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Effect of Reinforced Aerocon Block Infill And Double Diagonal RCC Strut RC Frames Under Cyclic Loading

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ABSTRACT

Traditional infill materials considerably influence the holistic response of framed structures due to their increased strength and stiffness. At present, aerocon autoclaved aerated concrete (AAC) blocks have widespread use around the world as a prospective infill material. Hence, a smaller scale prototype of a RC frame with Reinforced Aerocon Block Infill was constructed in the laboratory to evaluate its performance under lateral loading. Also, to enhance the load carrying capacity and stiffness characteristics, RC frame with Double Diagonal RC Strut was constructed and tested under lateral loading.This study is intended to investigate the behaviour of RC Frame with Reinforced Aerocon Block Infill and RC Frame with Double Diagonal RC Strut under lateral loading. The load carrying capacity, Stiffness degradation, Ductility factor , Cumulative ductility factor and Energy dissipation capacity of the RC frames had been documented. The response of the frames showed the complete behaviour of the RC frames under lateral loading. the infill contribution to the overall structural performance, significant enhancement of stiffness, strength and energy dissipation of frame is evident. Compression diagonal failure was eliminated in the brick infill by the presence of reinforcement layers.

Keywords*: Cyclic Loading, Aerocon AAC Blocks, Reinforced Block Masonry, Lateral Loading.*

1. INTRODUCTION

Under the action of in-plane lateral loads the infill acts as a diagonal strut. This changes the response of the bare RC frame from transfer of loads through frame action with predominant bending moments to that of a braced frame. The composite action of the frame and the infill is entirely different. The in-filled frames can withstand more lateral load and experience smaller displacement. The autoclaved aerated concrete (AAC) block/brick or unit has emerged as the best alternative of clay brick. Autoclaved aerated concrete (AAC) are used in the form of block and panel for masonry wall structure (load-bearing and non-load-bearing), floors, roof insulation, trench fills and for other insulating purposes. In the infill panels with bed joint reinforcement there is an evident increase in strength, ductility, energy dissipation capacity and the beneficial effects on the frame structural response also include a more regular response and damage limitations both to the panel and to the frame. Based on the previous experimental study conducted by [4]Jurko Zovkic et al the infill contributed to the stiffness and strength of the RC frame and improved the overall system behaviour. AAC block infilled RC frame showed better performance than clay brick infilled RC frame. Horizontally reinforced masonry (HRM) can be a valid alternative to currently used unreinforced, confined and vertically reinforced masonry. In general, frames with reinforced masonry infills showed lesser separation at failure between the frame and the infills, than that in the frames with unreinforced masonry infill. Under lateral loading, the infills walls exibit a diagonal strut action to resist the lateral force. When the infilled frame is subjected to horizontal load, the infill and the frame get separated over the region where tension occurs and remain intact where compression occurs. Only the diagonal portions are effective in resisting the loads as the remaining portions remain uneffective. So to provide the diagonal strut action, RC struts are being used in both windward and leeward side of the frame .

2. SCOPE OF THE STUDY

- The investigation of RC Frame od Aerocon block reinforced masonry is required because the horizontal reinforcement embedded in mortar plays a mojor role in controlling the diagonal crack propagation and Aerocon blocks are being widely used for building

construction nowadays.
- The investigation of RC frame with Double Diagonal RC Strut is required because the diagonal struts are very strong in compression, so it can withstand large lateral loads in seismic prone areas.

3. OBJECTIVE OF THE STUDY
- To investigate the behaviour of RC frame with Aerocon Block Infill and RC frame with Double Diagonal RC Strut by applying static lateral cyclic loading.
- To analyze the seismic parameters such as Load carrying capacity, Load deflection, Ductility, Stiffness degradation, Storey drift and Energy dissipation capacities of the aforementioned RC frames.

4. EXPERIMENTAL PROGRAM
4.1. Details of Test Specimen

Table -1: Geometry Description

X – axis	1850 mm
Y – axis	2910 mm
No. of storeye	G+1
Height of each Storey	1000 mm
No. of Bays	1
Beam	100 mm x 150 mm x 1250 mm
Column	150 mm x 100 mm x 2300 mm
Diagonal Strut	100 mm x 150 mm x 1600 mm
Foundation	1850 mm x 200 mm x 610 mm

4.2 . Material Properties
Ordinary Portland cement (53 Grade) conforming to IS: 12269-1987 with specific gravity 3.1 was used for the investigation. Well – graded crushed aggregate from quarries near Coimbatore, uniformly graded M-sand were procured and used. Potable water was used for mixing and curing of specimens. M25 grade concrete was designed as per IS 10262-1982 guidelines and used to cast the test specimens. The mix proportion and the materials required for one cubic metre of concrete are presented in Table 2.

The main reinforcement used for the specimen was HYSD (Fe415) bar of 12 mm, 10 mm and 8mm diameter. The reinforcement used for stirrups was HYSD (Fe415) bar of 6 mm diameter. The Aerocon block is a light weight AAC block of size 600 mm x 200 mm x 100 mm had been used. The block is scaled down to a size of 190 mm x 90 mm x 90 mm. The reduced size blocks were casted with a mortar joint of thickness 10mm in accordance with IS 6041-1985. Horizontal ladder type reinforcement of 6mm diameter was placed over the mortar joint at every third layers of the Aerocon block masonry.

