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Seismic Performance of Dry Stone Masonry Building

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Abstract
Dry Stone masonry is the oldest material technique used in hilly and mountainous region of Nepal.Analysis of such structure present on even bigger challenge due to high Vulnerability during the earthquake.This article presents the macro-modeling Finite Element analysis of unreinforced dry stone masonry Building to evaluate the seismic performance.Linear static analysis is done using ANSYS workbench. Different mode shapes with their corresponding natural frequencies and stresses (Compressive, tensile and shear) are obtained.These stresses are compared with the permissible stresses given in code of practice for unreinforced masonry structures (IS1905-1987).Results show that building is safe in all stresses under both gravity and earthquake loading and unsafe in tension and shear under seismic loads.The result thus obtained will be useful for finding some weak failure zones and thus it is easy to suggest some technique for enhancing seismic performance of building.

Keywords
Dry Stone Masonry, Macro-modeling Finite Element Method, Seismic Performance, Linear Static Analysis

1. Introduction

Nepal is one of the most earthquake prone countries in the world and has experienced several devastating earthquakes of magnitude exceeding Mw 7.5[1].The most recent of these, of Mw7.8, occurred in the central region of Nepal on April 25, 2015 with the epicenter located in Barpak village, Gorkha district, approximately 78 km northwest of Kathmandu with a focal depth of 15 km [2].The 2015 Nepal earthquake sequence resulted in damage to or the destruction of more than 750,000 residential buildings in ”most-affected” areas alone, of which 70% were low-strength masonry (LSM) buildings[3].

Stone masonry is the most ancient, durable, and widespread building method devised by mankind in Asian countries such as, Afghanistan, Pakistan, India, Nepal and Bhutan, which fall in the Himalayan belt. Stone building are built by stacking stones over stones normally in two leaves.Vertical joints are avoided as far as possible by placing various sized stones alternately. Corner stones are chisel dressed and mid span stones are hammer dressed.The construction practice varies with availability of the material in that area .Stone in mud mortar is one of the maximum used techquine in varies part of Nepal.The other types of building techniques are stone in cement mortar, stone with lime mortar and dry stone masonry construction.The structures are remarkably durable and, if correctly designed, can be made earthquake resistant.They resist fire, water, and insect damage.The mason needs a minimum of tools; the work is easily repaired; the material is readily available and is recyclable.Stone structures built without mortar rely on the skill of the craftsmen and the forces of gravity and frictional resistance.Most of stone masonry structures in Nepal were constructed by assembling regular stone blocks without the addition of mortar between bed and head joints.If used, the mortar was usually of low strength, and hence it has experienced mechanical degradation over time.Due to the partial or total disappearance of mortar, the behavior of these constructions can then become similar to those made of dry joint masonry.

The seismic performance of these buildings in the past earthquakes has been considered to be quite poor[4].Dry Stone-masonry structures that were subjected to earthquakes are found to be vulnerable, but more critical is that their seismic performance is found inconsistent. Shake table test on two storey unreinforced dry stone masonry building reveals that the structure is completely failed at PGA of

0.4g[5].Due to the low tensile strength of masonry both the newer and older masonry building are highly vulnerable to the earthquake.In general, the old traditional buildings are low-rise, and most of them have been constructed for residential purposes.The seismic assessment of such buildings is very essential for the conservation and for upgrading their performance for future earthquake.

Therefore, adequate assessment of the seismic performance and identification of the potential deficiency of dry stone-masonry structures are critical steps for determining the degree of intervention needed to preserve their value.The main purpose of this study was to determine the seismic performance of unreinforced dry stone masonry buildings built by people with a non-engineering background.

2. Mathematical Modelling

The modeling of masonry in a finite element software package can be achieved in numerous ways which range from modeling on a very detailed micro level to a composite macro level. The most common ways to model the masonry according to [6] are

1. Detailed micro modelling: Units and mortar are modeled with plane stress elements and the unit/mortar interface between these two components is created using discrete elements. This is the most accurate representation of reality which considers the properties of each individual component of the structure.
2. Simplified micro modelling: The mortar joint properties and the interface behavior are lumped in a discrete element with zero thickness and the bricks are expanded in two directions with the thickness of a joint to keep the dimensions of the model intact.
3. Macro modelling: The properties of all components, mortar, bricks and brick-mortar interface, are smeared out over a plane stress element using a cracking or plasticity material model.

