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Effect of Material Used for Infill Wall and Its Shape on the Seismic Performance of RC Frame

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Abstract: RC frame structure is one of common used building structures. Previous studies show that infill wall significantly contribute to the seismic performance imposed on RC frame structure, increasing structural stiffness and hence leading to decrease structure's natural period. However under strong earthquake, infill wall not only holds up large lateral seismic force but also limits the deformation of beams and columns. In most of the previous studies on the behaviour of reinforce concrete building considering the effect of infill wall, rectangular shape of brick is taken into account.

In this study, an attempt has been made to look over the effect of infill wall material type and its shape on the seismic performance of RC frame. This study will be restricted with single bay frame with two types of bricks a) Clay brick, b) Fly ash brick. The different shapes under consideration are rectangle and square. This study also contains the effect of size of infill wall units. The stress in concrete, lateral force resisting capacity and displacement results have been obtained by finite element analysis and compared for all the cases.

Keywords: RC frame, Infill, Micro modelling, FEA, ABAQUS

I. INTRODUCTION

This paper presents an investigation on the effect of material used for infill wall and its shape on the seismic performance of RC ductile frame, by using ABAQUS software. Effect of size is also considered in this study.

Within the context of the built environment, the term 'structure' refers to anything that is constructed or built from different interrelated parts with a fixed location on the ground. This includes buildings, but the term structure can also be used to refer to any body of connected parts that is designed to bear loads, even if it is not intended to be occupied by people. Structural systems are those elements of construction that are designed to form part of a building's structure either to support the entire building (or other built asset, such as a bridge or tunnel) or just a part of it. The Structural systems or structural frames can also be defined as the assembly of inter-related or inter-dependent elements which forms a complex structure, and they are designed and built for resisting different loads.

The structural systems as the whole are divided in into different systems.

1) Load Bearing System
2) Framed System
3) Shell System

A. Infill Wall

The infill wall is the supported wall that closes the perimeter of a building constructed with a three-dimensional framework structure (generally made of steel or reinforced concrete). Therefore, the structural frame ensures the bearing function, whereas the infill wall serves to separate inner and outer space, filling up the boxes of the outer frames. The infill wall has the unique static function to bear its own weight. The impact of social spam is already significant.

Reinforced concrete (RC) frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multi-family residential uses in seismic-prone regions worldwide. Masonry infill typically consists of brick masonry or concrete block walls, constructed between columns and beams of a RC frame. These panels are generally not considered in the design process and treated as non-structural components. It can be understood that if the effect of infill is taken into account in the analysis and design of frame, the resulting structure may be significantly different. Significant experimental and analytical research is reported in various literatures, which attempts to explain the behavior of in filled frames.

B. Finite Element Analysis

The finite element method (FEM) is a widely used method for numerically solving differential equations arising in engineering and mathematical modeling. Abaqus FEA (formerly ABAQUS) is a software suite for finite element analysis and computer-aided engineering, originally released in 1978. Users can define their own material models so that new materials could also be simulated in Abaqus. FEM for masonry is based on two main modeling approaches, namely, Micro modelling and Macro modeling, the choice depending on the level of accuracy and detail required.(based on [12]) In the Micro-model approach, the simulation can be detailed; the units and mortar are modeled as continuum elements and unit-mortar interfaces are modeled as discontinue elements. The detailed Micro-model can provide accurate results, but it is computationally intensive and thus limited to simulating relatively small masonry elements. In the simplified approach, the units are expanded by adding the mortar thickness, the expanded units are modelled as a series of continuum elements and the interaction between the expanded units is modelled as series of discontinuum elements. In the Macro-model approach, the masonry is considered as a homogenous material with no distinction between units and mortar, the material properties are obtained from average properties of masonry constituents and the masonry is modelled as a series of continuum elements. In our study the simplified micro modelling is used to model the infill wall. The more complex the contacts become, the more repetitive calculations ABAQUS/Standard has to solve, and the more time and disk space needed; ABAQUS Explicit is the optimal choice in this case.

II. LITERATURE SURVEY

Abdulla K. F. et al[1] studied a combination of constitutive models which has been employed together with the extended finite element method (XFEM) to simulate 3D masonry structures using a simplified Micro-modelling approach. In the new approach progressive cracking and non-linear post-failure behaviour between the masonry joint interfaces were well-captured by using a cohesive, surface based approach with a traction separation law. In addition, crack propagation within masonry units was identified by the novel use of XFEM without the pre-definition of crack location. The compressive failure of masonry was also included via a Drucker-Prager material constitutive model. Thus, all key local and global behavior and failure modes of masonry were captured. The capability of the proposed model was demonstrated by validation studies of the response of masonry structures under monotonic in-plane, out-of-plane and in-plane cyclic loads, which were able to reproduce experimentally observed behaviour with accuracy.

