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EARTHQUAKE VULNERABILITY EVALUATION OF BUILDINGS IN BANDUNG MUNICIPALITY

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SUMMARY

A study was carried out to evaluate the Bandung seismicity and applications of building design codes. A survey on conditions of buildings in the entire municipality was carried out at each of the 26 districts into which the Bandung Municipality was divided.

The results of the seismic risk analysis showed that the maximum peak acceleration at the base rock for a 200-year return period was approximately 0.09 g. After considering soil effects, it was found that the maximum peak ground acceleration was 0.17 g in the northwestern part, gradually increasing up to 0.35 g in the southeastern part of the municipality. The material surveys showed that 85.2 per cent of the buildings were concrete or masonry buildings, 13.2 % were wooden houses, and 1.6 % were steel structures. In low-income neighborhood the percentage of wooden houses was 34.4 while the rest were concrete or masonry buildings. The investigation on concrete or masonry buildings showed that 62.0 % were properly framed, 17.4 % were not framed, and 20.6 % were framed but inadequately. For concrete or masonry buildings the correlation coefficient between percentages of those in low-income neighborhoods and those without proper framing was 41 %. The correlation coefficient between the percentages of wooden houses recorded in the survey and non-permanent houses registered in each district was 57 %.

This study shows that there is a need for revising the present earthquake code, a very high percentage of buildings and houses need to be retrofitted in order to meet the building code requirements, low-income families tend to use wooden houses or low quality concrete or masonry buildings, and the accuracy of the survey method was acceptable.

INTRODUCTION

Indonesia has a unique position as an earthquake prone country. It is the place of interaction for three tectonic plates, namely the Indo-Australian, Eurasian and Pacific plates. Approximately ten percent of annual world earthquakes occur in Indonesia. The regional map of the Indonesian seismic source zone indicates that there is only one seismic source zone in West Java, one of Indonesian provinces which lies in the western part of Java island. In the recent research however, Kertapati [3] showed that there are six seismic source zones in West Java.

Bandung is the capital city of West Java Province, located at 7^o southern latitude and 107.5^o eastern meridian on top of the prehistoric lakebed of Bandung plateau, surrounded by mountains and active volcanoes. Situated in the upper stream of the Citarum River Basin, the region is also called the Bandung Basin. Bandung is the third largest Indonesian city after Jakarta and Surabaya with about two million inhabitants in the municipality and about 4 millions in the surrounding communities, which is known as the Greater Bandung Area. The

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Metropolitan City of Bandung is currently considered as one of the most densely populated city in Indonesia with about 120 people per hectare [3].

The geographical and geological condition makes Bandung susceptible to various natural disasters such as tectonic and volcanic earthquakes, floods, landslides, typhoons, fire hazards and possibly other types of disasters induced by its dense population. Bandung is located in Zone III of the Indonesian seismic zones, representing medium hazard. An active fault is located about 20 km north of Bandung, well known as the Lembang fault, among other several faults found around Bandung area, which shows that the Bandung area is tectonically unstable and potential to earthquake hazard. Although it is not as severe as the Zones I or II on the seismic zoning, Bandung can be considered as one of the most vulnerable city, due to its population density and soil condition, shown by the alluvium formation from the ancient lake bed sediment which covers a large part of the Bandung plateau.

MITIGATION EFFORTS AND RESEARCH ACTIVITIES

Due to the vulnerable conditions of Bandung various efforts have been exerted to reduce these unfavorable conditions. Many aspects have been addressed, starting from community awareness up to engineering solutions. Some of these efforts are described below.

Establishment of Official Organization

One of the most authoritative bodies in the implementation of disaster mitigation, the Department of Interior Affairs has issued a regulation in 1989 called “A Guide for Implementing Disaster Mitigation for the Regional Civil Defense." This regulation also serves as a guide for the civil defense in carrying out its function in civil protection. In this regulation, it is stated that the civil defense, which is located at every district or village is the main function for Community Protection in disaster mitigation. The district civil defense organization is lead by a qualified government employee proficient in planning, implementations, and control. The head of this organization is assisted by task groups. Non governmental socio-political, business, and community organizations are included in the task groups. Typically the various task groups are described as follows:

a. The health task group involving the local government health bureau, red cross organizations, hospitals, the armed groups and the Department of Transportation and Communications.

b. The rescue and evacuation task group involving the fire brigade, road and traffic bureau of the Department of Transportation and Communications, the Department of Social Affairs, the general hospital, red cross organizations, youth and scout organizations, woman organizations, and the army.

c. The sheltering task group involving the Department of Social Affairs, red cross organizations, civil defense, the state electricity company, and the army.

d. The mitigation task group involving the fire brigade, the state electricity company, the Department of Public Works, search and rescue organizations, and the local community.

e. The security and traffic task group involving youth organization, the road and traffic bureau, the army, and the civil defense.

f. The social aid task group involving the Department of Social Affairs, and the Department of Health.

g. The information task group involving the Department of Information, amateur radio organizations, the Department of Religious Affairs, and the Department of Transmigration.

h. The rehabilitation and reconstruction task group involving the Department of Public Works consists of irrigation and road bureaus, the Department of Agriculture consists of, fishery and livestock bureaus and the Department of Health.

