

# Alternative Design of Post-Earthquake Temporary Housing in Indonesia

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**Abstract** This article informs about temporary housing necessity for the Earthquake victim's refugees in Indonesia. After the disaster, management of mitigation is needed, especially to cover the primary necessities of housing. There is another temporary housing proposed by previous research, such as RISHA and RUSPIN, that are formed from precast concrete material. Huntara 1.0 by November 10 Institute of Technology are also proposed after Lombok Earthquake and were formed from timber. In this article, an alternative design of temporary housing using a combination of Steel and Cold-Formed Steel is proposed. The loading estimation used in proposed modeling assumes that the buildings are located in Yogyakarta as one of the cities that has the highest value of PGA. Another assumption of loading is based on the available Indonesia Building Code, include the calculation of structural ability and design. The roofing system is an essential component of this housing using a trusses system with a lip C75.35 profile, using available research trusses configuration. The central column of the moment-resisting structure system is using Double lip C100.50 profile and beam using trusses Lip C80.35 profile. Overall, a new alternative design of 36 m<sup>2</sup> temporary housing is presented in this article with a relatively economical budget. The prototype and experimental loading test have to be done first before this design can be safely used extensively.

**Keywords** Earthquake Disaster Mitigation, Lombok Earthquake, Temporary Housing, Cold-Formed Steel

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## 1. Introduction

Every country that is located in an earthquake-prone area must have its mitigation action to withstand the natural disaster. Therefore, disaster management strategies should be well planned and improved in order to avoid a large number of human losses and unnecessary demolition of

collapsed or damaged infrastructure in the future (Parwanto, 2014). Indonesia is an example of an earthquake-prone country, almost every day, and there are notification from Indonesia's Meteorology and Geophysics Agency application about earthquake shock (Badan Meteorologi dan Geofisika, 2019). Figure 1 shows about earthquake record in Indonesia. It describes how vulnerable Indonesia is due to the seismic attack.

In August 2018, Lombok was struck by 7 SR earthquakes that made more than 76.765 houses collapsed, and 555 fatalities counted (CNN, 2018). Another 7,7 SR earthquakes happened with tsunami and liquefaction in Palu and Donggala, which made more than 66.926 houses (Tempo, 2018) collapsed, and 2.081 fatalities counted (Tirto, 2018). A recent big earthquake in Ambon in October 2019 has made 6.795 houses damaged (Kompas, 2019).

After earthquakes disaster, people in that disaster area suffering in the social, economic, and physical integrity of life (Amori, 2010). In a chaotic post-earthquake situation, the house is not only a vital element to re-establish normality the life of the affected people, but also can prevent the rising of deaths and the spread of diseases, once personal hygiene conditions and protection against external factors are ensured (Félix, Monteiro, Branco, Bologna, & Feio, 2015). So, there is an urgent need for protection and shelter. Moreover, earthquake resistant temporary housing becomes the priority for the victims after their own houses have collapsed in disaster. Temporary housing itself is a longer-term arrangement than shelter, employed until permanent housing can be secured. It means that temporary housing allows a return to daily activities such as work and school, and often takes the form of a rented apartment, a prefabricated home, or a small shack. Making temporary housing that can withstand another earthquake strike and fulfill the need for the owner's safety feeling within a limited budget is a challenging one. Therefore, all these factors had created an idea about designing temporary housing that can resist seismic loading.

