Earthquake Resistant Structures on the Traditional Houses in Indonesia

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Abstract
Indonesia is one area of potential earthquake, the awareness for designing earthquake-resistant construction is an important role in conservation of traditional houses. In fact, the results of post-earthquake investigation since 2004 show that the traditional houses have a better resistance to earthquake loads. This drew the attention of architects to relearn the local wisdom of values embodied in traditional houses. In addition, change of civilization and technological progress causes a shift in the value of life. Shift in traditional values occur in the design and method construction of house. This study discusses the assessment of the reliability of a traditional houses against earthquake loads. Use of rapid evaluation based on the building typology on the traditional houses from four big island in Indonesia. For further analysis of the seismic performance would follow “World Housing Encyclopedia”. This study is limited to the assessment structural component resistance to earthquake load.

Keywords: earthquake-resistant, traditional houses, reliability, structure

INTRODUCTION

The traditional houses are different from building to building, country to country. They can vary in structural systems, material, and environmental. Houses have being formed due to the condition of specific place, time, and culture. Indonesia is archipelago country covers more than 1700 big and small islands have almost 700 ethnic, which is reflected in the shape of a traditional house. There are two types traditional buildings built some 200 years ago and second are built during the Dutch occupation 150 years ago. The first type traditional buildings still exist in several places in Indonesia, which will be focused for this study.

This study is present a procedure for assessing the reliability of traditional house based on evaluation of structural components that characterized by earthquake resistant features. For representative of various character of ethnic, this study has selected a few of traditional houses that scattered in four different islands.

EARTHQUAKE RESISTANT INDICATORS

The art of designing earthquake resistant building, as the structural and non-structural element play a central roles in determining the structural behavior sensitivity of damage. Some forms of traditional housing construction have been achieved without any specify technical knowledge, but rather through a type of natural selection process applied to building construction. Since the constant threat of earthquake, the local population has learned the principles of earthquake-resistant construction through a trial and error process. Poor earthquake performance which caused damaged or collapsed of some building traditional due to lack of maintenance (Boen, 2007).

For a building to be earthquake resistant it must be cover three requirements; (1) configured well, (2) detailed well, (3) constructed well. Weakness in any one of these will result weak-earthquake. It is important to recognize and identify the main features to enhance seismic performance of traditional buildings.

TYPOLOGY TRADITIONAL HOUSES

There are many physical features of traditional Houses from eastern region up to western region of Indonesia. Most of the houses have primarily a practical function. They are shelters, storage rooms and places for ritual performance. Depending on the material and technology used, traditional Houses can
generally distinguish between raised-floor house and landed houses. In most of western part houses the inhabitants are living on raised floor that is proposed for the technical, hygienic, and other advantages of such a solution on muddy and often uneven tropical soil, and in environmental full of dangerous animals.

For evaluation seismic performance of traditional Houses are selected randomly in several location as shown in figure 1.

![Figure 1. Location of the selected traditional houses](image)

Typology of those traditional Houses are described as following.

**Case # 1: Rumoh Aceh**

This house located in northeast part of Sumatera Island Nangrore Aceh Darussalam (NAD) province. The house is built as a log wooden post places. Under the house, between the posts which rest on flat stones or concrete soles. The wooden mainframe of structure is H-structure formed columns and beams. The beam was passing through a post and fixed by pegging. Three part floors are not same levels.

**Case # 2: Omo Hada Nias**

This a unique house exist on Nias Island, a small island at south part Sumatera Island. The features of house in north part has oval floor plan, slanting walls all around, rows of vertical pillars and diagonal bracing (X form) in the substructure and a huge hat-like roof. The feature of south part houses have a row house-like rectangular floor plan, straight load bearing side walls, a slanting front façade, V-shaped diagonal bracing in the front façade and a very high roof. Central Nias houses have influenced North and South Nias type. These traditional houses were used only locally grown plant material. The
bracing is placed in rows inside or outside a grid of vertical columns in both direction. Four pillars connect substructure with living floor and two pillars connect living room and roof. The joints of wood elements are used elaborate mortise and tenon connections.

**Case # 3: Rumah Gadang Padang**  
Source: Munaf & Is, 2007

Rumah Gadang (a bighouse) Pagaruyuang palace located in Batusangkar, Tanah Datar, West Sumatera. The house has a long rectangular plan with multiple gables roof. Normally, the house has three-tiered up swept gable, each with varying floor levels. The structure consists of substructure built woodpiles, board floors raised on piles with wooden mainframes and multilevel floors.

**Case # 4: Rumah Joglo Java**  
Source: Sardjono, 2

Joglo house is a typical traditional house in Central Java. The system structure of house uses wood material with knock down system. Therefore, allowable to reinstall in elsewhere without physical damage of the building. The main structure consists of three elements roof frame, columns and foundations stone masonry and pedestals brick masonry.

**Case # 5: Tongkonan Toraja**

Tongkonan is a traditional house of Toraja District Southern part of Sulawesi Island. Tongkonan means sitting together where people just gather. Type structure is silts house withstood small stone. The saddle-back roof is constructed with layered spliced-bamboo. The house has a rectangular plan. The wooden structure is assembled without nail. The wooden piles are shaped and mortises cut in them to take the horizontal tie beam. The piles are notched at the top to accommodate the longitudinal and transverse beams of the upper structure.
Case # 6: Laihe Gorontalo

This traditional house can be found in Gorontalo District, North part of Sulawesi Island. This house is still house with shape of plan square. Pillars of house are vary 1m to 1,5m height that use brick masonry. Upper brick masonry foundation is tied by longitudinal and transverse beams. The material for floor and wall use wood. The wooden structure is assembled without nail.

