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CHARACTERISTIC OF EXISTING RESIDENTIAL BUILDINGS IN INDONESIA AND THEIR TYPICAL DAMAGE DURING EARTHQUAKES

L. Putri[(1)], T. Hart[(2)]

[(1)] *Design Engineer, Build Change, laura@buildchange.org*
[(2)] *Engineering and Design Services Director, Build Change, tim.hart@buildchange.org*

Abstract

Indonesia is one of the most seismically active countries in the world. Hundreds of moderate to major earthquakes have hit the country in the last decade alone. As the fourth most populous country in the world, more people in Indonesia are at risk of earthquakes relative to other countries with similar seismicity. Poor construction practice, especially common for residential buildings, exacerbate the risk. In 2016 and 2018 alone, major earthquakes hit Indonesia in three cities on three different islands: Aceh (M6.5) on Sumatra Island, Lombok (M7) on Lombok Island and Palu (M7.5) on Sulawesi Island. The earthquakes affected approximately 3,500 commercial and government buildings, 4200 school buildings and 236,000 residential buildings, which led to 2,700 fatalities and 680,000 people left homeless.

Rapid visual surveys were conducted after each earthquake to investigate the characteristic features of residential buildings and their typical damage due to the earthquakes. The study was focused on four building types: unreinforced masonry, confined masonry, reinforced concrete frame with masonry infill, and timber frame (with either heavy infill or light infill). An evaluation was carried out to determine the compliance of different building types with minimum standards stipulated in the current Indonesia building codes.

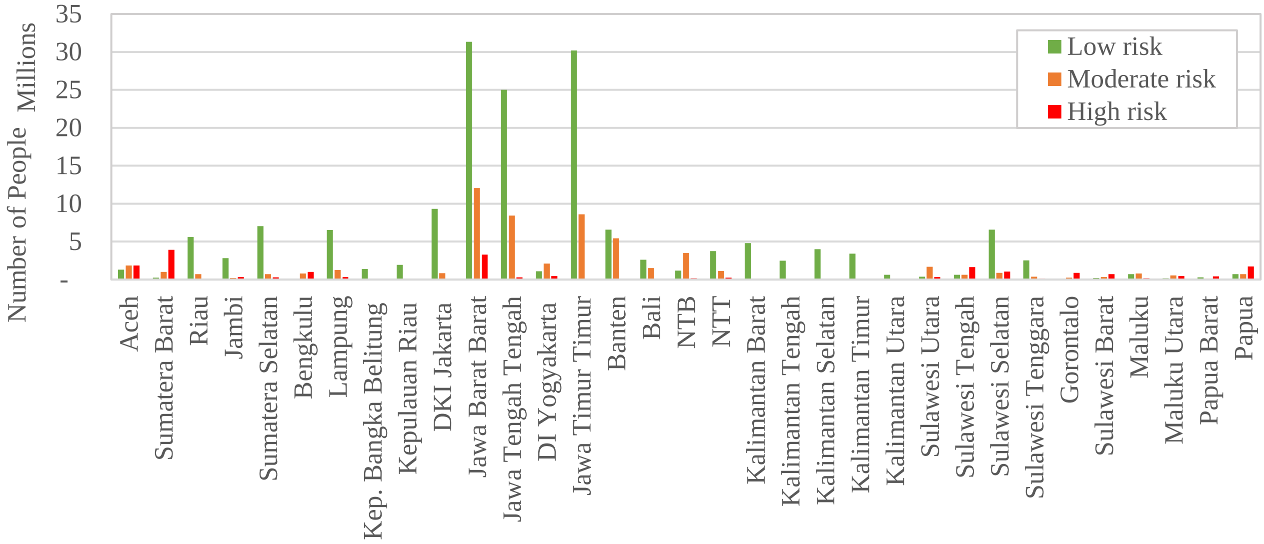
The study showed that the most common damage encountered were cracks in the foundation, separation between structural elements, separation of structural and non-structural elements, residual drift of the reinforced concrete (RC) frame or confining concrete/timber frame, cracks in the RC columns, out-of-plane collapse of the masonry wall, cracks in the masonry walls, toe crushing of the masonry walls, leaning masonry and timber walls, and tilted/collapsed structures due to activation of a soft story mechanism.

Statistical data show that each area has different building typologies. In general, unreinforced masonry, confined masonry, and timber frame with heavy infill houses experienced more severe damage compared to reinforced concrete frame with masonry infill and timber frame with light infill buildings. Except for houses located in the area where significant ground settlement occurred, timber frame with light infill houses only experienced minor or no damage even though the house was non-engineered and used materials that were below specified standards. Based on the observations, it is evident that most of the buildings observed did not fully meet the applicable standards. The deficiencies that were encountered, either due to building type, construction quality (e.g. material quality, structural detailing, workmanship) or the combination thereof, showed evidence of minimum (if not absent) involvement of technical support, such as engineers, technicians and authorized government agencies, during the design and construction process.

