Strategy for Earthquake Disaster Preparedness Design based on Structural Assessment and Geohazard Vulnerability Map
Pundong and Imogiri in Bantul,Yogyakarta, Indonesia as Study Areas

Diananta PRAMITASARI[1], Hendra AMIJAYA[2] , Ikaputra[1] , Ardhya NARESWARI[1] ,Deva FOSTERHAROLDAS[1] , Agus HARIYADI[1] , T. Yoyok WAHYU SUBROTO[1]

[1] *Department of Architecture and Planning,*
Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia
[2] *Department of Geological Engineering,*
Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia
Email:dpramitasari@ugm.ac.id,nares@ugm.ac.id,agus@ugm.ac.id,archugm@indosat.net.id

ABSTRACT :

This paper presents the relation of the earth condition as well the seismic risk of the area in the rural planning, especially in building structural principles. The field study was conducted in the area influenced by the Yogyakarta earthquake, May 2006. Based on the level of the vulnerability in Bantul District, the more detail mitigation consisting of assessments on structural damages of buildings and the survey on geological conditions of the areas were conducted, specifically in Soronanggan-Watu-Gedong three-subvillage cluster, Pundong Subdistrict and in Karangasem subvillage in Imogiri Subdistrict. Regarding the structural assessments, it is learned that the chronology of the collapsed building in the studied areas were usually started from the frame structure located just below the roof (usually because of the inexistence of supporting elements, such as ring balk) so that all the weight of all elements of roof become the burden to the elements under the roof. The geological survey result shows that Imogiri and Pundong Subdistrict have different soil characteristics. Imogiri area is covered by soil (regosol) with various thickness up to more than 2 m thick. Based on field observation and samples that have been taken, soil in this area can be differentiated into two groups (USC-ASTM, 1983), which are silt/clay (in the north part of the area) and silty sand (in the south part of the area), with the content of sand is about maximum 48%. While in Pundong area, the soil classification varies from silt size soil to silt sand with the content of sand reaches 79%. This means that Pundong area has more loose characteristics of soil rather than Imogiri, therefore, the area is more susceptible for the settlement. However, since the high demand of the land occupancy for the settlements, as structural recommendations, the use of light materials is strongly suggested in order to anticipate the bearing capacity of the soil which is considered low. Then, the use of close structure is also recommended to maintain the building rigidity.

KEYWORDS: Yogyakarta earthquake, earth condition, seismic risk, rural planning, building structure

1. INTRODUCTION

1) Background of Research

The history of several damaging earthquakes makes Yogyakarta Special Region and the southern part of Central Java had high seismic risk evaluations of Indonesia. However, the awareness of the seismic risk has not facilitated implementation of earthquake resistant planning and design codes on the buildings which are quite vulnerable to strong ground shaking. Previously, urban and rural planning does not put the geological condition of the area as important considerations to the spatial planning. After several natural disasters, especially the earthquake, shocked the people around the world and caused a large number of human losses, the information on earth condition becomes very important to collaborate in the land-use planning. Yogyakarta tectonic earthquake that strike on 27 May 2006 with a scale of 6.3 (according to USGS) had terrible economic effects to the people in the widespread area as well the physical damages of the buildings.

2) Objectives of Research

The objective of the research is obtain the earthquake disaster preparedness design based on the examination of structural damages assessment and the considerations of the geohazard concept/knowledge and the as main considerations to develop the earthquake preparedness village planning and design.

2. THE RESEARCH PROCEDURES

1) Selection of the Study Areas and Vulnerability Assessment

Based on the level of the vulnerability in Bantul, the more detail mitigation has been done in four villages in two sub-districts: Pundong and Imogiri. The Pundong case is focused on three subvillages, Gedong, Watu and Soronanggan at Panjangrejo Village. The Pundong district has ratio between *death victims* and *Totally Damaged House* at 1: 16, while the Imogiri one has the ratio at 1:18 (Bappeda Bantul, 2006). These selected subvillages in Pundong are located near the fault and categorized into the ring one level of vulnerability (see figure 1). The Panjangrejo village suffered 2,270 houses totally damaged and killed 145 people. The Imogiri case is focused on Karangasem Subvillage in Wukirsari Village. In Karangasem Subvillage, it is about 47 % of 332 house holds working for house scale industry especially leather craft industry. The subvillage located close to the fault system and is categorized into the ring two level of vulnerability. The purpose of the mitigation is to understand the vulnerability affected by the earthquake especially in those two different levels of vulnerability but considered as having strong influenced from the earthquake. The mitigation result is expected to be evidence to consider the importance of geohazards as one of planning components for a disaster (especially earthquake) preparedness village design.