Wu, H., Zhao et al[3] conducted Non-linear analysis of autoclaved aerated concrete (AAC) block masonry composite wall with reinforced concrete (RC) core columns using finite element software ABAQUS. Bilinear kinematic hardening model was embraced to simulate the behavior of reinforcement. Vertical stress is an important factor that affects the seismic performance of masonry walls. The vertical stress has more effects on the wall without openings than those with openings within its range. The results indicated that there was a good agreement between finite element simulation and experimental results.

Wararuksajja, W. et al[4] studied on Seismic design of RC moment-resisting frames with concrete block infill walls considering local infill-frame interactions. Two full-scale intermediate RC moment-resisting frame specimens with infill concrete block walls are tested under a horizontal cyclic load to study the infill wall-frame interaction. Finite element analysis is carried out by using DIANA 2019 to evaluate the response particularly on the infill-frame interactions. It was observed from the experiment that the strut actions in the wall restricted the bending of the column to only the upper portion of the column. For a frame with a relatively strong infill, the initial gap forms in the infill wall due to corner crushing following by an immediate column shear failure. On the other hand, for a frame with a relatively weak infill, the crushing of the infill wall continues downward, creating a progressively larger gap opening.

Shankar, B. et al[6] has done seismic Analysis of Interlocking Block as Infill Wall. In this study the static non linear analysis is used to analyze the model. Building frame, wall, foundation, soil is modeled using ANSYS. Comparison of results obtained is done between interlocking infill wall, brick infill walls and single storey single bay frame without any infill. It has been observed that overall displacement of interlocking block wall is reduced by about 47% when compared with frame without infill wall and about 21.4% when compared with brick infill wall. Structure with infill wall built using interlocking block has lowest value of stress when compared with other two models.

Dönmez, C. et al [7] studied the effect of infill walls on the drift behavior of reinforced concrete frames subjected to lateral-load reversals. A comparison of the average and the 1st story inter story drift ratios indicates that the upper floors of the frames with infill walls contribute less to the total drift than those of the bare frames. It is observed that the compartmentalized construction and the brittle behavior of the infill walls result in a discrete failure sequence among the floors that are controlled by the strength and stiffness interrelation.

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Bhosale S. D. et al [9] In this study numerical nonlinear analysis of wall panel is done by FE tool (ABAQUS). Using Concrete Damage Plasticity Model (CDP).Contact between adjacent masonry is General explicit surface to surface based contact. If the bond between masonry and mortar is strong it might be possible that diagonal crack will be a dominant failure in the same masonry.

III.METHODOLOGY

1) *Size and Shape of Infill Units:* RC frame with infill wall unit is made using two different shapes of masonry unit named rectangle and square of material burnt clay and fly ash. Different sizes are taken for study by multiplying the normal brick size (230mm x 110mm x 75mm) with factor. The depth of all the units of different sizes is same i.e. 110mm. For different shapes i.e. rectangle and square periphery of one size is almost same so that we can compare the results. The factors are listed in table below.

Table 1 Scale factor for masonry units

Size	1R	1S	2R	2S	3R	3S	4R	4S	5R	5S
Scale Factor (Approx)	0.5		0.75		1		1.5		2	

Table 2 Size of masonry units

Size No.	Rectangle (l x b x h)	Size No.	Square (l x b x h)
1R	115mm×110mm×38mm	1S	75mm×110mm×75mm
2R	187.5mm×110mm×60mm	2S	125mm×110mm×125mm
3R	230mm×110mm×75mm	3S	150mm×110mm×150mm
4R	375mm×110mm×112.5mm	4S	250mm×110mm×250mm
5R	460mm×110mm×150mm	5S	300mm×110mm×300mm

2) *RC Frame:* Reinforcement and section size: Single bay RC frame of size 1.5m x 1.5m is taken under study. Cross section of beam and column is 115mm x 175mm and 175mm x 115mm respectively. Reinforcement detailing is as shown in figure below. Design of reinforcement is done by taking the frame as a ductile one.

