International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.6., Issue.3, 2018
May-June

RESEARCH ARTICLE

ISSN: 2321-7758

BEHAVIOR OF SINGLY REINFORCED CONCRETE BEAMS WITH ELASTOMER IN HINGING REGION FOR OVERALL DEPTH

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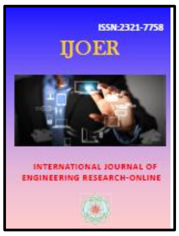

ABSTRACT

Ductility is the main factor for structures to have large yielding of members during earthquake, to have sufficient warning. Ductility is the essential attribute of a structure that must respond to strong ground motions. The structure has to be designed to possess adequate ductility so that it can dissipate energy by yielding and survive the shock. Therefore one of the primary task of an engineer designing is to ensure that the building possess enough ductility to withstand the size and types of earthquakes, which are likely to experience during its lifetime.

Considering this important aspect so many works have been carried out to improve the ductility by different methods using confinement, steel mechanism, and ductile material in compression yielding zone of the flexural members.

An attempt has been made for improving the ductility of the flexural member in plastic hinge zone. In experimental program two reference specimens with no rubber and six test specimens having varying thickness of rubber in plastic hinge portion, throughout the section were cast. It was observed that the test specimens having rubber at plastic hinge portion performed well in improving ductility, high yielding and there was no crushing in compression zone.

Key Words: Metakaolin, Quarry dust, Compressive Strength, Split Tensile Strength, Flexural Strength, Durability.

I. INTRODUCTION

The flexural deformation of structural members is due to their curvature. For reinforced concrete (RC) members, this curvature depends on the tensile strain of the reinforcement and the compressive strain of the concrete. As concrete is a brittle material with little ductility, RC members achieve ductility and adequate deformation capacity mainly through the tensile straining or yielding of the reinforcement.

Concrete is a brittle material. Conventional RC members reinforced with ductile bars also have ductility problems when the failure is caused by the compressive crushing of concrete, where as the tensile reinforcement does not yield. This occurs in over-reinforced RC beams and RC columns with a high axial load level. One of the researcher used FRP reinforcement to improve the performance of RC flexural members. In this case the ductility and deformability of RC members are significantly reduced, although significant confinement to concrete can partially offset this reduction. Furthermore, the use of more brittle high strength concrete (HSC), which has been increasing in a fast rate over the last 2 decades, has a similar detrimental side effect on the ductility of RC members replacement materials.

A. Definition of ductility:

According to IS 1893:2002, Ductility is the ability of structure to undergo distortion or deformation without damage or failure. Ductility is a mechanical property used

According to IS 1893:2002, Ductility is the ability of the structure to undergo distortion or deformation without damage or failure. Ductility is a mechanical property used to describe the extent to which materials can be deformed plastically without fracture.

Assessment of ductility: Ductility is generally measured in terms of ductility ratio of the maximum deformation that a structure or element can undergo without significant loss of initial yielding resistance to the initial yield deformation.

Ductility is defined by ratio of the total imposed displacements Δ at any instant to that at the onset of yield Δy

$\mu = \Delta / \Delta_y$

B. Existing methods of improving ductility:

Confinement increases ductility/ deformability of concrete, however, this method cannot avoid the rupture of non-ductile bars for under-reinforced beams. For over-reinforced beams or columns with significant axial load, heavy and excessive confinement reinforcement is usually needed to achieve the ductility requirement.

Placing Prestressed reinforcement in layers and design the effective prestress in each layer so as to provide a step-by-step progressive failure with increasing deformation. This method relies on the progressive fracture of FRP reinforcement to avoid sudden complete fracture of tension reinforcement.

Using partially prestressed concrete where prestressed FRP tendons are combined with conventional steel reinforcement to allow sufficient flexibility to achieve better ductility.

By using un-bonded tendons more deformation can be achieved on the tension side as the deformation of the tendons over the whole un-bonded length can be utilized. However, this implies the use of perfect anchorages that can sustain fatigue loading. Furthermore, external tendons can be very vulnerable to vandalism, and should they fail they will release an enormous of amount of elastic energy that can be devastating;

Designing the interface between the FRP reinforcement and the concrete so that a bond failure is triggered when the stress in the tendons reaches a threshold level, thus changing a bonded tendon configuration to an unbonded tendon configuration, and Designing the cross-section of a member to proportionate reinforcement in order to take the advantage of the full strain capacity of concrete simultaneously with that of the reinforcement.

C. Some concept on introducing hinge:

We proposed that replacing the concrete in the compression zone of the plastic hinge with a strong and more ductile material or mechanism leads to an increase in ductility of a flexural member.

In one broad aspect of the present study, provided a flexural member wherein at least a portion of the material in the compression zone of the plastic hinge or near the plastic hinge comprises a ductile compressive material. In particular the flexural member may comprise concrete, for example FRP bar or steel bar reinforced concrete, such as a concrete structural member such as a beam or column. Preferably the ductile compressive material comprises elasto-plastic or nearly elasto-plastic material. Possible materials for the ductile compressive material include metallic materials such as steel and alloys, cementitious material, plastics, elastomeric materials such as rubber, rubber cement material, composite material or combinations thereof.

Another method of producing a very ductile compression zone is by providing or forming holes (such as voids or bubbles) inside normal concrete or inside other materials such as plastic materials, metallic materials, composite materials or other materials.

The ductile compressive material is prefabricated and cast or installed into said flexural member. The ductile compressive material can also be cast directly into said flexural member. Preferably the flexural member may further comprise additional compression bars or compression plates in the compression yielding zone.

Viewed from another broad aspect there is provided a flexural member wherein at least a portion of the material in the compression zone of the plastic hinge or near the plastic hinge is occupied by a mechanism that provides the flexural member with a ductile compression zone. In particular the flexural member may comprise concrete, for example FRP bar or steel bar reinforced concrete, such as a concrete structural member such as a beam or column.

Preferably the mechanism is made from steel or other metallic materials, FRP, composite, plastic, cementitious material, elastomeric material or combinations thereof, and the mechanism may be encased in a protective material such as a lightweight concrete or other low strength materials.

The encased mechanism may be cast or installed into the flexural member to form a ductile compression zone. Viewed from another broad aspect it also provides a method of modifying a flexural member comprising casting an amount of ductile compressive material into the compression zone of the plastic hinge or near the plastic hinge of the flexural member.

II. OBJECTIVES OF STUDY:

The following objectives have to identify:

The main objective of study is to collect various methods improving of ductility and to come out with a new technique that can ensure recovery rotation at a section and avoid rupture of the ductile reinforcement or the crushing of concrete, regardless of whether the beams is under reinforced or over reinforced.

Normally failure of RC section in flexure is by crushing of concrete or yielding of steel. In both cases, the section may have sufficient ductility, thus enabling the section to rotate sufficiently before eminent failure occurs. However in the process the deformation may tend to be permanent. Small or large rotation at the section, if it is permanent, the repair of section is cumbersome, or sometimes impossible.

The section should be able to undergo sufficient rotation, yet should be able to recover the entire deformation. That to say, the section should behave fully elastic even at high or moderately, if not at large rotation. Hence it is contemplated that an elastomer, if introduced at the location of hinging region may serve the purpose of undergoing deformation under load and recovery after removal of load. This basic idea has been experimented earlier by embedding a steel mechanism in concrete. The experiment is successful but lacks practical feasibility. In the present study, an elastomer kind of material (rubber) is proposed to be introduced at hinging region and the behavior of beams under a few cycles of loads has to be studied.

III. SCOPE OF STUDY:

Ductility of structures is important to ensure large deformation and give sufficient warning while maintaining an adequate load carrying capacity before structural failure, so that total collapse may be prevented and lives saved. Ductility is also the basis of modern structural design approaches (e.g. moment redistribution). In seismic design, in particular, ductility becomes an extremely important consideration. The issue of ductility and methods of increasing ductility is one of the most active areas in the study of concrete structures.

Although significant efforts and enormous resources have been expended all over the world in this research area, a general and satisfactory method to increase the ductility of RC structures is yet to be found. This work addresses the problem from a novel and innovative point of view. The new technique involves the concept of compression yielding by using a ductile compressive material or mechanism in the compression zone of a plastic hinge in a RC member. With the technique of compression yielding, the ductility and deformation capacity of the RC member can be significantly increased for all of the above cases of nonductile deformation

IV. LITERATURE REVIEW

Various works have been carried out in the recent years by different techniques to improve the ductility in flexural members and are briefly illustrated below.

