Cost-benefit Analysis of Seismic Retrofitting Strategies for Residential Buildings in Surabaya, Indonesia

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Abstract
Surabaya has potential vulnerability to a seismic activity as it has residential buildings with unreinforced confined masonry structures. This building structure is vulnerable to the massive destruction during the earthquake. Retrofitting existing unreinforced masonry structures is necessary as a mitigation strategy. However, the lack of funding and the high cost of retrofitting adaptation have become major obstacles. This study discussed a cost-benefit analysis of the seismic retrofitting strategies in confined masonry buildings in Surabaya. We added practical column, structural beams and a combination of practical column and structural beams as the retrofitting model. The model was then compared to normal buildings for a cost-benefit analysis.

The results demonstrated that adding practical columns could significantly reduce the building damage by 4.75 %. The additional combination of a practical column and structural beams shows zero damage to the building after the earthquake. The reinforcement of structural beams represents the highest cost-benefit ratio (44.44) due to the lowest retrofitting cost with 30.73% of damage. The cost-benefit calculation is expected to give the community remarkable information regarding the critical value of seismic retrofitting to achieve the sustainable development.

Keywords: Retrofitting, cost-benefit analysis, unreinforced confined masonry, Surabaya.

Introduction

Earthquake is the most devastating unpredictable natural disaster caused by plate tectonics or a volcanic activity. Indonesia is located between the confluence of three large plates, the Eurasian, the Pacific and the Indo-Australian plate. The plates continue to experience movement every year. The Indo-Australian plate moves at a 6 cm/ year speed to the north and subducts into the Eurasian continental plate. The Pacific plate moves westward at a 12 cm/ year speed. Plate movements cause the formation of active faults and earthquakes with high intensity in Indonesia. In addition, earthquakes in Indonesia occur almost every year since it lies around the ring of fire located in the Pacific arc with a row of mountains stretching from Sumatra to Nusa Tenggara. The magnitude of the loss due to the earthquake is related to the vulnerability of the existing construction. The vulnerable may collapse quickly and may further result in fatalities and economic losses.

Construction in Indonesia is quite vulnerable to earthquakes which cause a lot of damage. The 2018 earthquake with a magnitude of 6.2 in Sulawesi caused more than 2,000 deaths and disrupted communication and a lot of houses[31]. A large earthquake occurred in 2004 in Sumatra, causing the deaths of 200,000 people and a tsunami. In 2018, Lombok experienced an earthquake[30]. The earthquake in Lombok caused 564 people dead and 1,584 injured. Nearly 150,000 houses were damaged[3]. In addition, earthquake in Yogyakarta was the most devastating earthquake in Indonesia, which caused a massive number of fatalities (5,757 deaths) and economic losses of $3.1 billion[14].

Another big earthquake occurred in Padang City, Indonesia, with a magnitude of 7.5 Mw. It resulted in significant building damage from the seismic ground and caused over 1,100 deaths and more than 2,900 injured[4]. While earthquakes in East Java are pretty frequent, but do not result in such massive damage. Recently, Surabaya, the second biggest city in Indonesia with a highly dense population, significantly had higher possibilities of earthquake disasters[9]. The activity of Kendeng trust might induce an earthquake with 6.5 magnitude[33]. On the other hand, Surabaya shows rapid population development which increases the high risk of vulnerability to earthquake disaster[17].

Earthquakes in Yogyakarta and Padang are known to be the most disruptive in Indonesia. One of their impacts is residential dwelling[1,2]. The residential building in Indonesia mainly consists of confined masonry (CM) structures. Confined masonry structure of buildings in Indonesia lacks a seismic design and follows the typical rule of a traditional carpenter[1]. Meanwhile, most of the destruction in Padang occurred because most of the buildings are unreinforced masonry and unreinforced concrete frames[4]. The unreinforced masonry structure demonstrates poor seismic performance due to lack of structural integrity and low tensile strength[19]. Due to the earthquake, the residential dwelling caused substantial economic losses[28]. Thus, reinforcing residential buildings in compliance with seismic construction designs and seismic rehabilitation is required to reduce the losses.

