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DEFECT STUDY ON SINGLE STOREY REINFORCED CONCRETE BUILDING IN WEST SUMATRA: BEFORE AND AFTER 2009 WEST SUMATRA EARTHQUAKE

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ABSTRACT: Indonesia has a high number of damaged buildings due to earthquake excitation. An event in 2009 (Mw 7.6) affected the buildings and infrastructure of Padang, where more than one hundred thousand were damaged to severe, medium, or slight levels. Previous studies have found that structural defects in the typical reinforced concrete buildings are the major cause of the catastrophic results of damage. However, the research that presenting the predominant defects suffered by RC building is limited. Hence, this research aimed at assessing the defects on the single-storey RC building in West Sumatra to arrange the defects list and finding the predominant defects on the target building type. Furthermore, by analyzing the data statistically, this study compared the defect found on the buildings that were built before and after the 2009 West Sumatra Earthquake. Hence, the information about the progress on building quality after the earthquake event can be provided. This research uses field survey and data analysis of 100 single storey RC buildings with masonry wall aged from 77 years till 0 years. The samples were selected randomly in the area of Padang-Pariaman district in West Sumatra, Indonesia. The results show that common defects found are 18% of the building do not have structural columns, 38% without structural beams, and 60% of the building's structural elements concrete cover do not follow the minimum concrete cover required by Indonesia National Standard. This study also found that 20% of columns are indicated to be corroded.

Keywords: Structural Defect, Reinforced Concrete Building, Masonry Wall, West Sumatra Indonesia

1. INTRODUCTION

West Sumatra Province is an earthquake-prone area due to its location on the western coast of Sumatra, which is adjacent to the subduction zone of the Indo-Australian plate beneath the Eurasian plate. According to the database of recorded earthquake events in the whole Indonesian region, the number of earthquakes events with a magnitude >4.0 that has occurred exceeds 60,000 since 1779 until 2020 C.E., and as many as 1,200 earthquake events occur every year, although most of these earthquake events occur in the shallow region (<100km) [1–3] (Figure 1). Province of West Sumatra is located close to three earthquake sources: subduction region in the west (called the Mentawai Mega-thrust), the fault line between Sumatra and Mentawai in the west, and the active fault line along Sumatra Island about 1800 Km long.

The Sumatran fault produces a very high annual rate of earthquake events. Based on the earthquake catalogue, the giant earthquake events have occurred in this region with magnitude >7Mw, such as those in 1779 (Mw 8.4), 1833 (Mw 9.2), 1861 (Mw 8.3), 2004 (Mw 9.2), 2007 (Mw 7.9 and 8.4), and 2009 (Mw 7.6) [4].

1.1. The Damage of Single Storey RC Building

Based on the data of damages from many earthquake records in the last years, Reinforced Concrete (RC) building with masonry wall experienced every stage of damages, from slight damage till collapse state [5–7].

The vulnerability of RC building is caused by the existence of buildings defect, which include bad quality of concrete due to the improper concrete execution, high irregularity due to the arrangement of a masonry wall, and the brittle behavior of the brick wall material.

However, the number of RC building structure keeps growing due to the locally available material and availability of labor. RC building also has better performance towards the high temperature when the firebreak occures [8].

