COST ANALYSIS OF RUBBLE RECYCLING AND CAST-IN-PLACE WALL SYSTEM FOR HOUSE RECONSTRUCTION SCHEMES OF THE YOGYAKARTA EARTHQUAKE AFTERMATH

Arief Setiawan Budi Nugroho[1] and Shin-ei TAKANO[2]

[1] Doctoral Student, Graduate School of Eng., Hokkaido University
(Kita-ku Kita 13 Nishi 8, Sapporo, Hokkaido 060-8628, Japan)
E-mail:arief_sbn@yahoo.com
[2]Member of JSCE, Assoc. Professor, Graduate School of Eng., Hokkaido University
(Kita-ku Kita 13 Nishi 8, Sapporo, Hokkaido 060-8628, Japan)
E-mail:shey@eng.hokudai.ac.jp

Earthquake is a disaster which often forces engineers and common people to pay attention, particularly, when large-scale earthquake occurs in residential where many non-engineered houses are present. The resulting destruction often leaves further social and environmental problems. Many are left homeless, and a large volume of rubble must be scrupulously handled. This research concerns the relief action of an earthquake aftermath, in which the reconstruction program for the victims becomes the focus of the analysis. Some previous researches on earthquake reconnaissance are reviewed, a case study is taken from the reconstruction program of the Yogyakarta earthquake aftermath, and a pilot project of cast-in-place re-mortar wall was conducted and observed. Three methods of rubble handling related to reconstruction schemes; new bricks and re-bricks system (Scheme-I), re-bricks and re-mortar blocks system (Scheme-II), and re-bricks and cast-in-place re-mortar wall system (Scheme-III); were analyzed and discussed. It has been concluded that the application of rubble recycling could reduce wall construction cost up to 20%. Although the case study was taken from Indonesia, the result may be applied to other reconstruction programs in other regions, especially those with similar conditions and developments.

Key Words : *cost analysis, house reconstruction, recycled rubble, cast-in-place wall*

1. INTRODUCTION

Earthquake is a disaster which often forces engineers and common people to pay attention, particularly, when large-scale earthquake occurs in residential where many non-engineered houses are present. Due to inadequate strength, the collapse and damage of non-engineered buildings [1), 2), 3), 4)], particularly residential houses, constitute the main cause of loss and fatalities [5), 6), 7)].The deaths are mainly due to asphyxia and internal hemorrhage caused by the collapse of the houses [5)]. Furthermore, the loss of facilities for services and large volume of rubble also deserve consideration [8), 9), 10)].

Large earthquake result in the damage or collapse of a large number of houses, which results in creating a larger problem: the homeless [8), 9)]. Providing temporary houses in the nearest and safest area with some supporting facilities such as roads, water supplies, electricity, health care and education; had been considered as the most basic solution to the problem [9)]. However, providing semi-permanent houses for the earthquake victims constituted a difficult and costly aid [8)], especially, when there was a lack of experience and financial support, such as in developing countries. Therefore, tent distribution became an alternative solution [8)]. Unfortunately, tents deteriorated easily along with time and weather changes especially for long occupancy. Accordingly, providing support for victims to reconstruct proper and permanent houses in their own places was more crucial and urgent.

This research concerns the relief action of earthquake aftermath, with focus on the reconstruction program for the homeless. Three methods of reconstruction schemes are described and analyzed: new bricks and re-bricks system (Scheme-I), re-bricks and re-mortar blocks system (Scheme-II), and re-bricks and cast-in-place re-mortar wall system (Scheme-III). As cost became the constraint of the program, finding the most reliable technique among the three schemes, which required the minimum cost, is the main aim of the research. In addition, two possible techniques for rubble handling, which directly affected the reconstruction cost, are also described and analyzed. A case study was taken from the reconstruction program of the Yogyakarta earthquake aftermath [11].

In the case of Scheme-III, as the technique of constructing walls using cast-in-place system was not a common wall construction method, we conducted a pilot project of cast-in-place wall using mortar of crushed rubble (re-mortar). The project was one among similar reconstruction projects supported by the Civil Engineering Department of Gadjah Mada University for Yogyakarta relief action. Material usage, labor involvement, and working rate of this project were observed and recorded. Accordingly, the result of laboratory experiment done by a previous researcher to examine the strength of the re-mortar was also reviewed and used as the reference for determining the re-mortar specification in the pilot project.

2. YOGYAKARTA EARTHQUAKE

On May 27, 2006 a great earthquake with a magnitude Ms=6.3 occurred in Yogyakarta region, Indonesia, at 5:50 a.m. and lasted for about 52 seconds. The epicenter was located 33 km south of Yogyakarta city while the hypocenter was placed 33 km beneath the earth. It destroyed a majority of residential houses in the region with a 4.5 million population. More than 154,000 houses collapsed, about 260,000 of which were severely damaged and another hundred-thousands were slightly damaged. It was reported that the number of collapsed and damaged houses in the affected areas reached 50% of the total number of houses [12]. The quake also claimed more than 5000 lives. Figure 1 depicts one view of the destruction caused by this earthquake. The full extent of the damage caused by the earthquake can be seen by the disfigured roofs and scattered debris. Except those houses made of confined brick masonry with proper strength, other non-engineered houses made of confined masonry,

Source: BAPPENAS [12].

Fig. 1 One view of the destructions caused by Yogyakarta great earthquake 2006.

unreinforced masonry, stone, adobe, or hand-made clay brick, were collapsed or severely damaged.

The 2006 Yogyakarta earthquake provided a valuable lesson, particularly for the people who lived in the affected area [1]. The collapsed houses forced the victims to leave their homes and seek shelters. On the other hand, the damaged houses, especially the severe ones, were not suitable to be occupied due to the risk of sudden collapse.

