Repair and retrofitting of buildings post earthquake

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Abstract. This paper discusses the damage types, repair methods and retrofitting of buildings post an earthquake. Data were taken by conducting surveys and assessment of buildings directly, both engineered and non-engineered buildings affected by the West Sumatra earthquake in 2009. Some causes of damage, among them is the detailing of reinforcement that do not follow the existing standard, soft-story effect, foundation failure, low material quality and does not meet the requirements, design and implementation of the construction do not follow the rules and technical provisions of the building earthquake resistant. Improvement and buildings retrofitting can be done after the buildings damage types or its components/parts and the quality of the building materials used were known. The structural analysis was done in order to know the cause of the building elements damaged and if the results of analysis with the latest regulations earthquake load, the building structures is able to withstand the earthquake loads and a repair is not required, but if not, the retrofitting is required.

1 Introduction

Earthquake disasters could cause many buildings to be damaged and may also collapsed. After the earthquake, many of the damaged buildings are to be destroyed based on the advice of experts, consultants or stakeholders, while actually the buildings could still be repaired and be retrofit so that the buildings can be reused (Ismail et al, 2011, 2014). To destroy the damaged buildings after an earthquake is an easy decision, but not supported by adequate data. Until now, Indonesia has not had a standard in damage assessment, repair and retrofit the damaged building post earthquake. The main advantages of repairs and retrofit the damaged buildings after earthquake will be save time and money (Ismail et al, 2011, 2014).

In general, civil engineering buildings could be grouped into non-engineered building and engineered building. Non engineered building is a simple building such as a community house that is no structural calculations while engineered building is a building that is designed and done structure calculations by consultants or structural experts (Boen, 2010). At West Sumatra earthquake of 2009, a ten years ago, many buildings were damaged, both non engineered building and engineered building.

Damages caused an earthquake could be divided as non-structural damages and structural damage. The damages of non-structural is a damage that occurs in non-structural parts of buildings such as wall plaster cracks, brick walls cracked or broken, ceiling damaged etc. While a structural damage is the damage that occurs at elements of building structures, such as cracks in the column, plates or beams, the crack of concrete covers of beams/columns or rupture at the parts column head or bottom (Boen, 2010)

Retrofitting of the post-earthquake building include repairs and restoration or strengthening a damaged buildings. Repair work is to restore the building architecture, such as; repair and retrofit of wall cracks, re-plaster, repair of power cables, water pipes, gas pipes, sewer, doors, windows or replace the window/door glass, etc. Restoration work is to improve the structural element strengths and restore to the original strength, such as; perform injection of cement grout or epoxy/polyurethane material at small cracks that occur on the wall, beam or column, increase the amount of reinforcement on the beam or column that has a large crack and then do injection of cement grout, adding and repairing the reinforcement then cast/grout back.

The strengthening is in order to make buildings stronger than the its original strengths, such as; eliminate the sources of weakness or that can lead to the concentration of stress in certain parts, among others: the location of columns/walls that are not symmetrical, the difference in the rigidity between the building floor, excessive openings, added the capacity of buildings to lateral forces, by adding shear walls, bracing, adding and enlarging column dimensions, increasing the building's ductility by repairing, use additional reinforcement (shear, bending, axial or torque stress) on the necessary parts, making the building in one unity to tying all the elements structure to each other (Arya, 2013).

This paper discussed the cause of damages, retrofitting methods and strengthening carried out on number of buildings damaged after the West Sumatra 2009 earthquake.

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2 Methodology

Data in this paper were taken directly after the earthquake by the buildings assessment team of Andalas University by conducting surveys and assessment on a number of buildings affected by the earthquake in the city of Padang.

Assessment were done to engineered building and non-engineered building. The collected data includes the type of damage of each building element, the quality of the building material (concrete and steel reinforcement), the configuration of buildings, buildings foundation and the cause of damages. Repair and retrofitting of damaged buildings carried out on structural elements as well as on non-structural elements in some public buildings such as schools and hotels.

3 Results and Discussion

3.1 Damage causes and types

From the survey and assessment that has been done in a number of buildings damaged in the city of Padang, is obtained some causes of damage or collapse that occurred in engineered building are :

a. Reinforcement detailing does not follow the standard include on the beam-column joints. Fig 1 and Fig 2 show the detailing do not meet the standards.

Fig. 1. Bad reinforcement detailing of beam-column joint

Fig 2. Reinforcement detailing do not meet a standards

b. Soft-story effects followed by the collapse of the beam-column joint as shown in the following Fig 3.

Fig 3. Soft-story effect on buildings

d. Foundation failure, especially in the soil-structure interaction, such as the liquifaction shown in Fig 4.

Fig 4. Foundation failure due to liquifaction effect.

d. The poor quality of materials and do not meet the requirements, both strength and its quality, as shown in Fig 5.

Fig 5. Building collapsed due to material quality do not meet the standards

e. Planning and implementation of construction do not follow the rules and technical provisions of the standard of building earthquake resistant.

On non-engineered buildings a lot of damage occurred on buildings without reinforcement (unreinforced masonry, URM). Some types of damage that occur in general are as follows: a. Crack on the wall in the corners of the openings, b. Diagonal crack on the wall, c. Separation occurs on the walls, d. Wall bricks collapsed, e. Beam-column joint failure, f. Building collapsed.

Fig 6, 7 and 8 show some types of collapse that occur in non-engineered buildings.

