



## **EARTHQUAKE RECONNAISSANCE REPORT 4 – 7 September 2018, LOMBOK - INDONESIA**

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## EXECUTIVE SUMMARY

A  $M_w$  6.4 earthquake struck Lombok Island in Nusa Tenggara Barat Province, Indonesia, on July 29, 2018, at 05:47 local time. It was followed with  $M_w$  7.0 a week later and  $M_w$  6.9 three weeks later. The earthquakes caused 564 deaths and damage to 149,715 houses, 1,235 schools, and 3,000 other buildings. The casualties were mostly due to building damage and collapse.

Following the events, Build Change deployed a small team to conduct a reconnaissance visit to the impacted areas from September 4<sup>th</sup> to 7<sup>th</sup>. The visit was focused on houses and school buildings located at the two majorly affected districts, Lombok Timur and Lombok Utara. The team conducted rapid surveys of 4 schools and 41 houses, and interviewed 10 homeowners, as well as builders, and village leaders. Surveys of local material stores and block producers were also made to understand the material availability and its quality throughout the area.

Four types of houses were identified: unreinforced masonry (60%), confined masonry (19%), timber frames with masonry skirts/infill (14%) and timber frames with lightweight wall panels (7%). All of the school buildings evaluated were (and were estimated as) reinforced concrete frame with masonry infill and/or confined masonry.

Generally, unreinforced masonry buildings were the most affected by the earthquakes, especially those with concrete blocks. Timber houses overall performed better than masonry ones. These observations are consistent with observations of housing performance made previously by Build Change following earthquakes in 2016, 2013, 2009, 2007, 2006, and 2004 in other areas of Indonesia. Historically, housing failures have accounted for a significant portion of the damage and casualties for earthquakes in Indonesia.

The most common damages encountered were: the cracks or collapse of foundations, the cracks of masonry (especially around openings, wall corners and mid-span), collapse of masonry walls and masonry gables, cracks/fracture/splitting/bending of reinforced concrete frame/ties, the shifting/misplacements of structural and nonstructural elements and falling roof covering. Regardless the type of the buildings, the connections between building components and/or confining elements were inadequate, resulting in the prevalence of separation between structural elements and/or non-structural elements. Out-of-plane collapse of masonry wall and/or gables was evident to have a disastrous impact on other building elements and surrounding buildings. From all buildings observed, none of them fully met the minimum requirements stipulated in the applicable standards.

This report presents an overview of each construction system encountered, observed damages to each system, a comparison to the existing guidelines and recommendations. The rapid building evaluations, the construction quality observed, the materials used, and the interviews with homeowners, builders, village leaders, material suppliers and producers reveal various quality

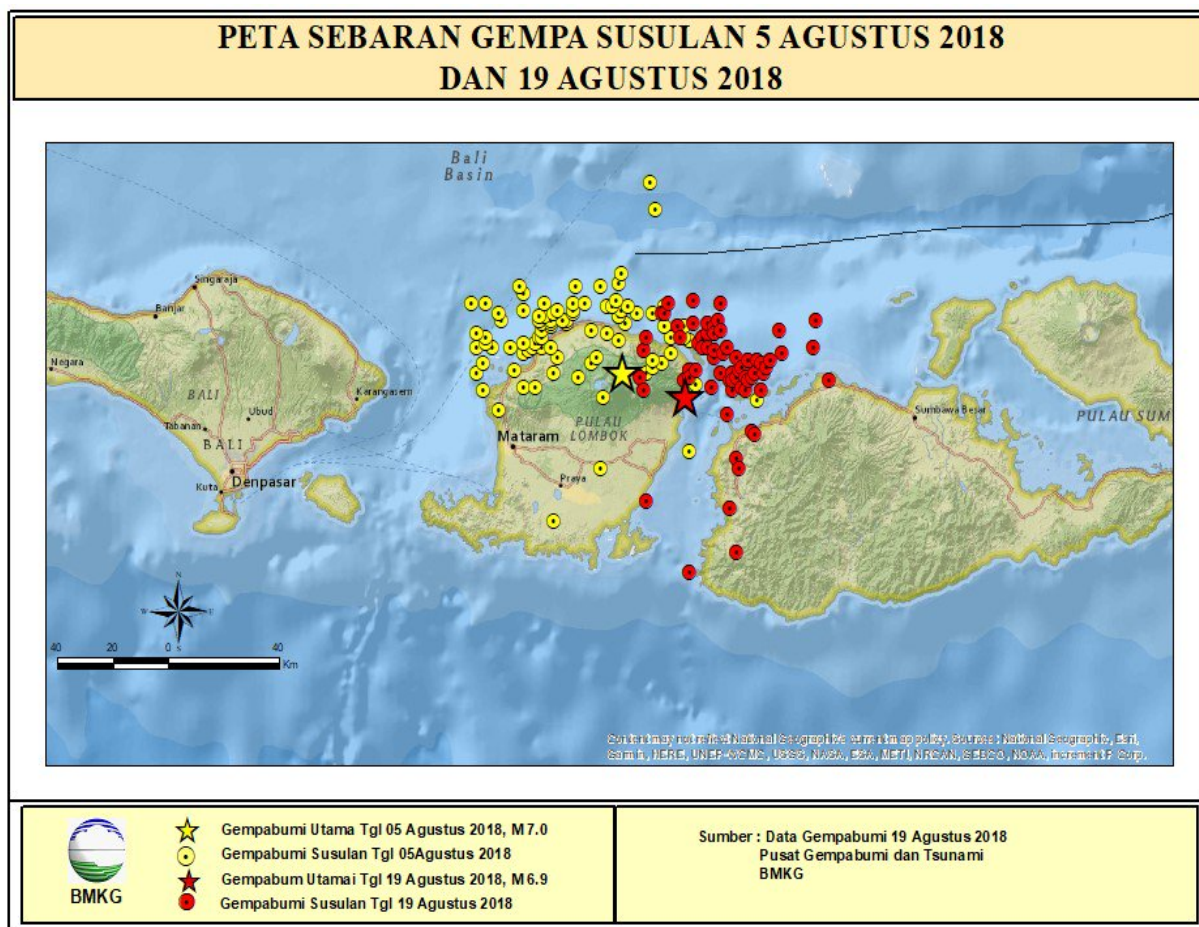
gaps in the value chain of building construction. An integrated approach combining technical and financial assistance would be vital to the reconstruction initiatives and to save lives in future earthquakes. General recommendations and relevant technical resources are included in the final section of this report.