Table-2: Details of Mix Design

S.No	Reference	Design Stipulations	Values/Description
1	IS 10262-1982	Characteristic Compressive strength	25 N/mm^2
2	Appendix A of IS 10262-1982	Degree of quality control	Good
3	Table 3 of IS 456:2000	Type of exposure	Mild
4	Target Mean Strength	fck+1.5*S	33.745 N/mm^2
5	Figure 1 of IS 10262-1982	W/C ratio	0.45
6	Mix Proportions	Cement	1
		Fine Aggregate	1.35
		Coarse Aggregate	2.02

4.3. Casting and Erection of RC Frames
The frame was casted and sufficient precautions were taken so that the specimen could be easily removed from the casting place and erected for testing. For mixing of concrete, an electrically operated concrete mixer was used and the concrete was placed immediately after mixing. Needle vibrator of 25 mm diameter was used for the compaction of concrete. The side planks of the mould were stripped after 24 hours and the specimen was covered with wet gunny bags and cured by periodical sprinkling of water for a period of 28 days from the day of casting.

Figure-1: Casting of RC Frames

The gunny bags were removed after curing the specimens for 28 days and the specimens were cleaned. The specimen was supported on 150 mm concrete cubes to carry out the lifting operations. At first, the frame was fastened securely to the chain block of the over-head moving crane after covering the beam-column junctions of the middle column with gunny bags to avoid even minor damages. Then the frame was lifted using the crane and moved towards the foundation block on the test floor. After that, the foundation beam of the test specimen was inserted in the gap between the two webs of the foundation block. Strong steel rods were inserted in the holes of foundation block before the crane was released and then tightened.

Blockwork construction was carried out on the next day of the erection. For infilling the frame with Aerocon block masonry, cement mortar 1:3 with a water cement ratio of 0.45 was used. The construction of block infill in the frame is shown in Figure 2. The horizontal reinforcement was placed over the mortar at every third layer, sixth layer and ninth layer of top and bottom storey infill of the frame.

Figure-2: Construction of Reinforced Aerocon Block Infill

4.4. Test Setup and Loading

The schematic representation of the test set up is shown in Figure 3. and Figure 4. which consisted of reaction frame, Jacks and Load Cells and instrumentations to take lateral displacement. The quasi-static lateral cyclic loading was applied at the first storey level and second storey level in line with the beam.

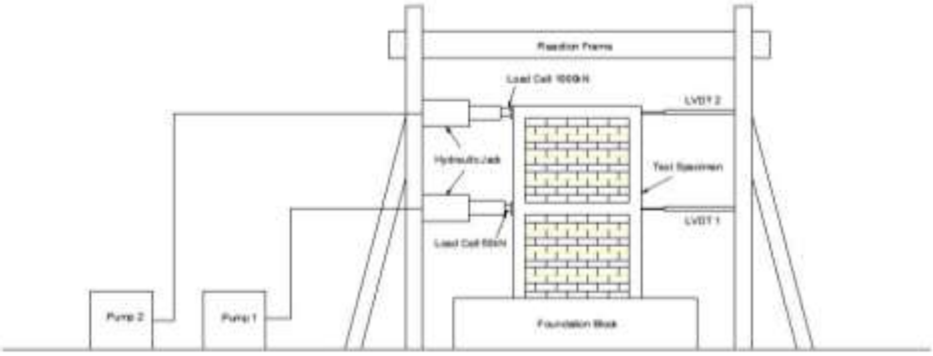

Figure-3: Schematic Arrangement of the test setup of RC Frame with Reinforced Aerocon Block Infill

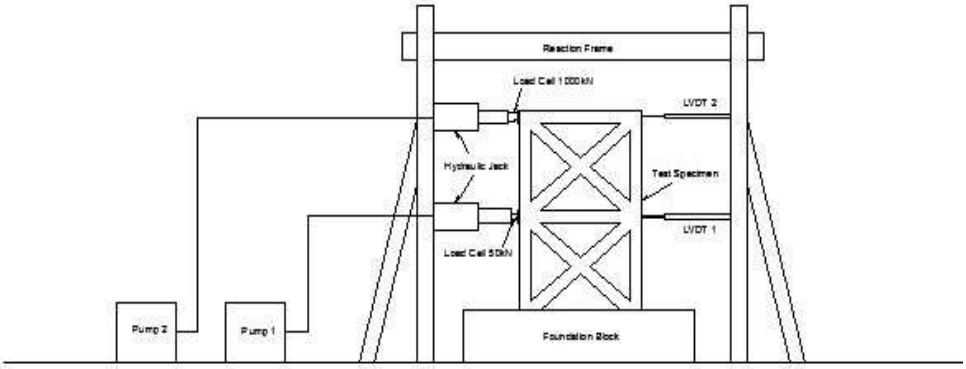

Figure-4: Schematic Arrangement of the test setup of RC Frame with Double Diagonal RC Strut

The RC frame specimens were loaded initially for small loads to check the effectiveness of the instrumentation setup. The RC frame specimens were subjected to equivalent lateral cyclic loading. For each loading stage, the readings of deflection and clockwise rotation of frames were recorded. Strain in concrete and steel were noted for zero and peak loading of each load cycle. Concrete strain in beam and column was noted till the initial crack occurred in concrete. Load was applied at the top (Q2) and bottom (Q1) storey of the frame from the left side with help of load cells. There is no gravity load other than the self weight of the frame – infill composite system. The lateral cyclic load was applied on the left side of the frame at each storey with the help of load cells of capacity 100t on top storey and 5t on bottom storey. The failure pattern for respective loading was noted to study the crack behavior of the frames. The application of lateral cyclic loading was continued till the ultimate failure of the RC frame specimens.

