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RETROFITTING OF HERITAGE MASONRY BUILDINGS WITH SPLINT BANDAGE TECHNIQUE USING GEOSYNTHETIC

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ABSTRACT

Heritage buildings are the dynamic linkage by each generation in the continuum of society. Once they are lost a part of history will be lost forever. 3D finite element analysis is carried to estimate the in-plane and out-of-plane performance of un-reinforced masonry wallette strengthened with geosynthetic. From the in-plane test it is estimated that the diagonal shear strength increased to 72 % as compared to un-strengthened panel, while out of plane test gives increase in flexural strength capacity to 129.23 % as compared to un-strengthened panel. Further seismic performance of geotextile as a retrofitting material for heritage masonry buildings using splint and bandage technique is estimated with similar modelling using historical earthquake. The stress contour and deformation results of the retrofitted model shows better control to mitigate earthquake forces.

KEYWORDS: Retrofitting; Geosynthetic; Masonry Structure; Seismic Response

INTRODUCTION

Beyond the obvious need to protect human life, one must also take the responsibility of protecting heritage buildings as these structures are the dynamic linkage of contribution by each generation in the continuum of society. Once they are lost a part of history will be lost forever. Masonry heritage structures (MHS) are an infinite number of buildings dating back to prehistory and in which many "value meanings"-historical, geological, esthetic, symbolic, financial, political, scientific / technological and economic-include making it a real treasure of the civilization of mankind. These structures are protected from seismic earthquake, natural or anthropogenic disasters, and the life expectancy and the protection from collapse. These heritage structures are old and constructed through combination of non-engineered bricks and mortar. Bricks, being good in compression, perform well under gravity loading acting vertically on the structures. However, such unreinforced masonry (URM) structures are usually inadequate in resisting horizontal load due to earthquake and cyclone because of their low tensile strength. The history of past earthquake has shown worst performance, suffered maximum damages and also accounted maximum loss of life and property. The poor seismic performance of URM buildings was demonstrated by past earthquakes in India and many other countries. The engineering community is therefore challenged to improve the shear capacity and stress of masonry structures in order to increase their suitability during earthquakes. URM walls have two failure: in-plane and out-of-plane. In in-plane, masonry walls tend to progress a diagonal crack, whereas the load acts on the walls in the perpendicular direction, causes the out-of-plane flexural bending of the walls (Figure 1) [1]. Lateral loading can produce diagonal cracking failure and shear failure modes of the horizontal bed joints. On shear walls, the effects of lateral loading due to wind, earthquakes, etc., depends on the strength of the material. For estimating the resistance of walls under lateral loads (wind, earth pressure), the bending strength of masonry is important. For the calculation of the crack strength of the walls without significant charges, tensile strength is necessary, where tensile stresses occur due to impaired shrinkage and heat stresses. This could be done with walls that bear veneer and non-load bearing (stressing parallel to the bed joints) and outside walls attached to internal cross-walls (stresses that run alongside the bed joints). Therefore, the increment of diagonal shear and flexural strength is important in un-reinforced masonry building.

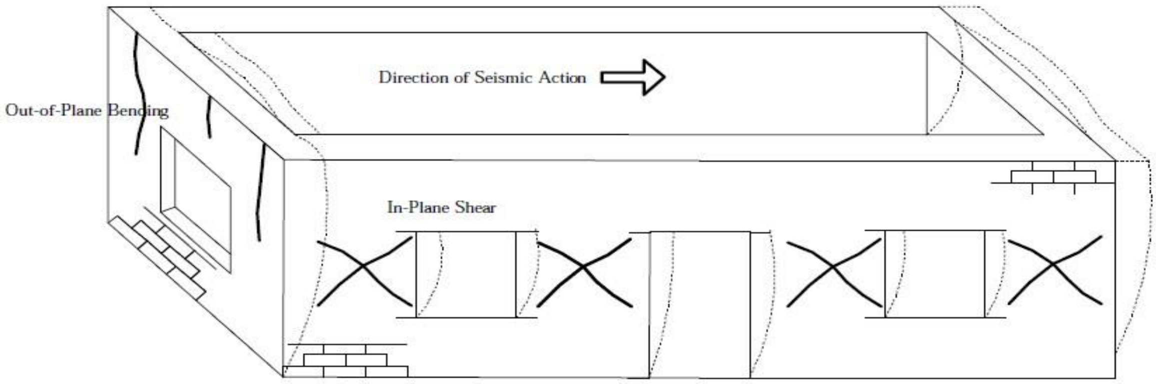


Fig. 1 Displacement of the building and typical collapse to structural walls [1]

