Comparison of Current Construction Practices of Non-Engineered Buildings in Developing Countries

Kenji Okazaki
National Graduate Institute for Policy Studies, Japan

Krishna S. Pribadi & Dyah Kusumastuti
Research Center for Disaster Mitigation, Bandung Institute of Technology, Indonesia

Taiki Saito
International Institute of Seismology and Earthquake Engineering, Japan

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SUMMARY:
The majority of the population in developing countries lives in buildings that can be considered as non-engineered, which unfortunately are often susceptible to many natural disasters, especially earthquake. As the construction techniques/practices and skill of masons/carpenters differs from country to country, strength of non-engineered constructions differ as well. A research was conducted jointly in seven selected developing countries, i.e. Egypt, India, Indonesia, Nepal, Pakistan, Peru, and Turkey, to collect data on their design and construction characteristics and information related to the local context. All of the countries have certain code or, at least, guidelines on building construction, which however do not seem to affect field practices. While construction practices are different from country to country, most of them have some similarities on certain parameters, such as design intervention, availability of materials and workers, supervision by the owner, construction tools, foundation types, wall thickness, type of plaster/mortar/concrete, workers' training, etc.

Keywords: Non-engineered buildings, construction practices, developing countries, earthquake vulnerability

1. INTRODUCTION

The majority of the population in developing countries lives in buildings that can be considered as non-engineered buildings, i.e. buildings and houses built in a traditional way without or with minimum engineering intervention from an architect or structural engineer in the design and construction process. In general, masonry and wooden structures are commonly found in this category of structure (IAEE, 1986) (Kusumastuti *et al.*, 2008). Unfortunately, this type of building is often susceptible to many natural disasters, especially earthquake. Past earthquakes revealed that the damage on non-engineered houses is responsible for the deaths of most of the total casualties in earthquakes (Narafu *et al.*, 2010) (Macabuag, 2008) (Grundy, 2007). As construction techniques/practices and skill of masons differ from country to country, strength of non-engineered construction differ as well. However, there is little knowledge about the comparative strength in various developing countries.

This research was conducted jointly in seven selected developing countries, i.e. Egypt, India, Indonesia, Nepal, Pakistan, Peru and Turkey, involving survey of construction of non-engineered buildings in various sites in each country to collect data on their design and construction characteristics and information related to the local context.

2. RESEARCH OBJECTIVES AND METHODOLOGY

2.1. Research objectives

The main purpose of the study is to obtain a better understanding of the current practices of non-engineered buildings in developing countries in order to improve policies and develop better appropriate technology for reducing their vulnerability against earthquakes. The research objectives include developing data sheet to collect data, sharing information and comparing the application on non-engineered construction, in selected developing countries. Based on the information obtained, general problems can be identified and recommendation for improving non-engineered construction in developing countries can be formulated.

2.2. Selected Samples

The seven selected developing countries involved in the study are responsible to select several non-engineered houses that represent the current practice of non-engineered construction in various sites in the country.

Table 1. Location of the Selected Samples

No	Country	City/Region
1	Egypt	15th May City, Helwan City, Giza Square, 6th October City/Haram City and El-Marg City
2	India	Balasore, Dehradun, Barmer, Portblair and Shimla
3	Indonesia	Bandung City
4	Pakistan	Potohar Plateau and Plains of Punjab
5	Peru	Puente Piedra, Carabayllo, Independencia, Huachipa and San Juan de Miraflores
6	Nepal	Balkot, Bhaktapur, Nankhel, Kirtipur, Kathmandu, Imadole, Lalitpur, Hattiban, Lalitpur of Kathmandu Valley
7	Turkey	Yenikapi, Sirkeci, Uskudar.

2.3. Methodology

The research work was divided into three stages. First, the development of survey forms that will be used in all of the selected countries, involving the experts from the following institutions and universities in the selected countries : National Research Institute of Astronomy and Geophysics (NRIAG), Egypt; SEEDS Technical Services (STS), India; Research Center for Disaster Mitigation - Institut Teknologi Bandung (RCDM ITB), Indonesia; Designmen Consulting Engineers (Pvt) Ltd/ETSSR Center, Pakistan; Japan Peru Center for Earthquake Engineering Research and Disaster Mitigation of National University of Engineering – CISMID – UNI, Peru; National Society for Earthquake Technology (NSET), Nepal; and Istanbul Kultur University and Istanbul Technical University, Turkey.