5. EXPERIMENTAL TEST RESULTS AND EVALUATION

5.1. RC Frame with Reinforced Aerocon Block Infill

The loading increment for each cycle was 2 kN, 5kN and 10kN upto sixth, fourteenth and seventeenth cycles respectively.

5.1.1. Observed Failure Pattern: The frame was subjected to lateral cyclic load at each storey upto its ultimate failure. There was no cracks found at the initial stages of loading. Sliding shear failure of bed joint occurred at a load of 20kN due to lateral deformation of RC frame and infill as mortar joint represents plane of failure. The yield crack of RC frame was found at a load of 40kN. Flexural cracks and shear cracks were seen at the one third height of the tension column at first and second storey. Numerous diagonal tension cracks had been found on the wall at a load of 60kN. Shear crack was found at first storey beam near the loading point at a load of 70kN. As loading increases in a cyclic manner, separation of infill and frame occurred and the width of cracks founded was increased to 4mm,6mm and 10mm. It was observed that the crack propagation was controlled by the reinforcement provided at the infill walls in each stages. Therefore the infills with bed joint reinforcement can survive in large deformation without a sudden failure. At increased loading more deformation of the frame and spalling of infill blocks were found. The RC Frame with Reinforced Aerocon Block Infill had sustained effectively up to a peak load of 85 kN. At the peak load, due to increased compression near the loading point in the top storey, the beam column joint and the infill had been crushed to a greater extent. During post cyclic loading, more cracks were found at the windward side column at a height of 40cm from bottom and the width of existing cracks get even more wider. The compression diagonal length was decreased from 160.1cm to 155cm for the first and second storey respectively due to diagonal compression effect. The tension diagonal was increased from 160.1cm to 162cm and 160.1cm to 164cm for the first and second storey respectively due to the diagonal tension effect.

Figure-5: Deformed Reinforced Aerocon Block RC Frame

5.1.2. Load Carrying Capacity: The influence of infill on the RC frame-infill system at high displacement was significant, since the reinforced infill developed better distribution of cracks. The deflection was also steadily increasing when the applied loading was increased. The ultimate base shear of 85 kN was reached in seventeenth cycle of loading for a displacement of 109.1 mm.

5.1.3. Load – Deflection Behaviour: From the idealized elastic-perfectly plastic curve, assuming bilinear behaviour, the yield deflection Δy is found to be 10.92 mm. At the beginning, beams and columns offered resistance till the first visible crack at 40 kN at the beam and continued to take the load together with brick infill. On formation of cracks in the infill at 60 kN, the composite action was taking place. The displacement was increasing without proportionately to loading due to inelastic behaviour. The top displacement at the ultimate load of 85 kN is 109.1 mm. At the post cycle of loading, the frame deformed as much as 259.39 mm. The deflections were found increasing when the load was progressively increased and could not close while unloading due to the internal bond failure between the concrete, reinforcement and block masonry leading to widening hysteretic curves. When the maximum base shear of each cycle is plotted against top storey deflection (Figure 6) there is a good correlation between the base shear and top storey deflection. The function of the deflection curve up to ultimate load is

$$y = 0.000x^3 - 0.06x^2 + 3.737x + 5.860 \qquad (1)$$

$$R^2 = 0.992$$

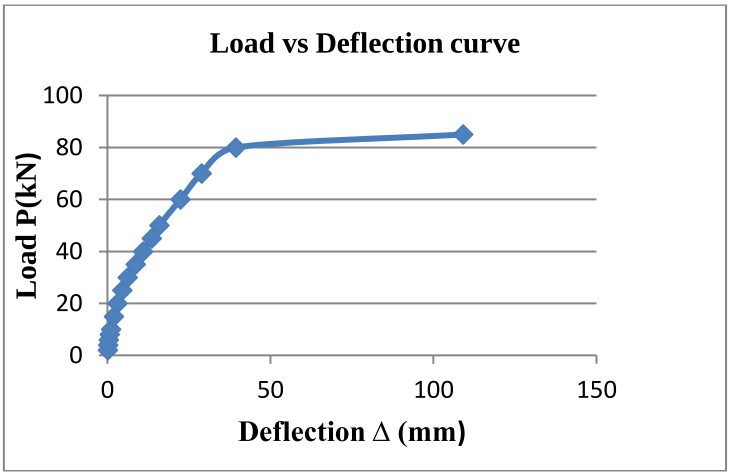

Figure-6: Peak Load vs Deflection

5.1.4. Stiffness Characteristics: The stiffness for RC Frame with Reinforced Aerocon Block Infill was found to decrease from 16.667 kN/mm during the first load cycle to 0.779 kN/mm during the last load cycle in forward loading. The reduction of stiffness occur due to the failure of bond, propagation of cracks and yielding of steel reinforcement. The trend line equation of stiffness is given by