In most cases, various aid came for housing reconstruction after earthquake, both from the Government and NGOs. NGOs donated $270,000 in housing assistance for earthquake reconstruction[22]. Earthquake occurred in Nepal in 2015 causing losses equivalent to 30% of Nepal's GDP[8]. The Government allocated their GDP for house reconstruction assistance to victims. Disaster aid is considered less effective and thus strengthening buildings should be done as preventive measures before the earthquakes occur. Such preventive measures are needed to increase community resilience, minimize damage and repair costs as post-disaster management is less effective than prevention.

Loss reduction measures are also necessary to apply because the earthquake is an unpredictable disaster. These can be done by improving the quality of building construction. Optimal building design can avoid casualties and can minimize house damage and economic losses. Retrofitting is one of the effective ways of seismic rehabilitation. The rehabilitation of existing unreinforced masonry structures is the most appropriate retrofitting technology.

Retrofitting technology usually involves strengthening of building foundation and frames[5]. Retrofitting with reinforced concrete provides high flexural stiffness, delays crack formation[25], offers homogenous structures and better seismic behavior[15]. The use of a minimal amount of reinforced concrete affects the load-bearing capacity of the building structure[26]. Lower cost of retrofitting and the flexible regulation of its application in compliance with the seismic standard satisfy most groups or parties[32]. However, alterations in construction building techniques and regeneration in retrofitting technologies are the challenges[6].

The high cost of retrofitting process and adaptation[13], lack of funding and inadequate legislation[16], the complexity in combining new technologies into existing buildings[13] and the demand in meeting the building code into seismic standard become major obstacles in implementing retrofitting technology. Most likely, the use of reinforcement in construction is constrained by costs. With the effectiveness of building retrofitting, the public might thrive their interest and willingness to invest. Research on the concept of cost-effectiveness of earthquake-resistant houses has been rarely done. Hence, it is necessary to discuss and analyze the cost and benefit of building retrofitting and which retrofitting method is more effective to implement.

Cost-benefit analysis has been used for seismic retrofitting of the residential buildings. In most cases, retrofitting strategies are proficient in reducing the seismic vulnerability of the existing buildings and provide a lower amount of replacement cost, reflecting economic viability[11]. Liel and Deierlein[10] conducted a cost-benefit analysis to investigate the effectiveness of various seismic retrofit strategies for older RC-framed buildings. In 2017, Paxton et al[18] performed a cost-benefit analysis on the retrofitting of unreinforced masonry (URM) buildings in downtown of Victoria, Canada. The retrofitting involved the building value, seismic hazard, several reinforcement measures and construction cost. The result demonstrated a favorable cost-benefit ratio to be a potential candidate for a risk mitigation program[18].

Strengthening residential buildings towards sustainable construction becomes the focus in this current research. It considers earthquake strength and building resistance to minimize house damage and loss to the lowest point. This study discussed a cost-benefit analysis of the seismic retrofitting strategies on confined masonry buildings in Surabaya, Indonesia. The strategies include installing the reinforcing bar using beams and columns. The cost-benefit analysis was performed to compare the benefits of construction retrofitting and normal construction structure after earthquake modelling.

This study brought issues on the investment costs and benefits of a certain method which is suitable for preventive measures. This study may add knowledge about the importance of building retrofitting as an earthquake mitigation. The results of the paper are essential to increase building resistance in earthquake-prone countries.

Study Area

This study was conducted in Kutisari residence, Trenggilis sub-district, Surabaya city, Indonesia. According to the preliminary survey data, 35 of 50 (70%) respondents were aware that their region has significantly increased possibilities of earthquake disasters. In addition, most of the residential buildings in this area are unreinforced confined masonry. Based on the previous study, the probability of Peak Ground Acceleration (PGA) in 500 years in the Trenggilis sub-district was 0.46 to 0.54 m/s^2. The Kendeng fault crosses the Surabaya area and is extended from the East to the Central Java[17]. This activity might cause an earthquake by the magnitude of 6.5 Mw[33].

