# STRUCTURAL BEHAVIOUS OF HYBRID ASH BRICK MASONARY PRISM AND MASONRY USING ABAQUS

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***Abstract*— The compressive strength of masonry, whether it is brick or concrete block (solid or hollow), is of paramount importance in the design of masonry structures which are now being increasingly used. The compressive strength of masonry depends on the strength and elastic properties of masonry unit, mortar etc. Experimental determination of masonry compressive strength requires a lot of time in addition to effort. This drawback can be overcome by effective and reliable computer simulation of masonry wall test. The present work aims at simulating the masonry wall test using ABAQUS software. Some of the masonry wall tests available in literature as well as the wall test conducted in the present work have been successfully simulated using the aforesaid software. There is a reasonable agreement between the experimental and numerical values for compressive strength of solid fly ash brick masonry as obtained from the wall test of present work. The experimental carried out to determine the efficiency of ash brick in strengthening of masonry wall. Masonry wall have been build using fly ash bricks and cement mortar such as 1:4 where the parameters such as ultimate load and stress strain behaviour are measured and analysed using ABAQUS. The crack patterns observed during the experiment (masonry prism test) and predicted by ABAQUS resemble each other to a good extent.**

***Keywords*— *Masonry wall; fly ash brick; compressive strength; finite element analysis; stress strain behaviour; ABAQUS, Gypsum, Eco- sand.***

## I. INTRODUCTION

Fly ash brick masonry is a popular construction throughout India and in developing countries. Fly ash bricks have better durability, strength and reliability and are easily available.

In recent years, growing awareness on the environmental impact of using fertile topsoil for brick manufacturing has prompted the search for alternative systems of masonry units. On the other hand, fly-ash and pond ash are produced in a large amount from thermal plants which causes environmental pollution. To overcome above problems fly ash and pond ash can is effectively utilized in making bricks as an alternative to clay in bricks and recommended to use in masonry construction

Masonry construction can be considered to mark the commencement of the civil engineering. It has a pleasing appearance. The international building code defines masonry as "a built-up construction or combination of building units or materials of shale, clay, stone, glass, concrete, gypsum or other units bonded together with mortar or without mortar or grout". ASTM (American Society for Testing and Materials) defines masonry as "construction usually in the mortar of natural stones or manufactured masonry units like a brick, concrete block, adobe, brick tile, manufactured stone and gypsum block".

The compressive strength of masonry is usually determined by testing the masonry specimens in compression. In general, 3 types of masonry specimens are considered, namely, masonry prism, and masonry Wallette and masonry wall. Masonry prisms consist of several courses of masonry units laid on the mortar. The prism could be stack bonded or in other bonds like English and Flemish. The masonry prism is usually of one brick or masonry unit of one width. Masonry walls are tested for compressive strength in accordance with American Standard Testing of Materials (ASTM) [4].

Testing of masonry wall is the simplest and least expensive. Masonry wallette is a short wall of several courses. The width of the wallette consists of 3 or more units of masonry. The wall usually contains number of masonry units than a prism. It has a number of perpend joints besides the bed joints. Walls are more realistic than a prism since they contain a number of perpend joints. However, testing of a wall is more expensive in terms of financial outlay and effects involved. A masonry wall has a height comparable to the actual wall. Such a specimen helps in evaluating the effect of slenderness more accurately [12]. A vast literature exists on masonry testing and a few of them are mentioned here.

## II. FEM ANALYSIS USING ABAQUS

Abaqus FEA (formerly ABAQUS) is a software suite for finite element analysis and computer-aided engineering, originally released in 1978. The name and logo of this software are based on the abacus calculation tool.