(Wu (2006): Describes that the ductility of flexural members is mainly due to yielding of tension reinforcement. When large flexural deformation occurs in a structural member, the plastic deformation is mainly concentrated in a small area called the plastic hinge zone that has a limited length (Paulay and Priestley 1992; Wu et al. 2002).

When large rotation of the plastic hinge cannot be achieved through elongation or yielding of the reinforcement on the tension side, the other way to achieve it is by shortening or yielding on the opposite compression side. The conceptual structural configuration that allows for compression yielding is illustrated with a simply supported beam in Fig. 2.1. The only difference between the new structural scheme and a conventional RC beam is in the plastic hinge zone where a special ductile compression material or mechanism is used to replace concrete on the compression side.

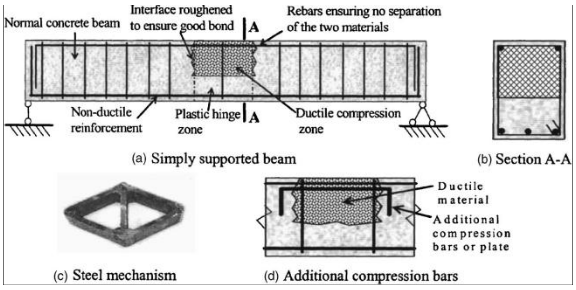

Fig: 1. Structural Configuration Of Compression Yielding Scheme.

There are two approaches to achieve compression yielding in a plastic hinge:

(1) Replacing concrete with a ductile material; and

(2) Using a ductile mechanism in the compression zone, such as that shown in Fig. 2(c). The simplest way of achieving compression yielding is by casting a block of ideal elastic-plastic material into the compression zone of the plastic hinge.

Experimental testing was conducted to investigate the effectiveness of the new structural scheme. Test specimens included one reference beam and two compression yielding beams. GFRP bars were used as the tension reinforcement in all the three specimens.

Reference beam designed as over reinforced and tensile resistance is slightly higher than compression reinforcement. The beams were tested under four point bending. Testing was conducted under a displacement control mode. The reference beam failed due to concrete crushing after that load dropped quickly. The first compression yielding beam failed due to sudden fracture of the tension bars. In order to avoid tension bar failure the steel plate width of mechanism is reduced in second compression yielding bar. And the load verses displacement shown below,

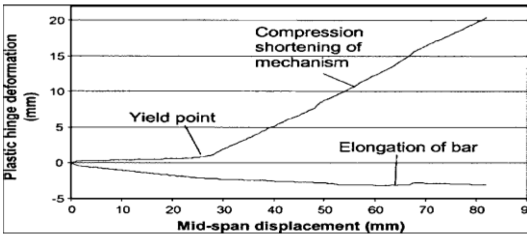

Fig 2. Plastic Hinge Deformation

Fig 2. Shows that the deformation of GFRP bars was greater than that of the compression mechanism before yielding. The compression deformation increased quickly and linearly after the yielding point, whereas the tension deformation of the plastic hinge essentially remained unchanged. The compression deformation was almost ten times that of the tensile deformation at the maximum midspan displacement.

The results are analyzed and observed that reference beam has ductility factor of 1.2, and compression yielding beam is 2.75.length of plastic hinge is observed as length of compression yielding zone. But the deficiency in the model is plastic hinge length depends on compression yielding zone than tension reinforcement and also shear strength is effected due to ductile block, requires additional stirrups.

Mahini et al. (2006): Attempts have been made to upgrade existing RC Ordinary Moment Resisting Frames (OMRF) into Ductile Moment Resisting Frame (DMRF). In practice, this can be implemented by controlling the plastic hinges locations. The results of experimental study performed to evaluate the ability of CFRP sheets in preventing the plastic hinge formation at the face of the column in exterior RC joints. Five plain/CFRP-retrofitted scaled-down joints of a typical OMRF were tested under monotonic/ cyclic loads to failure. The results show that carbon fiber can effectively relocate the plastic hinge away from the column face.

Mansur et al. (1997): The results of eleven reinforced high-strength concrete beams tested in flexure are presented. All but one beam was over-reinforced, and the compression zone of the beams was confined with either ties or fibers, or left unconfined. Test results indicate that the brittle type of failure in over-reinforced concrete beams can be arrested by introducing transverse ties or discrete steel fibers in the compression zone. For such a beam, both ultimate strength and ductility can be enhanced by increasing the concrete strength. Ductility also increases with an increase in the volume fraction of confining ties, but up to a certain limit. The stress-strain curves for concrete in compression obtained from the flexural tests are remarkably similar to those generated from uni-axially loaded specimens. The analysis based on the usual flexural theory, but using the stress-strain curves for uni-axially loaded specimens, gives close predictions of the experiment data on moment-curvature relationship and ultimate moment capacity of the beams. Evaluation of the present test data and the results from available literature show that Whitney's rectangular stress block can be used in the strength design of high-strength concrete flexural members.

Wu, Yu-fei (2008): presented that in a structural member, the ductile deformation comes from the plastic deformation or yielding of the materials. When large plastic deformation occurs in a structural member, it is mainly concentrated in a small area called the plastic hinge zone, which has a limited length. It is the rotation of the plastic hinge that produces the ductility of a flexural member. In conventional RC members, the plastic rotation mainly comes from the plastic yielding of the tensile reinforcement. When large rotations of the plastic hinge cannot be achieved through the elongation or the tensile yielding of the reinforcement on the tension side, for example, in the case of FRP RC members, the other way to achieve it is by shortening or CY on the opposite compression side

The only difference between a structural system with compression yielding and that of a normal RC beam is in the plastic hinge zone where a special ductile compression material or mechanism is used to replace concrete on the compression side. The compression yielding zone must satisfy the following general principles:

A) Deforming elastically at the serviceability limit state to ensure good working conditions such as low creep deformation and sufficient rigidity;

B) Deforming plastically at the ultimate limit state to ensure sufficient ductility; and

C) Providing a total compressive strength that is not greater than the total tensile strength of the reinforcement to ensure that no tensile rupture of the nonductile bars occurs. The ductile compression zone need not coincide exactly with the position of the maximum moment. In fact, the ductile compression zone acts as a fuse in the structural system. When excessive loading occurs, the fuse will be triggered and force the structural system to deform in a plastic manner to avoid abrupt reinforcement rupture or concrete crushing. In practical applications, a prefabricated compression yielding block can be cast into the beam like a built-in fitting. When the shear force is related to the flexural force in a structural member, for example, in the case of uniformly distributed load, this flexural fuse can also be used as a shear fuse to prevent the beam from a shear failure.

Kwan et al. (2004): Compared normal concrete, high-strength concrete has higher strength but is generally more brittle. Its use in a reinforced concrete structure, if not properly controlled, could lead to an unsustainable reduction in ductility. However, confinement could be provided to improve the ductility of the structure. In this study, the effects of concrete strength and confinement on the flexural ductility of reinforced concrete beams have been evaluated by means of complete moment–curvature analysis of beam sections cast in different concretes and provided with different confinements. The results reveal that the use of high-strength concrete at a constant tension steel ratio would increase the flexural ductility, but at a constant tension to balanced steel ratio would decrease the flexural ductility. In contrast, the provision of confinement would always increase the flexural ductility. It does this in two ways: first, it increases the balanced steel ratio so that, at the same tension steel ratio, the tension to balanced steel ratio is decreased; and second, it increases the residual strength and ductility of the concrete so that, at the same tension to balanced steel ratio, the flexural ductility of the beam section is increased.

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The evaluation of the ductility of reinforced concrete beams is very important, since it is essential to avoid a fragile collapse of the structure by ensuring adequate deformation at the ultimate limit state. One of the procedures used to quantify ductility is based on deformations, namely, the plastic rotation capacity. Knowledge of the plastic rotation capacity of certain regions of the structure is important for a plastic analysis or a linear analysis with moment redistribution.

Ricardo et al. (2005): Conducted an experimental program which is composed of 10 tests designed to study the moment redistribution and ductility of continuous high-strength concrete beams. Particular care was given to analyzing how the tensile reinforcement ratio and the transverse reinforcement ratio influence the plastic rotation capacity of the beams. A comparative study was carried out on several codes related to the moment redistribution permitted and the experimental findings. It was found that some of the recommendations are unsafe. It was also found that high-strength concrete beams, when properly designed, have enough deformation capacity to be used in plastic analysis.

