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# The shaking table test of strengthen / retrofitting with gabion mesh as jacketing method

Toward improvement of earthquake safety of non-engineered building in Nepal

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## Abstract

Most of the human casualties in past earthquakes were caused because of the collapse of buildings, particularly masonry constructions in developing countries. Most of these buildings are categorized into “Non-Engineered Construction”. In case of the Nepal earthquake in 2015, the majority of the damage was a non-engineered house made by stone masonry in a mountainous. After the earthquake, the goal of housing reconstruction program is to achieve "Build Back Better" (BBB), satisfying NBC 105 as seismic code. However, it is difficult to bring in construction materials such as cement in mountainous areas, there are also many existing non-compliance houses, and the development of a low-cost strengthen / retrofitting method for these houses is an urgent issue.

The reach this target, strengthen / retrofitting method will be developed. Till now, the National Research Institute for Earth Science and Disaster Prevention (NIED) with authors has been developing a jacketing method for brick masonry such as in Indonesia. Although chicken mesh methods needed plastering with cement mortar, this time the gabion jacketing does not need plastering, therefore, it is lower cost and construction is simple. Wire used for gabion jacketing is roll-able and portable, so it is possible to carry in manually by mountain area.

Stone masonry with mud mortar structure has not been studied so far. In particular, this type of masonry is mostly dependent on the shape of the stone, bonding condition of mud here, it is a structure which is difficult to analyze by computer. In order to recognize the seismic performance of this structure, the full-scale shaking table experiment is useful. Especially, it is possible to understand the destructive behavior to the collapse causing human damage, through shaking table tests.

In order to observe the performance of gabion wire mesh in stone masonry with mud mortar houses when shaken by earthquakes, the full scale shaking table test was conducted. The wall strengthened with gabion wire mesh is expected to deform, but not collapse and kill people. Therefore, the life safety performance level is fulfilled. This method is developed to improve the earthquake safety of non-engineered building in Nepal.

*Keywords: Retrofitting, Non engineered construction, Masonry, Shaking table test, Nepal earthquake*

# 1. Introduction

## 1.1. Characteristic on Collapsed Houses due to the 2015 Nepal Earthquake

A 7.8 magnitude earthquake struck Barpak in the Gorkha District on 25th April, 2015. Soon after this earthquake, a 7.3 magnitude earthquake occurred in the Sindhupalchok District on 12th May, 2015. Thirty-one of the country's 71 districts have been affected by the earthquakes. Table 1.1 shows the housing damage of structural type by the earthquakes in Nepal.

A total of 755,549 houses have been damaged by the earthquakes in 31 districts in Nepal. Of which, 498,852 houses (66.0%) were completely destroyed and 256,697 houses (34%) were partially damaged. The large-scale destruction of houses resulted primarily from the seismic vulnerability of the low strength stone or brick masonry with mud mortar houses that predominate in rural areas in Nepal. In the total of 755,549 damaged houses, 647,892 houses (85.8%) were made of low strength stone or brick with mud mortar.

Table 1 .1– Housing Damage of structural type by the earthquakes in Nepal

| Level of Damage | Low Strength Masonry | Cement Mortar Masonry | Reinforced Concrete | Total |
|---|---|---|---|---|
| Fully Destroyed | 474,025 | 18,214 | 6,613 | 498,852 |
| Partially Damaged | 173,867 | 65,859 | 16,971 | 256,697 |
| Total | 647,892 | 84,073 | 23,584 | 755,549 |

We conducted damage surveys in affected areas, such as Gorkha district and Sindhupalchok. The Most damaged/destroyed houses in these areas were constructed using random rubble masonry and bricks stacked in mud mortar. Most of them had corrugated galvanized iron sheet roofing. No earthquake resisting measures were used

## 1.2. Observation of Damage Houses

Findings are below;

- Non-Engineered Construction

  This type of construction is spontaneously and informally constructed in the traditional manner without any or only little intervention by qualified architects and engineers in their design. In Nepal, especially in rural areas, most residential houses are built by the house owner and masons who are not educated in engineering. Therefore, most damaged houses were Non-Engineered Construction caused by having no regard for earthquake resistance design.