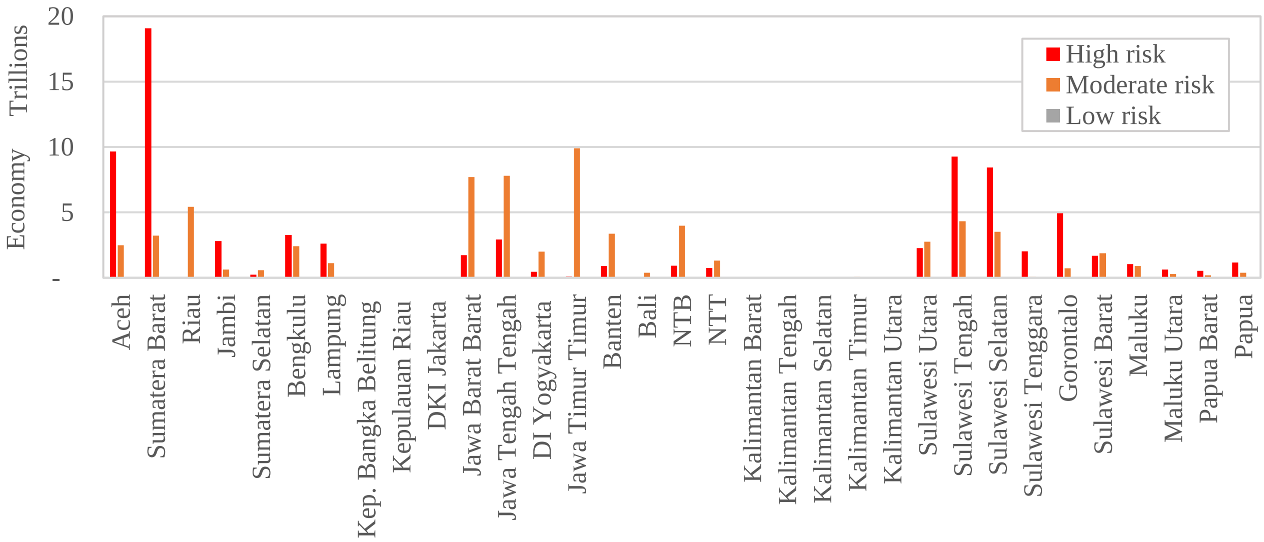
Keywords: Indonesia, residential buildings, earthquakes, seismic damage.

1. Introduction

Indonesia is one of the most seismically active countries in the world. It is recorded that five out of twenty of the biggest earthquakes in the world occurred in Indonesia and its vicinity [1] with hundreds of moderate to major earthquakes hitting the country in the last three years alone. As the fourth most populous country in the world, more people in Indonesia are at risk of earthquakes relative to other countries with similar seismicity. The total population of Indonesia is predicted to be more than 273 million in 2020 [2] with significant number concentrated in the area where moderate-to-major earthquakes frequently occur. The National Disaster Management Authority (BNPB) estimated that there is almost 20 million of total population and more than 77.6 trillion Rupiah of economic value in Indonesia that are exposed to high risk of earthquakes. As shown in Fig. 1a,b [3], the risk significantly varies by province depending on population spread, local economic conditions, and the proximity to known tectonic fault zones.



(a)



(b)

Fig. 1 – (a) earthquakes risk hazard in Indonesia to (a) social and (b) economic aspects (graphs were originally created based on data from [3])

In 2016 and 2018 alone, major earthquakes hit Indonesia in three cities/districts and their vicinities on three different islands: Pidie Jaya (M6.5) on Sumatra Island, Lombok (M6.5) in Lombok Island and Palu

(M7.5) on Sulawesi Island. The earthquakes affected approximately 3,500 commercial and government buildings, 4,200 school buildings and 236,000 residential buildings, which led to 2,700 fatalities and 680,000 people left homeless [4].

Build Change Indonesia visited the areas most affected by the three aforementioned earthquakes. Rapid assessment was conducted on residential buildings, school buildings and lifelines. However, this paper mainly discusses the findings of the assessment to residential buildings only. The characteristics of residential buildings in different areas in Indonesia and how these buildings performed after the last three major earthquakes are discussed. The shifting trend of residential buildings over the years is also provided. The results are then integrated with evaluations of related laws, codes, guidelines, standards and manuals to identify other external factors that directly or indirectly affect the quality and performance of residential buildings in Indonesia during earthquakes. Recommendations based on these evaluations are provided to identify the future steps that homeowners, builders, private sector entities and the government can take to improve the quality of residential buildings in Indonesia and reduce the life, social and economic losses due to earthquakes in the future.

