STRUCTURAL BEHAVIOUR OF LACED REINFORCED CONCRETE ELEMENTS- A REVIEW

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ABSTRACT

Laced Reinforced Concrete is widely used in the structures to resist the blast loading. Blast loading is different from other loadings, not only by the way it loads the structure, but also due to its transient nature. Peak pressures are much higher than the static collapse load of the structure, but their durations are generally short compared to natural periods of structure and structural components. The approach for the design of structure capable of surviving the effects of high-intensity but short duration loads has to be different from the one adopted for the conventional design. In this article, fundamental behavior of LRC under different loading conditions has been studied. Structural behavior of LRC with respect to crack pattern, load deflection response, residual deflection response, load strain behavior, ductility factor has been reviewed. On critically comparing the experimental investigation carried out by different researchers, useful conclusions, structural behavior on LRC have been presented.

KEYWORDS: Laced Reinforced Concrete, Resistance deflection curve, Load Strain Behaviour, Crack pattern, Ductility Factor

INTRODUCTION

A structural element which consists of equal reinforcement in tension and compression faces along with lacings is known as Laced Reinforced Concrete (LRC) structure.The main flexural reinforcement bars on both face of the element and the concrete components are bind together through the influence of truss action of lacing reinforcement. Lacing is a form of continuous shear reinforcement as compared to the form of conventional stirrup reinforcement.It is placed in the Plane of principal bending and anchored in position by means of transverse bars.

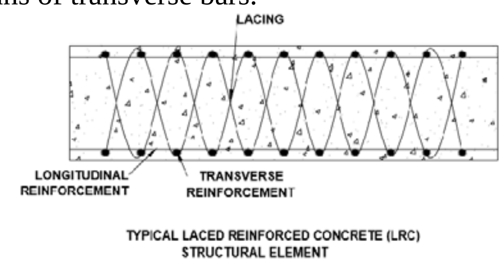

Fig.1 Laced Reinforced concrete beam

Depending on the magnitude of shear force, lacing can be provided in one or more planes. Different types of lacings may be inclined lacing (40^0 and 60^0) rectangular lacing (90^0) and single leg lacing.

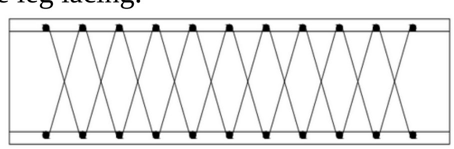

Fig.2 Inclined Lacing

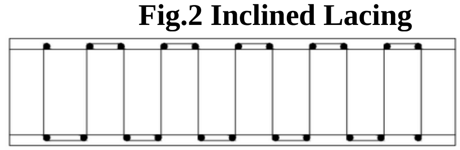

Fig.3 Rectangular Lacing

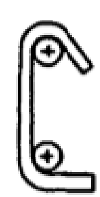

Fig.4 Single leg lacing

N. Anandavalli et al [1] is reported that structural components made of LRC can achieve support rotation as high as 4^0 compared to that of made of RCC which can achieve a maximum of about 2^0 support rotation. This resistance deflection curve was demonstrated by **N. Anandavalli et al [1]** to study the flexural action of a typical RCC element and it is depicted in the fig.5.

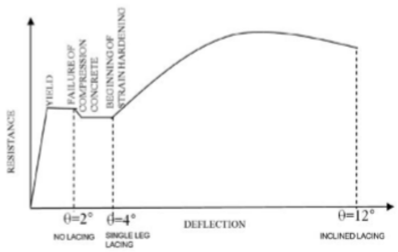

Fig. 5 Resistance Deflection curve

LRC enhances the ductility and provides better concrete confinement. Moreover, LRC is cost effective compared to RCC for the structures that are to be designed for a impulsive loading of a given magnitude. Despite extensive research done in this area, Laced Reinforced Concrete construction has not yet gained worldwide acceptance as a reliable and feasible method.

This can be mainly due to the following reasons.