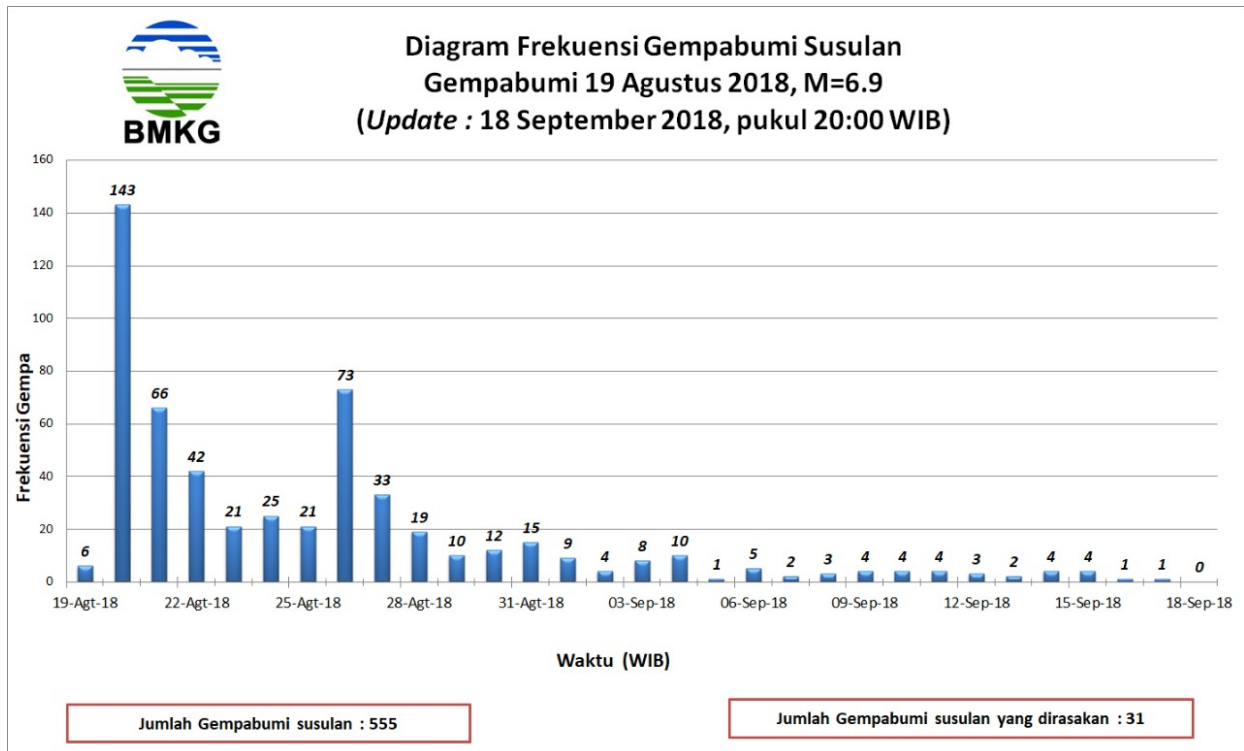
## A. EVENT INFORMATION

On 29 July 2018, an earthquake struck off the island of Lombok, Indonesia, followed with the series of major earthquakes and aftershocks, causing damage in the province of Nusa Tenggara Barat, including Lombok and Sumbawa islands, as well as the province of Bali.

According to the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), the events occurred as the result of shallow thrust fault on or near The Flores Back Arc Thrust. The foreshock,  $M_w$  6.4 (6.4 USGS), at 05:47 local time on July 29, was centered approximately 50 km northeast of Mataram City, at the depth of 14 km. Along with series of aftershocks, it then followed with the main shock,  $M_w$  7.0 (6.9 USGS), took place at 19:46 local time on August 5, at the depth of 34 km. The second main shock,  $M_w$  6.9 (6.9 USGS), took place at 22:56 local time on August 19, at the depth of 25 km. There were at least 555 aftershocks that happened after the second main shock. Aftershocks are still ongoing. **Figure 1** and **Figure 2** show the location and quantity of events.



**Figure 1.** Location of Main Shocks and Aftershocks, BMKG (2018)



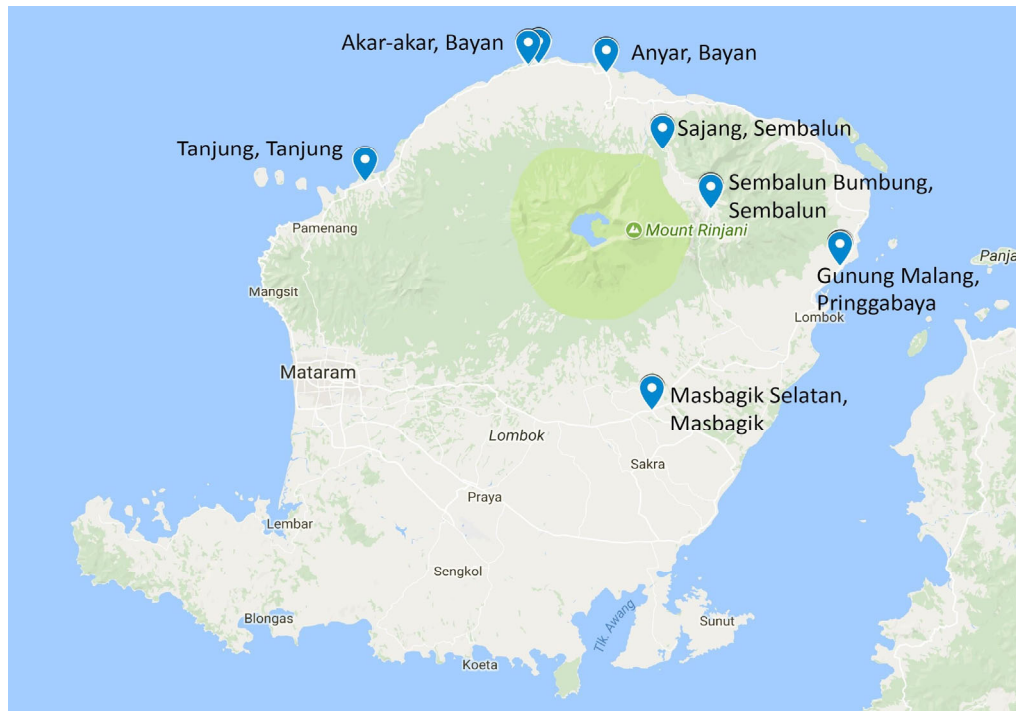
**Figure 2.** Frequency of Aftershocks since August 19 Main Shock, BMKG (2018)

The earthquakes mainly affected the northern coast of Lombok Island, but caused significant damage in the Lombok Utara, north of Lombok Timur, and north of Lombok Barat. According to a National Disaster Management Agency (BNPB) report dated September 30, the latest casualty figures stand at 564 killed, 1584 injured, and 445,343 people displaced. BNPB puts economic losses at IDR 8.8 trillion.