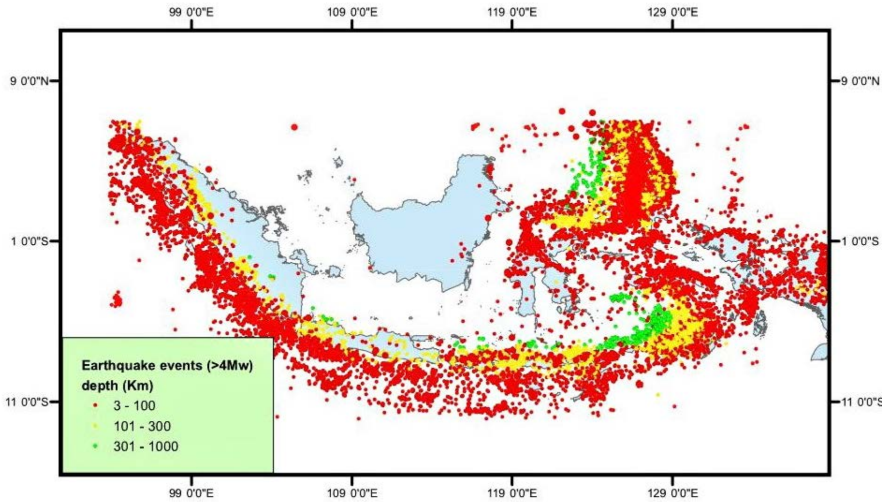

Fig 1. Seismicity of Indonesia from 1779 to–2020, with Mw>4[1]

Hence, if the structural defects keep occurs in the typical buildings, a massive number of RC buildings in a populated area will affect the increasing of the damages when the extreme loading subjected to the building, for example, the seismic excitation.

Observation of building damages due to 30th September 2009 in Padang City West Sumatra, shows that the performance of RC building with masonry wall was varied, with damage ranging from minor to total collapse. The majority of buildings suffered significant cracking in a masonry wall, and out of plan failure is often observed. The failure due to the development of plastic hinge at the top and bottoms of the column were majorly found [9].

1.2. Some Earlier Investigation Finding on Defects of Building in West Sumatra

Concrete structures are unique compared to structures made from other materials since its actual quality is determined through the execution of the actual construction site.

The observation found some defects in concrete structures in Padang City, Indonesia [10]. Most defects found are honeycombing, which is caused by improper compaction work and curing of placed concrete.

E. Juliafad, I. G. Rani, F. Rifwan, and Y. F. P (2019) observed and interviewed 100 builders in the study area and found that the concreting workmanship conducted by local builders seem to be inadequate. The builders mainly used rodding and hammering method to compact the concrete. Meanwhile, some percentage of the builders answered they do not compact the concrete. Some others answered they added more water to increase the workability of the placed concrete[11].

This finding indicated the poor concreting workmanship, which can reduce the concrete strength that also can increase the defects in the structure.

With so many cause and evidence that observed during the field investigation in 2018, which show many defects were found in RC structure primarily single storey RC building, hence the predominant defect still need to be determined, and the defect list should be obtained. It is also essential to compare the building conditions before the 2009 earthquake and, after also becomes essential to give the information about the progress of RC building quality in this recent year after many improvement efforts from government and other stakeholders.

Therefore, the objective of this study is to find the defects on the single-story RC building in Padang-Pariaman district West Sumatra to arrange the defects list and finding the predominant defects on the target building type. This study also compares the defect found on the buildings that were built before and after the 2009 West Sumatra Earthquake.

2. RESEARCH METHODOLOGY

This study targeted 100 single storey RC buildings with masonry walls that have been utilized as housing in the Padang-Pariaman district area of West Sumatra. The inspections were conducted between June 2019 to August 2019. The year of construction of the buildings is spread from 1945 through to 2019.

Building samples were chosen randomly in 3 sub-districts consist of 10 villages (Nagari). The selected building was investigated for gathering the information about the layout dimension, the total height of the building, the size of its opening (window and door), the availability of structural elements, the size of the structural dimension, and the cross-section detailing. This study also found out the construction year of each building through the interview with the owner.

This study used laser measurement with 1,5mm accuracy to measure the building's dimension. We use a rebar locator to obtain the detail of the structural element's cross-section. This tool can detect the location of longitudinal and stirrup rebar. By doing so, the thickness of concrete cover can be obtained. The actual diameter of rebar was measured by using a digital caliper. This research also observed the sign of deterioration of rebar visually.

Fig. 2. The location of 100 Housing Sample in 3 Sub-districts in Padang Pariaman Region, West Sumatra, Indonesia

The collected data were tabulated and analyzed to find the predominant structural defect on building targets. The defect was listed. The defect of the building constructed before the 2009 earthquake and after were compared to find the quality difference.