- The installation of the confinement needs to be more economically competitive.
- More reliable data is required to be tested on practical on long term basis.
- The design of such structural elements needs to be further developed.

Stanley C. Woodson [2] had explained that how shear reinforcement details interact with other physical details and in turn how they affect the response limits of a slab. More specifically, he developed and conducted an experimental investigation comparing the effects of stirrups and lacing bars on the large-deflection behaviour of reinforced concrete slabs

1. STRUCTURAL BEHAVIOUR

It is inevitable for a Structural Engineer to have knowledge on structural behaviour of Laced Reinforced Concrete structures in respect of the following parameters: Crack pattern, Load Deflection Response, Residual Deflection Response, Load Strain Behaviour and Ductility Factor.

1.1 CRACK PATTERN

Stanley C. Woodson [3] has investigated that the primary purpose of shear reinforcement in Laced Reinforced Concrete is not to resist shear forces, but rather to improve performance in the large deflection region by tying the main reinforcements together whereas the primary purpose of shear reinforcement in the conventional concrete structures is to prevent the formation and propagation of diagonal tension cracks. It was proved that the lacing bar permits the element to attain large deflection and fully develop the reinforcement through its strain hardening region.

Hayfaa Dhumaad Hasan Al-Aboodi et al [4] on testing the LRC beam under static loading observed that the shape of the cracks is parallel and vertical along the depth of the section up to the failure for the control beams as shown in fig. 6. While the cracks in Laced Reinforced Concrete are curved and connected together through the slab thickness as shown in fig. 7. He also observed that the first cracking load increase with increasing of lacing steel reinforcement.

Fig. 6 Crack pattern of specimen without lacing

Fig. 7 Crack pattern of specimen with lacing

1.2 LOAD DEFLECTION RESPONSE

A convenient means with which to represent the structural behaviour of a strengthened member is through its load deflection response. Generally when a specimen is subjected to a gradually load increase, the deflection increases linearly with the load in an elastic manner. Once the cracks gradually progressed, deflection of the slab increases at a faster rate. After cracks have developed in the slab, the load-deflection curve is approximately linear up to the yielding of flexural reinforcement after which the deflection continues to increase without an appreciable increment in load.

Hayfaa Dhumaad Hasan Al-Aboodi et al [4] observed that for a LRC beam tested under static loading that the mode of failure of beams is flexural shear failure mode. He experimentally proved that the first cracking load is proportional to the diameter of the lacing bar and lacing steel ratio. In addition, he also said that deflection decreases with the use of lacing shear reinforcement.

He also briefed that the LRC beams subjected to high frequency fatigue loading with low stress levels even on exceeding the limit of fatigue life did not fail. They compared the results with different laced reinforced concrete beams (LRC) to study the influence of lacing bar diameter, inclined lacing angle and lacing steel ratio at the magnitude of the deflection with cycles.

It has been summarized that when the cycling is increased it is observed that, the deflection is decreased with increasing of lacing bar diameter and lacing steel ratio for beams with lacing inclination 30^0, 45^0, and 60^0. Thus, He experimentally proved that the deflection of laced reinforced concrete beams is decreased with increasing of lacing bar diameter, inclined angle to beam axis and lacing steel ratio.

Abaas et al [5] finalized that increasing the lacing steel reinforcement causes an increase in the cracking load by 20% and improving the ultimate load capacity with respect to the control specimen for the Laced Reinforced Concrete slab tested under static loading. It was depicted in the fig. 8.