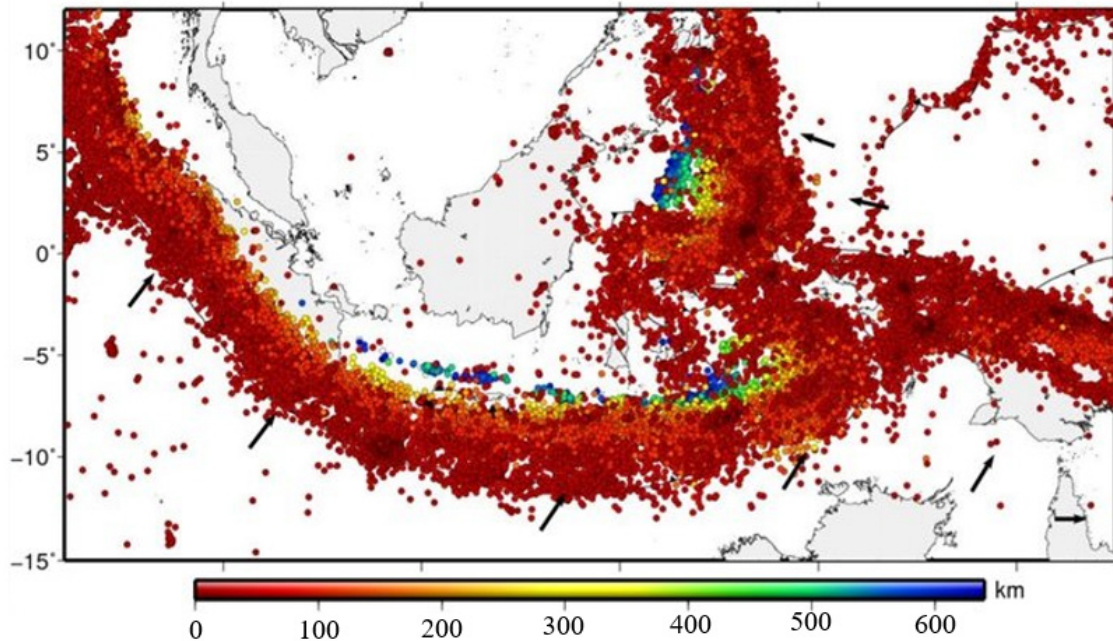


Figure 1. Earthquake record catalog 1907-2016 (Pusat Penelitian Gempa Nasional, 2017)

Furthermore, Indonesia's Ministry of Public Works has researched earthquake-resistant buildings, in this case, for housing. This product called RISHA (Instant Simple and Healthy House) and was first built after Aceh's earthquake and tsunami in 2004. RISHA itself is a house with a knockdown concept. Construction of RISHA does not need cement and masonry block yet using precast panel connected with bolt. That is why RISHA took faster construction time than a traditional house (LITBANG PUPR, 2019). Another development from RISHA was studied, RUSPIN (Instant Panel System Eminent Housing). The material used for RUSPIN is the same with RISHA, but it reduces the number of exterior displays of bolted connection room partition (LITBANG PUPR, 2019b). However, because they still use precast concrete, so if it is constructed in the post-earthquake area, material transportation will be a problem. In 2018, Institut Teknologi Sepuluh Nopember also launched Huntara (Hunian Sementara/Temporary Housing), this Huntara has 34,56 m<sup>2</sup> area and constructed from wood material (ITS News, 2018).

Moreover, the structural design of this Huntara cannot be applied uniformly in every building in the disaster area. These materials are easily obtained from nature or forest around the affected area. Unfortunately, this material's quality and durability cannot be ensured.

An alternative material for housing construction nowadays was proposed. That material is cold formed, cold-formed steel (CFS) structural elements itself has seen a dramatic expansion in the range application over the past decade. AISI has its standard for earthquake resistant building design so that CFS can be widely developed (American Iron and Steel Institute, 2013). Compared to their hot-rolled counterparts, CFS members are often more

economical and efficient due to their lightweight, ease, and speed of construction and greater flexibility in manufacturing (Mojtabaei, Kabir, Hajirasouliha, & Kargar, 2018). These are the main reason cold-formed can be used for the solution of temporary housing needs of the post-earthquake area. Unfortunately, due to the limitation of the cold-formed section dimension, the main column design is suggested from the double lip channel cold formed with a higher value of thickness.

Previous research available about cold-formed steel structure and its seismic behavior (including experimental test) have been done by Peterman. Overall, the work demonstrates the excellent performance of these structures under seismic excitation, while highlighting that this performance is related to the full system-level response and not just the designated elements in the lateral-force-resisting system (Schafer et al., 2016) and (Peterman et al., 2016). Another research by McCrum investigates the seismic performance of a single-story moment-resisting cold-formed steel (CFS) portal frame through cyclic testing. The research concludes that both perfect-fit tolerance bolt holes (PTBH) or normal tolerance bolt holes (NTBH) connections had stable hysteresis and good hysteretic energy dissipation capacity, and also good ductility (McCrurn et al., 2019). Another design alternative of Low-cost Earthquake resistant house using CFS has been done, in that research 51,84 m<sup>2</sup> house was designed with 36 million rupiahs in cost (Hardwani & Patil, 2013).