- Masonry in mud mortar

  Unreinforced mud mortar masonry is the structural method most vulnerable to earthquakes. This is because mud as a joint material is very vulnerable when it receives vibrations. In the rural areas, most houses use masonry employing rubble or dressed stone and brick, and the joint material is mud mortar.

- Failure pattern

  In the masonry walls, out-of-plane is the most typical failure pattern, and diagonal shear cracks as in plane failure also happened. But in this earthquake, wall separation (delamination) failure were found. Such houses are destroyed because of the weakness of the mortar used, and absence of bond stones across the thickness of the stone wall resulting in delamination of the inner and outer walls along with separation of the walls at the corners. These finally result in the total collapse of the buildings. Figure 1-1 shows typical failure pattern in this earthquake.

Gable wall failure

Delamination o the inner and outer walls

Fig. 1-1 Typical failure pattern of 2015 Nepal earthquake

To know the strength of the masonry in mud mortar, tensile strength test between stone and mud were conducted in Nepal. The results and photos of the test are shown in Fig.1-2 and Table 1-2. The strength was about 12% compared with the average value as 0.65N/mm2 of the result of previous tensile test of cement mortar and bricks.

Potable tensile test machine

Specimens of tensile test

Fig. 2-2 Typical failure pattern of 2015 Nepal earthquake

Table 1-2 Housing Damage of structural type by the earthquakes in Nepal

| Specimens | Max(N) | Area(mm2) | Tensile strength (N/mm2) |
|---|---|---|---|
| 1 | 238.00 | 2619.90 | 0.0908 |
| 2 | 252.00 | 3437.71 | 0.0733 |
| Ave. | | | 0.0821 |



## 1.3. Housing Reconstruction Program by the Government of Nepal (GON)

### 1.3.1. Housing Grant

GON has decided to provide the housing grant of 300,000 NPRs for reconsturction of house in three stages. The first stage of 50,000 NPRs is provided once the house owner has signed the Participation Agreement (PA) with the local government. The second stage of 150,000 NPRs is provided after inspection and approval of construction of foundation (i.e. plinth level), and the third stage of 100,000 NPRs is provided after inspection and approval of construction of wall (i.e. roof band). Similarly, the grant of 100,000 NPRs is provided to the beneficiaries for retrofitting of their damaged house in two stages.

### 1.3.2. Build Back Better

The goal of housing reconstruction program is to achieve "Build Back Better" (BBB), satisfying NBC 105 as seismic code. To achieve BBB and satisfying NBC105, The Design Catalogue for the Reconstruction of Rural Housing has been developed to support houseowners to start the reconstruction of houses, by providing prototypes and flexible house designs. And for the free architecurural design, the Minimum Requirements for housing reconstruction program based on NBC105 was developed. For the dissemination of these MRs for housing in the reconstruction programme for the beneficiaries, posters of each model were developed.

Two years after the earthquake of 25th April 2015 (meaning 2017), significant progress has been achieved in the current situation of reconstruction of houses.

## 1.4. Necessity to Development Low-cost Retrofitting Method

According to the NRA-CBS survey, 141,996 HHs across the 31 earthquake affected districts were categorized as Damage Grade 2, and 16,135HHs as Damage Grade 3 of Not Severely Damaged.

Under the housing reconstruction program, house retrofit grant of 100,000 NPRs is available to house owners, if their retrofitting complies with the relevant standards and specifications. Retrofitting steps are to check the damage situation of all building components, to check the seismic capacity of an existing building and decide technics about retrofitting.

There are huge demands, however, the number of beneficiaries of retrofitting construction is very little. Because, the retrofitting grant of 100,000 NPRs is not enough to meet NBC105. Furthermore, till now few study about mud mortar and stone masonry structure prevented the technical standard team from evaluating actual seismic capacity of house construction materials. For buildings with insufficient seismic capacity, the question is whether to retrofit or demolish them. To answer this question, several factors must be considered, such as, how low the current seismic capacity is, the target level of retrofitting (this case is NBC105), the availability of retrofitting materials, the cost of retrofitting, and future use of the building.