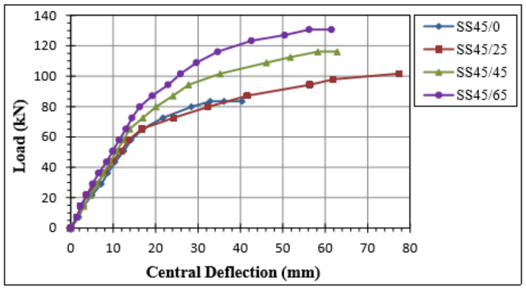

Fig. 8 Influence of the lacing steel ratio on load-central deflection behaviour

But it was experimentally proved that the influence of the lacing ratio on the recorded deflections at service stage is relatively small, where the deflection is reduced at service load with the respect to the control specimen. He also demonstrated that the deflection at the service load was decreased for the slab with the highest lacing steel ratio, and reduced for the specimens with the highest flexural steel ratio and with the smallest slenderness (L/d) ratio respectively.

Besides static loading, repeated loading was also conducted on LRC slab and following results were observed.

1. The ultimate load for a specimen under repeated load is smaller than the specimen subjected to static load.
2. Lacing steel ratio of 54.54% resulted in the higher ultimate load capacity than the control specimen.
3. It is also observed that with the increase in the number of load cycles, corresponding deflection and number of cracks were increased.

Stanley C. Woodson [8] concluded that the load-deflection curves for the slabs were very similar when compared for a laced slab and a slab with stirrups (all other parameters held constant). However, the experiments indicated (was not true for all of the experiments) that a laced slab may possess a slightly greater ultimate capacity than a similar slab with stirrups.

1.3 RESIDUAL DEFLECTION RESPONSE

Amount of deflection resulting from an applied load which remains after the removal of load is known as residual deflection. **Abaas et al [6]** have experimentally proved that the laced reinforced slab exhibited the lowest residual deflection and greatest stiffness. It is also noted that by increasing the lacing steel ratio, the residual deflection can be reduced, but the increase in the flexural steel reinforcement ratio for the specimens causes increase in the residual deflection. Fig. 9 shows us the influence of the lacing steel ratio on the central Residual deflection

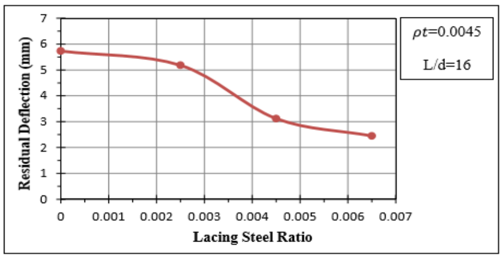

Fig. 9 Influence of the lacing steel ratio on the central Residual deflection

This is due to the increase in the stiffness of the specimen and the reinforcement in the slabs was not able to return to dissipate energy without permanent deformation. He finally discussed that the stiffness increases as the depth of the slab is increases thereby the residual deflection was reduced as a result of decrease in the deflection at peak load of first cycle.

Thus, the following inference was obtained.

1. Residual deflection is reduced for the specimen with the largest lacing reinforcement compared with the control specimen (without lacing bars).
2. Repeated loading produces a residual deflection which increases with the increased the flexural steel ratio, and the slenderness (L/d) ratio.
3. The flexural steel reinforcement is not able to return to dissipate energy without permanent deformation.

1.4 LOAD STRAIN BEHAVIOUR

Hayfaa Dhumaad Hasan Al-Aboodi et al [7] analysed the load strain behaviour. The flexural steel reinforcement resists the yielding in beams with maximum lacing steel ratio and larger diameter lacing bar. The performance of strain of tension bar at the beginning of each cycle for fatigue loading is also presented. It was noticed that the steel reinforcement includes both flexural and lacing bars remains within the elastic range when then the typical LRC beams were subjected to high frequency fatigue loading with low stress level.

He also clearly shown that the tension reinforcement bar resist the yielding with increasing lacing bar diameter in same angle of inclined lacing bar and this resistant capacity is increased with increasing lacing steel ratio by keeping the diameter of lacing bar and its angle as same.

Abaas et al [4] concluded that the load strain response for the flexural steel reinforcement of all the specimens with lacing reinforcement was similar and it is so clear that the effect of lacing reinforcement to re-strain it through the plastic region, while the concrete strain at the extreme compression fibre behaved non-linearly with load until failure of the specimen.

