



The Post-disaster House: Simple Instant House using Lightweight Steel Structure, Bracing, and Local Wood Wall

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ABSTRACT

Losing a house is the biggest threat to people during natural disasters, such as earthquakes that are frequent natural hazards in Indonesia. Post-disaster housing reconstruction becomes a construction challenge to build adequate houses contributing to personal safety, health and comfort. The invention of a simple ergonomic instant house using lightweight steel structure, bracing, and the local wood walls is urgently needed. This invention is proposed to provide quick and low-cost mass construction house which meet safety and comfort requirements. The house is designed in 6 meters by 3.5 meters while the height of the ceiling is 2.8 meters. The house's front side is equipped with a door and a window, while at the back is equipped with a window. The six criteria for appropriate technology are considered in the construction method. The criteria include technical, ergonomic, social and cultural, energy-saving systems, and environmentally friendly. The scheme of systemic, holistic, interdisciplinary and participatory (SHIP) is considered at stages of design, construction and maintenance. The structure system is analyzed with a 3D model of the finite element method using SAP-2000. The given questionnaires' feedback assesses the satisfaction of the residents living in the house. The conclusions are included in five substances: (1) The house materials are lightweight steels, bracings, and local wood; (2) The structure should meet the safety requirement; (3) The house satisfies the requirement of safety and health; (4) The residents are satisfied and positively improve their living conditions following the disaster; (5) The house satisfies a simple ergonomic house.

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1. INTRODUCTION

A nation ravaged by earthquakes has significant reconstruction problems after disasters [1, 2]. The damages of buildings, including houses, have been the most severe risk in the aftermath of natural disasters and earthquakes in Indonesia's archipelago, including Bali. After disasters, reconstruction of housing is becoming a challenge to create suitable houses for the community [3–6]. This obstacle is an important aspect of the rebuilding process after the earthquake [7]. The other task of providing an appropriate post-disaster house is to manufacture housing units for construction after an earthquake within a certain period and in mass numbers [1]. Many ring of fire areas, like Bali, are also facing this

threat, located in the tropical region and the fire ring, Bali is at high risk for natural hazards, including earthquakes [8]. Bali's earthquakes in 1815 and 1917, well known as "gejer Bali," caused numerous casualties of 10.253 people and 1500 people to lose their lives [9]. The other earthquakes in Bali that caused casualties and buildings' damage, including houses, were in Buleleng in 1862, known as the Buleleng earthquake; Seririt in 1976, called Seririt earthquake [10]; and Negara in 1890, called Negara earthquake [11]. Several other earthquakes also led to material loss. The earthquakes taking place outside Bali can also impact Bali. The earthquake with magnitude of 6.4 on the Richter scale on 29 July 2018 and the other one with a magnitude of 7 on the Richter

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scale in Lombok on 5 August 2018 [12] destroyed many buildings in Bali.

This paper then argues that instant houses need to be constructed for those whose areas are seriously affected by the earthquake as shelters and a temporary residence for the victims. A simple house with the structural system of lightweight steel structure, bracing and local wooden walls, which is sheltered but resistant to absolute earthquake magnitude and still endow with comfortable, are needed. A lightweight steel structure has strong seismic impact properties in an earthquake-prone environment [13]. This structure's benefits are economical, weight decline, excellent moisture type stability, fast site installation, easy prefabrication, good reusable recycling, and possible reuse [14]. This system can also be constructed within a short period, relatively inexpensive, environmentally friendly, secure, comfortable and accessible.

2. METHOD

To examine this system, a lightweight weight steel structure, bracing and local wooden walls house as a mockup structure was constructed in Selemadeg Bali. The building applied six criteria of efficient technology (technical, ergonomic, socio-cultural, energy-saving and environmentally friendly). These criteria were combined with the SHIP approach (systemic, holistic, interdisciplinary and participatory). This approach aims to produce appropriate, environmentally friendly and energy-preserving technology that matches local wisdom [15]. Both approaches are applied from the design, construction and maintenance stages [16].

To evaluate the building's performance as a post-disaster building, this paper then investigated three aspects: building structure performances, physical comfort, and people's perception. The building structure's performances were analyzed using the Finite Element Method (FEM) and based on IBC 2009 to determine their safety level. The Finite Element Method is one of the most widely used numerical methods in engineering. This method attempts to solve partial differential equations and other integration equations that result in the discretization of continuum objects. This method is known to be quite effective in solving a structure analysis. In this method, the simulation of the structure was analysed using the SAP-2000 computer program. In this structural examination, some elements were investigated, including static and live loads that were the main components to analyze building structured. Since the building is located in the ring of fire and tropical regions, the earthquake and wind loads were also important in analyzing the structure's stability.