Case # 7: Honai, Papua

This very simple house can be found on the remote area of Yahukimo District in mountain area of Papua Island. Lateral load path provided due to the shell action of cylindrical walls. The main structure consists of a single cylindrically shape room. The house has a built narrow and without window to keep warm avoids the cold mountains. This condition is favorable for the wall proportions and wall redundancy requirements.

METHODS

To assess the reability of the traditional Houses were evaluated by study the system structures of the house whether the requirements needed by earthquake-resistance have been considered. The measurement may be expressed by a numerical value to the element examined. This approach is organized in two step. The first step is collecting the structural typology of traditional house. The second step is evaluating the presence of earthquake-resistant features.

EVALUATE PROCEDURE

In order to define reliability of house performance is necessary to identify a reference to satisfy seismic requirement. The reliability assessment procedure should indicated by the strength points of a structure and given a relative measure of these consistencies. For evaluation of building simple include on vernacular building, World Housing Encyclopedia (WHE) have provide information the criteria earthquake-resistant should following:
1. Lateral load path: The structure contains a complete load path for seismic forces effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.

2. Building configuration: The building is regular with regards to both the plan and the elevation.

3. Roof construction: The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity i.e. shape and form, during an earthquake of intensity expected in this area.

4. Floor construction: The floor diaphragms are considered to be rigid and it is expected that the floor structures will maintain its integrity during earthquake of intensity expected in this area.

5. Foundation performance: There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.

6. Wall and frame structures redundancy: The number of line of wall or frames in each principle direction is greater than or equal to 2.

7. Wall proportions: Height-to-thickness ratio of the shear wall at each floor level.

8. Foundation – wall connection: Vertical load-bearing elements (columns, walls) are attached to the foundation.

9. Wall – roof connection: Exterior wall are anchored for out-of-plane seismic effects at each diaphragm level.

10. Wall – openings: The total width of door and window opening in a wall.

11. Quality of building materials: Quality of building materials is considered to be adequate per requirements of national codes and standard.

12. Quality of workmanship: Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).

13. Maintenance: Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements.

**BUILDING PERFORMANCE SCORE**

Once the earthquake-resistance of a building are obtained or met the requirement, then a score is added for every reailiability parameter. The score is ‘1’ if the criteria meet the requirement of earthquake-resistance and the opposite for score ‘0’. Since the evaluation referred on the drawing of typology house therefore the criteria of WHE’s procedure for criteria the quality of building materials, quality of workmanship and maintenance were ignored.

**DATA ANALYSIS**

Table 1 shows the relation between criteria of earthquake-resistance with house type.

<table>
<thead>
<tr>
<th>No</th>
<th>Type house</th>
<th>Seismic deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rumoh Aceh</td>
<td>Multilevel floor, short columns, unbraced sub-structure, no components embedded in the ground, soft story</td>
</tr>
<tr>
<td>2</td>
<td>Omo Nias</td>
<td>Slanting walls, no components embedded in the ground</td>
</tr>
<tr>
<td>3</td>
<td>Rumah Gadang</td>
<td>No components embedded in the ground, soft story, multi level floor, multiple gable roof, heavy roof, multi shape plan</td>
</tr>
<tr>
<td>4</td>
<td>Joglo Java</td>
<td>Soft story</td>
</tr>
<tr>
<td>5</td>
<td>Tongkonan Toraja</td>
<td>Unbraced sub-structure, no components embedded in the ground, soft story, heavy roof</td>
</tr>
<tr>
<td>6</td>
<td>Laihe</td>
<td>Joint sub-structure-upper structure, soft story, no components embedded in the ground</td>
</tr>
<tr>
<td>7</td>
<td>Honai Papua</td>
<td>No components embedded in the ground</td>
</tr>
</tbody>
</table>

**TABLE 1 SEISMIC FEATURES**

Total performance score was calculated from the initial score is reduced by factors of seismic deficiency as described in Table 1. The performance score for each house follow Table 2. Based on Table 2 indicate that no single house that the all criteria meet with the earthquake-resistance (see Table 2 below)
### TABLE 2 RELIABILITY PERFORMANCE OF HOUSE

<table>
<thead>
<tr>
<th>No</th>
<th>Criteria seismic features</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Lateral load path</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Building configuration</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>Roof construction</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4.</td>
<td>Floor construction</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>Foundation performance</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6.</td>
<td>Wall-frame redundancy</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7.</td>
<td>Wall proportions</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8.</td>
<td>Foundation-wall connection</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>9.</td>
<td>Wall-roof connection</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10.</td>
<td>Wall openings</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Reliability [%]</td>
<td>70</td>
<td>70</td>
<td>50</td>
<td>90</td>
<td>70</td>
<td>80</td>
<td>90</td>
</tr>
</tbody>
</table>

### CONCLUSION

Understanding of the structural performance of traditional houses is important. This study explores and measure earthquake-resistance features of traditional Houses in Indonesia. Recognize of local wisdom in traditional Houses is not means steadiness in the product. Traditional knowledge and qualities should not be lost but find a new and modern interpretation. For the houses that will be new, the traditional houses can be the key of many solutions. The reailyability of earthquake resistant building is influenced by the quality of construction, quality of building materials and fit in structural engineering.

### REFERENCES