2. Three Most Recent Major Earthquakes in Indonesia

2.1 Pidie Jaya (2016)

Pidie Jaya was struck by a M6.5 earthquake on 12th June 2016 with the hypocenter of 13km below the surface [5] [6]. The area within a 35km radius from the epicenter along the coast was significantly affected [7]. The shaking was intensified at the coastal area, perpendicular to ruptured fault strike, due to the sedimentary soil in the area [8]. The earthquake caused more than 100 casualties in three provinces and more than 3,000 people were evacuated [9]. The earthquake affected approximately 19,000 residential houses, 300 school buildings, and 80 commercial buildings [4].

2.2 Central Sulawesi (2018)

Sulawesi, and most of Eastern Indonesia region, is located at the triple junction of three main plates, namely the Pacific, Indo-Australia, and Eurasian Plates, as well as numerous micro-plates [10]. Sulawesi is also crossed by the Palu-Koro Fault (PKF), the Matano Fault (MF) and the North Sulawesi Subduction (NSS). The Central Sulawesi area where the PKF (with long-term slip-rate of 40 mm – 50mm per year) and MF met has been subjected to major active movements [11].The capital city of Palu, which is crossed by the Palu-Koro fault, has been hit by many destructive earthquakes [12]. Palu has various geological conditions and unique alluvial deposits with a sandy layer on top (1-7m) and a shallow ground water level [13]. The distribution of geological rocks in Palu is dominated by alluvial deposits [13]. Considering the type of soil, the shallow ground water level and the high seismicity, Central Sulawesi is highly susceptible to earthquake induced landslides and liquefaction. The 26 October 2018 earthquake and its subsequent liquefaction and tsunami caused 2,081 fatalities, with an estimated 1,309 people still missing or buried underneath the landslides [14]. Approximately 68,000 houses were damaged, and about 206,000 people were displaced from their homes [14].

2.3 Lombok Island (2018)

Lombok Island, located in East Nusa Tenggara Province, is seismically active due to active back arc thrust of the Australian tectonic plate over the Eurasian plate, resulting in arc-continent collisions near the island that frequently trigger shallow major earthquakes. It was reported that most of devastating earthquakes that occurred in East Nusa Tenggara were caused by this phenomenon [15]. On August 8th 2018, a M7.0 earthquake hit Lombok island with the epicenter depth of 14km, northwest side of North Lombok, followed by a M6.2 earthquake only four days later [15]. The earthquake caused more than 400 fatalities in Lombok island, and two in Bali island [16]. A total of more than 31,000 houses were heavily damaged, more than 3,000 moderately damaged and almost 40,000 lightly damaged. It was also reported that the earthquake affected 60 education facilities, 125 houses of worship, and 2 bridges [16].

2.4 BNPB’s Earthquake Risk Assessment

In 2016, BNPB estimated that more than 200,000 people in three districts in Central Sulawesi were at high risk of earthquakes of Mw ≥ 5.0 [3], especially in Palu where 100% of the population who resides in this city were identified to be at high risk. Meanwhile, in Nusa Tenggara Barat (NTB) province (especially in Lombok Tengah) and in Pidie Jaya, most of their population (98% and almost 80% respectively) were estimated to be at moderate risk. At the national level, 78% of Indonesia's population live in areas with moderate risk of damaging earthquakes and another 3% are in areas of high risk, which means that more than 8 million people in Indonesia may need immediate assistance after a significant earthquake. From an economic point of view, all of the areas in the three main provinces were identified to have at least a moderate risk of economic loss due to a significant earthquake. The highest loss was predicted to occur in the Donggala Regency (just north of Palu, Central Sulawesi) with an estimated loss amount of more than 1.1 trillion Rupiah. Palu was estimated to experience loss of 13.5 billion Rupiah, while all the areas in Lombok and Pidie Jaya are estimated to experience loss of 1.4 trillion and 85 billion respectively (see Fig. 2). Palu and Donggala experienced the highest number of casualties and economic loss within Indonesia due to the 2018 earthquake and tsunami.