On the other hand, the house's physical comfort, including humidity, temperature, wind speed, noise and

lighting, was measured in the built-up structure. This physical comfort is related to the ergonomic components that are associated with the occupants' satisfaction. People's expectations of safety, subjective comfort and satisfaction were then analyzed using questionnaires after the respondents used the structure for daily activities. These components are evaluated because they were related to the perception of people that used the structure.

3. RESULTS AND DISCUSSIONS

3. 1. The Characteristics of the Sample House

The house mockup was constructed as shown in Figure 1. Steel bracing was used since the method is easy to be applied and has low weight [17]. The construction took one week and one week for finishing such as painting and floor tiling. The construction was started from preparing the land (Figure 1a) and followed by constructing the concrete brick foundation (Figure 1b).

The lightweight steels and the concrete bricks were then built (Figure 1c) on the foundation. The final step was the installation of wooden walls on the concrete brick walls, floor tiling and painting the wall (Figure 1d.). The system used the structure's honesty, like the Balinese building when structural elements reveal and exhibit their purposes and materials [18, 19]. The Characteristics are presented in Table 1

3. 2. The Performance of the Building Structure

Structure performance is defined as the horizontal deviation ratio of the building peak divided by the total building height (H_{sx}). The building's performance was analyzed on three dimensions that evaluated the working earthquake weight before the maximum horizontal deviation was determined using SAP-2000 (Figure 2).

According to the loading characteristics and the post-disaster house design's actual working conditions, the structure's load could be analyzed. The paper analyzed the loads modeling, including static load, which consists of the weight of the structure, walls, floors and roofs, and live load, which is the external loads acting on the structure such as the weight of users, occupants or movable furniture (Figure 3). Since the environmental conditions are important and influence the structure, the temporary loads, including earthquake and wind load, were also analyzed (Figure 4). This figure shows the earthquake response spectrum for the Bali region to determine the earthquake load received by the structure.

Based on the three-dimensional analysis of SAP-2000, the maximum horizontal deviation of the building was 21 mm in the transverse direction (x) and 15 mm in the longitudinal direction (y). Meanwhile, the building's height from the floor to the peak (H_{sx}) was 4200 mm.

The structure performance was evaluated by multiplying 0.02 with H_{sx} ($0.02 \times H_{sx}$), in which, based

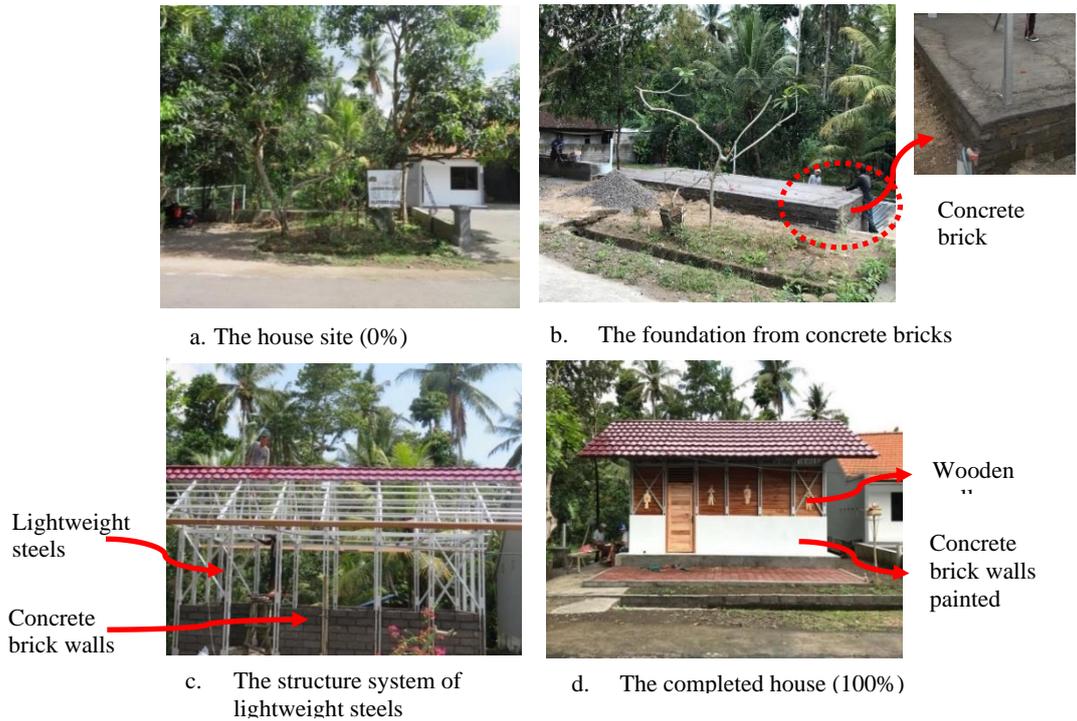


Figure 1. The construction stages of the instant simple house with the structural system of lightweight steels, bracing and local wooden walls

