REDUCING EARTHQUAKE VULNERABILITY OF NON-ENGINEERED BUILDINGS: CASE STUDY OF RETROFITTING OF SCHOOL BUILDING IN INDONESIA

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ABSTRACT :

Recent earthquakes in Indonesia caused major damage to buildings and infrastructures. Most of the damage occurred on non-engineered buildings, which were built traditionally with very little or no assistance from qualified engineers. About two thirds of the buildings in Indonesia are non-engineered, most of them are one-story and two-story structures. Studies show that problems for these buildings were caused by minimum reference to standards/codes, lack of detailing, wide variety of quality of materials and construction methods, and improper structural design. Therefore, non-engineered buildings tend to have low structural quality and to be susceptible to earthquake. However, experience also revealed that non-engineered buildings can survive earthquakes with little or no damage, provided that they were built properly using good quality of materials and good workmanship. Considering large number of non-engineered buildings, efforts should be made to make these buildings safer. Several applicable solutions include developing systems for dissemination of building standards/codes, producing field manuals/guidelines, developing seismic risk map for Indonesia, and developing appropriate building technology to reduce structural damage. These solutions should be accompanied by the evaluation of existing structures to improve their safety against future earthquake risk. If these buildings were found to be vulnerable to earthquake, retrofit strategies should be designed and conducted. A case study of retrofitting of a school building in Bandung was given as an example of efforts in reducing vulnerability for non engineered buildings. The retrofitting work was complemented with several activities to reduce the earthquake vulnerability of the school community.

KEYWORDS: Non-engineered structures, earthquake vulnerability, retrofitting, school buildings

1. INTRODUCTION

Past earthquakes showed that many fatalities and economic losses were caused by structural damage and fallen debris or objects located in the structures. Most of buildings damaged by earthquakes were non engineered buildings. This type of buildings refers to buildings that were built traditionally with very little or no assistance from qualified engineers. Traditional or vernacular houses such as timber structures or other indigenous dwellings are considered as non engineered structures. Many other buildings can also be considered as non engineered buildings, including masonry or reinforced concrete structures that were built without any engineering analysis. Most of typical houses in Indonesia fall into this category, since they were built by ordinary masons/workers.

From engineering point of view, about two thirds of the buildings in Indonesia can be considered as non-engineered structures, with most buildings are one-story and two-story structures. These structures include houses as a majority, as well as other public facilities, i.e. school buildings, mosques, and a number of other social gathering places. Non engineered structures in Indonesia are usually made of reinforced concrete (RC) frames with masonry walls, following the trends of modern buildings. The occupancy rates for these structures can be very high, especially for public facilities such as school buildings. If the buildings have poor quality, these buildings are vulnerable to earthquakes, and the occupants are susceptible to earthquake.

2. PROBLEMS FOUND IN NON ENGINEERED STRUCTURES

Problems for non engineered structures in Indonesia are mainly due to minimum reference to standards/codes. Many house owners do not verify if their structures comply to building codes since the houses are built traditionally, meaning that the structures are built by local masons/workers, using local materials and traditional construction methods. Engineers are not involved in the design process, thus design adequacy according to building codes is also rarely checked. The construction of houses or other non engineered buildings is typically left to the workers with minimum supervisions, and building permits are often issued without proper inspections. Therefore, these buildings are frequently found to have poor detailing, wide variety of quality of materials, and wide variety of construction methods, as presented in Figure 1. Consequently, the structures are more susceptible to damage during earthquake due to poor quality and high vulnerability.

The problems for non engineered structures are amplified by improper structural design. Many houses have building layouts and plans based on aspirations of the owners, which often follow the layouts and shapes of traditional houses. These traditional houses were originally made of woods or bamboo, thus they had a tendency to be flexible and lightweight. These houses could perform well under seismic load. However, current condition shows that people are more likely to build their houses using RC frames and masonry walls. These RC and masonry structures are considered more modern and show the prosperity of the owners. When the concept of the traditional houses is adapted to modern structures, the building shapes and layouts are usually maintained, but the traditional materials are replaced with concrete and bricks (see Figure 2). This creates problems due to structural irregularities, as well as heavy masses for roofs and facades. As a result, more and more non engineered structures were built with poor quality and to be vulnerable to earthquake. Considering large number of non-engineered buildings and their vital functions, as well as the high occupancy rates of these structures, efforts on making these buildings safer are significant in reducing the number of casualties and economic losses.

