Build Change, AARGI, and EERI
Earthquake Reconnaissance Report:
M6.5 Pidie Jaya Earthquake, Aceh, Indonesia on December 7, 2016

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1 REPORT OVERVIEW

A M6.5 earthquake struck Pidie Jaya Regency of Aceh Province in Indonesia on December 7, 2016 at 5:03 AM. An information release from Badan Nasional Penanggulangan Bencana (BNPB), the Indonesian National Agency for Disaster Management, estimated the total economic loss from this earthquake at IDR 2.94 trillion. The provincial government declared a state of emergency for 14 days following the quake, which caused 104 deaths, injured hundreds more, and displaced about 50 percent of the district's population. BNPB reported damage to 19,130 residential homes, 306 schools, and more than 500 commercial and public buildings, religious establishments, and healthcare facilities. Infrastructure damage to roads, bridges, transformers and electrical poles also resulted in disruption to services throughout the area (BNPB 2016).[1]

Following the earthquake, the Earthquake Engineering Research Institute (EERI), Build Change, and the Indonesian Earthquake Engineering Association / Asosiasi Ahli Rekayasa Gempa Indonesia (AARGI) jointly developed this report to present the results of technical investigations, surveys, and literature reviews on the earthquake and its impact to the infrastructures and communities. EERI members Edwin Lim and Hartanto Wibowo led the report development effort.

Two separate teams from Build Change and AARGI were deployed to the affected areas:

1. **Build Change**

Team members: *Mediatrich Triani Novianingsih, Danny Rosa, and Elwahyudi*
Visited area: *Bireuen, Pidie Jaya, and Pidie districts*
Date of surveys: *December 19-23, 2016*
Focus: *Schools and housing* (more information at http://www.buildchange.org/blog/)

2. **AARGI**

Team member: *Muhammad Riyansyah*
Visited area: *Pidie Jaya district*
Date of surveys: *December 9-12, 2016*
Focus: *Government offices, schools, and religious establishments*

This report presents an overview on the seismic and geotechnical aspects of the earthquake, followed by a detailed technical discussion on the impact of the earthquake on common building typologies in the affected areas. Afterward, a discussion on the social and economic impacts is presented along with the emergency response actions. This report is concluded with a discussion on lessons learned from this earthquake.

2 SEISMICITY AND GEOTECHNICAL EFFECTS

The epicenter of the M6.5 Pidie Jaya Earthquake was located at 5.283°N 96.168°E, 98.5 km southeast of Banda Aceh, the capital of Aceh Province, with a hypocenter 13 km below the surface. Pidie Jaya Regency has a population of 140,000 in an area of approximately 1,100 km^2. The main shock was felt for 10-15 seconds. Following the main shock, the Indonesian Agency for Meteorological, Climatological, and Geophysics reported several aftershocks.

Unfortunately, the seismometer located near the source of the earthquake did not provide any reliable data, due to some technical issues. Another seismometer located at a remote distance from the source recorded 23 gal of PGA that does not seem to properly describe the impact of the earthquake to the affected area. The fault line was predicted to stretch from

North to South of the area as shown in Figure 1. The impacted area was within the radius of 35 km from the fault line based on the observation of the damaged infrastructures conducted by AARGI (Figure 2).

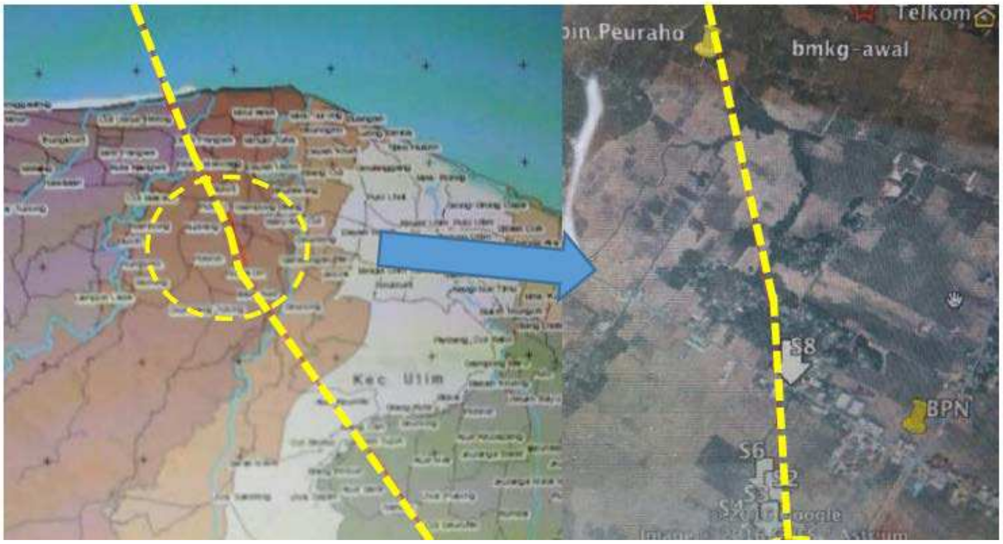

Figure 1. Prediction of the location of the fault line (source: Muhammad Riyansyah, AARGI).