Figure 1 describe the three types of modeling strategy used in finite element modeling of masonry structure .In this study using the ANSYS software, the geometry of the dry stone masonry wall was created by using the macro modeling technique. Masonry dry units were produced as a single material.Figure 3 shows the geometry and the finite element mesh of the masonry macro model.

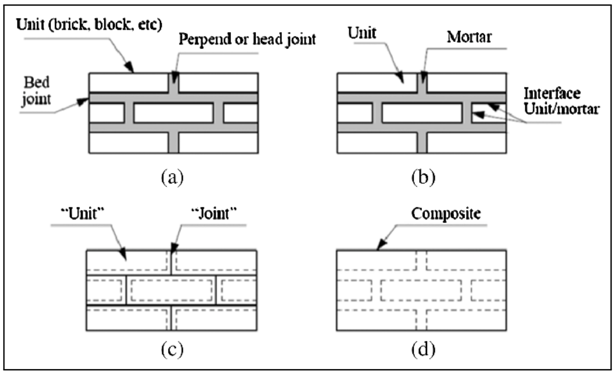

Figure 1: Modeling Strategies for Masonry Structure a) masonry sample b) detailed micro modeling c) Simplified micro-modeling d) macro-modeling [6]

3. Numerical modelling

3.1 Description of building

To evaluate the global performance of a dry stone masonry structure, first, a typical traditional unreinforced dry stone building is selected .The building is located in the mountainous area. This area is home to the traditional Sherpa settlement and most of the residential houses in this region are of the traditional type. The selected building is 2.8 meter high one storey building. The traditional buildings in Nepal usually have shorter story height than the modern buildings. The main load bearing element of the building is the masonry walls which are 450 mm in thickness. The wall generally has multiple layers stones along its thickness. The floor is made up of timber slab, the wood material generally being the Salwood. The general layout of the structure is presented inFigure 2. As can be seen from the figures, the building is rectangular in plan. The total length and breadth of the building are 6.65 m and 5.2 m respectively. The floor area of the building is 34.58 m^2.

3.2 Properties

The material properties are taken from the previous experiment work[7].The mechanical property of the masonry used in the calculations and simulation are as Follows:

Table 1: Material Properties of dry stone masonry

SN	Properties of masonry	Value
1	Unit Weight	17KN/m2
2	Young's modulus of Elasticity	200Mpa
3	Poisson's ratio	0.2
4	Shear modulos	83.33 pa