# 2. Strengthen/Retrofitting with Gabion Mesh for Mud Mortar Masonry Structures

## 2.1. Past study

Since 2006, we have been developing a jacketing method for brick masonry in Indonesia and other countries. Figure 2-1 shows the outline of the jacketing method. Masonry wall are covered with a wire mesh and cement mortar plaster for improving seismic performance. This method is already widely used in masonry in Indonesia and other countries and it has used reconstruction project in the 2019 Sulawesi and Lombok earthquakes. (Fig. 2-2)

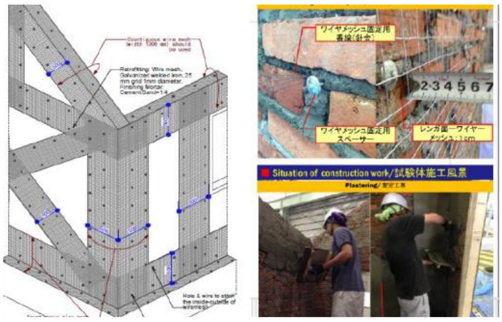


Fig.2-1 Past study of jacketing method

Fig.2-2 Reconstruction house in Sulawesi

## 2.2. Outline of proposed gabion mesh jacketing

As a Strengthening / Retrofitting method for masonry structure, a full jacketing method using Gabion mesh without cement mortar finishing is proposed. In Nepal, cement is quite expensive and is not easy to obtain by the people living in mountain regions. Therefore, to make mud mortar stone masonry houses earthquake safer, a simple, affordable, adaptable and economical method should be found. The method must also be familiar to local masons. Generally, Gabions for civil work are, packed with stones in baskets about 1m3, and are widely used in Nepal as slope strengthening for road embankment. (Fig.2-3)

In this study, the development strengthen/retrofitting method was carried out to divert to masonry structure, and it also should be applied to existing buildings.

The wire used for gabion jacketing mesh is galvanized with a diameter of 2-3mm has the same diameter and specification as those used for civil engineering works in Nepal, therefore, it can be found all over Nepal.

This wire is commercially available in the form of a rolls. Therefore, it can be carried into mountainous areas by man power. And then, preparing mesh from roll wires is performed near the building site. As shown in Fig.2-4, in Nepal, gabions for civil engineering are commonly used mountainous regions on site as molding technique. Installing is technically not difficult, it is considered that residents be able to lean the mesh forming technique by training for several hours.

Fig.2-3 Gabion baskets

Fig.2-4 Installing gabion mesh on site

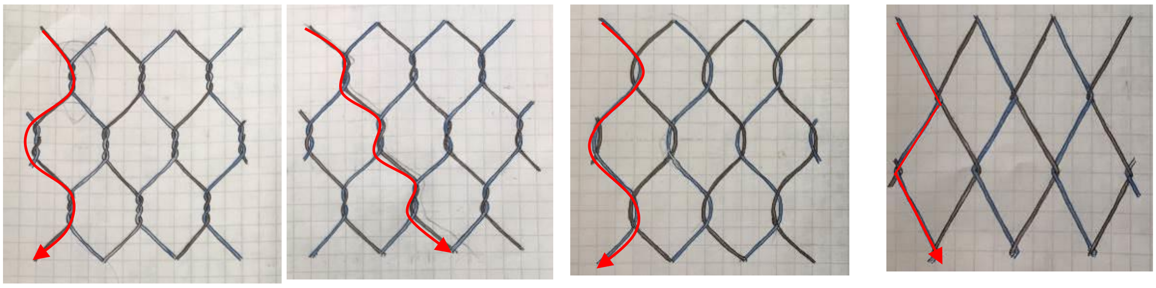


## 2.3. Producing hexagonal pattern mesh

Study for method of producing hexagonal pattern mesh is outlined below. The mesh used for gabions is often of hexagonal pattern. The point about hexagonal pattern mesh is that even if it breaks as a mesh, there is little effect on the adjacent wires because it has many contact points of the wire.

