Eartquake Vulnerability Level of Reconstructed Houses, Lesson Learned after Ten Years Java Eartquake 2006

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Abstract. Ten years after devastating earthquake May 27 th, 2006, housing reconstruction in the affected area has been done and development is still undergoing. Since then, houses are constructed in various forms and quality. Unrestrained housing development contributes uncertain quality of the buildings in term of building safety. This study examines the level of earthquake vulnerability on the reconstruction houses in the area according to the structural firmness. The method used is by assessing the structural completeness, especially the upper part of building elements, synchronized by the five damages classification for grouping the building affected by the quake. This method is aimed to predict damage level for the future similar earthquake. The outcome of this study shows the level of earthquake vulnerability in the every sub-district. It does also compare the level of building safety differences

Keywords: reconstruction development, earthquake vulnerability assessment, structural safety level, damaged prediction

Introduction

A strong earthquake of magnitude 6.3 struck Java Island, Indonesia, on May 27, 2006 at 5:54 am local time. The epicenter was located at 7.962°S, 110.458°E, about 25 km south-southeast of Yogyakarta with a fairly shallow focal depth, about 10 km [1].

The quake had affected two provinces Yogyakarta and Central Java of Indonesia. Due to this earthquake, 5,751 people loss of life and 29,473 injured, 145,929 houses were completely collapsed and 190,843 others were damaged [2]. This left 1.6 million people homeless [3]. The worst area destroyed was Bantul district of Yogyakarta province.

Table 1. The list of earthquake victims and houses damages (source: BAPPENAS, 2006a/the latest data, taken from Media Centre, June 17th, 2006[2].

Location	Death	Bad Injury	Light Injury	House Collapsed	House Severe Damaged	House Moderate Damaged
DI Yogyakarta	4,688	10,975	7,862	**115,170**	**124,748**	**170,543**
Kab.Bantul	4,143	8,673	3,353	**71,763**	**71,372**	**73,669**
Kab.Sleman	234	689	,539	19,113	27,687	49,065
Kodya Yogyakarta	204	245	73	7,186	14,561	21,230
Kab.Gunung Kidul	84	1,086		12,581	5,950	18,078
Kulon Progo	23	282	1,897	4,527	5,178	8,501
Central Java	1,063	18,498	-	30,759	66,095	103,136
Klaten	1,045	18,123		29,988	62,979	98,552
Magelang	10			386	386	546
Boyolali	4	300		307	696	708
Purworejo	1	4		10	214	780
Sukorharjo	3	67		51	1,808	2,476
Wonogiri		4		17	12	74
Total	**5,751**	**29,473**	**7,862**	**145,929**	**190,843**	**273,679**

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Fig. 1. Destructed houses of masonry-brick bearing wall.

Soon after implementation of emergency period, Indonesian government supported by various relief organizations redeveloped the destroyed area with reconstruction program. The program was successful to rebuild 279.000 houses and to restore 253.000 others within two year [4]. There were Eighty-five agencies who participated within the UN-OCHA humanitarian-cluster system redevelopment and 546 organizations recorded as delivering assistance. Budget confirmed allocated and distributed 5.4 trillion Rupiah (580 million USD) [3] from total plan about 15.3 trillion Rupiah (1.64 billion USD) for housing sector only [5].

Fig. 2. Reconstruction house and its upper roof reinforced concrete frame structural system.

Reconstructing the collapsed houses were involving many donors in various ways. Houses with any form, size, and structural type were constructed. The people were also given a chance to rebuild their houses themselves as a program so called the community based settlementa. Two reputable universities from Yogyakarta and Semarang soon after 2 years, when reconstruction program had finished, reported that all the houses are technically earthquake-proof with good quality [4]. However, there is no guarantee in building performance since reconstruction house were done in various schemes starting from providing complete house, core house, or only giving materials and funds in various quality level [7]. As a result, there are many types of new houses starting from simple to complex structural system, although reinforced concrete framed with brick wall houses are still the majority. Among the reinforced concrete framed houses themselves, the variety of structural system and construction is also wide. The people are also build or extend the houses autonomously afterward.