$$y = -0.000x^4 + 0.025x^3 - 0.175x^2 - 1.444x + 18.48 \quad (2)$$

$$R^2 = 0.999$$

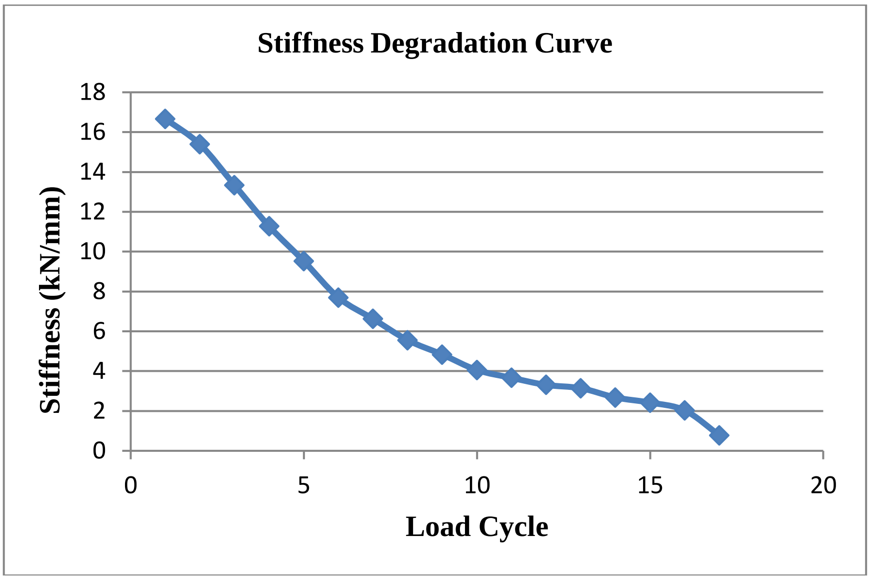

Figure-7: Load cycle vs Stiffness

5.1.5. Ductility Characteristics: The ductility factor for for RC Frame with Reinforced Aerocon Block Infill is found to vary from 0.009 during the first load cycle to 9.991 during the last load cycle. It is observed that ductility gets increased in each succeeding load cycle. The variation of ductility factor with load cycles for for RC Frame with Reinforced Aerocon Block Infill is shown in Figure 8. The trend line equation of ductility is given by

$$y = 5E\text{-}05x^6 - 0.002x^5 + 0.042x^4 - 0.375x^3 + 1.626x^2 - 3.113x + 1.926 \quad (3)$$

$$R^2 = 0.987$$

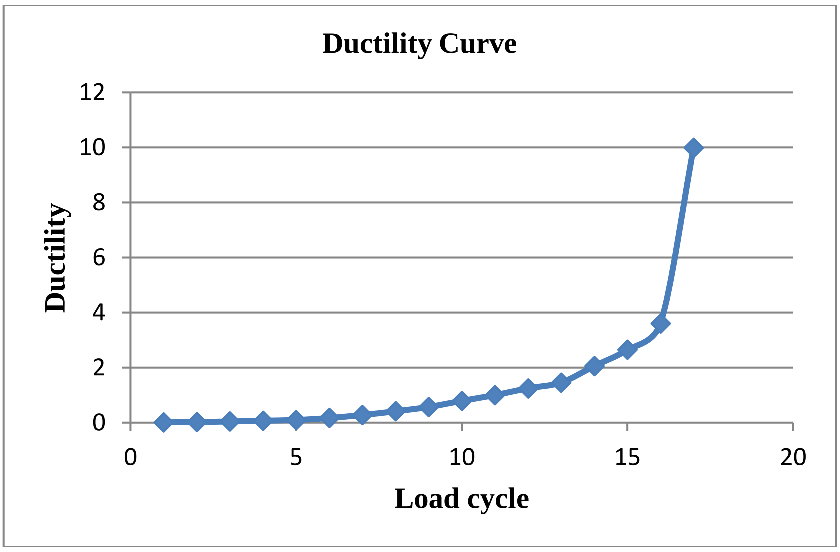

Figure-8: Load cycle vs Ductility factor

The cumulative ductility factor for for RC Frame with Reinforced Aerocon Block Infill is found to vary from 0.009 during the first load cycle to 24.456 during the last load cycle. It is observed that cumulative ductility factor gets increased in each succeeding load cycle. The variation of cumulative ductility factor with load cycles for for RC Frame with Reinforced Aerocon Block Infill is shown in Figure 9. The trend line equation of cumulative ductility is given by

$$y = 5E\text{-}05x^6 - 0.002x^5 + 0.048x^4 - 0.419x^3 + 1.805x^2 - 3.42x + 2.097 \quad (4)$$