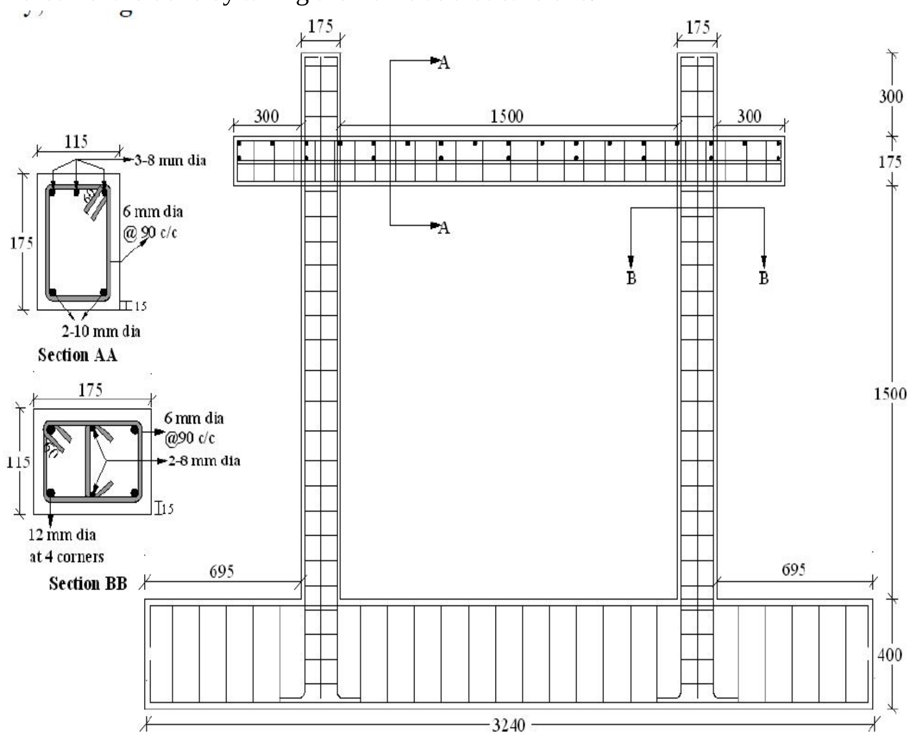

Fig. 1 Reinforcement detailing of RC frame [18]

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3) *Constitutive Modelling:* The constitutive behaviour of concrete and fly ash brick was modelled using concrete damage plasticity model and behaviour of clay brick was modelled using Drucker Prager model. Concrete Damage Plasticity: It provides a general capability for modelling concrete and other quasi-brittle materials in all types of structures (beams, trusses, shells, and solids).It uses concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behaviour of concrete. Drucker Prager model: It is used to model frictional materials, which are typically granular-like soils and rock, and exhibit pressure-dependent yield. It is used to model materials in which the compressive yield strength is greater than the tensile yield strength.
4) *Properties of Masonry Units:* Compressive strength of clay brick is 3.74MPa considering the bricks are common building bricks[14]. Elastic modulus is assumed based on the relevant data available in the literature. The brick modulus was calculated based on its compressive strength value reported in the experiments, elastic modulus of brick (E_u) is set as 300 times the brick compressive strength[1].

Table 3 Properties of clay and fly ash brick

Property	Clay Brick	Fly ash Brick[15]
Compressive strength	3.74MPa	5.7MPa
Shear strength	0.5MPa	0.5MPa
Poisson's ratio	0.22	0.16
Density	1.6 x 10^{-9}tone/mm^3	1.75 x 10^{-9}tone/mm^3

Table 4 Drucker Prager model property for Clay Brick[1]

Dilation angle (Ψ)(Degree)	Flow stress ratio (K)	Friction angle (β)
11.3	1	36

Table 5 Concrete damage Plasticity property for Fly ash brick[15]

Dilation angle (Degree)	Flow potential eccentricity (m)	Ratio of initial equibiaxial to initial uniaxial compressive stress (fb_o/fc_o)	Ratio of second stress invariant K	Viscosity parameter
12	0.1	1.16	0.667	0

5) *Elastic Modulus of Expanded Masonry Units:* The elastic modulus of the expanded masonry units must be adjusted and made to have an equivalent elastic response to the original masonry assemblage (unit and mortar). It is to be determined by taking the original masonry unit and mortar modulus of elasticity and geometry of the masonry assemblage into account. For this purpose, equation is proposed based on the assumption of a stack bond between masonry units and uniform stress distribution in masonry constituents by Abdullah[1].
6) *Properties of Material in RC Frame:* The non linear behavior of concrete in the reinforced concrete frame is modeled using concrete damage plasticity model available in the software.

Table 6 Properties of concrete and steel

Property	Concrete	Steel
Grade	M25	Fe500
Young's modulus	25000N/mm^2	200000N/mm^2
Poisson's ratio	0.15	0.3
Density	2.4 x 10^{-9}tonne/mm^3	7.85 x 10^{-9}tonne/mm^3

Table 7 Concrete damage Plasticity property for Concrete [14]

Dilation angle (Degree)	Flow potential eccentricity (m)	Ratio of initial equibiaxial to initial uniaxial compressive stress (fb_o/fc_o)	Ratio of second stress invariant K	Viscosity parameter
35	0.1	1.16	0.667	0

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7) *Interaction Property:* For modeling the interface elements of brick and concrete cohesive surface technique was adopted. Cohesive behavior was defined based on the properties given in table. Stiffness co efficient (K_{nn} , K_{ss} , K_{tt}) are calculated using the following equations[1]. For initiation of damage, tension bond strength was used in Mode I (normal) failure as intact strength between bricks and mortar was the only source of bond resistance against shear force along bed joints. The average compressive strength of mortar is 17.3MPa[15]. This value is used as damage initiation in the normal direction.