Even though located in the ring of fireb with frequent destructed earthquakes, Indonesia has less experience in post-quake reconstruction. Just like in any other post-quake reconstruction, it is almost impossible to build immediately a better housing in the affected area [6]. The most important action in such circumstance is to aid as soon as possible the people by means of appropriate ready-use shelters and houses. Trough the time, housing development must carry on in the areas with less attention than before. Lack of supervising and consultation service provided for the people turns the housing development in uncertainty. Though some public guidance in earthquake proof house were available, preliminary surveys indicate that the community members are still unable to afford quality of building without

[1] The re-housing scheme which gives the people some money (limited) and an autonomy to manage the reconstruction project by themselves with facilitators supported by government. It has an advantage for the people to have a chance to rebuild their houses according their preferences but has lack of quality since the limited availability of facilitator and the massive number of the project. Misappropriated in managerial issues also found in many steps of reconstruction starting from data collection to reconstruction process [8]

[2] The line of continental crushes as a result of the meeting boundaries; Indonesian territory surrounding by many ring of fires between Eurasia, Australia, Pacific, and Philippine plates.

professional skills involvement in order to build seismically resistant housing [9]. Building vulnerability is very essential issue since collapsed building has about 80 % of human fatalities affected by earthquake [10] and strong concern about vulnerability in the affected area is still in high level.

The Significant Role of Upper Structure Examination

From the previous 2006 earthquake experience, the failure of upper parts of the houses was the most significant aspect in contributing severe casualties. In fact, it was a very view cases involving the sub structure system issues such as house foundation and soil failures. Poor quality of materials and lack integrity among upper building components are the most causal factor to the collapse of the houses [13]. When the quake affects the defect upper parts, the houses were easily damaged and even easily collapsed without any notification. One of the most reasons was because of weak masonry brick wall or improper reinforced concrete structural system used mostly by the people.

The new houses in general are constructed by bricks wall and reinforced concrete frame with relatively better quality of materials. Unfortunately, houses with timber structure only found in view number. This is opposite way if compare to Japan where almost 90% of building stock in earthquakes prone made from timber [14]. Concrete framed core house with pitched roof type was majority constructed for replacing the collapsed houses. People were expected to extend by themselves afterward according to their need and ability. This was decided due to the limited budged and the large scale impact of disaster.

Concrete materials (Portland cement, sand, and gravel for 1:2:3) with reinforced 12mm diameter steel bar are used for the reconstruction. 60-70cm deep and 50cm wide stone foundation is also being used, while mortar usually contained 1 PC: 3 lime powder: 5 sand or 1 PC: 6 sand (without lime powder). The materials used for mortar are much better than previous collapsed houses which mostly very brittle [13], while roof uses mostly ceramic roof tiles. The whole construction seem well done since in the every sub-district had their own facilitators to guide the construction process.
Major aspects of building stability from earthquake are building configuration, structural collapse mechanism, beam-column joints, and material-construction quality [15]. Since the quality of materials is better than used before and the form is relatively simpler, house's structural collapse mechanism combined with structural integrity by the joints have important role to determine the level of structural stand-ability under quake.

The concept of 'roof first' actually is not merely emphasized on the function of roof as space giver but also the capability to protect inhabitant bellow since it was seen as considered element for causing a big number of casualties. In regard to the collapse mechanism in a simple form building, the upper parts are the most significant aspect to be evaluated. Most of the post-quake building mitigation was focused on column-beam joint appropriateness [15], yet roof frame and its connections to the main frame is less considered. For these reasons, re-evaluating upper structure focusing on main roof elements is essential.

Field Data

The 2006 Javanese earthquake stroke the middle part of Java Island. Bantul district of Yogyakarta province is one of the most affected areas beside Klaten region in Central Java. From the two areas, 72% of the total housing stock was destroyed resulting 95% of total fatalities and serious injuries [8]. More than 50% of houses destructed in Bantul was inhabitable (see table).

Table 2. Statistical Data of Houses Affected by 2006 Java Earthquake in Bantul region (source: updated from BAPPENAS, 2006a/the latest data, taken in June 17th, 2006[2]).