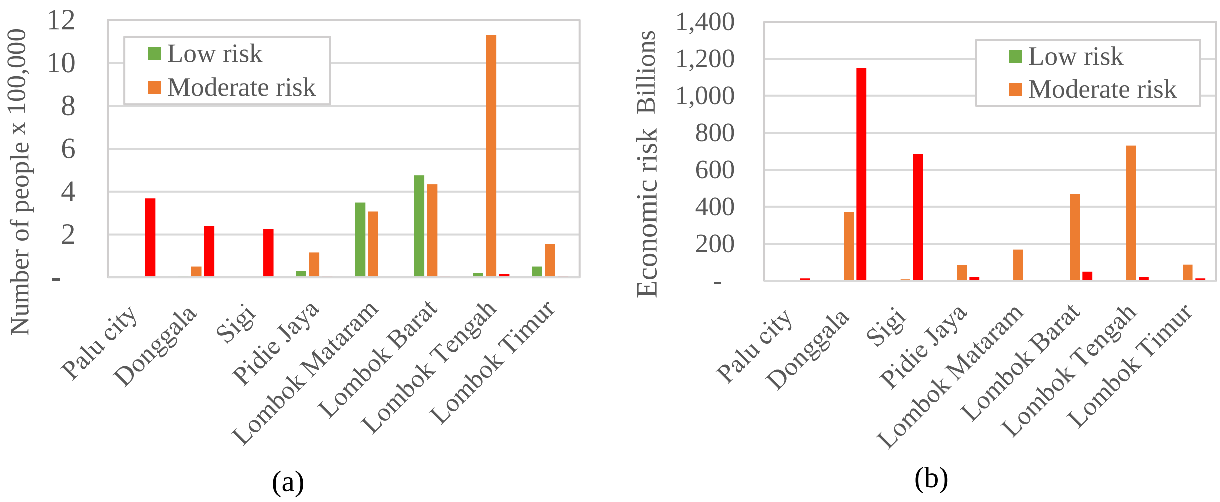


Fig. 2 – Earthquake risk hazard to (a) social and (b) economy aspects in Central Sulawesi, Pidie Jaya and Lombok Island (graphs were created based on data from [3])

3. Characteristics of Residential Buildings in Indonesia

3.1 Unreinforced Masonry (UM)

Despite the reduction in the number of unreinforced masonry buildings in Indonesia due to the shift in trend towards using reinforced concrete frames, unreinforced masonry buildings are still the most common building typology found in West Lombok and North Lombok. This type of house was also found in Aceh and Central Sulawesi, but the number is relatively low compared to other building types. From more than 150 of residential buildings that were evaluated in Central Sulawesi, less than 10% were unreinforced masonry.

The most common masonry type was either clay bricks or concrete blocks (see Fig. 3), placed in a running bond with cement mortar. Open gable, hip, and cross hip were the most common roof types found in the survey, with a few houses having a single-slope roof. Most of the houses inspected had roof trusses spaced at 2.5m - 4m. In some cases, purlins sat directly on top of the unreinforced masonry wall that was extended to gable roof in lieu of trusses. A construction practice that is considered unusual in Indonesia but is common in Lombok island is adding smooth rebar embedded into the URM walls at the top corner of the unreinforced masonry and hooked around the trusses. The roof framing members were usually of acceptable quality timber (Grade II with E ≈ 10,000 MPa and Grade I with E ≈ 12,000 MPa). In a few cases, a reinforced concrete beam was provided at the top of the walls, despite the absence of reinforced concrete columns. However, in those cases there were no connections between the masonry walls and the roof framing.

(a) (b)

Fig. 3 – Typical (a) clay brick and (b) concrete block of URM houses in Indonesia

3.2 Confined masonry (CM)

Confined masonry is the most common type of residential buildings found at the western to the middle part of Indonesia, such as Pidie Jaya, West Sumatra, Central Sulawesi and Java island. However, this type of house is less popular in the eastern part of Indonesia, such as West Papua. Similar to unreinforced masonry, the most common materials for masonry are clay bricks and concrete blocks (see Fig. 4) with size and strength varying significantly in different part of Indonesia. Heavy material (i.e. concrete block or clay brick) was the most common structure used for the gable wall (around 79% of total houses observed). Only 21% were framed with light material such as wood planks, plywood, or CGI sheets.

Buildings of this type were usually supported by a shallow continuous stone masonry foundation, where concrete plinth beams are not always provided. Confining concrete columns and beams of 13cmx13cm to 13cmx20cm are usually provided every 2m to 5m. The longitudinal rebar was usually smooth rebar between Ø6mm and Ø10mm (mostly Ø6mm). The stirrups were usually of smooth rebar between Ø4mm and Ø6mm, spaced between 20cm and 50cm apart. The roof framing is typically connected to the ring beam and/or column using protruding rebar from columns bent around truss chords. The use of proper mechanical connections such as steel plates, bolts or anchorage was rare.

(a) (b)

Fig. 4 – Confined concrete masonry house with (a) concrete block and (b) clay brick with gable roof

3.3 Reinforced Concrete Frame with Masonry Infill (RCF)

This type of house is the least common in the three areas, comprising only 6% of the total houses assessed. This type was usually one-story with floor areas ranging from 46m^2 to 153m^2, which is relatively large compared to the other types. The building configuration, quality and type of masonry infill used were similar to confined masonry and unreinforced masonry. The size of the reinforced concrete columns ranged from 10cm square to 20cm square. The reinforced concrete beams were typically 10cm wide and between 10cm and 15cm deep. The frames were typically spaced between 2.5m and 4m apart.