Table 8 Behaviour of Joints

Tangential Behaviour	Normal Behaviour	Cohesive Behaviour					
		Traction Sepration Behaviour			Damage		
		Stiffness Coefficients (N/mm^3)			Initiation(N/mm^2)		
Friction Coefficient	Contact	K_{nn}	K_{ss}	K_{tt}	Normal	Shear I	Shear II
0.8	Hard	122	49	49	17.3	0.3	0.3
		824	329	329			

8) *Loading on Assembly:* For loading the self weight of assembly wss considered and it is applied in terms of body force in the software. Second load which was applied on assembly is cyclic in nature and is applied on the left side surface of the beam i.e. in the positive X direction. It was given in the term of boundary condition while fixing the bottom. Total vertical pressure was applied on the column to create the dead load effect of the upper storey which is equal to 0.125MPa on each column. It was corresponding to an axial load ratio ($P/f_{ck}A_g$) of about 1% on each column of the frame where P, f_{ck} and A_g represent the axial load, compressive strength of concrete cubes at 28 days and gross area of column section respectively [18

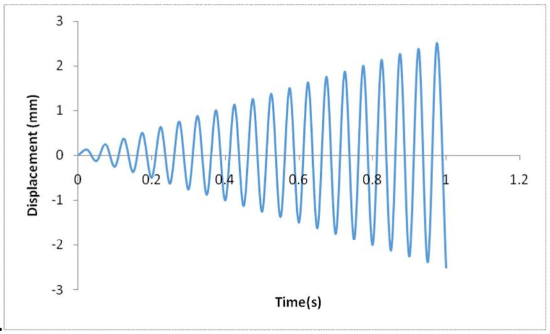

Fig. 2 Applied cyclic load

IV. MODELLING

Reinforcement bars are modelled as a wire element and are characterized by defining cross section area. All the bars are then meshed and assembled as per the detailing shown in the figure forming a cage. After that they are embedded in concrete frame. Size of meshing of reinforcement is taken as 5mm [14]. Concrete and infill units are modelled as a solid homogeneous material with size of mesh as 20mm [14].

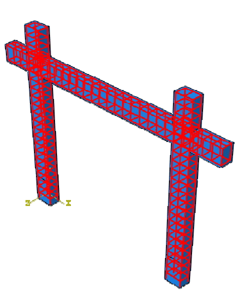

Fig. 3 Provided Reinforcement

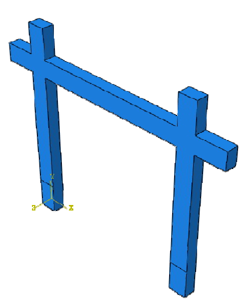

Fig. 4 Model of Bare RC frame

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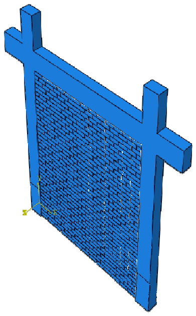

