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NONLINEAR STATIC (PUSH OVER) ANALYSIS OF MASONRY WALL

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Abstract- Present work investigates the seismic evaluation of unreinforced masonry (URM) wall using a non-linear static (pushover) analysis method with SAP2000. In this work modeling of six models (with openings and without openings) of a masonry wall is done, After that non-linear static (pushover) analysis was performed on all models of masonry wall for the selected meshing size (16x16) for intermediate masonry property (.25f'm). The Base Shear values for DBE and MCE hazard levels for the model (1, 2, 3, 4, 5, 6) are calculated as per IS 1893-2016. Displacement Vs Base Shear (Pushover Curve) values are obtained. Also, demands calculated from IS-1893:2016 and FEMA 356 is compared with the capacity of all models. The result shows an increase in the capacity of the wall with beam & columns and wall without openings shows better response as compared to other walls.

Keywords -Unreinforced masonry (URM), structures, seismic evaluation, intermediate.

I. INTRODUCTION

About 70% of the buildings in the world are masonry. Masonry structures are widely used due to the low-cost and easy availability of materials. The occurrence of past and recent earthquakes has highlighted that masonry building performed worst, causing huge loss of lives and properties. Since large no. of masonry buildings were built with no consideration for seismic design requirements, which results as the earthquake has damaged many such buildings seismically. Thus in order to save the life of peoples from losses caused by the earthquake it is required to make them earthquake resistance. Therefore in the last few years, demands for upgrading the masonry buildings are increased. The seismic evaluation of such buildings is still a challenge due to many reasons. Therefore non-linear analysis method was carried out in different parts of the world to investigate the requirements of URM structures.
The main objectives of the paper are (i) Modeling of different models of a masonry wall in SAP 2000. (ii) To perform a nonlinear (pushover) analysis on the masonry walls. (iii) To increase the strength of walls retrofitting is done.

II. LITERATURE REVIEW

The study of previous papers can be done for this work:

Naraine and Sinha [17] investigated the behavior of brick masonry under cyclic compressive loading. A general analytical expression was proposed for the curve which was found to provide a reasonable fit with the experimental data. Lourenco et al. [28] investigated that masonry was a composite material made of units (brick, blocks, etc.). Morbiducci [15] investigated the parameter estimation problem for brick masonry models. An identification procedure was proposed in which the uncertainties of known parameters and errors of measurements were the main elements of distinction. Lourenco et al. [25] investigated the chemical, physical and mechanical properties of handmade clay bricks. T.C. Nwofor [19] analyzed the mechanical properties of clay brick masonry.

Nagarajan et al. [16] investigated the material properties, compressive and shear behavior of brick masonry with different mortar ratios were presented. Pena et al. [20] investigated the macro element techniques for modeling the nonlinear response of masonry panels. The developed technique was efficient and suitable for the analysis of the seismic behavior of complex walls and buildings. Griffith et al. [9] presented the results of static and dynamic tests on unreinforced brick masonry wall panels subject to out-of-plane loading. Kaushik et al. (a) [11] concluded the stress-strain properties of unreinforced brick masonry and their relationship also showed. With the increase in the compressive strength of bricks and mortar, the compressive strength of masonry also increases. Kaushik et al. (b) [12] investigated the uniaxial monotonic compressive stress-strain behavior and other characteristics of unreinforced masonry. From the results and observation of this paper nonlinear stress-strain curves obtained for masonry. Bruneau [2] reviewed the seismic performance of existing unreinforced masonry building and mortar. Calio et al. [4] proposed a simplified model for the evaluation of the seismic behavior of masonry buildings. Sharma et al. [22] calculated the response reduction factor of masonry building using pushover analysis. FEMA 356-2000 procedure was applied in non-linear analysis using SAP-2000 software. Manjula et al. [14] compared the pushover method between the old procedure and advanced procedure. Sharma et al. (a) [23] investigated the seismic evaluation of unreinforced masonry walls when subjected to seismic (lateral) loading. Sharma et al. (b) [24] investigated a seismic evaluation of unreinforced masonry buildings with a flexible diaphragm. Endo et al. [7] presented the comparison among different nonlinear seismic analysis methods applied to masonry buildings. Azevedo et al. [1] analyzed the seismic behavior of structures composed of masonry blocks using the discrete element method. Magenes [13] presented a method for the nonlinear static analysis of masonry buildings. Yang and Wang [26] studied the improvement of the pushover analysis. After the analysis of several frame structures, it was observed that pushover analysis is better than dynamic analysis. Yoshimura et al. [27] investigated the effective seismic strengthening methods for masonry walls in developing countries. Nasini et al. [18] suggested some criteria for the seismic evaluation and design of the restoring and retrofitting intervention to be carried out on the masonry buildings. Rai [21] showed the guideline for seismic evaluation and strengthening of building. From this study, compressive stress-strain relationships at different confining stress levels from experimental results obtained.

