Evaluation on the Structural Safety of Reconstructed Houses in Padang

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SUMMARY:
The M 7.6 West Sumatra earthquake on the 30 September 2009 has caused damage to many non-engineered buildings and houses in the region. Efforts have been conducted to reconstruct the damaged non-engineered houses. A research was conducted to observe the quality and progress of the reconstructed houses, collecting related information which includes site location, structural system prior to reconstruction, quality of materials, planning and design of reconstruction, workmanship, procurement and supervision. Analysis of the collected information was conducted to assess the quality of reconstructed houses. The process of reconstruction was found to be deficient in planning, design, and construction aspects. Guidelines on how to reconstruct safer non-engineered houses developed and distributed by the government seem not to be totally effective in ensuring that the reconstruction practice will produce safer structures. Investigation also found that adequate technical mentoring and supervision was paramount factor in ensuring proper reconstruction by the community.

Keywords:, Community reconstruction, non-engineered building, structural safety, vulnerability

1. INTRODUCTION

More than one year after the 30 September 2009, M 7.6 West Sumatra earthquake, a number of activities have been conducted for reconstructing the affected area, which includes the reconstruction of damaged houses, mostly conducted individually by the community. Due to this approach, the qualities of materials, workmanships, and construction practices can vary greatly, which may affect their earthquake vulnerability in general. The survey on reconstructed non engineered buildings was conducted in Padang city, the capital of West Sumatra, to observe the practice of the reconstruction process. The study collected information related to the quality, progress and the practices implemented during the reconstruction of the non-engineered houses. Related information includes site location, structural system prior to reconstruction, quality of materials, planning and design of reconstruction, workmanship, procurement and supervision. Analysis was conducted to assess the quality of reconstructed houses based on prevailing local and national guidelines and codes. Although most of the reconstructed buildings are intended to be strengthened, the process of reconstruction was found to be deficient in planning, design, and construction aspects.

The purpose of the study is to understand better how the reconstruction process is conducted and what problems are typically found in the field. This information will provide clues for developing recommendations for a better practice in community reconstruction of non engineered structures in the future events.

2. METHODOLOGY

In order to achieve the purpose of this research, development of survey form and preliminary selection of the region of the samples were conducted by the Research Center for Disaster Mitigation at ITB and

Center for Disaster Study of the University of Andalas in Padang. Some information related to the site location, structural system of the non-engineered buildings prior to reconstruction, quality of materials, planning and design of reconstruction, workmanship, procurement and supervision were obtained by interviewing the workers or owners and observing the construction practices.

The survey was conducted on forty one undamaged and damaged houses and thirty nine reconstruction sites spread in nine districts in Padang City. During the survey, non-destructive test (rebound schmidt-hammer test) was conducted on each of the selected samples, and measurement of dimensions of structural components was carried out. In addition, some construction materials, such as bricks and reinforcement bar were also randomly taken to be tested at the laboratory. In order to understand the situation related to the existing situation, another survey was also conducted to collect information on structural condition of existing houses in Padang city, covering some parameters that are related to condition of building, such as site location of the building, structural system, connection and detailing, quality of materials, damage condition and perception of building's owners related to reconstruction. In addition, during survey, some documentation, such as notes and photographs, and non destructive test were taken to augment the information collected.

Based on the collected information, analysis was then conducted by the CDM-ITB team by referring to building codes, guideline and common practice of earthquake resistant design and construction of non-engineered buildings. There were three guideline referred in this study. Two guidelines were published by Department of Public Work for the purpose of reconstruction in Padang (abbreviated with Guideline) and Yogyakarta (abbreviated with Guideline 2006) and the third one was published by World Seismic Safety Initiative (WSSI) written by Teddy Boen with specific intention on retrofitting strategy (abbreviated with Guideline for Reconstruction).