Fig. 5 Model 1R

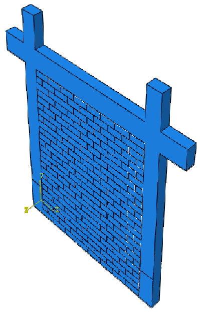

Fig. 6 Model 2R

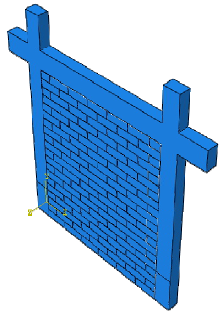

Fig. 7 Model 3R

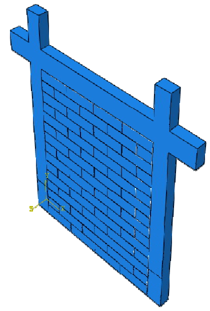

Fig. 8 Model 4R

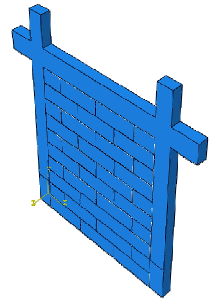

Fig. 9 Model 5R

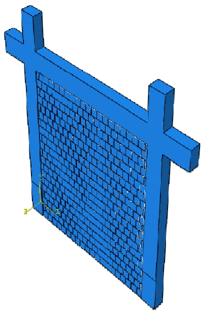

Fig. 10 Model 1S

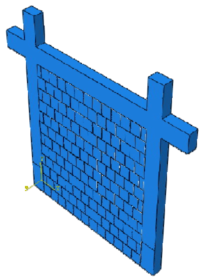

Fig. 11 Model 2S

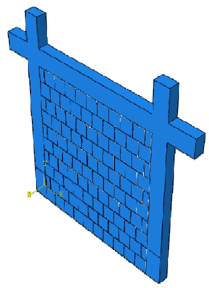

Fig. 12Model 3S

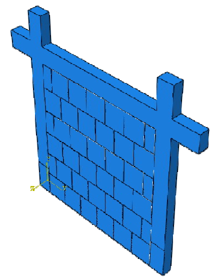

Fig.13 Model 4S

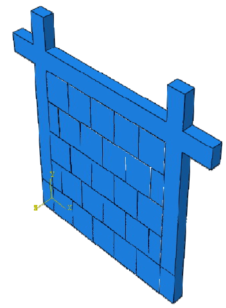

Fig. 14 Model 5S

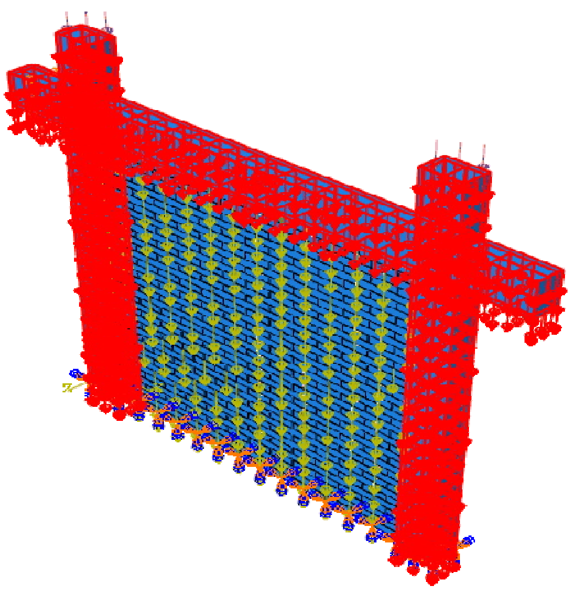

Fig. 15 Body force of assembly

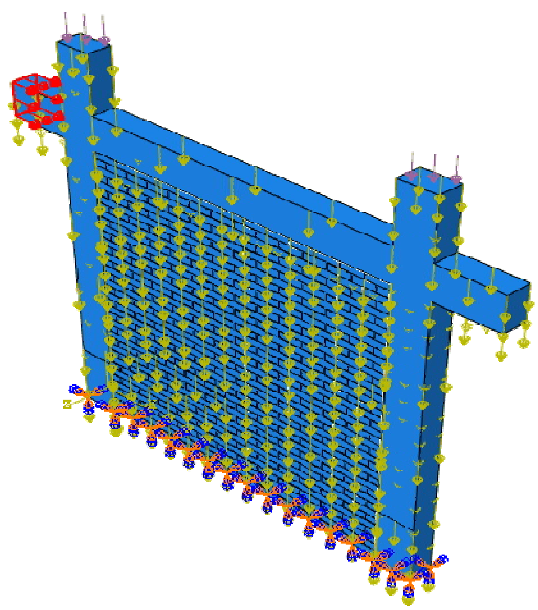

Fig. 16 Cyclic load applied at beam level with fixed boundary condition at base

V. RESULTS AND DISCUSSION

After the application of loads the finite element analysis was done and stress in concrete, lateral resistance of frame at base and drift of frame were taken out as an output parameter