The study offers a useful review of pushover analysis methods for masonry structures and shows the advantages and possible limitations of each approach.

III. **METHODOLOGY**

There are two parts of this work. In the first part selection of suitable seismic performance analysis method for unreinforced masonry buildings from previous research papers is done. After that, the modeling of walls is done by using SAP2000. Thus for modeling, suitable mesh size and the type of masonry is selected.

In the second part, seismic analysis of unreinforced masonry walls is done after the selection of suitable mesh size and masonry type by using SAP2000 as per different codes obtained from the previous studies.

A. Geometrical modeling of masonry walls

In this work, six models of free-standing (3m x 3m) walls are taken, and it is considered to fix at its end. A 20 kN/m of the vertical load is considered on the wall. Retrofitting is also done and for retrofitting of walls, beam and columns are used.

➢ Detailed Information about Section Properties is given:

- Size of Door - 940 x 1880 mm
- Size of Window - 750 x 940 mm
- Cross section of column - 250 x 250 mm
- Cross section of the beam - 250 x 250mm

➢ Types of walls:

For modeling of unreinforced masonry walls, six different cases are used with intermediate masonry properties. Types of walls used in this study are –

- A single wall without openings (Model 1).
- Wall with a single beam and without openings (Model 2).
- Wall with beam, columns and without openings (Model 3).
- Single wall with openings (Model 4).
- Wall with a single beam and openings (Model 5).
- Wall with beam, columns, and openings (Model 6).

B. Modeling of walls in SAP2000 software:

The shell area element is adapted to model the walls in SAP2000 by using the finite element method (FEM). In SAP2000 the shell element is a three or four node formulation that combines separate membrane and plate-bending behavior. Homogenous and shell layered are two types of shell elements. The shell element is one type of object area. The Shell element is used to model shell, membrane, and plate behavior in planar and three-dimensional structures.

C. *Material modeling of masonry walls:*

A homogenous modeling approach is applied. In which the test results curve and analytical curve are adopted which was suggested by Kaushik et al. (2007).The mesh size of walls for analysis is selected. According to Sharma et al. (2016), the suitable size of meshing for FEM analysis would be 16x16. Hence 16x16 mesh size is selected for further analysis.