3. SURVEY FINDINGS ON THE CONDITION OF THE HOUSES PRIOR TO RECONSTRUCTION

3.1. Condition prior to damage

Most of the selected samples (41 in total) are one story structure and have area of buildings greater than 36 m2. In addition, the survey also revealed that approximately two-third of the samples was vertically irregular. The referenced guideline requires the layout of the buildings to be symmetrical for both horizontal and vertical direction. The guideline also recommends the adoption of one story structure with building area of 36 m2. Therefore, most of the samples, prior to damage, do not fulfill this requirement (see Table 1).

Table 1: Information on site location and structural layout

No	Parameter	Percentage					Requirement in guideline
1	Horizontal layout	Simple & Symmetric (63 %)	L shape (20 %)	Irregular (10 %)	T shape (5 %)	Symmetric but too long (2 %)	Simple and symmetric
2	Vertical layout	Irregular/ too many openings (65 %)	Regular and Inline (35 %)				Regular and inline
3	Area of building	>64 m2 and ≤ 100 m2 (41 %)	>36 m2 and ≤ 64 m2 (34 %)	>100 m2 (16 %)	≤ 36 m2 (9 %)		36 m2

Most buildings in the selected samples adopted strip foundation as the foundation system and pebble/river stone as the main materials, which show compliance to the requirement specified in the guideline. The structural system of the non-engineered construction in Padang was dominated by confined masonry. However, some structures were lack in providing the complete confinement for the masonry wall, as some structure only provide one or two structural components. In addition, most of the structures provided confinement with RC column every 3 -4 meter of the length of the wall. This value is still acceptable in Guideline 2006 if the height of the structure is 3 meter. However, in some cases, it was found that practical columns were sometimes improperly placed.The typical dimension for column and beam elements found during survey was 150 x 150 mm, including the thickness of plaster. In guideline the minimum dimension of column and beam respectively is 150 x 150 mm and 120 x 150 mm (ring beam), 150 x 200 mm (tie beam). This finding reveals that most of the structures adopted adequate size of column and ring beam. However, it should be noted that the dimension measured during the survey included the thickness of plaster and, also, most of the dimensions measured for beam element was the dimension of ring beam instead of tie beam because it was easier to observe the ring beam than the tie beam (see Table 2).

Table 2: Information on structural system

No	Parameter	Percentage					Requirement in guideline
4	Type of foundation	Strip foundation (98 %)	Local footing (2 %)				Strip foundation
5	Maximum distance of practical column	> 3 m and ≤ 4 m (48 %)	≤ 3 m (43 %)	> 4 m (9 %)			3 m (in guideline) and 4 m (in guideline 2006) for building height up to 3 m
6	Minimum area of rc beam	≥18000 mm2 and ≤ 30000 mm2 (50%)	< 18000 mm2 (35 %)	> 30000 mm2 (15 %)			tie beam -> 150 x 200, ring beam ->120 x 150
7	Minimum area of rc column	≥ 22500 mm2 and ≤ 40000 mm2 (66%)	< 22500 mm2 (34 %)				150 x 150 = 22500 mm2
8	Thickness of wall	> 100 mm and ≤ 150 mm (90 %)	> 150 mm (8 %)	> 50 mm and ≤ 100 mm (2 %)			100 mm
9	Thickness of mortar used	20 mm (41 %)	30 mm (33 %)	25 mm (15 %)	15 mm (7 %)	40 mm (4 %)	15 mm

The detailing on non-engineered structures revealed that most buildings used Φ-8 mm reinforcement bar for main rebar and Φ-6 mm reinforcement bar for stirrups. These dimensions do not fulfill the requirements specified in guideline (Φ-10 mm for main bar and Φ-8 mm for stirrups). Moreover the spacing provided in structural elements was too large (200 – 250 mm), compared to the distance stated on the guideline (150 mm) (see Figure 1).