Table 9 Results of bare frame

Stress in Concrete (MPa)	Lateral Force (kN)	Drift (mm)
38.23	6.193	4.48

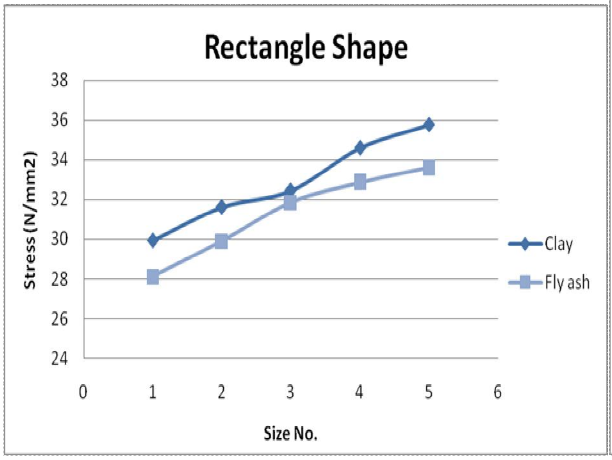

Fig. 17 Comparison of stress in concrete in rectangle clay and fly ash material

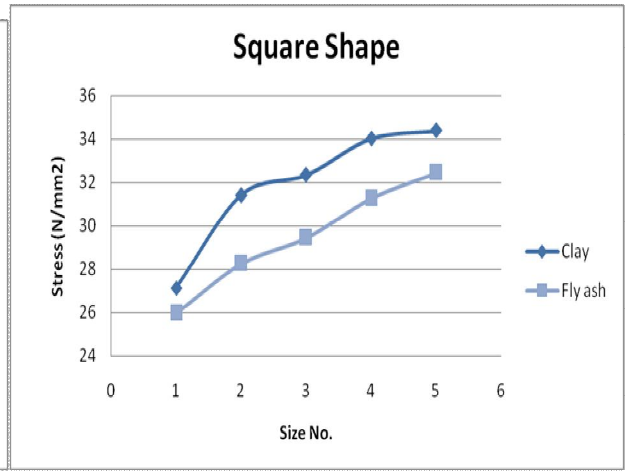

Fig.18 Comparison of stress in concrete in square clay and fly ash material

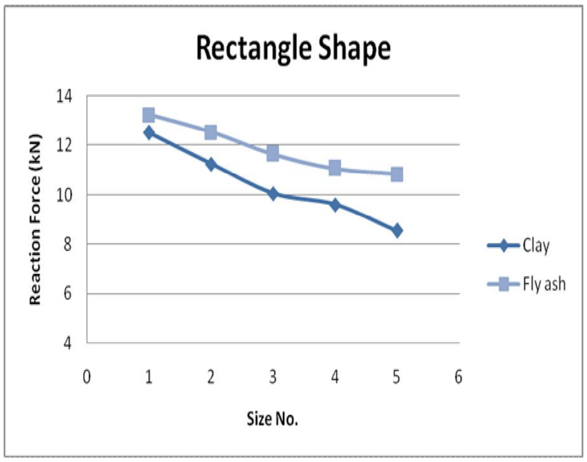

Fig. 19 Comparison of reaction force in rectangle clay and fly ash material

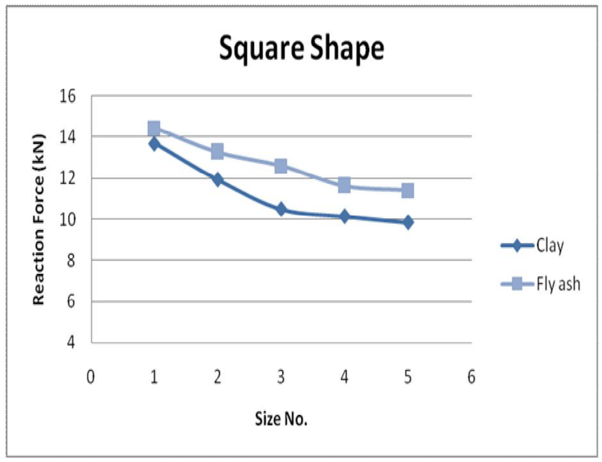

Fig.20 Comparison of reaction force in square clay and fly ash material

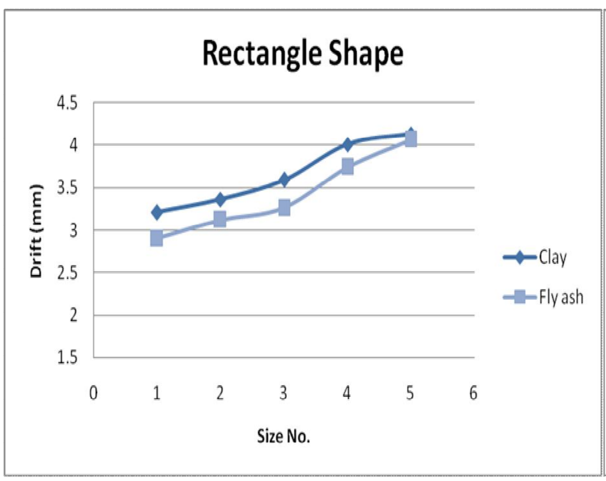

Fig. 21 Comparison of drift of frame in rectangle clay and fly ash material

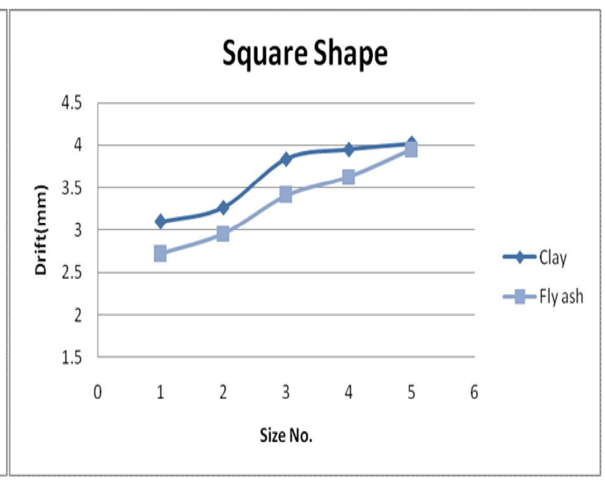

Fig.22 Comparison of drift of frame in square clay and fly ash material

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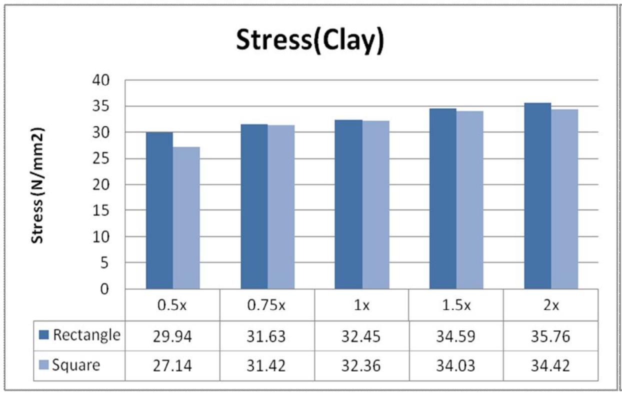