Building Regulations and Building Control

In addition to establishing official and authoritative organizations, the local government also enforces available regulations and codes for disaster prevention and mitigation purposes. These regulations and codes are:

- The Municipality Rule No 18 in 1977.

- The Planning Permit Decree by the City Planning Division.

- The Ministry of Public Work Decree No 02 in 1985.

- The Building Coverage Ratio Regulation by the Bandung Municipality.

- The Indonesian Concrete Structure Code.

- The Indonesian Steel Structure Code.

The list shows that the Indonesian earthquake code, DPW [2], was not included in the official regulations to be followed. Due to this situation, various earthquake related research groups are actively involved in promoting earthquake awareness in the country.

Research and Scientific Activities

Bandung is a city where a technological institute is located, e.g., the Institut Teknologi Bandung. It is a technological school in which earthquake engineering, including aseismic building design is covered in the civil engineering curriculum. It is expected that every civil engineering graduate will be proficient or at least aware of the importance of aseismic building design. There have been some earthquake mitigation efforts carried out by scientists and engineers to supplement efforts from government offices. JICA, for example, in collaboration with the institute and the Department of Public Works (DPW) has organized annual courses on earthquake engineering and seismicity held every year between August and September for more than ten years now. The participants come from the Asia-Pacific region. Basically this is an activity for disseminating current research results and increasing earthquake awareness to government officials and engineers. In addition to these activities there have been some researches carried out in the area of earthquake engineering such as a strategic research by Merati [5], Mangkoesoebroto [4] or the University Research for Graduate Education (URGE) by Surahman [9].

The research by Merati [5] was aimed to be used as a basis for revising the present Indonesian seismic code. The map shown in Fig. 1 is one of the research outcomes. The new zoning map, however, will be based on more recent research results such as Merati [6], Shah [8], Surahman [9], and Wangsadinata [10].

Researches on response spectra suitable to Indonesian conditions have been carried out by Mangkoesoebroto [5] and Surahman [9]. Various earthquake records have been analyzed. Based on this approach, a response spectra diagram for the elastic responses have been obtained and used to calculate R factor as defined by ATC [1]. To take the inelastic response into account, the following formula has been used:

$$R = R(\mu) \quad (1)$$

where μ is the ductility ratio and $R(\mu)$ shows that R depends on the stage of plastification.

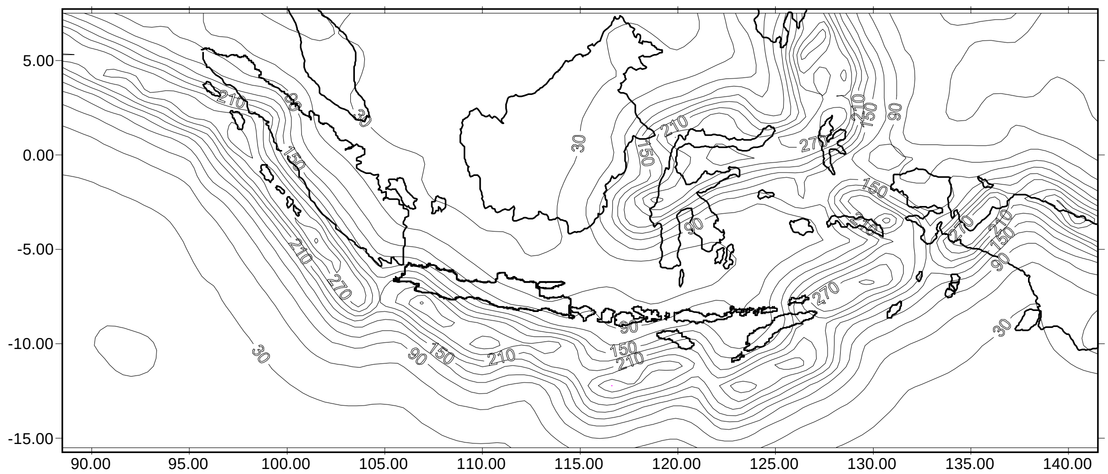

Figure 1: Peak Ground Acceleration Contour Map of Indonesia, Merati [5]