Figure 2-5 shows illustrations of the number of twists of the hexagonal mesh. A regular hexagonal mesh is twisted three times. Comparing with two twisting, three-times twisting workability is easy to apply tension because wire keeps same the vertical axis. Because twisting twice causes the wire to move diagonally at each step, it is difficult to apply tension and the surface bends. A single twist results in a rhombic mesh is, this shape cannot be held without tension when tension is applied to the mesh. Therefore, it is difficult to apply to the wall.

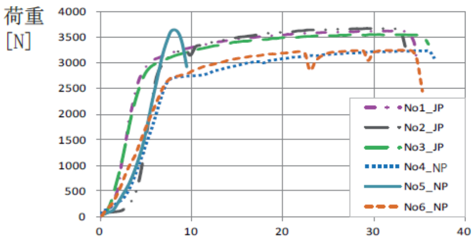


Three-time twisting Twice twisting Single twisting Rhombic pattern

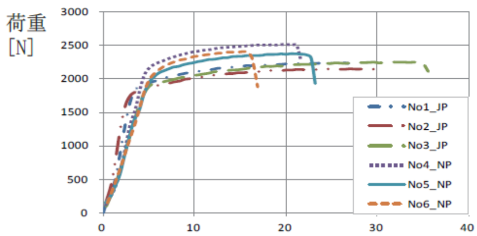
Fig. 3-5 Twisting number and mesh pattern

## 2.4. Elemental test of wire mesh

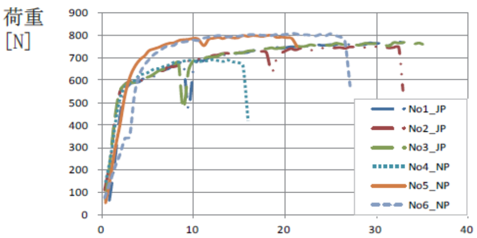
For shaking table test, Japanese wire mesh is used. Therefore, comparison study between Nepal wire and Japanese wire were conducted. A total of 18 tensile tests consists three wire types which diameter are 3.2mm, 2.6mm, 1.6mm made in Japan (J) and Nepal (N). The photos of the test and results shown in fig. 2-6. Nepal product were 10% lower than Japan made averagely. In addition, some of products Nepal made are remarkably low strength and it has variation in quality.




Diameter 3.2mm




Diameter 2.6mm




Diameter 1.6mm

Tensile test

Fig. 2-6 Result and photo of the tensile test



## 2.5. Durability of galvanized wire for Gabion mesh

In Nepal, gabion for slope strengthen and roadside fences are old and have been used for about 20 years. Durability of gabion mesh depends on the coating thickness of galvanized coat of wires. Table 2-1 shows material property of galvanized wires made in Nepal.

Table 2-1 Material property of galvanized wire in Nepal

| Wire | Material property | | | AI Component analysis |
|---|---|---|---|---|
| | Diameter(mm) | Tensile strength(N/m2) | Coating weight(g/m2) | |
| A | 3.15 | 601 | 9 | non |
| B | 3.18 | 445 | 269 | non |

There is a large difference in the coating thickness of Wire A and Wire B, however it can be seen that those that meet the coating weight of 155g/m2 of the Japanese JIS standard (JIS G3547) are also available.

The formulas for coating weight and durability indicated by Japanese manufacturers are shown below.

- The durability of the “Galvanized part” is expressed as the period until the coating weight is consumed, expressed by the following formula, based on the coating weight and the galvanizing corrosion rate.

$$\text{Durability of the “Galvanized part”(year)} = \frac{\text{Coating weight (g/m2)}}{\text{Galvanizing corrosion rate(g/m2/year)}}$$

*Galvanizing corrosion degree (g /m2/ year) is generally 5-20g / m2 / year, depending on the usage environment.