Similar to other recent earthquakes in Indonesia, houses were hit the hardest. BNPB reported that 149,715 houses were damaged, of which 55,497 were in Lombok Barat, 38,497 were in Lombok Utara, 15,642 in Lombok Timur, 11,232 in Lombok Tengah, 4,446 in Mataram City, and 9,040 in Sumbawa Island.

Meanwhile, the National Secretary of Disaster Safe School of the Ministry of Education (Seknas SPAB), reported that 1,235 educational facilities were damaged, which disrupted the learning activities of 218,493 students. SEKNAS SPAB reports 205 schools were damaged in Lombok Barat, 294 in Lombok Utara, 204 in Lombok Timur, 140 in Lombok Tengah, 84 in Mataram City, 244 in Sumbawa Island, and 64 in Bali Province.

This reconnaissance report was compiled after site visits to 2 sub-districts in Lombok Timur (Sembalun, Pringgabaya, Masbagik) and Lombok Utara (Pemenang, Tanjung, Bayan). The locations visited are shown in **Figure 3**. The focus of the observation was on the performance of houses and school buildings during the earthquakes.



**Figure 3. Map of the areas visited**

## B. HOUSES

Houses were significantly affected by the earthquakes. There are four primary structural housing types in both districts; unreinforced masonry (URM), confined masonry (CM), timber frame with masonry skirts/infill, timber frame with timber/bamboo panels. We conducted rapid survey of 41 houses. Of the surveyed buildings, URM (60%) and CM (19%) were the most common structure encountered, followed by timber frame with masonry skirt/infill (14%) and timber frame with lightweight wall panel (7%). Masonry (URM and CM) homes were found damaged more significantly than homes built with timber frames. The majority of masonry houses were built with concrete blocks (65%) and bricks (35%). Only 31% of all masonry houses surveyed were completely plastered. Hipped and pitched roofs were common for all types of house, with CGI or asbestos (93%), clay tiles, or thatch covering.

### **Building Types and Damages Observed**

#### B.1 Unreinforced Masonry

##### Construction System

Unreinforced masonry is the most common type of building found in Lombok Timur and Lombok Utara cities and villages. The masonry is made of concrete blocks (made manually in a mold)

(see **Figure 4**) or clay bricks (see **Figure 5**), assembled with cement and sand mortar. Particularly in Lombok Timur, people prefer to have rooms with large areas, creating a situation where most of the houses had walls with a relatively long span. From all the houses observed, the length of unbraced wall ranged from 1.75m to 7.5m.

Regardless of the type of masonry, walls are typically constructed with a running bond. The size of clay bricks was approximately 4.5cmx9cmx20cm and the concrete blocks was 10cmx14cmx38cm. The thickness of plaster, where present, varied from 1cm to 3cm. From the houses observed, most of the concrete blocks were of poor quality. The quality of clay bricks varied from poor to acceptable, but were typically acceptable. This housing type is typically supported by a shallow river stone or brick foundation.

Open gable, hip (see **Figure 6**) and cross hip (see **Figure 7**) were the most common roof types encountered, with a few houses having a single-slope roof. Most of the houses inspected were provided with roof trusses every 2.5m - 4m. In some cases, purlins sat directly on top of the unreinforced masonry walls in lieu of truss-framing (see **Figure 8**). In other cases, the roof truss was connected to the top of the wall by smooth rebars (6mm - 8mm diameter) embedded into the URM walls. The roof truss or rafters were usually of good quality timber (of Grade II or I). Bracing between roof trusses was absent as shown in **Figure 10**.

In a few cases, a reinforced concrete beam was provided at the top of the walls, despite the absence of reinforced concrete columns (See **Figure 9**). However, in most cases, there was no connection provided between masonry walls and roof framing.

Unconfined masonry gables were more prevalent compared to timber or bamboo panels.



**Figure 4.** Typical unreinforced clay brick masonry house with open gable roof



**Figure 5.** Typical unreinforced concrete block masonry house with open gable roof





**Figure 6.** Unreinforced masonry house with hipped roof



**Figure 7.** Unreinforced masonry house with cross hip roof



**Figure 8.** Roofing without trusses



**Figure 9.** Reinforced concrete beams were provided despite the absence of reinforced concrete columns



**Figure 10.** Typical roof trusses when present

### Damages Observed

The most common types of damage encountered for URM buildings were diagonal cracks around openings (see **Figure 11**), cracking due to out-of-plane movement at free corners of walls (see **Figure 12**) and vertical cracks/separation of wall panels at intersections (see **Figure 13**). In some villages, long wall spans were preferable, causing flexural cracks, partial or total out-of-plane (OOP) collapse of walls to be prevalent (see **Figure 14** and **Figure 15**). Some houses with plastered walls were evident to perform better than those without plaster. Since the roof truss structure was mostly made of good quality wood and light-weight, the damage to roof structure was minimum, aside from instances where damage was caused by collapsing wall. Buildings that completely collapsed usually had been demolished prior to survey, so the damage of the roof was not observable. An unusual but common practice of adding smooth rebar at the top corner of unreinforced masonry was encountered (see **Figure 16**). Since gables were mostly of clay bricks or concrete block without confinement, partial or total OOP gable collapse (see **Figure 17**) was also prevalent.



**Figure 11.** Diagonal cracks around openings



**Figure 12.** Cracking of top corners walls



**Figure 13.** Vertical cracks/separation of wall panels at intersections



**Figure 14.** Total wall panel OOP collapse





**Figure 15.** Heavy damage on walls



**Figure 16.** Adding smooth rebar at the top of URM as an anchorage from URM walls to roof truss was a common practice



**Figure 17.** Gable OOP collapse

## B.2 Confined Masonry

### Construction System

The next most common building system observed was the Confined Masonry (CM) typology (See **Figure 18** and **Figure 19**). The level of confinement varies between the houses evaluated, but it was generally insufficient. The size of the reinforced concrete ties, where present, was usually the same thickness as the infill wall, which was around 10cm. The longitudinal reinforcement typically consisted of four smooth rebars with a diameter of 6mm - 10mm (see **Figure 20**). Most of the transverse rebars or stirrups were not observable. However, in some cases, 4mm – 6mm smooth rebar was observed (See **Figure 20** and **Figure 21**). At several collapsed houses, the reinforced concrete ties were built with less than four longitudinal rebars (see **Figure 21**).