The Abaqus product suite consists of five core software products

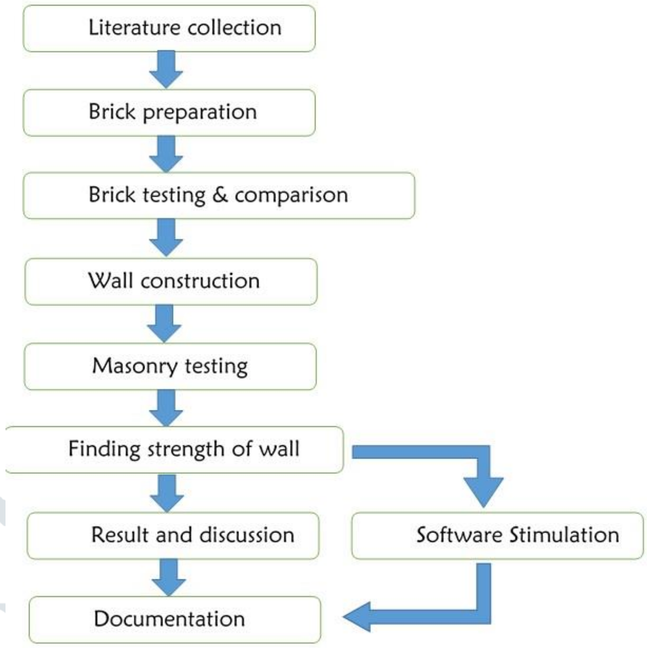
- Abaqus/CAE, or "Complete Abaqus Environment" (a backronym with an obvious root in Computer-Aided Engineering). It is a software application used for both the modeling and analysis of mechanical components and assemblies (pre-processing) and visualizing the finite element analysis result. A subset of Abaqus/CAE including only the post-processing module can be launched independently in the Abaqus/Viewer product.

- Abaqus/Standard, a general-purpose Finite-Element analyzer that employs implicit integration scheme (traditional).
- Abaqus/Explicit, a special-purpose Finite-Element analyzer that employs explicit integration scheme to solve highly nonlinear systems with many complex contacts under transient loads.
- Abaqus/CFD, a Computational Fluid Dynamics software application which provides advanced computational fluid dynamics capabilities with extensive support for preprocessing and postprocessing provided in Abaqus/CAE.
- Abaqus/Electromagnetic, a Computational electromagnetics software application which solves advanced computational electromagnetic problems.
- ABAQUS is used in the automotive, aerospace, and industrial products industries. The product is popular with non-academic and research institutions in engineering due to the wide material modelling capability, and the program's ability to be customized, for example, users can define their own material models so that new materials could also be simulated in ABAQUS.
- ABAQUS also provides a good collection of multiphysics capabilities, such as coupled acoustic-structural, piezoelectric, and structural-pore capabilities, making it attractive for production-level simulations where multiple fields need to be coupled.
- ABAQUS was initially designed to address non-linear physical behaviour; as a result, the package has an extensive range of material models such as elastomeric (rubberlike) and hyper-elastic (soft tissue) material capabilities. Every complete finite-element analysis consists of 3 separate stages:

1. Pre-processing or modeling: This stage involves creating an input file which contains an engineer's design for a finite-element analyzer (also called "solver").
2. Processing or finite element analysis: This stage produces an output visual file.
3. Post-processing or generating report, image, animation, etc. from the output file: This stage is a visual rendering stage.

Abaqus/CAE is capable of pre-processing, post-processing, and monitoring the processing stage of the solver; however, the first stage can also be done by other compatible CAD software, or even a text editor. Abaqus/Standard, Abaqus/Explicit or Abaqus/CFD are capable of accomplishing the processing stage. Dassault Systemes also produces Abaqus for CATIA for adding advanced processing and post processing stages to a pre-processor like CATIA.

## III. METHODOLOGY




## IV. ATTRIBUTES

### *A. Fly Ash*

Class: C - Fly ash normally produced by burring lignite or sub-bituminous coal.

Class : F – Fly ash normally produced by burning Anthracite or bituminous coal.