To overcome the problem, the Indonesian government provided funds for the victims to reconstruct their houses. However, solving homelessness was not as easy as just providing funds. Massive simultaneous house reconstruction caused huge demands for construction material, which were beyond what could be supplied. Consequently, material resources were exploited and material prices increased, particularly that of clay and sand, which constituted the main material for brick and mortar, respectively. Hence, the lack of construction resources became a big concern. Even though providing proper permanent houses is very crucial, environmental degradation caused by uncontrolled material exploitation is also a serious matter.

3. RESULT OF THE LABORATORY TEST OF THE RECYCLED RUBBLE

With regards to the large volumes of rubble caused by the destruction of the Yogyakarta earthquake 2006, the idea of recycling rubble to become fine aggregates replacing sand for mortar (re-mortar) was conceived. The re-mortar was considered to be used for brick bonding mortar, wall plaster, re-mortar block and or the cast-in-place re-mortar wall system.

A laboratory test was performed by a researcher at Gadjah Mada University. The test aimed to obtain the appropriate proportion of cement (pc) and crushed rubble (cr), in order to reach the required strength [10]. Rubble was collected from the road sides and brought to the laboratory. The rubble was sorted into those of mortar, burned clay brick and roof tile.

The result of the laboratory test, together with the types of mortar based on Indonesian National Standard (SNI), is shown in Figure 2. Using the proportion of cement (pc) and crushed rubble (cr) of 1pc : 8cr, 1pc : 6cr, and 1pc : 4cr, the mixture produced re-mortar which can be categorized as type-O, type-N, and type-S, respectively. The application for each mortar type is given in Table 1. As type-O, the mortar can only be used for walls which do not support loads, for instance, for decoration or partition walls. Meanwhile, as type-N, the mortar can be applied for common walls which resist loads. As type-S, it might be best to provide better alternatives. Therefore, based on the result, for making re-mortar block , cast-in-place re-mortar wall system, and brick bonding mortar, the proportion of 1pc : 8cr, 1pc : 6cr and 1pc : 4cr; are recommended respectively [10].

4. THE PILOT PROJECT

The pilot project was conducted in Desa Sriharjo, a sub-district of Imogiri, in the district of Bantul, Yogyakarta province [11]. This location was one of the severe areas affected by the 2006 Yogyakarta

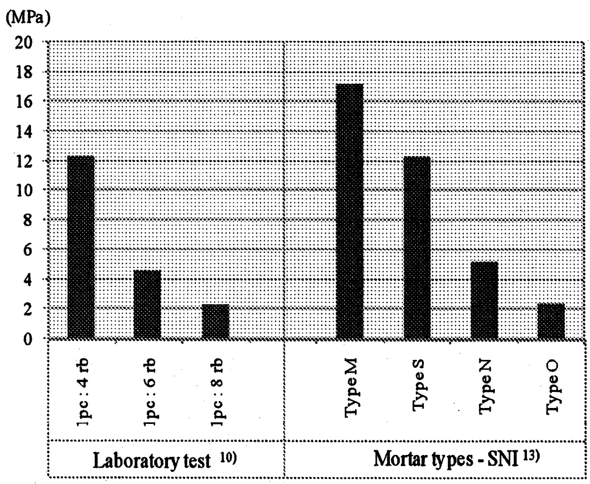


Fig. 2 Result of the laboratory test vs. SNI.

Table 1 Type of mortar and its application.

Location	Part of building	Type of mortar	
		Recommended	Alternative
Outer part, upper level	Load supporting wall	N	S or M
	Load not supporting wall	O	S or M
Outer part, lower level	Foundation of wall, load supporting wall, manhole, well	S	M or N
Inner part	Load supporting wall	N	S or M
	Load not supporting wall	O	N
Outer and inner part	Decoration	O	N

Source: SNI [13]

earthquake. Almost all houses had completely collapsed while the remaining ones were severely damaged.

(1) Description of work

The work was focused on constructing a simple earthquake-resistant house with the minimum construction cost possible. The house was constructed on the original foundation's layout size of 6x6 m^2. The remaining door and window frames, which were still in good condition, were reused. The house walls were made of crushed rubble, however, due to the unavailability of crushing machines in the location, the rubble was crushed elsewhere, about 15 km from the construction site. The crushed rubble was then processed into mortar, with cement (pc) and crushed rubble (cr) proportion of 1pc : 6cr.

(2) Construction technique

In general, the technique of recycling rubble is already well-known and widely implemented, particularly for concrete material [14), 15, 16)]. But, the application of rubble recycling for cast-in-place re-mortar wall systems has never been applied so far. Thus, a modified wall system, with reinforced concrete columns and beams confining reinforced re-mortar walls, was applied in the pilot project. The pilot project's views and stages are depicted in Figure 3.

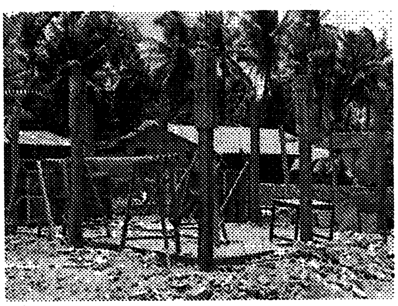
Based beams were made on the original foundation in which steel skeletons of the columns were previously stored together. The columns were then casted for every one meter height with one day curing period. They were constructed repeatedly until the desired height of 3 m was achieved.

In the modified wall system; steel rebars for wall were used. Single ϕ6 rebar was attached for every 50 cm wall height and width. This was aimed to avoid the shrinkage crack and increase the plane shear capacity of walls and prevent from brittle damage. The formworks for casting the walls were manufactured. Two sheets of 9 mm tick plywood were used and attached onto timber frames. In order to reduce the casting cost, the formworks were manufactured properly so that they could be used for 10 times repetition. The curing time for the re-mortar was one day. Therefore, similar to columns, repetitive work also occurred to walls since walls could only be casted for every 1.2 m height. This method was done with regard to the 1.2 m width of the formworks.