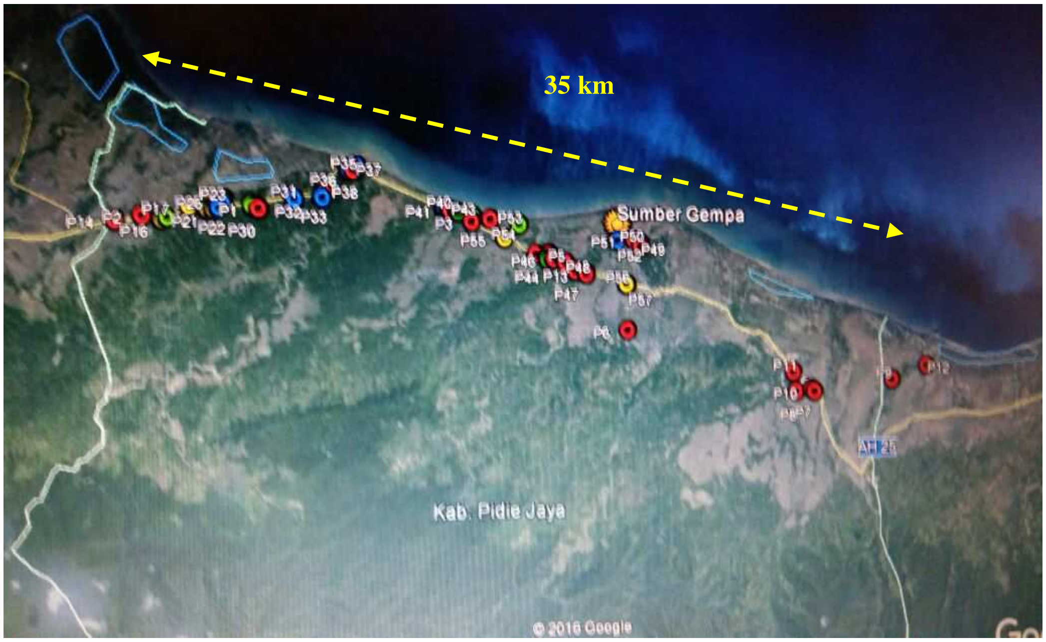

Figure 2. Area in Indonesia affected by the earthquake (source: Muhammad Riyansyah, AARGI).

3 BUILDINGS, LIFELINES, AND INFRASTRUCTURE

3.1 Unreinforced Masonry Buildings

While masonry buildings are popular in both cities and villages in Indonesia, very few are completely unreinforced buildings – instead it was common to observe partially confined or confined masonry buildings as described in Section 3.2 below. The unconfined masonry portions of houses, such as kitchens, usually fell outside of the primary footprint. In most cases, these unreinforced masonry portions of the buildings collapsed in the earthquake.

3.2 Confined Masonry Buildings

Confined masonry was one of the main building typologies encountered in the areas, especially for low-rise residential and single-story school buildings. These are typically non-engineered buildings. The level of confinement varied between the houses and schools observed. It was common to see reinforced concrete columns, plinth, and ring beams, but the sides of openings, sill, or lintel beams were made of unreinforced concrete. The foundations were typically built of stone masonry with a plinth beam at the level between the foundation and wall. Typically, the walls were only one brick wide, with the brick oriented along the narrow dimension parallel with the wall (approximately 10 cm wide) and were up to 4 m high. In many cases for both houses and schools, the walls spanned 4 m to 5 m or more between perpendicular walls. The confined masonry houses observed used wood trusses for the roof framing covered by metal sheets. Only several cases observed used ceramic tiles as the roof covering or shingles. For schools, the roof framing composed of either timber trusses or light-gage metal trusses, with metal sheet roofing. In both houses and schools, it was common to find masonry gable walls, and only a few observed were built using light materials, like metal sheets or timber. Some gable walls had openings for additional ventilation.

Confined or partially confined masonry houses and schools suffered a range of structural damage from minimal to collapse (Figure 3 and Figure 4). One of the more commonly observed damage for houses was out-of-plane wall failure due to failure of very tall or very long and slender walls (3.5-4 m high, 10 cm thick, with h/t ratio of 35 to 40) or failure of the upper ring beams which were not sized or reinforced with enough capacity to span the longer distances present (either along the span or at the joint). In some cases, walls supporting the roof dead load appeared to perform better than walls which were more lightly loaded axially (Figure 5). One particular out-of-plane failure that was common in both houses and schools was collapse of the masonry gable wall. While many gable walls had vertical reinforced concrete elements extending up through them, this appeared to be ineffective in preventing collapse (Figure 6) since the vertical concrete elements were small and minimally reinforced, thus providing insignificant lateral stiffness to the panel.

(a) (b)

Figure 3. (a) Confined masonry house with minimal damage and (b) with severe damage (photos: Build Change).

(a) (b)

Figure 4. (a) Confined masonry school with minimal damage and (b) collapsed school (already cleared) (photos: Build Change).