The following information was collected in the survey form; 1.General information (country facts), 2.General information on technical requirement from current local building regulation/code for the brick masonry construction, 3.General information on project and project site facts, 4.General building information, 5.Actual condition and compliance to regulation, 6.Masonry material technical data, 7.Concrete material technical data, 8.Other material technical data, 9.Non-structural material technical data, 10.Contractor data

Secondly, the survey was conducted by interviewing workers and/or buildings owners. Non-destructive test (hammer test) and laboratory test were conducted to obtain information related to quality of construction materials, such as compressive strength of concrete and bricks. Some countries conducted the survey on the existing building due to the rarity of non-engineered construction projects, supported by secondary data from literature studies. In Turkey the survey targeted the old non-engineered buildings as non-engineered construction is not common in urban areas.

Thirdly, comparison of the data of each site was based on parameters available in the data sheet, based on average value, smallest value, largest value, most used/available, or the availability of the items, possible similarities and differences. Specific problems for each country were also summarized. General problems are extracted from specific problems identified and recommendations are formulated to improve the construction of non-engineered building in developing countries.

4. CURRENT CONDITIONS OF NON-ENGINEERED CONSTRUCTION IN DEVELOPING COUNTRIES

4.1. Buildings Regulation on Non-Engineered Construction

Most of the selected countries have building regulation/codes and/or guideline on non-engineered construction at the national level, such as India, Indonesia, Pakistan, Peru and Nepal. Unfortunately, the building regulation/codes or guidelines on non-engineered structure are mostly not implemented by the countries, excepting for a few big cities. It was also found that some countries have problems on disseminating these regulations to the workers. In Turkey and Egypt, the non-engineered building code at the national level is not available. However, both countries have local offices in charge of building administration in the surveyed cities. In Turkey, the national building code is only for engineered structure.

4.2. Typical Non-Engineered Building Construction

4.2.1. India

The most common non-engineered building in India is masonry building (of various types of bricks) with G + 1 story high. Most of the brick masonry building uses mud brick (adobe), CSEB and quarry stone.

Figure 1. Typical Non-Engineered Buildings in India

4.2.2. Indonesia

In general, there are three most common non-engineered constructions found in Indonesia, i.e. unconfined brick or concrete block masonry, confined masonry, and reinforced concrete frame with infill masonry. Unconfined masonry building relies on the wall as the only load bearing structural elements (vertical and lateral). There is no confinement on this type of building and it is rarely found in Bandung area. Confined masonry building relies on the masonry walls as the main load bearing structural elements. The confinement will contribute also to maintain the integrity of the wall when the loads are applied to the structures. Most of the confined masonry structures in Bandung are confined by reinforced concrete practical column/beams. Reinforced concrete with infill masonry wall building relies on the reinforced concrete columns and beams as the main load (both lateral and gravity) bearing structural elements

Figure 2. Typical Non-Engineered Buildings in Indonesia

Figure 3. Typical Non-Engineered Buildings in Pakistan

4.2.3. Pakistan

Three types of non-engineered building (confined masonry, unconfined masonry and reinforced concrete with infill masonry are mostly adopted in non-engineered buildings in Pakistan.

Figure 4. Typical Non-Engineered Buildings in Peru

4.2.4. Peru

In Peru, there are three types of non-engineered buildings. Those are confined masonry building with horizontal and vertical confinements that support the bricks walls, Unconfined masonry walls building without reinforced collar beam and reinforced confined elements and Concrete moment resistant frame with concrete shear walls or infill masonry.

Figure 5. Typical Non-Engineered Buildings in Egypt

4.2.5. Egypt

The most common types of non engineered building in Egypt are reinforced concrete skeleton type buildings, wall bearing lime stone buildings and combined reinforced concrete and lime stone wall buildings.

Figure 6. Typical Non-Engineered Buildings in Nepal

4.2.6. Nepal

In Nepal, there are two types of non-engineered brick masonry buildings, i.e. unconfined brick masonry buildings and reinforced concrete buildings with brick masonry infill.

4.2.7. Turkey

There are three types of non-engineered building in Turkey, i.e. reinforced concrete frame with clay hollow brick infill wall, unreinforced brick masonry and wooden structures.