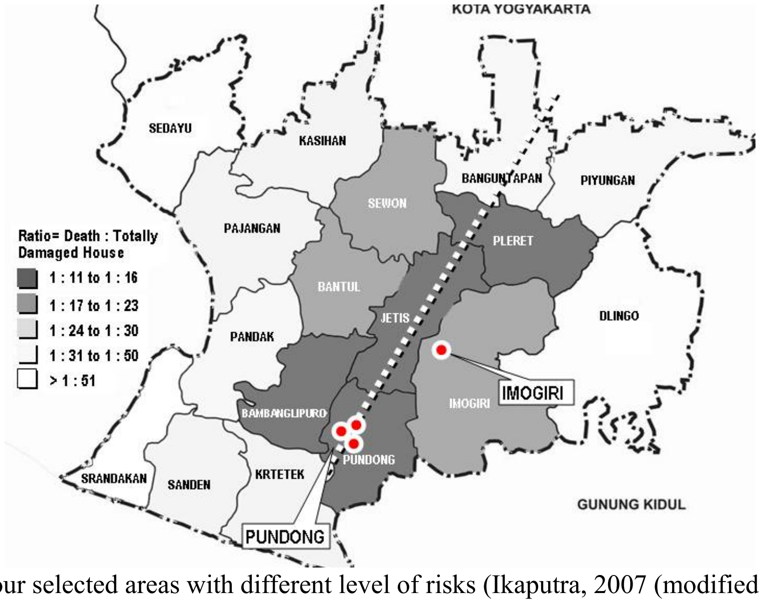


Figure 1. Location of four selected areas with different level of risks (Ikaputra, 2007 (modified from Bappeda Bantul))

2) Geomorphology of the Areas

Panjangrejo Village is located in Pundong on the west of Opak River and to the east is also bordered by west slope of Southern Mountains. Geomorphologically this area is very flat, the height difference is less than 5 m. The area is covered by thin soil (regosol, approximately only 20 – 40 cm) with sandy-clay size (see Figure 2). The soil lay above the old-Opak river sediment which dominantly consists of loose fine to coarse sand. No manifestations of geological structure are found in this area. If there any structures occur, they are probably on the bedrock in subsurface and already covered by recent surface sediment of old-Opak River and soil.

Figure 2. Ilustration of flat morphology and thin soil above loose sand deposit
in Panjangrejo Village, Pundong area.

Karangasem (Wukirsari) is located on west slope of Southern Mountains. Geomorphologically this can be divided into two units. First unit is the alluvial flat area, which has height difference less than 5 m. This unit is situated in the middle of studied area and stretching to SW-NE direction. The second unit is the structural hilly unit which covers most of the area. The slope of the hill varies from 20° to 50. The height difference can be up to 165 m. This area is covered by soil (regosol, fine to coarse sand in grain size) with various thickness up to more than 2 m thick. The thickest soil is deposited along the valley and the thinnest is on the hill top. Transportation of soil by erosion processes from the upper part of hill to the valley has caused this distribution of soil thickness. The soil is deposited above the bedrock which consists of intercalation of conglomerate (mix of various rounded volcanic rock fragment like tuff, pumice and andesite with volcanic sand matrix) and sandstone (composed mostly by tuff) layer. This unit covers almost all the area. A small andesitic intrusion is also found this area. The most prominent geological structures found in this area are anticline and normal fault. Anticline is the manifestation of folded rock layers which arches upward as the rock layers were compressed by tectonic stress. The axis of the fold is located at the centre of research area to the N-S direction. At the south side, a normal fault is identified also with N-S direction. The normal fault happened as the west block was slipped down in relation to the east block, downed the inclined fault plane. The fault was produced by a tension as the rocks are pulled apart. This fault is probably in a same system with major Opak fault.