Another objective was evaluation of the plastic rotation capacity of the critical sections of high-strength concrete beams to establish whether those sections have enough deformation capacity to allow the type of failure predicted by nonlinear analysis, linear analysis with moment redistribution, and plastic analysis.

Different types of failure are, some ductile (with steel yielding) and others fragile (rupture by concrete crushing without noticeable beam deformation). The purpose of this series of tests was to study the influence of the variation of the tensile reinforcement ratio on the plastic rotation capacity and the moment redistribution capacity. The transverse reinforcement was defined in such a way as to assure that failure was not due to shear force. The positive moment reinforcement was calculated considering a certain reserve capacity so that rupture in those sections would not occur prematurely. The objective was to ensure that the beam only collapsed after the region at the intermediate support had attained its full rotation capacity.

Stijn and Luc (2006) : Presented ductility requirements and design guidelines for FRP strengthening .Advanced composites are widely used for the strengthening of existing concrete structures. Current design guidelines give basic requirements on how to model the enhancement of structural performance of concrete members using surface bonded FRP (fiber reinforced polymer) reinforcement. With respect to this, it is of interest to evaluate the ductility requirements which are explicitly or implicitly imposed by design guides. Based on an evaluation of four major design guidelines in Europe, Japan and North-America, and a small parametric study, the ductility aspect of the design of FRP strengthened concrete members is verified. It appears that the ductility of flexural members strengthened with FRP should be considered with care, as reduced deformability is obtained at ultimate, though generally a minimum deformability is implicitly obtained in a proper design. At the other hand, ductility enhancement by means of FRP confinement is explicitly considered in the design guidelines.

Each year, considerable investments in construction engineering are related to the maintenance, repair (retrofit) and strengthening (upgrading) of infrastructure. Among the different techniques available for repair and strengthening of existing concrete structures, systems based on advanced composites as externally bonded reinforcement are nowadays often applied worldwide, as they appear efficient and competitive [1] L. Taerwe and S. Matthys, FRP for concrete construction: activities in Europe, ACI Concr Int **21** (1999) (10), pp. 33–36.. The application of FRP EBR (externally bonded FRP reinforcement) combines excellent material properties with ease and flexibility of application, which makes this technique attractive.

Applications in Europe have taken place since the late 1980's, commercial use of externally bonded FRP reinforcement (FRP EBR) started mainly in Switzerland around 1993 and soon followed in other countries . Based on extensive experimental and analytical investigations by various researchers and the appearance of different design guidelines during mainly the last 5 years, the use of FRP EBR is rapidly becoming a standard technique.

Existing design guidelines give basic requirements on how to model the enhancement of flexural and shear strength and confinement action on concrete. Further to these design models, it is of interest to understand which ductility requirements are considered with respect to FRP strengthening.

V. EXPERIMENTAL PROGRAM:

In the present experiment Quarry dust and Metakaolin are used as the partial replacement of fine aggregate and cement respectively in concrete mixes. On replacing fine aggregate with Quarry dust of different weight percentages the compressive strengths, split tensile strength and flexural strength are studied at two different ages (7 days & 28 days) of concrete cured in normal water. And the combined replacement of fine aggregate

[A]. *Program of Experimental Work:* The experimental program carries casting and testing of eight concrete beams in which four beams are M20 grade and another four beams are of M25 grade. In each four beams one is reference beam and other three are test beams having varying thickness of rubber in the plastic hinge zone. The size of the specimens is 600mm x 150mm x 100mm.The specimens are singly reinforced.

[B]. *Materials Used:* The different materials used in this investigation are

- 43 grade Portland pozzalona cement
- Fine Aggregate
- Coarse Aggregate
- Water
- Rubber

1. Cement *:* Cement used in the investigation was 43 Grade Portland pozzalona cement confirming to IS: 12269. The Specific gravity is 3.11.

2. Fine Aggregate: The fine aggregate conforming to Zone-2 according to IS: 383 were used. The fine aggregate used was obtained from a near by river source. Specific gravity of the sand is 2.65. The sand obtained was sieved as per IS sieves (i.e.2.36, 1.18,600,300 and 150μ). Sand retained on each sieve was filled in different bags and stacked separately for use. To obtain zone-2 sand correctly, sand retained on each sieve is mixed in appropriate proportionate proportion in which each size fraction is mixed is shown in Table 1

Table.1. Proportion of Different Size Fractions of Sand to Obtain Zone-2 Sand

Sieve size (mm)	**% Passing recommended by IS: 383[36]**	**Adopted grading**	**%Weight retained**	**Cumulative % Weight retained**	**Weight retained in gms.**
10-4.75	100	100	-	-	-
4.75-2.36	90-100	90	10	10	100
2.36-1.18	75-100	60	30	40	300
1.18-0.60	55-90	35	25	65	250
0.60-0.30	35-59	10	25	90	250
0.30-0.15	8-30	0	10	100	100
0.15	0-10	0	0	100	0

3. Coarse Aggregate: Crushed granite was used as coarse aggregate. The coarse aggregate was obtained from a local crushing unit having 20mm Normal size. 20mm well graded aggregate according to IS: 383 is used in this investigation. Specific gravity of the coarse aggregate is 2.76. The coarse aggregate procured from quarry was sieved through the sieves of sizes 20mm, 10mm and 4.75mm respectively; the material retained on each sieve was filled in bags and stacked separately.

4. Water: Potable water was used in the experimental work for both mixing and curing.

5. Rubber: MRF tier rubber of 25mm, 50mm, and 75mm thickness is used.

[C]. *Mix proportions*: Grades of Concrete used is M20 and M25 were considered. Mixes of M20 and M25 comes under Standard Concrete as Specified by IS 456-2000 and were designed by using IS 10262.The Mix proportions corresponding to M20 is 1:1.5:3:0.5 and 1:1.224:2.62: 0.44.

[D]. *Moulds used for casting:* 1.Cubes: Standard cube moulds of 150 x 150 x 150 mm made of cast iron were used for M30 grades specimens. Beams: All beams was casted in steel moulds

[F]. *Casting:* The standards moulds were fitted such that there are no gaps between the plates of the moulds. If there small gaps they were filled with plaster of Paris. The moulds were then oiled and kept ready for casting. The entire casting was done in two stages corresponding to M20 and M25 grades with/without rubber. A standard concrete mixer of rotating drum type of half bag capacity was used for mixing concrete, after the completion of the casting, the beam mould was vibrated and the thin plate was carefully removed. Table vibrator was used for casting beams. At the end of casting the top surface was made plane using trowel and a hacksaw blade to ensure a top uniform surface. After 24 hrs of a casting the moulds were kept for wet curing for the required number of days before testing. The casting of a beam is shown in Fig.3

Table 2. Compressive Strength Of Cubes At 28 Days.

Grade Of Concrete	No. Of Cubes	28 Days Compressive Strength
M20	1	23.84
M20	2	26.73
M20	3	23.84
M25	1	26.52
M25	2	28.63
M25	3	26.52

Fig 3. Details of casting of the specimen

[G]. ***Curing:*** After the completion of casting all the specimens were kept to maintain the ambient conditions viz. temperature of 27±2 C and 90% relative humidity for 24hours. The specimens were removed from the mould and submerged in clean fresh water until just prior to testing. The temperature of water in which the cubes were submerged was maintained at 27± 2 C. The specimens were cured for 28days. Fig.2 shows a beam after curing ready for testing.

[H]. ***Test setup and testing procedure:*** After the specimens were well cured for 28 days, the specimens were tested under 2000 KN TOTM testing system. In the setup of static testing, the specimen is simply supported at both sides with a cantilever of 50 mm. The beam is loaded by two symmetric point loads at a distance of 200 mm (four-point bending). Strain gauges are fixed to calculate moment-curvature of the specimen; dial gauge is fixed at the center of the specimen to calculate deflection. Load is applied at a constant rate. Load is applied up to first crack is observed and readings are noted down while loading and unloading. Load is applied for three cycles, after that load is applied up to ultimate.

[I]. *Details of Specimens*: ZR is a Reference Specimen and all other Specimens are the test Specimens. No shear Reinforcement is provided for the Specimens, and there is no steel in the compression zone, where as two bars of 8mm Diameter was provided in tension zone.

Table 3. Showing Details of Specimens.