Figure 7. Typical Non-Engineered Buildings in Turkey

5. COMPARISON OF THE SURVEY RESULTS

The information obtained during the survey on each site is extracted into single representative information of each country, based on the average value, the smallest value, the most common information or the available information, similarities, and differences.

5.1. Project and Project Site Facts

Most of the surveyed sites are located on flat/gentle slope. Most of the non-engineered buildings found in Nepal, India, Turkey, India and Peru are constructed by craft man assigned by owner to construct the buildings, using simple construction tools, instead of by hired contractor such as in the case found in Egypt and Pakistan. In general, there is no problem or limitation on the availability of construction material for the non-engineered buildings. Most of the buildings are owned by private sector and the design intervention is mostly from the owner. Most of the non-engineered buildings are found to be supervised by their owner (see Figure 8).

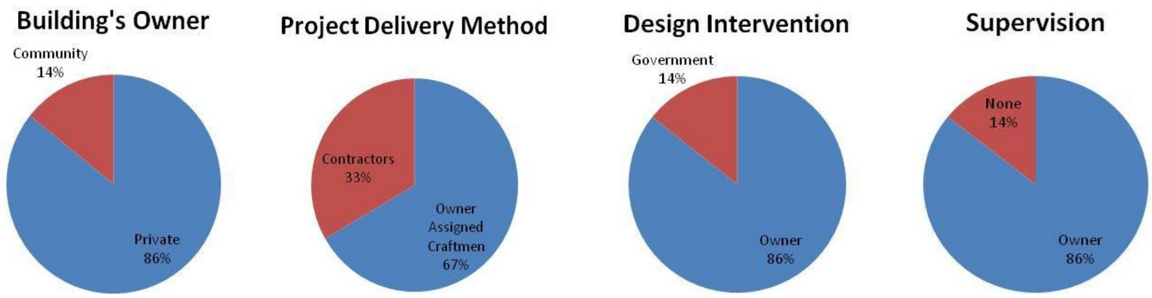

Figure 8. Building owner, project delivery method, design intervention, and supervision

Respondents (house owners as well as workers) in Nepal, India, Turkey, Indonesia, Peru and Pakistan agree that earthquakes become the most common natural disasters, while in Egypt and also in Indonesia wind is also considered as common natural disaster. Some other countries like India and Peru also suffer from flood. Typically a non-engineered building is constructed within 6 to 17 weeks (see Figure 9).

5.1. General Building Information

Most of the non-engineered constructions are used as residential buildings and small commercial places. Some of them are also found to be used as school buildings.

"Strip and isolated pad" (the simplest foundation system) is found mostly in the non-engineered buildings surveyed, constructed from various materials, such as stone and RC. For confined masonry, most of the buildings use reinforced concrete confinement. Wood is the most common material used for door and windows framing system (see Figure 10).

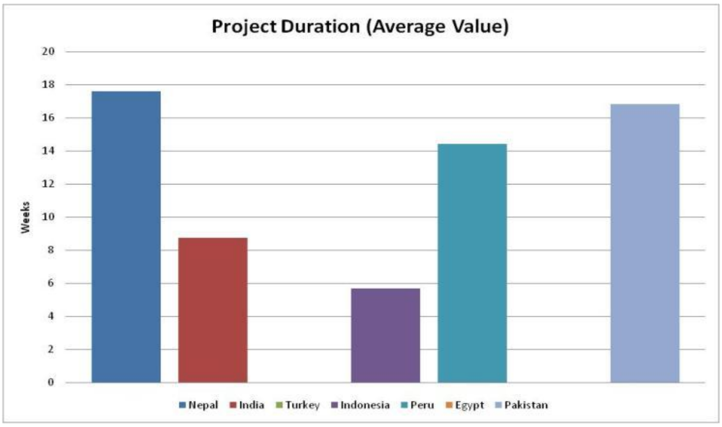

Figure 9. Construction period

It is found that most of the non-engineered buildings in the selected countries are unconfined masonry, except in Indonesia and Peru where the confined masonry is more popular. Building area depends on its main function. Average value varies from 80 m² to 187 m². Typical number of rooms varies for each country (see Figure 11)