Significance of geological condition to earthquake vulnerability

In Panjangrejo Village at Pundong area, the geological condition is relatively homogenous. The vulnerability to earthquake is relatively same on all area. On the other side, Imogiri has heterogeneous condition. Basically based on the geological condition, this area can be divided into two zones relating with the probability of risk caused by earthquake. First zone is the area on flat morphological unit (some parts of Wukirsari). This zone is located in area where the soil or loose sediments are thick. The earthquake can cause ground shaking which triggers structural damages. The possibility of damages is greater at sites with thick (and water saturated) soil than those on competent bedrock. However in the second zone (hilly area of Wukirsari), ground acceleration of earthquake can cause ground cracking and rupture since some existing geological structures are identified. This crack and rupture can produce landslides, subsidence or differential settlement.

The soil survey shows the different physical characteristic of soil in the two research areas. Based on field observation and samples that have been taken, soil in Imogiri area can be differentiated into two groups (based on ASTM 1983 classification), which are silt/clay (in the north part of the area) and silty sand (in the south part of the area), with the content of sand is about maximum 48.84% (see Table 1). While in Pundong area, the soil classification varies from silt size soil to silty sand with the content of sand reaches 79.3%. This condition of sand has loose characteristic. While the measurement for the reaction to shaking (dilatancy) can be considered poor.

Table 1: Physical characteristics of soil in the studied areas

Location			Imogiri					Pundong					
			STA 1	STA 2	STA 3	STA 4	STA 5	STA 6	STA 7	STA 8	STA 9	STA 10	STA 11
Grain size	Gravel	%	1,58	0,46	3,12	0,00	0,82	0,00	1,21	1,26	0,00	0,13	0,00
	Sand	%	17,06	12,89	48,84	41,80	23,11	28,76	79,30	63,09	31,60	34,61	10,80
	Silt/Clay	%	81,35	86,65	48,03	58,20	76,07	71,24	19,50	35,65	68,40	65,25	89,20
Soil Classification (USC - ASTM, 1983)			ML	ML	SM	ML	ML	ML	SM	SM	ML	ML	ML
Dilatancy			quick to slow		-	quick to slow			-	-	Quick to slow		

The specific condition on geological situations of each area is transformed into the specific requirements on spatial planning and building design guideline of the areas as described in the next part of this report.

3) The Examination on the Local Material and the Structures of the Damaged and Non Damaged Buildings

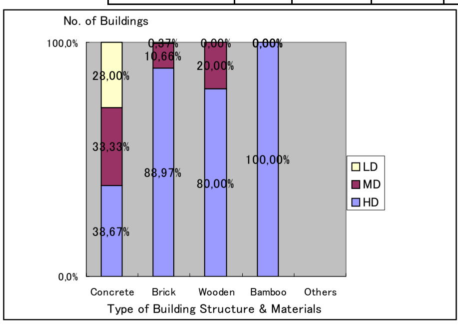
In Soronanggan-Watu-Gedong three-subvillage cluster at Pundong Subdistrict, most of the buildings are made from brick/stone (76.8%). In this type, around 89% was heavily damaged. The total numbers of Reinforced Concrete (RC) buildings is 75 buildings (21.2%), among this numbers 38. 7% severed heavy damages. While in Karangasem subvillage (Imogiri Subdistrict), 45% of the total buildings are reinforced concrete (RC) buildings and around 46.2% is wooden building. Among the total number of RC building, almost 40.7% was moderately damaged while 38,7% was lightly damaged. In wooden building, almost 76% was lightly damaged (severed minor damage). The wooden building that severed heavy damage reached 5,2%. Then, among the total numbers of buildings made from brick/stone (27 buildings), 48,1% were heavily damaged. The rest are moderately and lightly damaged. Although the subvillage located close to the fault system but it is categorized into the ring two level of vulnerability.

Table 2: The percentage of building damage levels according to type of building structure & materials, in the three subvillage-cluster, Pundong (a) and in Karangasem subvillage, Imogiri (b)

Main structure	No. of Buildings		HD		MD		LD	
Concrete	75	21,2%	29	38,7%	25	33,3%	21	28,0%
Brick	272	76,8%	242	89,0%	29	10,7%	1	0,4%
Wooden	5	1,4%	4	80,0%	1	20,0%	0	0,0%
Bamboo	2	0,6%	2	100,0%	0	0,0%	0	0,0%
Others	0	0,0%	0	0,0%	0	0,0%	0	0,0%