## 2. Method

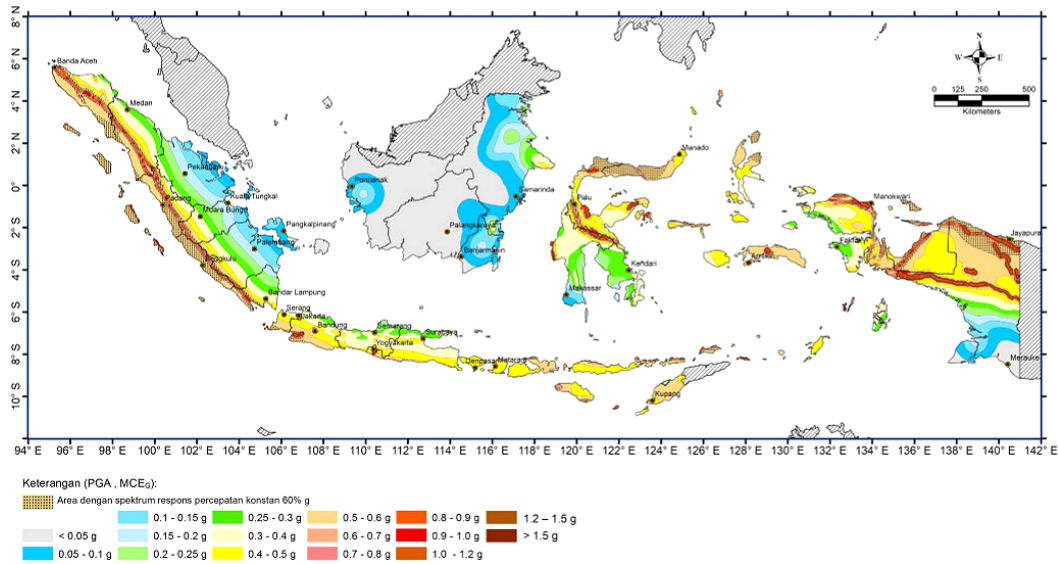
The methodology of this research consists of three different main steps includes loading estimation, modeling,

and data processing from the available model. Each of them starts with a proper literature review and is described in the following explanations. All the steps used in this research must fulfil an aim to get housing with the following criteria: comfortable, easy to be built or renovate being permanent housing and effective in cost.

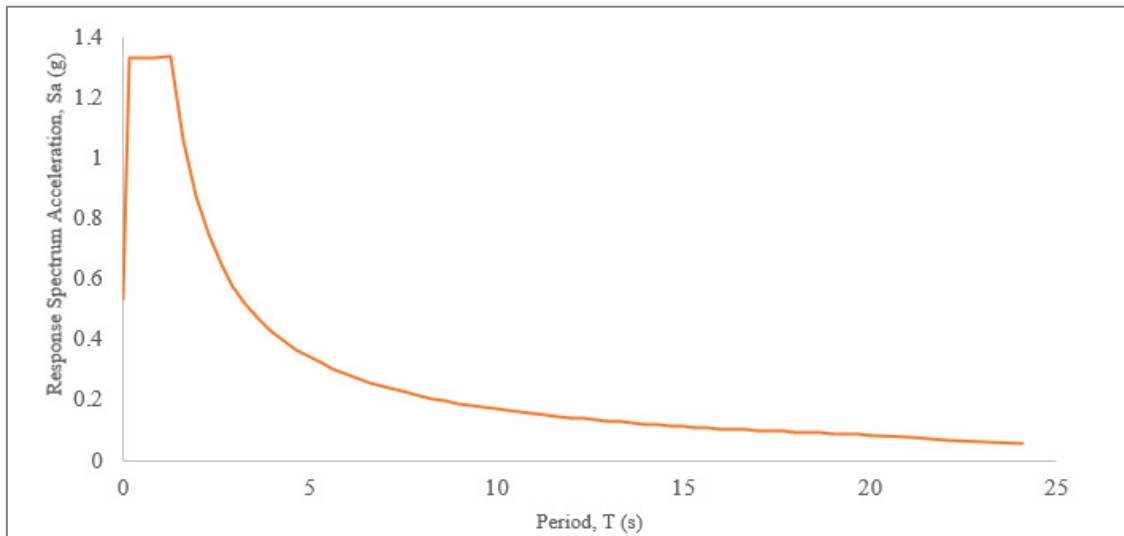
**Loading Estimation**

It is expected that the proposed design in this article can

be widely used in Indonesia, especially for the region where the earthquake potential hazard is very high. High seismic risk regions in Indonesia are pictured in RSNI 03-1726-201x (Badan Standarisasi Nasional, 2019). As seen in figure 2, almost every region in Indonesia has a risk of an earthquake disaster. Therefore, there is a region that has a higher potential seismic hazard, as seen in a higher number of PGA of that region.