Most URM walls necessity to be strengthened and retrofitted. Many methods have been successfully built to enhance the efficiency of URM structures in this field up to now. Traditional approaches include using shotcrete, FRP, outside coatings including ferrocement and the addition of external steel bracing elements [2-4]. Higher costs, necessary expertise and unavailability of composite materials lead to the development of cost-effective, easily available reinforcement techniques that require little technical rigour. In previous studies polypropylene (PP) band reinforcement and refurbishment of URM walls were experimentally studied [5]. In view of the above studies, numerical analyses to predict the effective charging of in-plane and out-of-plane masonry walls were carried out recently. The numerical simulation can be used as an important method in these studies, to test the mechanically efficient retrofitting/reinforcing of masonry. Mahini suggested a macro-modeling approach and a CFRP-retrofitted output in historic buildings. The building's brick and adobe, prism samples were modelled by commercial code using shamed-crack materials and eight-noded solid isoparametric elements [6]. Bernardeschi et al. described the numerical techniques for structural analysis of masonry constructions implemented in the finite-element code NOSA [7]. In order to test its structural activities and seismic sensitivity, Mele et al. [8] investigated the basilica-like Church. For this reason, an appropriate two-stage method comprising the static and dynamic linear 3D structural complex analysis and the 2D nonlinear push-up analysis was used [8].

It is important to mention that geosynthetic is a material that is recyclable, resistant to corrosion, inexpensive and widely used in different civil engineering application. It, therefore, has benefits over alternate strengthening material in numerous civil construction [9-10]. Many researchers tried geosynthetic as strengthening materials in brick masonry buildings. Geosynthetic enhances the in-plane and flexural strength of masonry panels effectively [11-15].

The present investigation focuses on the performance of masonry heritage building retrofitted with geosynthetic material viz. geotextile subjected to a ISZV and Loma Prieta (1989) earthquake numerically.

NUMERICAL MODELLING

1. Introduction

Masonry is a heterogeneous material with a complicated, non-linear, anisotropic conduct owing to various material parts and mortar joint presence. Masonry construction's complicated uneven nature makes precise structural assessment a challenge. The numerical investigation described in this study were conducted using the commercial ANSYS [16] software for multi-purpose finite elements. This software, which is commonly utilised for studies, in particular, includes a big database of engineering material models as well as finite elements.

2. Modelling Approach

To depict the heterogeneous and anisotropic feature of masonry wallettes utilising finite elements, it is possible to follow distinct modelling approaches reported by Roca et al. [17]. The detailed design of the masonry was regarded for this numerical model, and bricks and mortar were modelled individually. Masonry units-interfaces of mortar joints were simulated by components of contact/interface. There are three strategies in numerical modelling called comprehensive micro-modelling, simplified micro-modelling and macro-modelling [18]. In this study, micro-modelling is used.

3. Material Model and Analysis Utilised in Numerical Simulation

Masonry is a composite material produced from anisotropic units of masonry and mortar. The mechanical models that have been created to characterise the structural behaviour of masonry constructions fall under the no-tension material models category. In specific, when exposed to compressive stress, the URM walls are regarded as unable to withstand important tensile stresses and thus act as a linear elastic material. However, the mechanical model and the numerical model by definition varies from linear-elastic and elasto-plastic material models, depending on the elastic and mechanical properties of the constituent materials. The mechanical models that have been created to describe the structural performance of masonry buildings fall under the no-tension material models category. In specific, when exposed to compressive stress, the URM walls are regarded as unable to withstand important tensile stresses and thus act as a linear elastic material. The dimensions of bricks, mortar and geotextile are kept the same as that of experimental test wallettes by authors both for the in-plane and out-of-plane actions independently before and after strengthening [11-15]. In this study, the modeling of brick and mortar was conceived for SOLID 187 tetrahedron elements. This is a ten tetrahedron nodded, with a three grade plasticity and a quadratic moving. Because of its bending and membrane capabilities, SHELL 63 element is utilised for geosynthetics modelling. The design elements are utilised to obtain the proposed bond-slip law for the relationship between geosynthetic and masonry. A model of degradation is proposed and utilised to reproduce the experimental findings for interface performance. Cohesive components are taken among composites of masonry (brick, mortar) on the floor [11-15]. The analysis is based on the use of the cohesive crack model for detailed modelling of brick and mortar. First of all, specific tests are determined by the mechanical features of bricks, mortar and geotextiles as shown on Tables 1 and Table 2 and then utilised separately for bricks and mortar joints in the numerical strategy. Table 1 depicts the mean compressive and tensile strength of the components of masonry along with their coefficient of variation (C.o.V). For the nonlinear investigation, iterative solution is received with load applied at incrementally. The nonlinear static investigation is implemented, and the Newton-Raphson iteration strategy is executed by actuating the energy norm condition to verify the convergence at each time step successively. Incremental loads applied and at each load step, the computer program may execute a few substeps in which equilibrium iterations are prepared until convergence conditions are fulfilled and a converged solution is come to.