3. RESULT AND DISCUSSION

This section discusses the investigation results, which divided into two parts, which are the percentage of each defect that was found on the target buildings and the comparison between the building's defect before the 2009 West Sumatera earthquake and after.

3.1 Defect of Single Storey RC Building

3.1.1. The availability of Structural Column

The structural column is a critical element on RC building that support the building and transfer the load from beam to foundation. The field study shows that most of the buildings already have the columns, but there are 18% that do not have a column (Figure 3). The buildings without structural columns dominate the building population in the earlier year, consist of masonry brick walls only. Indonesian construction experts name this type of building as a bearing wall structure.

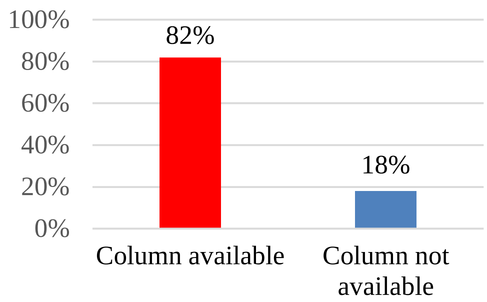

Fig. 3. The availability of Structural Column

3.1.2. The availability of Structural Beam

There are still many single storey RC buildings that are not constructed with a structural beam or tie/ring beam (Figure 4). This structural defect will increase the vulnerability towards the earthquake hazards due to less horizontal confinement to resist the lateral forces from earthquake excitation. As shown in Figure 5, the ring beam is typically installed over the masonry wall; then, the ring beam confines the masonry wall together with the structural column. However, as we can see in Figure 5, many surveyed buildings do not have the ring beam.

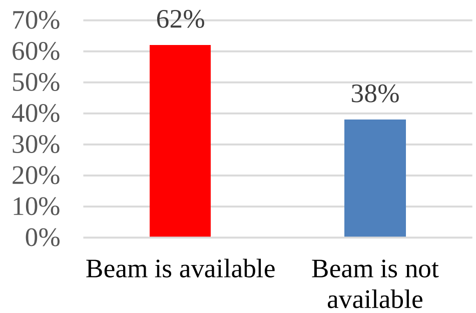

Fig. 4. The availability of Structural Beam

Fig. 5. Single Storey RC Building with Masonry wall without Ring Beam

3.1.3. Corrosion at Structural Elements

Many of the surveyed buildings made from RC with masonry wall show corrosion at its column (Figure 6). The plaster does not cover some of the building that selected randomly. Hence, corroded steel and porous concrete can be observed easily. However, some of the samples are covered by the plaster. To find whether the steel suffers corrosion, they should be checked visually from the top of its column. The surveyors climbed by using a ladder to check the beam and the tip of reinforcement of the column.

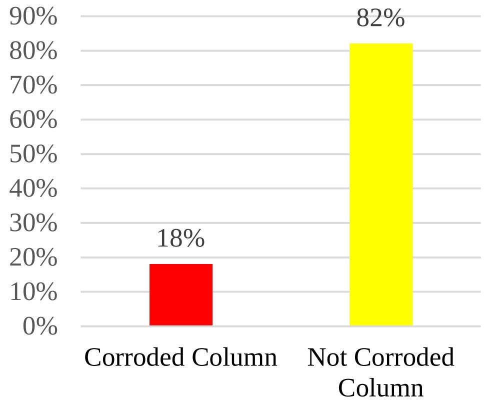

Fig. 6. Corrosion at Structural Column

The improper compaction can cause the high porosity of concrete and reduce its compressive strength for more than 50%[11–13]. This evidence supports the results of actual concrete strength investigation in Indonesia that conducted by Juliafad (2018) which presented the results that most of the actual concrete strength that extracted from existing and demolished buildings tend to not meet the requirement of Indonesia standard[14]

Fig. 7. Corroded steel and porous concrete at Outer Structural Column

3.1.4. Beam-Column Joint Condition

Beam-column joint connection functions as the area to transfer the load from beam to column. This area also dissipates seismic energy that is endured by the structure. Based on Indonesia National Standard, SNI-2847-2013 beam-column joint should be confined with the confinement and anchor properly.

