The development of structure in the limasan- and joglo-style vernacular houses after the 2006 Yogyakarta earthquake

J A Rini¹ and N C Idham²

¹,² Department of Architecture, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta, Indonesia
E-mail: johanita@uii.ac.id

Abstract. After a great earthquake hit the Special Region of Yogyakarta, Indonesia, in the year 2006, some of the owners of the limasan- and joglo-style vernacular houses rebuilt their houses according to the education they received about the principles of earthquake-resilient building. This study investigates the structural development on the 11 (eleven) houses located in the Kabupaten (district) of Bantul, which was among the areas most affected by the earthquake. The owners combined the existing wooden main structural frame withstanding the earthquake with the new reinforced concrete structural frame. The owners also conducted various structural enhancements perceived as increasing the safety against possible future earthquakes. Despite this perception of future safety, in reality some of the owners’ practice were not in accordance with the principles of earthquake-resilient buildings. This study also revealed the practice of combining two naturally different systems: the flexible wooden structural frame and the rigid reinforced concrete structural frame.

1. Introduction

Years have passed after a great earthquake hit the Special Region of Yogyakarta, Indonesia, in the year 2006, and the owners of the damaged houses have repaired and rebuilt their houses. Some of the owners chose to preserve the limasan or joglo vernacular style by maintaining the existing houses’ main structure withstanding the earthquake. Limasan and joglo are two vernacular styles which are most favoured in Central Java, Yogyakarta, and East Java [1]. The wooden main structural frame of most of the limasan and joglo-style houses remained functional and reusable after the earthquake.

The owners were given the chance to rebuild their houses independently through a program called community-based settlement [2], and various choice of forms, sizes, and structural types were accommodated. This resulted in combinations of various structural materials and structural systems, for example a combination between wooden structural frame and reinforced concrete structural frame. The owners have also been given education on the principles of earthquake-resilient buildings both from government and by non-government organization [3].

These combinations between different structural systems may result in various consequences. For example, the combination between wooden structural frame and brick load-bearing wall has been proven more prone to the earthquake. In the occurrence of real earthquake, this combination may give mixed reactional forces since the constructions have both flexible and rigid characteristics [4]. This kind of issue must be taken seriously since the combination of structural frame and brick infill wall is quite popular. If the structural frame is not constructed properly as a closed portal or closed system, the brick infill wall will act as load-bearing wall and this may result in structural vulnerability.
Independent development or enhancement of the structure by the owners may also affect the effectivity of the application of the principles of earthquake-resilient building such as selection of soil type and slope stability, mass configuration and floor plans, design of openings, building weight, stiffness, strength, dimensions of structural components, quality of structural materials, and construction processes [5,6,7,8]. In principle, the basic configurations of limasan- and joglo-style houses mostly concur with those principles. It is important to observe whether the newest development of these limasan- and joglo-style houses still maintain or conversely violate the resilience principles.

Beside the technical factors, perceptual factor also determines the building’s resilience against earthquake. The owner develops or enhances the structure according to certain manner because the owner perceives that manner as increasing safety in terms of earthquake. However, it must be evaluated again whether the perception and assumption of the owners do concur with the actual principles of earthquake-resilient buildings. Mistaken perception or flawed understanding may result in a false sense of security which in turn may be harmful for the inhabitant in the case of possible future earthquake.

2. Materials and Methods
The investigation was conducted upon 11 (eleven) vernacular houses consisting of 9 (nine) limasan-style houses and 2 (two) joglo-style houses, as seen in Table 1. These houses are located at the Kabupaten (district) of Bantul. Among the districts of the Special Region of Yogyakarta, this district was the area most affected by the 2006 earthquake. During and after the earthquake, all these houses endured heavy and light damages, and the owners have conducted structural repairs. According to the interviews, these owners have been educated on earthquake-resilient houses, both from the government and the non-government organizations, both in formal programs and on informal occasions.

| Table 1. Limasan- and joglo-style houses investigated in this study. |
|---------------------------------------------------------------|
| 1 (Limasan) | 2 (Limasan) | 3 (Limasan) | 4 (Limasan) |
| ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) | ![Image](image4.png) |
| 5 (Limasan) | 6 (Limasan) | 7 (Limasan) | 8 (Limasan) |
| ![Image](image5.png) | ![Image](image6.png) | ![Image](image7.png) | ![Image](image8.png) |
| 9 (Limasan) | 10 (Joglo) | 11 (Joglo) |
| ![Image](image9.png) | ![Image](image10.png) | ![Image](image11.png) |

Rapid visual screening is a method developed to identify the structural vulnerability of a building in a rapid manner. Usually, the conditions of various structural aspects were quantified through simple scoring [9]. For this study, the rapid visual screening was conducted despite without the quantitative scoring. The aspects of the houses which were observed for this study are: front elevation, side
elevation(s), main structure, construction details, and joint details, as seen in table 2. Interviews with the owners were also conducted to obtain information about what types of repairs have been conducted to increase the houses’ resilience against earthquake. Furthermore, these interviews also revealed the owners’ perception of their houses’ safety in case of possible future earthquakes.