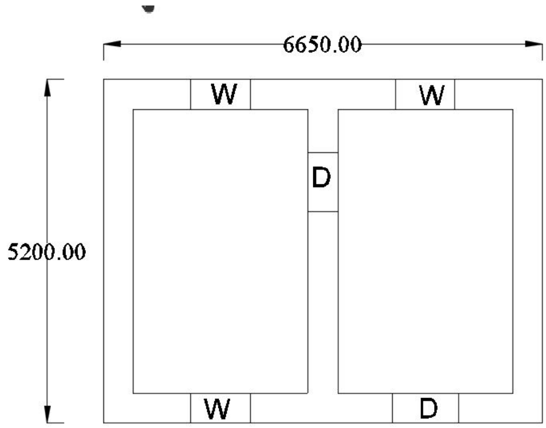

Figure 2: Plan of the bulding selected

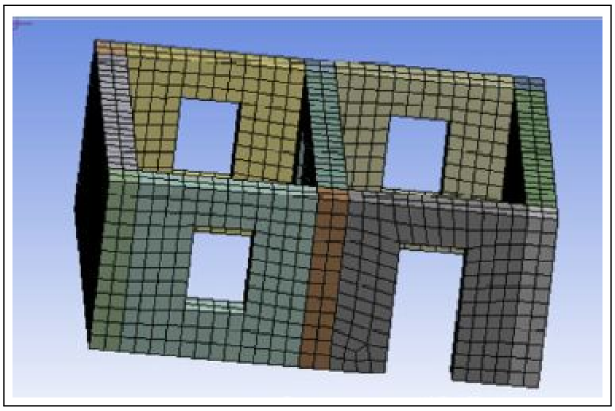

Figure 3: 3D model of the building in ANSYS workbench with meshing

3.3 Modeling

Modeling of dry stone building is carried out using ANSYS workbench. In ANSYS there is solid 65 elements for the modeling of the brittle materials like concrete which has capabilities to undergo crushing on compression and cracking on tension .Since the masonry is also brittle material solid65 element used for the modeling of the masonry[8].

3.3.1 solid 65

SOLID65 is used for the three-dimensional modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The geometry nodes locations and coordinate system for this element are shown in Figure 4.

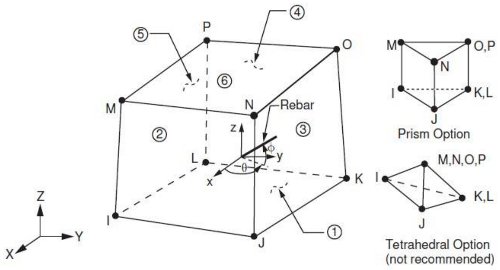

Figure 4: Sold 65[8]

4. Seismc Analysis

The following are the methods recommended for seismic analysis of buildings: (i)Linear static analysis – Equivalent static analysis, (ii) Linear dynamic analysis – Response spectrum analysis and (iii) Non-linear static analysis – Push-over analysis and (iv) Non-linear dynamic analysis-time history analysis. The most rigorous analysis among above is nonlinear dynamic time history analysis, but it is more involved and time consuming method and hence not recommended for normal building.

The model is analyzed by the Seismic Coefficient method,in which seismic effect, that is, a horizontal force is considered as the percentage of the total weight of the building. In this method, dynamic forces, which act on the structure during the excitation, are converted into equivalent horizontal force. In this work the seismic coefficient method is used as described by the IS 1893 (Part I): 2002[9]. The commonly adopted inverse triangular force distribution is not applicable to the flexible floor diaphragm. Because, the in –plane stiffness of the thick shear wall is relatively larger than the floor and the magnitude of lateral force at all level were nearly equal or same. Therefore, uniform pattern of 5KN/m^2

loading was used for the analysis of the loosely connected timber floor and roof including both dead and live load. For simulations of the numerical model a commercial program ANSYS workbench is used. In this analysis, different parameters are taken for calculation of design seismic coefficient according to IS 1893(part I):2002[9] are as shown in Table 2.

Table 2: Design Parameters

SN	Paramerters	Value
1	Zone factor(z)	0.36
2	Response reduction factor(R)	1.5
3	Importance factor	1

5. Analysis of stresses

In this analysis work,different value of permissible stresses are calculated as per as IS 1905:1985[10].The value of permssible shear,tension and compressive stresses are given below in table 3.

Table 3: Permissible value of stresses

SN	Permissble stress	Value
1	Tensile stress	0.1Mpa
2	Compressive stress	0.69Mpa
3	Shear stress	0.1 Mpa

6. Analysis Result

6.1 Analysis of Modes Shapes and Frequencies

The dry stone masonry building is modeled using homogeneous macro-modeling with solid 65 elements in ANSYS workbench. The first 6 natural frequencies of building are obtained by Modal Analysis as shown in Table 4 and first three mode shapes are shown in Figure 5.It is seen that the first 3 fundamental frequencies are closely spaced and other 3 fundamental frequencies are widely spaced.