5. RUBBLE HANDLING

(1) Rubble removal

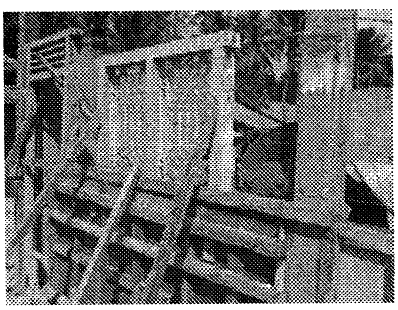
Due to the number of damaged and collapsed houses, a large amount of rubble was present. Assuming that the damaged walls were without plaster and each damaged or collapsed house produced about 10 m^3 wall rubble, BAPPENAS, the Indonesian National Development Planning Board,



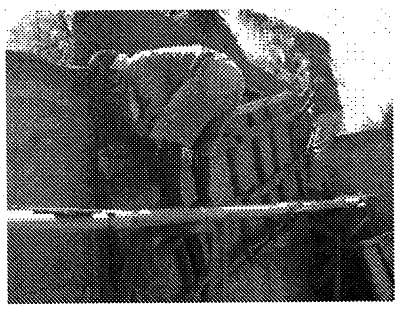
(a) The construction site

(b) Formwork manufacturing

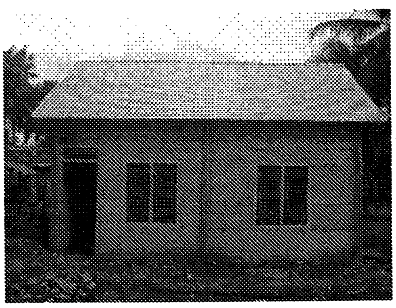
(c) Formwork assembling



(d) Re-mortar pouring



(e) Formwork dismantling



(f) The constructed house

Fig. 3 The reconstruction's views and stages of the Yogyakarta pilot project.

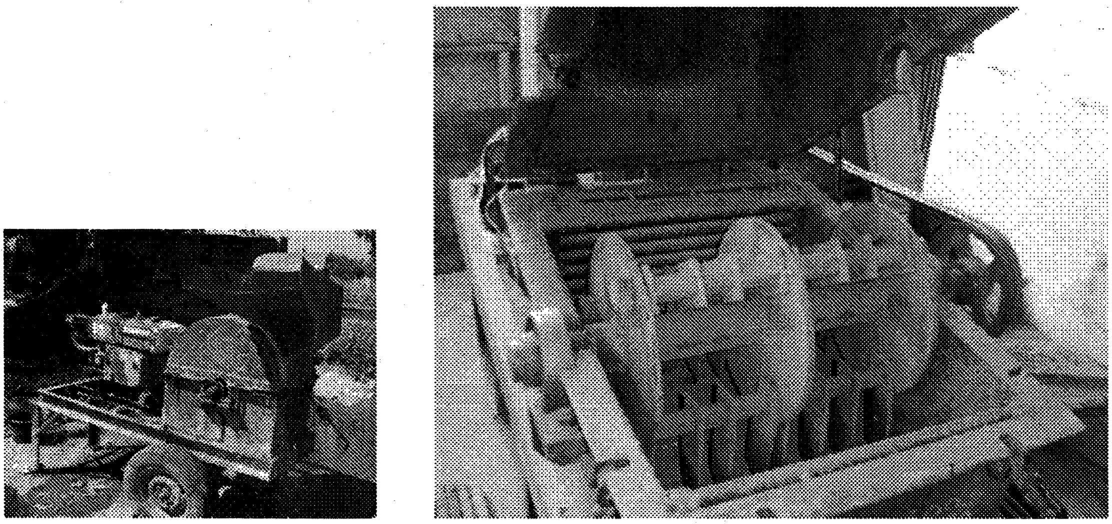


Fig. 4 The crusher machine.

estimated that the total volume of rubble reached 4.1 million m^3. Forty five percent of which was categorized as reusable material [12], which was in the form of reusable bricks (re-bricks). The amount was equal to 45 units of reusable bricks. With the need of bricks per 1 m^2 of wall as equal to 70 units, the amount of the re-bricks was equal to 64% towards the total number of bricks per m^2 of wall. Meanwhile, the rest of the 55% of the damaged wall, which was a mix of damaged bricks and mortar, remained as rubble. Using back-hoes, dozers and dump trucks mobilized by local government, the rubble was brought to the dump site, about 10 km in average from the destruction area.

Assuming that 50% of discarded rubble (27.5 % of the total volume of rubble) was removed while other 50% remaining was discarded on site as fill, BAPPENAS estimated that the number of dump truck trips with 4 m^3 bucket capacity was equal to 280,864 trips. The total cost of this work was estimated to be as much as 109,579 million IDR or about 97,537.9 IDR per m^3 of the removed rubble [12].

(2) Rubble recycling

Considering the wasteful disposal of rubble, recycling was strongly considered. To accommodate the large production of crushed rubble for real application, a mobile crushing machine was developed. The machine was developed by Suharto, a local contractor who was involved in the program. A 115 cc diesel engine was used as the motor and a couple of belts were used to transfer the power from the engine to the machine. Three sets of blades made of steel plate in the crushing drum took the role as the crusher. One set of blades, consisting of eight series of steel plates, was attached at a shaft. The plates were hinged so that they might swing during rotation. Meanwhile, a series of deformed rebars were welded at the bottom of the drum with a specified distance. These rebars acted as anvils for the impact of the blades and as sieves for the crushed rubble. This machine is depicted in Figure 4.