3.4 Timber Frame (TF) with Either Heavy or Light Infill

This type of building was the most common at the eastern part of Indonesia such as West Papua, either the most or the second most common in the middle part of Indonesia such as Central Sulawesi and Lombok, but the least common in the western part of Indonesia such as Aceh and Sumatra in general. The buildings studied were usually one-story with an average floor area of 70m^2. These buildings were typically supported by a shallow continuous stone foundation with sill plates between the foundation and the wall infill. The size of timber posts varied from 4/5cm to 10/10cm. The posts were usually embedded into the foundation, though in some cases they simply sit on top of foundation without mechanical connections. Posts were usually provided every 2m to 4m. The most common timber frame member connections were mortise and tenon cuts using wood pegs.

4. Factors that Affect the Quality of Residential Buildings in Indonesia

4.1 Material Quality

The quality of most construction materials in Indonesia varies significantly, especially for non-industrial materials such as clay bricks, concrete blocks, gravel, and timber. This is because most of these materials are produced manually by untrained laborers who are not familiar with the minimum standards of construction materials specified in the relevant Indonesian National Standards (SNIs). There is also minimum (if not absent) effort made by the government to regulate and inspect home-based material production sites. The production quality is only regulated for industrial producers, where homeowners rarely purchase their material from. The buyers of industrial produced materials are usually parties who understand the related standards (or can afford to hire professionals who do). Meanwhile, the buyers of home-based products are those who are not aware of the applicable standards and at the same time cannot afford hiring professionals. Thus, the shifting attention and priority to small material production sites is considered to be crucial. A government body is needed to collect data on home-based production sites, regulate permits that depend on conformity with related standards and conduct periodical inspection and/or supervision of home-based production.

Direct inspection and measurement of almost 80 clay bricks production sites in West Sumatra, for example, showed that most of the bricks and blocks produced did not meet the minimum compressive strength of 5 MPa stipulated in SNI 15-2094-2000 [17]. The study of concrete block production in West Sumatra, Palu and Lombok also found that most of the concrete blocks produced had a compressive strength of less than 7 MPa as required in SNI 03-0349-1989 [18] for blocks used in exposed structural walls. A study of 450 samples of bricks produced in five districts on Java Island also found that less than 50% of the bricks produced met the size and compressive strength standards [19] stipulated in the SNI 15-2094-2000 [17].

4.2 Building Permits and Law Enforcement

One key factor that could control the quality of houses in Indonesia is through the issuing of building permits, where the government could provide technical input and prohibit those who do not follow the standards to construct a building. Indonesia law [20] also specifies that every building must meet certain administrative and technical requirements. The main administrative requirements include the provisions for land ownership, building ownership and building permits, while the main technical requirements include provisions for spatial planning and building resilience. For residential buildings, one of the technical requirements for a building permit is submission of design drawings. To produce this drawing, the homeowner will need to hire architects or engineers, which for low-income families is not affordable. This may be the main reason for the low number of buildings in Indonesia constructed without a building permit. It was reported that most of the residential buildings in areas in Indonesia were built without construction permits from the government [21], despite the fact that by Indonesian law all building construction requires a building permit [22]. Thus, most homeowners build their houses without a building permit. Due to the large gap between the number of building department staff assigned to checking buildings and the number of buildings that need to be checked, enforcement of the building regulations is relatively weak, resulting in a prominent number of houses built without a building permit. The inspection, when it happens, is focused more on the administrative requirements instead of technical aspects [23]. This was worsened by the practices of illegal intermediaries, where people pay extra fees for a facilitator to get a permit [21] almost immediately without going through the proper checking and review on building documents, while people who do not pay the intermediary fees will face the long and tangible process. All of these factors increase the number of substandard residential buildings in Indonesia.

4.3 Socio-Cultural Aspects

Most old residential buildings in Indonesia were built from the available materials in each region and their vicinity. The techniques and the skills to construct the house were developed based on decades of experience. Back then, people upheld their custom firmly, thus controlling the quality of houses was much easier. Someone could not build their house without following specific customs and rituals. The construction was usually preceded by a discussion with family members, the chief of the village, village officials and experienced builders to determine the type of a house someone could build, the builders who would be involved, the location, the size, the cost and the schedule. The social and financial status of homeowners significantly determined the type of houses they could build, which prevented low income people from building a house that they could not afford. Each stage of house construction was done carefully based on factors that affected the quality of materials, such as the climate season. And there were strict rules on what materials could be used for certain parts of the house. In West Sumatra for example, there is a proverb that explains how local people used different types of timber that mentioned how the timber for posts could only be built using strong timber and certain types of timber could only be used for the ridge. The quality of traditional houses to withstand major earthquakes have been proven in some cases [24].