$$R^2 = 0.998$$

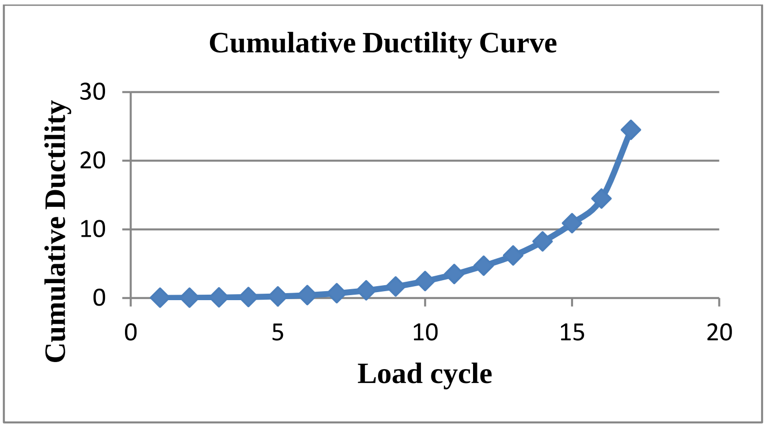

Figure-9: Load cycle vs Cumulative Ductility factor

5.1.6. Storey Drift: The base shear verses top story drift curve is plotted and presented in Figure 10. It is observed that until 60 kN, the drift is proportionate and beyond this, greater drift occurs due to high inelastic behavior which is attributed to the ductility of the framed system. Accumulated residual strains in the reinforcement over the load cycles prevented the cracks from closing during unloading sequence causing bond slip. At the ultimate stage drift is as much as 0.047. There is a good correlation between the base shear and top storey drift. The function of the top storey drift curve up to ultimate load is

$$y = 4E{+}06x^3 - 31749x^2 + 8595.x + 5.860 \quad (5)$$

$$R^2 = 0.992$$

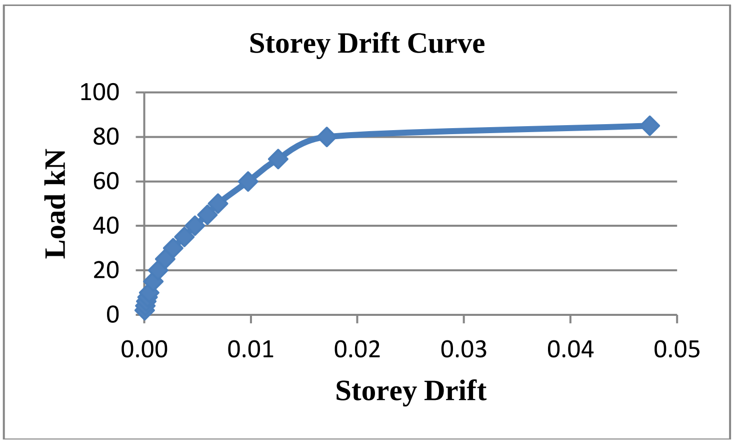

Figure-10: Storey drift vs Load

5.1.7. Energy Dissipation Characteristics: The energy dissipation capacity of the frame during various load cycles was calculated as the sum of the area under the hysteresis loops from the base shear versus top storey deflection diagram obtained. The energy dissipation capacity during first cycle of loading was 0 kN mm and that during 17th cycles was 5722.5kN mm. The function of the energy dissipation up to ultimate load is

$$y = 0.041x^6 - 2.027x^5 + 37.68x^4 - 336.0x^3 + 1467.x^2 - 2835.x + 1756 \quad (6)$$

$$R^2 = 0.964$$

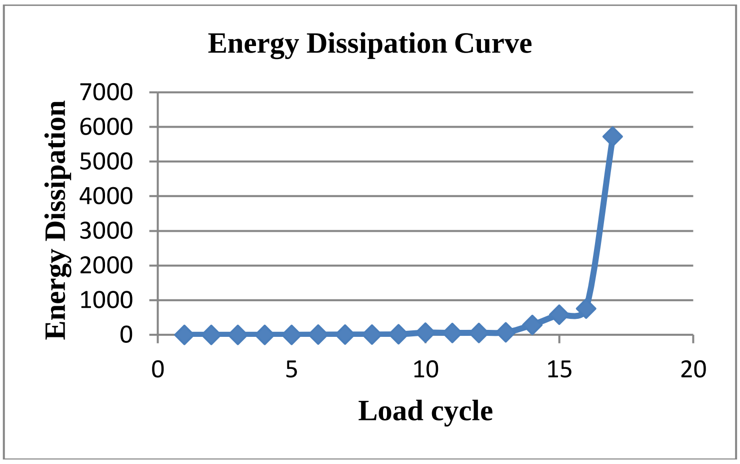

Figure-11: Load cycle vs Energy dissipation

The cumulative energy absorption for RC Frame with Reinforced Aerocon Block Infill is found to vary from 0 kN.mm during the first load cycle to 7633.22 kN.mm during the last load cycle. It is observed that cumulative energy absorption gets increased in each load cycle.