The crusher machine required 1 operator and 6 helpers in its operation. In normal use, it could produce 15 m^3 of crushed rubble per day by consuming 3 liters of diesel fuel and changing the lubricant oil once a week for the maintenance.

Based on the machine's specification, given in Table 2, and considering the labor costs and material prices, given in Table 3, simple cost calculation of rubble crushing can be obtained.

Table 2 Specification of the crusher machine.

Manufacturing cost	20,000,000 IDR
Motor type	Diesel engine
Cylinder x piston	110 x 115 (mm x mm)
Max output	22/2200 (HP/rpm)
Number of workers	
Operator	1 man
Helper	6 man
Production rate	15 m3/day
Fuel consumption	3 lt/day
Lubricant consumption	1 lt/week

Note: a week is equal to 7 days

Table 3 Costs and prices.

Operator	35,000.00	IDR/man/day
Helper	27,000.00	IDR/man/day
Lubricant oil	25,000.00	IDR/lt
Fuel	4,300.00	IDR/lt

IDR : Indonesian Rupiah.

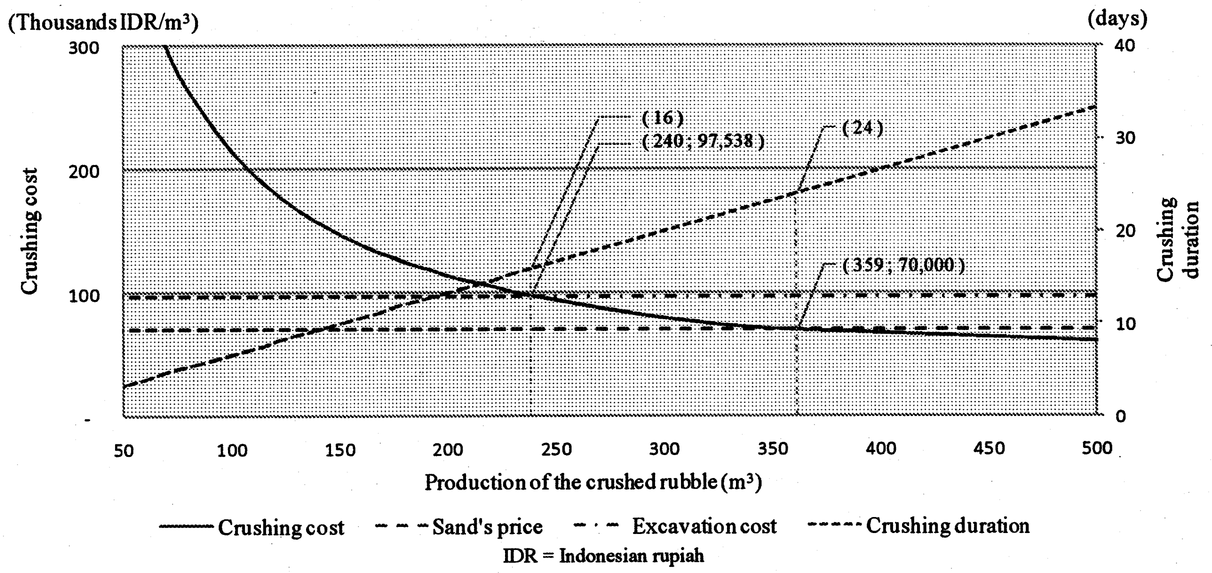


Fig. 5 The relationship between the production of the crushed rubble toward the crushing cost and duration.

Calculation of each cost obtains:

Cl $= 1 \times 35{,}000 + 6 \times 27{,}000$
$= 197{,}000$ IDR/day

Co $= 3 \times 4{,}300$
$= 12{,}900$ IDR/day

Cm $= 25{,}000 / 7$
$= 3{,}571$ IDR/day

in which:

Cl : labor cost (IDR/day)
Co : operation cost (IDR/day)
Cm : maintenance cost (IDR/day)

Therefore, the investment cost (Ci) for providing the crushing machine decrease along with the total production of crushed rubble:

$$Ci = 2.10^7 / Vp \tag{1}$$

in which:

Ci : Investment cost (IDR/m^3)
Vp : Total production of crushed rubble (m^3)

Thus, the total cost (Ct) per m^3 of crushed rubble (IDR/m^3) can be calculated as:

$$Ct = (Cl + Co + Cm) / 15 + Ci$$
$$= (197{,}000 + 12{,}900 + 3{,}571) / 15 + 2.10^7 / Vp$$
$$= 14{,}231 + 2.10^7 / Vp \tag{2}$$

Meanwhile, the crushing duration (Tcr, in day) can be calculated as:

$$Tcr = Vp / 15 \tag{3}$$

Figure 5 shows the relation between the production of the crushed rubble toward its recycling cost and duration. It is shown that the crushing method seems feasible for huge production as the investment cost decreases with an increase of crushed rubble production. The crushing cost was equal to the excavation cost, which was 97,538 IDR, when the production was equal to 240 m^3 with duration was 16 days. Therefore, when the production was larger than this volume, the crushing cost was lower than the removal cost. Meanwhile, the crushing cost was the same as the sand price of 70,000 IDR, when the crushed rubble production reached 359 m^3 for 24 days.

6. HOUSE RECONSTRUCTION ANALYSIS

(1) Resources' coefficient

Based on the possibilities of rubble handling, house reconstruction techniques can be divided into three schemes: the new bricks and re-bricks system (Scheme-I), the re-bricks and re-mortar blocks system (Scheme-II), and the re-bricks and cast-in-place re-mortar wall system (Scheme-III). Scheme-I is the program in which the possibility of recycling rubble is neglected, whereas, Scheme-II and Scheme-III are the programs in which the possibility of recycling rubble is accommodated. However, these three schemes still accommodate the usage of re-brick for conventional brick wall system in some parts of the walls. Nevertheless, as the difference of the construction system is only with the wall work, while other works such as foundation, beams, columns, ring beams, and roof, are the same, thus, the analysis is only done to distinguish the effect of the different application of wall work to the wall construction cost. The schemes are depicted in the flowchart in Figure 6.