Earthquake Mitigation Projects

All researches carried out are considered as parts of earthquake mitigation activities. Some of the results can be used for designs of earthquake resistant structures. One of the projects aimed to implement various research results for earthquake mitigation purposes is the Indonesian Urban Disaster Mitigation Project. This is an

Earthquake Hazard Mitigation project for the Municipality of Bandung which was established within the framework of the Asian Urban Disaster Mitigation Program (AUDMP) that was initiated by the Asian Disaster Preparedness Center (ADPC), Asian Institute of Technology, Bangkok. The core funding of this project comes from USAID's Office of Foreign Disaster Assistance. The goal of the Indonesian Urban Disaster Mitigation Project (IUDMP) is to reduce natural disaster vulnerability of urban populations, infrastructures, life-line facilities and shelters in Indonesia. The objective of the Project is to establish sustainable public and private sector mechanisms for disaster mitigation in targeted urban areas of Indonesia, with the Municipality of Bandung, West Java taken as the city case study.

A project with similar goal is also being carried out for Bandung. This project is the Risk Assessment Tools for Diagnosis of Urban Areas Against Seismic Disaster (RADIUS). This project is organized by the United Nations Office for the Coordination of Humanitarian Affairs as part of their activities in the International Decade for Natural Disaster Reduction (1990 - 2000), known as the IDNDR project.

CASE STUDY APPLICATIONS AND EVALUATIONS

Based on the collected earthquake data obtained in various researches and projects mentioned above, the seismic risk analysis for Bandung Municipality was carried out to estimate earthquake intensity at the base rock for a 200 year return period as shown in Fig. 1. Then the results were further refined to obtain microzonation scale ground accelerations, including local soil effects, rather than base rock accelerations. The resulting peak ground accelerations for various places in Bandung are shown in Table 6. By using Eq. (1) damages were estimated for buildings in the Bandung Municipality with the qualifications assumed to be represented by the survey samples. The results are qualitatively shown in Table 1.

Survey

The qualities of buildings and houses in the Bandung Municipality were obtained from a survey conducted at each district of the Bandung Municipality. The survey recorded conditions of each building evaluated. At every district of the municipality 100 buildings or houses were sampled at random, trying to pick them as representative samples. The number of samples was picked to be evenly distributed among subdistricts. This methodology, however does not necessarily exclude the possibility of subjective biases due to instant conditions such as facility, access, bureaucracy, security, or the notion that the survey should be intended to evaluate the vulnerability of the buildings and houses to earthquake.

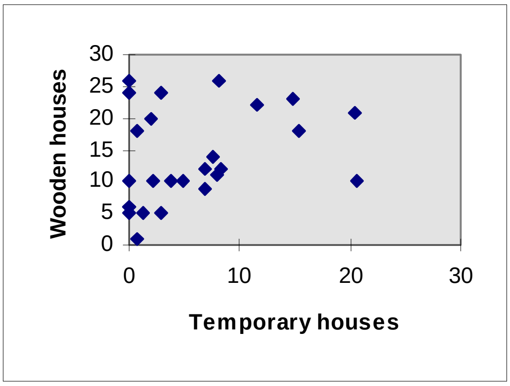

Figure 2: Correlation between temporary houses and wooden houses

Based on the results, it was found that most of the buildings were made of masonry. Steel buildings were mostly used for industrial purposes. The framing of concrete buildings was varied. This showed that quite a few of the concrete buildings were not property designed. Among concrete buildings, most used masonry foundations. The number of concrete buildings was randomly distributed among various neighborhoods. From the data of buildings surveyed, 1.6% were steel buildings, 13.2% were wooden or bamboo houses, and 85.2% were concrete or masonry buildings. In the low income neighborhood, where it was expected to be the most vulnerable, concrete buildings were used more than wooden or bamboo houses (70.4% versus 29.6%). However, it was clear that the average percentage of wooden or bamboo houses in low-income neighborhoods was higher than the average statistics of 13.2%. The determination of neighborhood type was very subjective, depending on the surveyor's judgment. In general, it was determined by general appearance such like density or neatness. These concrete buildings were 17.5% located in low income neighborhoods, 42.1 % in the medium income neighborhoods, and 23.5 % in high income neighborhoods.