Grade of Concrete	Specimen Notation	Rubber Thickness(mm)	Steel
M20	ZR	No rubber	2-8mm Ø(Bottom)
	Z1	25	2-8mm Ø(Bottom)
	Z2	50	2-8mm Ø(Bottom)
	Z3	75	2-8mm Ø(Bottom)
M25	ZR	No rubber	2-8mm Ø(Bottom)
	Z1	25	2-8mm Ø(Bottom)
	Z2	50	2-8mm Ø(Bottom)
	Z3	75	2-8mm Ø(Bottom)

VII. RESULTS AND DISCUSSIONS

[A]. ***SPECIMEN ZR M20***: The reference specimen ZR M20 is loaded for three cycles up to a load of 41.04 KN, in order to determine load deflection and moment curvature curves. In the initial stages of loading small flexural cracks were observed, while increasing the load a diagonal crack was propagated from support to the loading point. After the first cycle of loading the reference beam has undergone into a permanent deflection of 0.45mm,soon after completion of first cycle second and third cycles of load has been applied, and it was found that the curves obtained for second and third cycles were almost similar.Load vs deflection curve was shown in fig.4.The specimen failed in shear at a load of 41.04 KN where deflection was 1.83mm.Fig.5 shows the moment curvature curve.At 38.556 KN of loading the curvature was 0.002037 radians.

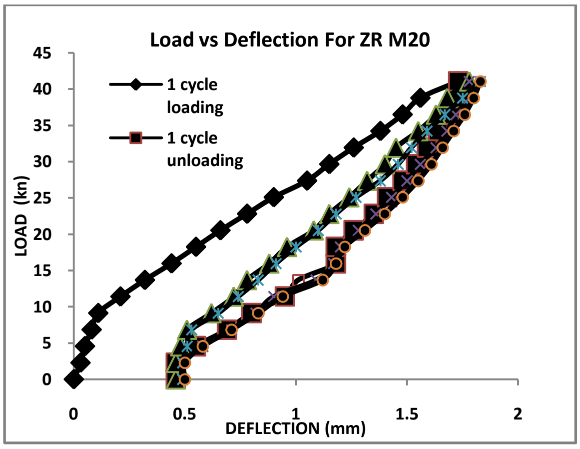

Fig.4. Load vs. Deflection curve for specimen ZR M20

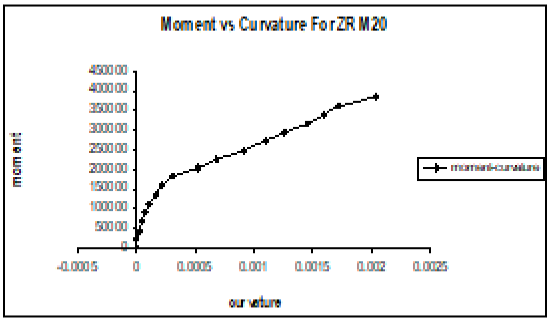

Fig.5. Moment vs. Curvature curve for ZR M20

[B]. *SPECIMEN Z1 M20*: Z1 M20 is a specimen which has rubber in the plastic hinge region throughout its depth. The thickness of the rubber is 25mm.The specimen was tested for two cycles. For the first cycle the loading was applied gradually till 15.96 KN, some small flexural cracks were observed in the first cycle. In the second cycle of loading the load was applied gradually, while doing so shear cracks were observed which were propagating from support to the loading point and the beam was failed in shear at a load of 38.76 KN where the deflection was recorded as 11.95mm. Fig.6. shows Load vs. Deflection curve for specimen Z1 M20.Moment vs curvature graph was also plotted. And was shown in Fig.7 .In the moment curvature diagram at 36.288 KN of load the curvature observed was 0.0675 radians.

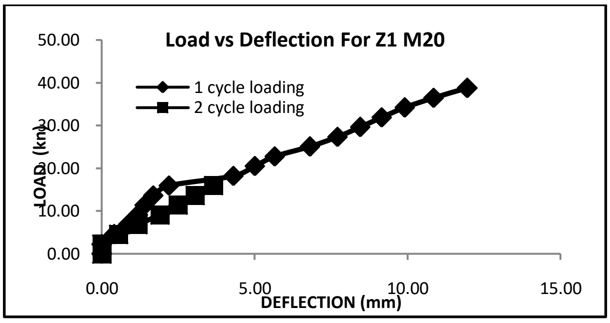

Fig.6. Load vs. Deflection curve for specimen Z1 M20

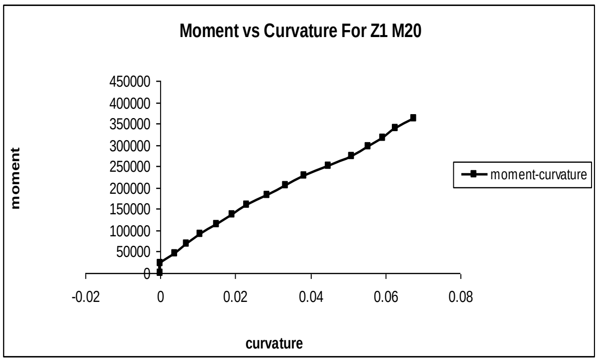

Fig.7. Moment vs. Curvature curve for Z1 M20

[C]. *SPECIMEN Z2 M20:* Z2 M20 is a specimen which has rubber of thickness 50mm in the plastic hinge region throughout its depth. The specimen was tested for two cycles, and then it was loaded to ultimate in order to determine the load deflection and moment curvature curves. In both first and second cycles the curves was almost linear and the recovery while unloading was good. In the first cycle the load was applied till 27.36 KN where the deflection was 10.35mm and the recovery after unloading was 2.2mm.

While in the second cycle same load was applied and the deflection was 9.95mm and the recovery was 2.05mm.In both the cycles the curve behaved in the same manner and the recovery was good enough.

After the completion of two cycles the specimen was loaded till ultimate ,in the initial stages of loading small flexural cracks were observed, main crack observed at the contacting surface of rubber and concrete face, crack widened. Fig.8. shows Load vs. Deflection curve for specimen Z2 M20.The ultimate load was recorded as 50.16 KN where deflection was 15.7mm. Fig.9 shows Moment vs. Curvature curve for Z2 M20 initially curve was linear, after that the curve shifts from linear which shows first crack, after a load of 6.804 KN a small increase in the load gave high rotations. At a load of 27.216 KN the rotation was 0.123 radians.

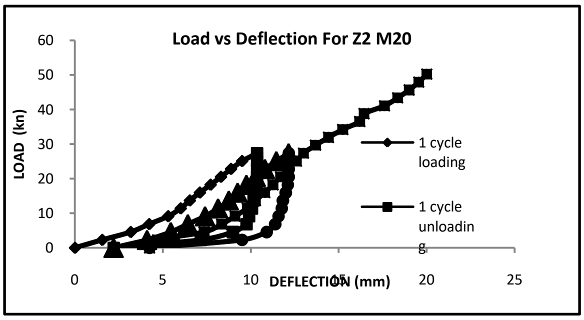

Fig.8. Load vs. Deflection curve for specimen Z2 M20

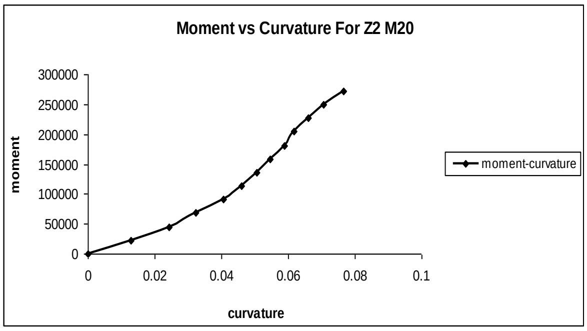

Fig.9. Moment vs. Curvature curve for Z2 M20

[D] ***SPECIMEN Z3 M20:*** Z3 M20 is a specimen which has rubber of thickness 75mm in the plastic hinge region throughout its depth. The specimen was tested for three cycles, in order to determine the load deflection and moment curvature curves. In the first cycle of loading the curve was linear till 4.80 KN, after this load shifting of curve was observed indicating the initial crack, with small increase in the load after 5.00 KN it was observed that the specimen has undergone large deflection indicating that the rubber has taken the load i.e., compression of rubber has occurred. The cracks which were observed was flexural cracks, main crack observed at the contacting surface of rubber and concrete face, crack widened.