Sub-districts	Total Houses*	Collapsed	Heavily Damaged	Lightly Damaged	Total uninhabited	% uninhabited **
BAMBANG LIPURO	8853	6587	2732	816	9319	75.19
BANTUL	12403	4708	7378	3295	12086	69.60
IMOGIRI	11480	5664	5353	4471	11017	68.55
PLERET	8821	8139	2322	1438	10461	84.71
JETIS	10352	11195	2532	655	13727	94.72
KRETEK	6838	1081	4665	2486	5746	60.02
PANDAK	9576	2886	5185	4065	8071	60.20
PIYUNGA N	9916	5514	4801	3135	10315	74.30
PUNDONG	7297	6793	1903	500	8696	85.12
SEWON	20976	8281	8496	6004	16777	57.13
BANGUN-TAPAN	20009	5557	8232	7452	13789	49.22
DLINGO	6501	1377	3380	4720	4757	52.27
KASIHAN	19735	1790	4657	12103	6447	23.33
PAJA-NGAN	7344	1228	2216	2610	3444	33.50
SANDEN	7135	97	2052	4650	2149	21.51
SEDAYU	10266	243	1800	4591	2043	14.21
SRANDAK AN	6544	342	3054	3506	3396	37.07
total	**184046**	**71482**	**70758**	**66497**	**142240**	**55.20**

*Based on year 2003 census statistical data (podes 2003)
*** Ratio of total uninhabited to baseline data by 1.4 growing level assumptions in 3 years*

Ten sub-districts having higher percentage of deserted houses in Bantul region of Yogyakarta province had been selected for field samples. About 300 houses had been picked randomly by observing 30 houses in each sub-district. The reconstruction houses with additional room or building are examined for their completeness of main upper and roof structural system. In order to validate the sample, the reconstruction houses which are taken as samples should be observed visually.

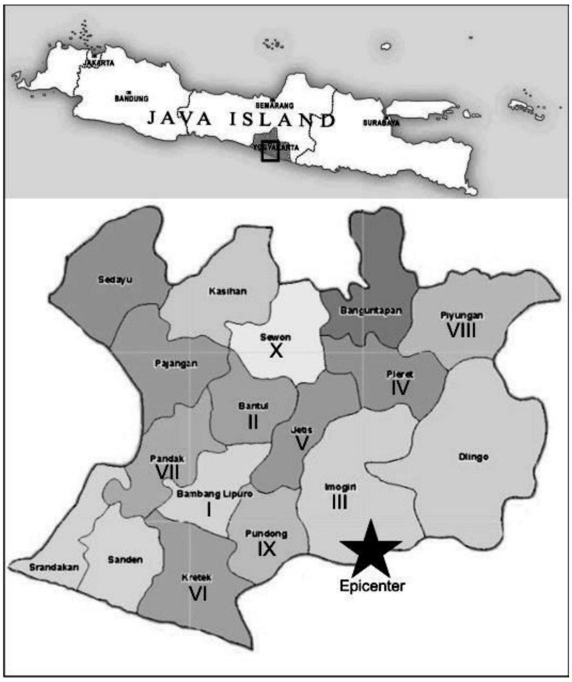


Fig. 3. Data gathered from the most affected areas ten Sub-districts of Bantul region in Yogyakarta Province of Indonesia.

This study offers the simple way to evaluate the earthquake vulnerability of the houses by visual method developed for the case of Java Indonesia. The similar procedure was proposed by FEMA 154 [11, 12] and followed by various scholars in some countries. The method assess a simple structure performance and will not involving detailed structural investigation nor complicated consideration. Only visual applicable aspect of the houses will be examined.

The most problem to observe the reconstruction houses especially for these 'semi-vernaculars housing', is the limitation of technical information about houses e.g. the exact use of material and technical construction system used. For this reason, the best way for visual assessment is by inspecting the comprehensiveness of upper parts of the houses and roof structures. The presence or absence of appropriate structural elements is vital. Incomplete, incorrect, or misplaced part of structural elements represents the improperness the system as a whole. Identification will be listed in order to classify in which grade the houses will be. Although this is simple technique, since it does contain the most important aspect of building stand-ability from the quake, the study is worth enough to decide either the building is structurally acceptable or not. In order to confirm the classification, the grading method is proven by utilization of SAP 2000 program.

Fig. 4. Roof Structural failed both for bearing brick wall and reinforced concrete frame.