However, with the shift in trend from traditional to modern lifestyle (which for housing included using masonry, concrete, steel and other man-made materials), local housing norms and wisdoms were gradually left behind with only a small portion remaining. The knowledge that had been developed is not passed down to the younger generation, mainly because of the preference of the younger generation to adapt something new. The old rules and customs for how to build a house are no longer followed and people started to build their own houses with new materials that they and their builders had minimum knowledge about. This is exacerbated by the fact that in some areas (especially rural), houses built with man-made materials are associated with higher income and social status. Thus, what frequently occurs is when the financial situation of a low-income family improves, the homeowner will start to convert their houses, often only partially, from timber to masonry, without realizing how the changes significantly affect the strength and the stability of their new houses. Considering that *Badan Pusat Statistic* (BPS) Indonesia or Statistics Indonesia estimated that almost 25% of Indonesians are families with low-income (around 15% are in rural areas and 10% in cities), it means that there may be as many as 40 million people who are engaging in this activity.

5. Comparison of Existing Residential Buildings in Indonesia with Related Standards

SNI 15-2094-2000 [17] specifies a minimum compressive strength for clay bricks to be no lower than 5 MPa. SNI 03-0349-1989 [25] specifies that concrete blocks used for masonry wall construction should have compressive strength of at least 7 MPa when used for structural walls and walls exposed to weather. However, most of the concrete blocks that were encountered in the survey were of poor quality and had estimated strengths of less than 5 MPa.

SNI 2847:2013 [26] specifies that the compressive strength of structural concrete be no less than 17 MPa. Although the compressive strength of structural concrete elements of houses were not taken for all houses assessed in this study, the result from a rebound hammer test for representative houses in Central Sulawesi showed the compressive strength to be less than 10 MPa. In some cases, the concrete could even easily be broken by hand. SNI 2847:2013, article 3.5.1 specifies that the longitudinal rebar of reinforced concrete must be deformed. However, the use of smooth longitudinal rebars was commonly observed. Due to the smaller surface area of smooth bars, they have approximately 40% of the strength of deformed bars of the same diameter. The smaller surface areas also affect the development and splicing of the bars. The concrete cover of structural concrete is also limited in SNI 2847:2013 to be no less than 4cm. However, it was observed in the surveys that exposed rebar due to thin concrete cover was prevalent.

SNI 1726:2012 [27] article 7.14.2 specifies beam and column ties to be no less than Ø8mm and must be provided every 150mm. However, the field investigation found that the transverse rebar was typically 4 to 6mm in diameter and was spaced at 200mm or more. Only in a few cases was the transverse rebar found to be provided every 150mm. The technical guideline for simple houses issued by the Ministry of Housing and

Infrastructure No 403/KTPS/M/2002 [28] states that the longitudinal reinforcement for beams in a reinforced concrete frame building (both for confined masonry and reinforced concrete frame infill) must be deformed with the diameter of no less than 12mm. However, almost all of the houses assessed had smooth longitudinal rebar with a smaller size.

The Ministry of Public Works and Housing requirements for permitting of house construction [29] specifies that the maximum area of masonry walls between columns be limited to be no more than $9m^2$, which means that for buildings with a wall height of 3m, the length of a single wall panel should be no more than 3m, and as a consequence, the distance between columns must be no more than 3m. However, most houses appeared to have walls with areas that were more than the maximum area prescribed. In some cases, the columns were spaced up to 6m apart. In addition, the size of reinforced concrete columns must be no less than 15cm square. However, houses with column dimensions of 13cm square were prevalent.

6. Typical Seismic Damage of Residential Buildings in Indonesia

Based on the observations of damaged houses in Pidie Jaya, Central Sulawesi, and Lombok, the most common types of seismic damage of residential buildings were found to be as follows.

6.1 Cracks in Foundation

Cracks in the foundation were very common due to ground settlement (especially in the area where liquefaction happened such as in Palu) and poor mortar quality, mostly caused by the lack of cement in the mortar. The partial settlement usually led to damage to other structural elements such as columns, plinth beams and walls. Separation of the plinth beam from the foundation was typical, showing the absence of adequate connections between plinth beams and their foundations.

6.2 Separation Between Structural Elements

The separation of confining elements (i.e. column – beam, foundation – columns, column – plinth beam) was common due to poor seismic detailing (Fig. 5a), poor concrete strength and insufficient concrete capacity (Fig. 5b). Separation between concrete confining elements and the masonry wall was also commonly encountered (Fig. 6). A case was found where a wall panel without a top confining element led to splitting of the adjoining column that had to support all the lateral load at the adjoining wall (Fig. 7).