Table 4: Natural Frequencies

SN	Frequency(Cycles/sec)	Time period(sec)
1	6.883	0.145
2	7.252	0.138
3	7.404	0.135
4	10.701	0.093
5	11.186	0.089
6	11.644	0.086

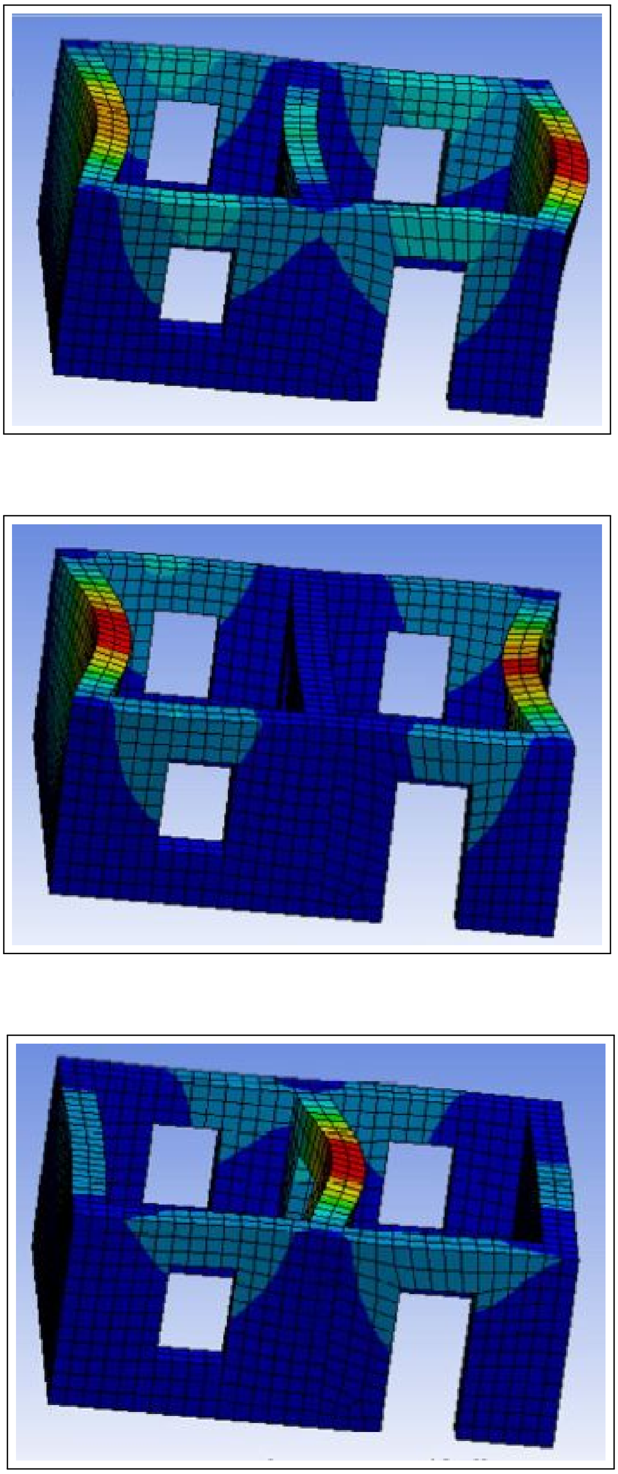

Figure 5: First three natural modes of building

6.2 Analysis of stresses under gravity loading

6.2.1 Compressive stress

The value of permissible Compressive stress calculated using IS 1905:1987 is 0.69 Mpa. From analysis, maximum part of the building are found within permissible limit of compressive stress.

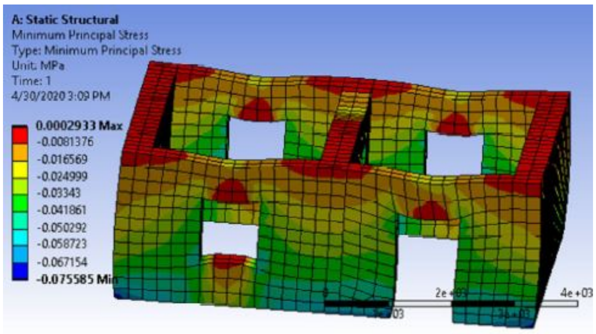

Figure 6: Compressive stress due to gravity loading

6.2.2 Tensile stress

The value of tensile stress are found to be within permissible limit as given in IS 1905:1987 .But value of maximum tensile stress is found in some places like around the opening, L and T corner of building.