The fly ash for the present investigation was procured from Mettur Thermal Power plant. The specific gravity of fly ash was 2.08. In all the samples, fraction finer than 2% was maintained as 7.7%. Its LL, PL, and PI were 15%, 15%, and 0% respectively. The OMC and MDD were 45% and 800 kg/m3 respectively. The chemical composition of fly ash is presented in Table

Fly ash is obtained from Mettur Thermal Power plant (near Salem).The specific gravity and particle size of fly ash are 2.31 and (10-50) µm respectively. From chemical composition of Fly ash, CaO content is less than 5%, so the fly ash is classified as class F according to the IS code. Lime is procured from Pollachi. This material activates fly ash and pond ash in mix. As per IS 6932-1973, the minimum 20% CaO content in lime is present for addition in manufacturing of brick. Gypsum is procured from Trichy.

It is used to accelerate the hardening process and obtaining the early strength. The local available sand is used to achieve the mix content. As per IS 353:1970, the sand is categorized as Zone II type. The specific gravity of sand is 2.66. Usage of sand in the manufacturing of brick reduced laminar crack in the mix

Physical Properties

| | |
|---|---|
| Specific Gravity | 2.54 to 2.65 gm/cc |
| Bulk Density | 1.12 gm/cc |
| Fineness | 350 to 450 m2/Kg |

*B. GYPSUM*

Gypsum is a non- hydraulic binder occurring naturally as a soft crystalline rock or sand. Gypsum have a valuable properties like small bulk density, incombustibility, good sound absorbing capacity, good fire resistance, rapid drying and hardening with negligible shrinkage, superior surface finish, etc. In addition it can strengthen material or increase viscosity. It has a specific gravity of 2.31 grams per cubic centimetre. The density of gypsum powder is 2.8 to 3 grams per cubic centimetre.

*C. ECO- SAND*

Eco sand are very fine particles, a bi-product from cement manufacture which can be used to increases efficiency in concrete.. Its micro-filling effect reduces pores in concretes and provides better moisture resistivity and thus durability. It has more consistent grading than many extracted aggregates. Effective use for waste material and thus cost effective and performs as well as naturally occurring sand.

The use of eco sand rather than extracted or dredged natural sand will help designers and contractors address issues of sustainability. The present study is checking the compressive strength of concrete cube using eco sand, cement and supo flow.

The eco sand has various advantages such as energy efficient, fire resistant, reduction of dead load, environmentally friendly, durable, light weight, low maintenance low construction cost.

Many researchers have been carried out investigated on Eco sand in the past years to assess the properties and its behaviour. Some of the works carried out are discussed below. S.L. Beckwith, J.M. Justice, L.H. Kennison, B.J. Mohr (2014) investigates the performance of two metakaolins as Supplementary Cementitious Materials (SCMs) was evaluated at 8% by weight cement replacement. The metakaolins varied by their surface area (11.1 vs. 25.4 ECO25%/g). Performance of metakaolin mixtures was compared to control mixtures at water-to-cement ratios of 0.40, 0.50, and 0.60 where no SCM had been used and to mixtures where silica fume had been used as partial replacement for cement. In both mixtures containing metakaolins, compressive, splitting tensile and flexural strengths increased, as well as elastic modulus, as compared to control mixtures. Setting time was reduced in the pastes with both metakaolins. Additionally, considering durability, both metakaolins reduced rapid chloride ion permeability and expansion due to alkali-silica reaction when compared to control and silica fume mixtures. In general, the finer of the two metakaolins proved more effective in improving concrete properties, although both performed superior to silica fume.

Vishnumanohar (2014) investigates by carried out Eco sand (finely graded silica) is a locally available, low cost, and inert industrial solid waste whose disposal is a matter of concern likes construction waste. On an overall, the Eco sand can be comparable to the natural river sand. The Eco sand satisfies the zone III gradation for not only to partially replace the sand, but for making good concrete. From the obtained results we observed that the maximum strength is achieved by 15% of fine aggregate replacement with eco sand in concrete. While increasing the percentage of eco sand the compressive strength value is getting decreased. From the SEM analysis, at a 15% replacement the mix remains homogeneous as the micro pores are filled and the transition zone is densified. Higher the percentage of fine aggregate replacement higher was the strength activity index. The strength activity index nearly varies linearly with percentage replacement of fine aggregate with eco sand. The maximum strength activity index was 1.49 at 15% replacement level. From the experimental investigation it was found that 15% replacement level is the optimum level.