**Figure 2.** Earthquake Peak Ground Acceleration Maps (Badan Standarisasi Nasional, 2019)



**Figure 3.** Response Spectrum Loading (Badan Standarisasi Nasional, 2019)

**Table 1.** Seismic Parameter (Badan Standarisasi Nasional, 2019)

Location	PGA (g)	S <sub>s</sub> (g)	S <sub>1</sub> (g)	F <sub>a</sub>	F <sub>v</sub>	S <sub>MS</sub> (g)	S <sub>M1</sub> (g)	S <sub>DS</sub> (g)	S <sub>D1</sub> (g)	T <sub>0</sub> (s)	T <sub>s</sub> (s)	T <sub>l</sub> (s)
Yogyakarta	1,5	2	1,5	1	1,7	2	2,55	1,333	1,7	0,157	0,784	20

**Table 2.** Seismic Parameter for Building (Badan Standarisasi Nasional, 2019)

Location	Risk Category	I	Seismic Design Category	R	Seismic Resistance System
Yogyakarta	II	1	D	4,5	Intermediate -Moment Resistance Frame

In this paper, Yogyakarta city is used as a model location with 1,5g PGA value and assumed that both locations have soil category SD (medium soil). Yogyakarta itself chosen because of pointed as one of the cities in Indonesia that has a higher value of PGA (as seen in figure 2) and other seismic parameters. Another reason is, Yogyakarta earthquake attack in 2006 has made 390.077 house collapsed (Yuwono, 2017), this number is higher than in other cities, so the seismic risk needs attention.

**Table 3.** Design Load

Component	Load Values	Unit
Cold-Formed Steel	7850	kg/m <sup>3</sup>
Lightweight Wall Panel	600	kg/m <sup>2</sup>
Roof	10	kg/m <sup>2</sup>
Wall Panel	10	kg/m <sup>2</sup>
Rain Load	20	kg/m <sup>2</sup>

For his seismic loading process, some parameters that are necessary to draw response spectrum function are in table 1.  $S_s$  and  $S_1$  values are extracted from the Seismic Code maps. Seismic maps to be extracted as the same configuration with PGA Maps in figure 3 with different colors and values. After extracted that values, we need an assumption of soil to gain  $F_a$  and  $F_v$  value,  $F_a$  and  $F_e$  itself is site classification. Using medium soil as an assumption value of  $F_a$  can be gained. Then, the value of  $S_M$ s and  $S_{M1}$  can also be gained, after multiplying  $S_s$  with  $F_a$  and  $S_1$  with  $F_v$ .  $S_D$ s and  $S_{D1}$  are the design spectral acceleration that is the result of two per three multiplied with  $S_M$ s and  $S_{M1}$ .  $S_D$ s and  $S_{D1}$  values are used to define the value of  $T_0$ ,  $T_s$ , and  $T_L$  in making a response spectrum graph. The response spectrum of Period versus Acceleration resulted from available parameters for both cities is captured in figure 3.

Another parameter that has to be defined is the building parameter. These building parameters are used to define scale factor in response spectrum function loading, include  $I$  (seismic primary factor) and  $R$  (Coefficient of Response Modification) based on RSNI 03-1726-201x (Badan Standarisasi Nasional, 2019). The required parameters are described in table 2. Moreover, besides seismic loading, some loads needed to assume for this design process. The load is defined under Indonesia National Standard (Direktorat Penyelidikan Masalah Bangunan, 1981) (Badan Standarisasi Nasional, 2013a). All the required loads other than the seismic load that is used are described as: roofing panel with load maximum load values 10 kg/m<sup>2</sup> and rain load used is 20 kg/m<sup>2</sup>, as seen in Table 3.

