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Research Article

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Brief Report of Shaking Table Test on Mud Mortar Stone Masonry House Strengthened with 2mm-Gabion Wire

Teddy Boen*[1], Hiroshi Imai*[2]

*[1]Structural Engineer, CSI Indonesia
E-mail: tedboen@cbn.net.id
*[2]Institute of Technologists, Japan
E-mail: h_imai@iot.ac.jp

Abstract During the April 25, 2015 Nepal earthquake, most of the houses that collapsed are mud mortar stone masonry houses. Therefore, a simple, affordable, replicable, and economical method is introduced to make suchmud mortar stone masonry houses earthquake resistant. The method described in this report is based on the field observation during site visit on November 2015 and March 2016, i.e. using gabion wire mesh to strengthen the walls. Numerical analysis results and shaking table tests is discussed in this paper.

Keywords mud mortar, stone masonry, gabion wire mesh, shaking table test, numerical analysis

Introduction

Nepal is one of the countries located in the Himalayan Belt with long history of destructive earthquakes. The typical house in mountainous areas in Nepal is mud mortar stone masonry as natural choice of the common people because stone is an abundant and easily available construction material compared to burnt clay bricks and concrete in these areas. In Nepal, there is a variety of stone masonry buildings, however, are fairly similar. During the April 25, 2015 earthquake, approximately 262,600 buildings were damaged, and 489,500 buildings collapsed [1]. Unfortunately, most of the buildings that collapsed are non-engineered buildings, i.e. mud mortar stone/brick masonry houses (

Figure 1). According to the Nepal Building Code for Earthen Buildings [2], the building shall be single-story in height plus an additional attic floor with floor to floor height shall not be less than 1.8 m and not greater than 2.5 m. The thickness of wall should be tapered with 600 mm at bottom and 450 mm at the top. For earthquake resistant design, NBC 204:1994 stated that bamboo or timber vertical reinforcement and horizontal bands (at plinth, sill and lintel levels of the building) shall be constructed. However, in actuality, not many houses follow the NBC (Figure 2). If the horizontal bands are replaced using reinforced concrete bands, the performance of stone masonry houses during earthquakes will improve. However, cement in Nepal is quite expensive and is not easy to obtain by the people living in mountainous regions. Therefore, to make mud mortar stone masonry houses earthquake resistant, a simple, affordable, replicable, and economical method should be found. The method must also be familiar tolocal masons.

Figure 1: Mud mortar stone masonry houses collapsed due to April 25, 2015 earthquake

Figure 2: Mud mortar stone masonry houses without horizontal bands

When the first author visited Nepal in November 2015 and March 2016, the first and second authors observed that many gabions along the winding roads in the mountainous regions that were utilized as retaining walls and almost all gabions were still intact and not damaged (Figure 3).

Figure 3: Gabion is used as retaining walls

The gabion wire mesh is produced in Nepal and can be found easily (Figure 4). Hence, the gabion wire mesh can be used to strengthen the mud mortar stone masonry houses by covering all inner side and outer side of the walls. The inside and outside gabion wire mesh should be tied by 2mm wires as close as possible, approximately at a distance of 30cm. The aim of the ties is to ensure that the inside and outside gabion wire mesh work together to resist the earthquake forces and to provide "bonding" between the stone masonry wall and the wire mesh. The wire mesh used is diameter 2mm, smaller than the common gabion wire mesh which is usually larger than 3mm. Besides gabion wire mesh, rectangular welded wire mesh can also be used for strengthening walls.

Figure 4: Gabion wire mesh produced in Nepal

On February 26, 2019 and June 4, 2019, shaking table tests were conducted at NIED (National Research Institute for Earth Science and Disaster Resilience), in Tsukuba, Japan, in order to observe the performance of gabion wire mesh in mud mortar stone masonry houses when shaken by earthquakes. The wall strengthened with gabion wire mesh is expected to deform, but not collapse and kill people. Therefore, the life safety performance level is achieved.