From those concrete buildings, 62.0% were framed, 17.4% were unframed, and 20.6% were inadequately or improperly framed. Most steel buildings were used for industrial activities. I was revealed that the percentages of unframed or improperly framed concrete buildings were higher in the lower income neighborhoods. Also it was found that 78.9% of concrete buildings were supported by shallow masonry foundations, 3.4% by concrete footings, and 1.7% by deep foundations.

A statistical evaluation was carried out. For concrete or masonry buildings the correlation coefficient between percentage of those in the low income neighborhood and those without proper framing was 41 %. The correlation coefficient between the percentage of wooden houses recorded in the survey and non permanent houses registered in each district was 57 % obtained from scattered data samples shown in Fig. 2. This shows that the accuracy of the survey was acceptable.

Damage and Casualty Estimate

The damage estimates were based on the assumptions used in and interpreted from the Indonesian seismic design code, DPW [2]. This code requires that in Bandung, any buildings with a displacement ductility capacity of 4 located on hard or soft soil should be designed against an earthquake acceleration of 0.05 g or 0.07 g respectively. For buildings without ductility capacity, the design load should be multiplied by a factor of 4. A quantitative assessment was made by using the inelastic response of Eq. (1) which then qualitatively assigned into a certain damage status. Table 1 shows the qualitative damage status based on the estimates. The quantitative elaboration of the damage status is given in Table 3.

Table 1: Damage status for buildings as function of p.g.a (a)

Building Structural Condition	$a \le 0.07$ g	$a \le 0.17$ g	$a \le 0.238$ g	$a > 0.238$ g
Perfectly adequate	O	A	B	C
Partially adequate	A	B	C	D
Inadequate	B	C	D	D

Table 2 shows the estimates for fatalities and injuries. The data were taken from Pauls [7] for over crowding and Wiggins [11] for casualties in collapsed office buildings. For these two cases the values of 1.0 and 0.05 were respectively assigned for occupancy per square meter.

Table 2: Casualties (c) per person involved

Occupancy per square meter	0.050	1.000
Light injuries	0.300	0.800
Severe injuries	0.024	0.064
Deaths	0.003	0.008

For occupancy ratios other than tabulated the casualty values were obtained by linear interpolations. The casualties also depend on the building damage status. For statistical purposes it was necessary to assign a percentage value, p for building damage and damage multiplying factor, d for casualty estimates. These assigned values are shown in Table 3.

Table 3: Building damage percentage (p) and building damage factor (d)

Damage status	Qualitative meaning	Percentage (p)	Multiplying factor (d)
O	intact	0	0.000
A	slightly damaged	25	0.001
B	heavily damaged	50	0.100
C	collapsed	75	1.000
D	demolished	100	2.500

For casualty estimates it was assumed that concrete buildings were the most severe, followed by steel buildings and wooden houses. To include material effects a material multiplier factor (m) of 1.0 was assigned for concrete buildings, 0.5 for steel buildings and 0.3 for wooden houses.

The contribution of building height is usually significant for casualty evaluation. In this case the number of high rise building occupants was relatively negligible for Bandung case. In this study a story height factor of 1.0 was assigned to single story houses and factors larger than one, proportional to the number of stories were used for higher buildings. All of the multipliers described above were used such that the total casualties cannot exceed 100% of the total building occupants.

Based on the above description the number of damaged buildings and casualties were estimated by Eqs. (2) and (3).

$$\text{Number of damaged buildings} = \sum_{i=1}^{n} p_i \tag{2}$$

$$\text{Number of casualties } c_j = \sum_{i=1}^{n} c_{ij}\, d_i\, m_i\, s_i \tag{3}$$

where i is each building damage status considered, j is type of casualty (as shown in Table 2) and n is the total number of buildings evaluated. The results are summarized in Table 4