(a) (b)

Figure 5. Confined masonry houses where walls supporting roof trusses performed better than other walls which suffered out-of-plane failure: (a) ring beam failure and (b) wall panel failure (photos: Build Change).

(a) (b)

Figure 6. Collapsed masonry gable wall in (a) a school building and (b) a residence (photos: Build Change).

The practice of confined masonry construction is also common on low-rise shop-houses (typically 2-3 stories). This type of building is typically used for commercial purpose on the first story and residential purpose on the upper stories. Similar to the typical damage observed in other past earthquakes, the failure was attributed to soft-story mechanism of the first floor where wide opening exists as the main entrance for the commercial activity. Figure 7 shows the typical shop-houses in the affected area. BNPB reported that 78 shop-houses (BNPB, 2016) were damaged due to the earthquake. This number is relatively small compared to the number of damaged residential houses of 19,000 (BNPB, 2016). In the survey, the AARGI team observed that additional floor constructed above the existing building might have caused the damage because there were similar unmodified shop-houses located near the damaged ones that were unaffected by the earthquake. This additional floor changed the dynamic characteristics of the structures, and there was a great possibility that the existing structural components were not designed to carry that additional load (Figure 8).

Figure 7. Typical shop-house in the affected area (photo: Muhammad Riyansyah).

Figure 8. Damages on the some shop-houses that have been modified from existing construction (photo: Muhammad Riyansyah).

3.3 Reinforced Concrete Buildings

Reinforced concrete building with masonry infill are typically used for low-rise buildings. In most practices, the masonry units are jointed using cement plaster with limited or no connection to the adjacent structural components. This building type is commonly used as office, education, and commercial establishments. Unlike the confined or unconfined masonry structures, this building type is usually designed by engineers and approved by the local department of public work before it can be constructed. The process typically involved a more sophisticated construction method and supervision than the construction process for residential housing. Past surveys on this type of structure indicated major damages on the infill wall.

AARGI surveyed 8 government offices, a low-rise school building, and a mosque that were constructed using reinforced concrete and masonry infill. Most damage was characterized by failure of non-structural components, such as damage on the masonry infills, gable walls, and ceilings (Figure 9 and Figure 10). The damage on the ceilings may be caused by fallen debris from the gable wall or poor detailing of the ceiling framing system.

(a) (b)

Figure 9.Damage on infill and gable wall of reinforced concrete building (photos: Muhammad Riyansyah).

(a)

(b)

Figure 10. Damage to the same ceiling in both (a) and (b) (photos: Muhammad Riyansyah).

Of the investigated buildings, significant structural damages were observed in three buildings. Causes of the damages were determined to be:

a. Poorly constructed beam-column joints

This failure was observed in a government office. The failure was characterized by spalling and bursting of construction joints where the rebar was spliced, near the beam-column connections (Figure 11). Poor design and detailing may contribute to this failure, considering that the location of the construction joint is close to a highly stressed region of the building. Poor construction quality, indicated by debris in the connection, may also worsen the quality of the joint.

Figure 11. Construction joint failure (photo: Muhammad Riyansyah)

b. Shear and flexural cracks on beams

This failure was observed in the same government building in which the construction joint failed. Shear and flexural cracks (Figure 12) were observed on some beams located at the basement of that building. However, shear cracks were observed more often during the survey. Poor detailing may be the main factor that caused these cracks.

(a) (b)

Figure 12. Shear and flexural cracks on a beam (photos: Muhammad Riyansyah).

c. Soft-story mechanism

Soft-story mechanism was observed on a four-story college building and a mosque. The first story of the school building collapsed as shown in Figure 13. Based on the observation, poor structural configuration and reinforcement detailing contributed to this failure. It is also important to note that the rebar used in most collapsed buildings was undeformed rebar, both as longitudinal and transverse reinforcements.

(a)

(b)

Figure 13. Soft story collapse on a low-rise reinforced concrete building: (a) overview of collapse, (b) mangled rebar due to collapse (photos: Puskim Kemenpupera).

On the other hand, significant structural damage was observed on slender columns of a mosque (Figure 14). At the time of the earthquake, the mosque was still under construction with remaining nonstructural and decoration work. The columns on the second floor were approximately 6 m tall and they had to support a large mass of the roof and the dome. More detailed investigations showed that the slender column was poorly detailed with inadequate longitudinal reinforcement, largely spaced transverse reinforcement, and the use of undeformed rebar (Figure 15).

(a)

(b)

Figure 14. Soft story effect on a mosque structure: (a) overview of mosque with scale, (b) damage to column (photos: Puskim Kemenpupera).

(a) (b)

Figure 15. Poor detailing on the slender columns (a) and (b) (photos: Puskim Kemenpupera).

3.4 Wood Framed Buildings

Several different types of wood frame buildings were observed. Wood-framed houses were either raised up on posts above grade (from 30 cm to 2.5 m), or were built directly on grade (Figure 16). In houses built directly on grade, a portion of the wall below the windowsill level was typically constructed using masonry or a cement-sand mortar (called skirt wall). Timber wall and roof framing were then subsequently placed above this skirt wall. One timber school building was observed following this style of construction.