Figure 1 Problems in quality of material and construction techniques

Figure 2 Typical houses with façade and canopy adapted from traditional house concept

3. IMPROVING PERFORMANCE OF NON ENGINEERED STRUCTURES

When non engineered structures are properly built using good quality of materials and good workmanship, these buildings can survive earthquakes with little or no damage. Thus, the focus on improving the performance of non engineered structures should lie on how to ensure that these structures are built properly according to the building codes/standards. The efforts in improving the structural performance are multidisciplinary aspects and involve all parties in the building construction, including government, building owners, contractors, construction workers, and building inspectors, as well as covering technical, economy, social, and political aspects.

With the vast number of houses and other non engineered buildings, the solutions to improve structural performance should be conducted at national level. Development of a system for dissemination of building standards/codes which involve local government and communities is necessary to ensure that all parties in building constructions are aware and have good understanding of the codes. Next, a national standard of field manuals and guidelines for proper design and construction for non-engineered structures should be published. To ensure that the guidelines are followed, a system for strict enforcement (regulations) for building construction should be installed. The government plays a pivotal role in reenacting these solutions with cooperation from other parties in building construction.

A common perception regarding damage level should be introduced in educating the community regarding buildings' safety and earthquake vulnerability. Since damage on buildings depends on the intensity of earthquakes and the capacity of the structures, the strategy for reducing damage for non engineered structures can also be countered from better understanding the hazard and the structure itself. Thus, the solution should include the development of seismic risk map for Indonesia that considers local soil characteristics and potential seismic sources. From engineering aspect, the development of appropriate building technology to reduce structural damage with better knowledge of local materials and construction techniques is essential. These solutions will have direct impacts on new buildings, which will be constructed according to standards/codes. Unfortunately, many existing structures are not directly affected by the above solutions. For the existing structures, the efforts should include an evaluation of existing structura conditions to improve their safety against future earthquake risk. Should the building evaluation reveals that the existing structures have deficiencies and will behave poorly under seismic loads, appropriate retrofitting strategy should be applied to reduce their vulnerabilities. With the large number of existing non engineered structures, this enormous task should become a priority for ensuring the safety of the community. Therefore, buildings with high occupancy rates such as school buildings merits higher priority for technical evaluation and possible retrofitting/strengthening efforts.

Following the notion to reduce the vulnerability of school buildings, actions have been done to improve the structural quality of new and existing structures. The construction of new school buildings is carried out with close supervision to ensure the compliance to the building codes. Then, technical audits are performed for existing school buildings, followed with necessary repair and retrofitting. Guidelines and manuals are also developed for the masons/construction workers on how to build earthquake resistant non engineered structures properly. It should be noted that past earthquakes revealed that children are more vulnerable than adults during disaster. Therefore, training activities were also conducted for the school community, particularly students, to increase their preparedness for earthquake hazards. The government works together in these efforts with various partners, such as school communities, universities, and donors.

4. CASE STUDY: RETROFITTING OF SD CIRATEUN KULON II

A collaboration work of United Nations Centre for Regional Development (UNCRD) and Center for Disaster Mitigation (CDM) ITB was carried out to reduce the vulnerability of existing school buildings in the corridor of School Earthquake Safety Initiative (SESI) project. Prior to conducting any retrofitting, the location and building layout were checked to ensure that the buildings can be retrofitted. Then, the existing structures were investigated to determine the type and quality of materials used, as well as the lateral resisting system. Finally, the retrofitting was designed based on the structural deficiencies/weak parts and their accessibilities, weighing in factors of retrofit on buildings' life time, earthquake resistance capacity, buildings' function, and appropriate retrofit strategy/techniques. The design of retrofit strategy also considered factors of continuation of normal function, availability of materials and skilled construction workers, needs of upgrades for non structural components, and total costs.