Table 1: Properties of the components utilised in the experiment (C.o.V. shown in parenthesis) [11-15]

Sample	Test	No.	Average stress (MPa)
Brick	Compressive	6	9.43 (0.28)
	Tensile	6	1.46 (0.24)
Mortar	Compressive	6	4.46 (0.31)
	Tensile	6	0.66 (0.29)
Masonry prism	compressive	6	3.41 (0.37)

The polymer geotextile is made of polypropylene, polyester, polyethylene, polyamide, polyvinylidene. It is considered strong and very long-lasting. It consists of heat bonding, resin binding or a punching of needles, and it presents a strong strain and can deform under significant load. Polyester gives outstanding strength and creep properties. In this study, polyester type of nonwoven geotextile was used for strengthening of brick masonry. It is considered to be strong and very durable. They are usually 25 to 100 mm long or casually dispersed in layers as a continuous filament [19]. The geotextile tensile strength was measured in accordance with ASTM D4595–17 [20]. The mechanical parameter of geotextile and epoxy resin is reported in Table 2.

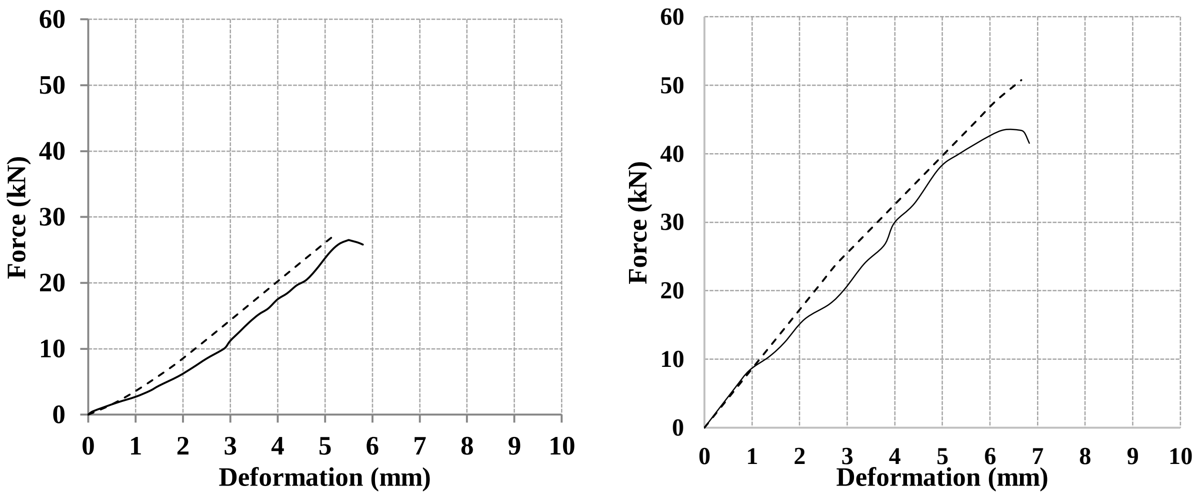
Table 2: Non-woven geotextile mechanical parameter acquired from the tensile tests (C.o.V shown in parentheses) and epoxy resin of the manufacturing company [11-15]

Material	Tensile strength (kN/m)	Poison's Ratio	Thickness (at 2kPa) (mm)	Mass per unit area (kg/m^2)	Elongation (%)
Geotextile	12 (0.06)	0.3	2.1	255	90 (0.04)
	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Density (gm/cm^3)	Bending Strength (MPa)	Impact Energy (kJ/m^2)
Epoxy Resin	72 (0.12)	3.2 (0.11)	1.17	120 (0.17)	35

Nonlinear static analyzes are carried out and Newton-Raphson's iteration technique is successively used in order to track convergence at each point by controlling the energy standard state. Incremental loads and a computer program will conduct a number of substations at each loading point during which equilibrium iterations are carried out before the convergence conditions are met and a converged solution can be achieved.