- The durability of the "Iron wire" is expressed by the following formula from the Iron wire corrosion margin and the Iron wire corrosion rate as the period until the tensile strength (cross-sectional area) corrodes to 1/2.

$$\text{Durability of the “Iron wire”(year)} = \frac{\text{Corrosion margin(mm)}}{\text{Iron corrosion rate(m2/year)}}$$

$$\text{Corrosion margin(mm)} = \frac{\text{Diameter(mm) x (1-}\sqrt{\frac{1}{2}}}{2}$$

The durability year of the wire B is calculated by using the above-described formula.

- In the case of the unfavorable environment conditions,

  269 (g/m2) / 20 (g/m2/year) = 12.10 years

- In the case of the favorable environment conditions,

  269 (g/m2) / 5 (g/m2/year) x 0.9 = 48.42 years

Therefore, it is considered that even galvanized wire widely used in Nepal has sufficient durability unless it is a particularly inferior product.



## 3. Full scale shaking table test of mud mortar stone masonry wrapped with gabion mesh

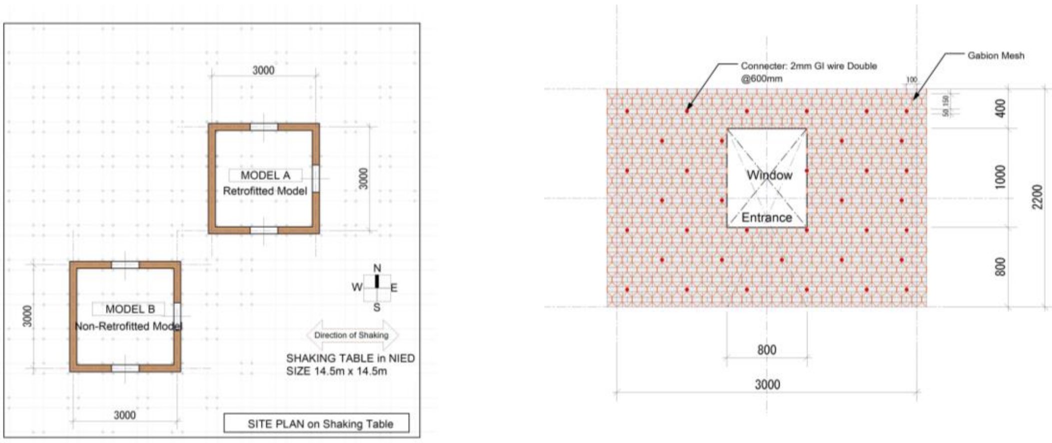
The shaking table test of mud mortar stone masonry with gabion mesh was conducted for investigation of its seismic performance at National Research Institute of Earth Science and Disaster Prevention (NIED), Tsukuba. This shaking table is a one-direction horizontal with displacement ±22cm (44cm stroke) and velocity 100cm/s. The table dimension is 14.5meter by 15.0meter.

The main aim of this study is to assess the effects of the gabion mesh jacketing when shaken by earthquakes and to demonstrate to the people the effectiveness of such retrofitting method.

Two model structures were built on the shaking table on Feb. 2019. Both models were of the same size and built as unreinforced mud mortar masonry houses. Model A is the original unreinforced mud mortar masonry house without plaster. And model B is the same masonry structure strengthened by wrapping 2mm gabion wire mesh on both sides of the walls, shown in Fig.3-1.

Each model consisted of four walls with size 3200mm x 2200mm with galvanized corrugated sheet roof. The wall thickness is 210mm. Figure 3-2 shows the drawings of masonry walls. The west wall is without opening, perpendicular to the direction of the shaking.


Fig.3-1 Two models on shaking table




Site plan

Elevation

Fig.3-2 Drawings of shaking table test

## 3.1. Producing gabion mesh

In the case of D.I.Y house owners themselves will produce gabion mesh, we inspect and assist of constructing the gabion mesh.