TABLE I. PHYSICAL PROPERTIES OF ECO-SAND

| Properties | Result |
|---|---|
| Specific gravity | 2.42 |
| Fineness modulus | 0.028 |

TABLE II. PHYSICAL PROPERTIES OF ECO-SAND

| Sl. No | Chemicals | Amount % |
|---|---|---|
| 1 | Silica ($SiO_2$) | 68.1 |
| 2 | Alumina ($Al_2O_3$) | 10.7 |
| 3 | Potassium ($K_2O$) | 4.3 |
| 4 | Calcium (CaO) | 2.2 |
| 5 | Iron ($Fe_2O_3$) | 1.7 |
| 6 | Sodium ($Na_2O$) | 0.6 |
| 7 | Magnesium (MgO) | 0.5 |
| 8 | Loss of ignition ($H_2O$) | 11.5 |

*D. BOTTOM ASH*

It is collected at the bottom of the boiler furnace and is characterized by better geotechnical properties. Coal bottom ash and fly ash are different physically, mineralogical and chemically. Bottom ash is a coarse, granular, incombustible by product that is collected from the bottom of the furnaces that burn coal for the generation of steam, the production of electric power or both. Bottom ash is coarser than fly ash, and grain sizes varying from fine sand to fine gravel. The type of by-product produced depends on the type of furnace used to burn the coal.

*E. LIME*

Lime is an important binding material in building construction. It is basically Calcium oxide (CaO) in natural association with magnesium oxide (MgO).Lime reacts with fly ash at ordinary temperature and forms a compound possessing cementitious properties. After reactions between lime and fly ash, calcium silicate hydrates are produced which are responsible for the high strength of the compound.

## V. BRICK CASTING

Using materials for the hybrid ash brick with eco-sand, bottom ash, black fly ash, lignite ash, lime, gypsum are used in various mix proportions, given below in the table

TABLE III. MIX RATIOS FOR BRICKS

| Materials/Sample | S-1 | S-2 | S-3 | S-4 | Market Proportion |
|---|---|---|---|---|---|
| Eco- sand | 52 | 54 | 56 | 58 | 53 (crusher powder) |
| Black fly ash | 16 | 14 | 12 | 10 | 13 |
| Bottom ash | 2 | 2 | 2 | 2 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| Lignite ash | 14 | 14 | 14 | 14 | 15 |
| Lime | 13 | 13 | 13 | 13 | 14 |
| gypsum | 3 | 3 | 3 | 3 | 3 |

*A. BRICK DETAILS*

Size of brick

Stretcher = 23 cm
Header = 10 cm
Depth = 7.6 cm

Frog

- Outer

L = 19 cm
B= 4cm
D= 1.5cm

- Inner

L = 18 cm
B= 3.2cm

Volume of frog = L x H x [(P+Q) / 2]
= 19 x 1.5 x [(4+3.2) / 2]
= 102.6 cm3
= 1.026 x 10-4 m3

- ❖ 102 bricks can be casted for total weight of material is 278kg in a batch
- ❖ Initial curing days = 3 Days
- ❖ Total curing days = 15 days

Fig.1 Brick Material Mix Using Double Drum Mixer

Fig.2 Transportation Of Mix Using Conveyor Belt

Fig.3 Mix Sample

Fig.4 Molding

Fig.5 Casted Hybrid Ash Brick Bricks


Fig.6 Wet weight of conventional fly ash brick


Fig.7 Wet weight of hybrid ash brick

## VI. TEST AND RESULT

### A. COMPRESSION TESTING

Compressive strength is one of the important fundamental properties of bricks. The compressive strength test on bricks was conducted as per IS 3495 (Part-1):1992- Methods of Test Fly Ash Building Bricks- Determination of compressive strength using compression testing machine of capacity 100 tones. 30 brick specimens were tested for determination of compressive strength.