(a) (b)

Figure 16. Timber frame houses: (a) raised, (b) on-grade with skirt wall (photos: Build Change).

For raised timber houses, the lower level posts were typically unbraced and poorly connected to the foundation, in some cases simply resting on top of stone bases. This lead to the observed racking of the lower level, sliding the posts off the bases or unseating of the posts, and in some cases, fracture of the posts due to large drift in the earthquake (Figure 17).

(a) (b) (c)

Figure 17. Damage to raised timber frame houses: (a) racking/drift of posts, (b) posts shifted off base, and (c) fractured posts (photos: Build Change).

Both raised and on-grade timber buildings typically used horizontal planks as the wall covering. Although horizontal sheathing can provide lateral strength to walls, in many cases the planks did not seem to be sufficiently nailed to the wall framing, or were placed with large gaps between them, reducing the effectiveness of the planks to contribute to lateral strength and stiffness. In some of these cases, racking of the walls and permanent story drift were observed (Figure 18).

Figure 18. Racking in timber framed house (photo: Build Change).

Damage specific to the on-grade timber houses with masonry skirt walls consisted of cracking or partial collapse of the skirt wall – typically due to poor construction of the wall and low quality materials, inadequate connection to the timber posts, and/or a lack of top beam on the skirt wall (Figure 19).

Figure 19. On-grade timber house with partially collapsed skirt wall (covered by tarp) (photo: Build Change).

It should be noted that although some of the observed timber houses suffered damage, almost all of them exhibited life-safety or collapse prevention performance, and only a few had collapsed or partially collapsed.

3.5 Lifelines and Infrastructures

The earthquake interrupted the electrical distribution to over 40,000 customers. It was recorded that 84 transformers, electrical cable lines, and more than 100 low-voltage and medium-voltage electrical poles (Figure 20) were damaged during the earthquake. The damage was concentrated at electrical facilities located in Samalanga, Meureudu, and Beureunun regions. The power distributed in the Samalanga region is 500 kW, and the power distributed in Meureudu and Beureunun is around 6 MW (Jati 2016).[2] Some retrofit and reconstruction measures, such as reconnecting the broken electrical cable and reconstruction of low-voltage pole, were conducted by the state electricity company (Perusahaan Listrik Negara, or PLN) to recover the interruption. The electrical distribution was 50% recovered within two days after the earthquake, and it was completely recovered within four days after the earthquake (PLN 2017).[3]

(a) (b)

Figure 20. (a) Damage on electrical poles during the Aceh earthquake, (b) recovery efforts conducted by the State Electricity Company (photos: Augustinus 2016).[4]

The disruption on the electrical distribution also slightly interrupted the telecommunication services in the region after the earthquake, although the telecommunication facilities were relatively undamaged during the earthquake. This interruption was overcome by providing a number of diesel generators for the telecommunication facilities until the electricity was fully recovered (Agung 2016).[5]

Figure 21 shows the road network in the affected area. All the primary roads from Banda Aceh – Aceh Besar – Pidie – Pidie Jaya were functional although localized cracks were spotted at some locations between Pidie and Pidie Jaya (AHA Centre 2016).[6]

Figure 22 shows the cracks on some roads in the Pidie Jaya region. This earthquake also caused damage on some bridges in Pidie Jaya, Pidie and Bireuen. Efforts were carried out to repair and reconstruct the damaged road and bridges. In addition, the Aceh International Airport located around 100 km to the west of the epicenter was unaffected by the earthquake. [7]