Structure Model

Two model structures were built on the shaking table in NIED, Tsukuba on February 2019. Both models were of the same size and built as unreinforced mud mortar stone masonry houses (without horizontal bands). The first model (Model A) is the original unreinforced mud mortar stone masonry without plaster, and the second (Model

B) is the same masonry structure strengthened by wrapping 2mmgabion wire meshon both sides of the walls (Figure 5).

Each model consisted of four walls with size 3000mm x 2200mm with three simple roof trusses and galvanized iron-sheets roofing. The wall thickness is 210mm. Figure 6 shows the schematic drawings of masonry walls. There are no gable walls in these two models. The West wall is without opening, perpendicular to the direction of the shaking.

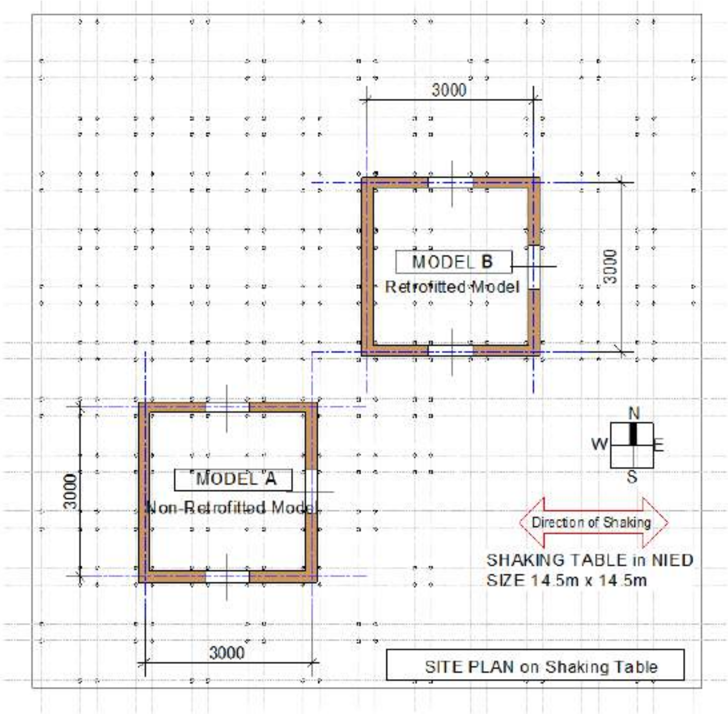


Figure 5: Two models for the shaking table test: Model A: original unreinforced mud mortar stone masonry without plaster; Model B: unreinforced mud mortar stone masonry strengthened by wrapping 2mmgabion wire mesh on both sides of the walls.

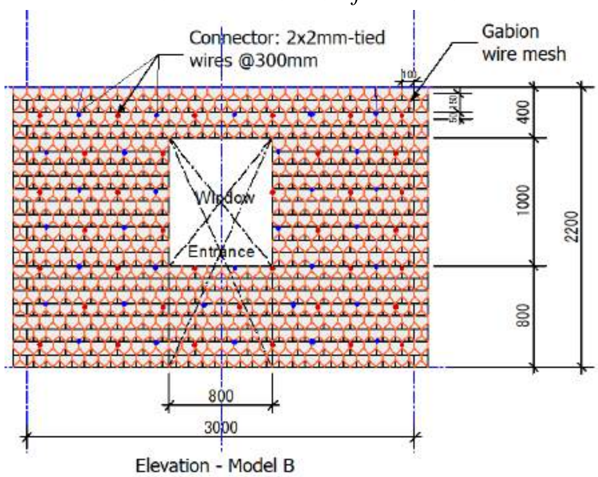


Figure 6: Schematic drawings of shaking table test

Since stone is not a common material to build houses in Japan, the stone material is specially made using cement mortar with the similar characteristics as the stones in Nepal. The size of one stone is 210x100x60mm, with weight 2.5kg. The essential materials to construct the models e.g. stone, 2-mm gabion wire mesh with spacing 100x150mm, and tie wires (**Figure 7**). The gabion wire mesh produced manually by the second author

(**Figure 8**). **Figure 9** shows the construction of mud mortar stone masonry houses wrapped with gabion wire mesh.