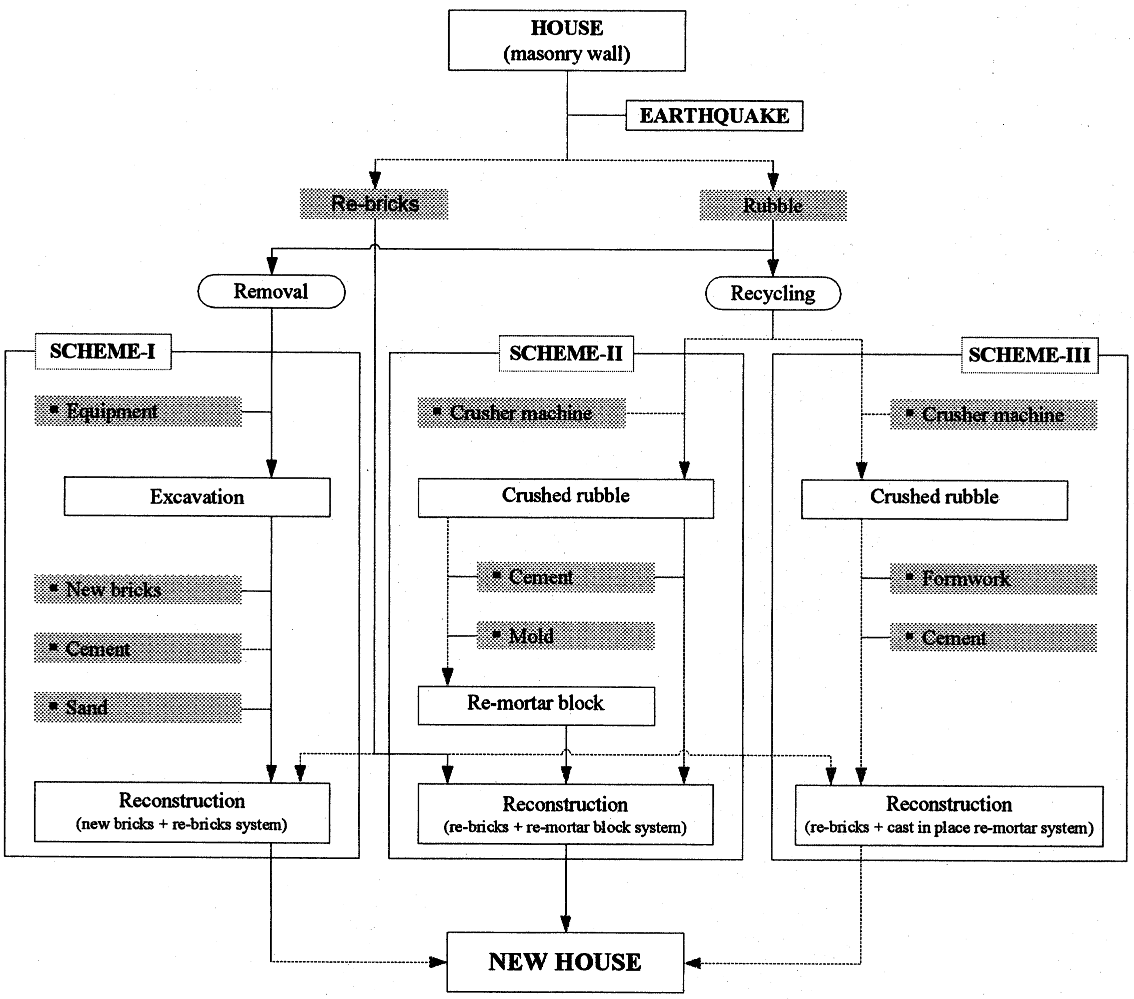


Fig. 6 Flowchart of the house reconstruction schemes in three different rubble handlings.

In Scheme-I, rubble is considered as non-recycled material, it has to be removed and disposed of. Thus, the equipment cost for excavation, removal and disposal are taken into account. Therefore, based on the BAPPENAS, as previously explained, the removal cost is taken as much as 97,537.9 IDR per m^3 of the removed rubble. Sand, cement, and some additional number of bricks are purchased. The conventional wall system, confined brick-masonry wall, is applied. The wall work is then finished with plaster to the whole walls.

In Scheme-II and Scheme-III, instead of removing the rubble, it is recycled using a crushing machine. The machine is considered to be operated as long as 304 days or about ten months. This length is taken as equal to the reconstruction stage duration of the earthquake recovery program planned by the Indonesia government [17].

Table 4 Resources coefficient and notation per m^2 of basic works.

Material	Unit	Brick [18]		Re-mortar block [18]		Plaster [18]		Cast-in-place [11]	
Sand/re-rubble	m3	0.049	B_a	0.027	R_a	0.023	P_a	0.132	CI_a
Cement	kg	8.320	B_c	7.500	R_c	3.680	P_c	19.800	CI_c
Brick	unit	70.000	B_b	-	-	-	-	-	-
Mortar block	unit	-	-	12.500	R_m	-	-	-	-
Steel rebar	bar	-	-	-	-	-	-	0.333	CI_s
Formwork	unit	-	-	-	-	-	-	0.100	CI_f
Skilful labor	man. day	0.1	B_l	0.1	R_l	0.15	P_l	0.128	CI_l
Helper	man. day	0.32	B_h	0.32	R_h	0.2	P_h	0.450	CI_h

Table 5 Resources amount of each scheme per m^2 of wall.