After a load of 7.00 KN again shifting of curve was observed. The specimen was loaded till 27.36 KN in the first cycle and the deflection was 28.6mm, the recovery of the specimen was good, and the recovery of the specimen after unloading was 5.6mm, the curves in second and third cycles were almost similar, at a load of 27.36 KN the deflection in second and third cycles were 16.35 and 17.55 respectively. Fig.11. shows Moment vs. Curvature curve for Z3 M20.The curvature of the specimen was very high. The dial gauges which were used to record the curvature values rotated fully to its capacity and were removed in the middle of the experiment, since the dial gauge cannot take further values.

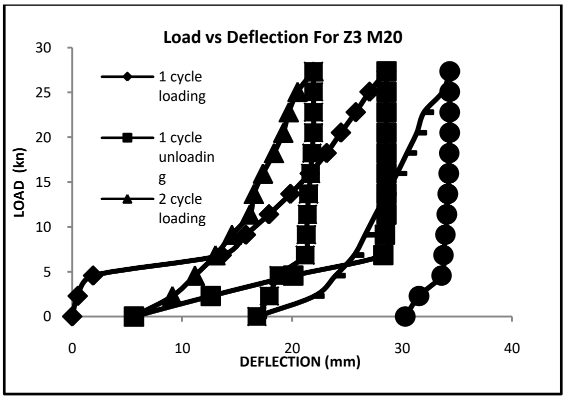

Fig.10. Load vs. Deflection curve for specimen Z3 M20

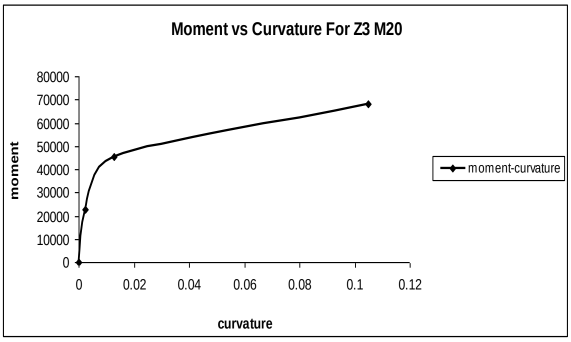

Fig.11. Moment vs. Curvature curve for Z3 M20

[E]. SPECIMEN ZR M25**:** ZR M25 a reference specimen was tested to failure in order to determine load deflection and moment curvature relationship. The specimen was tested for three cycles and then ultimate load was applied. In the first cycle till a load of 5.00 KN the curve was linear ,after that there was a slight shift in the curve indicating the initial crack. In the second and third cycles the curves obtained were similar. In all the three cycles the specimen was loaded till 29.64 KN and the deflections were 1.05mm,0.73mm and 0.84mm respectively. After the application of three cycles of load the specimen was loaded till an ultimate load of 38.76 KN, where the specimen failed in shear and the shear cracks were developed from support to the loading point.

In the initial stages of loading some flexural cracks were observed .At an ultimate load of 38.76 KN the deflection was 1.79mm and after unloading specimen recovery was 0.8mm, while in the first ,second and third cycles the specimen was recovered to 0.35mm,0.01mm and 0.1mm respectively.At a load of 29.484 KN the rotation observed was 0.0023 radians which is shown in the Fig.12. Moment vs. Curvature curve for ZR M25.

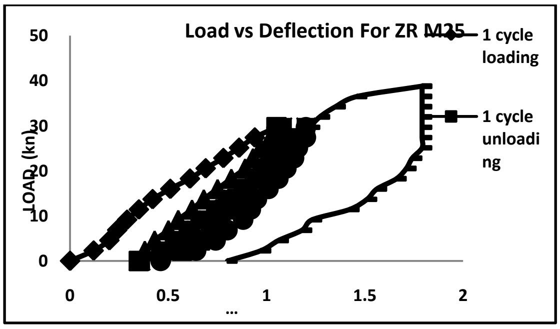

Fig.12. Load vs. Deflection curve for specimen ZR M25

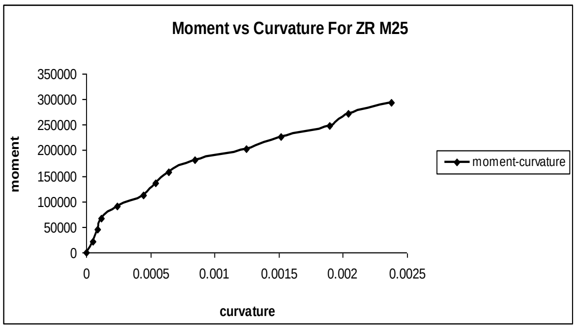

Fig.13. Moment vs. Curvature curve for ZR M25

[F].*SPECIMEN Z1 M25:* Z1 M25 is a specimen which has rubber in the plastic hinge region throughout its depth. The thickness of the rubber is 25mm.The specimen was tested to three cycles upto a load of 29.64 KN in all the three cycles. In the first cycle of load some small flexural cracks were observed in the initial stages of loading, where as in the final stages of loading a shear crack was developed from support to the loading point. At a load of 4.90 KN there was shift in the curve indicating the first crack.

In the first cycle of load the specimen was loaded till 29.64 KN where deflection was 6.53mm and while unloading it was recovered to 2.05mm.In the second cycle of load the deflection for 29.64 KN of load was 4.96mm and recovery after unloading of second cycle was 0.05mm, where as the deflection in the third cycle for the same load was 4.75mm and the beam recovered fully when unloaded.

After the application of three cycles the specimen was loaded till an ultimate load of 63.84 KN, where the specimen failed in shear and the diagonal crack from support to the loading point widened. At an ultimate load of 63.84 KN the deflection was 33.8mm. Fig.15. shows Moment vs. Curvature curve for Z1 M25.At a load of 29.484 KN the rotation was 0.035 radians. The curvature of the specimen was very high. The dial gauges which were used to record the curvature values rotated fully to its capacity and were removed in the middle of the experiment, since the dial gauge cannot take further values.

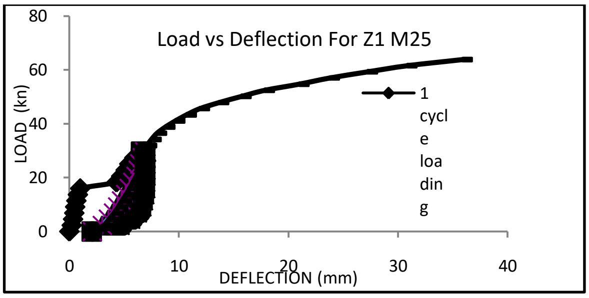

Fig.14. Load vs. Deflection curve for specimen Z1 M25

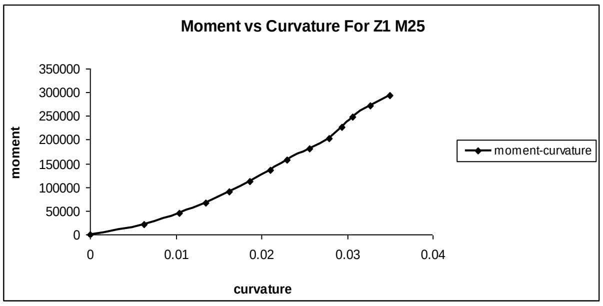

Fig.15. Moment vs. Curvature curve for Z1 M25

[G]. *SPECIMEN Z2 M25:* Z2 M25 is a specimen which has rubber of thickness 50mm in the plastic hinge region throughout its depth. The specimen was loaded to two cycles and then loaded to ultimate .In the initial stages of loading small flexural cracks were observed ,main crack observed at the contacting surface of rubber and concrete face, crack widened. In the first cycle, initially the curve was steep along load axis, then the shifting of curve was observed showing initial crack and also increase in deflection was observed with small increase in load, recovery after unloading was good. In the second cycle with increase in load there was increase in the deflection, at a load of 29.64 KN the deflection was 22.55mm and after unloading the recovery was 2.6mm.

After that the specimen was loaded to an ultimate load of 57.00 KN where the deflection was 36.4mm , and the recovery of the specimen after unloading was excellent which was observed to be 5.5mm.the beam failed in flexure. Fig.17. shows Moment vs. Curvature curve for Z2 M25.At a load of 18.144 KN the curvature observed was 0.123 radians.