Figure 7: Materials used to construct mud mortar stone masonry

Figure 8: The gabion wire mesh produced manually by the second author

Figure 9: Construction of mud mortar stone masonry houses wrapped with gabion wire mesh.

At the end of May 2019, same Model B, unreinforced mud mortar stone masonry strengthened by wrapping 2mm gabion wire mesh on both sides of the walls, was constructed again. However, the gabion wire mesh was different than the February 2019 model. The wire mesh used is the commercially available gabion wire mesh. (see Figure 10). This shaking table test was conducted to make sure that commercial type gabion wire mesh also can be used to strengthen the mud mortar stone masonry.

Figure 10: Model B, mud mortar stone masonry strengthened by wrapping 2mm commercial type gabion wire mesh on both sides of the walls, constructed at the end of May 2019

Material Properties

The material properties are as follows:

1. Mud mortar stone masonry wall:
    a. Modulus elasticity = 300 MPa
    b. Tensile strength = 0.056 MPa
2. Gabion wire mesh:
    a. Modulus elasticity = 69,000 MPa
    b. Tensile strength = 435 MPa
3. Gabion wall (stone and wire mesh):
    a. Modulus elasticity = 1.47 MPa [3]

The tensile strength of gabion wire mesh is obtained from the tensile test of 3.2mm gabion wire mesh (Figure 11)

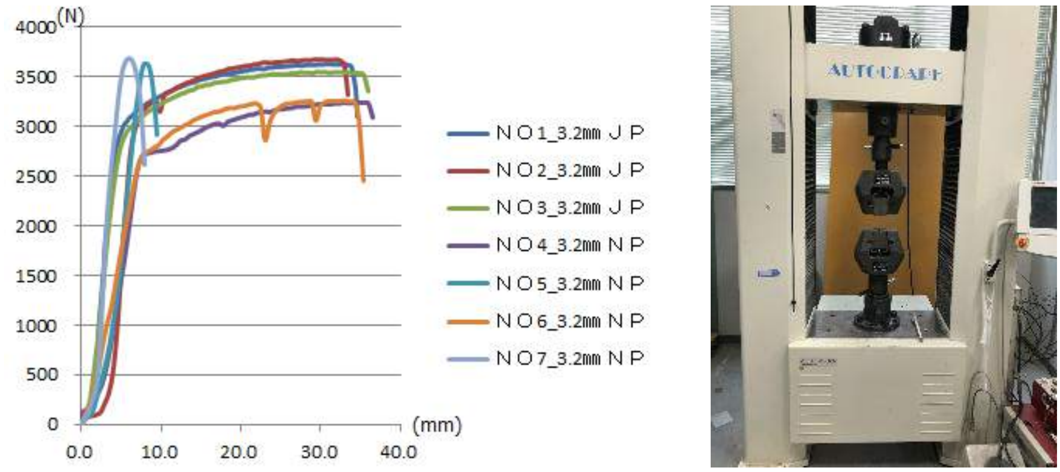


Figure 11: Tensile test of 3.2mm gabion wire mesh: the results (left) and the experiment tool (right)

Input Motions

The shaking table was a horizontal uniaxial movement type. JMA Kobe NS earthquake records (Figure 12) was used as input motions for this test. The excitation increased gradually as follows:

a. JMA Kobe (10%)
b. JMA Kobe (20%)
c. JMA Kobe (30%)
d. JMA Kobe (50%)
e. JMA Kobe (70%)
f. JMA Kobe (100%)