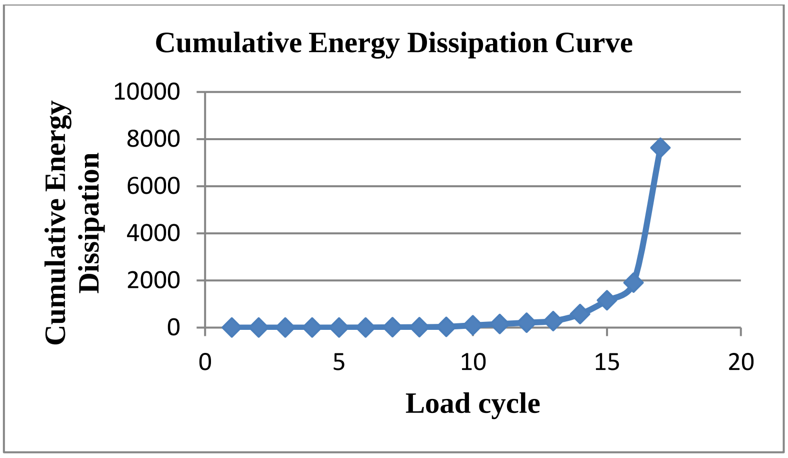

Figure-12: Load cycle vs Cumulative Energy dissipation

5.2. RC Frame with Double Diagonal RC Strut

5.2.1. Observed Failure Pattern: The cyclic lateral loading of intervals 2 kN, 4kN, 5 kN and 10 kN was given to the RC Frame with double diagonal RC strut at each storeys. During lateral loading, the infill within the frame exhibits a diagonal strut action to resist loads(i.e, compression effect). This diagonal strut action creates an additional resisting mechanism within the frame. During initial loading there were no cracks found at the frame indicates higher stiffness. The yield crack was found at the one-third height of the tension column in the first and second storeys at load of 40kN. As loading increases, smaller flexural cracks are developed at the tension column and the tension diagonal of both the storeys due to tension force acting. As concrete is very strong in compression, there was no crack found at the compression diagonal even at higher loads. As the beam column joint is made very strong in this case, no major cracks had been developed there. The RC Frame with double diagonal RC strut sustained upto a peak load of 130 kN. The maximum deformation of 110.7mm was observed at the peak load of 130kN.

Figure-13: Deformed Double Diagonal RC Strut Frame

5.2.1. Load Carrying Capacity: The RC Frame with Double Diagonal RC Strut was tested under lateral cyclic loading. The load increment was done in four stages as 2kN, 4kN, 5kN and 10kN upto the final failure of the specimen. The deflection was steadily increasing when the applied loading was increased. The ultimate base shear of 130 kN was reached in twenty fourth cycle of loading for a displacement of 110.7 mm.

5.2.2. Load – Deflection Behaviour: The displacement was increasing without proportionately to loading due to inelastic behaviour. The top displacement at the ultimate load of 130 kN is 110.7 mm. The deflections were found increasing when the load was progressively increased and could not close while unloading due to the internal bond failure between the concrete and reinforcement leading to widening hysteretic curves. When the maximum base shear of each cycle is plotted against top storey deflection (Figure 14) there is a good correlation between the base shear and top storey deflection. The function of the deflection curve up to ultimate load is

$$y = -2E\text{-}06x^4 + 0.000x^3 - 0.055x^2 + 3.403x + 8.284 \quad (7)$$

$$R^2 = 0.993$$

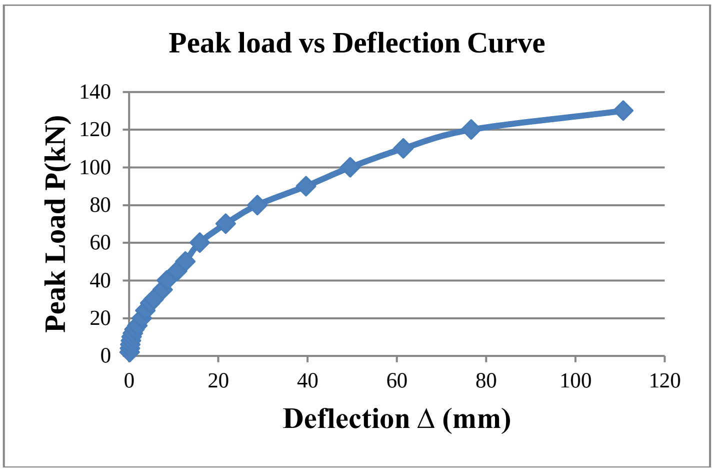

Figure-14: Peak Load vs Deflection

5.2.3. Stiffness Characteristics: The stiffness for RC Frame with Double Diagonal RC Srut was found to decrease from 25 kN/mm during the first load cycle to 1.174 kN/mm during the last load cycle in forward loading. The reduction of stiffness occur due to the failure of bond, propagation of cracks and yielding of steel reinforcement. The trend line equation of stiffness is given by

$$y = -4E\text{-}06x^6 + 0.000x^5 - 0.012x^4 + 0.214x^3 - 1.721x^2 + 3.517x + 22.57 \quad (8)$$

$$R^2 = 0.996$$

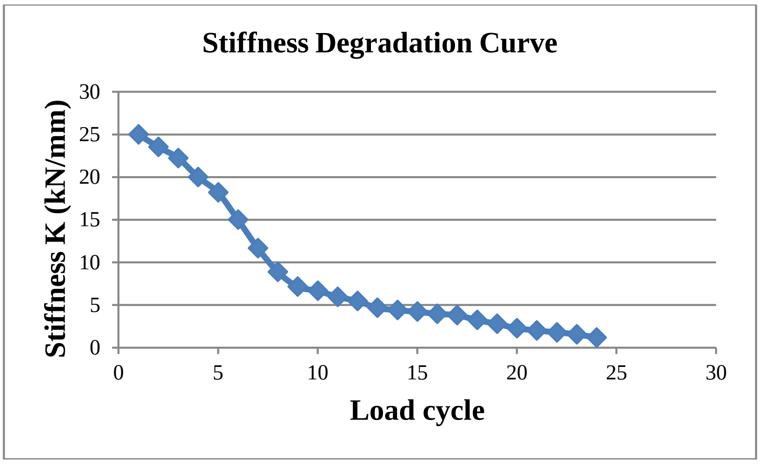

Figure-15: Load cycle vs Stiffness

5.2.4. Ductility Characteristics: The ductility factor for for RC Frame with Double Diagonal RC Strut is found to vary from 0.009 during the first load cycle to 12.165 during the last load cycle. It is observed that ductility gets increased in each succeeding load cycle. The variation of ductility factor with load cycles for for RC Frame Double Diagonal RC Strut is shown in Figure 16. The trend line equation of ductility is given by