1.5 DUCTILITY FACTOR

Ductility factor is generally defined as the ratio of deflection at failure to the deflection of steel at yielding for the tested specimens. **SrinivasaRao et al [8]** described the ductility behaviour of Laced Reinforced Concrete beams. Yield deformation of a member depends on the type of reinforcement, diameter of bars and position with in the cross section. Similarly the ultimate deformation depends on the criteria of failure. He conducted monotonic and cyclic loads on LRC beams to find out the specimen behaviour such as tensile cracking limit, yield limit and post yield range.

He concluded that the lacing can be effectively used to obtain ductile failure even under the influence of high cyclic shear. In order to overcome the cost of fabrication, they have adopted prefabrication measures such as tack welding of lacing. It is also found that inclined lacing with and without steel fibres provides better response as compared to other forms of lacings. The hysteresis loops are well stabilized particularly for inclinedlaced members. He summarized that a combination of conventional and lacing shear reinforcement can also be used at the plastic hinge locations for additional confinement at cross sections.

Abaas et al [5] noticed that the ductility factor for all specimens was found to be higher compared with the specimen without reinforcement and it was recorded the maximum enhancement in ductility factor by about 91.34% for the specimen with the lower lacing steel ratio. He concluded that ductility factor decrease with increasing the lacing steel ratio.

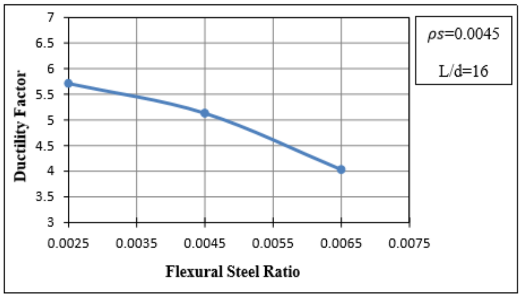

Fig.10 Ductility factor versus flexural steel ratio

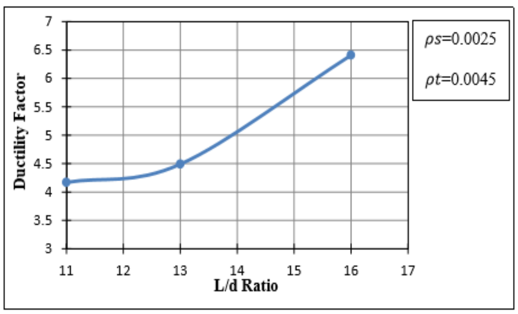

Fig. 11 Ductility factor versus L/d ratio

For slabs, the ductility factor increased with decreasing the flexural steel ratio or increasing with the slenderness (L/d) ratio.

Stanley C. Woodson **[2]** critically given a result that the lacing and stirrups contribute to the ductility of a one-way slab in a similar manner and at a similar magnitude. Failure modes were nearly identical for the slabs comparing the two types of shear reinforcement. Consequently, based on this series of statically loaded slabs, design guidelines restricting the use of stirrups significantly more than theuse of lacing, for the purpose of improving large-deflection behaviour, are overly conservative

CONCLUSION

On investigating the past researches and findings, it is found that the primary purpose of a blast resistant design is to avoid the overall collapse of the respective structure. It is essential to increase the ductility of the structural element to withstand the dynamic loads. Generally, retrofitting is adopted for the structural members of existing buildings to enhance its ductility property. Considering its practicability and cost factor, it is concluded that a new technique with enhanced structural behaviour has to be implemented for the newly constructed structures in the earthquake prone areas. Following inferences were concluded from the above literatures.

1. First cracking load increase with increasing of lacing steel reinforcement.
2. The deflection of laced reinforced concrete beams is decreased with increasing of lacing bar diameter, inclined angle to beam axis and lacing steel ratio.
3. Both flexural and lacing bars remains within the elastic range when then the typical LRC beams were subjected to high frequency fatigue loading with low stress level.
4. Ductility factor decrease with increasing the lacing steel ratio.

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