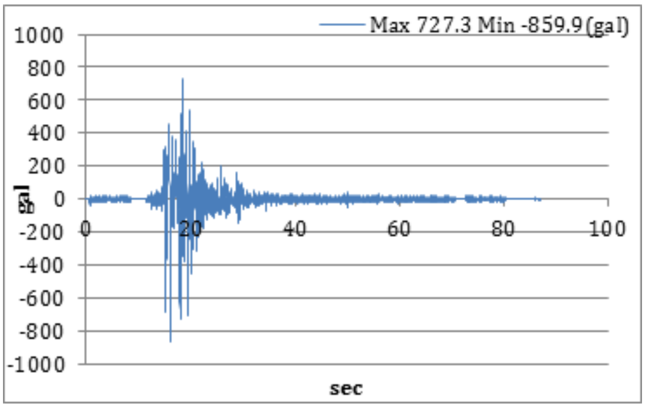


Figure 12: Input motion of JMAKobe NS

Analysis

Computer analysis were performed for the two tested mud mortar stone masonry houses, first the unreinforced masonry structure without plaster, and the second is the masonry structure strengthened by wrapping with 2 mm gabion wire mesh on both sides of the walls. The analysis used sandwich structures analogy.

The analysis is elastic-linear-time-history and utilizing commercial softwares. Material properties used for this model are as described in Section 0. For the analyses of 30% JMA Kobe and 50% JMA Kobe, the damping is 5% and the strengthened mud mortar stone masonry walls are modeled using sandwich analogy. From the damage observation after the April 25, 2015 earthquake, most of the mud mortar stone masonry houses that collapsed became a pile of stones since after being shaken by a0.8–1.0gearthquake in much of the affected districts (1.0–1.2g in some parts of Sindhupalchok district) [4], it seemed that there is no more bonding between mud mortar and stones (see Figure 1). Therefore, for the analysis, it is assumed that after being shaken by JMA Kobe 50% (approximately 0.4g), the mud mortar stone masonry walls behave like gabions. Based on the above facts, for the analyses for 70% JMA Kobe and 100% JMA Kobe, the modulus elasticity of walls is assumed to be approximately 1.47 MPa [3]. The analyses are assumed as gabion walls and the damping for analyses of 70% JMA Kobe is 10% and for 100% JMA Kobe is 15%. The maximum deformation of the West wall for JMA Kobe 70% is approximately 34.45cm and for the JMA Kobe 100%, the maximum deformation of the West wall is approximately 42.07cm (Figure 16).

It must be emphasized that in an elastic design, the damages by previous earthquakes cannot be taken into consideration because all analysis for different levels of earthquake intensity starts from the intact building condition. In non-linear analysis, previous damages can be taken into consideration, meaning the analysis can be sequential. The purpose of the analysis is not to simulate the actual behavior, but to get reliable information that there is a correlation between the observed damages and the results of the analysis and the results of the shaking table tests. The correlation is not perfect but is good enough to get an idea on how to build appropriate non-engineered constructions that can withstand earthquakes.

indicates the maximum tensile stress exceeded, meaning substantial cracks start to develop in walls.

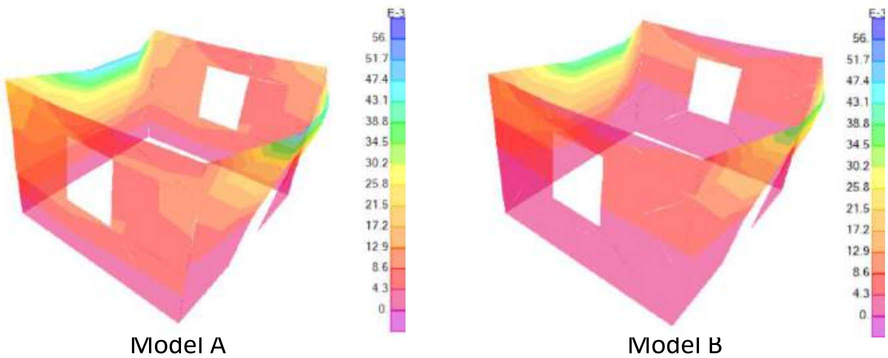


Figure 13: Maximum tensile stress pattern in stone wall due to 30% JMA Kobe; no stress exceeded