Trenggilis area, located in the west of Surabaya, is more prone to earthquakes than the East Surabaya area[33]. The proximity of the area to the fault is associated with higher PGA values. Furthermore, the soil characteristics of this area increase the potential risk indicating that the ground motion can easily occur from the epicentrum to the surrounding areas including Surabaya city[23,33]. On the other hand, Surabaya shows fast infrastructure growth, leading to higher vulnerability to earthquake threats.[17]

Material and Methods

This study was a randomized home-based survey for a building model. First, the building model was chosen from the most common type of residential houses in the target area. The building area is 42 m^2 and the land area is 70 m^2. The model is a one-story confined masonry building representing the most common type of residential house in Surabaya. The house design plan is shown in figure 1 and the building structure detail is presented in table 1.

The model was then measured and modeled on a software for retrofitting. There were three ways of retrofitting model. In model 1, the building was added by a practical column. Model 2 strengthens the unreinforced part with the structural beam. Model 3 added the combined practical column and structural beam. These three models were then compared to a building without retrofitting model. The retrofitting model was then done by adding the load into the building.

The loads were the dead load, live load and earthquake load. The dead load was caused by the weight of the reinforced concrete structure at 2400kg/m^3. It was then covered by the roof with battens and rafters, with the roof area of 50 kg/m^2 and the weight of the ceiling and hanger of 1.8 kg/m^2. The average live load is 9.6 kg/m^2, the rainfall load is 20 kg/m^2 and the wind load is 25 kg/m^2. Furthermore, the earthquake loads were modeled based on the soft soil characteristics and the response spectrum was adapted to the Indonesian National Standard number 1726-2019 as shown in figure 2.

For the safety aspect, seven combination loads were added according to the Indonesian National Standard number 2487-2019 consisting of dead load (D), live load (L), rain load (R), wind load (W) and earthquake load (E). The combination load modelled is described in table 2.

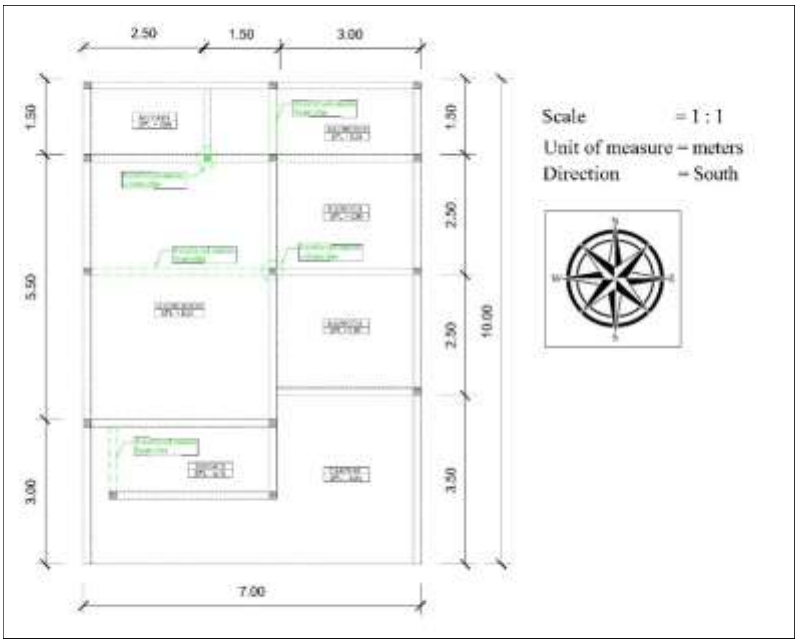
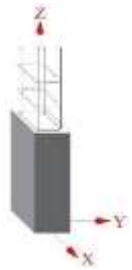
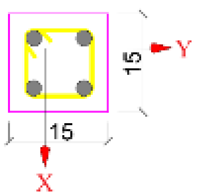


Fig. 1: House design plan

Table 1
Building structure detail

Picture	Type: reinforced concrete	
	Type: reinforced concrete	
	Column dimensions:	
	Length	: 0,15 Meters
	Width	: 0,15 Meters
	Tall	: 3,4 Meters
	Beam dimensions:	
	Length	: 0,15 Meters
	Width	: 0,15 Meters
	Tall	: -
	Reinforced dimensions:	
	Brace	: Ø 8
	Strap	: Ø 6
	Number of columns	: 12 Unit
	Number of beams	: 17 Unit