Resources	amount	Remark
Scheme-I (new bricks and re-bricks system)		
Crusher machine	- -	no recycled rubble process, all rubble were disposed
Molder	- -	no recycled rubble was molded to make re-block
Formwork	- -	cast-in-place system was not applied
Cement	15.680 kg	$B_c + (2 \times P_c)$
Sand	0.095 m^3	$B_a + (2 \times P_a)$
New brick	70.000 unit	B_b
Steel rebar	- -	Steel rebar is not used for wall reinforcement
Re-brick	45.000 unit	Re_b
Re-rubble	- -	No rubble was recycled, all of those were removed
Excavation	0.055 m^3	$(1.00 \times t_{wall}) - (Re_b \times Q_b)$
Skillful labor	0.400 man.day	$B_l + (2 \times P_l)$
Helper	0.720 man.day	$B_h + (2 \times P_h)$
Re-mortar block molder	-	no re-mortar block molder was assigned to make re-mortar block
Scheme-II (re-bricks and re-mortar blocks system)		
Crusher machine	2.729E-5 unit	$((B_a \times Re_b / B_b) + (Q_m \times R_m \times (1- Re_b / B_b)) + (R_a \times (1- Re_b / B_b)) + (2 \times P_a)) / (V_{machine} \times T)$
Molder	5.874E-5 unit	$(R_m \times (1- Re_b / B_b)) / (V_{molding} \times T)$
Formwork	- -	cast-in-place system was not applied
Cement	21.360 kg	$(B_c \times Re_b / B_b) + (Q_m \times R_m \times (1- Re_b / B_b) \times P_c / P_a) + (R_c \times (1- Re_b / B_b)) + (2 \times P_c)$
Sand	- -	Re-rubble was used for fine aggregate
New brick	- -	Only re-bricks were used
Steel rebar	- -	Steel rebar was not used for wall reinforcement
Re-brick	45.000 unit	Re_b
Re-rubble	0.124 m^3	$(B_a \times Re_b / B_b) + (Q_m \times R_m \times (1- Re_b / B_b)) + (R_a \times (1- Re_b / B_b)) + (2 \times P_a)$
Excavation	- -	Rubble were recycled, not excavated or disposed,
Skillful labor	0.400 man.day	$(B_l \times Re_b / B_b) + (R_l \times (1- Re_b / B_b)) + (2 \times P_l)$
Helper	0.720 man.day	$(B_h \times Re_b / B_b) + (R_h \times (1- Re_b / B_b)) + (2 \times P_h)$
Re-mortar block molder	0.018 man.day	$(R_m / V_{molding}) \times (1- Re_b / B_b)$
Scheme-III (re-bricks and cast-in-place re-mortar wall system)		
Crusher machine	2.373E-5 unit	$((B_a \times Re_b / B_b) + (2 \times P_a \times Re_b / B_b) + (CI_a \times (1- Re_b / B_b)) / (V_{machine} \times T)$
Molder	- -	no recycled rubble was molded to make re-block
Formwork	3.571E-2 unit	$(CI_f \times (1- Re_b / B_b)$
Cement	17.150 kg	$(B_c \times Re_b / B_b) + (2 \times P_c \times Re_b / B_b) + (CI_c \times (1- Re_b / B_b)$
Sand	- -	Re-rubble was used as the fine aggregate
New brick	- -	Only re-bricks were used
Steel rebar	0.333 bar	CI_s
Re-brick	45.000 unit	Re_b
Re-rubble	0.108 m^3	$(B_a \times Re_b / B_b) + (2 \times P_a \times Re_b / B_b) + (CI_a \times (1- Re_b / B_b)$
Excavation	- -	Rubble were recycled, not excavated or disposed,
Skillful labor	0.280 man.day	$(B_l \times Re_b / B_b) + (2 \times P_l \times Re_b / B_b) + (CI_l \times (1- Re_b / B_b))$
Helper	0.553 man.day	$(B_h \times Re_b / B_b) + (2 \times P_h \times Re_b / B_b) + (CI_h \times (1- Re_b / B_b))$
Re-mortar block molder	- -	no re-mortar block molder was assigned to make re-mortar block

Note:
Q_m : Volume of re-rubble to make re-mortar block = 8.360E-3 m^3
Q_b : Volume of a unit of brick ($5 \times 10 \times 20 cm^3$) = 0.001 m^3
Re_b : Number of re-bricks per m^2 of damaged wall = 45 unit
$V_{machine}$: Crushing machine's production rate = 15 m^3/day
$V_{molding}$: Molding rate = 250 unit/man/day
T : Reconstruction duration = 304 days (10 months)
t_{wall} : wall's thickness = 0.10 m

In Scheme-II, the crushed rubble is used for making the necessary number of re-mortar blocks, bonding mortar and plaster. The amount is equal to the amount of material required to reconstruct one

Table 6 Resources costs and prices.

Resources	Price/honorarium	
Crusher machine	20,000,000.00	IDR
Mould	300,000.00	IDR
Formwork	154,073.99	IDR
Cement	700.00	IDR
Sand	70,000.00	IDR
New brick	350.00	IDR
Steel rebar	9,500.00	IDR
Re-brick *)	(350.00)	IDR
Re-rubble	18,616.00	IDR
Excavation	97,537.90	IDR
Skilful labor	35,000.00	IDR
Helper	27,000.00	IDR
Re-mortar block molder	43,750.00	IDR

*) Negative value

unit of house. To comply with the production rate of the crusher machine, a certain number of block molds are purchased. Finally, combining the usage of the re-bricks and the re-mortar blocks, confined re-brick and re-mortar block masonry system are applied. Same as Scheme-I, the wall work is then finalized by plaster to the whole walls.