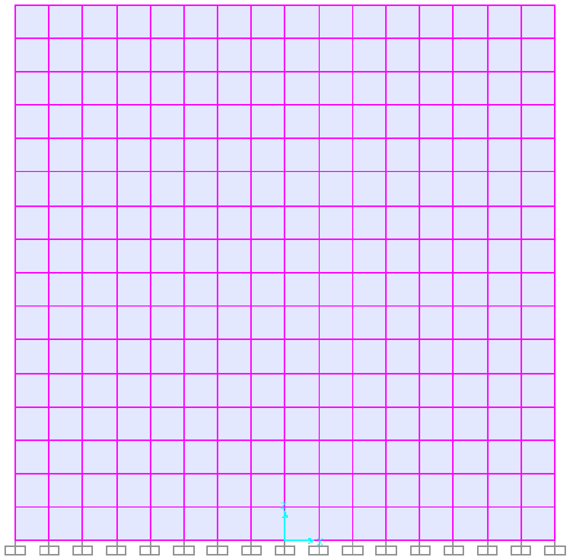

Figure 1 shows the 16x16 mesh

There are three types of masonry properties which were given by Kaushik et al. (2007) are weaker masonry mortar, Intermediate masonry mortar, and stronger masonry mortar. From previous work, it has been observed that intermediate masonry is more suitable for the non-linear static analysis, and then intermediate masonry mortar is selected. For intermediate masonry, stress-strain values are taken from the analytical curve. The stress values are taken up to 0.25f'm as per IS 1905:1987 [5].

Table: 1 Parameter Considered For Masonry

Parameters	**Masonry (0.25f'm)**
Prism strength(f'm)	1650 kN/m^2
Modulus of elasticity (E)	907.500x10^3 kN/m^2
Modulus of rigidity (G)	391163.8 kN/m^2
Poisson's ratio	0.16
Coefficient of expansion	5.5x10^{-6}
Weight per unit volume (W)	20 kN/m^2
Density (p)	2.038

IV. PUSHOVER ANALYSIS OF MASONRY WALL

Pushover analysis is a non-linear static analysis method; it is a procedure where a structure is subjected to continuously increasing lateral loads till a targeted displacement is achieved, or structure is unable to resist further loads. Plotting of the base shear to displacement in a structure is obtained by this analysis that shows any premature failure or weakness. FEMA 356 is adopted for the pushover analysis. Pushover analysis is performed on the masonry wall by using SAP2000.

In this work, the pushover analysis is carried out for six different cases of an unreinforced masonry wall. For the selected masonry wall meshing size (16x16) and intermediate masonry property nonlinear static (Pushover) analysis is performed. Performance is obtained for Design-Based Earthquake (DBE) and Maximum Considered Earthquake (MCE) hazard levels situated in Zone V of India. From the pushover analysis, the pushover curve is obtained.

- *Pushover Curves For Various Models Of Wall*

Displacement Vs Base Shear (Pushover Curve) values for Models of the wall, having a property of Intermediate masonry (0.25f'm), assume the model is situated in Zone V.

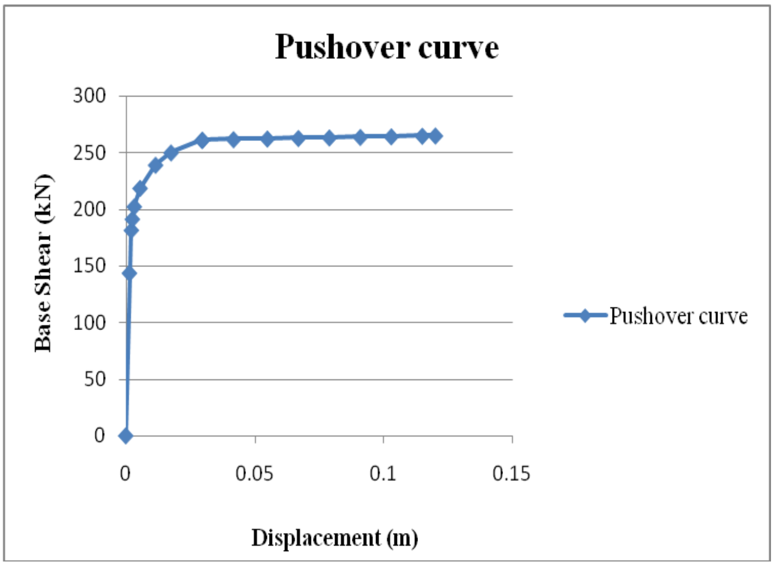

Fig.1 shows the pushover curve for Model 1.