Fig.23

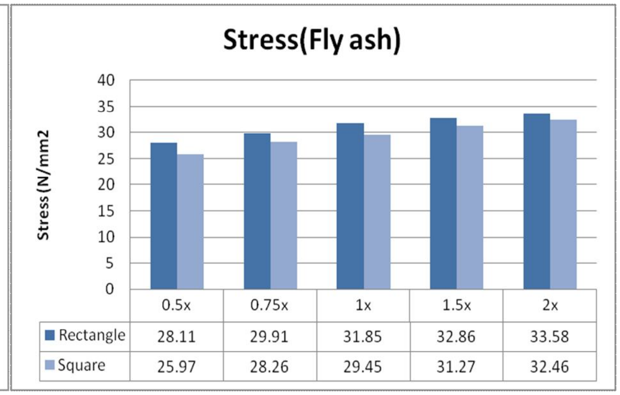

Fig.24

Fig.23 and Fig.24 Comparison of stress in concrete between rectangle and square shaped masonry unit of clay and fly ash

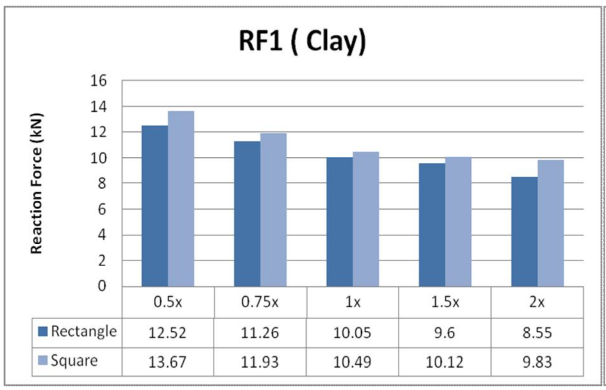

Fig.25

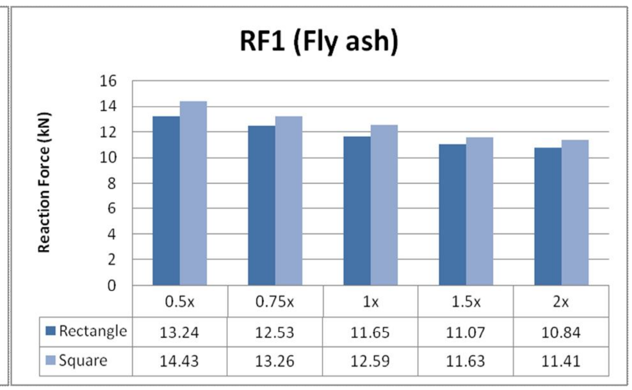

Fig.26

Fig.25 and Fig.26 Comparison of reaction force in direction 1 between rectangle and square shaped masonry unit of clay and fly ash

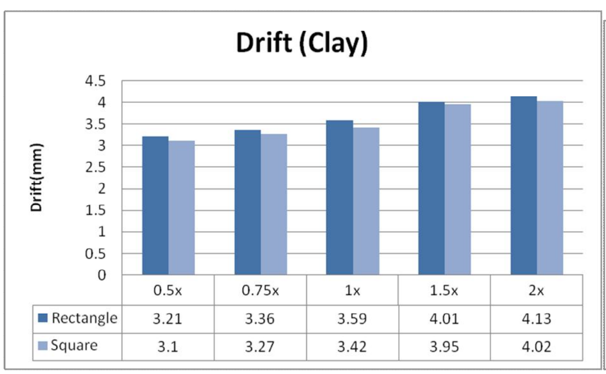

Fig.27

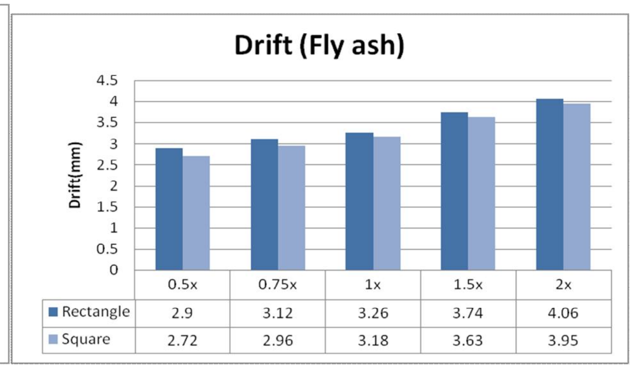

Fig.28

Fig.27 and Fig.28 Comparison of Drift of RC frame between rectangle and square shaped masonry unit of clay and fly ash

From the results obtained after the analysis it is shown that average lateral load resisting capacity of RC frame with square brick of clay material is 7.23% higher than the rectangle brick and it is 6.3% for fly ash material. Average stress in concrete for square brick of clay material is 3.12% lesser than the rectangle brick and it is 0.6% for fly ash material. Average drift of RC frame with square brick of clay material is 0.8% lesser than the rectangle brick and it is 2.4% for fly ash material. The best combination of size, shape and material is Size 1S of fly ash. The lateral load carrying capacity of bare frame is significantly low i.e. 57% less than the size 1S (fly ash) frame. In terms of displacement (storey drift) behaviour the range is 2.72-4.13mm and for bare frame it is 4.48mm which is 7.8% higher than the maximum value from the range.