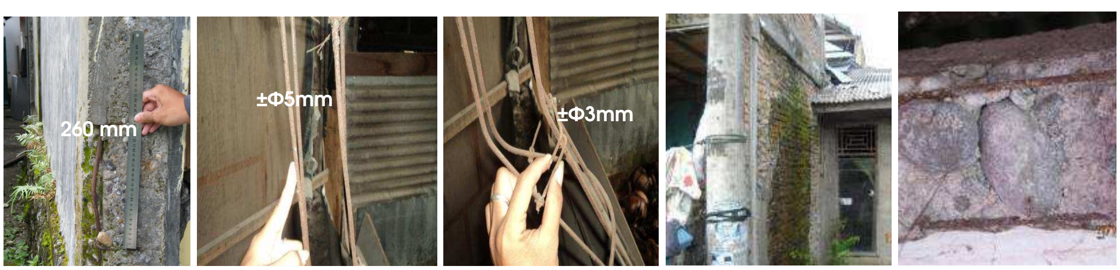

Figure 1: Spacing of stirrups, diameter of stirrups, diameter of main rebar, lichen on bricks & aggregate of damaged concrete (left to right)

Almost all buildings did not provide anchorage between column and wall and even if it existed, it was not installed with appropriate distance and length. This deficiency was also found on the connection between roof structure and column/beam. Even though the number of building providing this anchorage was quite significant, however, most of the connections were inadequate (just on the side of the truss without crossing the rebar on the truss). On the other hand, most of the connection in roof truss member used nails for the connection instead of bolt and steel plate as specified in guideline. The other connection that was improperly constructed was the connection of beam and column. Most of the buildings did not provide proper development length as specified in guideline (40 d) (refer to figure 3). Coarse aggregate used in the mixture of concrete and the pebble used in foundation was dominated by round-shaped aggregate/stone. This finding does not comply with the requirement specified in the guideline where flaky/split aggregate is recommended (Table 3).

Table 3: Information on quality of materials

Parameter	Percentage					Requirement in guideline
Materials used for foundation	Rounded stone (79 %)	Split/flaky stone (21 %)				Flaky/split (illustrated)
Quality of bricks	Uneasy to scratch (52 %)	Easy to scratch (41 %)	Easy to scratch with hand (7 %)			No requirement
Shape of coarse aggregate	rounded (50 %)	Mix (44 %)	Flaky (6 %)			Flaky (illustrated)
Source of water	Well (74 %)	PAM (17 %)	River (9 %)			No requirement

In this survey, a qualitative method for measuring the strength of brick by scratching the brick was utilized, and the quality of bricks in some of the buildings was found to be adequate. Although the average quality of brick was good, some sites showed poor quality of bricks with several defects on the materials, such as crack at the edge and lichen. Based on the field test using Rebound Schmidt Hammer Test, the average strength of the concrete was 158.23 kg/cm2 (cubical). This value is still below the minimum requirement specified in Indonesian National Standard (20 MPa (cylindrical) / 243.9 kg/cm2 (cubical)). It is possible that the use of round-shaped coarse aggregate (reduce the bonding strength), poor gradation of aggregate and poor workmanship in the concrete preparation have caused the low quality of the concrete. Almost all samples adopted plain/undeformed reinforcement bar as the main rebar and stirrups, which is inline with the requirement specified in the guideline.

3.2. Condition of the damage

Damage on foundation system was dominated by differential settlement. One of the main reasons for this damage was the adoption of round-shaped stones used as foundation materials, which will have poorer bonding interaction than sharp-edged stone. Poor quality mortar, poor workmanship, unavailability of tie beam, soil condition may also contributed to the damage severity.