Grading System

Method used for grading system is by giving safety values in the levels of structural integrity. The minimum requirement for surviving from quake should be taken as starting point as a 'minimum standard' level, by means that the less should be mark as negatives and the more as positives. According to the five levels of damages classification used by Indonesian authority, damages are classified starting from very slight, slight, moderate, severe, and very severe. In this regard, moderate damage level is the minimum circumstance of the building after earthquake that still can be emergency occupied and expected to be still stand up without affecting the inhabitant's safety at the moment. In order to link with structural safety, the moderate damage level is then correlated with a minimum requirement stated as sufficient level of structural system in facing quake (see table2).

Five grades for structural classification starting from strong, less strong, sufficient, weak, and very weak then parallelized to the five damage levels of very slight, slight, moderate, severe and very severe (figure 8). To be having positive or negative values, the middle level of minimum accepted level is given by 0 values. The other higher accepted for strong and less strong structure are grouped as positive one and two (+1 and +2), while lower groups as rejected level or weak and very weak structures are stated as negative one and two (-1 and -2).

Table 3. Damage classification level used for vernacular house (developed from Dirjen Ciptakarya PU 2006 [16]).

Damage Level	Meaning	Building Condition	Building Items Affected
1	No or Very slight damage	No or Small crack in non-structural parts of building	Non structural wall Roof tiles Openings
2	Slight damage	Some cracks in non structural members	Non structural wall Roof tiles, floor tiles Openings
3	Moderate damage	Crack on structural members such as bearing wall, column, beam and connection	Structural wall Column, beam Ceiling, Roof frame
4	Severe damage	Severe cracks or lost connection between main structural members	Structural wall Column, beam, ceiling Roof frame, Foundation
5	Very Severe, Collapse	Some parts or whole building collapsed	Structural wall Column, beam Roof frame, Foundation

In order to apply the point system in the structural integrity, the level from strong to very weak then translated to the structural grading system by grouping the most complete to the least one. In case of reinforced concrete frame system, the rigidity level which is directly related to stand-ability is judged by the structural comprehensiveness which is confirmed by the presence and absence of structural members and its proper connection. Since the most type of reconstruction houses is pitch roof, the most concern then focused to gable system and its connection with main frame underneath. The presence of brick wall inside the frame is also taken into account since it affects significantly the work of frame system.

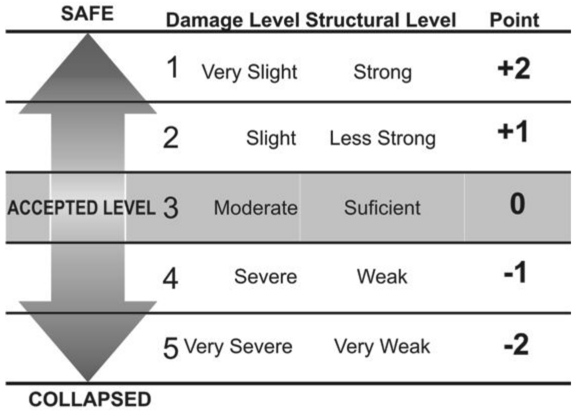
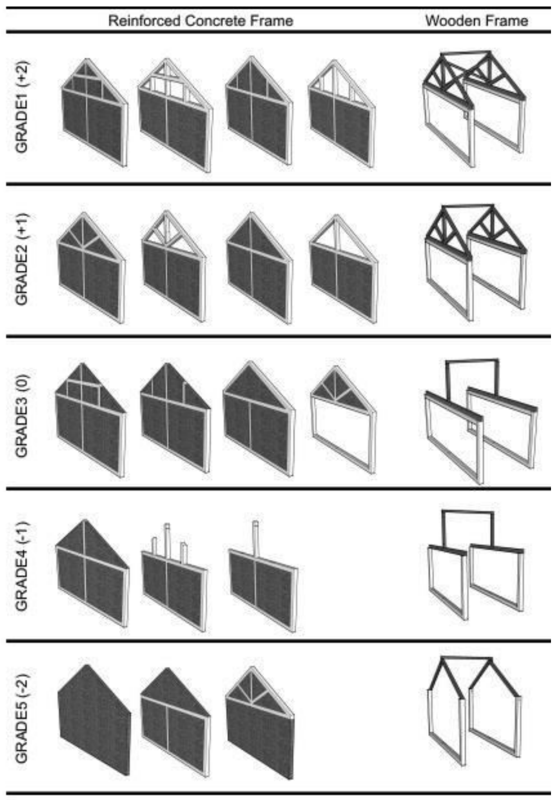


Fig. 5. Point system applied for structural levels paralyzed with damage level chart.