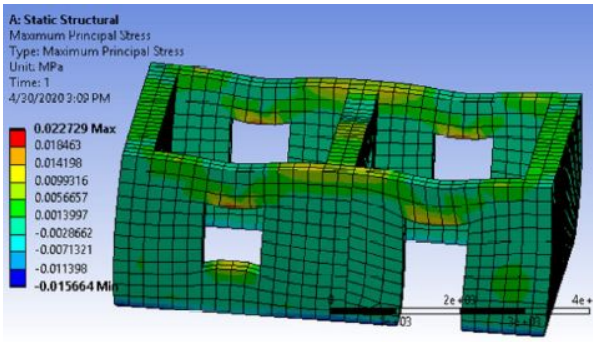

Figure 7: Tensile stress due to gravity loading

6.2.3 Shear stress

The value of permissible shear stress calculated using IS 1905:1987 is 0.1 Mpa .From analysis,the maximum value of shear stress is found 0.026 Mpa .Hence most of the part of building are found to be within permissible limit.

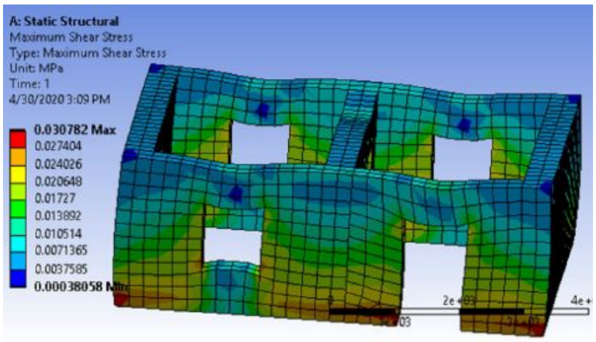

Figure 8: Shear stress due to gravity loading

6.3 Analysis of stresses under seismic loading

The dr stone masonry building is analyzed for seismic laoding in which the building is subjected to dfferent PGA levels (0.2g,0.30g,0.35g,0.4g and 0.45g) as input ground motion and the seismic performance of building is determined in terms of compressive ,tensile and shear stresses as given in Table 5 and Table 6.

Table 5: Maximum Value of stresses reached for different PGA due to seismic loading in x-direction

PGA	Compressive stress (Mpa)	Tensile stress (Mpa)	Shear stress(Mpa)
0.2g	0.150	0.086	0.063
0.3g	0.195	0.126	0.082
0.35g	0.218	0.146	0.097
0.4g	0.240	0.166	0.102
0.45g	0.263	0.186	0.111

Table 6: Maximum Value of stresses reached for different PGA due to seismic loading in y-direction

PGA	Compressive stress(Mpa)	Tensile stress(Mpa)	Shear stress(Mpa)
0.2g	0.124	0.047	0.053
0.3g	0.159	0.063	0.067
0.35g	0.176	0.071	0.074
0.4g	0.193	0.082	0.082
0.45g	0.221	0.101	0.089

6.3.1 Compressive stress

The value of permissible Compressive stress calculated using IS 1905:1987 is 0.69 Mpa. From analysis, maximum part of the building are found within permissible limit of compressive stress in both x and y direction seismic loading.

