International Journal of Engineering and Technology Innovation, vol. 6, no. 2, 2016, pp. 152 - 164

Structural Behaviour of Precast Reinforced Concrete Frames on a Non-Engineered Building Subjected to Lateral Loads

Mochamad Teguh*

[1]Department of Civil Engineering, Islamic University of Indonesia, Yogyakarta, Indonesia.

Received 11 January 2016; received in revised form 22 February 2016; accepted 29 February 2016

Abstract

Past earthquakes in Indonesia have caused loss of life and major damage to buildings and infrastructure. Most of the damage was experienced on non-engineered buildings, which were conventionally built with less consideration of earthquake resistant design. In this research, a precast system was introduced for non-engineered building structures to connect their practical beams and columns as a reinforced concrete frame. This paper presents experimental tests on precast reinforced concrete frames with and without infill masonry walls using local materials. All undamaged and repaired specimens were set up with the same loading arrangements where lateral loads were gradually applied to one side of the beam column joint until the ultimate load was reached. Simple retrofitting and strengthening techniques were applied to the damaged specimens were conducted. The results were compared based on the experimental tests, and showed that retrofitted and strengthened specimens significantly increased their strength, stiffness, and displacement ductility to improve the structural behaviour of non-engineered building structures.

Keywords: structural behaviour, precast reinforced concrete, retrofitting, strengthening, earthquake, ductility

1. Introduction

In recent years, earthquake disasters in Indonesia have frequently produced major damage to buildings, infrastructure, and other objects. The primary cause of the damage and destruction is total ignorance about earthquake-resistant construction in the society at large. Indonesia is considered one of the top 10 earthquake-prone countries in the world. Every day more than 20 earthquakes rock various parts of Indonesia, resulting in a total of about 7000 subterranean movements each year. Of that number, only about 60 are felt, and, among those are killer quakes having high magnitudes, destroying buildings, roads and infrastructure and harming humans and the environment.

The random nature of earthquake motions may directly cause structural problems to building structures and non-structures; therefore, the building structure should be sufficiently strengthened. Past earthquakes occurring in the devastated areas showed that most of the loss of life was due to the collapse of building components constructed with traditional materials without considering an earthquake resistant design concept. In Indonesia, non-engineered buildings constructed in small towns and villages [1] are commonly built according to tradition, types suiting the culture, and materials available in the area. Most of the non-engineered buildings built without assistance from qualified engineers were seriously damaged, compared to engineered buildings. Studies on past destructive earthquakes [1-4] show that general problems for these non-engineered buildings were caused by minimum reference to the national standards/codes of Indonesia [5], producing

* Corresponding author. E-mail address: m.teguh@uii.ac.id
Tel.: +62-274-898471; Fax: +62-274-895330

poor detailing, a wide variety of material quality and construction methods and improper structural designs as well. This condition produces a low quality of non-engineered building structures and a lack of resistance to seismic action. In contrast, previous experience reveals that some non-engineered buildings can survive earthquakes with minor damage, demonstrating that they were built properly by utilizing good quality materials and workmanship. Considering the large number of non-engineered buildings damaged, simple efforts to strengthen their structural components should be able to make these buildings safer. Given this condition, it is essential to introduce earthquake resistant features in their construction [6].

The majority of non-engineered buildings damaged included school buildings, mosques and conventional houses as well as other public facilities. The non-engineered building structures are commonly made of reinforced concrete (RC) frames with masonry walls infill. The occupancy rates for these structures can be very high, especially for public facilities, such as school buildings. If the buildings have low quality, these buildings and their occupants are susceptible to earthquakes. It is observed that most of the structural failures in past earthquakes were associated with deficiencies in the structure as built, whether caused by improper design, a lack of supervision or improper construction practices, such as poor materials and workmanship [1].