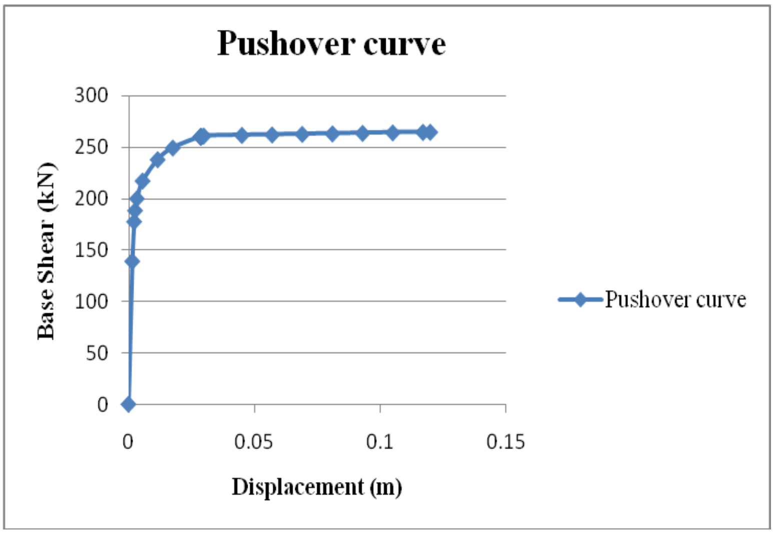

Fig.2 shows the pushover curve for Model 2.

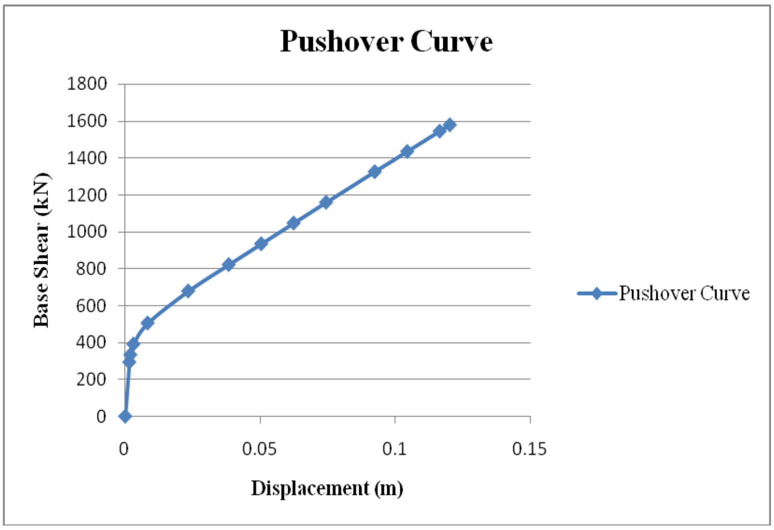

Fig.3 shows the pushover curve for Model 3.

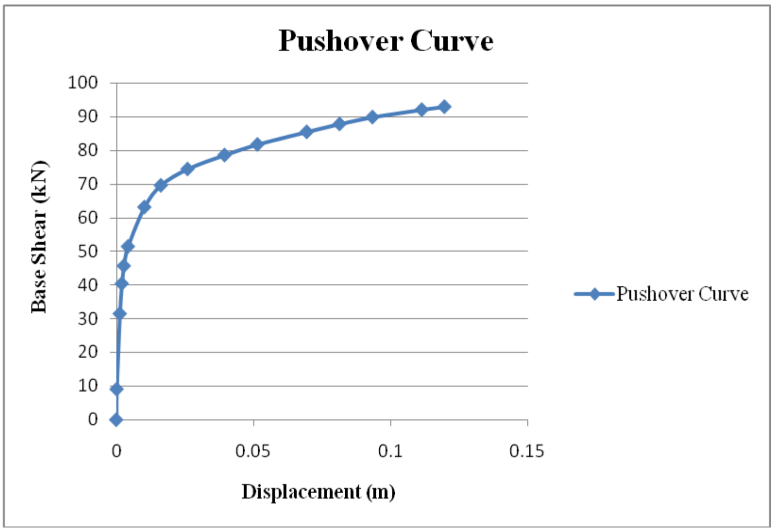

Fig.4 shows the pushover curve for Model 4.