4. Verification of the Numerical Model

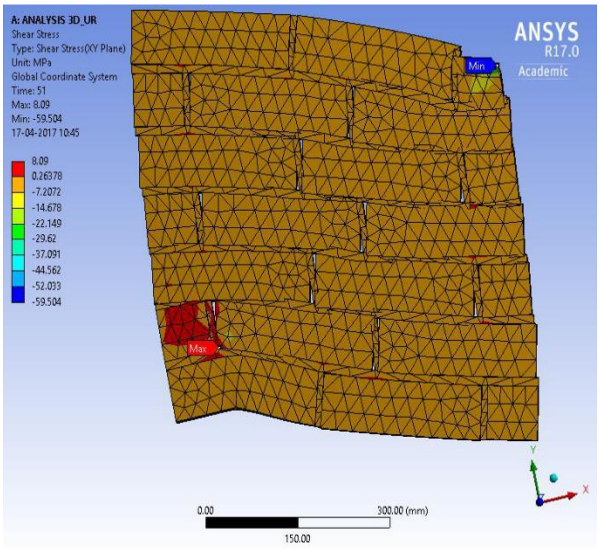
In this part, the analytical estimation of strengthened and un-strengthened wallette under pure in-plane and out-of-plane is made with the help of modelling approach discussed in previous section. The analytical estimation is compared with experimental observation made by authors [11-15]. In experimental study, the constant load at the rate of 0.05 mm/s under displacement control with the servo control dynamic actuator was applied. Figure 2 shows a comparison of the force-deformation response estimated numerically and experimentally subjected to in-plane loading. From the figure it is clear that the load carrying capacity increases due to geosynthetic and analytical estimation matches with experimental findings. From the load displacement results diagonal shear strength is estimated [11]. In comparison with the un-strengthened panel, the diagonal shear intensity increased to 80.62 %.



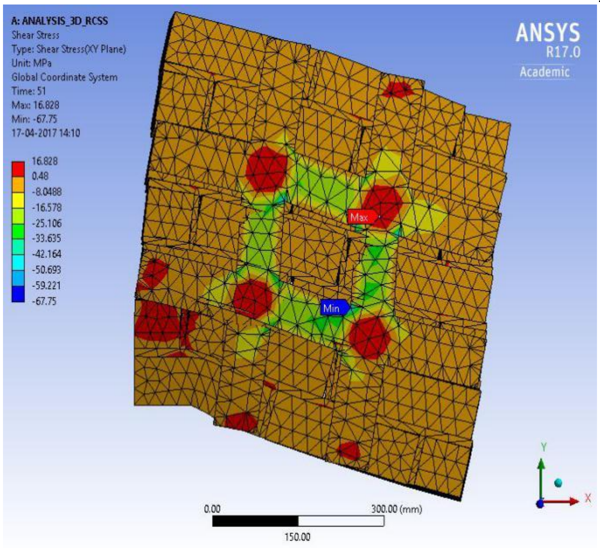
(a) Un-strengthened Wallette (b) Strengthened Wallette

Fig. 2 Comparative force versus deformation diagram under pure in-plane loading (…. Analytical, __Experimental)

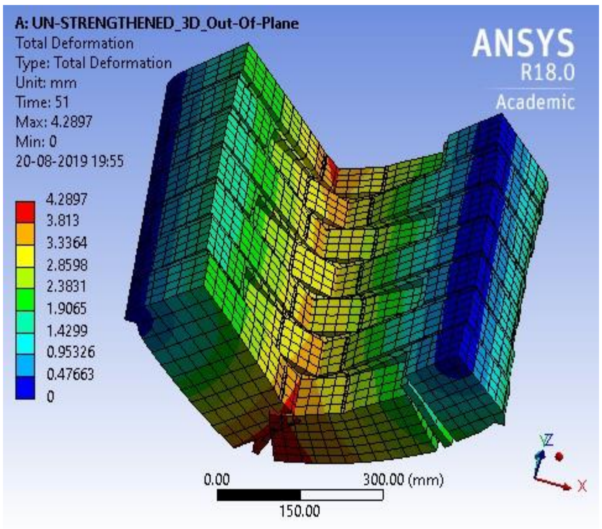
The wallets subjected to out of plane bending modelled in similarly as discussed. Figure 3 shows the failure mode by out-of-plane bending experimentally and analytically. Figure 4 shows a comparison of the force-deformation response estimated numerically and experimentally by the strengthened walls over un-strengthened made by Khan and Nanda [12]. The analytical result is used to calculate flexural strength of the masonry wallet. In contrast to un-strengthened panel, the flexural strength increased to 129.23 %.