In general, useful technology and knowledge for disaster risk reduction and resilience is conceptualized in implementation technology consisting of implementation-oriented technology, process technology, and transferable indigenous knowledge. An innovative seismic resisting system of precast reinforced concrete is implemented on non-engineered building structures as shown in the following sections. In this paper, a research novelty for retrofitting and strengthening techniques is presented with a special concern on precast reinforced concrete frames with and without infill masonry walls of non-engineered building. The innovation includes a damaged specimen which is successively retrofitted with cement mortar, strengthened with wire mesh, and plastered at both sides of each specimen. The most advantage of utilizing this technique is low-cost repair for damaged houses and it produces higher strength and ductility compared to the original. This is mainly oriented to the people who live in an earthquake-prone area having less skill and knowledge in earthquake-resistant building design in an attempt to easily implement this simple repair technology. This is also applicable and suitable for repairing other buildings. This paper presents current research on the structural behaviour of precast RC frames with and without infill masonry walls subjected to lateral loads. In this research, three different specimens comprising open/bare frame, frame with infill concrete block, and frame with infill masonry brick were tested to determine their structural behaviour after achieving ultimate loads. The damaged specimens were repaired with simple retrofitting and strengthening techniques to restore strength, stiffness, and ductility. To compare their structural behaviour with the intact specimens, the entire repaired specimens were re-examined using the same lateral loading arrangement.

2. Common Building Types and Building Damage

Past earthquakes have shown that poor performance of unreinforced masonry and non-ductile RC frame construction caused unacceptably high human and economic losses. This prompted a need for developing and promoting alternative building technologies [7]. The main goal is to achieve an enhanced seismic performance of building structures utilizing technologies, which require a similar (preferably lower) level of construction skills and are economically feasible. The most popular building technologies used in Indonesia depend primarily upon the availability of local materials and local skilled masons. Building materials, such as brick, stone, mud, timber, and galvanized iron, are widely used to build the non-engineered traditional houses [4]. In recent years, people have started using new building technologies of reinforced concrete frame structures for their homes and for infrastructure buildings. A reinforced concrete component, for instance, has recently become prevalent with some as well.

It has been observed that two types of RC building technologies comprising confined masonry and RC frame infill masonry (Table 1) are commonly used in construction practices globally [6, 8]. More importantly, many existing buildings in the highly earthquake prone area like South Asia, Middle and South America and other developing countries have not been precisely designed for withstanding severe earthquake load. Although, the seismic standards for non-engineered structures in Indonesia have been published but they are not fully adopted by local workers and masons due to law enforcement of the standards is ineffectively applied. These buildings have also been constructed by utilizing very economical building materials such as clay mud bricks and concrete blocks. In the main concept, a composite block masonry wall commonly comprises block masonry wall surrounded by RC beams and columns. In such condition, many unsafe conventional houses have been occupied for a long time and built in the earthquake prone area of Indonesia as evidenced in Fig. 1.

(a) Improper RC additional canopy (Padang Pariaman) (b) Un-reinforced non-engineered house (Bantul)

Fig. 1 Unsafe conventional houses built in different earthquake prone area of Indonesia

In contrast, Fig. 2 presents under-construction conventional houses that have been recently built with incorrect prevailing practice resulting inadequate strength of the building structure in resisting severe earthquakes in 2006 and 2009. Besides, many owners have traditionally built their houses by employing less knowledgeable local masons and using low-quality materials as well as traditional construction methods resulting in built-house structures that are insufficient at resisting seismic actions. In fact, those built-houses were improperly constructed neglecting building codes and technical controls. This condition causes the built-buildings found with poor detailing, low material quality, low quality of workmanship, and wide variety of construction methods. Subsequently, the structures are more susceptible or vulnerable to damage subject to seismic ground motion. This phenomenon shows how important it is to educate and train people especially workers and masons in order to improve their knowledge on earthquake resistant structures.