TABLE IV. COMPRESSION STRENGTH

| Sample | Compression (N/mm$^2$) |
|---|---|
| S-1 | 7.9 |
| S-2 | 8.2 |
| S-3 | 7.5 |
| S-4 | 7.2 |
| Conventional | 7.4 |

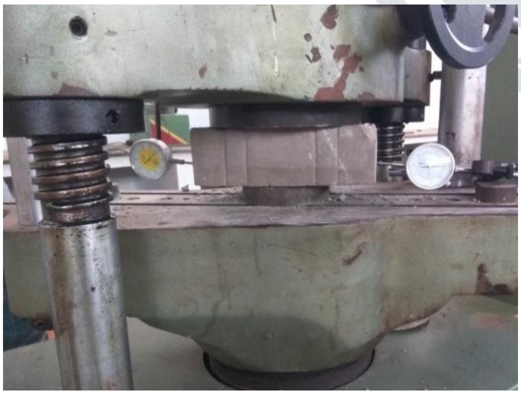


Fig.8 Compression strength test

### B. WATER ABSORPTION

The water absorption test was conducted as per IS: 3495(Part-2): 1992. Method of Test of Fly Ash Building Bricks. Determination of water absorption. A batch of 30 brick specimens of each type were tested for water absorption capacity. Figure shows the experimental setup for water absorption test.

Fig.9 Water absorption test

TABLE V. WATER ABSORPTION TEST

| Sample | Water Absorption (%) |
|---|---|
| S-1 | 10.6 |
| S-2 | 9.6 |
| S-3 | 10.5 |
| S-4 | 11.3 |
| Conventional | 10.5 |

### C. WEIGHT DENSITY

Totally 3 brick specimens of each type were tested for weight density. The volume of the brick was calculated. The weight of the brick was measured by weighting balance. The weight density of the brick is defined as the ratio of weight of the brick to volume of the brick. Figure shows the experimental setup for weight density test.

Weight density = (weight / volume) Kg/m3

Size of bricks used for volume calculation is as follows:

Fly ash brick: 230mm x 100mm x 76mm

TABLE VI. WEIGHT DENSITY TEST

| Sample | Weight Density (Kg/m$^3$) |
|---|---|
| S-1 | 1740.78 |
| S-2 | 1729.27 |
| S-3 | 1753.13 |
| S-4 | 1735.24 |
| Conventional | 1812.76 |

### D. EFFLORESCENCE

The efflorescence test is performed to know the presence of any alkaline matter in the bricks. It was performed as per IS: 3495 (Part-3): 1992. Method of Tests of Fly Ash Building Bricks – Determination of Efflorescence. The efflorescence test was conducted on 15 brick specimens of each type.

The brick was placed in the container the depth of immersion in water being 25mm. the whole arrangement was placed in warm and well ventilated room; the brick specimen absorbed almost all water in the container. When the water was the depth of 25mm water in the container and the same procedure was repeated. Figure shows the experimental setup for efflorescence test. The brick was examined for white/grey patches after 24 hours. The development and appearance of white/grey patches could be described as nil, slight, moderate, heavy or serious.

TABLE VII. EFFLORESCENCE

| SAMPLE | EFFLORESCENCE |
|---|---|
| S-1 | Nil |
| S-2 | Nil |
| S-3 | Nil |
| S-4 | Slight white patch |
| CONVENTIONAL | Nil |

Fig.10 Efflorescence test

## E. SOUNDNESS

Soundness test of brick shows the nature of brick against sudden impact. In this test, 2 brick are chosen randomly and struck with one another / or any harden object. Then sound produced should produce should be clear bell ringing sound and brick should not break. Then it is said to be good.