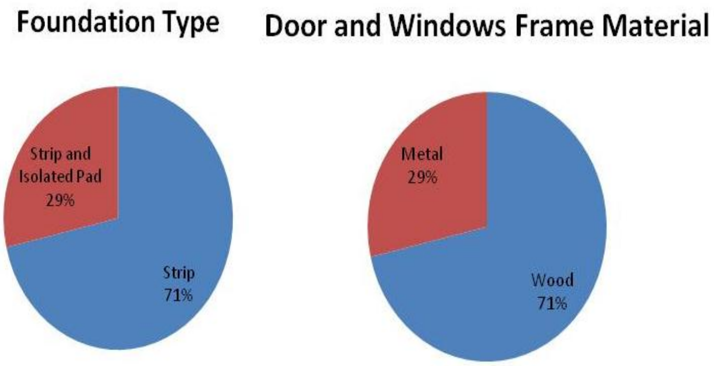

Figure 10. Foundation type and door/window frame material

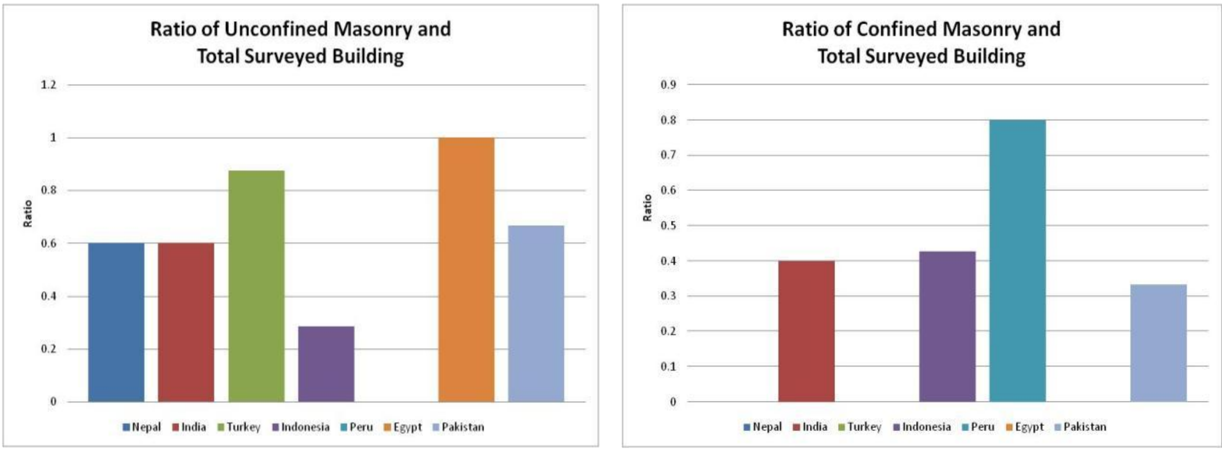

Figure 11. Ratio of Types of Structure to Total Surveyed Buildings

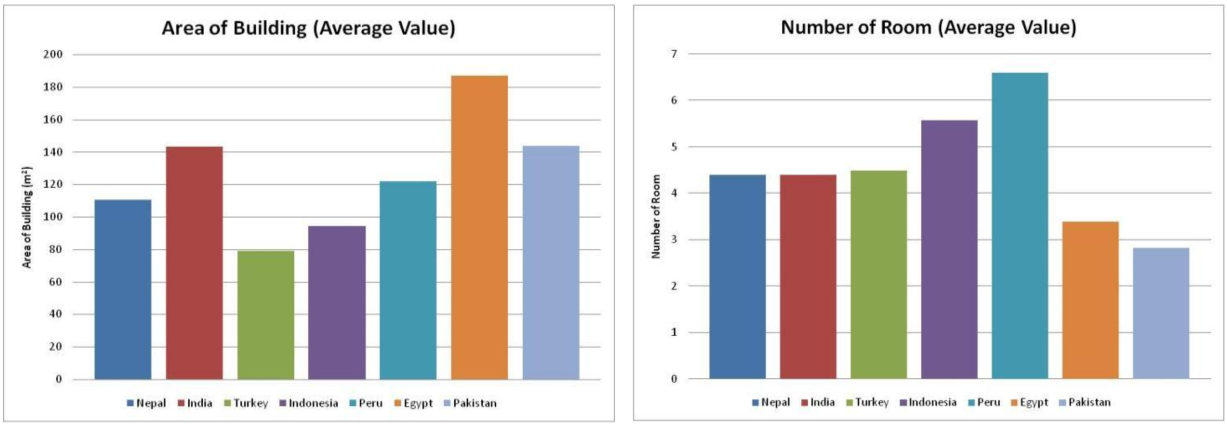

Figure 12. Area of Building (left) and Number of Room (right)