Table 2. Example of data obtained by rapid visual screening in limasan-style house number 5.

| Front elevation | Left elevation | Right elevation |
|-----------------|---------------|----------------|
| ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |

| Main structure | Construction detail | Construction detail |
|----------------|---------------------|---------------------|
| ![Image](image4.png) | ![Image](image5.png) | ![Image](image6.png) |

3. Results and discussions

The results of the visual screening are then analyzed according to the choice of structural system and materials, structural enhancement, and the owners’ perception of the houses’ resilience against earthquake.

3.1. The choice of structural system and materials for the post-2006 earthquake house developments

In the most original form, limasan- and joglo-style vernacular houses are fully built with wooden structural frame system. Throughout the development, these houses started to adopt the bearing wall structural system [4]. However, all the vernacular houses investigated in this study have been developed by incorporating the reinforced concrete frame as the main structural system as shown in figure 1. The reinforced concrete frame was generally used for the houses’ perimeter and filled by brick wall.

Figure 1. The combination of a wooden central frame structure (rong-rongan) with a reinforced concrete perimeter frame in house number 11.
As structural system, the wooden frame was still used mainly for the central part of the houses and for the main structural frame of the roof. This type of example can be observed in the joglo-style houses number 10 and 11, as shown in figure 2. These houses still utilize the rong-rongan (the wooden structural system forming the central part of the joglo-style house) which survived the 2006 earthquake. Likewise, some of the limasan-style houses such as houses number 2 and 5 are still preserving the wooden structural frame forming the central part of the house as well as the main frame of the roof, as seen in figure 3.

**Figure 2.** The use of the existing wooden central frame structure (rong-rongan) in houses number 10 and 11.

Despite preserving parts of the wooden structural frame, all these houses have already combined the wooden structural system with reinforced concrete frame as seen in figure 4. At the joglo-style house number 11, the original wooden perimeter structural beams have been replaced by reinforced concrete beams. Likewise, at the limasan-style house number 6, the original wooden structural frame of the roof has been combined with (i.e., not replaced by) reinforced concrete beams.

**Figure 3.** The use of wooden frame structures as central posts and roof frames in houses number 2 and 5.
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Figure 4. Replacement and combination of horizontal wooden frames with reinforced concrete frames in houses number 11 and 6.

This condition in which the existing wooden structural frame was combined with the reinforced concrete structural frame and brick infill wall brought some consequences. In principles, reinforced concrete structural frame and wooden structural frame respond to earthquake in different manners. Reinforced concrete structural frame tends to rely on stiffness and strength [9], while the wooden structural frame found in vernacular houses tends to be non-rigid and permit rotating moments on the joints in the event of earthquake [10]. If the reinforced concrete structural frame combined with the wooden structural frame is not constructed properly, the house may be even more prone to earthquakes.

This type of potentially harmful combination can be observed at the limasan-style house number 4, where the reinforced concrete structural frame has not been completed into a closed frame. As seen in figure 5, the side and rear walls were left without reinforced concrete perimeter beams; consequently, these walls act as bearing walls which would not be resilient against earthquake forces [4]. The insertion of reinforced concrete structural frame as the primary roof structure can also affect the performance negatively since the upper part of the house become heavy [11]. Whereas, the original wooden structural frame of vernacular roof is sufficient and suitable for earthquake-prone areas.

Figure 5. The reinforced concrete frames are not connected to form a closed portal due to the absence of perimeter beams in house number 4.

3.2. Structural enhancement conducted by the owners to increase resilience against earthquake

After being educated on the principles of earthquake-resilient building both by government and by non-government organizations, the owners conducted various enhancements on the houses’ structures to increase the houses’ resilience against possible future earthquakes. These enhancements consist of the insertion of the reinforced concrete structural frame, the use of standardized mixing ratio of the elements for the concrete, the strengthening of the foundation, the insertion of point foundations in the form of reinforced concrete footings, the insertion of reinforced concrete practical columns at every 3 m, and the
insertion of reinforced concrete structural perimeter beams to the wall at the height of 3 m. The detailed list of enhancements for each house is presented in table 3.

### Table 3. Post-earthquake structural enhancements in each house.

| No | Style | Post-earthquake structural enhancements | Owner’s perception of house resilience in future earthquakes |
|----|-------|-----------------------------------------|--------------------------------------------------------|
| 1  | Limasan | • Insertion of reinforced concrete structural frame  
• Use of standardized mixture for the concrete | Safe |
| 2  | Limasan | • Insertion of reinforced concrete footing foundations | Safe |
| 3  | Limasan | • Strengthening of the foundation | Safe |
| 4  | Limasan | • Insertion of reinforced concrete structural frame  
• Insertion of reinforced concrete practical columns | Safe |
| 5  | Limasan | • Insertion of reinforced concrete structural frame  
• Insertion of reinforced concrete practical columns | Safe |
| 6  | Limasan | • Insertion of reinforced concrete structural frame  
• Insertion of reinforced concrete practical columns | Safe |
| 7  | Limasan | • Insertion of reinforced concrete structural frame | Safe |
| 8  | Limasan | • Strengthening of the foundation | Safe |
| 9  | Limasan | • Insertion of reinforced concrete structural frame  
• Insertion of reinforced concrete practical columns | Safe |
| 10 | Joglo  | • Insertion of reinforced concrete structural frame  
• Insertion of reinforced concrete practical columns  
• Insertion of reinforced concrete perimeter beams | Safe |
| 11 | Joglo  | • Insertion of reinforced concrete structural frame  
• Insertion of reinforced concrete practical columns | Unsafe |