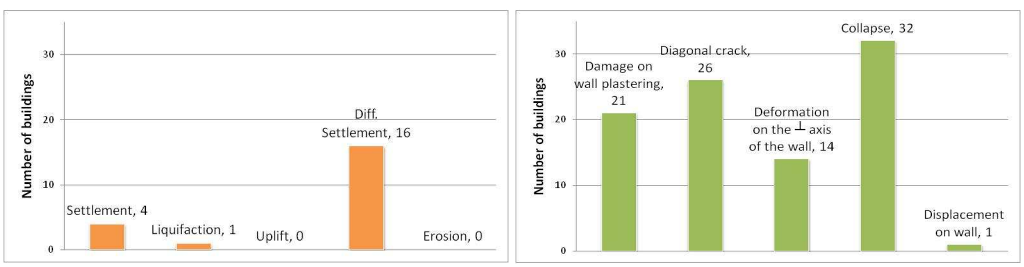

Figure2: Types of damage in foundation system (left) and wall construction (right)

Figure 3: Damage on foundation, corner crack, damage on wall, damage on orthogonal wall & damage on beam column connection (left to right)

Wall was found to be the weakest part of the construction since most damage occurred in this load bearing element. Various types of damages, such as damage on wall plastering, crack, deformation/displacement and collapse were observed to be occurred on this element. There are many factors that contribute to damage on wall, such as the poor quality of material, structural configuration, structural confinement from the frame, workmanship, etc. The damages on beam and column were mostly characterized by concrete spalling. The intensity of damage varied from spalling on the outer surface to total loss of concrete in the core of elements. Other types of damages, such as crack, deformation and collapse, were observed as well during the survey. The charts in Figure 4 show the number of buildings subjected to those damage. For columns, horizontal and diagonal cracks indicate lateral force caused damage and vertical cracks indicate axial force caused damage. Meanwhile for beams, vertical and diagonal cracks indicate the contribution of gravitational force and horizontal cracks indicate the contribution of axial force. As the principal damage on columns and beams was spalling, the poor quality of concrete and confinement may be the main causing factors. The use of round-shape aggregate and small diameter size and greater spacing of stirrups may be the most possible factors that cause this damage. Similar factors may be the most possible reason of collapse on columns and beams.

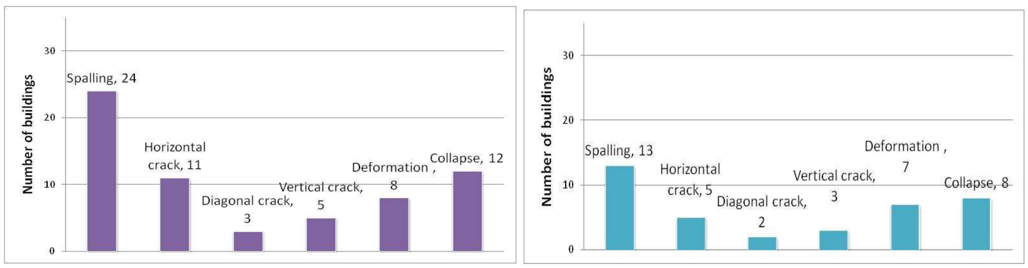

Figure 4: Types of damage on column (left) and beam element (right)

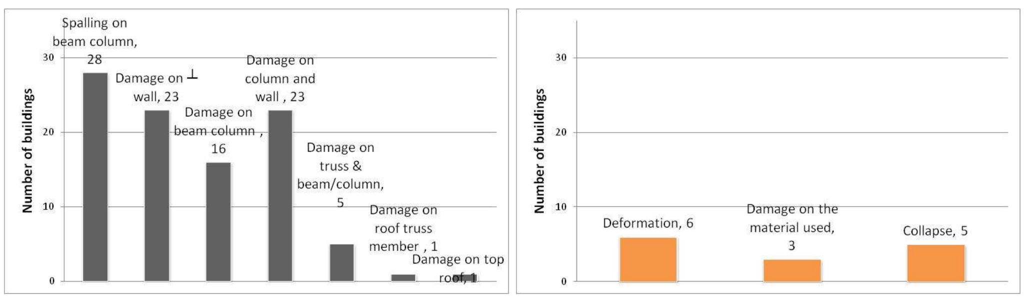

Figure 5: Types of damage on connection (left) and roof (right)

Similar types of damage on column and beam were also found in the damage on the connection between those elements. A significant number of buildings were also subjected to damage between orthogonal wall connection and connection of column and wall. No anchorage with reinforcement bar between the connection of column and wall is the main reason for this type of damage (Figure 3 – second from the right). However, only a small number of damage on roof truss connection and connection of roof truss and beam/column were observed. For roof structure, only a few numbers of samples were subjected to damage. The typical damages on roof were deformation along the span of the roof, damage on roof material and collapse of roof structure.