5.2. Technical characteristics

Foundation dimension varies in different countries. The widest strip foundation is found in (0.8 m), while the narrowest were found in India and Peru (0.4 m). In Turkey, foundation as deep as 1 to 2 m is common, while in Egypt foundations are shallower (0.7 m).

Most of the buildings utilize fired clay bricks as wall material, with one brick thickness (see Figure 13). In terms of wall height to thickness ratio, the highest ratio is found in Indonesia (19.83), while the smallest is found in Egypt (9.00). The higher value of the ratio indicates the lower wall stiffness (see Figure 14). The ratio of total length of wall to floor area indicates the capacity of the building in absorbing lateral forces, and the highest value was found in Nepal. The highest wall opening ratio is found in Turkey.

Most of non-engineered constructions provide beams and few of them provide columns. This depends on the structural system adopted in the surveyed country. In Indonesia, most of the surveyed sites exhibit confined masonry, so both columns and beams are available. On the other hand, in Pakistan, Egypt, and India, where most of the selected sites are unconfined masonry, the buildings are only provided with beam/lintel. From all of the selected countries, it was found that most of non-engineered construction had poor detailing on the connection of the structural elements. Pakistan exhibits the largest beam area, while Turkey exhibits the largest columns area. (see Figure 15)

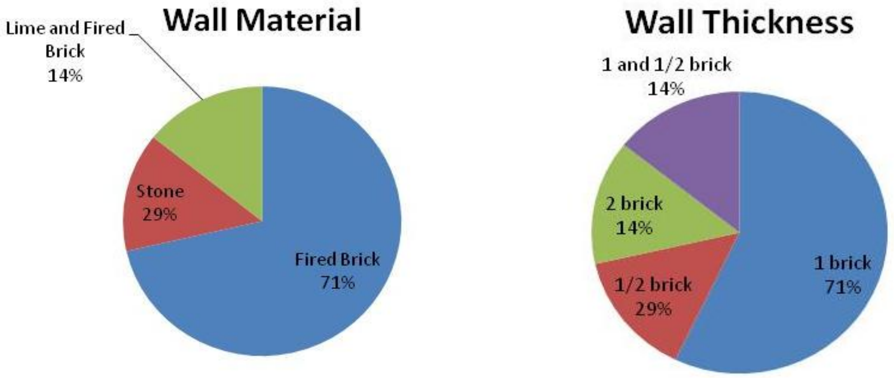

Figure 13. Wall material (left) and wall thickness

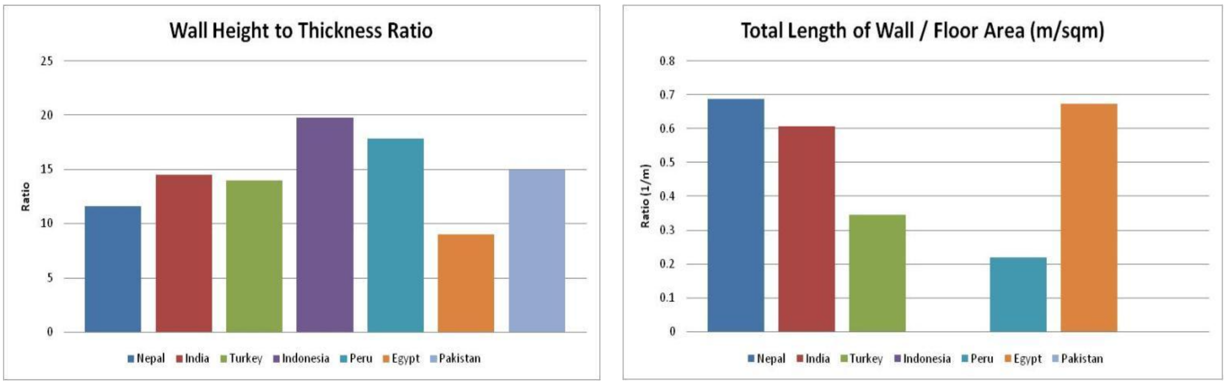

Figure 14. Wall height to thickness ratio (left) and total length of wall / floor area (right)

