs in slabs with natural coarse aggregate and recycled coarse aggregate was almost equal. After first crack load, the crack width at a particular load in recycled coarse aggregate slabs is more compared to natural coarse aggregate slabs because of less bonding between the recycled coarse aggregate compared to natural aggregate and reinforcement in slab specimens. The variation at 0.5%pt is observed to be more in the later stages after first crack.

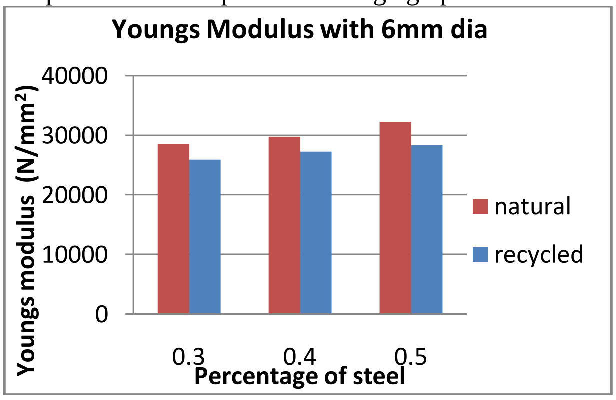
3.5 Modulus of Elasticity

Table.8 Modulus of elasticity of slab specimens

Specimen	Modulus of elasticity (N/mm2)
S0.3% (6Ø)+RA (50%)	25884
S0.3% (6 Ø)	28498

S0.4% (6Ø)+RA (50%)	27205
S0.4% (6 Ø)	29738
S0.5% (6Ø)+RA (50%)	28321
S0.5% (6 Ø)	32223
S0.3%(8Ø)+RA (50%)	27719
S0.3% (8 Ø)	29278
S0.4% (8Ø)+RA (50%)	31033
S0.4% (8Ø)	31374
S0.5% (8Ø)+RA (50%)	33738
S0.5% (8Ø)	33772

Modulus of elasticity of the reinforced cement concrete for different slab specimens was tabulated above and the comparisons were represented trough graphs shown below.



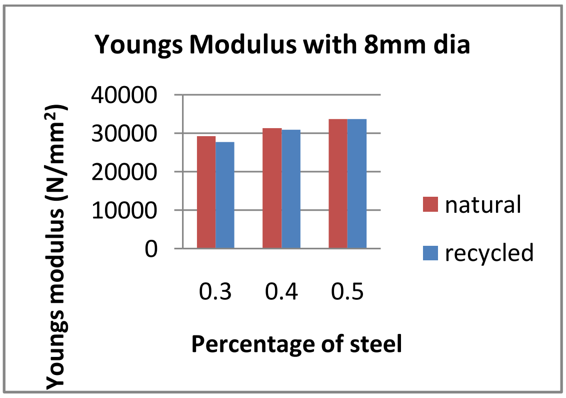


Figure.9 Relation between modulus of elasticity v/s percentage of steel

The variation of modulus of elasticity of natural aggregate slab and recycled aggregate slab with different percentages of reinforcement with 6mm diameter was shown in the above graph. The modulus of elasticity for natural aggregate specimen is more compared to recycled aggregate specimen. The variation of modulus of elasticity of natural aggregate slab and recycled aggregate slab with different percentages of reinforcement with 8mm diameter was shown in the above graph. The modulus of elasticity for natural aggregate specimen is almost equal compared to recycled aggregate specimen. By using 8mm diameter reinforcement in slab specimens, it can be observed that the modulus of elasticity is more compared to 6mm diameter reinforcement slab specimens.

IV. CONCLUSIONS

After conducting a detailed study on the Flexural characteristics of two-way slabs with natural aggregate and recycled aggregate, the following can be concluded.

1. By using 50% recycled aggregate the flexural strength of the slabs are almost same as that of the natural aggregate slab strength.
2. Upto the first crack point, the deflections are linear beyond that the deflections increases non-linearly and rapidly.
3. As the percentage of steel increases the crackwidth decreases. The decrease in percentage of crackwidth is 60% between 0.3% and 0.5% percentage of steel.
4. Modulus of elasticity of the slab increases with increase in percentage of steel. The increase in percentage of modulus of elasticity is 14% between 0.3% and 0.5% percentage of steel.
5. The modulus of elasticity obtains by deflections and strain of slabs gives almost equal values.

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