(a) Incorrect prevailing practice of RC frame (b) Absence of RC tie-beams and tie-columns

Fig. 2 Under-construction conventional houses built in Sumatra and Java Islands of Indonesia

Table 1 Building material technology of masonry wall construction

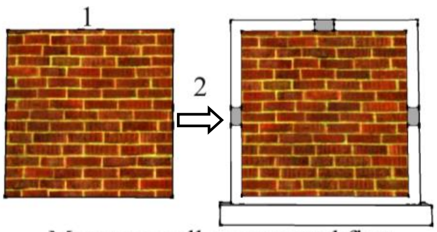
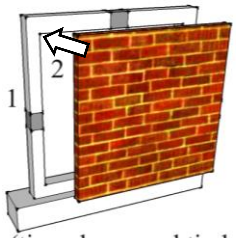
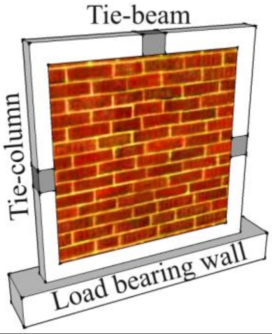
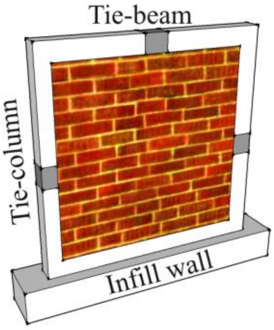
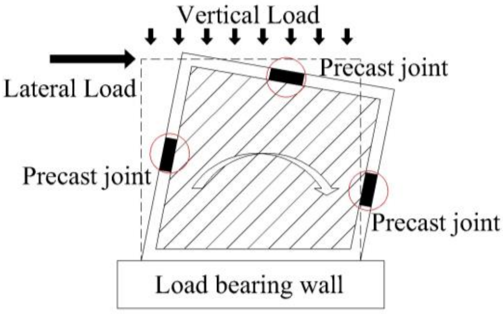
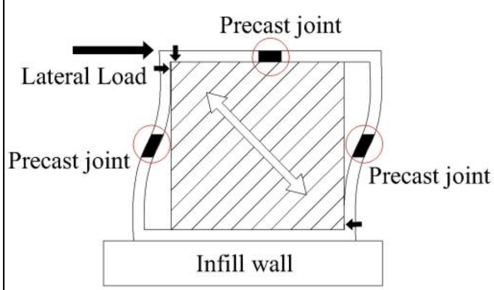
No	Description	Precast System	
		Confined Masonry	RC Frame Infill Masonry
1	Construction method	 Masonry wall constructed first	 Frame (tie-column and tie-beam) constructed first
2	Installed masonry frame		
3	Structural behaviour		
4	Structural system	Rigid: wall should be stiff under seismic loading	Ductile: frame should be flexible under seismic loading
5	Gravity load	Load bearing confined masonry wall	Frame: columns and beams
6	Seismic load	Confined masonry wall (shear wall)	Frame: columns and beams
7	Beam and column design	Ductile detailing not required in columns and beams, usually done empirically (smaller sections and bar diameters, fewer stirrups). Beams and columns are confining elements acting in tension but connections are critical	Ductile detailing and design required in columns and beams (larger sections and diameter steel bars, more stirrups at close spacing)
8	Construction process	Masonry wall constructed first	Frame (columns and beams) constructed first
9	Infill/wall system	Structural shear wall – workmanship quality is critical, as is attached to the tie column and bond beams	Nonstructural: for space partitioning, generally not attached to frame, but should be restrained from falling out (lightweight material best – masonry infill can have a negative effect on frame)

Table 1 presents a schematic of walling construction practices as a part of building technologies for masonry walls, and these two different systems provide altered structural behaviour, particularly in withstanding seismic loads. In confined masonry, the masonry wall is constructed first and the RC frame is installed later whilst, in the RC frame infill masonry is constructed in a vice versa installation procedure. The wall can be selected either from concrete blocks or brick masonry. The RC confining elements should be well designed in order to minimize crack propagation and improve the wall ductility from the wall into critical regions of RC confining elements. In practice, masonry walls are confined on all four sides by reinforced concrete members consisting of bond-beams or tie-beams and tie-columns, and interconnected their connection is critical point of strength. This can be achieved if critical regions of the RC tie-columns or practical columns are designed to resist the loads corresponding to the onset of diagonal cracking in masonry walls.