There was little to no connection between the columns (ties) and masonry walls. It was common to see concrete columns at wall intersections, but much rarer to see reinforcement around door and window openings or the use intermediate tie beams. The majority of walls were not plastered.

Similar to unreinforced masonry, this building type was typically supported by a shallow river stone masonry strip footing or mixed with bricks (see **Figure 22**), with a reinforced concrete plinth beam in several cases (see **Figure 23**).

The roof is supported with timber and covered by metal sheets or clay tiles (see **Figure 24** and **Figure 25**). Unusual yet common practice to use timber frame confined masonry as roof support was encountered in few houses (See **Figure 26**). The roof is typically connected to the walls by protruded longitudinal rebar from columns that are bent around the rafter (see **Figure 27**).



**Figure 18.** Typical Confined Masonry house, unplastered, with open gable



**Figure 19.** Typical Confined Masonry house, plastered, with open gable



**Figure 20.** Longitudinal concrete reinforcement with four smooth rebar



**Figure 21.** Longitudinal concrete reinforcement with three smooth rebar





**Figure 22.** Stone masonry foundation



**Figure 23.**Observable reinforced concrete plinth beam



**Figure 24.** Roofing without truss with CGI covering



**Figure 25.** Roofing with timber truss and clay tiles covering



**Figure 26.** Partial confined masonry as the replacement of timber roof truss



**Figure 27.** Protruding rebar as connector between ties and roof timber

### Damages Observed

Most of the confined masonry houses experienced light damage. The most common damages of this type of building were the diagonal cracks of masonry around openings (see **Figure 28**) and cracks at the boundaries of wall panels and reinforced concrete elements. Vertical cracks along the connection between walls and reinforced concrete elements caused the separation between concrete columns and walls (see **Figure 29**). Some walls also experienced OOP collapse (See **Figure 30**). Horizontal cracks on some wall panels were encountered (see **Figure 31**), however it was not prevalent. Even though severe damage to the concrete elements was not encountered and therefore reinforcement details were not visible, it was estimated that the reinforcement did not meet the minimum earthquake resistant standards (consistent with typical practice). The concrete observed was mostly of poor quality. In contrast to the heavy damage in the walls, the roof truss usually remained undamaged or only minor damage was observed.



**Figure 28.** Diagonal wall cracking



**Figure 29.** Vertical cracks in masonry walls and reinforced concrete beam



**Figure 30.** OOP wall collapse



**Figure 31.** Horizontal cracks at walls



## B.3 Timber Frame with Masonry Skirt/Infill

### Construction System

Timber frame houses are the most common type of housing structure in Sembalun Sub-district, especially in Sajang Village. The walls were usually 2.5m - 3m tall. The bottom 1m were made out of masonry: concrete block or bricks. The upper half of the walls were made of timber or bamboo panels (See **Figure 32**). In some cases, the infill extended to the top of wall (see **Figure 33**). The masonry infills were poorly connected to the timber posts. Generally, the wall frames were not braced, but knee bracing in corners was present in several cases. There was rarely a plinth beam present and connections between the timber posts and the footing were minimum, if not absent.



**Figure 32.** Timber frame with masonry skirt



**Figure 33.** Timber frames with masonry infill

### Damages Observed

Many houses of this building type did not fully collapse in the earthquake - despite the collapse of the wall infill/skirts, the timber frame was merely damaged (see **Figure 34**). The walls that were supported by knee bracing performed better compared to other timber frame houses in the same area. The damage observed for this type of building usually happened on the masonry infill/skirts, instead of the timber frames. The damage to these structures consisted of shifting of timber posts from the footing (see **Figure 35**) and cracking of the masonry panel as shown in **Figure 36**. Poor connection between the timber frames and the heavy infill (see **Figure 37**) caused the OOP collapse of infill panels/skirts (see **Figure 34** and **Figure 38**) to almost all buildings observed. Despite the poor inter-connection between timber elements, the damage to timber frames was at a minimum. Cracks on foundation (see **Figure 39**) of few houses were also encountered, especially for those that were positioned above ground level. The poor quality of foundation's mortar, that seemed to lack cement, was considered as the main cause of the foundation cracks/damage/collapse.



**Figure 34.** OOP collapse of masonry infill panels



**Figure 35.** Shifting of timber post



**Figure 36.** Cracks on masonry infill



**Figure 37.** Poor connection between timber frames and masonry infill



**Figure 38.** OOP collapse of masonry infill, leading to damage to the bamboo panel above



**Figure 39.** Cracks of foundation



## B.4 Timber Frame with Timber or Bamboo Panels

### Construction System

Timber frame houses are common in Sajang Village, Sembalun Sub-district. They are typically one-story houses, with a shallow stone masonry footing. The wall panel was usually made of timber (see **Figure 40**) or bamboo (see **Figure 41**). Sill plates were usually not provided. Posts occurred roughly every 2m. The timber was mostly of good quality (estimated to be of Grade I and II). The roof truss usually was built of timber, in either a hipped or pitched roof, with metal sheets or thatch covering. The gable was either made of timber or bamboo panels.



**Figure 40.** Timber frames with timber wall panel



**Figure 41.** Timber house with bamboo wall panel

### Damages Observed

There was no significant damage observed in timber frames due to the earthquake for this type of building. However, cracks in the foundation (see **Figure 42**) was encountered along with cracks in the concrete floor (see **Figure 43**). Foundation damage was evident due to the poor quality of mortar. Some damage observed in the roof of one house was mainly due to timber deterioration. Foundation collapse that led to the damage of the lower part of the wall as was encountered (see **Figure 44** and **Figure 45**). Some posts were not embedded into the foundation, causing the posts to shift and building to tilt. However, because homeowners had already done some emergency actions to their houses, only minor wall displacement was encountered during the survey.



**Figure 42.** Cracks on foundation



**Figure 43.** Cracks on concrete floor



**Figure 44.** Damages on lower parts of wall due to foundation collapse and the absence of sill plate



**Figure 45.** Foundation collapse (lacking cement mortar)

## B.5 Other Construction Systems

A few unusual construction practices were encountered in Akar-akar Village, Bayan Sub-district. In one case, lightweight steel was used for the main frame of the house (see **Figure 46**). Even though the house was already demolished by homeowner, the lightweight steel seemed to not be able to resist either the gravity loads or the lateral loads due to the earthquakes. In another case, bamboo was used as concrete reinforcement for a house that was estimated to be reinforced concrete frame with masonry infill or confined masonry (see **Figure 47**). The bamboo was also proven to be too weak and crushed due to the earthquake.