TABLE VIII. SOUNDNESS

| SAMPLE | SOUNDNESS |
|---|---|
| S-1 | Good |
| S-2 | Good |
| S-3 | Good |
| S-4 | Good |
| CONVENTIONAL | Good |

TABLE IX. OVER ALL COMPARISON OF BRICKS

| Testing/ Sample | S-1 | S-2 | S-3 | S-4 | Conventional |
|---|---|---|---|---|---|
| Compression ($N/mm^2$) | 7.9 | 8.2 | 7.5 | 7.2 | 7.4 |
| Water absorption % | 10.6 | 9.6 | 10.5 | 11.3 | 10.5 |
| Weight density ($Kg/m^3$) | 1740.78 | 1729.27 | 1753.13 | 1735.24 | 1812.76 |
| Efflorescence | Nil | Nil | Nil | Light white patch | Nil |
| Soundness | Good | Good | Good | Good | Good |

## F. BRICK MASONRY PRISM

Prism is the assemblage of individual units laid in and bound together by mortar. The common materials of masonry construction are brick, stone, marble, granite, and travertine, limestone, cast stone, concrete block, glass block, stucco, tile and cob. Masonry is generally a highly durable from of construction. However, the materials used, the quality of the mortar and workmanship, and the pattern in which the units are assembled can significantly affect the durability of the overall masonry construction. There are many types of bond is available. In this project, stacked bond was used for construction of brick masonry prism

Fig.11 Hybrid ash brick masonry prism

Size of brick masonry wall,

Length = 220cm

Breadth = 220cm

Depth = 330cm

Mortar mix ratio

Cement (OPC), Fine Aggregate (river sand) are mixed in the ratio of 1:4,

Calculation

Total volume of mortar = 0.0041 m3

Cement = 1440 x 0.0041 = 5.9 Kg

= (1/5) x 5.9
= 1.18 Kg

Fine aggregate = 1520 x 0.0041 = 6.232 Kg = (4/5) x 6.232

= 4.98 Kg

Mix ratio (1:4) = 1.18: 4.98 Kg

## G. STRESS STRAIN BEHAVIOUR OF MASONRY PRISM

The stress-strain behaviour of clay brick, fly ash brick and coal ash brick was studied by using universal compressive testing machine of capacity 100 tones. A dial gauge with least count of 0.01mm was used to measure the deflection. The dial gauge was fixed with respect to lateral and longitudinal direction of brick specimen. Two dial gauges were fixed in lateral direction. Figure shows the experimental setup for stress strain behaviour test of bricks. Compressive load was applied gradually at uniform rate and at equal intervals of loading and the corresponding deflections were measured with the help of dial gauges. The failure load was noted. The stress-strain curves for the two types of brick were obtained by averaging the stress strain data from 2 sample of each type of brick. Modulus of elasticity of the various bricks was found by using stress-strain curves of brick. Totally 2 brick specimens of each type were used for the determination of young's modulus of two types of bricks.

| Stress ($N/mm^2$) | Strain | Young's modulus (GPa) |
|---|---|---|
| 2883 | 0.0032 | 1.21 |
| 2920 | 0.0037 | 1.22 |

ANALYSIS TEST RESULTS ON HYBRID ASH BRICK MASONARY PRISM

| Stress ($N/mm^2$) | Strain | Young's modulus (GPa) |
|---|---|---|
| 3119 | 0.002 | 1.695 |
| 3019 | 0.0025 | 1.72 |