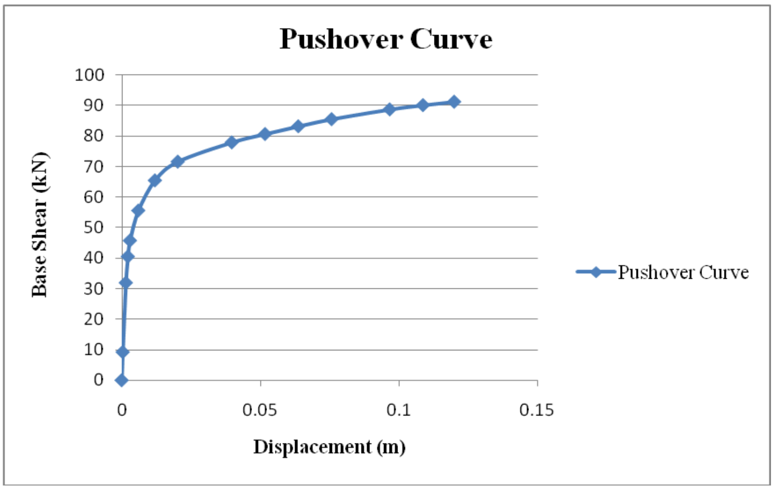

Fig.5 shows the pushover curve for Model 5.

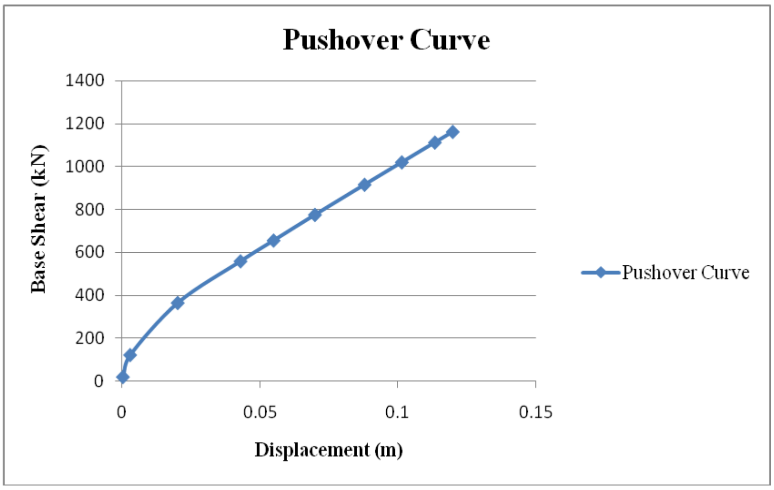

Fig.6 shows the pushover curve for Model 6.

- *Outcomes of the pushover analysis*

A. Based on Base Shear

1) For Model 1, capacity obtained at both hazard levels DBE and MCE is 265.06 kN.

The demands obtained from IS-1893-2016 and FEMA 356 is 111.626 kN and 197.744 kN for DBE and 223.253 kN and 211.110 kN for MCE respectively. Hence, the capacity is more than the demands.

2) For Model 2, capacity obtained at both hazard levels DBE and MCE is 264.90 kN.
The demands obtained from IS-1893-2016 and FEMA 356 is 114.438 kN and 197.085 kN for DBE and 228.876 kN and 210.769 kN for MCE respectively. Hence, the capacity is more than the demands.

3) For Model 3, capacity obtained at both hazard levels DBE and MCE is 1580.13 kN.
The demands obtained from IS-1893-2016 and FEMA 356 is 120.061 kN and 176.876 kN for DBE and 240.122 kN and 347.115 kN for MCE respectively. Hence, the capacity is more than the demands.

4) For Model 4, capacity obtained at both hazard levels DBE and MCE is 92.95 kN.
The demands obtained from IS-1893-2016 and FEMA 356 is 86.025 kN and 76.302 kN for DBE and 172.05 kN and 81.672 kN for MCE respectively. Hence, the capacity is less than the demand (172.05 kN) in the MCE hazard level.