$$y = 7E\text{-}06x^5 - 0.000x^4 + 0.005x^3 - 0.046x^2 + 0.157x - 0.137 \quad (9)$$

$$R^2 = 0.999$$

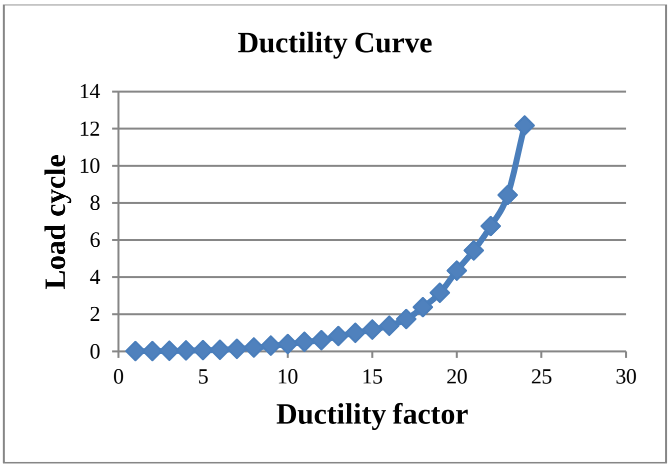

Figure-16: Load cycle vs Ductility factor

The cumulative ductility factor for for RC Frame with Double Diagonal RC Strut is found to vary from 0.009 during the first load cycle to 51.173during the last load cycle. It is observed that cumulative ductility factor gets increased in each succeeding load cycle. The variation of cumulative ductility factor with load cycles for for RC Frame with Double Diagonal RC Strut is shown in Figure 17. The trend line equation of cumulative ductility is given by

$$y = 1E\text{-}06x^6 - 7E\text{-}05x^5 + 0.001x^4 - 0.022x^3 + 0.130x^2 - 0.313x + 0.24 \qquad (10)$$

$$R^2 = 1$$

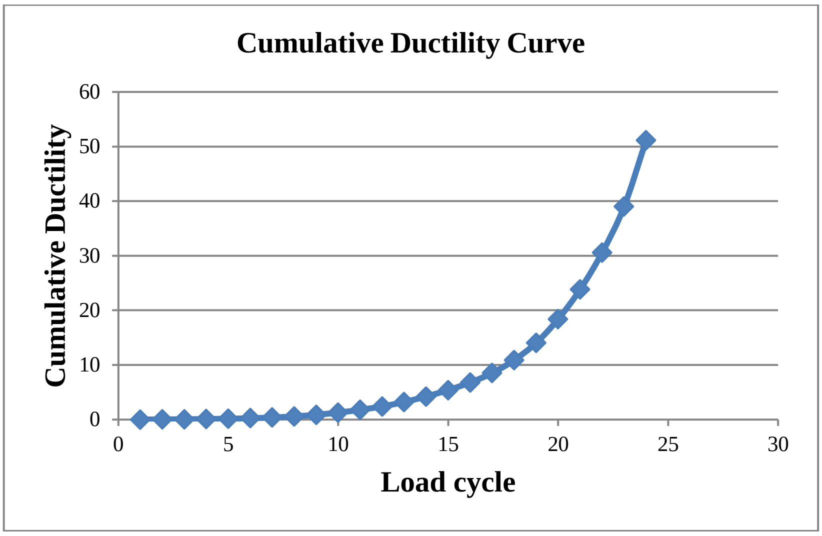

Figure-17: Load cycle vs Cumulative Ductility factor

5.2.5. Storey Drift: The base shear verses top story drift curve is plotted and presented in Figure 18. Accumulated residual strains in the reinforcement over the load cycles prevented the cracks from closing during unloading sequence causing bond slip. At the ultimate stage drift is as much as 0.048. There is a good correlation between the base shear and top storey drift. The function of the top storey drift curve up to ultimate load is