One of the buildings that were retrofitted in this project is an elementary school in the city of Bandung, West Java, which is located on moderate seismic zone. The school, SD Cirateun Kulon II, has 423 students and 14 teachers. Considering that it is occupied from 7AM to 4PM, the safety of the building is crucial. Moreover, the school also functions as a social gathering place for the community, and it can play significant role during post-earthquake recovery efforts. Therefore, the buildings should perform satisfactory during earthquake. The school buildings consist of two buildings made of RC frames and masonry walls, as presented in Figures 3 and 4. Survey showed that the buildings had inadequate foundation system (shallow foundation, no tie beam). The structural system of Building I were made of pilaster columns a, ring beams with poor materials and detailing (longitudinal reinforcement of 4ϕ8, fy=240 MPa, and stirrups of ϕ8-400/500mm), and no tie beams. Building II had RC tie beams, ring beams, and columns, with poor materials and poor detailing (longitudinal reinforcement of 4ϕ8, fy=240 MPa, and stirrups of ϕ8-400/500mm). Both buildings showed poor beam-roof connection and poor roof truss element and connection. However, the walls were of good quality.

Structural analysis was performed on the existing structures using the actual material and structural components obtained from survey and tests. Earthquake risks were introduced to the buildings by applying loads based on potential seismic risks and local soil conditions. The result of the analysis showed that the two buildings were considered likely to behave poorly under seismic loadings. Based on the evaluation of the structural quality and earthquake vulnerability, repair and retrofitting was necessary. With funding from Hanshin Department Store Labor Union from Japan, the physical works were then conducted to improve the structural quality.

Two types of retrofitting strategies were applied to these structures due to different structural qualities, as well as needs and capabilities of the school communities, as shown in Figure 5. Building I which was considered to have lower quality was retrofitted by adding adequate RC frames with mat footings, and proper detailing of connections of structural elements. Anchorage was provided to connect walls with columns and beams. Building II which was in better condition was retrofitted using wire mesh for strengthening wall elements. Double tie beams were added adjacent to the existing one for better foundation system. For both structures, proper detailing was applied to roof truss systems, and repair was carried out for nonstructural elements such as doors/windows and ceilings. Various stages of construction work are presented in Figure 6. Repair of sanitary facilities was also conducted to the structures.