TABLE 1. Characteristics of the instant simple house

No.	Specification	Value	Unit
1	The length of the building	6	m
2	The width of the building	3.5	m
3	The height of the building	4.2	m
4	The structural system of lightweight steels	40	m2
5	Metal tile roofs	51.2	m2
6	Local wooden walls	23.5	m2
7	Concrete walls covered with plaster	18	m2
8	A door	1.6	m2
9	Windows	0.8	m2
10	The ceramic floor	20	m2
11	Concrete foundation	18	m

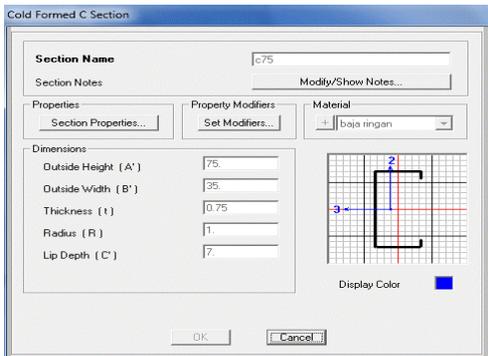


Figure 2. Dimensional modeling of the structural system of the house

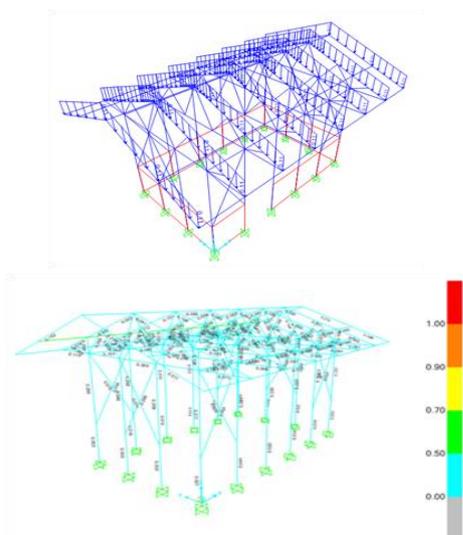


Figure 3. Static and live load

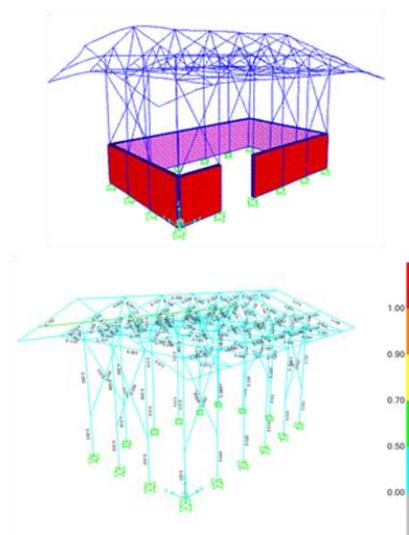


Figure 5. Deflection and the stress ratio

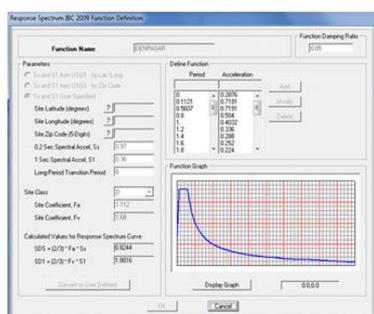


Figure 4. Earthquake and wind load

on the data, the structure is in good condition. This good performance can be analyzed since the result is 84 mm in which the result was less than the allowable value.

The stress ratio for all structural components resulting from peak, wind and earthquake loads can be described by colors in which green means under 70% and light blue means under 50%. Based on the SAP-2000 analysis, the post-disaster house structure's stress ratio was less than 50% in the lightweight steels and less than 70% on the foundation (Figure 5).

3.3. The Physical Comfort

The aspects of measuring the physical comfort consist of the humidity,

air temperature, wind velocity [20], natural illumination and noise. These parameters were measured at 6 AM, 8 AM, noon, 2 PM, 4 PM and 6 PM. The higher humidity was at 6.00 AM (82.1%), while the lowest (63.2 %) was at noon. The results contrasted with the temperature where the higher temperatures were at noon and 2.00 PM (30.6 °C and 31.5 °C). These results parallel to the natural illumination in which the highest was at noon (260 lux) and the lowest was at 6.00 PM (135 lux). The detail of the results is presented in Table 2.