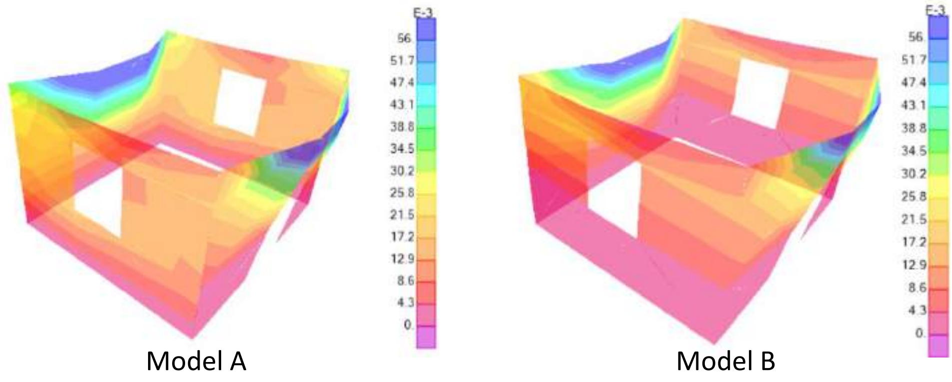


Figure 14: Maximum tensile stress pattern in stone wall due to 50% JMA Kobe; the stresses at some part of walls were exceeded (in blue colors), walls can be damaged or collapsed

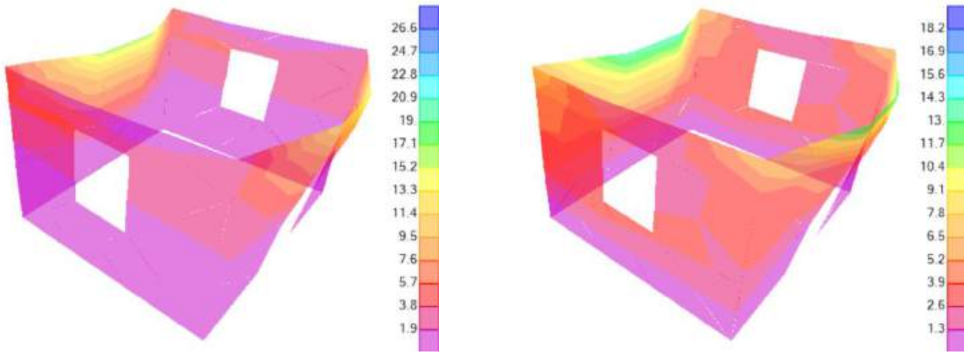


Figure 15: Maximum tensile stress pattern in gabion wire mesh for Model B due to 50% JMA Kobe; maximum stress 27MPa is small than the allowable stress (435MPa)