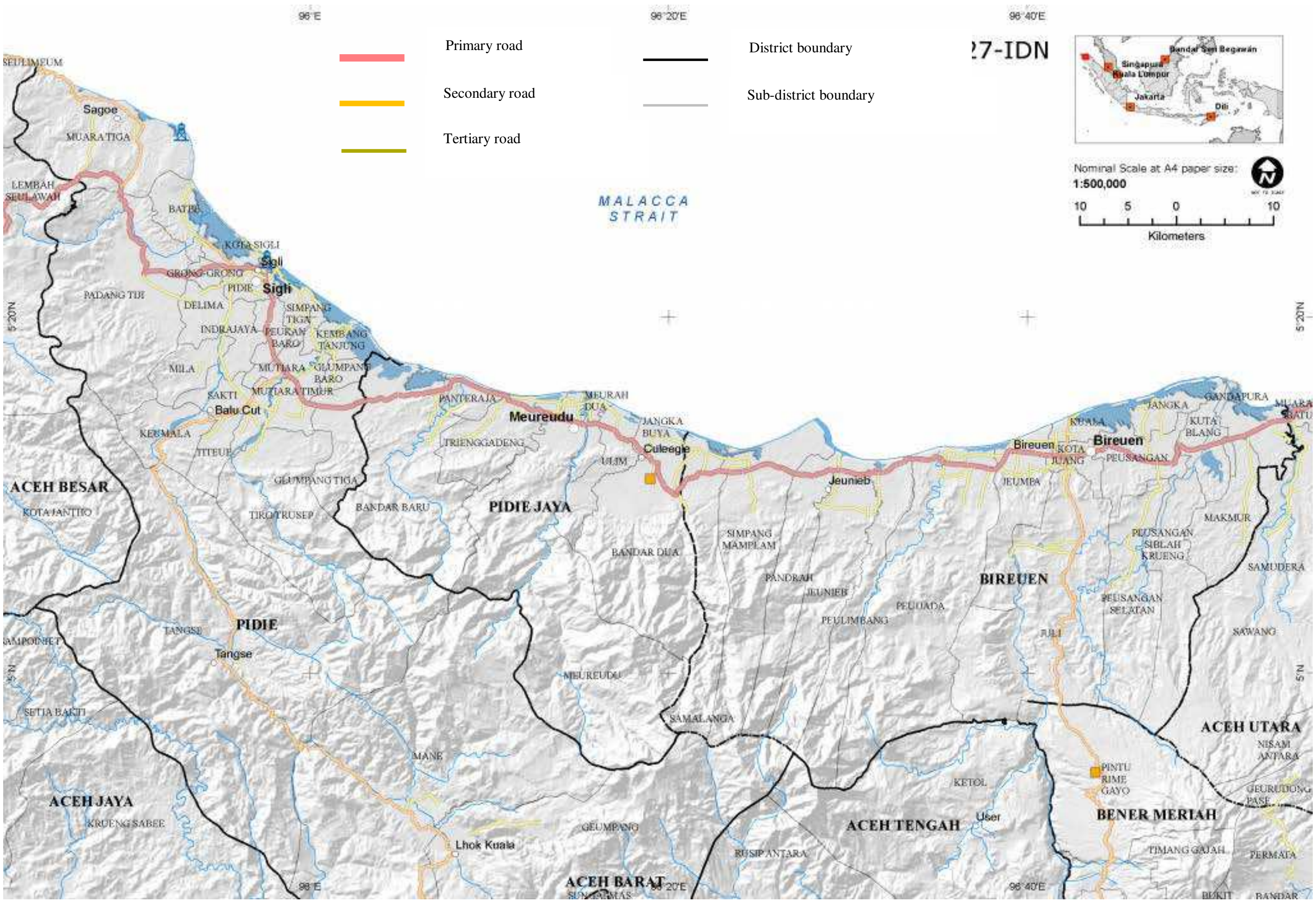

Figure 21. Road network in the affected region (figure: World Food Programme 2016).[8]

(a)

(b)

Figure 22. *Cracks on the road in the Pidie Jaya region (photos: (a) Siswoyo 2016[9], (b) Antara News 2016).[10]*

4 COMMUNITY, SOCIAL, AND ECONOMIC IMPACTS

4.1 Housing

Build Change team visited 3 districts that were affected by the earthquake: Bireuen, Pidie Jaya, and Pidie. Pidie Jaya was the district that was most significantly impacted by the earthquake. Over 6,700 houses were damaged in Pidie Jaya District. According to BNPB, there were 2,202 houses that were severely damaged and 4,654 houses that were moderately and slightly damaged (Firman 2017).[11] Confined masonry was the main structural typology for the houses encountered during the visit in the villages. It was the structural system of approximately 80% of houses in the areas observed, with the other typologies for houses being the timber frame and timber-frame with masonry skirt.

Overall, masonry buildings (unreinforced, as well as partially or fully confined) were extremely affected by the earthquake. In Kuta Pangwa village, one of the most affected villages in Pidie Jaya District, around 85% of the houses were confined masonry buildings. All of those visited structures suffered moderate to severe damage, with 75% suffering moderate to severe damage on the primary structural members and walls. This type of damage varied from cracks in the masonry to total collapse of the structure.

Almost all houses were non-engineered and built improperly, with little to no input from qualified engineers or construction professionals. The concrete quality is generally low, using large round aggregates and low cement content, often combined with minimal concrete cover. Although some villages had access to aggregates from local sources, good quality bricks as well as cement and other manufactured building products were difficult to be found locally. Some villages even had local brick kilns, but homeowners still preferred the quality of bricks sourced from other cities due to the better quality.

The earthquake struck early in the morning when most people were sleeping or preparing for the morning prayer. Following the earthquake, many people were in panic and ran out of their house. Hundreds of people also mobilized to higher ground in fear of a tsunami similar to the event that affected another part of the Aceh province in 2004. After the earthquake, many people in some communities chose to stay in temporary shelters and tents although their houses were undamaged by the earthquake. For those whose houses were damaged by the earthquake, many of the homeowners in the villages did not know when they would reconstruct their houses, as most were waiting to receive potential grants from the government for reconstruction and did not have their own resources to rebuild. Some homeowners had moved to other family members' houses in the meantime, and others had temporarily boarded up or covered collapsed walls in their house to try to collect and secure their belongings.