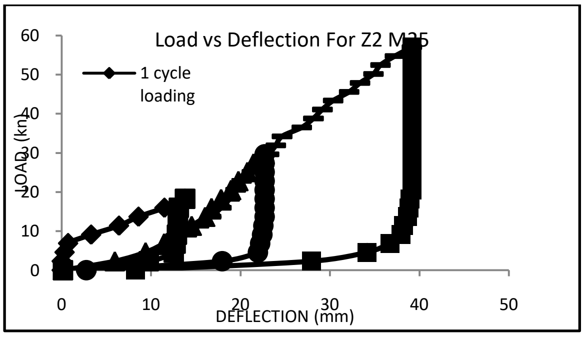

Fig.16. Load vs. Deflection curve for specimen Z2 M25

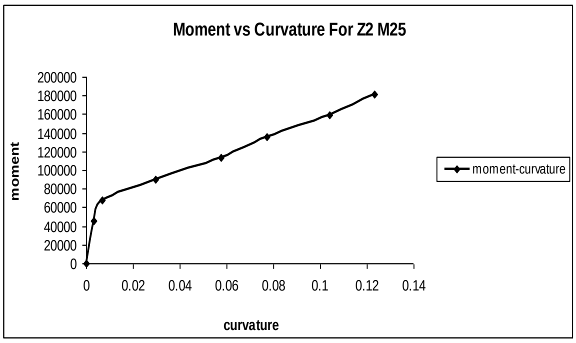

Fig.17. Moment vs. Curvature curve for Z2 M25

[H]. ***SPECIMEN Z3 M25:*** Z3 M25 is a specimen which has rubber of thickness 75mm in the plastic hinge region throughout its depth. The specimen was tested for 3 cycles and then it is loaded to ultimate in order to determine the load deflection and moment curvature curves. In the first cycle of loading with increase in load there was increase in deflection and at a load of 18.24 KN the deflection was 10.9mm and after unloading the recovery was 0.87mm.In the second cycle the load was applied till 27.36 KN and the deflection was 15.5mm and after unloading the recovery was 3.36mm.In the third cycle the load was applied till 27.36 KN and the deflection was 13.12mm and after unloading the recovery was 0.5mm.

At an ultimate load of 50.16 KN the specimen failed in flexure where the deflection was 19.22mm and recovery of the specimen after unloading was 0.8mm. Fig.19. shows Moment vs. Curvature curve for Z3 M25.the curvature for a load of 15.876 KN was 0.0716radians.

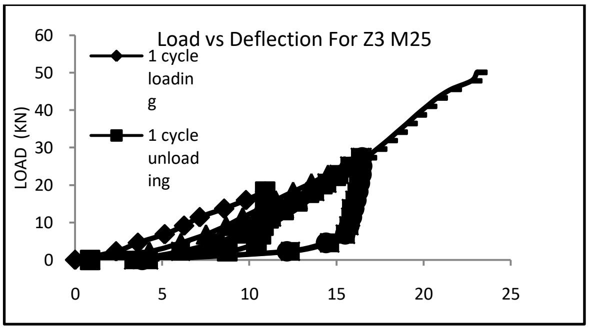

Fig.18. Load vs. Deflection curve for specimen Z3 M25

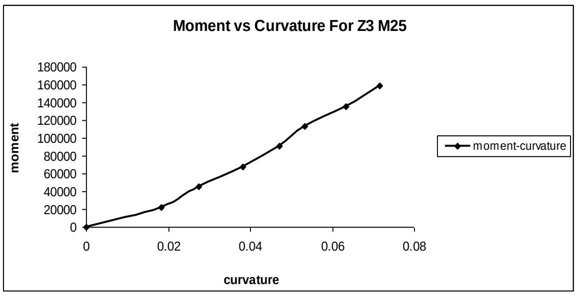

Fig.19. Moment vs. Curvature curve for Z3 M25

Table: 4. Curvature comparisons for different specimens at a specified value of moment.

SPECIMEN		**MOMENT (KN-mm)**	**CURVATURE (radian)**
M20	ZR	68.04	0.00004655
	Z1	68.04	0.0069
	Z2	68.04	0.0323
	Z3	68.04	0.105
M25	ZR	68.04	0.00011
	Z1	68.04	0.0135
	Z2	68.04	0.0295
	Z3	68.04	0.0382

Table:5. Flexural strength comparison for different specimens

SPECIMEN		**FLEXURAL STRENGTH(KN)**
M20	ZR	41.04
	Z1	38.76
	Z2	50.16
	Z3	27.36
M25	ZR	38.76
	Z1	63.84
	Z2	57.00
	Z3	50.16

[I]. *Flexural Strength Comparisons and Curvature Comparisons for the Specimens*

From Figures 21. and 22. it is observed that at a specific value of moment (68.04 KN-mm), curvatures of specimens Z1, Z2, Z3 were increased with respect o reference specimen ZR. It shows that the ductility of the specimens increased with providing rubber and also increasing thickness of rubber in plastic hinge portion. From Figure 4.8.5it is observed that with increasing grade of concrete Flexural Strength is also increased.

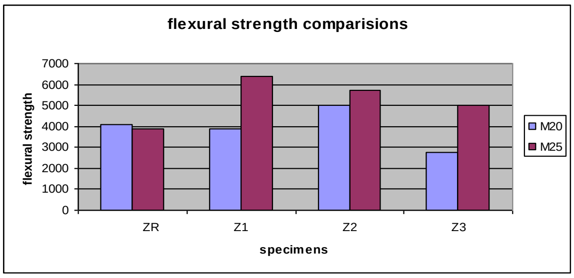

Fig 20. Flexural Strength vs Specimens

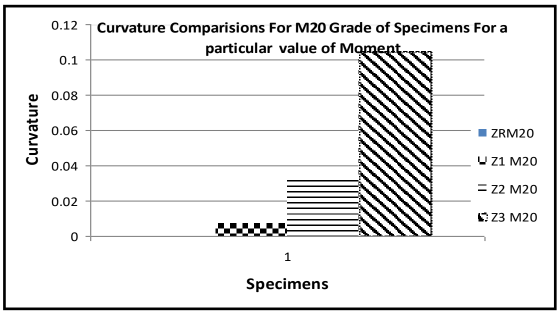

Fig 21. Curvature omparisions For M20 Grade Of Specimens For a Particular Value of Moment (68.04 KN-mm)

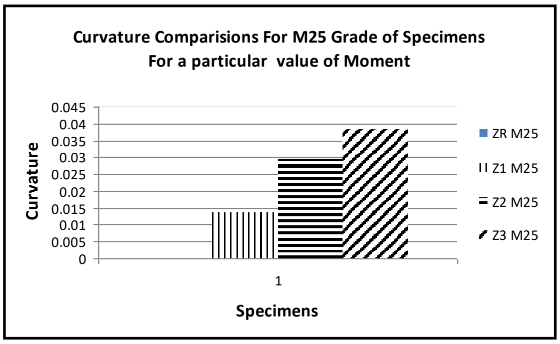

Fig 22. Curvature omparisions For M25 Grade Of Specimens For a Particular Value of Moment(68.04 KN-mm).

Table .6. Central dial gauge readings for reference specimen ZR M20

ZR M20						
central dial gauge readings						
Load	L1	UL1	L2	UL2	L3	UL-3
0	0	0.46	0.46	0.49	0.49	0.5
2.28	0.03	0.46	0.46	0.49	0.49	0.5
4.56	0.05	0.55	0.48	0.58	0.51	0.58
6.84	0.08	0.69	0.51	0.71	0.53	0.71
9.12	0.11	0.8	0.62	0.82	0.65	0.83
11.4	0.21	0.95	0.72	0.9	0.74	0.94
13.68	0.32	1.01	0.78	1.09	0.83	1.12
15.96	0.44	1.18	0.88	1.17	0.91	1.18
18.24	0.55	1.18	0.96	1.2	1	1.22
20.52	0.66	1.26	1.08	1.28	1.1	1.31
22.8	0.78	1.35	1.15	1.36	1.18	1.4
25.08	0.9	1.41	1.24	1.43	1.27	1.48
27.36	1.05	1.48	1.32	1.5	1.38	1.55
29.64	1.15	1.54	1.4	1.56	1.46	1.61
31.92	1.26	1.59	1.45	1.63	1.52	1.66
34.2	1.38	1.64	1.55	1.68	1.59	1.71
36.48	1.48	1.69	1.63	1.72	1.67	1.76
38.76	1.56	1.73	1.68	1.78	1.75	1.8
41.04	1.73	1.73	1.78	1.78	1.83	1.83

Table .7. Central dial gauge readings for test specimen Z1 M20

Z1 M20				
Central dial gauge readings				
Load	L1	UL1	L2	UL2
0	0		0	
2.28	0		0	
4.56	0.55		0.4	
6.84	1.18		0.85	
9.12	1.9		1.18	
11.4	2.5		1.4	
13.68	3.05		1.68	
15.96	3.65		2.2	
18.24			4.3	
20.52			5	
22.8			5.65	
25.08			6.8	
27.36			7.7	
29.64			8.45	
31.92			9.15	
34.2			9.9	
36.48			10.85	
38.76			11.95	