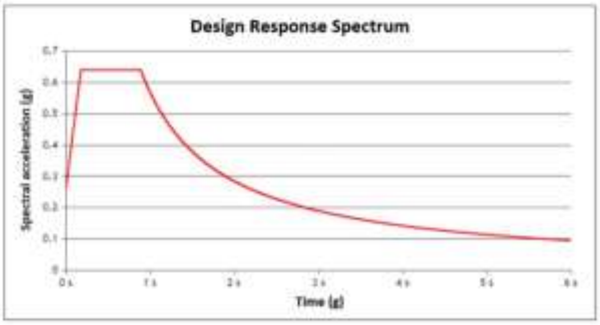


Fig. 2: Response spectrum design of soft soil characteristic in Surabaya

Table 2
Seven combination loads according to Indonesian National Standard number 2487-2019

Combination Number	
1	U = 1.4 D
2	U = 1.2 D + 1.6 L + 0.5 (R)
3	U = 1.2 D + 1.6 R + (1.0 L or 0.5 W)
4	U = 1.2 D + 1.0 W+ 1.0 L + 0.5 R
5	U = 1.2 D + 1.0 E+ 1.0 L
6	U = 0.9 D + 1.0 W
7	U = 0.9 D + 1.0 E

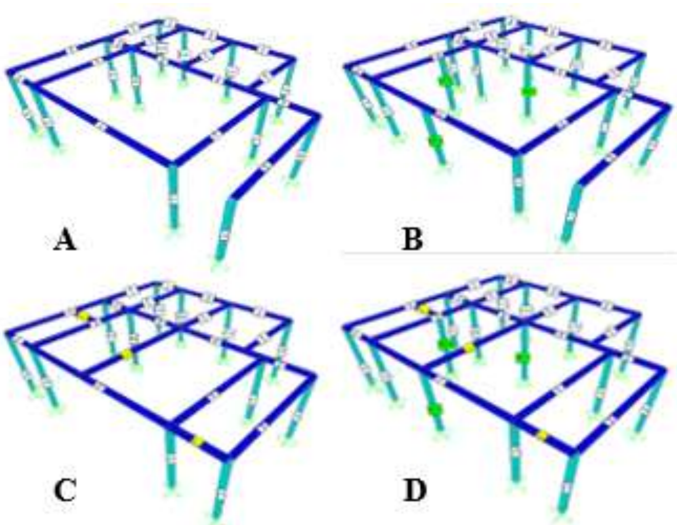


Fig. 3: The building structure of (A) without retrofitting, (B) Model 1, (C) Model 2 and (D) model 3

Furthermore, the failure percentages of three models due to the earthquake were calculated by comparing the intact and collapsed volume of the buildings. After obtaining the percentages of failure, the cost of adding the practical column and structural beams was compared to the benefits obtained. The cost-benefit analysis was performed by comparing the benefits of the undamaged building after earthquake modeling with the costs associated with the preventive retrofitting of the building. The total losses were calculated by multiplying the percentage of damage and the house price. The cost-benefit ratio was obtained by the following equation:

$$\text{Cost benefit ratio} = \frac{\text{the house price} - \text{total losses}}{\text{retrofitting cost}} \tag{1}$$

Results and Discussion

Structure Analysis: The retrofitting model on the residential house in the target area is depicted in figure 3. Figure 3 (A) shows the model without any reinforcement. The building was then reinforced by adding the practical column in the living room as shown in figure 3 (B) with structural codes K3, K10 and K12. The living room has the biggest area and needs reinforcement for the earthquake disaster. The second retrofitting model depicted in figure 3 (C) was done by adding the structural beam in the kitchen room and in the carport and terrace with structural codes B1 and B5. Furthermore, figure 3(D) combines retrofitting model 1 and model 2 by adding both practical column and structural beams.

Furthermore, figure 4 (A) shows the simulation results of the building without reinforcement. The result indicated that structural failure was presented in most of the concrete framed building. There were 15 collapsed structures in concrete frames of the unreinforced building when it was loaded by dead load, live load, rain load, wind load and earthquake load. The failures are mainly found in the part of structural beams due to the low quality of construction[24,25,27]. Therefore, the unreinforced building did not meet the seismic safety standards[29]

As compared to the building with the practical column reinforcement as shown in figure 4 (B), the building model showed significantly strengthening structures. The collapsed structure in concrete frames of the reinforced building decreased to three failures which occurred in structure codes B4, B7 and B8. When added by the beams to the concrete frames, as depicted in fig. 4 (C), the model showed nine structural failures. These results showed that the addition of a practical column offered a greater strength than the structural beam addition. Most likely, adding the practical column increases the dissipation of seismic energy, the ductility and the moment capacities of insufficient columns[12].