For the 2,202 houses that were severely damaged, the Pidie Jaya District Government has allocated funds to provide a 24 m^2 temporary housing for the families while waiting for another subsidy from the national government to rebuild permanent houses. Some of those temporary houses currently had been completed and the families had started to occupy them, while some others were still living in the tents next to their houses at the time this survey was conducted. According to BNPB, the Indonesian Government would provide 85 million Rupiah (approximately $6,300 USD) for each family to subsidize the construction of their new houses (BNPB, pers. comm.). The design would be provided by the government with a footprint size of 36 m^2.

4.2 Schools

Based on BNPB data and the latest verification by the Ministry of Public Works, 24 schools were severely damaged and 68 schools were moderately and slightly damaged by the earthquake. Almost all of the school buildings observed during the visit were of confined masonry construction. Among the 11 schools that were visited, one school classroom building was timber-frame with masonry skirt. The buildings were typically single story, especially for primary school, but there were several schools that had two stories and constructed of reinforced concrete frames with infill walls. In these buildings, the floor system was usually a reinforced concrete slab.

There was relatively little variation in type, configuration, and construction quality of the observed schools. All observed buildings have many windows along the front and back of the building. Although the amount of damage varied, there were commonalities observed, such as the collapse of tall and thin unreinforced masonry walls, the collapse of gable end walls, wall cracks at the openings, cracking through wall piers and at longitudinal cracking at the wall-column interface, damage to beams at column faces, and cracks on the floor due to poor compaction of backfill (Figure 23). The quality of concrete was generally low due to the use of poor quality materials, such as round gravel (Figure 24). Inadequate concrete cover was also observed, exposing corroded reinforcing bars and spalled. It was observed that undeformed rebars were used for both main longitudinal and transverse reinforcement. The use of deformed bars was not observed in the schools visited. Damage to the dropped ceiling systems was also common, where ceiling panels and framing fell into the classroom, possibly due to insufficient support and bracing of the system to the building structure (Figure 25).

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

Figure 23. Damages at School Buildings: (a) gable wall collapse, (b) failure of wall pier and column, (c) failure of beam to column connection, (d) cracking in the floor slab (photos: Build Change).

Figure 24. Low quality concrete in school column (photo: Build Change).

(a) (b)

Figure 25. Ceiling damage in classroom buildings (photos: Build Change).

Collapsed school buildings were almost completely cleared or demolished by the time of the visit. The school reconstruction and renovation will be overseen by the Ministry of Public Works (PU). PU built temporary building structures (Figure 26) for the 24 schools that were badly damaged, targeted to be completed by end of February. The budget and planning for reconstruction of permanent schools were still under confirmation and waiting for approval. Once started, the expected time frame for reconstruction is 6-12 months.

Figure 26. Construction of temporary school (photo: Puskim Kemenpupera).[12]

This earthquake also caused trauma to some students in the impacted area. Trauma specialists from some institutions (e.g. Indonesia Red Cross Society, NGOs) were sent to the area to provide assistance and therapy sessions. One of the methods that was used by these volunteers was folklores storytelling to help the students overcome their traumatized earthquake experience (Enggal, 2016).[13]

4.3 Religious Establishments

Mosque is an essential religious facility for most of the Aceh residences whom are majority Moslem (Muslim). It is used not only as the place of worship for the community but also religious education and social activities. The earthquake damaged at least 60 mosques (BNPB, 2016) in the Pidie Jaya, Bireuen and Pidie regencies. Typical damage was caused by soft-story mechanism (Figure 27) since the mosques carry heavy dome/roof structures and tend to have slender columns.

Figure 27. Damage to mosques: a) Damaged mosque at Meuko Kuthang, b) *Damage of Mosque Jami Nur Abdullah at Lueng Putu, c) Damage of Mosque Baitul Muttaqin (photos: Antara News, 2016).*[14,15,16]

Reconstruction of the mosques was one of the main priorities for the government. Figure 28 shows the community gathered beside the collapsed central mosque to conduct their routine Friday prayer.

Figure 28. Friday prayer near the central mosque at Pidie Jaya following the earthquake (photo: Antara News, 2016).[17]

4.4 Government Offices

The AARGI team visited eight government offices that are located adjacent to one another (Figure 29). The building typology of the government offices is reinforced concrete frame with masonry infill. Most of the buildings performed well during the earthquake, with notable non-structural damage to the infill wall, ceiling, and roofing material. Some sections in the buildings were advised to be closed for access until further investigations were conducted to clean the falling hazard from the damaged nonstructural components. One building experienced structural damage to the columns and beams at the basement floor. This building was labeled unsafe, and further investigations, as well as retrofit design and construction, were later conducted.

Figure 29. Location of surveyed government offices.