5) For Model 5, capacity obtained at both hazard levels DBE and MCE is 91.283 kN.
The demands obtained from IS-1893-2016 and FEMA 356 is 88.837 kN and 67.042 kN for DBE and 177.67 kN and 71.980 kN for MCE respectively. Hence, the capacity is less than the demand (177.67 kN) in the MCE hazard level.

6) For Model 6, capacity obtained at both hazard levels DBE and MCE is 1162.94 kN.
The demands obtained from IS-1893-2016 and FEMA 356 is 94.46 kN and 190.847 kN for DBE and 188.92 kN and 246.139 kN for MCE respectively. Hence, the capacity is more than the demands.

***B.* Based on Displacement**

1) For Model 1, from the curve, the achieved displacement is 119.92 mm.
The target displacements 2.97 mm for DBE and 4.49 mm for MCE are obtained respectively. So, the achieved displacement is more than the target displacement.

2) For Model 2, from the curve, the achieved displacement is 120.1 mm.
The target displacements 3.18 mm for DBE and 4.77 mm for MCE are obtained respectively. So, the achieved displacement is more than the target displacement.

3) For Model 3, from the curve, the achieved displacement is 120.01 mm.
The target displacements 9.11 mm for DBE and 2.15 mm for MCE are obtained respectively. So, the achieved displacement is more than the target displacement.

4) For Model 4, from the curve, the achieved displacement is 119.78 mm.
The target displacements 32 mm for DBE and 51 mm for MCE are obtained respectively. So, the achieved displacement is more than the target displacement.

5) For Model 5, from the curve, the achieved displacement is 120.01 mm.
The target displacements 14 mm for DBE and 21 mm for MCE are obtained respectively. So, the achieved displacement is more than the target displacement.

6) For Model 6, from the curve, the achieved displacement is 119.96 mm.
The target displacements 7.72 mm for DBE and 12 mm for MCE are obtained respectively. So, the achieved displacement is more than the target displacement.

V. CONCLUSIONS

The observations made from the pushover analysis are:

All models from Model 1 to Model 6 (with and without openings) are safe for DBE hazard level but for MCE hazard level, Model (1,2,3,6) are safe and Model (4,5) are unsafe. The value of base shear for model 3 is more than all other models. Hence model 3 (without opening and with beam and columns) shows better performance as compared to other models.

VI. REFERENCES

[1] Azevedo, J., Sincraian, G., & Lemos, J. V. (2000). Seismic behavior of blocky masonry structures. *Earthquake Spectra*, *16*(2), 337-365.

[2] Bruneau, M. (1994). State-of-the-art report on the seismic performance of unreinforced masonry buildings. *Journal of Structural Engineering*, *120*(1), 230-251.

[3] Building Code Requirements for Masonry Structures, ACI 530- 02/ASCE 5-02/TMS 402-02:2002, Masonry Standards Joint Committee, USA.

[4] Caliò, I., Marletta, M., & Pantò, B. (2005, August). A simplified model for the evaluation of the seismic behavior of masonry buildings. In *Proceedings of the 10th international conference on civil, structural and environmental engineering computing. Stirlingshire, UK: Civil-Comp Press, Paper* (Vol. 195).

[5] Code of Practice for Structural use of Unreinforced Masonry, IS 1905:1987, Bureau of Indian Standards, New Delhi

[6] Criteria for Earthquake Resistance Design of Structures, IS 1893:2016(1), Bureau of Indian Standards, New Delhi.

[7] Endo, Y., Pelà, L., & Roca, P. (2017). Review of different pushover analysis methods applied to masonry buildings and comparison with nonlinear dynamic analysis. *Journal of Earthquake Engineering*, *21*(8), 1234-1255.

[8] Erberik, M. A., Citiloglu, C., & Erkoseoglu, G. (2019). Seismic performance assessment of confined masonry construction at component and structure levels. *Bulletin of Earthquake Engineering*, *17*(2), 867-889.

[9] Griffith, M. C., Lam, N. T., Wilson, J. L., & Doherty, K. (2004). Experimental investigation of unreinforced brick masonry walls in flexure. *Journal of Structural Engineering*, *130*(3), 423-432.