Observation on non structural elements was limited to ceilings, floor and stairs. Many ceilings fell during earthquake, yet only a few of them completely collapsed. Crack was the main damage observed in floors. Popping up and changing pattern on tiles were also observed in some samples as well. Settlement of floor system was uncommon, as shown by the data (Figure 6 and 7)

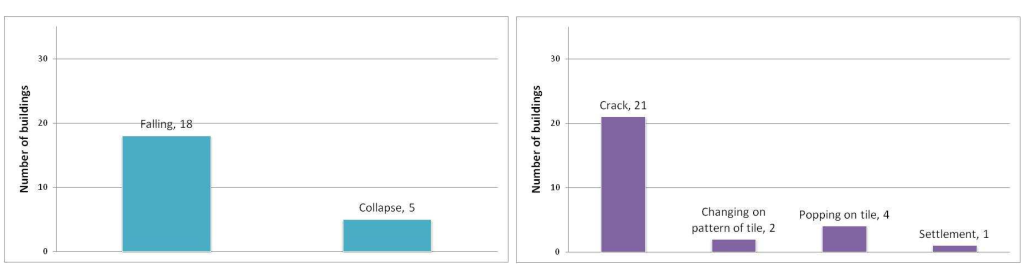

Figure 6: Types of damage on ceiling (left) and floor (right)

Figure 7: Damage on ceilings and floor

3.3. Perception of buildings owner to reconstruction

In collecting the perception of buildings owner to reconstruction, the buildings owner was subjected to these question: (a) Is your building safe enough if an earthquake occurred again?; (b) If it is safe, what will you do?; (c) If it is unsafe, what will you do?; (d) Do you have enough fund for the reconstruction?; (e) If the answer of question d is no, from which parties do you wish for assistance?; (f) How many fund do you need to reconstruct your house?; (g) Will you get involve in supervising the reconstruction process?. Figure 8 summarizes the results. It seems that the willingness of the building owner to repair/rebuild their own building is questionable. Even, when they did believe that their building is unsafe and they had some funding to repair/retrofit their house (from the point of view of engineer), most of them preferred to wait for the government aid disbursement.