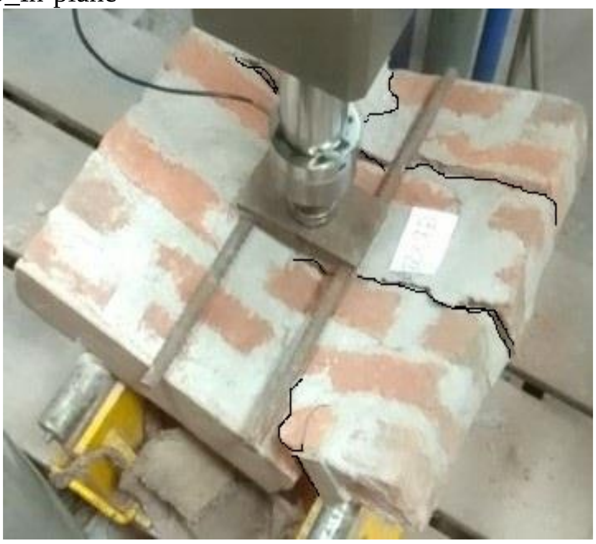


US_In-plane

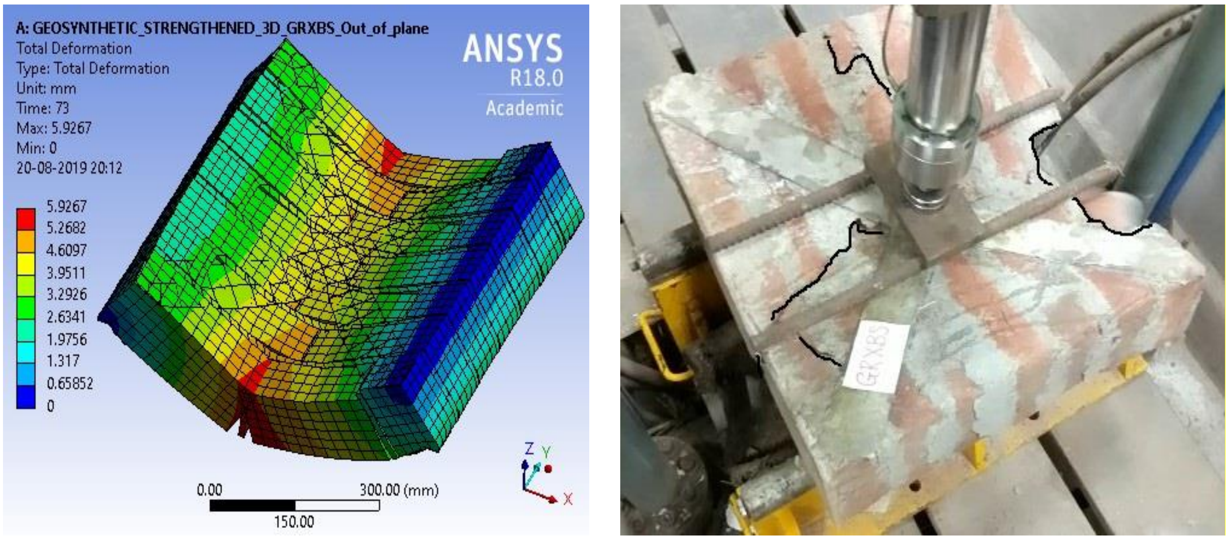


GRXBS_In-plane



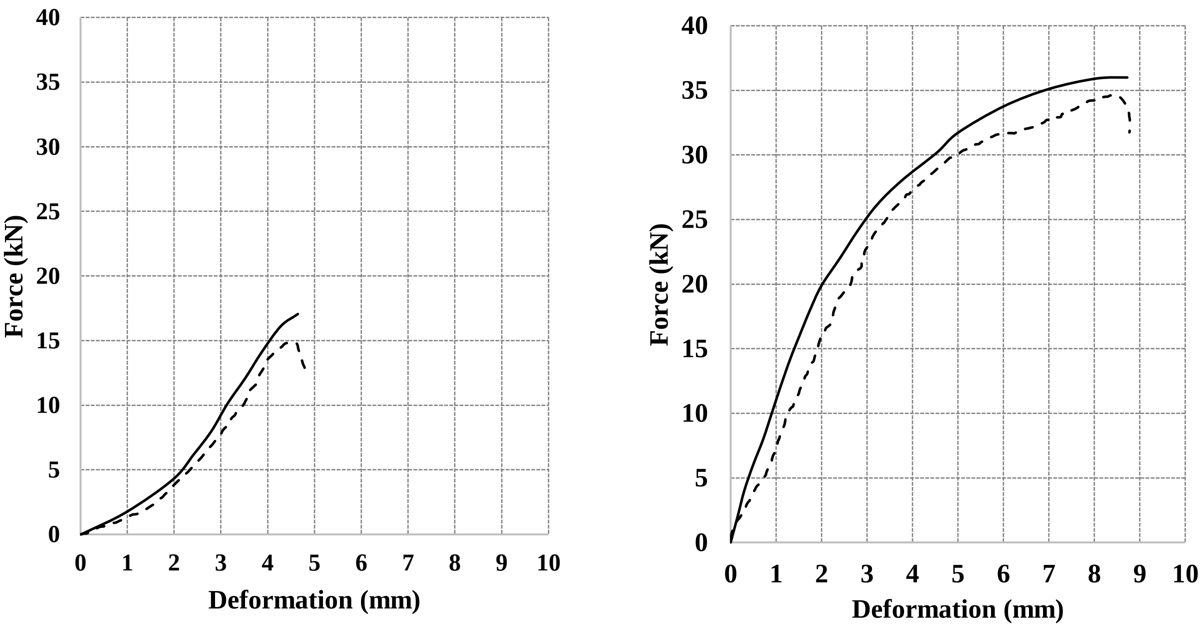


US_Out-of-plane



GRXBS_Out-of-plane

Fig. 3 Deformed shape of masonry wallette: numerical (left) with experimental (right) under in-plane and out-of-plane loading [11-12]



(a) Un-strengthened Wallette (b) Strengthened Wallette

Fig. 4 Comparative force versus deformation diagram for the different pattern under out-of-plane loading (…. Experimental, ____ Analytical)

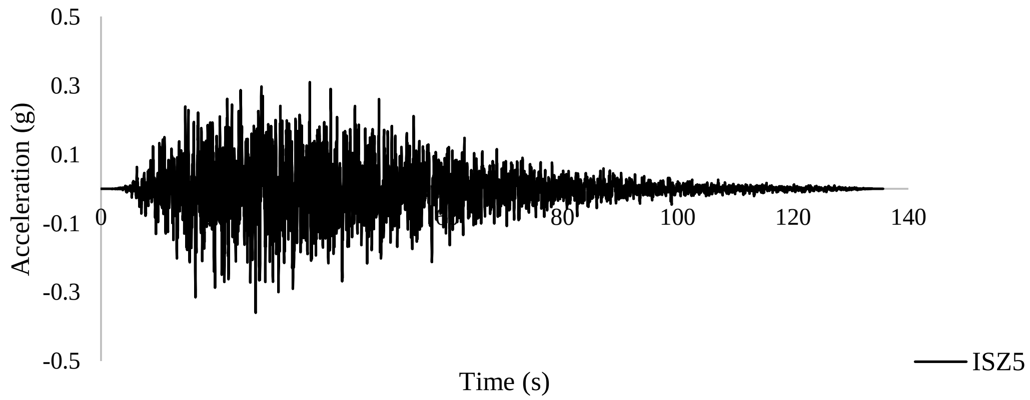
SEISMIC RESPONSE OF HERITAGE MASONRY BUILDINGS RETROFITTED WITH SPLINT BANDAGE TECHNIQUE

A model of a heritage masonry building with openings and concrete spherical dome at roof level is considered for the analysis. The study of historic masonry buildings is a challenging task. Masonry domed mosques are very complex with respect to their structural behaviour and seismic resistance. Thus, they require strict construction standards and advanced engineering. Nowadays, different sizes, styles, and materials may be used for domes depending on the mosque's size, style, and structural conditions. It is imperative to identify various types of domes and their structural capabilities. In order to determine the structural protection requirements for these structures, a better understanding of their behaviour and structural integrities is needed. These structures should be protected and preserved for the next generations since they are part of the cultural heritage. Thickness of the walls 250 mm, room dimension 3 m ×3 m, and height of floor 3 m, one central dome of diameter 3 m is considered in this study. Several strong beams at the top of the windows and doors are mounted to avoid bending damage to the walls. In the modelling masonry is considered to be an isotropic material with Drucker-Prager model due to elastic-perfectly plastic nonlinear behaviour in ANSYS. For seismic evaluation of the present masonry buildings, the mechanical properties of the material in table 3 have been extracted from the literature [21]. The artificial limit plays an important role in seismic research. To eradicate the issue of seismic response reflection, rather limits should be employed. The brick, mortar is modelled using a synthetic accelerogram and the registered accelerogram in similar modelling to the seismic input direction to apply the rather limiting condition. orthogonally. The building base is considered to be fixed. This bottom limit is restricted both horizontally and vertically. To check the validity of the proposed model, a spectrum-compatible time history (ISZ5) estimates absolute acceleration response at the roof level for with a friction coefficient 0.1 (geosynthetics).