**Figure 46.** Lightweight steel frame with masonry infill



**Figure 47.** Bamboo reinforced concrete



## C. SCHOOL BUILDINGS

The team visited three schools in Lombok Utara District (Pemenang and Tanjung) and one school in Lombok Timur (Sembalun). One school was a 2-story building (**Figure 48**), while the rest were 1-story buildings (**Figure 49**, **Figure 50** and **Figure 51**).



**Figure 48.** Pesantren Assyafiyah, Tanjung



**Figure 49.** SDN 2 Penjalin, Tanjung



**Figure 50.** SDN 02 Sokong, Gunung Sari



**Figure 51.** SDN 1 Sajan, Sembalun

### C.1 School Building Types Observed

There were two primary structural school building types that were encountered: the 2-story classroom building with reinforced concrete frames and masonry infill, and confined or partially confined masonry single-story buildings. The infill of all school buildings investigated were made of clay bricks. In all cases, the roof structure is lightweight, made from steel or timber truss, and covered with CGI sheets or clay tiles. The masonry gable walls of all schools visited were made of clay bricks. The foundations were unobservable.

For one-story school buildings, the column and beams dimensions ranged from 13cmx13cm to 20cmx20cm. For two-story buildings, the column and beams were 20cmx30cm. For both one and two-story buildings, the columns were provided every 2.5m - 4m (see **Figure 52**), and the wall spans ranged from 7m to 12m. Mostly, a single building consisted of one to four adjacent classrooms at 7mx7m to 8mx8m. The openings typically took approximately 50% of the wall panels area and more than 80% of wall panels length. Typically for multi-classrooms buildings, the interior wall panels were made of full masonry wall without openings, yet some of interior transverse walls were made of removable wood planks to create larger rooms that can be used during meetings or special events. The exterior transverse wall panels were either made of solid masonry or masonry with small openings.

The concrete of columns ranged from poor to fine quality. Poor concrete composition and mixing process were evident (see **Figure 53**). The concrete frames were reinforced with smooth rebar with diameter of 8mm, 10mm and 12mm in the longitudinal direction and 6mm - 8mm in the transversal direction. The stirrups were placed every 20 cm or more in most cases, though rarely a spacing of 15cm was encountered (see **Figure 54**, **Figure 55** and **Figure 56**).

The connection between frame elements (e.g columns-beams, column-plinth beams) were poor with insufficient ductility detailing. Inadequate or excessive concrete cover of columns (see **Figure 57**) and slabs (see **Figure 58**) were common, while for beams, the concrete cover and reinforcement were not observable.

The dimension of bricks was approximately 4cmx9cmx22cm and of fair quality. The masonry walls had minimal connection to the reinforced concrete frames. At one school, a minimum effort to connect the masonry wall to columns using nails was found (see **Figure 59**).



**Figure 52.** Columns were provided every 2.5m - 4m length



**Figure 53.** Concrete of one school building





**Figure 54.** 6mm stirrup was provided every 20cm or more



**Figure 55.** 6mm stirrup was provided every 20cm or more



**Figure 56.** Smooth 10mm longitudinal rebar



**Figure 57.** Column with both inadequate and excessive (10cm) concrete cover with poor quality of concrete





**Figure 58.** Slab with thin concrete cover and exposed rebars



**Figure 59.** Minimum connection between masonry infill and the reinforced concrete frames

## C.2 School Building Damages Observed

- Cracks on reinforced concrete frames

Cracks on columns and beams, especially near the joints were common. Diagonal cracks on columns (**Figure 60**), beam sliding cracks (**Figure 61**), cracks on columns due to corrosion of reinforcing rebar (**Figure 62**), and splitting cracks of columns (**Figure 63**) were also encountered. Especially at RCF joints, columns and beams were cracked or crushed. Where ductility or seismic detailing was not sufficient and the cracks were severe, the separation between frames (i.e column-beam, column-plinth beam) were encountered (**Figure 64**). Captive column damage near door/windows openings was also common (**Figure 65**). At one school building, it was evident that the buildings were renovated and the height of the building was increased. This was done by adding new columns and masonry walls to the top of old ones without providing a good connection between the new and old structures. The significant difference of quality between the old and new structures caused severe damage at the adjoining areas **Figure 66**).



**Figure 60.** Diagonal cracks on reinforced concrete columns



**Figure 61.** Beam sliding cracks



**Figure 62.** Cracks on columns due to rebar corrosion



**Figure 63.** Splitting crack on columns



**Figure 64.** Separation of reinforced concrete frames (columns from gable frames)



**Figure 65.** Captive columns damage



**Figure 66.** Damage due to significant quality difference between old and new structure

- Out-of-Plane Collapse of Walls and/or Gables

For school buildings that were severely damaged, out-of-plane collapse of masonry walls and gables were prevalent (**Figure 67**, **Figure 68** and **Figure 69**). Partial or total OOP collapse was encountered due to the long (3m-4m), tall (usually 3.7m to 4m), slender (around 13cm) wall panels, large distances between cross walls, poor quality of material and workmanship, and the poor connection provided between masonry and frames/ties. Despite being confined, it was observed that heavy masonry gables experienced heavy damage. At one school, the falling masonry gable and/or masonry wall of a two-story building crushed another one-story building nearby (see **Figure 70**). At another school, similar case also showed how an OOP collapse of wall and gable inward the building causing the damage to roof truss and ceilings (see **Figure 71**). The last two cases showed how disastrous OOP wall/gable collapse was.



**Figure 67.** Partial OOP collapse of wall panel





**Figure 68.** Total OOP collapse of wall panel



**Figure 69.** OOP collapse of masonry gable



**Figure 70.** A building impacted by the falling walls/gables that collapsed OOP of two-story building nearby



**Figure 71.** OOP walls and gable collapse caused roof truss and ceiling damages

- Cracks on Walls

Aside from OOP collapse, other common damage to walls encountered were: diagonal cracks around openings (**Figure 72**), flexure/vertical cracks (**Figure 73**), separation of walls from beams and columns (**Figure 74**) and crushing at wall toes (**Figure 75**).



**Figure 72.** Diagonal cracks around openings



**Figure 73.** Vertical flexural cracks at mid-span of wall



**Figure 74.** Separation of walls from beams and columns



**Figure 75.** Crushing at wall-toe

- Damage to roof truss, roof covering, gable and stairs

The damage to roof trusses was mainly caused by movement of a heavy gable, causing the damage mainly to occur at the end of the roof near gables (see **Figure 68** and **Figure 69**). The damaged ceiling was also found near falling gables or collapsed walls (see **Figure 71**). For schools with clay tile coverings, falling clay tiles was also encountered, causing the damage on roof trusses that were made of lightweight steel (see **Figure 76**).