[10] Jain, S. K. (2016). Earthquake safety in India: achievements, challenges, and opportunities. *Bulletin of Earthquake Engineering*, *14*(5), 1337-1436.

[11] Kaushik, H. B., Rai, D. C., & Jain, S. K. (2007). Stress-strain characteristics of clay brick masonry under uniaxial compression. *Journal of Materials in Civil Engineering*, *19*(9), 728-739.

[12] Kaushik, H. B., Rai, D. C., & Jain, S. K. (2007). Uniaxial compressive stress-strain model for clay brick masonry. *Current Science (00113891)*, *92*(4).

[13] Magenes, G. (2000, January). A method for pushover analysis in seismic assessment of masonry buildings. In *Proceedings of the 12th world conference on earthquake engineering* (Vol. 42).

[14] Manjula, N. K., Nagarajan, P., & Madhavan, M. T. P. (2013). A comparison of basic pushover methods. *International Refereed Journal of Engineering and Science*, *2*(5), 14-19.

[15] Morbiducci, R. (2003). Nonlinear parameter identification of models for masonry. *International journal of solids and structures*, *40*(15), 4071-4090.

[16] Nagarajan, T., Viswanathan, S., Ravi, S., Srinivas, V., & Narayanan, P. (2014, March). An experimental approach to investigate the behavior of brick masonry for different mortar ratios. In *Proceedings of the International Conference on Advances in Engineering and Technology, Singapore* (pp. 586-592).

[17] Naraine, K., & Sinha, S. (1989). The behavior of brick masonry under cyclic compressive loading. *Journal of Structural Engineering*, *115*(6), 1432-1445.

[18] NASINI, U., DE SORTIS, A., DI PASQUALE, G., & MOLLAIOLI, F. (2000). Evaluation and design criteria for restoring and retrofitting damaged masonry buildings. In *Proceedings of 12th World Conference on Earthquake Engineering, Auckland*.

[19] Nwofor, T. C. (2012). Experimental determination of the mechanical properties of clay brick masonry. *Canadian Journal on Environmental, Construction and Civil Engineering*, *3*(3), 127-145.

[20] Peña, F., Lourenço, P. B., & Mendes, N. (2008). Seismic assessment of the Qutb Minar in Delhi, India. In the *14th World Conference on Earthquake Engineering* (pp. S11-058).

[21] Rai, D. C. (2005). Seismic evaluation and strengthening of existing buildings. *IIT Kanpur and Gujarat State Disaster Mitigation Authority*.

[22] Sharma, A., & Khare, R. (2016). Pushover Analysis for Seismic Evaluation of Masonry Wall. *International Journal of Structural and Civil Engineering Research*, *5*(3).

[23] Sharma, A., Malviya, S., Khare, R., & Melani, A. (2016). Seismic Evaluation of Masonry Buildings with Flexible Diaphragm: A Performance-Based Approach. *IUP Journal of Structural Engineering*, *9*(2), 7.

[24] Sharma, A., & Khare, R. (2016). Pushover Analysis for Seismic Evaluation of Masonry Wall. *International Journal of Structural and Civil Engineering Research*, *5*(3).

[25] Shreekant, R. L., Aruna, M., & Harsha, V. (2016). The utilization of mine waste in the construction industry–a critical review. *International Journal of Earth Sciences and Engineering*, *9*(01), 182-195.

[26] Yang, P., Li, Y., Wang, Y., & Lai, M. (2000). A Study on Improvement of Push-over Analysis [J]. *Journal of Building Structures*, *1*.

[27] Yoshimura, K., Kikuchi, K., Kuroki, M., Nonaka, H., Kim, K. T., Wangdi, R., & Oshikata, A. (2004, August). Experimental study for developing the higher seismic performance of brick masonry walls. In *Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, Canada, Paper* (No. 1597).

[28] Zucchini, A., & Lourenço, P. B. (2002). A micromechanical model for the homogenization of masonry. *International Journal of Solids and Structures*, *39*(12), 3233-3255.