In Scheme-III, instead of molding the crushed rubble into re-mortar block, a cast-in-place re-mortar wall system is applied. The cost for providing formwork is taken into account. Therefore, to accommodate the usage of re-bricks, some parts of walls are constructed using cast-in-place re-mortar wall system and the others using re-brick masonry system. Both are confined by reinforced concrete structure. The crushed rubble volume required to reconstruct one unit of house is calculated based on the volume of crushed rubble which is used for constructing walls with cast-in-place re-mortar system plus the volume for brick bonding mortar and plaster of the re-brick masonry wall system. However, as the walls' surface constructed using cast-in-place system were smooth as plaster, in the Scheme-III, plaster is only applied to the part of the wall which is constructed using the re-brick wall system.

The list of resource coefficients of the related basic works is shown in Table 4. The resource coefficients of brick, re-mortar block and plaster work are taken based on Indonesian National Standard [18]. Therefore, since re-mortar block work is similar to mortar block work, their coefficient are taken as the same. The coefficients of brick and plaster work are used for Scheme-I's analysis, whereas those of re-mortar block and plaster work are used for Scheme-II's. Meanwhile, the coefficients of the cast-in-place work taken from the result of the pilot project observation are used for Scheme-III's calculation. The notation of each coefficient is listed at the right side of each.

In Table 5, the analyses of resources' amount of each scheme are presented. The values are calculated based on the amount of each resource needed to construct 1 m^2 of wall. In Scheme-I, crusher machine, molder and formwork were not utilized as the scheme did not accommodate the rubble recycling system. On the other hand, in Scheme-II and Scheme-III, sand and new bricks were not purchased. Re-rubble was used as the fine aggregate and also re-mortar block. The calculation remark of each resource's amount can be seen at the right column in the table.

In Table 6, cost of the excavation, rubble crushing, and workers, and prices of the crushing machine and other necessary materials, are given. In the case of re-rubble, its cost is obtained by substituting Equation (3) to Equation (2). Considering that the operating time and production rate of the crushing machine is 304 days and 15 m^3/day, respectively, the cost for re-rubble becomes:

$$\begin{aligned} Ct &= 14{,}231 + 2.10^7 / Vp \\ &= 14{,}231 + 2.10^7 / (Tcr \times 15) \\ &= 14{,}231 + 2.10^7 / (304 \times 15) \\ &= 18{,}616 \text{ IDR/m}^3 \end{aligned}$$

(2) Scheme comparison

The comparison is focused on distinguishing the wall construction cost of three schemes.

Assuming that one unit of house required 63. 79 m^2 of wall [6], and multiplying with the respective resource values given in Table 5 and Table 6, the cost of each resource of each scheme is obtained. The result of the analysis is shown in Figure 7. The resources are grouped into four categories: supporting tools, new material, rubble processing, and labor.

To distinguish the contribution of the re-brick usage toward cost reduction, re-bricks are considered to have negative value. Therefore, as its value is actually zero, thus a negative amount is not counted in the total cost. Among the three schemes, Scheme-I gives a highest cost than the other two, while the Scheme-III results in the cheapest house reconstruction technique.

If the government covers the machinery cost, such as the cost for mobilizing heavy equipment in the Scheme-I, and cost for providing crusher machines in the Scheme-II and Scheme-III, the total cost can be differentiated into two types: the total-real cost, which is the total cost spent for the whole work, and the total-dweller cost, which is the only cost covered by a house owner to reconstruct a unit of house.

Therefore, as the amount of re-bricks used by the three schemes is the same, thus the usage of re-bricks contributes the same cost reduction to each scheme. But considering the percentage reduction toward