### Design Modelling

Design modeling in this article uses a finite element based structural analysis program. Firstly, the proposed design from the architect is processed by using a linear model to find the optimal size of each structural element. The proposed housing architectural design in a three-dimensional model and floor plan are captured in Figure 4. The design is chosen to accommodate enough room for earthquake victim's family needs. Three-dimensional models have been used for structural analysis.

All the materials used in the proposed model are based on the Cold-formed steel catalog from the Ministry of Public Works (Kementerian Pekerjaan Umum, 2018) that also based on SNI 7971:2013 (Badan Standarisasi Nasional, 2013b). The model has been running automatically using AISI-LRFD96 design code (Brockenbrough, 1996) to check the stress ratio before manually recalculated using Indonesia's Code. The design of the roof trusses frame used in this proposed construction model used previous research by Wuryanti using the C75 profile (Wuryanti, 2018). This frame has successfully resisted 14.083 N loads.

Half-height of the wall is designed using a masonry panel. Masonry panel used in this proposed model is defined as an equivalent diagonal strut. For linear analysis in previous research found (Amalia & Iranata, 2018) that as substitution of masonry panel Holmes equation (Holmes, 1961) is the closest to the experimental test of Mehrabi (Mehrabi, Shing, Schuller, & Noland, 1996). Equivalent diagonal strut defines in the structural analysis must have the same thickness and elastic modulus with the masonry panel. Meanwhile, the calculation of the equivalent width of the strut ( $w$ ) to be input can be calculated as 1/3 of the diagonal length of the infill panel.

The response spectrum load function is entered as a user-defined function using .txt table from the formula specified before. Scale factor to be entered are derived from the multiply of  $I$  (primary seismic factor) and  $g$  (gravity acceleration of 9,81 m/s<sup>2</sup>). That value than derived by  $R$ . So, the scale factor calculated for this model is 2,1778 for the major axis, and the thirty percent of that value in the minor axis is 0,6533.

## 3. Result and Discussion

All the results presented here have been through a proper structural analysis process. From the modeling process, there are some results gathered, include a three-dimensional model in structural analysis software.

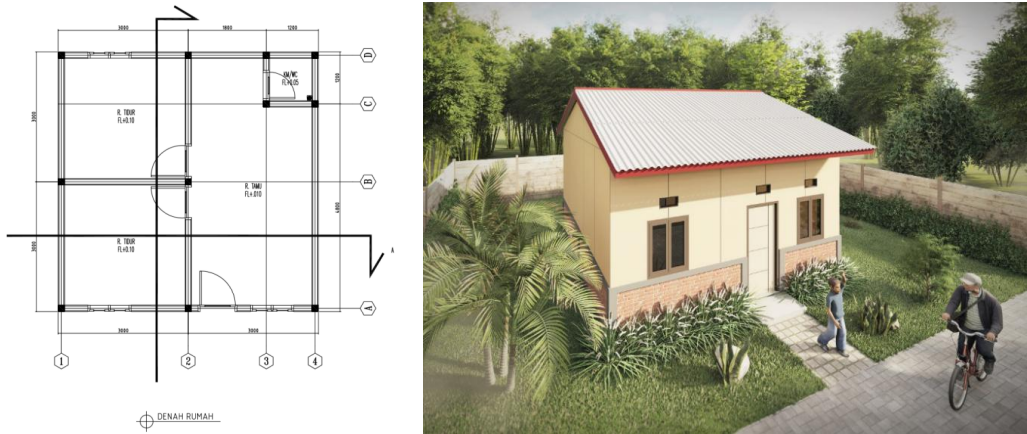


Figure 4. Response Spectrum Loading (Badan Standarisasi Nasional, 2019)