Meanwhile, adding the beams causes inadequate transfer of the bending moment from the beam to the column, a decrease in lateral stiffness and energy dissipation capacity (benavent-climent). This shortcoming mainly occurs due to structural beam reinforcement anchored in the perpendicular of beams adjacent to the column, not in the center of the column (benavent-climent)[21]. Thus, the load-carrying is not directly transferred to the building foundation.

Cost Benefit Analysis: Most of the homeowners in the target area were from civil society who did not understand the seismic standard of the building, but they only knew that the house was sturdy enough. To improve the safety of the building, the community should understand more about the significance of strengthening the building with greater benefits and lower costs. However, people often fail to understand the benefits over money they spent for construction retrofitting.

The cost-benefit estimation was performed by obtaining all the costs of reinforcement and the benefits of all retrofitting models. On the expense of the retrofitting, model 1 includes preparation fee, wall demolition, practical column addition, wall painting, wall finishing and cleaning fee. The total cost of retrofitting model 1 is $661.74. The model 2 includes preparation fee, ceiling demolition, structural beams addition, installation of ceiling wooden frame, lamp installation, ceiling finishing and cleaning fee with a total cost of $280.64. Furthermore, the model 3 includes all the fees with a total cost of $784.05. The detailed estimation for the retrofitting costs is summarized in table 3.

The benefit calculation was done by calculating the percentage of undamaged buildings due to earthquake modelling to the retrofitting cost. Table 4 shows the recapitulation of cost-benefit for all retrofitting models. The building without retrofitting is predicted to experience 64.42% of damage if earthquake disaster occurs. The total losses are $11,597.20. After practical column addition, the building damage significantly reduced to be 4.75%, with a total loss of $855.12. The cost-benefit ratio of the retrofitting model 1 showed 25.91 indicating that the benefit gained from the added practical column is more than 25 times the cost issued for retrofitting.

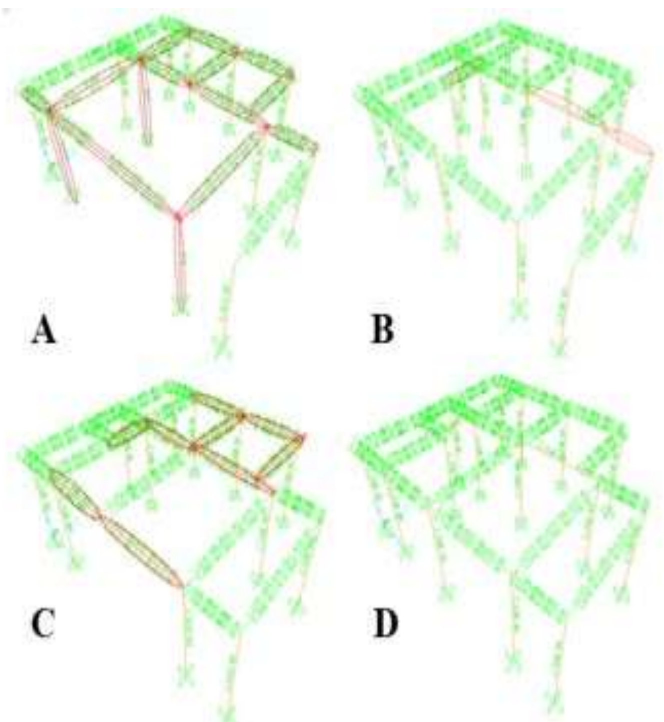


Fig. 4: Simulation result of building (A) without retrofitting, (B) model 1, (C) model 2 and (D) model 3