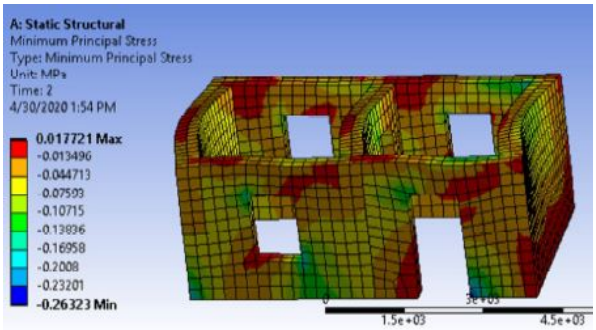

Figure 9: Compressive stress due to seismic loading in x-direction

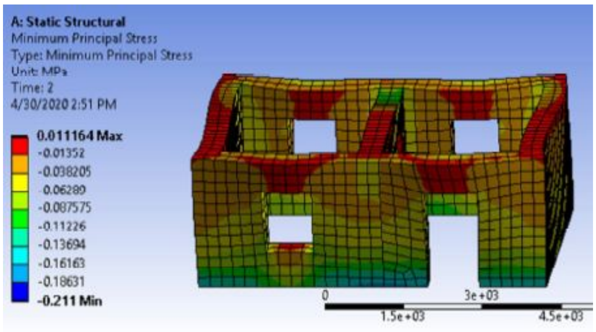

Figure 10: Compressive stress due to seismic loading in y-direction

6.3.2 Tensile stress

The value of maximum tensile stress is found to be exceeded in most part of the building for both case of loading as the PGA value is increasing .The value of tensile stress is exceeded at 0.3g and 0.45g when the loading is in x-direction and y- direction respectively as shown in Figure 11.

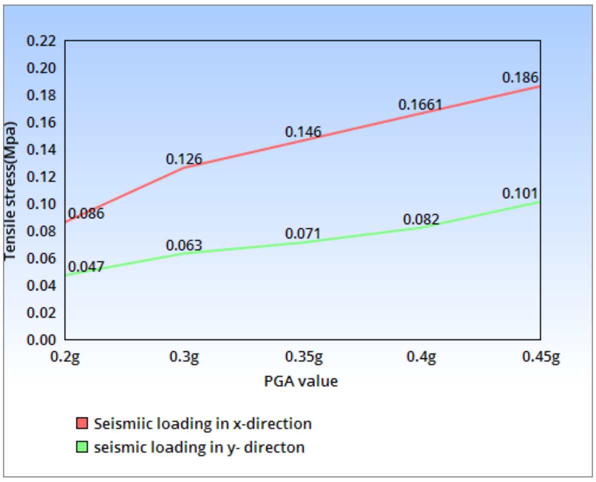

Figure 11: Variation of tensile stress with different PGA value

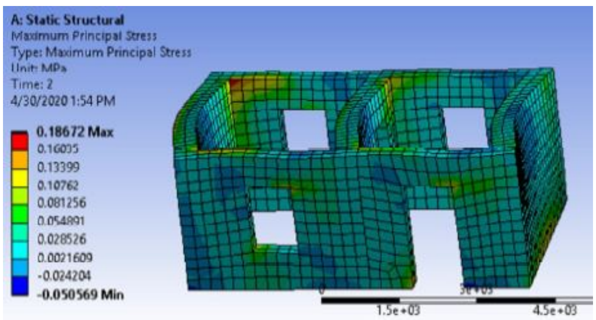

Figure 12: Tensile stress due to seismic loading in x-direction

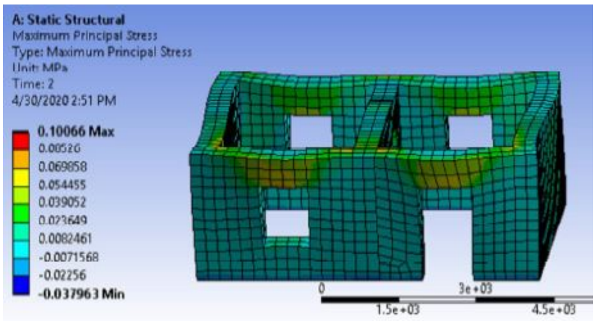

Figure 13: Tensile stress due to seismic loading in y-direction

6.3.3 Shear stress

Permissible shear stress in most of wall of building is exceeded for both X- direction and Y-direction seismic loading .The value of shear stress is exceeded at 0.45g and the value is 0.111 Mpa in case of x-direction loading whereas the value is not exceeded up to 0.45g in case of y-direction loading as shown in Figure 14..