## VII. ANALYSIS

### A. *ABAQUS MODELLING*

Basic steps of ABAQUS modelling
Start windows – run ABAQUS CAE

1. Start session – run the explicit model
2. Add part – sketch the part- done- add depth – enter the valid depth
3. Add property- select part – edit material- (mechanical, plastic, elastic )
4. Enter young's modulus & passion ratio- assign material to the elements
5. Assembly – create an instance
6. Step- initial- static general -continue
7. Load- loads- pressure – set surface- set load value
8. Create boundary conditions-symmetry/ asymmetry/ Encastre – set surface of support / select Encastre
9. Mesh- select part-set mesh part( yes) – set global size of the mesh
10. Set job- select model- run a full analysis
11. Job manager- select job – submit- run analysis- complete analysis
12. Result

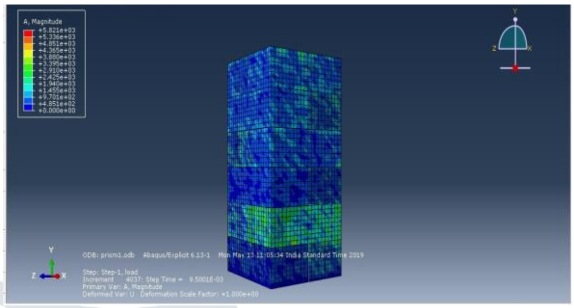


***Figure 13 A.Magnitude of hybrid fly ash bricks in masonry prism***

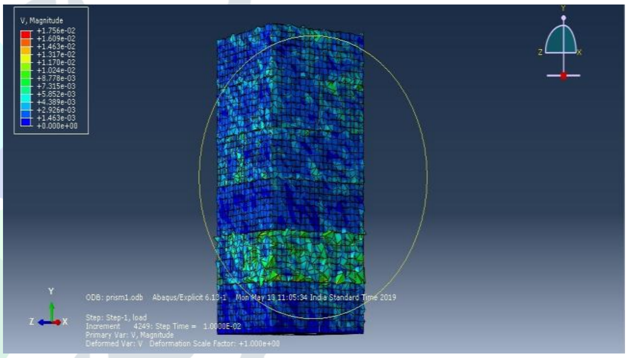


***Figure 13 V.Magnitude of hybrid fly ash bricks in masonry prism***

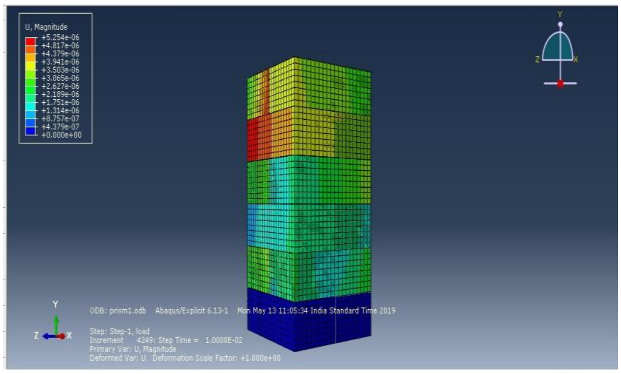


***Figure 14 U. Magnitude of hybrid fly ash bricks in masonry prism***

| BRICK | LOAD (KN) | Experimental lab analysis | ABAQUS analysis |
|---|---|---|---|

| | | STRESS ($N/mm^2$) | STRAIN | STRESS ($N/mm^2$) | STRAIN |
|---|---|---|---|---|---|
| Conventional | 170.2 | 7.4 | 0.0056 | 7.2 | 0.0055 |
| HB-2 | 188.6 | 8.2 | 0.0054 | 8.1 | 0.0052 |
| Clay brick | 156.4 | 5.7 | 0.0052 | 5.4 | 0.0051 |

## VIII. CONCLUSION

As following above analytical results we concluded that as following,

- Ash brick masonry had 20% more load carrying capacity compared with Conventional brick masonry.
- Ash brick masonry had 15% more strength capacity compared with Conventional brick masonry.
- Ash brick masonry had 25% less Strain compared with Conventional brick masonry.
- Ash brick masonry had 30% more Elastic property compared with Conventional brick masonry.
- So, Ash brick masonry will be good alternate for conventional brick masonry.

## REFERENCES

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first ..."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

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