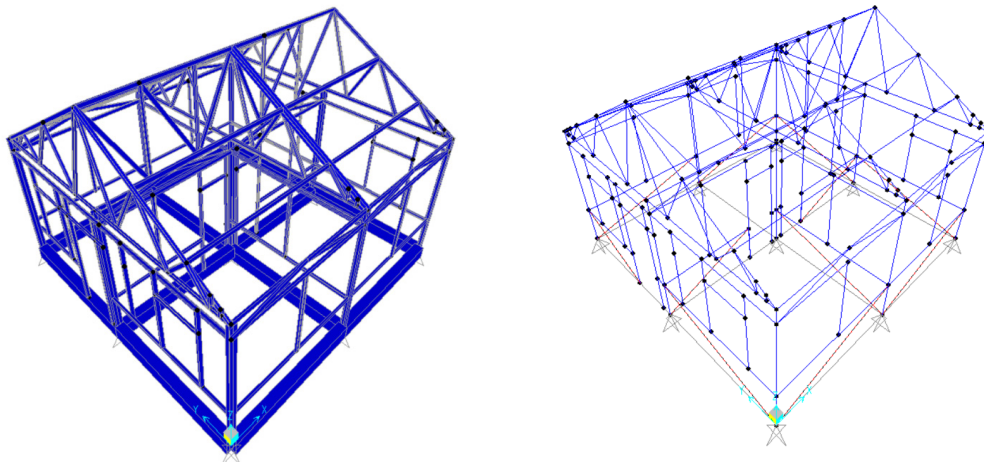


Figure 5. Three-dimensional view structural analysis model

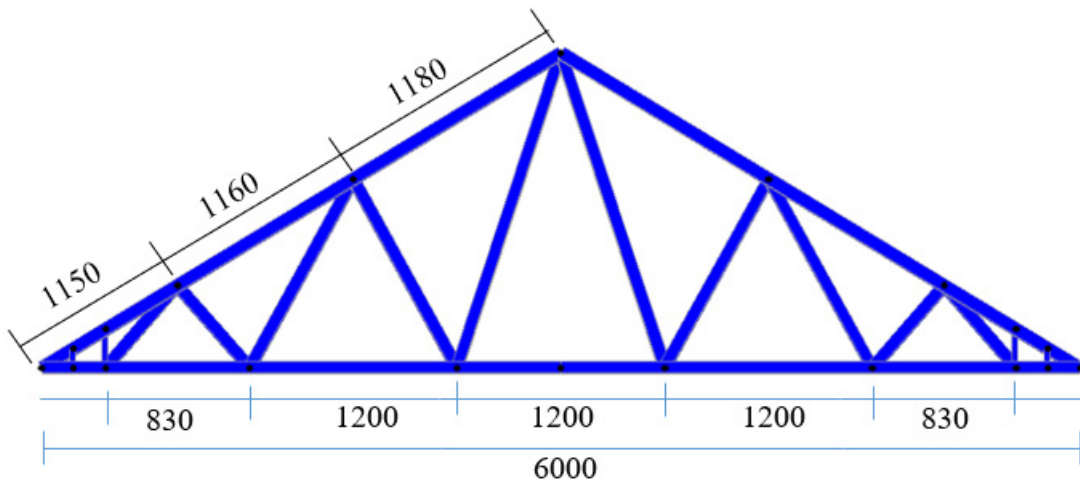


Figure 6. Trusses frame roof model configuration

**Table 4.** Material weight summary

Section	Total Weight
Lip C75.35.0,75	196.54
Lip C80.35.0,75	65.25
Double Lip C75.35.0,75	156.99
Double Lip C100.50.2,3	143.99

The first section of this result is directed to the layout plan and three-dimensional view of this proposed building, as presented in figure 4. The layout of this housing consists of two main bedrooms, one functional room, and one bathroom inside the house. Bedrooms are separated using a wall panel, 90 cm masonry wall height are designed around the building and in the required cover or separating panel. As the previous description, the masonry wall is defined as equivalent diagonal strut using Holmes equation. The three-dimensional view of this proposed building designed to has a simple view and enough ventilation. All this proposed design has already been adjusted to available previous research.

Figure 5 shows the three-dimensional view of the structural analysis model; the left side of figure 5 is the extrusion mode of the three-dimensional structural analysis model. As seen in the picture above, the model uses the moment resistant frame system that connected every column in this designed building using a beam. As described in the previous chapter, the masonry wall in the modeling projected as equivalent diagonal strut using Holmes equation. The diagonal strut presented as a red line (right side of figure 5).