Table .8. Central dial gauge readings for test specimen Z3 M20

Z3 M20						
central dial gauge readings						
Load	C-L1	UL1	L2	UL2	L3	UL-3
0	0	5.6	5.6	5.6	16.8	19
2.28	0.5	12.6	5.6	7.88	18.35	23.95
4.56	1.9	20.1	5.6	10.16	19.97	25.78
6.84	13.6	28.3	5.6	12.44	21.02	26.55
9.12	15.8	28.45	5.6	14.72	22.1	26.7
11.4	17.9	28.59	5.6	17	22.81	26.85
13.68	19.85	28.59	5.6	19.28	23.33	26.95
15.96	21.61	28.59	5.6	21.56	23.9	27.01
18.24	23.15	28.59	5.6	23.84	24.51	27.13
20.52	24.45	28.59	5.6	26.12	25.1	27.15
22.8	25.8	28.59	5.6	28.4	25.67	27.15
25.08	27.05	28.59	5.6	30.68	26.3	27.15
27.36	28.59	28.59	5.6	32.96	27.15	27.15

Table.9. Central dial gauge readings for reference specimen ZR M25

ZR M25								
central dial gauge readings								
Load	C-L1	UL1	L2	UL2	L3	UL-3	L	UL
0	0	0.35	0.35	0.36	0.36	0.46	0.46	0.8
2.28	0.12	0.57	0.38	0.55	0.46	0.64	0.48	0.97
4.56	0.2	0.66	0.43	0.63	0.53	0.74	0.54	1.06
6.84	0.24	0.73	0.5	0.71	0.6	0.8	0.61	1.18
9.12	0.29	0.75	0.55	0.77	0.66	0.88	0.69	1.23
11.4	0.35	0.79	0.62	0.83	0.74	0.92	0.76	1.42
13.68	0.42	0.85	0.68	0.83	0.8	0.95	0.83	1.51
15.96	0.51	0.9	0.75	0.89	0.88	1.01	0.9	1.56
18.24	0.61	0.94	0.82	0.95	0.94	1.06	0.97	1.66
20.52	0.69	0.98	0.89	0.99	1	1.1	1.02	1.71
22.8	0.78	1.02	0.93	1.03	1.05	1.14	1.08	1.74
25.08	0.86	1.04	0.97	1.06	1.11	1.16	1.14	1.79
27.36	0.94	1.05	1.02	1.08	1.16	1.2	1.18	1.79
29.64	1.05	1.05	1.08	1.08	1.2	1.2	1.22	1.79
31.92							1.27	1.79
34.2							1.35	1.79

36.48							1.46	1.79
38.76							1.79	1.79

Table .10. Central dial gauge readings for test specimen Z2 M25

Z2 M25						
central dial gauge readings						
Load	C-L1	UL1	L2	UL2	L	UL
0	0	0.15	0.15	2.75	2.75	8.25
2.28	0	9.75	5.95	17.95	7.85	27.95
4.56	0.33	12.52	9.4	21.95	10.55	34.15
6.84	0.73	12.75	11.45	22.2	12.45	36.7
9.12	3.3	12.9	12.85	22.43	14	37.95
11.4	6.4	13	14.55	22.55	15.35	38.25
13.68	8.6	13	16.05	22.7	16.7	38.65
15.96	11.5	13.1	16.75	22.7	17.85	38.82
18.24	13.8	13.8	17.85	22.7	18.8	38.95
20.52			18.95	22.7	19.45	39.15
22.8			19.75	22.7	20.12	39.15
25.08			20.75	22.7	21.28	39.15
27.36			21.45	22.7	22.52	39.15
29.64			22.7	22.7	23.19	39.15
31.92					23.95	39.15
34.2					24.65	39.15
36.48					26.85	39.15
38.76					28.15	39.15
41.04					29.15	39.15
43.32					30.35	39.15
45.6					32.15	39.15
47.88					33.35	39.15
50.16					34.85	39.15
52.44					35.65	39.15
54.72					37.25	39.15

Table .11. Central dial gauge readings for test specimen Z3 M25

Z3M25							
central dial gauge readings							
Load	C-L1	UL1	L2	UL2	L3	UL-3	Ultimate
0	0	0.87	0.87	4.23	3.36	3.86	3.86
2.28	2.35	8.73	4.27	12.37	6.06	12.16	6.9
4.56	3.6	10.4	6.07	14.62	8.06	14.4	8.7
6.84	5.14	10.66	7.52	15.52	9.41	15.51	10.13
9.12	6.25	10.8	8.67	15.72	10.41	15.74	11.11
11.4	7.15	10.9	9.62	15.82	11.27	15.9	11.97
13.68	8.55	10.9	10.62	15.86	12.01	16.02	12.76
15.96	9.8	10.9	11.52	16.06	12.81	16.14	13.43
18.24	10.9	10.9	12.52	16.17	13.76	16.26	14.2
20.52			13.57	16.27	14.46	16.36	14.97
22.8			14.52	16.35	15.16	16.44	15.68
25.08			15.47	16.35	15.76	16.48	16.18
27.36			16.37	16.37	16.48	16.48	16.74
29.64							17.34
31.92							17.94
34.2							18.5

36.48							19.07
38.76							19.61
41.04							20.2
43.32							20.81
45.6							21.61
47.88							22.78
50.16							23.08

Table: 12. Moment and Curvature values for all the specimens

CURVATURE								MOMENT
ZRM20	Z1M20	Z2M20	Z3M20	ZRM25	Z1M25	Z2M25	Z3M25	
0	0	0	0	0	0	0	0	0
0	0	0.012216	0.00227	0.000082	0.000897	0	0.011264	22680
0.000024	0.00373	0.025184	0.012918	0.000106	0.001459	0.003124	0.017825	45360
0.000074	0.006919	0.033717	0.105018	0.000119	0.001946	0.006735	0.024341	68040
0.000092	0.01054	0.042698		0.000238	0.002411	0.029527	0.029743	90720
0.000102	0.014853	0.048071		0.000443	0.003027	0.057687	0.033577	113400
0.000167	0.019198	0.052223		0.000541	0.003849	0.077155	0.039396	136080
0.000223	0.022958	0.056858		0.000638	0.005157	0.104023	0.044306	158760
0.000307	0.028425	0.061436		0.000843	0.031535	0.123072		181440
0.000521	0.033371	0.064828		0.001243	0.034635			204120
0.000679	0.03836	0.069187		0.001514	0.037669			226800
0.000912	0.044705	0.07365		0.001892	0.040043			249480
0.001098	0.050875	0.080797		0.002043	0.043108			272160
0.001256	0.05551			0.002378	0.047057			294840
0.001451	0.059228							317520
0.001591	0.062513							340200
0.001721	0.067519							362880
0.002037								385560

[J]. *Moment vs Curvature comparisons for the Specimens:* Moment vs Curvature comparisons have been done in Figures , 23,24,25,26, it was observed that ZR M25 has undergone higher rotations than ZR M20,and same as was the case in Z2 M25 and Z2 M20.But Z1 M20 has undergone higher rotations when compared to Z1 M25 and same was the case in Z3 M20 and Z3 M25.