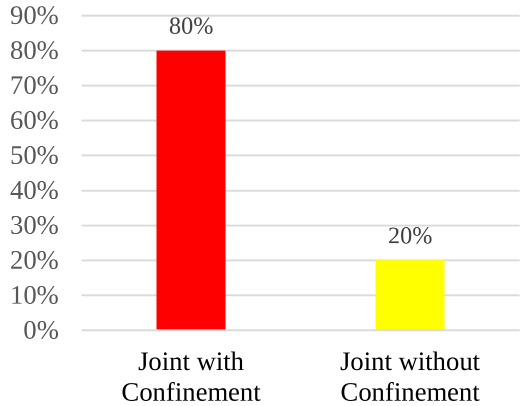

Fig. 8. Beam-Column Joint Confinement

This study checked the availability of steel for joint confinement by using a rebar detector. The rebar detector was scanned in the middle area of the joint, and when the tool did not detect any signal of steel than that observed joint was concluded as do not have steel confinement.

Fig. 9. The inspection process of availability of beam-column joint confinement.

Investigation results show that most of the buildings (80%) have the confinement in the joint area. However, to be noted that almost 40% of the inspected buildings do not have a beam element, and 18% do not have a column (Figure 8). Hence only 40 buildings can be checked for joint confinement. It means that the increasing sample can improve the precision of the results. This analysis comes as the finding of observation that shows much improper work of beam-column joint confinement. We locate and detect the availability of joint confinement by using the rebar locator as shown in Fig.9

3.1.5. *Masonry Wall without Plaster*

We checked whether the single storey RC buildings cover the masonry wall with plaster made from the mortar or not.

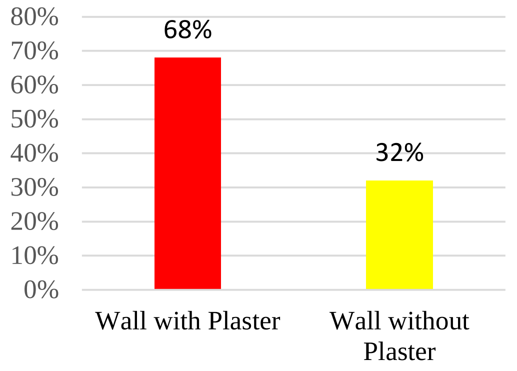

Fig. 10. Masonry Wall Finishing Condition

The results show that there are still many buildings that do not finish the wall construction by using plaster (Figure 11). While by plastering the masonry wall will give stronger wall and show the different behavior comparing to the wall without plaster [15–16]

Fig. 11. Masonry Wall on Building without Pilaster

3.1.6. *Reinforcement Defect; Improper Stirrups Space*

The sole purpose of the shear reinforcement is to confine the longitudinal reinforcement at a specific location and shear resistance. Usually, the stirrups are placed at specific spacing, which is a minimum 150mm, according to Indonesia National Standard SNI-2847-2013.

The investigation results show the percentage of single-story RC building from 1945 till 2019 and the stirrup space for three construction year period (1945-1969; 1970-1994, and 1995-2019 (Table 1). This data shows that the percentage of buildings which has less than 150mm of stirrups space increase. In contrast, the number of buildings that do not have stirrups also decreases.

Table 1. Stirrups Space in Structural Column.