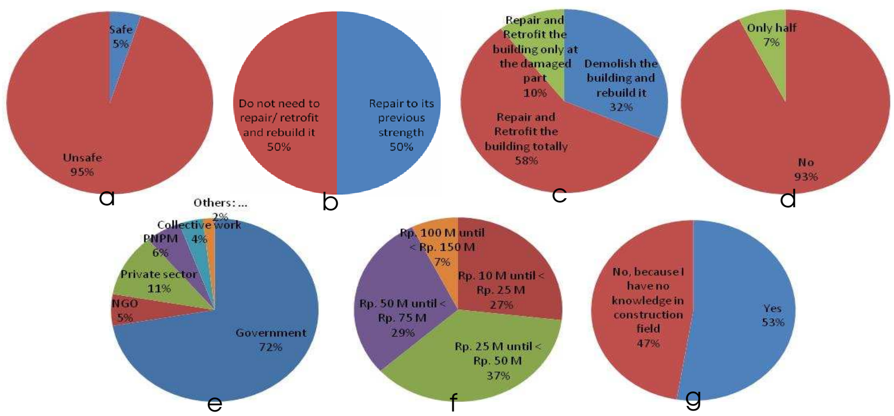

Figure 8: Information on perception of buildings' owner to reconstruction

4. PLANNING AND DESIGN OF THE RECONSTRUCTION

In general, there were three reconstruction practices observed during survey, namely repair, retrofit and rebuild. In repair, the buildings were partially reconstructed and the final output of this process will maintain the previous strength of the structure prior to damage. In retrofitting, the buildings were partially reconstructed and strengthened. In rebuilding, the buildings were totally demolished and then reconstructed, intended either to increase or maintain the previous strength of the structure. The repairing practices were dominated by repairing damaged walls, which consists of either only plastering the cracks, filling gaps on walls, replacing some brick materials and covering/plastering the wall panels, or rebuilding of partially collapsed walls, also repair of damaged column and beams. Repairing the column and beams consisted mostly of filling or plastering the cracks and spalling, or in some cases rebuilding the elements with the same dimensions and detailing as in the previous condition. In small number of samples, repairing damaged roof structure, replacing damaged roof material and replacing loose foundation were observed during the survey as well.

The retrofitting practices were also dominated by repairing the damaged wall elements and sometimes damaged beams. There were many cases where more columns or practical columns were installed to increase the strength of the structure. Increasing the capacity of column and repairing damaged column were found on some structures as well. Installing new elements such as adding lintel beam, new beam and new wall panels was also common. In a few structures, adding foundation elements such as strip foundation, local footing and tie beam, or replacing damaged roof were also common.

Rebuilding the structure with totally new elements was conducted when the house is totally unusable. In some cases, it was found that the design is strengthened with the use of practical column and lintel beams, which were not available in the original design. According to the information collected during survey, most of the damaged buildings were subjected to repairing and retrofitting. Only a small percentage of samples were rebuilt and most of them were intended to be strengthened (Figure 9d). Although the survey shows that most buildings (67 %) were intended to be strengthened (Figure 9c), further observation reveals that most of the strengthening practices were still questionable. This might be due to the fact that most selected samples had limited or no access to the information on proper construction and detailing of seismic resistant structures.

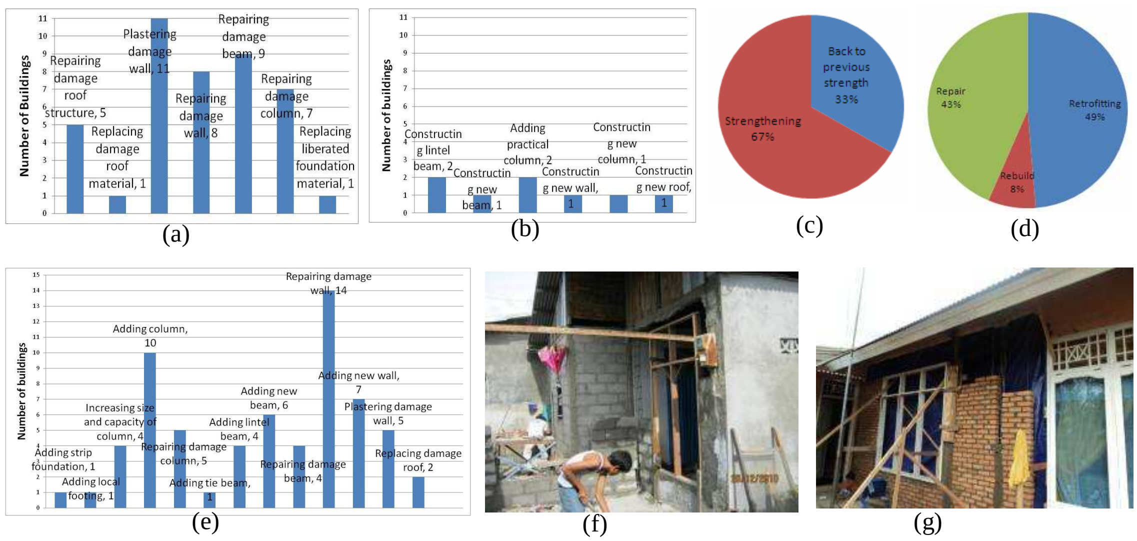

Figure 9: a) Repair, b) rebuild, c) intension in rebuilding, d) portion in reconstruction, e) retrofitting, f) expanding the structural layout & g) installing new practical column