Main structure	No. of Buildings		HD		MD		LD	
Concrete	150	45,0%	31	20,7%	61	40,7%	58	38,7%
Brick	27	8,1%	13	48,1%	8	29,6%	6	22,2%
Wooden	154	46,2%	8	5,2%	29	18,8%	117	76,0%
Bamboo	2	0,6%	0	0,0%	1	50,0%	1	50,0%
Others	0	0,0%	0	0,0%	0	0,0%	0	0,0%

Note:
HD = Heavily Damaged,
MD = Moderately Damaged,
LD = Lightly Damage



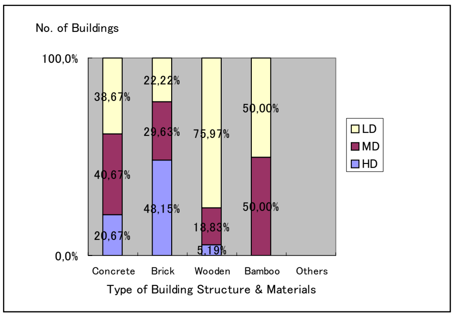


Figure 3: Building damage levels according to type of building structure & materials, in Pundong (a)and Imogiri (b)

Figure 4. Most of buildings in Pundong made of brick and concrete, severed heavily damage.

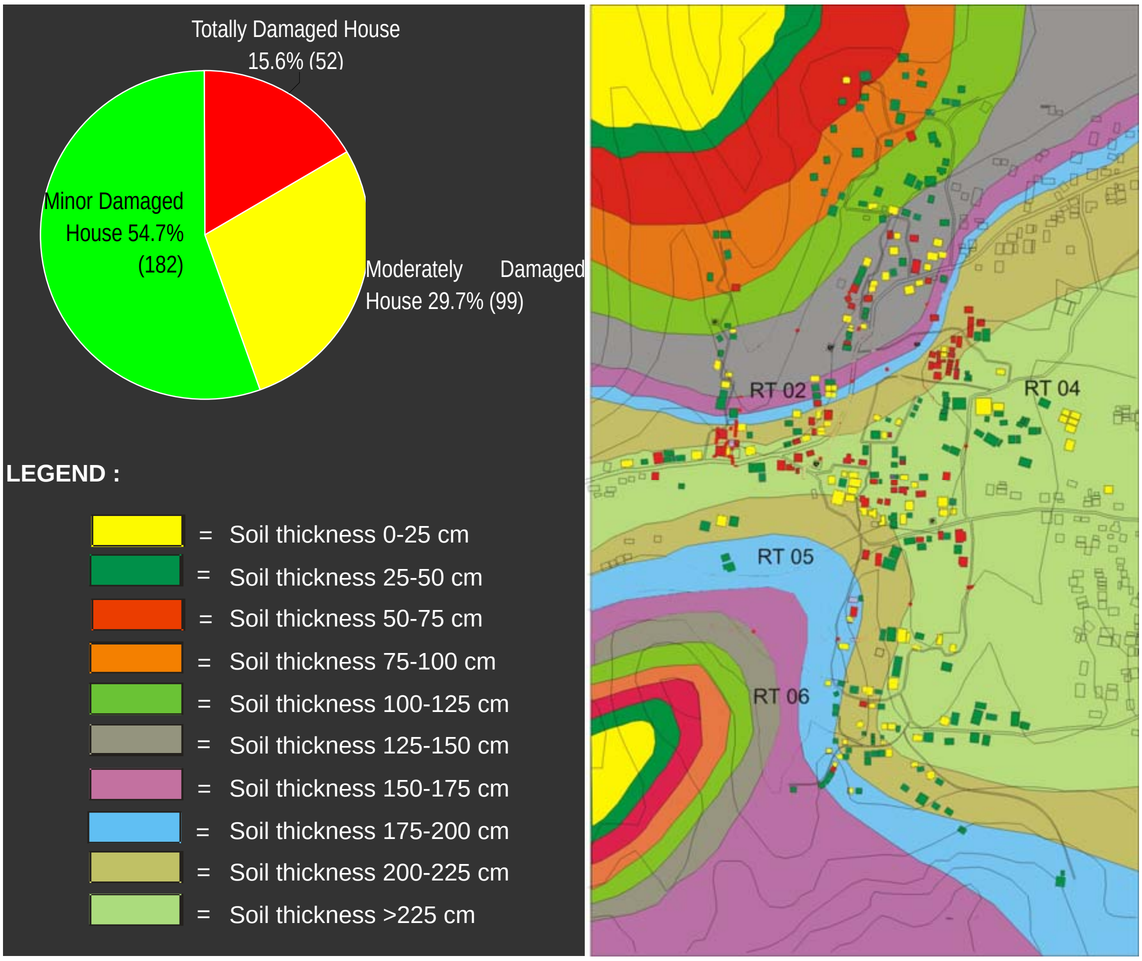


Figure 5. Building damage mapping in Karangasem, Wukirsari Village, Imogiri combined with soil mapping