An observation of a two-story, four classrooms school building showed that only one stair (less than 1m wide) was provided (see **Figure 77**) to accommodate hundreds of students who used



the second floor classrooms. This stair was fractured (see **Figure 78**), showing the insufficient reinforcement provided (see **Figure 79**).



**Figure 76.** Falling clay tiles, causing damage to lightweight steel roof truss



**Figure 77.** Partial collapse of only egress stair to upper classrooms that accommodate hundreds of students



**Figure 78.** Fracture of reinforced concrete stairs.



**Figure 79.** Insufficient stair reinforcement



## D. COMPARISON OF EXISTING BUILDINGS TO CURRENT STANDARDS

Based on the observations, it is evident that none of the buildings observed fully meet the applicable standards. Deficiencies were always encountered, either of material quality, structural detailing, workmanship or the combination of all, showing the minimum (if not absent) involvement of technical support, such as engineers and authorized government body during design and construction process. The most notable discrepancies between the existing buildings observed and the related standards are provided below.

The SNI 15-2094-2000 (regarding clay brick for masonry wall) stipulated the compressive strength of clay bricks to be no lower than 5 MPa. Most bricks seemed to meet this minimum standard, but some clearly not. For concrete blocks, it was regulated in SNI 03-0349-1989 (regarding the concrete block for masonry wall) that concrete blocks for masonry wall should have compressive strength no less than 10 MPa. However, most of the concrete blocks encountered were of poor quality and it was estimated to be less than 5 MPa. The SNI 2847:2013 (regarding the requirement of structural concrete for buildings) limits the structural concrete compressive strength to be no less than 17 MPa. Although the compressive strength of structural concrete was not tested in the field, most structural concrete in buildings observed was estimated to be of poor quality. In some cases, the concrete could easily be broken by hand.

In SNI 2847:2013, article 3.5.1, it is mentioned that the longitudinal rebar of reinforced concrete must be deformed, while from all building observed, it was found that all of the longitudinal rebars were smooth. Due to the smaller surface area of smooth bars, around 40% more are required to achieve the same strength as deformed bars and the development and splicing of the bars is affected. The concrete cover of structural concrete is also limited in SNI 2847:2013 to be no less than 4cm. However, from the observation, exposed rebar due to thin concrete cover was prevalent.

In SNI 1726:2012 (regarding design procedures for earthquake resistant-buildings) article 7.14.2, it is stated that the minimum transverse rebar of no less than Ø8mm must be provided every 150mm. However, the field investigation showed that the transverse rebar with diameter 4mm-6mm was provided every 20cm or more. Only in a few cases where the transverse rebar was provided every 150mm.

Based on the decree of Ministry of Housing and Infrastructure No 403/KTPS/M/2002 (regarding the technical guidelines for simple houses), it was stated that timber post should be no less than 5cmx7cm every at least 100cm. In reality, some timber houses evaluated, smaller posts were provided and the distance of each post usually more than 1m. The longitudinal reinforcement must be of deformed rebar with the diameter of 12m, while all of the houses assessed used smooth rebar with smaller size. Roof truss must be placed on top of columns, while many roof trusses encountered were of placed on ring beams. For timber frame with masonry skirt house, a

sill plate with dimension of no less than 5cmx10cm must be provided, while during investigation, most buildings were not supported by sill plates.

Based on the Ministry of Public of Work and Housing No 05/PRT/M/2016 (regarding the permit of house construction) and stated that the maximum area of walls is limited to be no more than 9m<sup>2</sup>, which means that for buildings with 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 area of more than the maximum area prescribed, where at some cases, the columns were only provided every 6m. The size of reinforced concrete columns must be no less than 15cmx15cm, while houses with columns dimension of 13cmx13cm were prevalent.

## E. RECOMMENDATIONS

The affected communities should be supported in recovery from this disaster through both financial and technical assistance for reconstruction. Our general recommendations for this support are:

1. **Reviewing the existing location.** Reconstruction initiatives or any new constructions should be initiated with a careful site selection, discouraging reconstruction among stakeholders in hazard-prone sites. The information of the hazard in the existing location also should be made available to the communities, including for those that may tend to rebuild in the hazardous locations, such as adjacent to the fault lines, liquefaction and tsunami zone.
2. **Providing access to the communities to clear and simple, low-cost, culturally appropriate technical resources to rebuild, or repair and retrofit, disaster-resistant homes.** The consideration includes local materials availability, sources, quality, and cost; common structural system (which may vary depending on the materials availability and builder skill); architectural and cultural preferences; and climate and other hazards, such as tsunami zone, high winds, landslides, and flooding.

- a. Prescriptive design guidelines (for engineers and architects).

- b. Simple step-by-step construction guidelines (for builders and homeowners).

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 (Pedoman Teknis Pembangunan Rumah Sederhana Sehat, 2002) and Technical Guidelines for Earthquake Resistant Houses and Buildings, Including Recommendations for Damage Repair (Pedoman Teknis Rumah dan Bangunan Gedung Tahan Gempa, 2006).

Build Change has also developed an image-based booklet that contains the recommended practices for improving the performance of timber and masonry houses in Indonesia, as seen in **Figure 80** which can be used as guideline by builders and homeowners.



**Figure 80.** Handbook titled [“You Can Keep Your Family Safe from Earthquakes: How to Build Strong and Sturdy Houses”](#) (Build Change, Indonesia, [link here](#))

- c. Promotional materials, such as posters and flyers, which contain core messages of disaster-resistant design and construction (see **Figure 81** and **Figure 82**).



## BAGIAN 1. BAHAN BANGUNAN

- Gunakan semen tipe I
- Gunakan pasir dan kerikil bersih
- Gunakan kayu berkualitas baik dengan ciri-ciri : keras, kering, berwarna gelap, tidak ada retak dan lunas
- Untuk Fondasi gunakan batu kali yang keras

### BETON

1 semen + 2 pasir + 3 Kerikil

1 Semen + 2 Pasir + 3 Kerikil + 1/4 Air

Catatan: Perlu diperhatikan perbandingan air dituangkan sedikit demi sedikit dan diaduk hingga benar benar tercampur sempurna (jika terlalu encer dan tidak terlalu kental)

Pengaliran sederhana  
Letakkan beton dan pasir  
seperit gambar berikut

\* Referensi dari: [www.kompas.com](http://www.kompas.com)  
Departemen Rekayasa Hidrologi di Indonesia

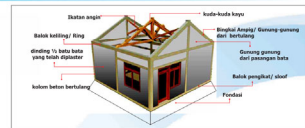
### MORTAR

1 semen + 4 pasir

1 Semen + 4 Pasir

Seperit gambar  
• Berkualitas baik  
• Keras  
• Kering  
• Berwarna gelap  
• Tidak ada retak  
• Lurus

## BAGIAN 2. STRUKTUR UTAMA



FONDASI	DINDING
<p>Gunakan batu kali atau batu gunung yang keras, dengan ukuran sebagai berikut:</p> <p>≥ 30 cm</p>	<ul style="list-style-type: none"> <li>- Dinding menggunakan pasangan bata dengan tebal sir 1,5 cm</li> <li>- Dinding dilapster dengan campuran 1 semen : 4 pasir dengan tebal 2 cm.</li> </ul>

Diagram showing a stone structure (left) and a house (right) with dimensions and labels.