In most samples, no building drawings and specification neither building permits were found. In some sites, the reconstructed houses were even more vulnerable than the previous condition, layout became more irregular due to additional space, with a lot of wall openings. New columns were found installed without ring beams, therefore compromising the structural integrity. Some structures were observed using reinforcement bar of inadequate size and different types of bricks in one panel of wall. In some samples, the utilization of used reinforcement bar (yielded)- (Figure 11 left) in newly constructed structural elements were also found. Pre-cast architectural columns utilized in some structures are considered to be improper because of the questionable strength of the concrete and the way they are connected to the other parts of the building.

Figure 10: Large opening, different wall materials, no tie beam & pre-cast column (left to right)

5. QUALITY OF MATERIALS AND WORKMANSHIP

5.1. Material

The laboratory test on samples of brick-mortar specimens shows that the average compressive strength was 20.91 kg/cm2. This value was below the minimum requirement of 30 kg/cm2 based on guideline 2006. In addition, the average yield stress of Φ-8 mm rebar was 369 MPa and the yield stress of Φ-6 mm rebar was 415.93 MPa. In addition, non-destructive test conducted on RC elements during the survey revealed that the average compressive strength of concrete was 182.17 kg/cm2, which was below the minimum requirement (243.9 kg/cm2/20 MPa). The use of round-shaped aggregate/pebble and poorly graded aggregate was observed in the sites. In addition, many bricks were observed in poor condition, such as having cracks along the edge and lichens (Figure 11).

Table 1: Compressive strength of brick – mortar specimen

No	Age of specimen (days)	Load (kg)	Area (cm^2)	Compressive strength (kg/cm^2)
1	3	2500	105	23.8
2	3	1500	95	15.7
3	3	1800	97	18.5
4	3	1000	90	11.1
5	3	1200	95	12.6
6	3	2000	97	20.6
7	3	3000	90	33.33
8	3	2850	90	31.67
Average				**20.91**

Table 2: Tensile strength of reinforcement bar

No	Diameter (mm)	Initial length (mm)	Final length (mm)	Elongation (%)	Maximum load (kg)	Yield load (kg)	σ_y (kg/mm^2)	σ_u (kg/mm^2)
1	8	30	38.9	29.7	1650	1150	41	59
2	8	6.00	37.65	25.5	1740	1210	43	62
3	6	100	126	26	1650	1200	42.44	58.36
4	8	100	128	28	1450	2200	28.85	43.77

Figure 11: Yielded rebar, lichens in brick, poor aggregate & round-shaped pebble (left to right)

5.2. Workmanship

In constructing the foundation, most workers laid the stone randomly, which is quite appropriate as it will provide good interlocking of the stones.

In concrete pouring, proper strutting to support the formwork was usually found. However, in many cases, formworks were found to be using scraggly/haphazard wooden materials which were unsuitable according to the guideline. In mixing the concrete, it was observed that the workers did not mix the concrete evenly and, in some of the samples, the workers added too much water in the mixture. In measuring the composition of cement, fine aggregate and coarse aggregate, approximately half of the workers used bucket or similar other container. However, in significant number of projects, some workers still did not measure the composition of concrete mixture and relied on their feeling. Also, it was found during the survey that some workers did not use the same measurement container for different components (e.g one sack of cement for 2 carts of sand and 3 carts of aggregate). For the construction of structural elements, improper methods were also observed. Although most of the workers had stated that they compacted the concrete mixture using reinforcement bar, but in some structures it was found that the quality of concrete was still poor due to honey comb. In addition, most of the workers did not cure the concrete by maintaining the moisture. It is commonly known that the process of curing is very important to achieve a proper concrete compressive strength.

In brick laying, most of the workers did not wet the bricks by soaking them in water. However, most of the workers used string to control the neatness. Unfortunately, the controlling string was not used for every layer of brick as specified and brick layers are not always in line.