$$y = -6E+07x^4 + 6E+06x^3 - 29416x^2 + 7827.x + 8.284 \qquad (11)$$

$$R^2 = 0.993$$

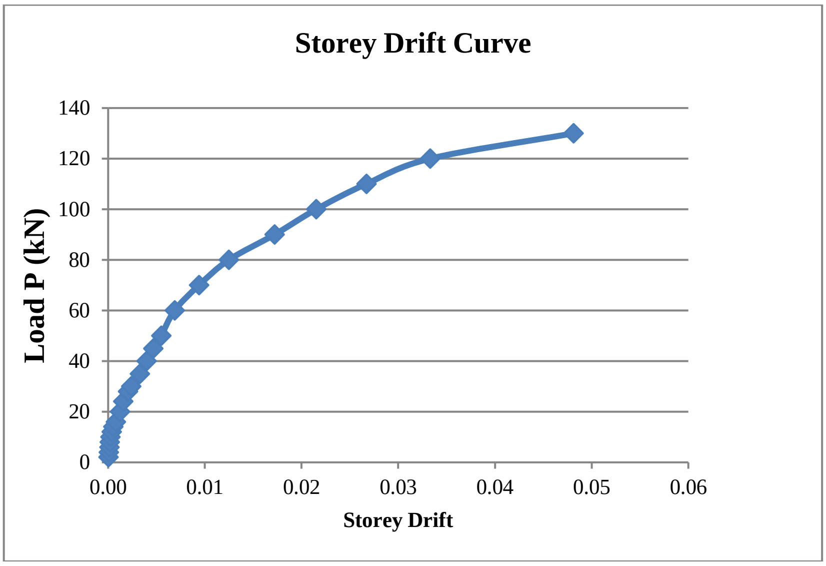

Figure-18: Storey drift vs Load

5.2.6. Energy Dissipation Characteristics: The energy dissipation capacity of the frame during various load cycles was calculated as the sum of the area under the hysteresis loops from the base shear versus top storey deflection diagram obtained. The energy dissipation capacity during first cycle of loading was 0 kN mm and that during 24th cycles was 3900.375kN mm. The function of the energy dissipation up to ultimate load is

$$y = -0.000x^6 + 0.009x^5 - 0.271x^4 + 3.455x^3 - 20.40x^2 + 51.09x - 38.49 \qquad (12)$$

$$R^2 = 0.998$$

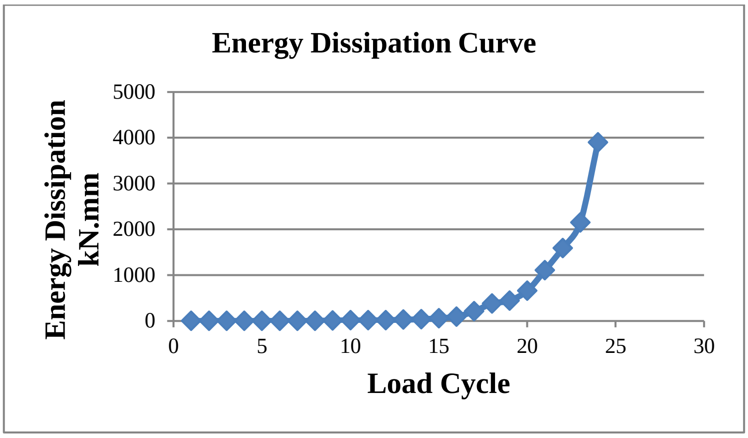

Figure-19: Load cycle vs Energy dissipation

The cumulative energy absorption for RC frame with with Double Diagonal RC Strut is found to vary from 0 kN.mm during the first load cycle to 10712.715 kN.mm during the last load cycle. It is observed that cumulative energy absorption gets increased in each load cycle.

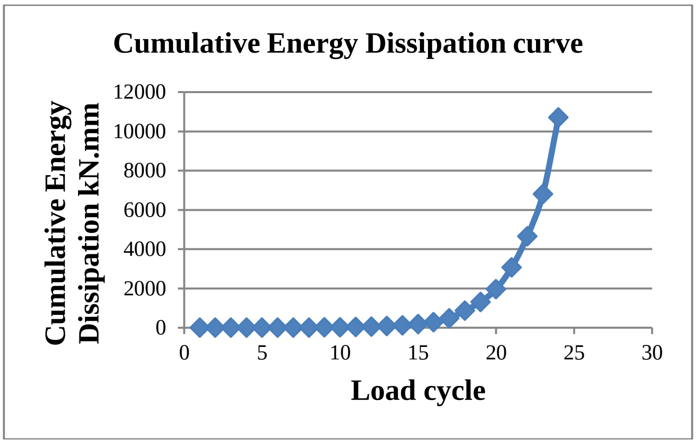

Figure-20: Load cycle vs Cumulative Energy dissipation

6. SUMMARY AND CONCLUSION

6.1 RC frame with Reinforced Aerocon Block Infill

- The behaviour of RC frame with Reinforced Aerocon Block Infill under lateral loading was investigated experimentally and analytically.
- The test results shows that at failure, Aerocon block infill developed strut mechanism in the form of diagonal cracking.
- As the load deflection behaviour of the RC frame demonstrated better hysteretic behaviour, it can be concluded from this study that Aerocon block can provide good behaviour of infilled frame under lateral loading. Therefore, this material can be used to replace clay brick units as infill material for RC frames built in earthquake prone region.
- Taking into account the infill contribution to the overall structural performance, significant enhancement of stiffness, strength and energy dissipation of frame is evident.
- Compression diagonal failure was eliminated in the brick infill by the presence of reinforcement layers.

6.2. RC frame with Double Diagonal RC Strut

- The behaviour of RC frame with Double Diagonal RC Strut under lateral loading was investigated experimentally and analytically.
- Due to combined effects of flexure and tension, there were cracks developed at the tesion diagonal and the bottom of windward column.
- There was no such cracks developed at both the top and bottom storey beams and the compression diagonal.
- As the energy dissipation capacity was higher in this frame, it can be used in severe earthquake prone areas.

7. ACKNOWLEDGEMENT

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