RISBARI: an alternative house model for the 2018 Lombok earthquake affected people

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Abstract: Right after the 2018 Lombok earthquake, a huge number of housings were considered to be rebuilt or partially repaired. Out of more than 216,519 damaged houses, around 75,138 houses have to be demolished and rebuilt at the same location. This construction process is required to carry out immediately as majority of affected dwellers are now living at temporary shelters with very limited privacy. A house model made from cold formed steel structure, RISBARI, was proposed. RISBARI was developed to meet two essential criteria: fast erection process and construction budget constraints. A full scale test of RISBARI was conducted to evaluate its lateral strength capacity. This paper summarize the earthquake-resistant RISBARI house as well as the planning of its implementation in massive production through 5Ms principles.

1. Introduction

In 2018 Lombok island was shocked by three major earthquakes as follows: M6.4 at July 29; M7.0 at August 5; and M6.9 at August 19. Epicenter and seismic intensity measured in Modified Mercalli Intensity (MMI) scale of those three earthquakes are shown in Figure 1 (National Center for Earthquake Study 2018). It was reported by the National Agency of Disaster Mitigation (BNPB) that there were around 216,519 damaged houses, in which 75,138 houses were heavily damaged; 33,075 houses were moderate damage; and 108,306 houses were minor damage (Housing Directorate of Nusa Tenggara Barat Province 2018). Those heavily damaged houses were completely demolished afterward since the construction of new houses must take place at the same location. During this reconstruction, the affected people stayed for couple weeks or months ahead at temporary shelters or tents, which are in general have significant limitation in terms of household privacy (Felix D et al 2014), comfortness and durability against weather especially during raining seasons.

Reconstruction and rehabilitation program is started from August 23, 2018, where the Indonesian Government through BNPB has prepared a stimulant fund worth IDR 50 million, IDR 25 million, and IDR 10 million, respectively, in case of a heavily damaged house, a moderate damaged house, and a minor damaged house (President of Republic of Indonesia 2018). In this program, only house models
that are proven to be an earthquake-resistant house are permitted to be constructed. At that moment there were three recommended house models: RISHA, RICO, and RIKA. RISHA has an open-frame structure made from precast concrete panels connected to each other through steel plates and bolts. RICO is an open frame structure house where column and beam elements are reinforced concrete. Both RISHA and RICO use masonry infilled walls. RIKA is the last house model, it is made from timber. RICO and RIKA are well known house models to majority of Indonesian, while RISHA couple years ago is an innovation product of the Human Settlement Research Center of the Ministry of Public Works and Housings.

![Figure 1](image)

Figure 1. Three major Lombok earthquakes in 2018 (Pusat Studi Gempa Nasional, 2018)

After some months passed by, the reconstruction progress and number of rebuilt houses is still below the people’s expectation due to various reasons both technical and non-technical problems. This delayed progress is becoming another sorrow for the affected people as they were currently staying in temporary shelters or tents, instead of temporary houses as generally adopted (Felix et al, 2014). Lacking number of skilled workers to rebuilt over 75 thousands of damaged houses, in addition to insufficient construction materials in Lombok island required by the above mentioned three house models were some problems that authors observed. As reported by Wu and Lindell (2004) during their study comparison on housing reconstruction project between aftermath the 1994 Northridge earthquake in southern California and the 1999 Chi-Chi earthquake in Taiwan, effective coordination among involved recovery agencies and availability of access to funding source are significantly influenced the speed of recovery process.

In the early of December 2018, the authors proposed a new house model RISBARI that is made from cold formed steel (CFS) plus reinforced concrete foundation. Cold formed steel is widely known for its special features: fast and easy erection, lightness in weight, uniform quality and cheap in transportation and handling (Alex et al, 2016). This paper summarized the lateral resistance and durability aspects of RISBARI as well as implementation plan at site based on 5M construction management principles: manpower, materials, machines, methods, and money.

2. RISBARI House Model

RISBARI house model has a floor plan as shown in Figure 2 composing of two bed rooms, one multi function living room, and one bath room/ water closet. The RISBARI house is placed above the ground via a 150-mm thick reinforced concrete foundation layer and there are 30 dynabolds (diameter 10 mm,
embedding length 70 mm) connected the walls to the foundation layer to provide lateral support during wind or earthquake events.

Both roof structures and walls systems are made from G550 cold formed steel having minimum tensile strength of 550 MPa. Figure 3 shows the roof structures used C-shaped cross-section C75,75,0.75, corner and intersection columns used box-shaped cross-section that are derived from two members of C81,100,1, columns in between these corner or intersection columns used C-shaped cross-section C81,75,1. (Numbers followed letter C at, for instance, C75,75,0.75 means: 75 mm section depth, 75 mm total length of top and bottom flanges, and 0.75 mm thick of CFS sheet, respectively). When obtaining a box-shaped section from two C-shape sections, self-tapping screws were used to connect them at an interval of 300 mm as a maximum interval 4 times of section depth was recommended by a previous study (Wang et al, 2018). Columns of the RISBARI house model are connected through diagonal members of CFS strap of cross-section 28 mm by 1 mm to improve its lateral resistance (see Figure 3.b.). Fiber cement boards are used as sheathing material of interior walls, while wood planks that are water resistant are used as sheathing material of exterior walls. Figure 2.b, c, and show the front, back and side view of the RISBARI.