VI. CONCLUSIONS

In plane cyclic load was applied on RC frame with infill wall made of units with different shapes, sizes and material. Based on the detailed numerical study, following conclusion were drawn:

1) RC frame with infill wall perform good than bare frame.
2) Performance of fly ash brick infill frame found to be better than the clay brick infill frame.
3) Smaller size and square shaped infill units gave good response than the bigger size and rectangle shaped infill units.
4) The best combination of size, shape and material is Size 1S of fly ash.

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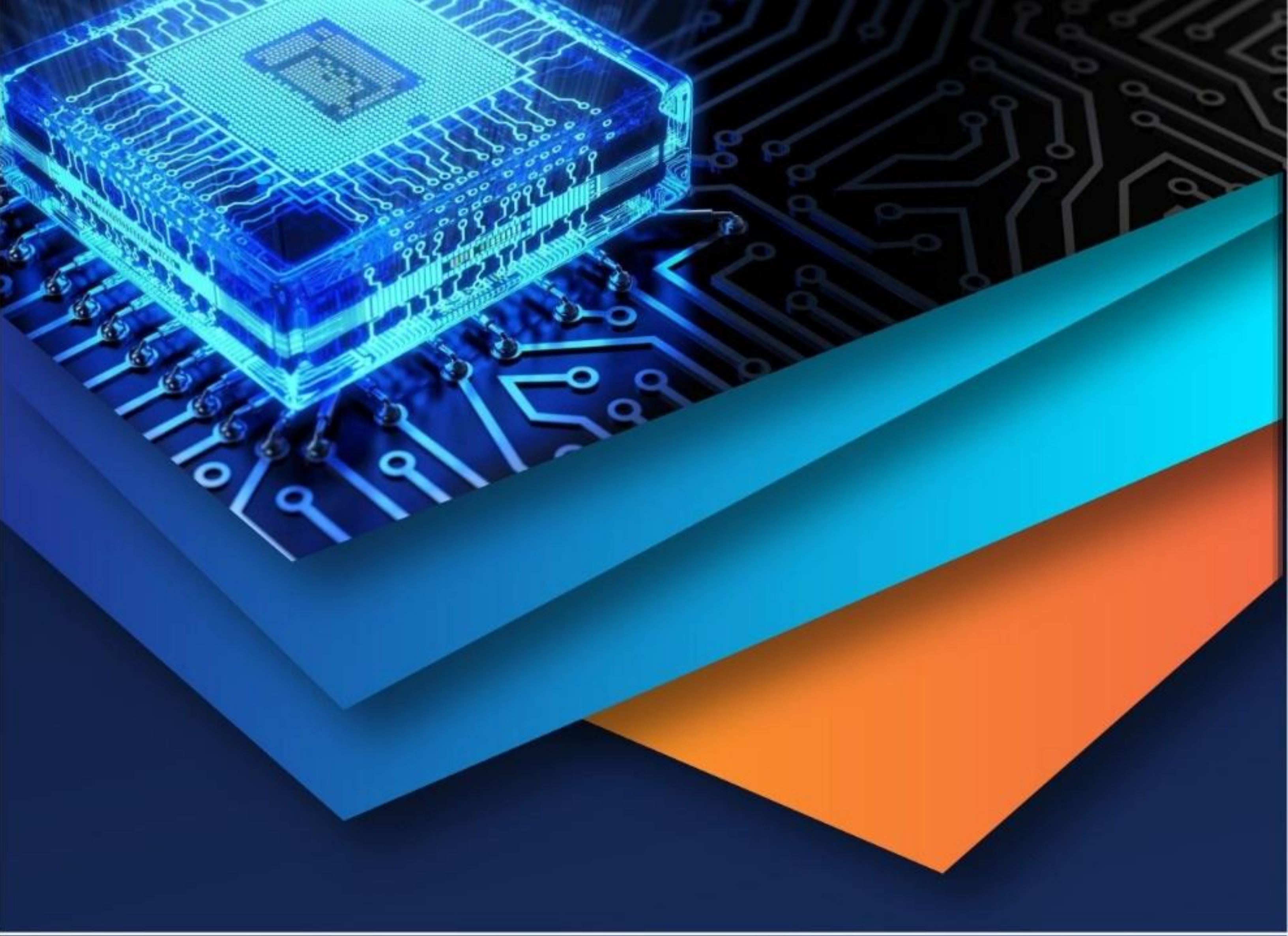

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