(a) (b)

Fig. 5 – (a) poor seismic detailing and (b) poor concrete quality

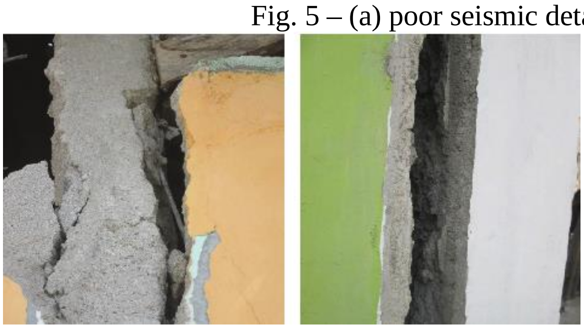


Fig. 6 – Separation of confining elements and masonry

Fig. 7 – Splitting column due to poor concrete quality

6.3 Separation Between Structural Elements and Nonstructural Elements

Especially for reinforced concrete frame with masonry infill, separation between reinforced concrete frame and the infill (Fig. 8) was prevalent.

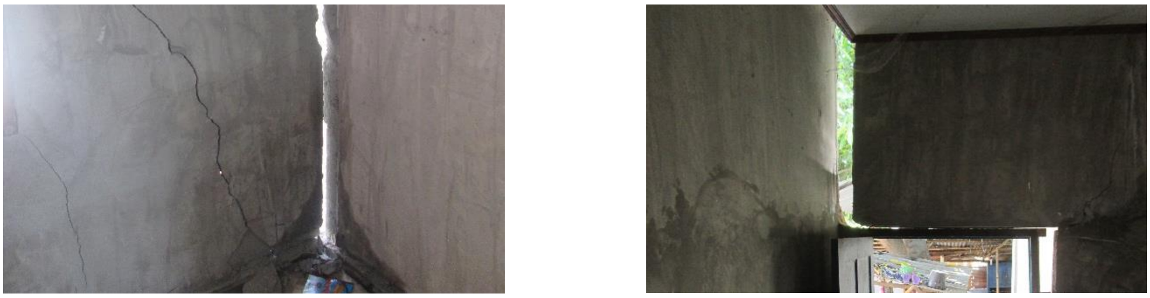
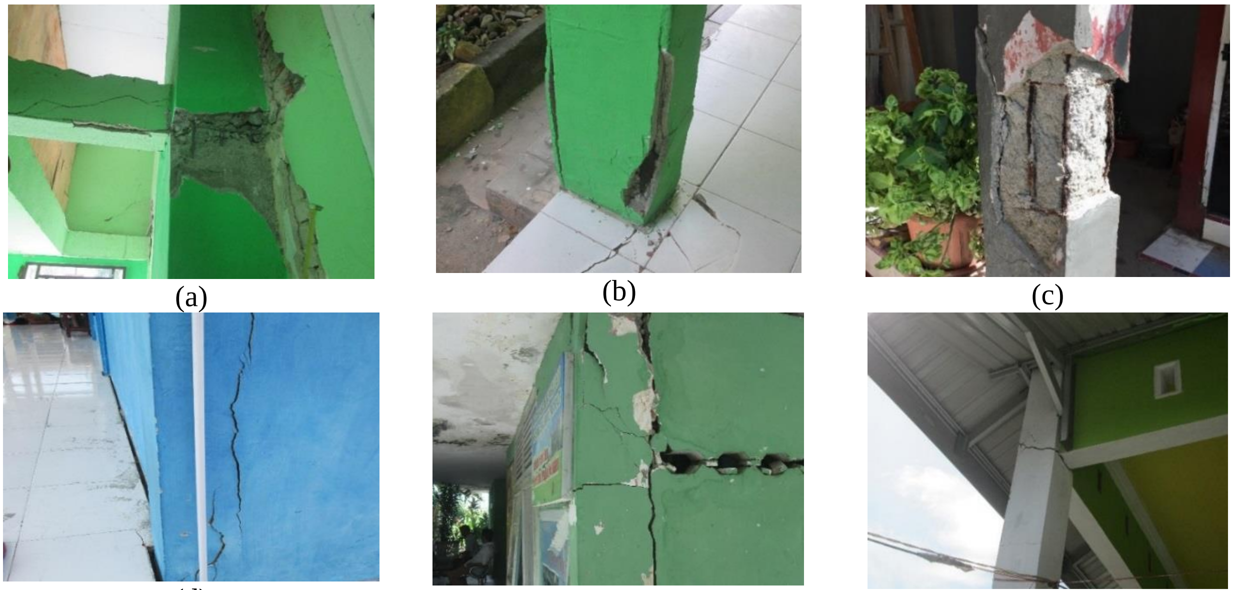


Fig. 8 – Separation of confining elements and masonry

6.4 Cracks in the RC Columns

Several common cases of cracks on columns include crushing at joints (Fig. 9a), splitting cracks (Fig. 9b), cracks due to corrosion of rebar (Fig. 9c), diagonal cracks ((Fig. 9d), horizontal cracks (Fig. 9e) and cracks due to captive columns (Fig. 9f).