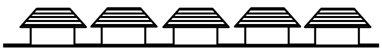
According to the result of geological survey, the heterogeneity of the rock composition made the hilly area relatively safe since there is no accumulated soil comparing with the valley area. The thick soil accumulated in the valley part of the sub-village has easily been shaken by the earthquake comparing to the hilly one. As the result, the houses particularly the weak house structures were easily destroyed. In figure 4 it can be seen that the heavily damaged building mainly are located in the area with he relatively thick soil. Still in Imogiri area, the topography of the other part is hilly but on hard rock, and the building structure has strong sub structure which relatively fixed on the hard rock layer. In the damage mapping, it is shown that the buildings located in the hilly area mostly severed minor damages. It can be learned that, beside the structural vulnerability, the soil condition and characteristics are also becoming the determinant factors for the vulnerability of the area.Regarding the structural assesments, it is learned also that the chronology of the collapsed building in the studied areas were usually started from the frame structure located just below the roof (usually because of the inexistence of supporting elements, such as ring balk) so that all the weight of all elements of roof become the burden to the elements under the roof. More specific to the study area, most of the heavily damaged houses in Pundong Area are because of: a) the use of 1 brick with clay which has no strong force again lateral force (from seismic force), b) the new houses (±10 years) do not have full element of structure, such as the absence of ringbalk). Since that, the damage of the house was begun from roof structure which causes total damage of the entire house.

3. RESEARCH RESULTS

1) Spatial arrangement

Based on the analysis on the significance of the geological condition of the research area, this research learnt that both Imogiri Subdistrict and Pundong Subdistrict are susceptible. Imogiri Subdistrict is considered susceptible because of the heterogenuous steepness of land, while Pundong Subdistrict is quite susceptible, more because of the soil physical characteristic. Moreover, for Pundong area, the content of sand with loose characteristic is quite high in the whole area. This situation can be derived into the spatial planning in messo scale that this area is relatively more appropriate for the green area or farming, rather than for human settlement or housing. However, when the land occupancy for the human settlement is inevitable, the planning codes must be suggested.

- *Suggested building design codes for Pundong area*



- Relatively flat (slope 0-2%)
- Moderate density (BCR 50 - 60%)
- Strong structure
- Allowed domination of permanent materials

- 2 storeys is not allowed / suggested
- Suggested excaping path and open space for emergency exit

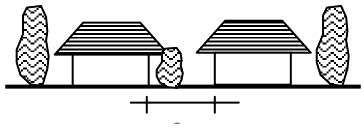


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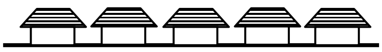
Figure 6: Suggested building codes for Pundong

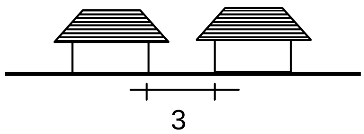
For Imogiri area, since the land consists of hilly and relatively flat surface, the recommendation on the spatial arrangement of the buildings also varies according to the levels of steepness. The recommendations are as follow:

- *Suggested building design codes for Imogiri area*

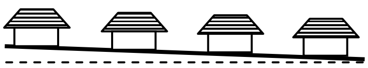


- Relatively flat (slope 0-2%)
- Moderate density (BCR 50 - 60%)
- Strong structure
- Allowed domination of permanent ı

- Allowed 2 storeys, but not fully loaded
- Suggested excaping path and open space for emergency exit

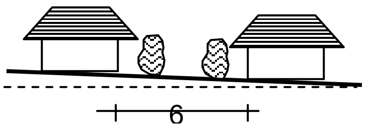


- Minimum distance between walls / housing: approx. 3 m

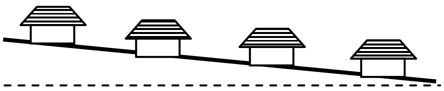


- Slope slightly (slope 2-8%)
- Low density (BCR 40-50%)
- Strong structure
- Allowed permanent material, with dc of semi permanent materials