(a) Floor plan
(b) Front view
(c) Back view
(d) Side view

Figure 2. RISBARI House model
3. Structural Analysis of RISBARI House Model

Structural analysis of RISBARI house was carried out based on a structural model as shown in Figure 4(a) developed by SAP2000 program. External loads considered in the analysis were gravity loads, wind loads assuming maximum speed of 80 km/h, and earthquake loads defined by the Indonesian standards SNI 1727 (2013) and SNI 1726 (2012). Figure 4(b) shows the response spectrum used in the seismic analysis that is synthesized for Lombok area.
Following this structural analysis, CFS members capacity as well as connections strength evaluation were conducted in load resistance factored design (LRFD) format according to the Indonesian standard SNI 7971 (2013), while pull-out strength evaluation of the dynbolt anchorage system was performed using the Indonesian standard SNI 2847 (2013). When the soil type in a location may vary, it will affect the base shear caused by earthquake. The effect of different soil types gives an insignificant value to the dynamic scale factor for high rise building. The opposite happens to lower buildings, the softer the soil, the higher dynamic scale factor will happens (Tanjayya and Kwandou, 2019) while this research uses the medium soil type. In brief it is concluded that the structural performance of RISBARI house complies to design criteria set by those aforementioned standards.

Figure 4. Structural Analysis: (a) Structural model of RISBARI; (b) Selected response spectrum for Lombok

4. Latest test of RISBARI House Model

Figure 5 shows the RISBARI house model that was constructed inside a workshop building and subjected to lateral forces to verify its lateral resistance. A schematic of the test is shown in Figure 6 where a load cell of 100 kN capacity and three LVDTs (Linear Variable Displacement Transducer) of 50 mm capacity were utilized to continuously measured the applied lateral force and deformation of the house model, respectively. This lateral force was facilitated through a system of steel wire that horizontally and uniformly pushed the house model at elevation of 3 m above the ground as can be seen in Figure 5. The steel wire was pulled by a mobile crane until reached the maximum lateral capacity or significant damages of the house model were observed.
Figure 5. Constructed RISBARI house model

Figure 6. Schematic of the lateral test

Figure 7 shows lateral load vs. house model displacement measured at two different locations of LVDT in which both curves are almost identical. This ensures that the applied lateral load is uniformly distributed to the house model, and structural elements of the house model performs unity as expected.
The lateral test was stopped at lateral load equals to 28 kN as damages shown in Figure 8 were observed. A close look to load-displacement curves given in Figure 7, it is clear that the performance of the house model has reached inelastic region though might be able to bear more lateral load. Assuming that maximum lateral load capacity of this house model equals to 28 kN, equivalent static analysis formulation $V = C \times I \times K \times W_t$ roughly estimates $C$ equals to 0.96g or 0.48g, respectively, for building ductility factor $K$ equals to 1.0 and 2.0 (I equals to 1.0; $W_t$ or total weight of the house model equals to 29 kN).

![Figure 7. Lateral load vs displacement obtained from the test](image)

![Figure 8. Observed damages of the house model: (a) buckling of some wood planks; (b) cracks/ separation between cement boards](image)
5. Implementation plan
Concept of 5Ms (materials, machines, manpower, methods, and money) is implemented as follows. Materials of CFS, bending and cutting machines are being concentrated only in this center along with skillful workers to ensure quality and uniformity of RISBARI house production. To reduce significant construction time at site, RISBARI house is divided into several panel modules which are fabricated at one production center at the city of Lombok. Figure 9 shows RISBARI house decomposition into ten exterior panel modules and six interior panels modules. All those panel modules are transported to sites by small truck to reach most of the affected areas.

Parallel to house production activities at the production center, the preparation of house foundation which mostly utilized and modified of the existing foundation of the damaged houses is also conducted at sites. Local community are involved in this house foundation preparation as well as installation of panel modules of RISBARI house. Therefore, construction time and cost will be reduced as generally found in previous study (Forouzandeh et al 2008).

As the stimulant fund of this reconstruction project needed by the affected people is provided by the government, thus problem related to financing issues is not crucial. However, close coordination among RISBARI house producers, local communities and local building engineer institution in Lombok is necessary to meet administrative and technical requirements set by the BNPB.

6. Conclusion
Aftermath 2018 Lombok earthquake, massive reconstruction of damaged houses have been initiated since end of August 2018. In addition to existing earthquake-resistant house models, the authors proposed RISBARI house model, which is constructed from cold formed steel laid on reinforced concrete foundation. Key success factors of RISBARI house models are: 1) modular design; 2) pre-fabricated products; 3) ease of delivery; 4) structurally safe; and 5) involvement of local community at installation process at sites.

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