	Building's Construction Year			
stirrup space (mm)	1945-1969	1970-1994	1995-2019	Grand Total
60	0%	2%	0%	2%
70	0%	2%	2%	4%
80	0%	4%	10%	14%
85	0%	2%	0%	2%
90	0%	6%	2%	8%
95	0%	0%	2%	2%
100	0%	0%	18%	18%
110	0%	2%	8%	10%
120	0%	2%	8%	10%
130	0%	0%	8%	8%
140	0%	0%	2%	2%
150	0%	0%	2%	2%
no columns	4%	8%	6%	18%

3.1.7. *Concrete Cover of Structural Elements*

Table 2. Concrete Cover for Column Element

	Building's Construction Year			
Concrete Cover (mm)	1945-1969	1970-1994	1995-2019	Grand Total
20	0%	2%	4%	6%
25	0%	0%	12%	12%
30	0%	8%	24%	32%
35	0%	6%	4%	10%
40	0%	4%	14%	18%
45	0%	0%	2%	2%
50	0%	0%	2%	2%
no columns	4%	8%	6%	18%

We measured the actual concrete cover on the column of 3 construction period (1945-1969; 1970-1994; 1995-2019). Even there are still many buildings that do not follow the minimum requirement of Indonesia Standard for concrete cover (40mm), the results show that there is an improvement in its quality. For example, 40mm of the thickness of concrete cover the percentage of building with that condition rose from 4% before the Year 1994 to 14% after the Year 1995 (Table 2).

3.1.8. *Defect List*

Finally, the defects of the investigated buildings were compiled and be listed. In table 3, 10 predominant defects have been found during the investigation. One of the most predominant defects is improper concrete cover at the column element. These defects increase threats that the column will endure significant deterioration and corrosion at its reinforcement in the future.

Table 3. Defect List for all of Building Sample

No	*Defect list*	Percentage of building samples suffered defects
1	Without Column	18%
2	Without Beam	38%
3	Corroded Beam	16%
4	Corroded Column	20%
5	Unconfined Beam-Column Joint	12%
7	Wall without plaster	32%
8	Concrete Cover at Column does not follow Indonesia Standard	60%
9	Concrete Cover at Beam does not follow Indonesia Standard	16%
10	Stirrups at Beam does not follow Indonesia Standard	18%

3.2 Comparison of Defects Found on Single Storey RC Building before the 2009 Earthquake and After

This section presents and discuss the comparison of defects found on single storey RC building before the 2009 Earthquake and after. As the reconstruction and rehabilitation program conducted after the 2009 Earthquake event, the Indonesian government, together with experts and many stakeholders, including university, disseminate the building standard to people and also mason (construction worker).

This section also answers the question of whether all of the efforts can improve the quality of building construction, especially the housing or single storey RC building.

The investigation of the comparison of stirrup space at column before the 2009 earthquake shows that the percentage of building with improper stirrup space reduced, although it is still insignificant change (Table 4).

This research provided the investigation results about the comparison of concrete cover quality at beam and column (Figure 12 and Figure 13). The results show the decrease of building with an improper concrete cover. This condition leads to the probability of corrosion of reinforcement in column and beam elements

Table 4. Stirrups Space of Column before the 2009 Earthquake and After

	before 2009 earthquake	after 2009 earthquake
Stirrups Space (mm)	1998-2009	2010-2019
70	3%	0
80	10%	7%
90	0%	3%
95	0%	3%
100	13%	17%
110	3%	7%
120	10%	0%
130	7%	7%
140	0%	3%
150	0%	3%
No Column	3%	0%

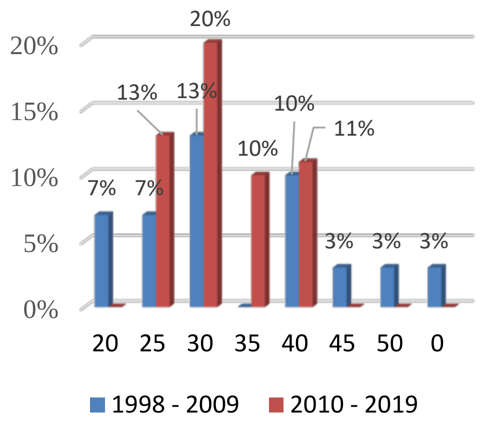

Fig. 12. Comparison of Concrete Cover (in mm) at Structural Column before the 2009 Earthquake and after.