The specimen used for the shaking table test is a cement brick (Length 210mm x Width 100mmx Height 60mm) and the wall thickness is 210mm. A diameter of 2mm galvanized wire was used based on the weight of the wall and the tensile strength of the wire.

The gabion mesh used three twisting and the size of the stitch is 150mm long and 100mm wide to prevent the collapse wall and even of one piece of stone / brick.

The process for producing gabion mesh is shown below. (Fig. 3-3)

1. In preparing a wooden frame 1200mm x 2400mm with 2x4 Wood.

2. Attach the weaving guide to the wooden frame. Tap the tapping screw 50mm at intervals of 150mm in length and 100mm in width according to the mesh size.

3. Some small roll of about 10mm in diameter is made from a commercially available wire roll (about 30mm in diameter) for weaving. Wire length shall be 2times of the height of the completed plus 50% margin. Prepare the eleven vertical line for one sheet.

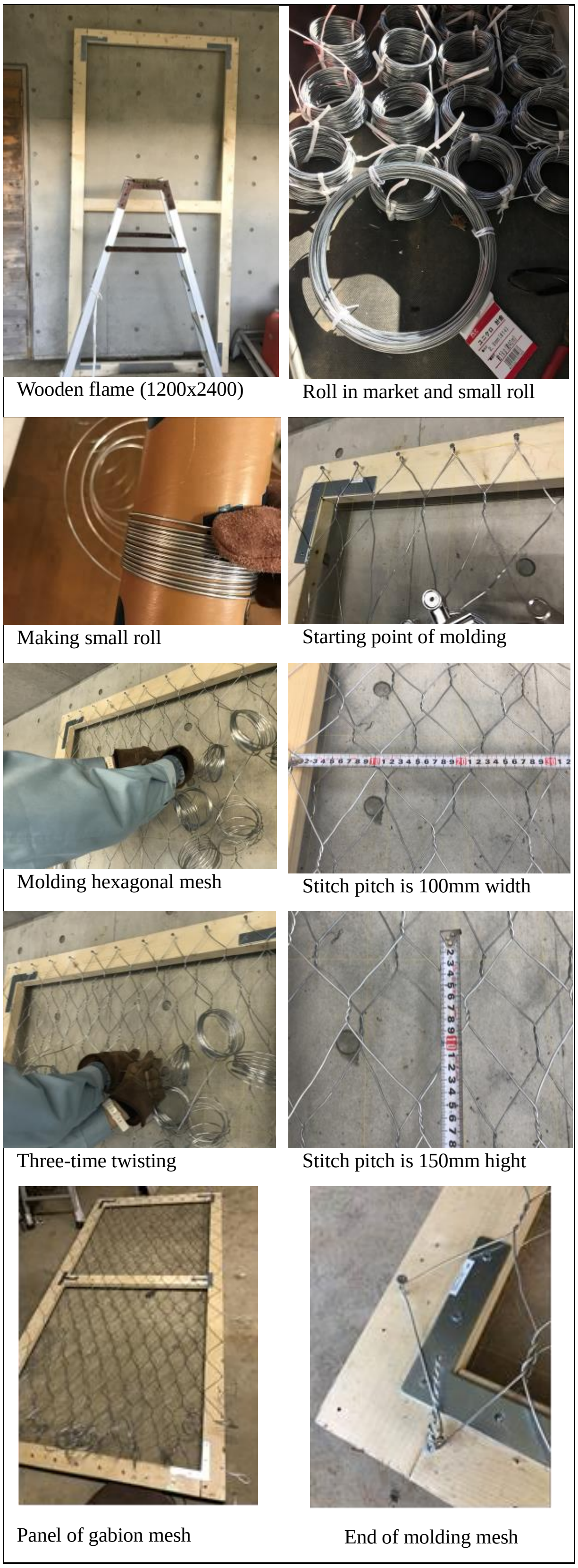
4. Fold the small roll created in step into a V-shape at the center.

5. Start knitting according to the guide of the wooden frame. The hexagnal gabion mesh is twisted three times. (If the number of twists is an odd number, the vertical members pass through the same vertical line. If the number is an even number, the wire moves diagonally.)