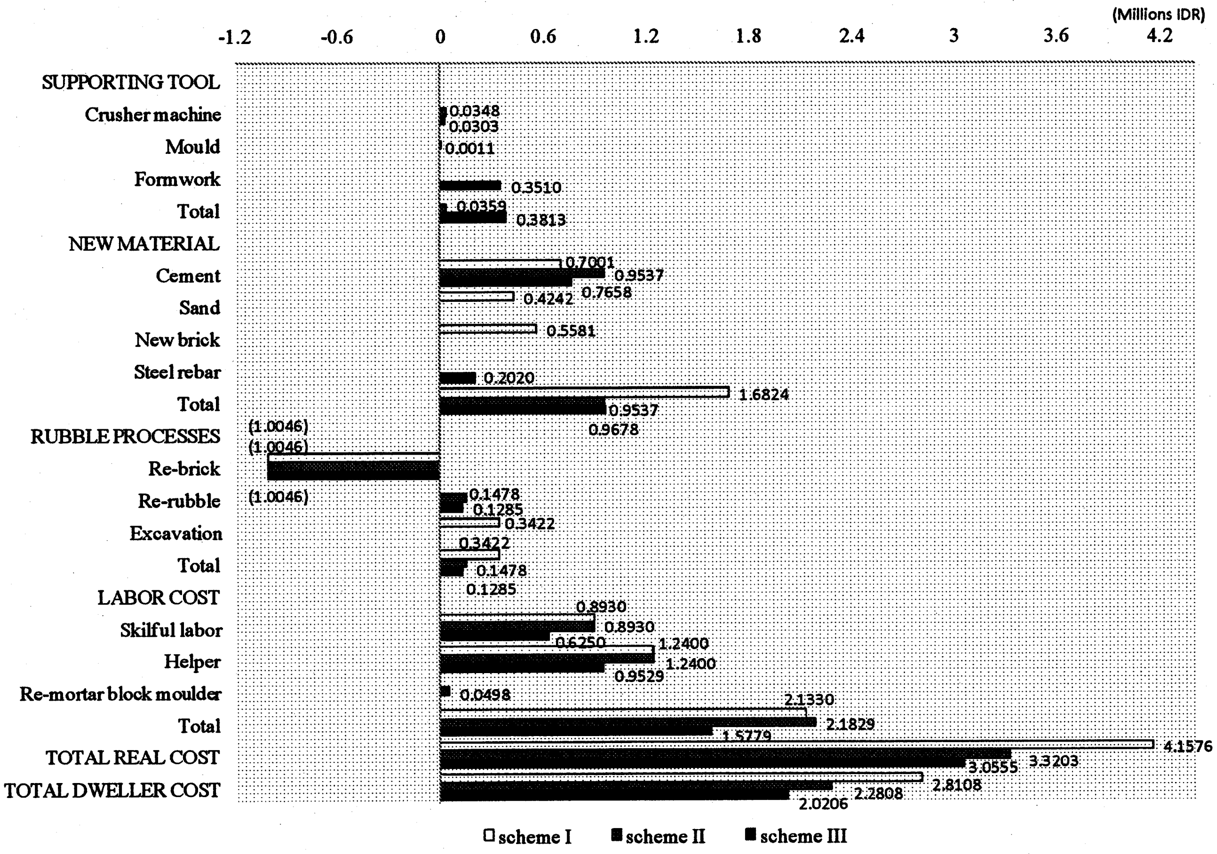


Fig. 7 The comparison of the reconstruction cost of each work item.

each scheme's total-real cost, this contribution becomes different. The use of re-brick can reduce 19.46%, 23.23% and 24.74% of the total-real cost of scheme I, Scheme-II, and Scheme-III, respectively.

The total-real cost required by Scheme-II and Scheme-III are 3.32 million IDR and 3.06 million IDR respectively. Based on these costs and compared to Scheme-I which requires 4.16 million IDR, Scheme-II offer 20.14% cost reduction while Scheme-III can decrease the cost up to 26.51%. Whereas, in terms of total dweller cost, Schemes-II offer 18.86% cost reduction while Scheme-III can reduce the cost up to 28.11%, compared to the Scheme-I.

7. DISCUSSION

Based on the cost comparison of the three schemes, the rubble recycling scheme offered by Scheme-II and Scheme-III provides lower reconstruction cost. Considering that Scheme III results in the cheapest cost, Scheme-III has become a promising scheme to be widely implemented. In addition, the pilot project has encouraged the victim's willingness to recycle their houses' rubble. In fact, the recycling scheme also offered benefits not only to the victims but also to the environment:

a) cheaper reconstruction cost;
b) reduced the problem of rubble excavation such as air defiling dust during the excavation process, the dump site, and unnecessary excavation cost;
c) eliminated the need for sand and brick as the main material of wall construction which further maintain their prices in order not to increase drastically or even steady;
d) avoided the uncontrolled construction material exploitation caused by the same period of enormous number of house reconstruction, particularly sand and clay as the main material for mortar and bricks, respectively. Thus, environment degradation was minimized.

However, due to the lack number of crusher machines, the recycling schemes faced difficulties. The rubble crushing process could not be done smoothly and much rubble still remained without any action. Neither Scheme-II nor Scheme-III could be widely implemented. In addition, lack of knowledge transfer also caused the slow spread of the recycled system to other victims who lived far from the pilot project. Moreover, due to the fund given by government which required the victims to proceed with their reconstruction progress within a determined time, brick wall system, Scheme-I, became the only alternative which could be accommodated, although the victims were forced to buy bricks with much higher price than it should be.

Regardless of the cost benefit and the environmental problem, in terms of construction technique, the three schemes provide different advantages and disadvantages. Scheme-I and Scheme-II constitute the common wall system used in the affected region. The technique to construct houses using these systems has been widely known. Using bricks or mortar-blocks, the systems are relatively easier compared to the cast-in-place system in Scheme-III, particularly to construct houses with complex wall shapes. However, considering the whole construction processes, including the bricks or mortar-blocks fabrication and the plastering stage which should be done, these two schemes require longer construction time compared to the Scheme-III.

In contrast, Scheme-III with cast-in-place system constituted a new system which was applied for wall construction of residential houses in the earthquake affected region. Its technique was not well known both by the people and also common construction workers. Training was required to make the construction workers accustomed to the technique. Intensive supervision was needed prior to the construction stage. In addition, low motivation of the construction workers to learn new construction techniques became another problem that had to be solved.

Other problems may be faced as the cast-in-place system applied in the pilot project was limited for constructing simple houses, which have a simple layout. The pre-determined size of formworks will not compatible for constructing complex houses. Casting difficulties may occur due to the different wall size and shape.

However, considering the whole construction processes, this scheme may offer the faster work since its casting system directly produced smooth wall surface and not require the plastering stage.

8. CONCLUSION

Previous research of the reconnaissance missions of great earthquake attacks in some regions has been reviewed. The case study of house reconstruction program of Yogyakarta earthquake aftermath has also been discussed.

Regarding the post-earthquake phase, the homeless often becomes a crucial problem, which needs to be rapidly solved. However, overcoming homelessness in the earthquake aftermath is not as easy as providing the funds to the victim, but the problems which may emerge right after also need to be considered. The need for houses for the homeless is urgent, therefore, placing survivors in improper temporary shelters for a long period as a quick answer to the house crisis may not be a good solution. On the other hand, allowing people to rebuild their houses without proper guidance is the same as placing them in the same risk as before for the next earthquake.

The pilot project of house reconstruction post 2006 Yogyakarta earthquake, for instance, offers one good example. The usage of crushed rubble of the damaged and or collapsed houses reduced wall construction cost up to 20%. Therefore, among two recycling systems, Scheme-II and Scheme-III, Scheme-III with cast-in-place system may provide lower cost.

Although the cast study was that of a reconstruction program in Indonesia, the results may be applied to other similar programs in other regions, especially those with similar conditions and development.

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