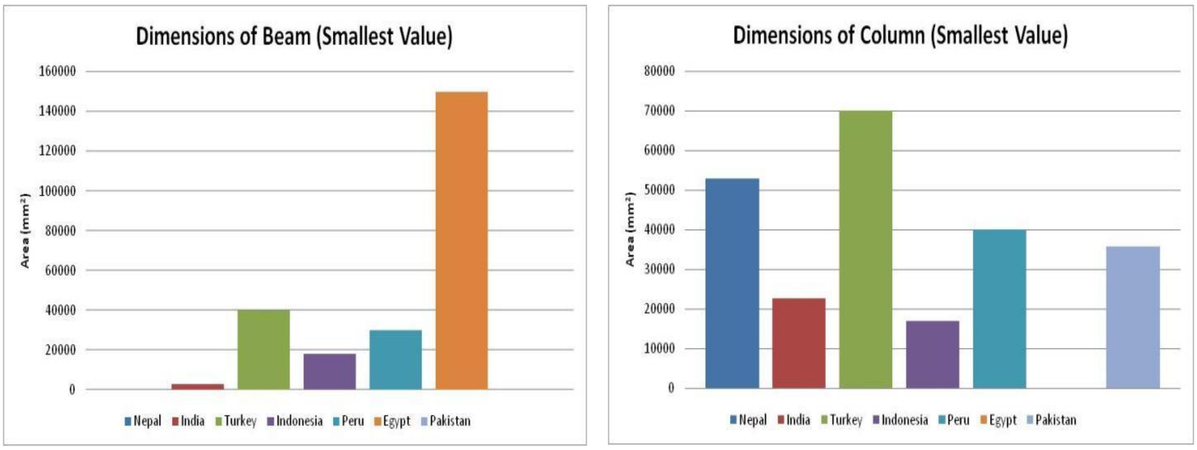

Figure 15. Dimension of Beam (left) and Dimension of Column (right)

5.3. Masonry Material

Most of the non-engineered constructions at the selected countries use baked clay or stone masonry for the wall materials. Brick sizes in Turkey, Nepal, Indonesia, Peru and Pakistan are relatively similar, meanwhile in India and Egypt bricks have different sizes compared to the others. Peru has the highest brick compressive strength, while Turkey has the smallest brick compressive strength compared to the other countries. Test results from sites in each country showed that some do not have adequate strength for the brick (see Figure 16).

Most of the countries use ordinary Portland cement as plaster and mortar cementing agent. Pakistan found to have the highest mortar strength, even though the mix is similar with other countries. On the other hand, Peru has different mortar mix compared to the other countries, but it produce the same compressive strength. The mortar thickness in Egypt is found to be the thickest (25 mm), while Turkey and Pakistan have the thinnest mortar layer (10-20 mm and 11.5mm respectively). The common plaster mix is either 1:6 or 1:4 (pc : sand) , except in Peru where the mix is 1:1. Turkey has the thickest plaster (20-30 mm), while Nepal has the thinnest plaster (10 mm) (see Figure 17).