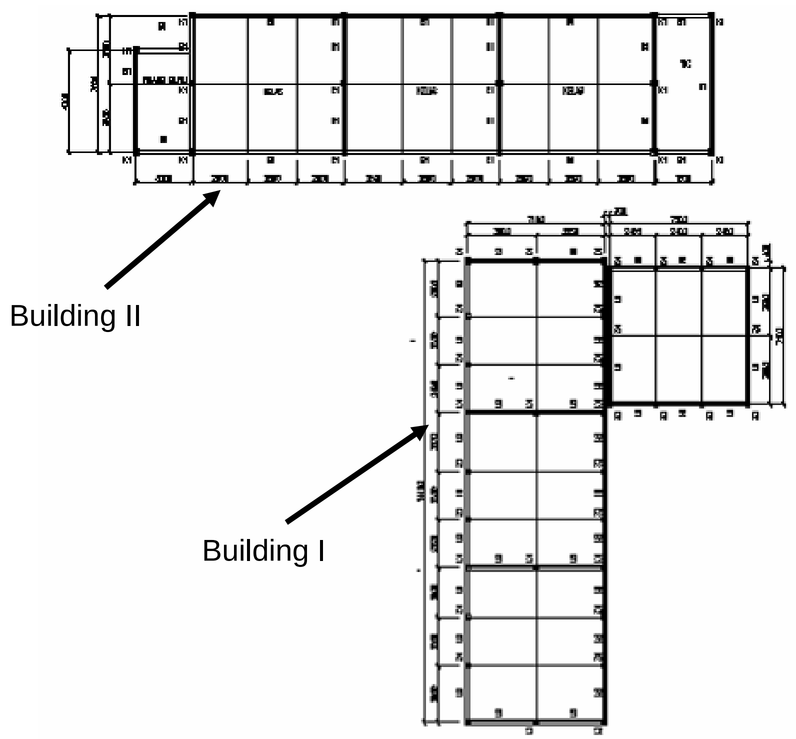
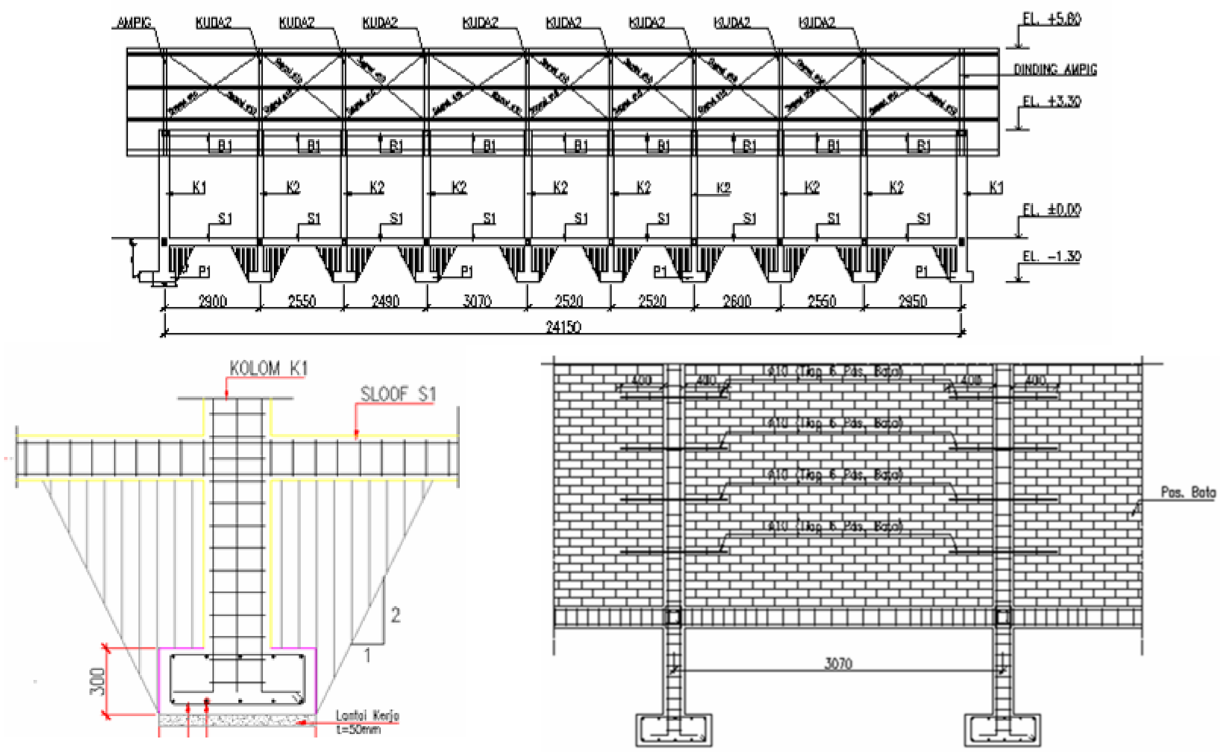
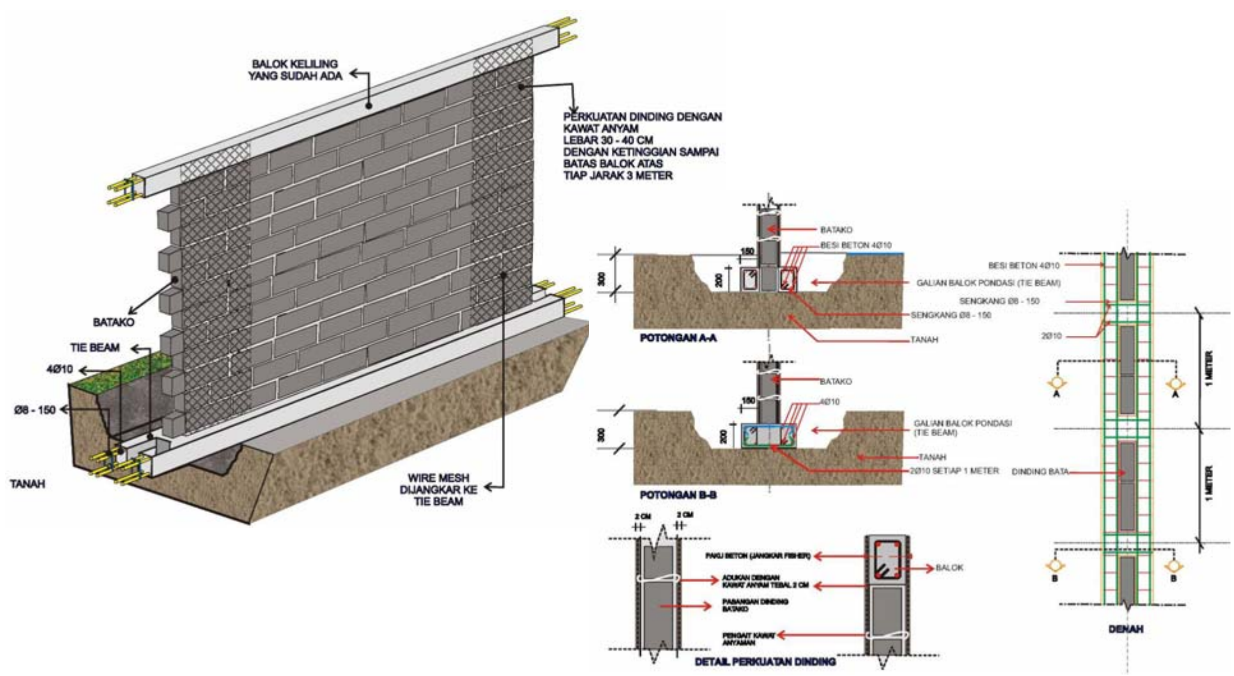