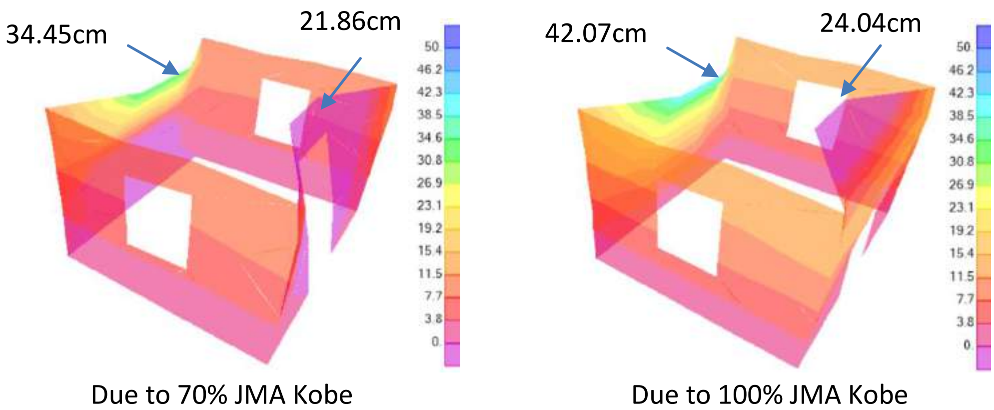


Figure 16: Maximum deformation pattern of Model B

Experiment Results

Both models survived when shaken by 10% JMA Kobe and also20% JMA Kobe. There were no significant cracks or damage. When shaken by 30% JMA Kobe, the West wall (without opening) and the East wall (door opening) of Model A (original unreinforced mud mortar stone masonry) deformed at the top of walls but did not collapsed. Significant damage for Model A occurred at 50% JMA Kobe. Both West and East walls collapsed at the top of walls. Meanwhile, for the same input motion level, Model B, the structure strengthened by wrapping 2mm gabion wire mesh on both sides of the walls, did not show any significant damage although the walls deformed [5].

The input motion was increased to 70%JMA Kobe. All of the West and East walls in Model A collapsed due to out-of-plane loading and almost at the same time large cracks from window openings in North and Southwalls occurred. Model B still survived although the West wall deformed [6]. The input motion of 100% JMA Kobe conducted for Model Bonly on June 4, 2019 test, showed substantial cracking and deformations of the West and East walls, however, did not collapse (Figure 17 & Figure 18). Therefore, the gabion wire mesh on both sides of the walls served the purpose to save human lives. From Figure 18, it can be seen that the deformation for Model B for 100% JMA Kobe in West wall is approximately 45 cm and in East wall is approximately 29 cm. Those figures are in the same range as the analysis (see Figure 16).

West wall Model A from outside (left) and from inside (right)
West wall Model B from inside

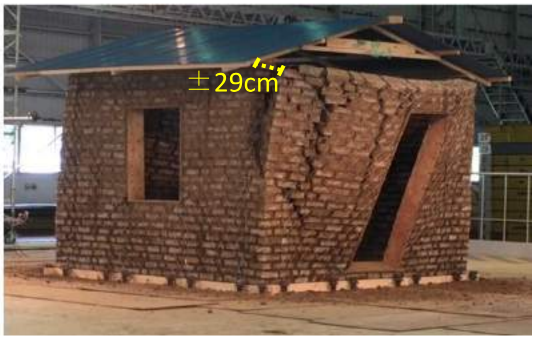
Model A (left) collapsed; Model B (right) survived

Figure 17: February 26, 2019 shaking table test: Model A collapsed due to 50% JMA Kobe; Model B survived

Model A: West and East walls collapsed due to out-of-plane loading; large cracks from window openings in North and South walls

Figure 18: February 26, 2019 shaking table test: Model A collapsed & Model B still standing due to 70% JMA Kobe

Figure 17: June 4, 2019 shaking table test with 50% JMA Kobe (left) and 70% JMA Kobe (right) input motion for Model B only



West Wall East Wall

Figure 18: June 4, 2019 shaking table test with 100% JMA Kobe input motion for Model B only: substantial cracking and deformations but did not collapse

Conclusion

The shaking table tests demonstrated that the strengthening using gabion wiremesh, is effective in preventing collapse of mud mortar stone masonry walls when shaken by earthquakes. Therefore, the ”traditional” practice to build mud mortar stone masonry houses strengthened by wrapping with 2 mm gabion wire mesh can save human lives. Wrapping gabion wiremesh to existing houses can be done without too much disturbance, therefore, it is suitable for strengthening existing buildings. The assumptions taken for the analysis were in line with the results of the shaking table tests, this can be observed from the damage and deformations which are similar.

The advantages to build mud mortar stone masonry houses wrapped in gabion wiremesh: (1) additional cost is not significant; (2) construction is easy.

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Name: Teddy Boen
Affiliation: Structural Earthquake Engineer CSI Indonesia
Brief Career:
1962 until now: work in the field of non-engineered construction
2015-2016: work as JICA expert for retrofitting houses in Nepal, in the month of November 2015 and March 2016

Name: Hiroshi Imai, Architect
Affiliation: Institute of Technologists, Japan
Brief Career:
1988 until now: work in the field of non-engineered construction
2015-2019: Mohri Architect, Japan, served as JICA expert in Nepal
2019 until now: Professor in Institute of Technologists, Japan