- 2 storeys is not recommended
- Excaping path for emergency exit and open space is strongly suggested

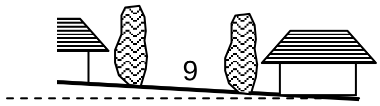


- Minimum distance between walls / housing: approx. 6 m
- Plant is strongly suggested as filled element



- Relatively steep (slope >8%)
- Very low density (BCR <40%)
- Strong structure
- Semi permanent materials is strongly suggested

- 2 storeys is not allowed
- Excaping path and open space for emergency exit is a must



- Minimum distance between walls / housing: approx. 9 m
- Tree is strongly suggested as filled element

Figure 7: Suggested building codes for Imogiri

2) Structural Recommendations

As a part of the building, the foundation is the main element of the building construction which has significant role to support the whole building. The building susceptibility towards the ground shaking or earthquake can be reduced through an appropriate design of the foundation. Based on the soil bearing capacity data of Imogiri and Pundong areas, the result can be described as follow:

Table 3: Soil Test Result

	INDEX PROPERTIES			UNCONFINED COMPRESSION TEST			DIRECT SHEAR TEST	
Boring Name	Wn	γd	γm	α	Φ	c	φ	c
	%	g/cm3	g/cm3	....o	....o	kg/cm2	....o	kg/cm2
IM 1	39,35	1,3	1,81	-	-	-	20,04	0,15
IM 2	39,97	1,35	1,89	55	20	0,29	20,23	0,15
PU 1	33,25	1,42	1,89	-	-	-	21,43	0,1
PU 2	35,74	1,39	1,89	59	28	0,02	21,7	0,05

From the above data, by using the common local materials (stone), also the foundation size (60 cm depth and 70 cm width), the maximum bearing capacity for building can be determined as follow:

Imogiri

γ= 1,89 g/cm3 1,89 t/m3
φ= 20,23 o
c= 0,15 kg/cm2 1,5 t/m2
t= 60 cm 0,6 m
l= 70 cm 0,7 m
F= 2,5

φ= 20,23 --> N`c 7,9
N`q 3,88
N`γ 2

qu = 2/3.c.N`c + q.N`q + 0,5γ.B.N`γ
qu = 7,9 4,39992 1,323
qu = 13,623
Soil bearing capacity
qa= 1/2.5 . qu
qa = 5,4492 t/m2
qa = 0,5449 kg/cm2

Pundong

γ= 1,89 g/cm3 1,89 t/m3
φ= 20,23 o
c= 0,05 kg/cm2 0,5 t/m2
t= 60 cm 0,6 m
l= 70 cm 0,7 m
F= 2,5

φ= 20,23 --> N`c 7,9
N`q 3,88
N`γ 2

qu = 2/3.c.N`c + q.N`q + 0,5γ.B.N`γ
qu = 2,6333 4,39992 1,323
qu = 8,3563
Soil bearing capacity
Qa= 1/2.5 . qu
qa = 3,3425 t/m2
qa = 0,3343 kg/cm2

This result shows that the bearing capacity of soil towards the building in Imogiri is greater than that in

Pundong area. Therefore, some recommendations related to the strategy to reduce the whole building weight are strongly suggested considering the small soil bearing capacities in both locations.
Regarding the structural assessments, the damaged buildings in the studied area do not have complete required elements (foundation, column, balk). The chronology of the collapsed building in the studied areas were usually started from the frame structure located just below the roof (usually because of the inexistence of supporting elements, such as ring balk) so that all the weight of all elements of roof become the burden to the elements under the roof.
The use of light super structure is strongly recommended. Light super structure is formed by applying light materials of construction, i.e. wood or bamboo. The materials are traditionally utilized for constructing in both area case studies. However bricks and stones are recently more familiar because easier to be applied and more economical, even though those are heavy materials.
Several cases indicate that light super structure was more enduring towards the earthquake than heavy structure. Some buildings demonstrated that the bearing capacity of the foundations which was designed as closed structure were able to maintain the rigidity of the building when the earthquake hit. In case the light super structure as constructing material, closed structure foundation tolerated the earthquake though the bearing capacity of soil is low.

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