In general, the enhancements deemed crucial by the owners are the ones related to the insertion of the reinforced concrete structural frame and the strengthening of the foundations. This finding concurs to the tendency previously explained in the Subsection 3.1., in which the owner tends to insert reinforced concrete structural frame deemed more rigid and permanent. This tendency affects the stiffness and strength of the structure positively and increases the attachment and connectivity among the structural components. It should be remembered that the requisite for building strength is the attachment between all building frames to form a closed portal [5,6,7,8].

The owners seemed to pay less attention to other aspects of earthquake-resilient buildings, such as the size as well as the position of fenestrations and the weight of the building (or building parts). The owners still located fenestrations randomly without regards to the axis of the building and the symmetry of the mass. Relatively large fenestrations located at the edge of the mass and far from the axis can be found in some houses; there is also a façade with fenestrations all over most of its surface. Since the earthquake-resilient principles demand that the fenestrations should be small in size and located close to the building’s axis [12], this finding is negative. Likewise, in regard to the weight of the building (or building parts), the use of heavy reinforced concrete structural frame as the structure of the roof made the upper parts of the houses heavier, and this is contradictory to the principles of earthquake-resilient building [11,12].

One advantage of the relatively stable aesthetical style of vernacular houses is that the owners tended not to extremely modify the building masses into irregular configurations. The *joglo-* and *limasan-*style vernacular houses have a relatively regular and symmetrical floor plan and building mass, which already suit the principles of earthquake-resilient building [12]. The owners tended to insert partitions inside the existing building masses or built separated additional building masses.
3.3. The owners’ perception of the houses’ resilience against earthquake
Among the 11 (eleven) houses investigated, 10 (ten) owners perceived their houses as resilient against earthquake, and only one person perceived the house as still not resilient enough. However, according to the visual observation, some enhancements made by these owners were considered contradictory to the principles of earthquake-resilient buildings: reinforced concrete structural frame not forming close portal/close system, large size of fenestrations, random positioning of fenestrations, and the use of heavyweight building materials as structure for the upper part of the buildings. These findings suggest that the owners’ perception on their houses’ resilience does not always concur with the actual resilience.

This disparity between the perceived and actual resilience may be harmful in the case of possible future earthquakes. There is a tendency among the owners that they felt safe after using the reinforced concrete structural frame, and yet in utilizing reinforced concrete as structure, there are some parameters that must be controlled: the size of steel rebars, the proper manner of connecting the steel rebars, the dimension of various members of the reinforced concrete structural frame, the correct ratio for mixing the elements of the concrete, and the proper method for the in-situ casting. It is in regard of these parameters that the human error in the use of reinforced concrete structural system was occurred during the reconstruction phase of the damaged houses post-2006 earthquake. For most of the owners, it was the first time they use the reinforced concrete structural system after being used to the bearing wall system for a relatively long period [3]. Overall, there is no long-term technical assistance and community habituation to keep reminding homeowners about the benefits of earthquake-resistant houses [13]. Continuous education on the principles of earthquake-resilient building is still required.

4. Conclusion
The structure of the limasan- and joglo-style vernacular houses investigated in this study have been enhanced and developed by the owners after the 2006 earthquake by combining the existing wooden structural frame with reinforced concrete structural frame as the main structure. The reinforced concrete structural frame in general was utilized in the perimeter of the houses with brick infill wall.

After receiving education on the principles of earthquake-resilient building both from the government and the non-government organizations, the owners conducted repairs which they believe may increase the building safety, and these repairs consist of the insertion of reinforced concrete structural frame, the use of proper mixture of the elements for the concrete, the strengthening of the existing foundation, the insertion of new point foundations (reinforced concrete footings), and the insertion of reinforced concrete practical columns. In enhancing the structure, the owners tended to pay less attention to other aspects of earthquake-resilient buildings such as sizes and positions of the fenestrations and the distribution of the weight of the building parts.

Although most of the owners perceived the house as safe against earthquake, this study found that some practices were contradictory to the principle of earthquake-resilient buildings, such as reinforced concrete structural frame which does not form a closed portal or closed system, the large sizes of the fenestrations, random locations of the fenestrations, and heavyweight materials used as structure on the upper part of the buildings. The continuous education on the principles of resilience is still required to bring the owners’ perception closer to the proper standards of earthquake-resilient houses.

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