Similar grading technique is also used for wooden and reinforced concrete frame-wood combination structural system regarding the flexible joint system principles. Since the wooden frame for gable roof is easily collapsed in front-rear direction, strengthening between the frames is most concerned beside the frame configuration properness as a main factor that easily affected by earthquake (figure 6).



Structural Definition	
GRADE 1 (+2)	**Strong Connection** Completed roof frame with more than three connection to the main frame either with or without walled brick in between. While for wood has 3 D connection to other frame. When earthquake strike it will stand completely
GRADE 2 (+1)	**Less Strong Connection** Completed roof frame with less connection to the main frame. For concrete categorized as upper group as long as has rigid connection (3D connection) to other frame, for wood less connect. When earthquake strike it will little affected and still stand completely
GRADE 3 (0)	**Sufficient Connection** Uncompleted roof frame structure or completed one but less sufficient support bellow. For wood has no diagonal element for both sides. When earthquake strike it will severe affected but still stang completely.
GRADE 4 (-1)	**Weak Connection** Uncompleted roof frame structure but still has sufficient connection with the main frame bellow. For wood has no diagonal element for both sides with small horizontal under. When earthquake strike it will affected easily and some part will easily collapsed.
GRADE 5 (-2)	**Very Weak Connection** Incompleted roof frame structure with improper structural system without any connection between roof and main structural system. For wood without horizontal bracing member. When earthquake strike it will affected easily and the whole roof structure will easily collapsed.

Fig. 6. Grading systems criteria for reinforced concrete and wooden gable roof structure types.

Results

The vulnerability level had been analyzed in two ways, firstly by discovering the structural stand-ability level and secondly by estimating the level of unaccepted building in the area. The higher structural stand ability level means the less vulnerability while the level of unaccepted building related directly with the level of vulnerability. Both are needed in order to discover the level of vulnerability in different ways as the level of 'accepted' and 'non-accepted' for original and additional reconstruction houses. Though they are correlated each other, the structural stand-ability explains the general-average level of structural integrity which is taken from point system examination directly (see appendix 1) while the level of unaccepted building uses percentage system in order to show only the distribution of vulnerability in each area (see appendix 2).

Structural Stand-ability

Structural stand-ability level from earthquake shake which is defined by points system from +2 to -2 is applied for all data in the every sub-districts. The outcome shows that all levels are found in the areas. In general, all original reconstruction houses level are always above the additional houses. The levels of original and additional houses are not always parallel, and even some sub-districts such as Imogiri and Pandak have big difference between the two. Point system applied to samples had shown that -1 to 2 point levels had been found in almost the every sub-district. Unfortunately there are level -2 for original reconstruction house in the four sub-districts; Kretek (2 cases or 6.66% data), and Pundong (1 case or 3.33% data). For additional building, the -2 level is also found in Bantul (1 case or 3.7% data), Imogiri (1case or 3.33% data), Kretek (7 cases or 23.33% data), and Pundong (3 cases or 10% data).

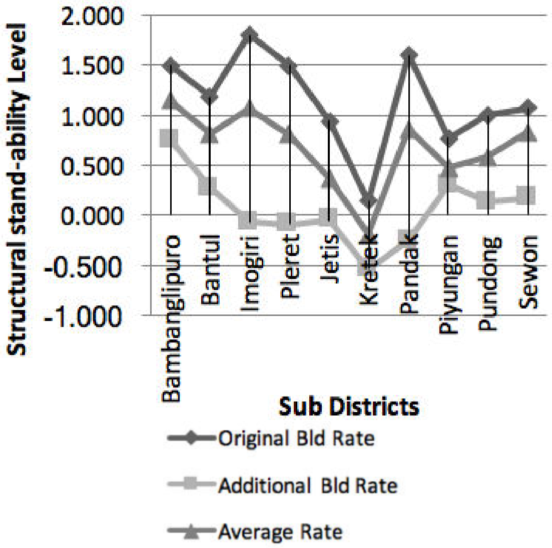


Fig. 7. Result chart of stand-ability level which is directly in opposite with vulnerability level of the houses.