6. By changing the torsional directions of the odd-numbered steps and the even-numbered steps in the horizontal direction, it is possible to prevent the entire mesh from being twisted.

7. The length of each dimension consists of diagonal part 50mm, twisted vertical part 50mm, and again diagonal part 50mm. The vertical length of the hexagnal part is 150mm and the horizontal length of the hexagnal part is 100mm.

8. After weaving to the bottom of the wooden



Wooden flame (1200x2400) | Roll in market and small roll | Making small roll | Starting point of molding | Molding hexagonal mesh | Stitch pitch is 100mm width | Three-time twisting | Stitch pitch is 150mm hight | Panel of gabion mesh | End of molding mesh

Fig.3-3 Process for molding gabion mesh



frame, fix the ends to the mesh and remove it from the frame.

The making time for a gabion mesh (1200mm x 240mm) is about 4hours for weaving and about 30minutes for small roll production.

The shaking table test specimens (3200mm x 3200mm x 2200mm) were prepared in a total of 23pieces, and the total amount of wire (2mm) used was about 1920m in length and 96kg in weight. It took 20working days. The price of galvanized wire in Nepal is NRP200/kg, therefore, the material cost for one building will be about NRP20,000.

### 3.2. Stitching inner and outer gabion mesh

The inner and outer stitched gabion mesh is at the joint of the masonry by a galvanized wire diameter 2mm.

This connector uses two pieces of about 400mm in length and wall thickness + 100mm x 2(both sides), and is arranged at intervals of 600mm in width and 300mm in height.

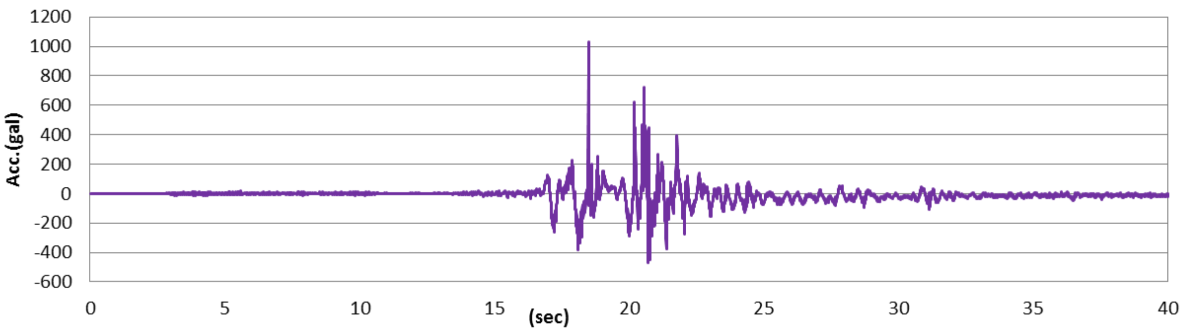
In addition, Gabion meshes which size is 2400mm x1100mm were used vertically. Its hangs down from the upper part of the wall, and the inside and outside meshes are tied together by connectors from the upper part. The workability is improved by using bending wire when temporarily fixing. The meshes are joined together by knitting same dimension of wires without overlapping.

Connector through outside to inside of the wall
Fixing gabion mesh by connector
Attached gabion mesh
Top of wall
At corner of wall, Outside
At corner of wall, Inside

Fig.3-4 Installing gabion mesh

### 3.3. Input motions

The input motions for this test were based on 1995 Kobe earthquake, such as JMA Kobe NS wave. (Show in Fig.3-5) The excitation increased gradually 10% to 70%.