This study shows that the percentage of the building constructed with the column increased, and the one without column decrease (Figure 14). The awareness of housing owners to follow the key requirement for safer housing is increasing. However, the quality of concrete work is still poor. This study shows the evidence that many buildings do not have adequate stirrups space and still suffer the corrosion due to improver concrete cover thickness (Table 4).

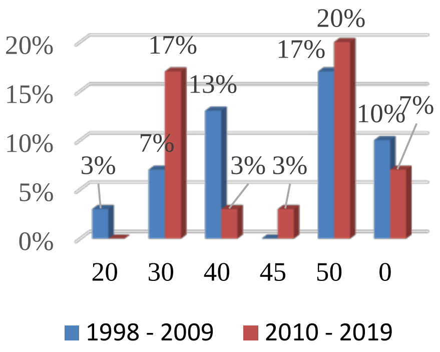

Fig. 13. Comparison of Concrete Cover Structural Beam (in mm) before the 2009 Earthquake and after.

At last, from overall observation and measurement, the list that compares the percentage of the single storey RC Building which suffered defects before the 2009 West Sumatera and after 2009 Earthquake are shown in Table 5.

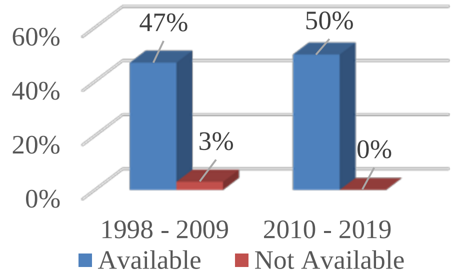

Fig. 14. Comparison of Structural Column Availability before the 2009 Earthquake and After.

There is some improvement in the quality of RC building indicated by the decrease in the percentage of defects suffered by the buildings, such as the availability of structural columns. From 2008 until 2009, there are 7% of building population that does not have the column, but after the 2009 West Sumatra Earthquake, all of the building population already has the column (Figure 14)

Table 5. Defect Before and After 2009 Earthquake

No	Defect list	Percentage of buildings suffered defects	
		Before the 2009 Earthquake	After the 2009 Earthquake
1	Structural Column is not available	3%	0%
2	Beam Element is not available	10%	7%
3	Deteriorated and Corroded Column	13%	7%
4	Deteriorated and Corroded Beam	10%	7%
5	Beam-Column Joint Area without Confinement	0%	7%
6	Masonry Wall Truss (Gunung-Gunung) without Confinement	10%	7%
7	Masonry Wall without Plaster made from Mortar	23%	13%
8	Concrete Cover thickness at Outer Structural Column less than 40 mm (Indonesia standard required at least 40 mm thickness)	27%	40%
9	Concrete Cover thickness at outer structural beam less than 40 mm (Indonesia standard required at least 40 mm thickness)	10%	17%

4. CONCLUSION

The characteristic of the single-story building in West Sumatra in Indonesia is permanent buildings. Generally, the floor area is 62.5 to 92.5m^2. Type of the wall is a masonry wall with the confined masonry wall type. Most of the building use line foundation from river stone, and the roof frame are made from timber, and the roof cover consists of zinc material.

The typical defects found are 18% of the building does not have structural columns, 38% without structural beams, and 60% of the building's structural elements concrete cover do not follow the minimum concrete cover required by Indonesia National Standard. This study also found that 20% of columns are indicated to be corroded.

The comparison of the building's defect found on the building built before the 2009 West Sumatera Earthquake and after show that there is some improvement, but slightly improved. Hence, it necessary to improve the efforts to increase the quality of the building, especially its workmanship in the future. This result can be used as necessary information for the government on strengthening the housing with the defect and calculate the risk of housing damage in the future.

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