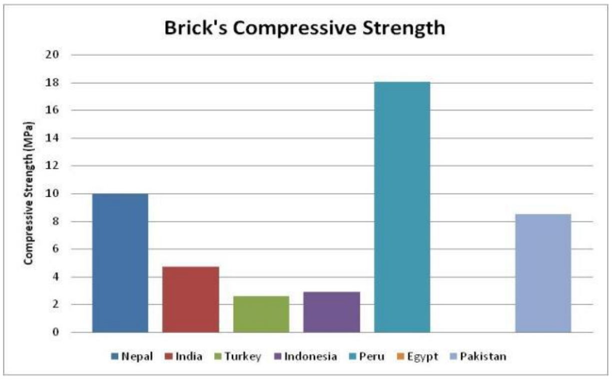

Figure 16. Brick’s Compressive Strength

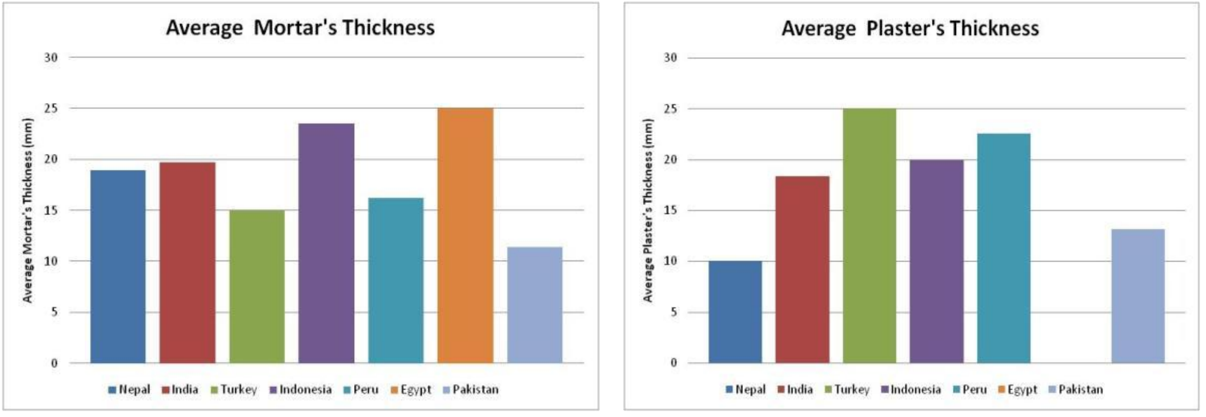

Figure 17. Average mortar’s thickness (left) and average plaster’s thickness (right)

5.4. Concrete Material

Based on the survey, some of the non-engineered constructions use very poor concrete strength for the structural elements. Highest concrete compressive strength is found in Indonesia (21.75 MPa) while the smallest was found in Turkey (8-10 MPa). All of the countries use ordinary Portland cement as the construction materials. Most of the aggregate are taken from river and mountain quarry. Concrete mix of 1 cement : 2 sand : 4 aggregate is used in Nepal, India and Pakistan, while in Indonesia mix of 1 cement : 2 sand : 3 aggregate is common. Concrete mix of 1 cement : 1.2 sand : 4 aggregate is found in Peru. Both concrete mix in Indonesia and Peru produces relatively high compressive strength (see Figure 18). In some countries, it is found that workers on some sites do not use any measurement in mixing the concrete. Highest rebar yield strength is found in Nepal.

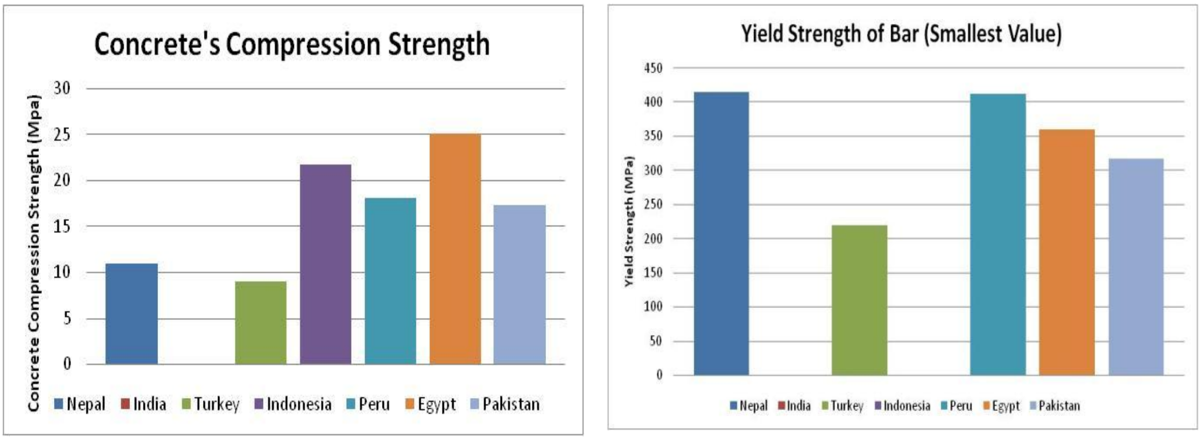

Figure 18. Concrete strength (left) and rebar yield strength (right)

5.5. Contractor/builder

In Egypt, most of the buildings are built by contractor together with foreman and workers. Most of the workers in the selected countries do not receive any training in construction, and they gain their skills form experiences. Numbers of workers per project varies, in Egypt being the highest. Indonesian workers in non-engineered buildings have the highest working experiences (see Figure 19).