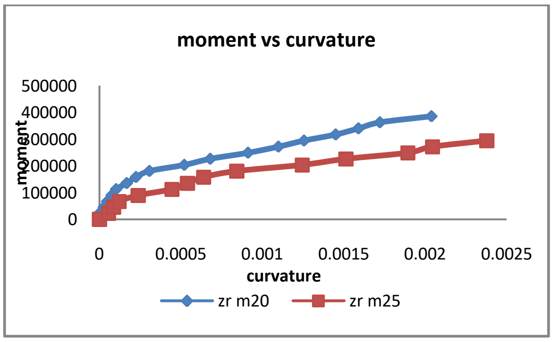

Fig.23. Moment vs Curvature comparisons of specimens ZR M20 and ZR M25

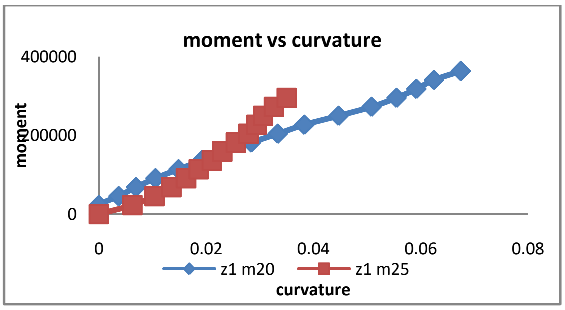

Fig.24.Moment vs Curvature comparisons of specimens Z1 M20 and Z1 M25

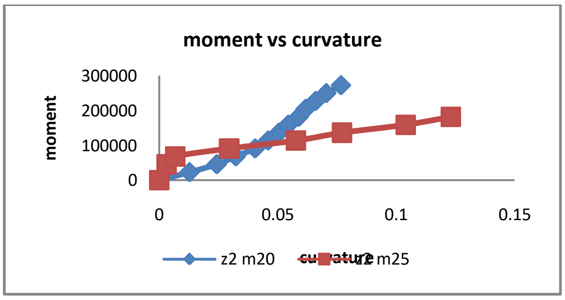

Fig .25.Moment vs Curvature comparisons of specimens Z2 M20 and Z2 M25

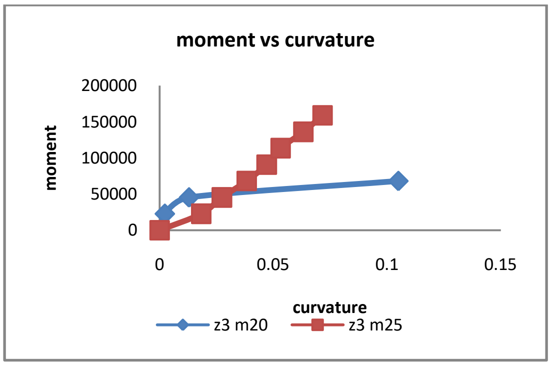

Fig .26.Moment vs Curvature comparisons of specimens Z3 M20 and Z3 M25

[K]. *Load vs deflection comparisons for the specimens*: Load vs deflection comparisons were made between the specimens in Figures 27,28,29,30, and it was observed that Except in Fig4.16 all the other figures 4.13, 4.14, 4.15 indicates that increase in the grade of concrete increases the deflection ,keeping the rubber material of same thickness.

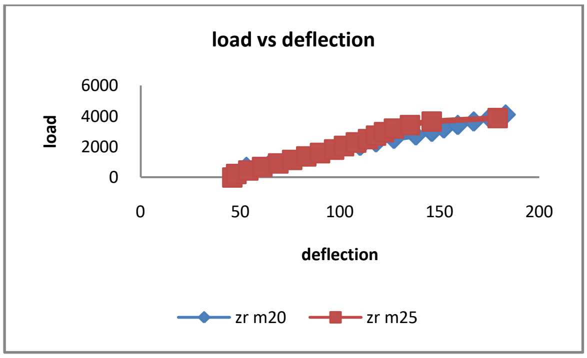

Fig .27. Load vs Deflection comparisons of specimens ZR M20 and ZR M25

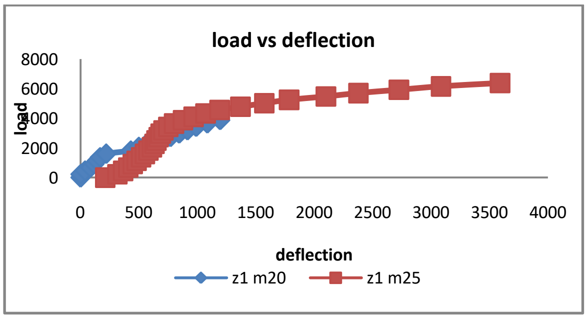

Fig .28. Load vs Deflection comparisons of specimens Z1 M20 and Z1 M25

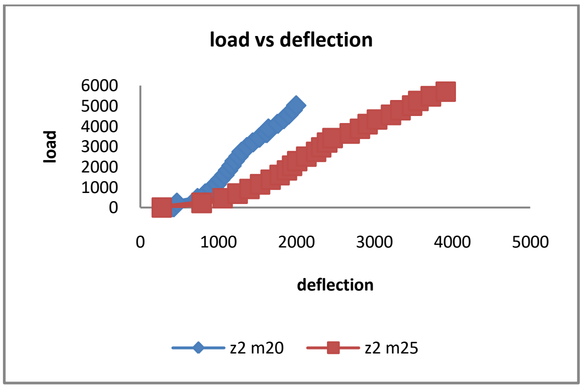

Fig .29. Load vs Deflection comparisons of specimens Z2 M20 and Z2 M25

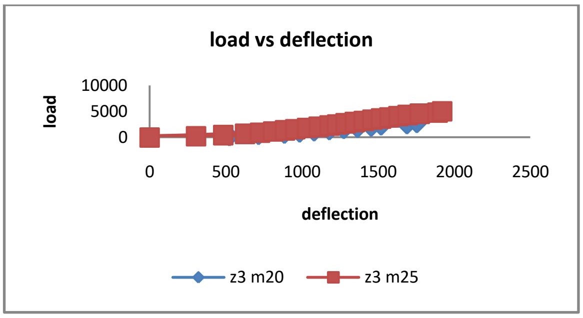

Fig .30. Load vs Deflection comparisons of specimens Z3 M20 and Z3 M25

Table 13. Percentage recovery of all the specimens after first cycle of loading

SPECIMEN		% RECOVERY AFTER FIRST CYCLE
M20	ZR	73
	Z1	75
	Z2	78.74
	Z3	80.41
M25	ZR	66.6
	Z1	68.6
	Z2	98.9
	Z3	99.2

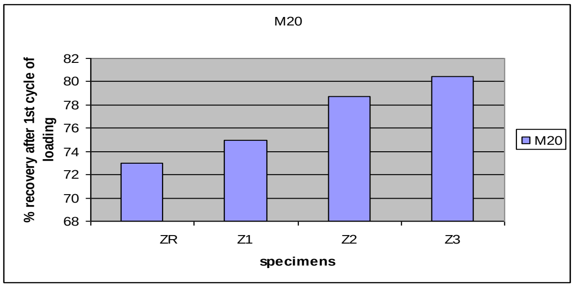

Fig 31. Percentage Recovery after first cycle of loading vs M20 grade of specimens.

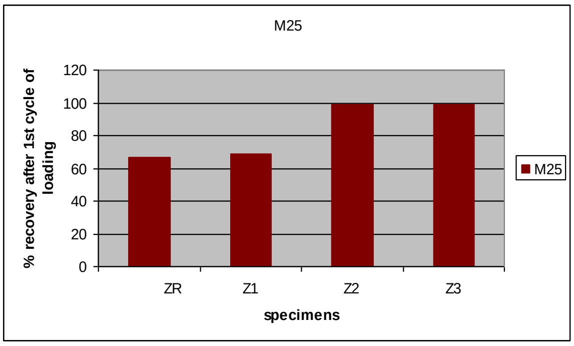

Fig 32. Percentage Recovery after first cycle of loading vs M25 grade of specimens.

[L]. *Percentage recovery of the Specimens after first cycle of loading*

From the Figures 31,32, it can be seen that as the thickness of rubber is increased percentage of recovery of the specimen was also increased, all the test specimens have higher percentage of recovery when compared with the reference specimen.

XI. CONCLUSIONS

- With Increase in thickness of elastomer there was increase in curvature for the same grade of concrete.
- For M20 grade of concrete for the specimen with Rubber thickness of 50mm there was increase in flexural strength compared to the reference specimen, and for other specimens having Rubber thickness of 25mm and 75mm there was decrease in flexural strength.
- For M25 grade of concrete all the test specimens have higher Flexural Strength when compared to the test specimen.
- Comparisons were made between Specimens of same thickness but with varying grade of concrete for Moment vs Curvature and it was observed that ZR M25 has Undergone Higher Rotations than ZR M20 and similarly Z2 M25(Elastomer Thickness 50mm) has Undergone Higher Rotations than Z2 M25.
- While Z1 M25 (Elastomer Thickness 25mm) has Undergone Lesser Rotations than Z1 M20 and similarly Z3 M25 (Elastomer Thickness 75mm) has undergone lesser than Z3 M20.
- Comparisons were made between Specimens of same thickness but with varying grade of concrete for Load vs Deflection and it were observed that with increase in grade of concrete there was increase in Deflection, except in the case of Specimen having Elastomer thickness 75mm.
- With Increase in thickness of elastomer there was increase in recovery after First cycle of loading for both the grades of concrete.

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