5 EMERGENCY RESPONSE

The emergency response (Figure 30) of this earthquake was led by the Indonesian government through BNPB assisted by Indonesian National Military, Police, National Search and Rescue Agency (BASARNAS), Indonesian Red Cross Society (PMI), volunteers, as well as local and international NGOs. The Indonesian government announced that the response operation to the disaster was within the capability of the country (AHA Center, 2016a)[18]. Some neighboring countries or regions (e.g. Singapore, Malaysia, Australia, and ASEAN) and International NGOs also offered humanitarian assistance to aid the emergency response. In total, over 3,000 persons (AHA Center, 2016b)[19] were mobilized for this response. The command center for the emergency response was located at the Pidie Jaya mayor's office (Figure 31), which suffered from relatively minor non-structural component damages. After the disaster, the Governor of Aceh set disaster emergency status to Emergency Response Disaster for 14 days for the following districts: Pidie Jaya, Pidie and Bireuen (Nugroho, 2016).[20] This situation was different than the response to the 2004 Aceh earthquake and tsunami in which militaries of multiple nations, UN agencies, internationals NGOs, and private corporations played important roles. This difference is understandable, considering the scale of the 2004 Aceh earthquake and tsunami was much larger and affected multiple countries (Piccuci, 2017).[21]

Figure 30. Search and rescue response from Indonesian governments, multiple institutions and volunteers (photos: BNPB, AHA Centre 2016).

Figure 31. The emergency response command post located at the Pidie Jaya mayor's office (photo: BNPB, AHA Centre, 2016).

Medical personnel from some nearby hospitals and clinics were sent to the impacted area. The patients at Pidie Jaya Hospital were evacuated to the adjacent health facilities considering damage on the hospital after the earthquake. Some NGOs sent emergency specialists and physical therapists to the affected areas. Emergency health units with standardized medicine, paramedics, and equipment were deployed to the affected areas. In addition, psychosocial support specialists were provided to help the traumatized victims. Initial observation indicated that some survivors were traumatized by the earthquake and hesitated to get back to indoor areas in fear of the aftershocks. Furthermore, The Ministry of Social Affairs of Indonesia announced that financial assistance would be provided to the family of the deceased and injured victims.

Thousands of emergency tents, hygiene and family kits, tarpaulins, and blankets were provided by the Indonesian Red Cross Society (PMI) and other supporting agencies. A number of water tanks, knockdown toilets, and water hydrants were also provided by PMI, Ministry of Public Works, and other supporting agencies in the impacted areas (AHA Center, 2016). In general, the Indonesian government was more prepared for the emergency response despite some challenges regarding the overlapping assistance, considering that more than 200 organizations were involved in the emergency response. This challenge continued as the impacted communities moved to the reconstruction stage.

6 LESSONS LEARNED AND CONCLUSIONS

For improved housing performance in earthquakes, following pre-engineered regulations for design or engaging a professional would contribute significantly compared to the current common practice of using non-engineered housing construction. The Ministry of Public Works and Housing has several documents which include requirements for pre-engineered simple housing which can be referenced during reconstruction, such as *Technical Requirements for the Construction of Simple, Healthy Housing* (MPWH 2002) and *Technical Guidelines for Earthquake Resistant Houses and buildings, Including Recommendations for Damage Repair* (MPWH 2006).

For non-engineered informal housing, timber structures overall performed better than masonry ones. Reconstruction efforts encouraging homeowners to properly construct timber frame or timber frame with masonry skirt wall houses would likely be more successful at preventing injuries and deaths from future earthquakes than supporting increased construction of masonry structures. Needed improvements to timber frame houses include bracing of the post level for raised houses, connection of posts to proper foundations, adding frame bracing, proper sheathing, or other materials, like ferro-cement, to provide lateral resistance in walls, and ensuring skirt walls are built adequately with good materials and well connected to the timber frame.

If houses are reconstructed using masonry, they should follow design and construction recommendations for confined masonry and would require significant improvements to the configuration, connections and construction quality to ensure satisfactory performance in future earthquakes. The Indonesia Ministry of Public Works has previously approved resources for the construction of houses in confined masonry, such as the technical guidelines noted above and other visual media; an example is shown in Figure 32.