Most of the construction did not provide adequate development length in beam-column connection. Approximately one third of the samples did not provide anchorage between column and wall. In addition, about half of the samples did not provide seismic hook in the stirrups as required by the guideline. Only one third of the samples provided anchorage between roof structure and column/beam/wall, and many of them were still not properly installed, most of them just nailed the sides of roof truss members without using reinforcement bar as anchorage to tie up the roof structure. Most of the main truss connection on roof trusses used nails instead of bolts and gusset plates. The same deficiency as the other connection/detailing was also found on the implementation of anchorage between foundation and tie beam. Many samples still did not provide such anchorage as specified in the guideline (Figure12).

Figure 12: Detailing and connection observed during reconstruction

Most of the samples utilized inappropriate methods in repairing the wide and depth crack in wall construction. Steel wire mesh for strengthening the walls specified in the guideline was not widely used. Inappropriate methods in strengthening the column were observed. Figure 13 shows that the workers inappropriately tried to put “jacketing” on the columns.

Figure 13: Improper methods: jacketing (left and middle) & crack repairing (right)
procurement and supervision

5.3. Reconstruction Implementation

The survey reveals that the main source of funding for the reconstruction was provided by the government and approximately a quarter of the buildings owner provided the funding by themselves. Almost all of the owners assigned craftmen to reconstruct their house but the procurement of the materials was conducted by the owner. In addition, all of the materials were obtained locally from the local market. Half of the samples constructed their houses for less than a month. However, there were still some samples that took more than 3 months to reconstruct their house. The supervision of the project was conducted mostly by the owner and the period of supervision was everyday. Nevertheless, the supervision given by the owner was more to the funding/material supervision rather than technical supervision.

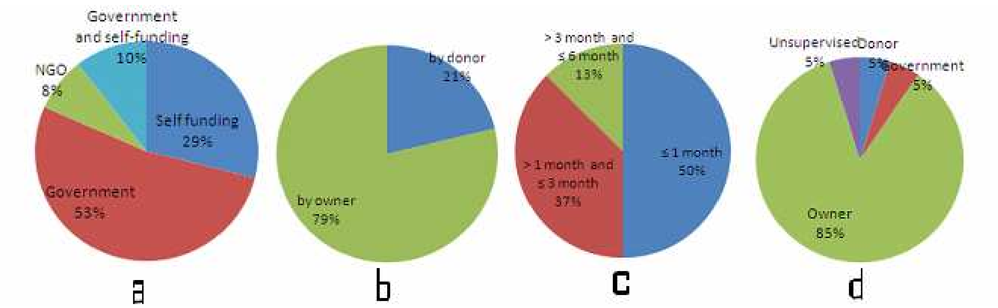

Figure6:a)Source of funding,b)material's procurement,c)reconstruction period,d) supervision

6. CONCLUSION

From the result and observation of the survey, it can be summarized that the reconstruction process of Padang City has not been running smoothly. During the survey, 25 percent of government stimulus fund had been disbursed (first stage) and according to the information from the government board the second stage (50 percent) will be disbursed later. According to the survey, most owners had a willingness to increase the strength of the buildings or made their building safer. However, assessment to the construction methods, planning and design has shown many deficiencies, varied from poor building layouts, poor structural integrity, improper structural connection, poor quality of material and improper reconstruction method. An interesting fact obtained from the survey is that most of the owners have the ability to differentiate/categorize the damage level of buildings even when they have no technical background in construction practices. Based on that assessment, the buildings' owners can judge whether to repair, retrofit or rebuild their building. Therefore, providing manuals/guidelines on how to reconstruct damaged houses to produce safer non-engineered structures is a commendable effort, but it is not enough. These guidelines should be well disseminated to the community to ensure that the reconstruction practices yield safer and less vulnerable non-engineered structures. Next, technical assistances in the forms of supervision should also be provided to ensure the quality of the implementation of the community reconstruction projects.

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