**Stone Structure Dimensions:**

- Top width: 3 m
- Height: 2 m
- Bottom width: 60 cm

**House Dimensions and Labels:**

- Roof slope: 1 semen : 4 pasir
- Roof thickness: 2 cm
- Roof area: 9 m<sup>2</sup>
- Roof material: Dinding bata dipaster
- Roof height: 3 m
- Roof width: 3 m
- Roof area: 9 m<sup>2</sup>

The diagram illustrates the layout of a 3m x 3m reinforced concrete slab. It shows the overall dimensions and the placement of reinforcement bars (Balk Pengikat/Sloof, Kolom, and Balok Kelingking/Ring) and the reinforcement on the underside (Tulangan pada begi). The reinforcement bars are spaced at 100mm intervals. The diagram also shows the reinforcement on the underside (Tulangan begi bagian 8 mm) and the reinforcement on the underside (Tulangan begi bagian 10 mm). The reinforcement on the underside is shown with a cross-section of the slab, indicating the reinforcement bars are placed at a distance of 100mm from the bottom surface. The reinforcement on the underside is shown with a cross-section of the slab, indicating the reinforcement bars are placed at a distance of 100mm from the bottom surface. The reinforcement on the underside is shown with a cross-section of the slab, indicating the reinforcement bars are placed at a distance of 100mm from the bottom surface.

Detail 1

Detail 2

Detail 3

Detail 4

Plat baja tebal 4 mm, lebar 40 mm atau Papan tebal 20 lebar 100 mm, Batas min. Ø 10 mm

Gording Ø 112

Balok Ring

Klem baja Ø 40 mm

Postur ini digunakan sebagai PERATAPAN POKOK UNTUK RUMAH YANG LEMAH ANJAN

Di Nageahati oleh: Mr. Teddy Doko, Prof. Priyo Suparno, Prof. Sarwadi,

Poster ini diajukan sebagai PERSYARATAN POKOK UNTUK RUMAH YANG LEBIH AMAN untuk pengembangan di masa mendatang demi menghindari jatuhnya korban jika terjadi gempa bumi. Di Nasehati oleh: Mr. Teddy Boen, Prof. Priyo Suprobo, Prof. Sarwidi, Dr. Krishna S. Pribadi, Ir. Mudji Irmawan A, Dr. Iman Satyarno, Dr. Ashar Saputra

BAGIAN 3  
IKATAN ANTAR STRUKTUR UTAMA

FONDASI - BALOK PENGIKAT (SLOOF)
 BALOK PENGIKAT (SLOOF) - KOLOM

Detail of floor construction showing cross-section and top view. The cross-section labels include: Angkur Besi  $\phi$  10 mm, Batas maksimum antar angkur 50 mm, Batu Kali/ginger, Aspalak Beton, Batu kosong, and Lantai Karja & Pasir. The top view labels include: Tulangan beton dilambungkan ke arah dengan panjang (lewatan minimal 40 (20 cm)), Tulangan Ujung 10 mm, and Renda. The bottom labels are: KOLOM - DINDING and KOLOM - BALOK KELING (RIN).

Angkur/baut logam ini  
diameter 20 mm

Brank Head  
Headling 90° Cg  
Dua kaku 4.0 mm  
6°

dengan cara berikut:  
Angkur menggunakan besi  
diameter 20 mm yang dilubangi  
kedua belah beling/ ring

Atas untuk menghubungkan angkur  
pipa besi diameter minimum 3  
dengan 2 lubang

Atas untuk menghubungkan angkur  
dengan besi diameter minimum 3  
dengan 2 lubang

**GUNUNG GUNUNG (AMPIG) - KOLOM**

Jangan lupa untuk memasang angkur baja pada penyanggah - penyanggah Angkur besi minimum 10 mm. Sepanjang 40 cm, setiap 8 lapis baja.

Tulangan tumpang dengan diameter minimal 10 mm

Tulangan tumpang dengan diameter minimal 10 mm

Study dari Buku "Gooding's Architectural Reinforcing Ironing & Reinforcing", July 2008, 2008

Detail A

Kayu 6/12

Detail B

Baut Diameter 33 mm

Kuda-kuda menggunakan kayu 6/12

## BAGIAN 4. PENGECORAN BETON

**PENGECORAN KOLOM**

- Pastikan cetakan rapat dan kuat/kokoh.
- Pengecoran kolom dilakukan secara bertahap setiap 1 m
- Pada saat pengecoran beton ditroyok dengan besi tulanang atau bambu agar tidak ada yang keropos
- Pelepasan bekisting minimal 3 hari setelah pengecoran



Pemilihan dan pengangkatan/cetakan beton bertulang dan rapi

Pengisian pertama setinggi 1 m

Beton dituang dengan besi tulangan atau bambu agar tidak ada yang keropos

### PENGECORAN BALOK

- Tulangan diuangkur diatas dinding
- Cetakan pada balok gantung harus diberi penyangga
- Cetakan dapat dilapas setelah 3 hari untuk balok yang memmpu di dinding, dan 14 hari untuk balok gantung






pengambilan di masa mendatang dari menghidari jatuhnya korban jika terjadi gempa bumi.