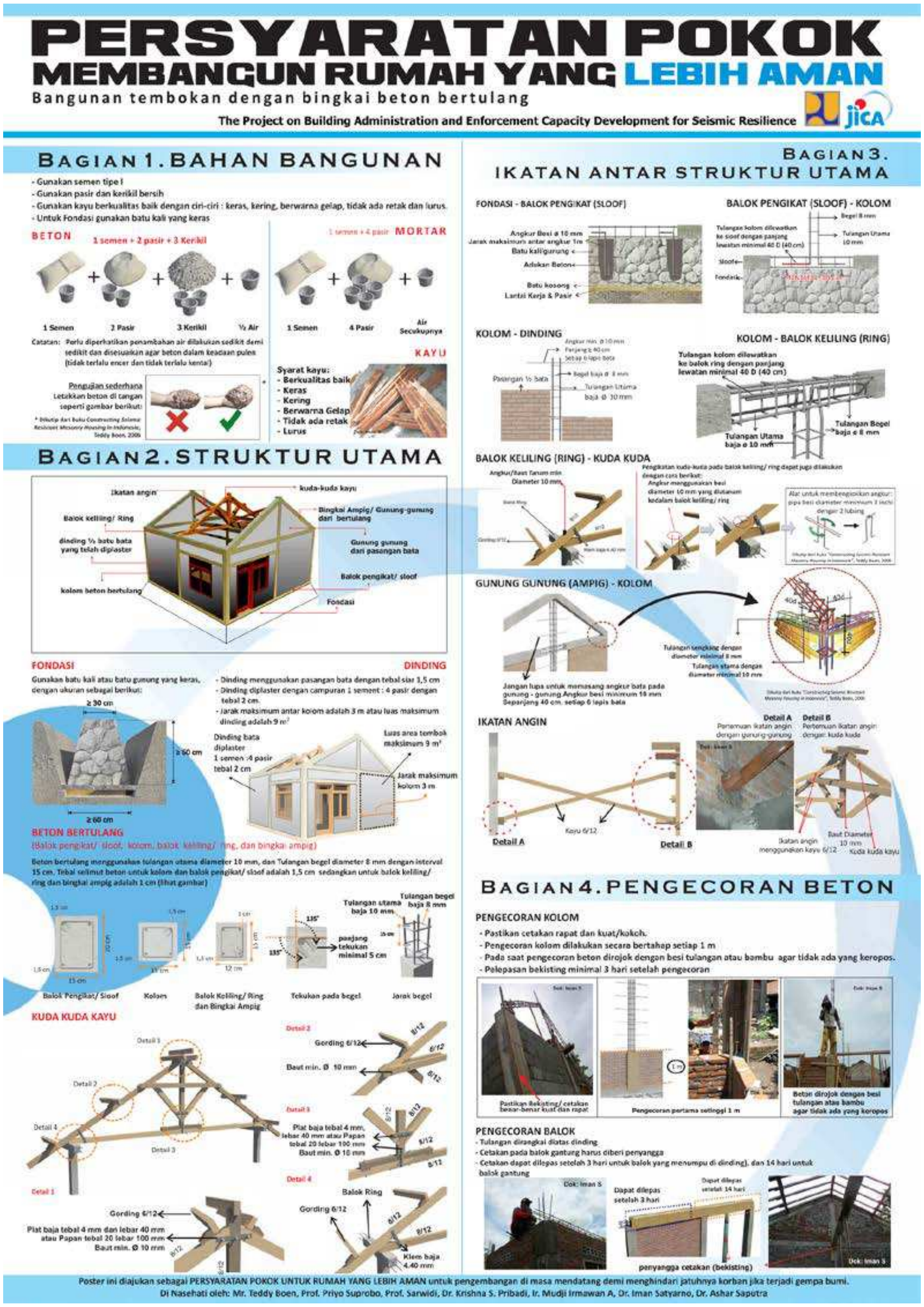

Figure 32. Principal Requirements for a Safer House (source: JICA and Ministry of Public Works and Housing, Indonesia).[22]

Considering the damages observed, the following recommendations can be made for improvements to confined masonry housing:

Configuration:

- Use a regular shape in plan, such as square or rectangle and only build one-story high
- Use a light weight gable or a hipped roof instead of a masonry gable
- Use smaller wall openings or confine openings
- Reduce the weight of entrance canopies and verandas, and use better connections
- Limit the size of unreinforced masonry wall panels between confining elements, such as 3m high walls maximum and cross walls at 4m distance maximum.

Connections:

- Plinth beams should be anchored to the foundation with reinforcing.
- The longitudinal reinforcement in confining columns and beam should be extended and lapped at joints for effective connections.
- Masonry panels should be toothed or connected to columns with horizontal dowels at every 6-7 courses.

Construction Quality:

- Use high-quality materials, clean sand, deformed bars, and strong bricks
- Mix concrete and mortar with enough cement (1:2:3 concrete, 1:3 mortar) and not too much water
- Use concrete spacers to ensure adequate concrete cover on reinforcement.
- Masonry should be of good quality: staggered joints approximately 1.5cm thick and soak bricks in water before placement.

A more detailed and visual description of recommended practices for improving the performance of timber and masonry houses in Indonesia can be found in the Build Change booklet, "How to Build Strong and Sturdy Houses."

Damage can be reduced and collapse can be prevented in the common school building typologies observed with some simple improvements to the observed structures. Construction quality must be improved, such as by providing adequate rebar cover and improved connections between masonry and reinforced concrete elements (toothing or bed joint dowels). Better quality materials, such as concrete, deformed reinforcing bars, and stronger bricks are needed. In addition, adequate detailing of the reinforcement in beam and column joints is required, so that proper bar hooks and lap splices are provided.

Configuration changes are also required:

- Gable walls should be constructed of light materials.
- Although it is important for classrooms to have adequate windows and ventilation, it is also important that lateral-resisting elements, such as confined masonry shear wall panels be provided along the longitudinal sides of the classroom buildings.
- Long walls in both directions should be adequately braced and stiffened at the top by an engineered ring beam or horizontal diaphragm, such as wood sheathing or horizontal bracing. Frequent columns along the length of the walls, or plaster and wire mesh on each side and connected through the wall, can help brace walls out-of-plane over their height.
- Masonry panels above windows and doors should be eliminated and replaced with light-weight materials or louvers for ventilation, or should be supported by adequate reinforced concrete lintel beams.
- Dropped ceilings should be supported and braced sufficiently to the building structure.

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