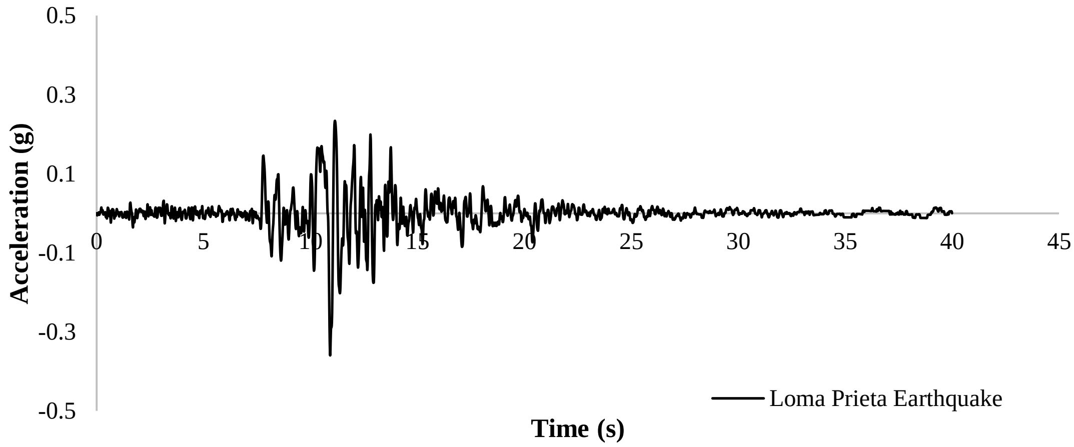
Table 3: Mechanical properties of the masonry mosque

Material	**Modulus of elasticity 'E' (N/mm^2)**	**Poisson's ratio 'μ'**	**Mass density (kN/m^3)**
Brick masonry	2100	0.13	19.2

Real ground movement is important for earthquake resistant analysis and structural design. In most cases, strong motion on a given site cannot be recorded. There's no way to assume that a potential earthquake will cause the same or similar earthquake, even though these records are visible. Another benefit in the methodology of ASCE-41-2107 [22] and FEMA 695 [23] is that it specifically recognizes uncertainties in ground motion, modeling, design and test results, and employs nonlinear analytical techniques to describe the nonlinear static and dynamic behavior of the proposed seismic resistance system. The design needs of the seismic measures ASCE-41-2107 and FEMA 695 are developed in this report. Real ground movement is important for earthquake resistant analysis and structural design. For most cases, a good motion record should not be documented at a particular spot. There's no way to assume that a potential earthquake will cause the same or similar earthquake, even though these records are visible. A computer program [Figure 5(a)] is prepared (ISZ5) [24] to simulate a synthetic accelerogram, which simulates the artificial earthquake accelerogram to a particular target response range, namely, the design spectrum of the Indian Standard [25] that corresponds to the maximum tremor in the seismic area with the highest vulnerability. The building has been analyzed by using a recorded accelerogram [Figure 5(b)] with 0.36 PGA, Loma Prieta Earthquake at Santa Cruz Mountain on 17th October 1989. The structure is studied in X directions with respect to the seismic forces. The structural behaviour of masonry can be assessed with and without retrofitting following the application of seismic load within a not-linear dynamic analysis scheme. Vertical (splint) as well as horizontally (bandage) as grid pattern is used as in brick wallettes in the retrofitted structure.