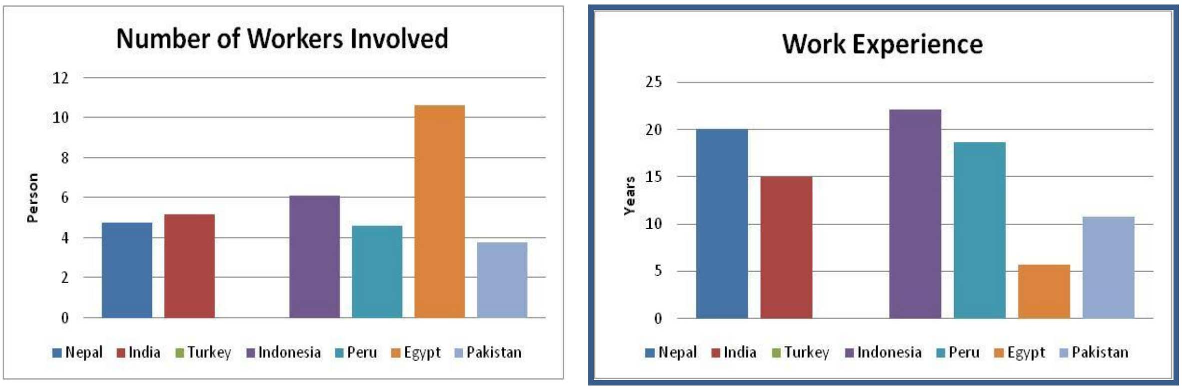

Figure 19. Number of workers involved (left) and work experience (right)

6. GENERAL REMARKS ON NON-ENGINEERED CONSTRUCTION IN DEVELOPING COUNTRIES

Many building owners and craftsmen have limited knowledge on proper construction methods and they do not consider earthquake as potential hazard. Most of the owners put deeper attention to the construction cost rather than building safety. Some of the craftsmen/ masons have relatively insufficient formal education or training on proper building construction. They gained their skills only from both the guidance from the foreman and their own experiences. This may be one of the reasons why improper detailing on the building's structural elements occurred.

All of the selected countries have code, at least guidance, on earthquake safety construction. However, it is deplorable that the dissemination of the code or guideline does not seem working properly. Most of the workers do not know that their country has such code or guideline. Hence, the quality of the works also cannot be assured. Lack of awareness from the community on earthquake safer construction due to lack of knowledge on earthquake hazard adds to the problem.

Lack of integrity on building's structural elements, improper detailing on building's structural elements, low quality of material's construction are typical problems found on many sites, probably because the workers do not know how to build earthquake safe buildings or the workers might have the knowledge but, due to the intervention from the owners to reduce the construction cost, they reduce the quality of works.

In many cases there is no particular construction quality control system from the local or national authority, as even though some country have a particular system on construction quality control, the workers who are working on the construction sites never or seldom being investigated or supervised by local or national authority.

The following actions are recommended to improve the situation:

- Guideline or code on earthquakes safety construction should be simpler and disseminated widely and properly to home owners, builders and craftsmen. The main point in this recommendation is to encourage the local or national authority to provide easy-learning code or guideline.
- Awareness raising programs to community need to be conducted to improve the community awareness. Some awareness raising programs which have been conducted (such as community workshop, etc.) had effectively improved the community awareness to earthquake hazard.
- Strengthening is needed for poor quality existing structures. Some elements on the buildings, such as wall, connection, column, beam, need to be strengthened in order to have proper behavior of building when subjected to future earthquake.
- Quality control or inspection is needed from the local authority in order to control the implementation of building's guideline or code and good construction practice.
- Certification program to masons/ craftsmen or foremen will ensure the quality of the workers. Moreover, building owners will be more comfortable when they entrust their building to qualified workers.
- Experts should more often communicate and discuss with the workers or contractor related on safe construction. This will reduce the gap between the experts and the field practitioners. Periodical surveys to the field by experts might be an effective effort to disseminate their knowledge.

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