(a) (b) (c)

(d) (e) (f)

Fig. 9 – Types of cracks on columns

6.5 Out-of-Plane Collapse of the Masonry Wall

Out-of-plane collapse is one of the most common damage types encountered at masonry walls, especially where the roof and floor were timber frame. This is because the timber framing is relatively weak relative to the heavy infill and because there were only minimum connections provided between the timber framing and the masonry walls (Fig. 10a). Out of plane collapse was also common at unconfined masonry walls (Fig. 10b), where there was a lack of anchorage to the roof and no reinforcement to resist flexure of the wall. This type of damage was also prevalent for RCF with masonry infill, where the lack of connection between the frame members and the infill caused the infill to fall out of plane. In some cases, the infill collapsed even when the frame experienced little or no damage (Fig. 10c). There were also houses where there was out-of-plane collapse of confined masonry walls because of incomplete confining elements (e.g. absence of a reinforced concrete ring beam), masonry of poor quality (e.g. weak bricks and poor mortar quality, see Fig. 10d) or confining concrete tie elements that were of poor quality and failed to transfer the lateral load to the wall.

(a) (b) (c) (d)

Fig. 10 – Out-of-plane collapse of wall

6.6 Cracks in the Masonry Walls

Common failures that were found included diagonal cracks around openings, caused mainly due to the absence of confining elements such as lintel beams to resist the shear stresses acting at the corners of the openings. In some buildings, there were walls with long horizontal spans that had flexural vertical cracks at their mid-lengths. Poor mortar quality also led to the prevalence of stair-step diagonal cracks in the walls.

6.7 Leaning Masonry Walls

Similar to the out-of-plane collapse, leaning masonry walls were frequently encountered. This type of damage was usually caused by the lack of anchorage of the wall panels to the roof framing, especially when the roof was timber frame and the wall was masonry. There were also confined masonry walls that were found to be leaning, likely due to poor construction quality and/or excessive spans of the confining tie beams.

7. Lessons Learned

As discussed in Section 3.3, in Indonesia there is the trend of homeowners to choose heavy materials (such as concrete and masonry) over lightweight ones (such as timber). Heavy materials require more attention to detailing (which in turn requires professional engineers' involvement) to ensure the stability of the house. However, there are two common scenarios of this shifting trend where attention to detail appears to be lacking. The first scenario is when homeowners do not have enough resources to convert their houses completely, so that parts of the timber framing remain as part of the structure along with the new concrete and/or masonry (usually the wood post remains and only the walls are converted into clay brick or concrete block). The second scenario is when the homeowners have enough resources to build or convert their house completely into heavy material (e.g. reinforced concrete frame with masonry infill or confined masonry), but are not well-informed about the minimum earthquake-resistant building standards. Both types of houses can be unsafe in an earthquake and were proven to harm and cause casualties to thousands of people in the last three years alone.

The Indonesia government is facing many challenges in improving the quality of houses in Indonesia. The richness of culture in Indonesia that significantly contributes to the diversity of house typologies demands the government to provide standards that cover a wide range of housing typologies. However, the currently available codes and standards only cover a few of them. The result of studies of the most recent earthquakes in Indonesia reveals the need to constantly update the available housing construction standards. However, the long and complex process of updating the standards by different government bodies at different levels has caused many standards related to housing construction to not be updated. This is exacerbated by the decentralized system in Indonesia, where each region is responsible in updating the local standards based on the National Laws and implementing them. With a total of more than 440 jurisdictions in Indonesia, it was reported that only less than 50% of them that have developed local government building regulations [23]. In addition to that, without a common standard there is a high chance of different interpretations of the building code by different building officials. Build Change conducted a review of school building guidelines used in different areas in Indonesia, which found that there were significant differences in code interpretations, and also misinterpretations of building code that reduced the quality and safety of buildings. Adapting a centralized system so that only one body that is responsible to develop building codes, construction manuals, and guidelines for all areas in Indonesia is strongly recommended. Finally, with up to 17 million new houses constructed ever year, the Indonesia government is also challenged with enforcing the laws and standards because the number of houses to be monitored significantly outnumber the staff that is available to perform this task.

Many positive efforts have been made by the government to tackle the aforementioned challenges and to increase the community awareness of earthquake risk and earthquake-resistant house standards. However, with the immense number of existing buildings that need to be improved and new buildings that need oversight and quality verification, active participation from private sector firms, non-government organizations, builders and homeowners themselves are required in order to support these efforts and accelerate the process towards standardizing high quality housing construction in Indonesia. A two-way approach should be taken to improve the quality of common materials used for residential buildings. Training for owners and laborers of material production sites are needed to improve the quality of their products, along with constant technical support such as periodical visits and supervision by government officials or other parties. At the same time, an active campaign to improve the awareness of the importance of using standardized materials can also be done so that the number of homeowners who purchase substandard materials decreases, which likely will encourage the home-based production owners to improve the quality of their products.

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