Table 3
The retrofitting cost for all model

S.N.	Activity	Vol.	Units	Unit Price	Model 1	Model 2	Model 3
1	Preparation fee	42.00	m^3	$0.86	$36.08	$36.08	$36.08
2	Wall demolition	5.04	m^3	$72.48	$365.32	-	$365.32
3	Practical column addition	0.23	m^3	$455.97	$104.87	-	$104.87
4	Wall painting	5.04	m^3	$3.77	$19.00	-	$19.00
5	Wall Finishing	5.04	m^3	$2.82	$14.22	-	$14.22
6	Cleaning fee	42.00	m^2	$2.91	$122.25	$122.25	$122.25
7	Ceiling demolition	4.80	m^2	$1.15	-	$5.52	$5.52
8	Structural beam addition	0.13	m^3	$455.97	-	$59.73	$59.73
9	Installation of ceiling wooden frame	4.80	m^2	$6.12	-	$29.37	$29.37
10	Lamp installation	1.00	Point	$9.68	-	$9.68	$9.68
11	Ceiling finishing	4.80	m^3	$3.75	-	$18.01	$18.01
Total Cost					$661.74	$280.64	$784.05

Table 4
The recapitulation of cost-benefit for all retrofitting models

Models	House Price (USD)	Damage (%)	Retrofitting cost (USD)	Total Losses (USD)	Cost-Benefit Ratio
Without Retrofitting	18,002.49	64.42	0	11,597.20	-
Model 1		4.75	661.74	855.12	25.91
Model 2		30.73	280.64	5,532.17	44.44
Model 3		0	784.05	0	22.96
Without Retrofitting		64.42	0	11,597.20	-

The addition of structural beams in the model 2 indicated that the building damage after retrofit modelling is 30.73% with a total loss of $ 5,532.17. The cost-benefit ratio of retrofitting model 2 is higher than model 1 because the cost of adding the structural beams is three times lower than adding the practical column. Meanwhile, the combination of practical column and structural beams in model 3 demonstrated zero damage due to earthquake modelling with no losses. The cost of retrofitting model 3 is $784.05 with a cost-benefit ratio of 22.96.

The cost-benefit values for all models are more than one. This means that it is more profitable to reinforce the building. It is expected that by the cost-benefit calculation, the community will properly understand the value of retrofitting. In the future, it is necessary to disseminate the benefits of retrofitting to the public with a more understandable language.

Unreinforced masonry buildings, as found in Surabaya, have a shortage in earthquake resistance capacity because building strength quality, especially the connection between the parts, is low. Construction with reinforcement requires additional costs and many people are still constrained by funds. To reduce retrofitting costs, it is necessary to build cooperation between the Government and private sectors. Giving incentives also benefits the Government to reduce housing vulnerability, casualties and economic losses. Construction incentives and community development, for example, have been given by the Nepal Government and NGOs[7].

Reconstruction is a challenge for developing countries, especially for the community with lower-middle income. House retrofitting also minimizes the budget for post-earthquake repair. Many people are still unfamiliar with the concept of building retrofitting. The lack of society's knowledge is the main reason for the less sustainable building against the seismic standards of building construction[20]. Therefore, this current study contributes to improving society’s knowledge in building resilience management.

In this case, the Government plays an essential role to improve society's knowledge. Counseling is needed to educate people about the merits and demerits of building retrofitting adaptation. Hence, the public perception of the invisible benefits of retrofitting can be minimized by providing counseling or education. It is expected that society can be more aware to build reinforcement building. Thus, monetary incentive and society’s understanding about building retrofitting may contribute to more inclusive sustainable development[2]

Conclusion

This study estimated the cost-benefit analysis of building retrofitting after the earthquake modeling. The three retrofitting models of confined masonry building were applied and compared to a normal building. The retrofitting modelling was done by adding a practical column, structural beams and a combination of practical column and structural beams. The building with the practical column showed decreased damage by 4.75 % and cost benefit-ratio of 25.91. Adding the practical column increased the dissipation of seismic energy, the ductility and moment capacities of insufficient columns. In the last model, the combination of the practical column and structural beams showed zero damage with a cost-benefit ratio of 22.96.

The beam-column joints minimize the element weight and development of resisting frame structures in seismic regions. The reinforcement of structural beams had the highest cost-benefit ratio (44.44) due to the lowest retrofitting cost with 30.73% of damage. The cost-benefit calculation could give remarkable lessons to the community about the importance of building retrofitting to reduce earthquake venerability. The Government has to inform the community about retrofitting benefits and give monetary incentives for building retrofitting to achieve sustainable development.

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