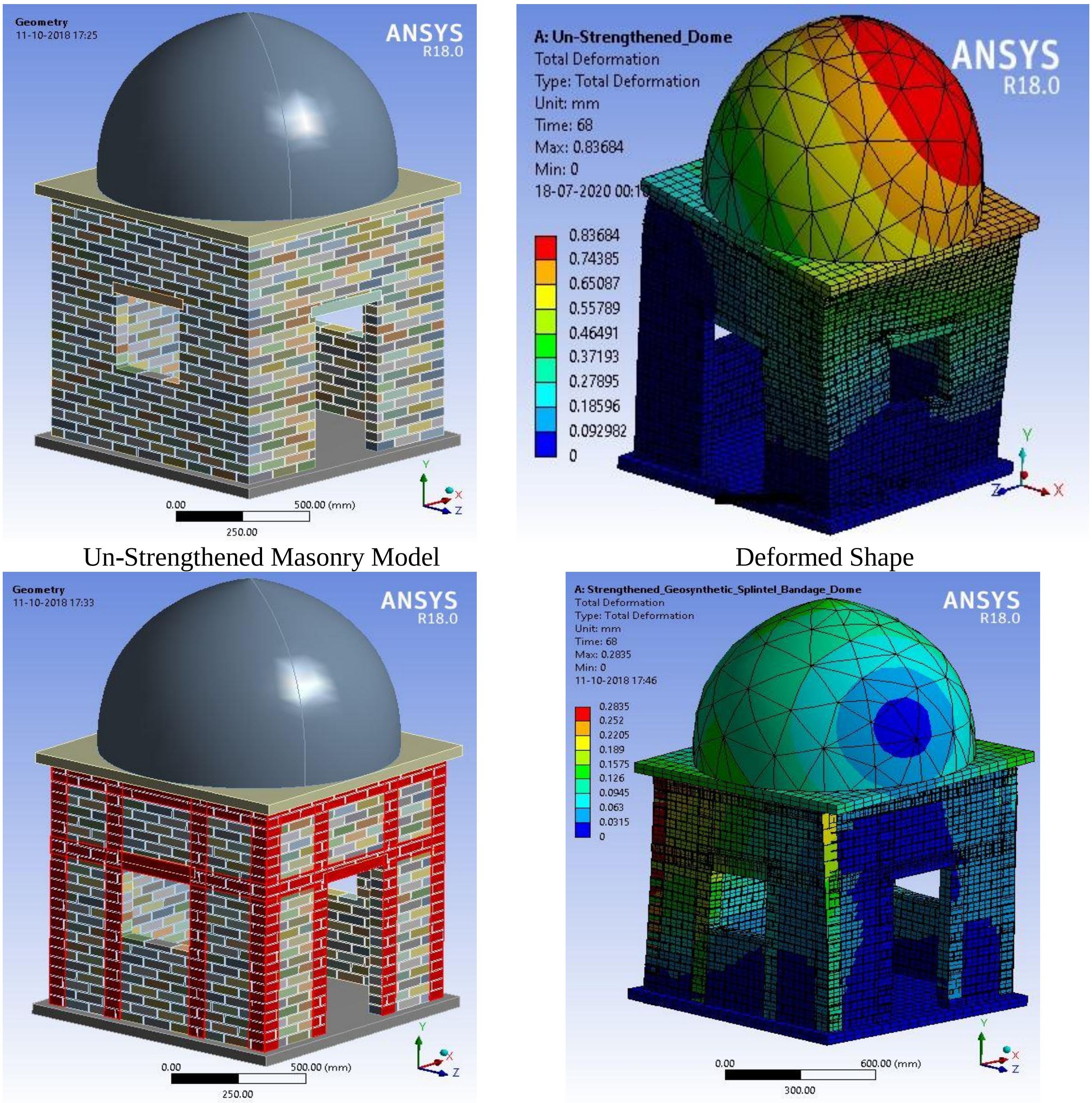


(a)



(b)

Fig. 5 Input ground acceleration (a) ISZ5, (b) Loma Prieta Earthquake



Un-Strengthened Masonry Model
Deformed Shape

Retrofitting with Splint Bandage
Deformed Shape

Fig. 6 Shape of Masonry structure before and after Earthquake

The seismic force (ISZV and Loma Prieta Earthquake) was applied and responses were noted in the form of a shear and bending stress (Figure 6). For in-ground seismic forces, shear stresses and out-of-plane bending strains have been recorded only while for both perpendicular directions for out-of-ground seismic forces tensile stresses have been reported. The stress contour and deformation results of the retrofitted model shows better control to earthquake forces. The stress contour responses for splint bandage strengthened over un-strengthened for masonry mosque with a design range of Indian standard which corresponds to the maximum seismic sequence in the most vulnerable seismic zone (PGA = 0.36 g) and Loma Prieta ground motion are shown in Table 4. The present strengthened technique gives more increment in stress (33.97 %). It is also noted that the increment in principle stress responses for splint bandage strengthened buildings over conventional buildings subjected to different ground motions.

Table 4: Comparison between responses obtained at roof level with and without strengthened

Building	Earthquake	Principle Stress (MPa)		Increment (%)
		Un-strengthened	Splint bandage strengthened	
Masonry Mosque	Indian Standard	1.0648	1.3959	31.09
	Loma Prieta	1.1564	1.5492	33.97

CONCLUSIONS

Numerical study is conducted using geosynthetic as strengthening materials for brick masonry wallets using 3D finite element simulation in ANSYS. It is observed geosynthetic can increase in-plane and out of plane strength of masonry wallettes. From the in-plane test it is estimated that the diagonal shear strength increased to 72 % as compared to un-strengthened panel, while the out of plane test gives increase in flexural strength capacity to 129.23 % as compared to un-strengthened panel. The numerical prediction is validated with previous studies with good agreement. Seismic performance of geotextile as a retrofitting material for heritage masonry buildings using splint and bandage technique is estimated with similar modelling using synthetic accelerogram and recorded accelerogram. This retrofitted model shows a better way of controlling the stress and deformation forces of earthquakes and can preserve heritage buildings.

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