The Wall panel frame in the model required Lip C75.35.0,75 profile to accommodate slenderness control in the structural analysis, even though the stress ratio is relatively low at 0,25 on average. The roof trusses frame in this proposed design is using the lip C75.35.0,75 profile. The model of trusses using the same configuration as Wuryanti's trusses, unfortunately, due to the higher value of load in the midspan of this proposes design. The primary compression member of the trusses frame is changed to the double lip C75.35.0,75. This model is suggested to have a moment-resisting frame system that has a beam and column as a primary member to resist seismic loading. The column in this proposed design using C type profile but with higher thickness, double Lip C100.50.2,3. The beam used in the design model consists of C80.35.0,75 that stiffed in the middle joint using a diagonal brace. The purlin is using lip C75.35.0,75.

The material summary of this model is presented in table 4. From the cold-formed material summary of this model, 526 kg of cold-formed material needs to be used for one housing. If we assume that the price per kilograms of cold-formed material is 17.000 rupiahs, so the total budget for material only is around 9,6 million rupiahs. This price is still reasonable with the resistance offered by this housing.

## 4. Conclusions

Every country that is in earthquake-prone areas must have its mitigation action to withstand the natural disaster. The post-disaster management includes planning for housing for victims of the earthquake in the affected area. Recently, there are so many earthquakes happens that made thousands of houses damaged, and thousands of fatalities also counted. After earthquakes disaster, people in that disaster area suffer in the social, economic, and physical integrity of life. In a chaotic post-earthquake situation, the house is not only a vital element to re-establish normalcy of the life of the affected people, but also prevent the rising of deaths and the spread of diseases, once personal hygiene conditions and protection against external factors are ensured. So, there is an urgent need for protection and shelter.

Moreover, earthquake resistant temporary housing becomes the priority for the victims after their own houses have collapsed in disaster. Making a temporary housing that can withstand another earthquake strike and fulfil the need for owner needs in safety feeling and limited budget is a challenging one. Therefore, all those factors had created an idea about designing temporary housing and studying its behavior under seismic loading.

Furthermore, Indonesia's Ministry of Public Works has researched earthquake-resistant buildings, in this case, for housing. This product called RISHA (Instant Simple and Healthy House) and RUSPIN (Instant Panel System Eminent Housing). The material used for RUSPIN is the same as RISHA, which is formed from precast concrete. However, because they still use precast concrete, so if it is constructed in the post-earthquake area, material transportation will be a problem as well as limitation of production if it only depends on one type of material. In 2018, Institut Teknologi Sepuluh Nopember also launched Huntara 1.0 (Hunian Sementara/Temporary Housing). This Huntara has 34,56 m<sup>2</sup> areas and were derived from wood material (ITS News, 2018). These materials are easily obtained from nature or forest around the affected area. Unfortunately, this material's quality and durability cannot be ensured.

An alternative material for housing construction nowadays was proposed. That material is cold formed, cold-formed steel (CFS) structural elements itself has seen a dramatic expansion in the range application over the past decade. In this article, a 36 m<sup>2</sup> temporary housing design using CFS material was proposed. The housing consists of two bedrooms and one functional room.

The model was assumed to be built in Yogyakarta, one of the regions that have the highest value of PGA in Indonesia. Another assumption used in this model is the roof and wall panel that has no more than 10 kg/m<sup>2</sup> load, 20 kg/m<sup>2</sup> rain loads, and 40 kg/m<sup>2</sup> wind load. The stress ratio check is automatically done using AISI LRFD 96, then manually checked using Indonesia's code. The model also accommodates the stiffness of the masonry panel using

Holmes equation for infill panel's equivalent diagonal strut.

The roofing system used in this temporary housing using the trusses frame, using the same configuration as Wuryanti's research of trusses that consist of the C75 profile. The modification of this configuration has been done only in the primary triangle compression member in the midspan. The Lip C75.35.0,75 profile has to be improved to double the Lip C75.35.0,75 profile. The column in this proposed design using C type profile but with higher thickness, double Lip C100.50.2,3. The beam used in the design model consists of C75.35.0,75 that stiffed in the middle joint using the truss system. Overall design need 563 kg of the cold-formed section, and the material the only price should be roughly 9,6 million rupiahs, and this price is still relatively reasonable.

Near in the future, the prototype making, and experimental loading test are required to be done to ensure the safety of this proposed design to be used extensively. Join relation with cold-formed industry sector to create proper and easy to construct design are the next aim. That leads to the possibility of a faster recovery in the post-disaster area that supports mitigation after an earthquake.

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