Figure 3 Layout of SD Cirateun Kulon II

Figure 4 Existing structural condition



(a) Retrofitting strategy for Building I



(b) Retrofitting strategy for Building II

Figure 5 Design of retrofitting strategies (courtesy of PT Teddy Boen Konsultan)

Figure 6 Various stages of the retrofitting process

The improvement of the structural quality of SD Cirateun Kulon II was accompanied by increasing the earthquake preparedness of the school communities. In this case, hands-on training was conducted for masons and workers on how to build proper structures prior to retrofit, and manual/guideline on building construction was also developed. To complete the efforts in earthquake preparedness of the community, dissemination of earthquake mitigation strategy was conducted for the school community which included earthquake drills for students, teachers, and parents.

5. CONCLUDING REMARKS

Various earthquakes occurred in Indonesia recently revealed that damage on structures could cause high casualties and economic losses, therefore buildings should perform satisfactorily under earthquake loads. Experiences have shown that non-engineered structures can be susceptible to poor structural quality and high earthquake vulnerability due to inadequacy in the building practices. The common problems found in non engineered structures are mostly due to minimum reference to standards/codes, inadequate detailing, wide variety of quality of materials and construction methods, and non conformity of 'traditional houses' adapted to 'modern structures'. Considering that two thirds of buildings in Indonesia are non-engineered structures, it is necessary that these structures behave satisfactory under earthquake loadings. Therefore, a step must be taken to ensure that new buildings are built according to building codes, and existing buildings should undergo a technical audit to check their vulnerabilities against earthquakes. If the existing structures were found to have deficiencies in their lateral load resisting systems, appropriate retrofitting strategy should be designed. The retrofit can be tailored to the needs, while also considers the capacities of the building owners.

A case study of retrofitting for school building reveals that this strategy can be applied successfully. Efforts on reducing earthquake vulnerability were carried out for SD Cirateun Kulon II, Bandung, Indonesia. The first step was to evaluate the structural condition to find the weaknesses and to assess the applicable retrofitting strategies. Based on survey and structural analysis, retrofitting was necessary to be conducted. Therefore, two different retrofitting techniques were employed, based on the structural condition, as well as needs and capabilities of the school communities. The retrofit of the school buildings was accompanied with activities to increase earthquake preparedness of the school communities, such as trainings and development of manuals of proper building construction for non engineered structures.

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