3.4. The People's Perception

The information on the people's perception of the instant simple house was obtained through questionnaires. The perception, which was measured, included security, subjective comfort, adaptive comfort, and satisfaction. Mostly, the respondents thought that the structure was secure, comfortable and satisfied (Table 3).

TABLE 2. Physical comfort of the house

No	Description	The time when it was measured (Bali Time)						
		6:00 AM	8:00 AM	10:00 AM	12:00 AM (noon)	2:00 PM	4:00 PM	6:00 PM
1	Temperature (°C)	15.2	26.8	28.8	30.6	31.5	29.5	29.2
2	Humidity (%)	82.1	84.1	75.6	63.2	68.5	72.8	77.6
3	Noise (dBA)	44	41	43	38	45	43	44
4	Natural Illumination (lux)	150	185	230	260	255	225	135
5	The wind velocity (m/second)	0.1	0.15	0.1	0.2	0.2	0.1	0.1

TABLE 3. People's perception

No.	Number of Samples	Description of Perception	People's Perception
1	11	Security	Secure
2	11	Subjective comfort	Comfortable
3	11	Thermal comfort	Comfortable and acceptable
4	11	Satisfaction	Highly satisfied

3. 5. Discussion

3. 5. 1. Performance and Security of the Structural System

The structural system showed a highly good performance based on the deviation to the building's height towards both the house's width and length. The structure performance value that was 84 mm means that the value was less than the allowable value. This value presented that the structure was in a good performance. The stress ratio under 70% demonstrated that the structure could address the loads on the structure.

The analysis of the earthquake load on this structure was necessary. Many researchers such as Yosafat [21], and Almeida et al. [22] suggested that the structure resistance to the earthquake loads was highly prominently evaluated since most parts of Indonesia's earthquake intensity, including Bali, ranges from being moderate to high. Based on the Indonesian National Standard, the stress ratio smaller than 70% means that the house was satisfied and secure to be used, based on the requirement.

3. 5. 2. The Physical Comfort

The house's physical comfort is affected by temperature, relative humidity, wind velocity, lighting, and noise. The house's temperature ranged from 25.2°C to 31.5°C (Table 2). These data demonstrated that the average temperature was 28.8°C. This temperature level produced thermal comfort for the occupants or users based on the requirement of thermal comfort level in the equator (22.5°C to 29.5°C [23] or 22.8°C to 30.2°C [24]).

The comfortable temperature was also parallel to the humidity in which relative humidity (RH) of the outdoor and indoor was almost similar, between 62.3% and 84.1%. It is better and safer if the RH is higher than 20% all year, 60% during the dry season, and under 80% in the winter [24]. RH more than 80% may cause less comfortable, disrupt the health of the inhabitant, and cause fungus on the skin.

The wind speed influences the percentage of RH. The wind movement influences the velocity of lost heat through evaporation and convection. The wind speed requirement for human comfort ranges from 0.1 to 0.3 m/s [23, 24]. It would be better if the wind speed is higher than 0.2 m/s [25]. These requirements have been fulfilled by the sample house in which the room's wind velocity

ranged from 0.1 to 0.2 m/s during day time. However, at night it was 0 m/s as the ventilation and window were closed. When the window and door closed, the fresh outdoor air could not enter inside, so that the air velocity was 0 m/s. This condition presents that the room still needs ventilations open all day to maintain the room's air circulation.

The outside wind is a potential air motion to reduce high temperatures, humidity and solar radiation in the room. The move also plays a role in air movement in the building through the ventilation. The house components, including a window installed on the front side and ventilation installed on the backside, have caused air motion and cross circulation inside the room. The fresh cooling air enters the room and pushing the hot air to the outside. This air circulation has produced indoor thermal comfort. Therefore, the thermal comfort created by this cooling air motion eliminates the need for artificial devices. This inside air circulation has impacted human healthiness and has increased the occupants' comfort [26, 27].

The natural illumination within the room during day time ranged from 135 Lux to 260 Lux. These data demonstrated that the natural illumination in the room still addressed the requirements (115 Lux) [28]. The natural illumination intensity was highly influenced by the width, position and type of the windows and door. In this structure, a window was installed at the front side, and another window was installed at the back. This position has produced cross air circulation from the front to the back and vice versa. In this term, the fresh air circulation and natural illumination were interrelated. According to Hindarto [29], the natural illumination from the window spreads into the room, and the air circulation in the room has caused not only comfortable but also energy efficiency [30] in which the house does not need another illumination device.