Non-Acceptable Evaluation

Building vulnerability as lower level of acceptable structure or stated as non-acceptable is defined by percentage of failed house from the total sample in the area. Again, as shown in structural stand ability examination, the additional buildings have higher vulnerability. However, this examination considers only the amount lower level quality without concerning the higher as accepted group. This is useful method in order to focus the vulnerability level. The chart shows that the areas having higher level in structural stand-ability are not always have less percentage in vulnerability. Furthermore, only one district (Imogiri) that have 100% of original new reconstruction houses are accepted (0 to +2 levels), however, the rest of sample areas have unacceptable houses. Unfortunately, this is not followed by new additional buildings which are found in every sub-district with the unaccepted percentage starting from 20% to almost 78%. This is showing us that, by this way, the complete situation on vulnerability of reconstruction houses can be identified more clearly.

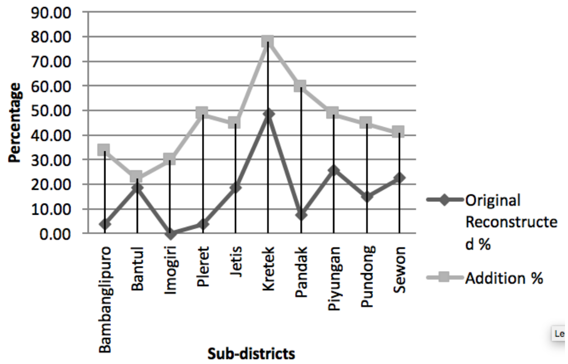


Fig. 8. Percentage of Non-Acceptable Reconstruction houses which directly shows the level of vulnerability.

Discussion

The examination of new reconstruction house and the additional building have no correlation in between. Imogiri, Pleret, and Pandak are sub-districts that have higher-positive level in building safety for original houses, but in the same time, the three are also have higher level in vulnerability. For additional houses are even found below zero as under accepted level (see figure 11). In percentage table, Imogiri, which has all new reconstruction house accepted, have some significant percentages of non-accepted additional buildings (see figure 12).

From this study, some aspects found:

1. Not all the reconstruction houses have similar quality in structural stand-ability to stand with future earthquake
2. Original reconstruction houses have no parallel quality with the additional in every sub-district
3. The percentage of non acceptable level is higher in additional buildings than in original buildings in any sub-districts.
4. In average, almost original construction houses are above the accepted level but still there is below level in one sub-district (Kretek)
5. 100% structurally accepted only found in Imogiri for original buildings, the others still have un-accepted building in certain levels.
6. Half of total sub-districts examined have under accepted level for additional building (Imogiri, Pleret, Jetis, Kretek, Pandak)
7. The highest quality for original reconstruction houses is sub-district Imogiri while the least one is Sub-district Kretek
8. The highest quality for additional buildings is Sub-district Bambanglipuro while the least one is Sub-district Kretek
9. The highest unaccepted percentage found in Kretek both for original and additional buildings

Biggest difference between original and additional is sub-district Imogiri while the smallest one is Sub-district Piyungan.

Conclusions

The ten most affected sub-districts had been analyzed and the outcome is that there is still high in vulnerability level even though new reconstruction houses had been constructed. Some other conclusions from the study are:

1. Not all reconstruction house in the area safe from the future earthquake threat
2. Non accepted building is still found in high percentage for new post-earthquake houses
3. Additional building is the most source of structural failure and there is high possibility to make any casualty in the future similar disaster
4. The trend of structural quality of additional building is going to decrease

By this result, this study has discovered the level of earthquake vulnerability applied to regions after Java earthquake 2006. Damage level from similar future earthquake can also be predicted accordingly in every district examined. The procedures presented here is simple which will facilitate the work of the inspection teams easier and will reduce the time required to complete the job. The next study for this issue is still need to be carried on in regard of other aspect such as structural quality level and relation with the building type, structural type, and materials used. The other aspect may set off with occupant issues such as the relation with craftsmanship and ability level since this vernacular reconstruction deal not only with technical matters.

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