Table 4: Casualty and building damage estimates in Bandung

District	p.g.a [g]	Number of Houses	Damaged Houses	Total Population	Slight Injuries	Heavy Injuries	Deaths
Andir	0.23	20324	12348	92565	5012	401	50
Arcamanik	0.29	5936	5050	42549	10629	850	106
Atana Anyar	0.26	12791	10682	74683	19899	1592	199
Babakan Ciparay	0.26	15908	13043	83168	21844	1748	218
Bandung Kidul	0.30	5135	4168	31160	8433	675	84
Bandung Kulon	0.25	16007	13399	85840	22162	1773	222
Bandung Wetan	0.20	6035	3093	36579	1146	92	11
Batununggal	0.22	20978	13193	105897	6145	492	61
Bojongloa Kaler	0.25	16389	14301	93323	23979	1918	240
Bojongloa Kidul	0.28	10480	8546	60137	15973	1278	160
Cibeunying Kaler	0.17	13846	4666	51281	161	13	2
Cibeunying Kidul	0.17	17963	6122	90713	481	38	5
Cibiru	0.35	6420	5353	55952	14497	1160	145
Cicadas	0.22	16360	9917	81191	4700	376	47
Cicendo	0.22	14128	8756	90547	5537	443	55
Cidadap	0.18	8214	4620	40154	1687	135	17
Coblong	0.20	17768	11793	89420	6315	505	63
Kiaracondong	0.22	14882	9301	103169	6697	536	67
Lengkong	0.25	10460	8515	70633	18623	1490	186
Margacinta	0.30	13486	10354	62600	17111	1369	171
Ranca Sari	0.34	8235	7007	44202	11065	885	111
Regol	0.26	12592	10121	71452	19149	1532	191
Sukajadi	0.21	15486	9107	82630	4135	331	41
Sukasari	0.19	11104	7117	64981	4189	335	42
Sumur Bandung	0.20	6907	3994	38358	1754	140	18
Ujung Berung	0.34	10143	8685	53137	13288	1063	133
Total		327977	223251	1796321	264612	21169	2646

The damage and casualty table shown above proves that the vulnerability of Bandung Municipality against a 200 year return period of earthquake is severe. The numbers of building damages and casualties are too high for such a moderate earthquake. A positive action plan is required to remedy this situation. The existing code should be revised and the existing buildings should be retrofitted.

CONCLUSIONS

The author wishes to acknowledge the presence of the ongoing AUDMP, RADIUS and URGE projects, in which the author is currently involved, enabling the author to share information written in this paper. From the study case described above it was shown that Bandung, even though lies in a moderate seismicity region, is vulnerable to earthquake disaster. The main contributors of the vulnerability amongst other are the high density human population and the relatively poor quality control enforcement of the buildings. The survey carried out to evaluate the city's vulnerability against earthquake was reasonably accurate, and should a 200 year return period earthquake strike the Bandung Municipality, heavy losses are expected to inflict the community. Extensive and intensive earthquake awareness program should be applied to the community.

REFERENCES

1. Applied Technology Council, ATC (1995), "Structural response modification factors," *National Science Foundation, National & Center for Earthquake Engineering Research*.
2. Dep. Of Public Works (1989), "Indonesian Seismic Building Code (In Indonesian)," SNI-1726-1989-F.
3. Kertapati, E., (1997) "Earthquake source and post event disasters in Bandung area and earthquake based microzonation (in Indonesian)," *Seminar on Earthquake Risks in Bandung Municipality*, Bandung, Indonesia.
4. Mangkoesoebroto, S. P. (1997), "Evaluation and Recommendation for Improvement of Indonesian Buildings Structural Design Code (In Indonesian)," Strategic Research Report, *Institute for Research, Institut Teknologi Bandung and Institute for Human Settlements, Department of Public Works*, Bandung, Indonesia.
5. Merati, G.W., Surahman, A., Sidi, I.D., and Irsyam, M (1996), "Indonesian earthquake zonation development," *Proceedings of the XI WCEE*, Paper No. 1618, Acapulco, Mexico, 18pp.
6. Merati, G.W., Surahman, A., Sidi, I.D., and Irsyam, M (1997), "Identification and Evaluation of Earthquake Parameters and its Mitigation Through Provision of Indonesian Seismic Building Code (In Indonesian)," Strategic Research Report, *Institute for Research, Institut Teknologi Bandung, Bandung*, Indonesia.
7. Pauls, J. L., (1977), "Management and Movement of Building Occupants in Emergencies," *Proceedings of the Second Conference Designing to Survive Severe Hazards, IIT Research Institute*, Nov. , pp. 103-130.
8. Shah, H. C., and Boen T. (1996), "Seismic Hazard Model for Indonesia," *HAKI Conference 1996 on Civil and Structural Engineering, HAKI (Indonesian Society of Structural Engineers)*, Jakarta, Indonesia.
9. Surahman, A. (1998), "Analytical and Experimental Evaluations of Earthquake Induced Stresses on Structures for Building Code Purposes," URGE Graduate Team Research Report (Ongoing), *Institute for Research, Institut Teknologi Bandung*, Bandung, Indonesia.
10. Wangsadinata W. (1998), "The Draft of the new Indonesia's Seismic Code," *International Seminar and Workshop on International Standards on Loading and Structural Design*, Singapore.
11. Wiggins, H. H. (1977), "National Losses and Mitigation Effects for Air, Earth and Waterborne Natural hazards," *Proceedings of the Second Conference Designing to Survive Severe Hazards, IIT Research Institute,* Nov., pp. 47-97.