The natural illumination makes the room brighter and healthier. The sun's daylight penetrated the house so that the use of artificial illumination could be reduced. This condition influenced the maintenance and operational cost of the house [31]. The natural illumination could also kill any germs or bacteria that can grow well in a humid environment. The natural daylight is also related to Vitamin D, which is useful for the bone and skin [28].

Moreover, the maximum noise within a room during daytime is 45 dBA, which is still under the noise standard in Bali in which the standar is 50 dBA during day time and 45 dBA at night [32].

3. 5. 3. People's Perception

The people's perception of the building, which was already constructed, was positive in which the people feel secure and comfortable. In these terms, construction solutions have been proposed to improve human comfort, including the building's thermal performance [30]. The

environmental condition, which includes the temperature, humidity, noise, natural lighting and the wind velocity, made the people feel comfortable.

They were also satisfied with the building materials used, the construction process and the final result of the house. The instant simple house construction satisfied what is required to be healthy, secure, and ergonomic. This condition contributed to the living quality of its dwellers. If a house can fulfill its dwellers' needs and desires, it acts as a facility capable of improving the quality of life of its dwellers.

4. CONCLUSIONS

Located in the tropical region and the ring of fire, the Bali's construction practices and analysis are influenced by natural hazards, including earthquakes and environmental conditions such as wind, humidity, temperature, natural illumination and noise. In order to investigate the safety, the computer modeling of the structure was analyzed with the finite element method using SAP-2000. This method was an effective way to analyze the stress and stability of the structure. On the other hand, the satisfaction and comfort of the occupants were investigated through questionnaires.

The instant simple house using lightweight steel structure, bracing and local wooden wall has fulfilled the requirement. The structure has produced the structural system that has met the safety requirements in terms of static, live, earthquake and wind loads. Through analyzing these four aspects, the house could be safely used by occupants.

In terms of comfortable and perception of the occupants, the house designed was also to fulfill the requirements to safety and positively improve their living conditions after the disaster. Since the house produced comfortable and satisfying to the occupants, the house also addressed the ergonomic requirements.

However, the house designed should be installed ventilation so that at night, where a door and windows were closed, the fresh air can effectively enter the house and produce thermal comfort for the occupants.

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Persian Abstract

چکیده

از دست دادن خانه بزرگترین تهدید برای مردم در هنگام بلایای طبیعی مانند لرزه‌هایی است که مکرراً خطرات طبیعی در اندونزی است. بازسازی مسکن پس از فاجعه به یک چالش ساختمانی برای ساخت خانه‌های مناسب تبدیل می‌شود که به ایمنی، سلامتی و آسایش شخصی کمک می‌کند. اختراع یک خانه فوری ارگونومیک ساده با استفاده از ساختار فولادی سبک، مهاربند و دیوارهای چوبی محلی به شدت مورد نیاز است. این اختراع برای تهیه سریع و کم هزینه ساخت و ساز خانه‌ای ارائه می‌شود که شرایط ایمنی و آسایش را داشته باشند. این خانه در ۶ متر در ۳.۵ متر طراحی شده در حالی که ارتفاع سقف ۲.۸ متر است. قسمت جلویی خانه به در و پنجره مجهز است، در حالی که در پشت به پنجره مجهز شده است. شش معیار برای فن آوری مناسب در روش ساخت در نظر گرفته شده است. این معیارها شامل فنی، ارگونومیک، اجتماعی و فرهنگی، سیستم‌های کم مصرف و سازگار با محیط زیست است. طرح سیستماتیک، جامع، میان رشته‌ای و مشارکتی (SHIP) در مراحل طراحی، ساخت و نگهداری در نظر گرفته شده است. سیستم سازه با استفاده از نرم افزار SAP-2000 با مدل سه بعدی از روش اجزای محدود تجزیه و تحلیل می‌شود. بازخور پرسشنامه‌های ارائه شده رضایت ساکنان ساکن خانه را ارزیابی می‌کند. نتیجه‌گیری در پنج ماده گنجانده شده است: (۱) مواد خانه فولادهای سبک، مهاربندها و چوب‌های محلی هستند. (۲) ساختار باید الزامات ایمنی را برآورده کند. (۳) خانه نیازهای ایمنی و بهداشت را برآورده می‌کند. (۴) ساکنان راضی هستند و به طور مثبت شرایط زندگی خود را پس از فاجعه بهبود می‌بخشند. (۵) خانه یک خانه ارگونومیک ساده را ارضا می‌کند.