Sina S. Prihadi, R. Mufid Irmawan A, Dwi Mingsihardjati, Nurhikmah, Dr. Ashkar Saputra

**Figure 81.** Poster of Principal Requirements for a Safer House (JICA and Ministry of Public Works and Housing, Indonesia)

# GEMPA BUMI TIDAK MEMBUNUH MANUSIA

## KONSTRUKSI YANG BURUK DAPAT MEMBUNUH MANUSIA




## SAMBANGAN YANG BAGUS DAPAT MENYELAMATKAN MANUSIA



**Buruk**

Sambungan pembeesian yang tidak kuat akan membahayakan nyawa dan keluarga kita



Gegangan yang lemah tidak akan menahan guncangan atau tarikan dan mudah terlepas



**Bagus**

Sambungan pembeesian yang kuat akan menyelamatkan nyawa dan keluarga kita



Gegangan yang kuat akan menahan guncangan atau tarikan dan tidak mudah terlepas



**BUILD CHANGE**

Yayasan Bangunan Berorientasi Perubahan

kegiatan pembangunan yang mengutamakan perubahan

Jl. Kemuning No. 2, Komplek Perumahan Bangsar Tebi  
Padang, Sumatera Barat, Indonesia  
website : [www.buildchange.org](http://www.buildchange.org)

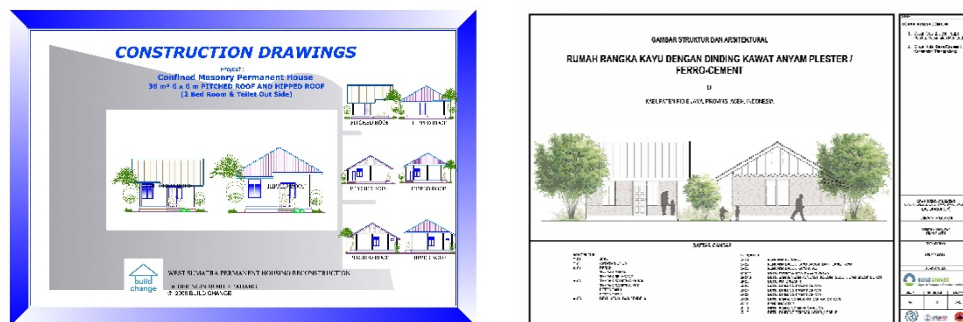
©sumatera BAILD CHANGE 2018

[illegible]



**Figure 82.** Posters/Flyers (a), (b), (c), and (d) Contain [Key Messages](#) for Good Connections, Confined Masonry House Construction, Timber Frame House Construction, and How to Choose Good Quality Materials (Build Change, Indonesia)

- d. Detailed design drawings, bills of quantity, technical specifications for a range of housing options. Build Change has developed several design packages for a disaster-resistant confined masonry house type and a timber frame house type that available for public use (see **Figure 83**).



**Figure 83.** Design and Drawing Set for [Confined Masonry House](#) and [Timber Frame House](#) (Build Change, Indonesia)

- e. Simple guidelines to improve the quality of building materials (for traditional material producers, such as blockmakers and brickmakers). Many of masonry wall materials, such as blocks and bricks, were visually observed in bad quality. Our



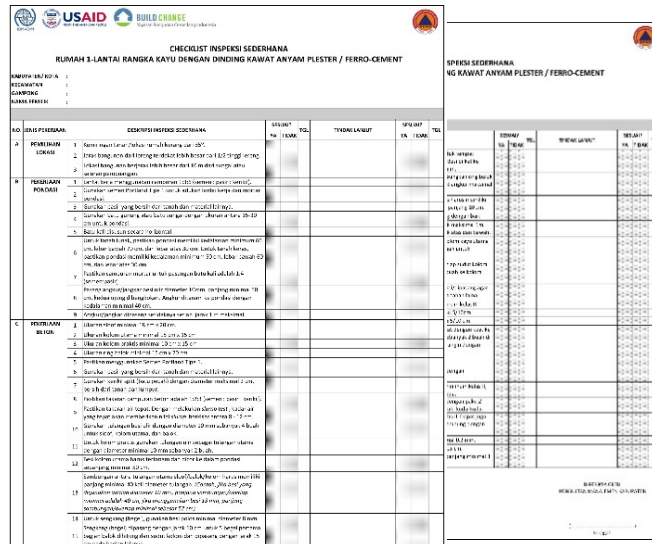
recent study shows that majority of bricks in several areas in Indonesia are below the requirement of building codes. Providing better quality control, coaching, and a simple manual that contains recommended practices for the traditional producers to improve the quality of their materials, as shown in **Figure 84**, would be beneficial to improve the construction quality.



**Figure 84.** Manual on [How to Produce Good Quality Bricks](#) (Build Change, Indonesia)

3. **Providing training of good construction practices.** Depending on the level of construction familiarity, skills, and training objectives for each homeowners, school communities, builders, village leaders, local authorities, and engineers, specific training needs to be provided for each segment in order to improve understanding of and building awareness on disaster-resistant design and construction. Build Change has developed a [training module](#) to accommodate specific targeted communities in Indonesia.
4. **Providing technical assistance during construction.** Technical assistance should be provided in accordance with the applicable standards and latest building code, SNI, to aim for proper implementation of disaster-resistant structures. The trained technical facilitator should also be accompanied with technical documents, such as construction quality checklist. A simple construction quality checklist can be developed for each building type, as shown in **Figure 85**, to be used by facilitators and homeowners.





**Figure 85. [Simple Checklist](#) and [Visual-based Construction Quality](#) for Timber Frame House with Masonry Skirt and Ferro-cement Wall (Build Change, Indonesia)**

## 5. Enforcing the building code/guideline implementation and ensuring sufficient funding is available to meet the standard.

- At the moment, many houses in Lombok and in Indonesia generally were not built according to the applicable building codes. The post-disaster reconstruction initiatives, as well as obtaining building permit (IMB) for new construction, provide opportunity to take a step toward building code enforcement for houses.
- School buildings should always be designed and constructed according to the latest building codes and standards. Beside funding allocated to retrofit or rebuild damaged schools, the implementation of good construction practices is equally as critical as ensuring the design meets code requirements.

Recommended improvements to school buildings include:

- replacing masonry gable walls with lightweight materials,
- replacing clay tiles for roofing with CGI sheeting, or strengthening the connection of clay tiles to the framing and truss members and providing additional bracing,
- ensuring long spans between cross walls are braced by an adequate ring beam or horizontal bracing system to connect the top of walls to perpendicular cross walls,
- providing confined masonry shear wall panels along the open longitudinal sides of the classroom buildings and/or at open/missing transverse walls,
- replacing masonry panels above windows and doors with lightweight materials or louvers for ventilation, or otherwise support with adequate reinforced concrete lintel beams,
- upgrading roof truss framing and connections to strengthen,
- strengthening the support and connection of ceilings to the building structure.

In certain building conditions, retrofitting could be a cheaper option to increase the safety than rebuilding. You may find [here](#) an example of school building retrofitting drawing package which would need some adaption to similar school buildings that are also one-story masonry buildings with light-framed roofs.