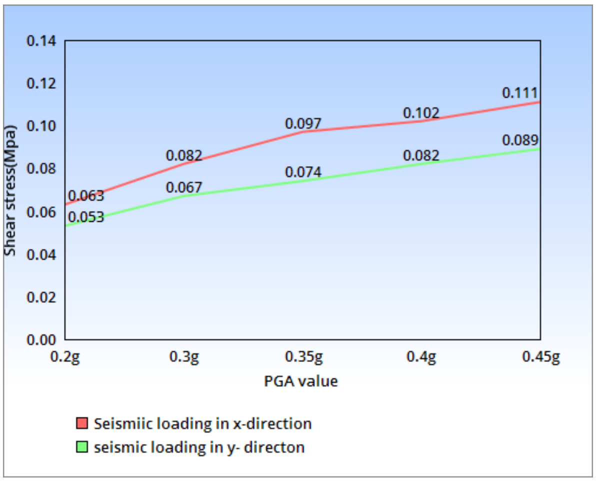

Figure 14: Variation of shear stress with different PGA value

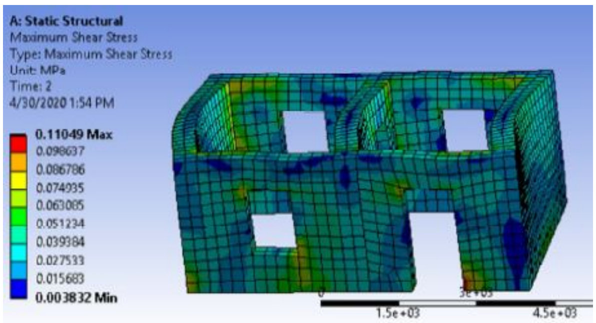

Figure 15: Shear stress due to seismic loading in x-direction

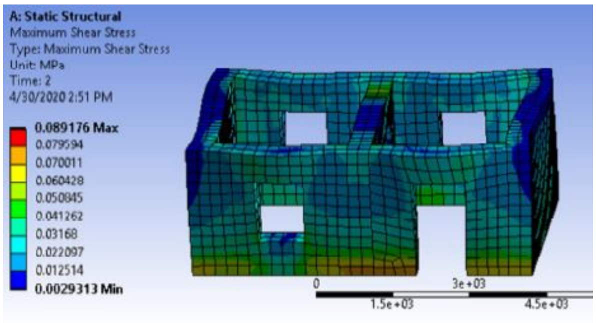

Figure 16: Shear stress due to seismic loading in y-direction

7. Conclusion

The dry stone masonry un-reinforced building is modeled using homogeneous macro-modeling with solid 65 elements in ANSYS workbench .The finite element model is analyzed for both gravity and seismic loading. The first 6 natural frequencies of the building are obtained by Modal Analysis.It is seen that the first 3 fundamental frequencies are closely spaced whereas the other 3 frequency are found to be widely spaced. Due to all stresses are within the permissible limit, the building does not show any cracks under gravity loads.The principal tensile stresses and shear stresses in the building subjected to earthquake loading in x and y direction are found within the permissible limit at most part of the structure but the value exceeds beyond the permissible limit at few places. Permissible shear stresses (0.1 MPa) are exceeded for PGA of 0.45g for seismic loading in X direction whereas the value is not exceeded up to 0.45g for seismic loading in y-direction. Tendency of structure to fail in tension increases with increase in PGA level. tensile stress is exceeded (0.1Mpa) for PGA 0.3g for seismic loading in X-direction .The portions around the openings were found to be highly vulnerable in all cases because presence of opening in the bearing wall reduce their strength under the action of horizontal forces and lead to local failure.Similarly L and T corner are vulnerable due to insufficient connection between wall at corner.

The study shows that without reinforcement, seismic performance of building was highly vulnerable because of the lack of effective connection between walls at corner and the insufficient in-plane and out-of –plane strength If no proper reinforcement is applied ,this kind of building will undergo severe damage with increase in seismic loading and responsible for casualties during a strong earthquake.Therefore, necessary suggestion concerning to increase the seismic performance of various part of the building can only made after the numerical modeling of structure under the given condition are properly investigated.

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