(A) JMA Kobe NS, Japan

Fig.3-5 Input motion of JMA Kobe NS



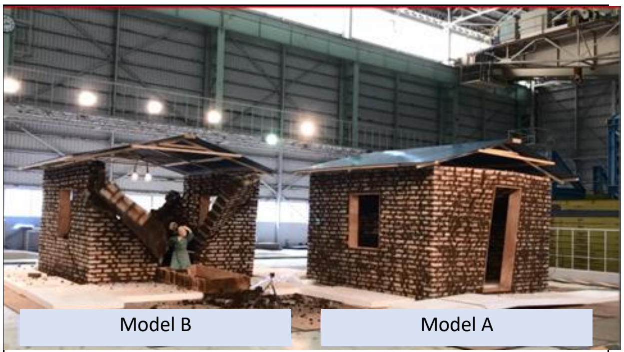
### 3.4. Observations of main inputs (Fig.3-6)

- Model A: Original unreinforced mud mortar stone masonry house
  - JMA Kobe 30%: Deformation and large cracks occurred on the West wall (without opening) and the East wall (door opening)
  - JMA Kobe 50%: Out-of-plane failure on the West and East walls occurred partially. The entrance wooden frame and masonry wall on the frame collapsed.
  - JMA Kobe 70%: Failure of both East and West walls spread to out of plane. In-plane shear crack occurred on the North and South walls from the openings, then leading to complete collapse.
- Model B: Mud mortar masonry structure strengthened by wrapping 2mm gabion wire mesh
  - JMA Kobe 30%: Deformation and large cracks occurred on the West wall (without opening) and the East wall (door opening)
  - JMA Kobe 50%: Failure of both East and West walls spread on out of plane.
  - JMA Kobe 70%: This model still survived although large deformation happened on the out-of-plane. Even there was no fall down one piece of bricks.

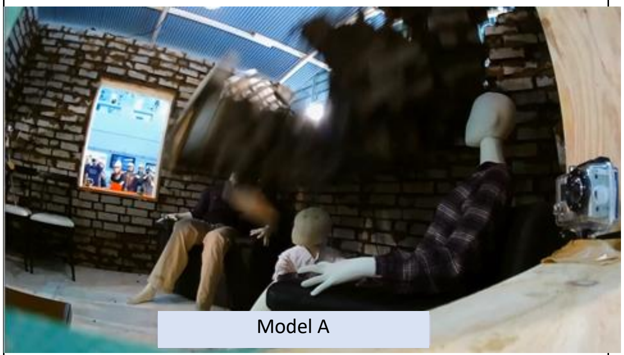
Through this experiment, the effects of the gabion mesh for earthquake resistance are as follows.

(1) Prevents the brittle collapse pattern of walls especially out-of-plane and provide elastic effectiveness for masonry structure.

(2) The jacketing on both sides of the walls prevent wall collapse and thus served the purpose to save human lives.




JMA Kobe 70% (583gal)




JMA Kobe 50% (410gal)


After JMA Kobe 70% Model A


After JMA Kobe 70% Model B

Fig.3-6 Photos of shaking table test

## 4. Conclusion

Through this experiment and the construction of the test specimen, the gabion mesh has advantage to a strengthen/retrofitting method that can be disseminated locally due to the following points.

(1) Low cost and locally available material. Since this wire is commercially available in Nepal. And it can be manually transported into mountainous areas. The material cost for one building this time is about NRP20,000.

(2) Easy construction without special skills. Producing gabion mesh technology does not require special tools and is not technically difficult, so residents can produce gabion mesh by minimal training.

(3) It is flexible and can be applied to all building shapes and damages, and reduces human casualties.

(4) The shaking table test indicates that the jacketing of mud mortar stone masonry houses can safe human lives.

Further study, it is necessary to continue research on the ultimate strength-based analysis method based on the results of this experiment. In the construction method, research and development of cheaper and simpler methods will be promoted.

The test results and videos have already been used for dissemination of seismic reinforcement as a tool for raising awareness of disaster prevention to reduce damage in developing countries such as Nepal.

## 5. Acknowledgements

We would like to give special thanks to National Research Institute of Earth Science and Disaster Prevention (NIED), Tsukuba for arranging the shaking table test and related masonry properties tests.

Dr. Hari Ram Parajuli, NRA, Dr. Ramesh Guragain, N-SET and all those who supported this study are gratefully acknowledged.

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