Fig 6. Brick walls collapsed

Fig 7. Wall separation of URM

Fig 8. Some brick walls are collapsed

In general, the main cause of damage that occurred, especially in the engineered building due to the West Sumatera 2009 earthquake could be concluded as follows:

a. Understanding and awareness of construction actors (owners, contractors and consultants) regarding the provisions of regulations/building standards of resistance/safe earthquake are still low.
b. Implementation of regulations/standard earthquake of low construction actors.
c. Supervision of the construction of the stakeholders, especially for public buildings is still lacking.
d. Tendency is less concerned with structural needs (safety) and more concerned with the needs of aesthetic (architectural).
e. Especially for non-engineered buildings that are severely damaged is a building that has no reinforcement on its structural elements (unreinforced masonry building, URM).

3.2 Post-earthquake building retrofitting and repair methods

The steps of repair and retrofitting work in a damaged building after the earthquake could be done as follows:

1. Conducting field survey to determine the type of buildings damaged or components/parts of buildings and the quality of the building materials used.
2. For engineered buildings carried out structure analysis based on the latest earthquake standard in order to know the cause of a damaged building elements, whether due to shear force, compression, tensile, bending, torque or other causes.
3. Once the type of damage can be determined, repair and restoration of the components separately can be done.
4. If the results of the analysis with the earthquake load in accordance with the latest regulations, building structures are able to withstand the earthquake loads then the retrofitting is not required, but if not, then it is necessary to repaired and do retrofitting.

3.2.1 Repair and retrofitting of elements structure

Some types of retrofitting work of structural and non-structural elements conducted are as follows:

Fig. 1 shows the repair process of column damaged at the bottom. The damaged column at the bottom (1. a). Installation of the temporary support (1.b), then done concrete chipping (1.c) addition of longitudinal and shear reinforcement (1.d). Then installation of form work and concrete casting (1. e), and the final result on (1. f)

(a) Damaged column (b) Temporary support installation (c) Concrete chipping

(d) Addition longitudinal and shear reinforcement (e) Installation of form work and concrete casting (f) After repaired and retrofitting

Fig. 9. Repair and retrofitting process of damaged column at the bottom.

(a) Damaged column at the top, lack of reinforcement (b) Addition of longitudinal and shear reinforcement (c) Form work installation and concrete casting (d) After repair and retrofitting

Fig. 10. Repair and retrofitting process of damaged column at the top.

The repair process and the retrofitting of the damaged columns at the top were shown in Fig. 2. The damaged column at the top with lack longitudinal and shear reinforcement (2.a), addition of shear and longitudinal reinforcement (2.b). installation of the form work and concrete casting (2.c), and the final result as in (2. d).

Fig. 3 shows a repair process of the damaged beam as follows. Repair and retrofitting were done by adding a shear reinforcement on the beam, and done the concrete grouting.

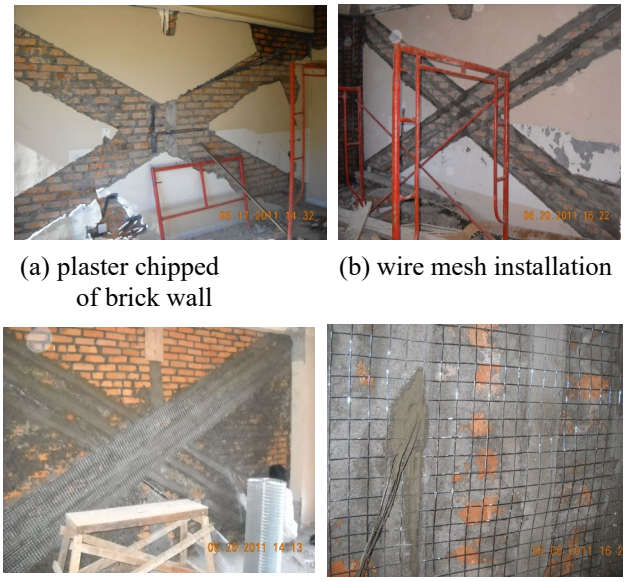
Fig. 11. Repair and retrofitting process of damaged beams

Non-engineered building repairs and retrofitting were shown in Fig 9 below. The building without reinforcement (Unreinforced Masonry, URM) was added with the reinforcement of the tie beams, columns and link beams. The brick wall were retrofitted with the wire mesh.

Fig. 12. Repair and retrofitting of *non-engineered* building by adding the reinforcement of tie beams, columns and link-beam

3.2.2 Repairs and retrofitting of non element structures

Repairs and retrofitting in a non-engineered buildings are shown as in Fig. 4 below. The wall that will be strengthened was chipped in diagonally direction (4a), then install the wire mesh material and do plaster back (4b). For the new brick wall retrofitting can be done with the installation the wire mesh diagonally (4c) or install the wire mesh on the entire wall (4d), then do the plaster work.



(a) plaster chipped of brick wall

(b) wire mesh installation

(c) wire mesh installation diagonally

(d) wiremesh installation on the entire brick wall

Fig. 13. Repairs and retrofitting process of brick wall with wire mesh materials.

4. Conclusions

From the evaluation and discussion, it could be concluded as follows:

1. Repair and retrofitting can be used to restore and strengthen damaged buildings due to an earthquake.
2. Before the retrofitting, firstly do a numerical simulation in order to know the capacity of the building to an earthquake load based to the latest standards.
3. The type of retrofitting performed to the structural elements depends on the damage level of structure itself.
4. The main advantages of the repair and retrofitting of buildings damaged due to an earthquake could save a cost and work implementation time compare to the new building.

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