Typical damage observed on built traditional houses was simply identified in two categories consisting of walling and the roof. Tearing apart, a diagonal/shear crack, a vertical crack, a horizontal crack and failure at a corner and at a rigid joint are types of walling damage. Releasing a wall and separating it from its roof supports, breaking of an individual element and collapse of a partial or full element are typical roof damage types. When lateral loads are progressively applied to the rigid joints of a masonry wall, it may experience either an in-plane shear failure or out-of-plane wall damage [4, 9]. Recent experimental investigations [10-12] have emphasized their research objectives on slenderness and boundary conditions of specified panel, mechanical characteristics of used masonry, stiffness of surrounding frame elements, and presence of cracks due to prior in-plane damage noticeably in affecting out-of-plane carrying capacity of infill walls. Furthermore, the out-of-plane response of infill walls for limiting damage on non-structural components has become a global issue of experimental investigation for highlighting damage after earthquakes where out-of-plane failures of masonry infill walls may often occur even in case of low or moderate earthquakes [10]. It can be summarized that both types of masonry wall construction are widely utilized over the world. In Indonesia, the confined masonry is applied to single story houses and small shops, whilst the RC frame with masonry infill is commonly used for multistory commercial buildings, schools, mosques, 2-story houses for wealthier residents. They are not comparable in cost, engineering input required as well as skill of workers. Using the RC frame with masonry infill is more expensive, more engineering requirements, and higher workmanship skills rather than the confined masonry.

3. Application of Precast System for Non-engineered Building Structure

Reinforced concrete has been widely used for building construction either as a part of buildings or whole structures, resulting in the development of structural engineering [13]. The collapse history of buildings was observed after each disastrous earthquake. Various types of damage were observed in the past, providing important information relevant to the improvement of design and construction practices [4]. Besides, previous researchers [1, 6-7, 9] likewise reviewed the development of earthquake resistant building design.

A new innovative seismic resisting system has been introduced by previous researchers [14-15]; for instance, concrete walls connected to RC frame and strengthened with low-cost mild steel connectors are fabricated as a precast wall with an end column (PreWEC). This system is being developed, and its performance has been verified using large-scale specimens under cyclic loading schemes with respect to minimizing damage, particularly in seismic-prone regions where buildings must be well designed to withstand large lateral forces. In general, precast reinforced concrete has been practically used for multi-storey building structures resulting in more benefit; however its application to non-engineered building structures is still limited. In addition, research information referring to the precast system of non-engineered building structures has not been significantly published. To reduce the disadvantage of the precast system, each joint should be well installed to produce precise connections. For this important reason, the structural component of non-engineered buildings subjected to cyclic lateral loads was investigated [9]. In general, lateral loading arrangements used in experimental tests can be static, cyclic or dynamic, depending on research objectives. A confined masonry wall for non-engineering building construction is categorized as a simple building technology that offers an alternative to minimally reinforced masonry with vertical and horizontal RC bands. It contains masonry walls either made of concrete blocks or clay brick materials that are confined with tie-columns (practical columns) and tie-beams (practical beams) at the four wall sides. Both tie-columns and tie-beams should be rigidly connected to each other to construct an RC frame. The investigation of precast RC frames was divided into several precast components consisting of typical joints and member components as they have been briefly outlined in the previous research report [9]. The most benefit of using precast system applied to the non-engineered buildings is easier to control the quality, ease installation, low-cost for multiple small products, and less labour skill. Structural performance of precast system, however, is not too much different compared to on-site construction. It is dependent on the accuracy of construction-joints installation.

4. Experimental Setup

4.1 Material properties and typical specimens

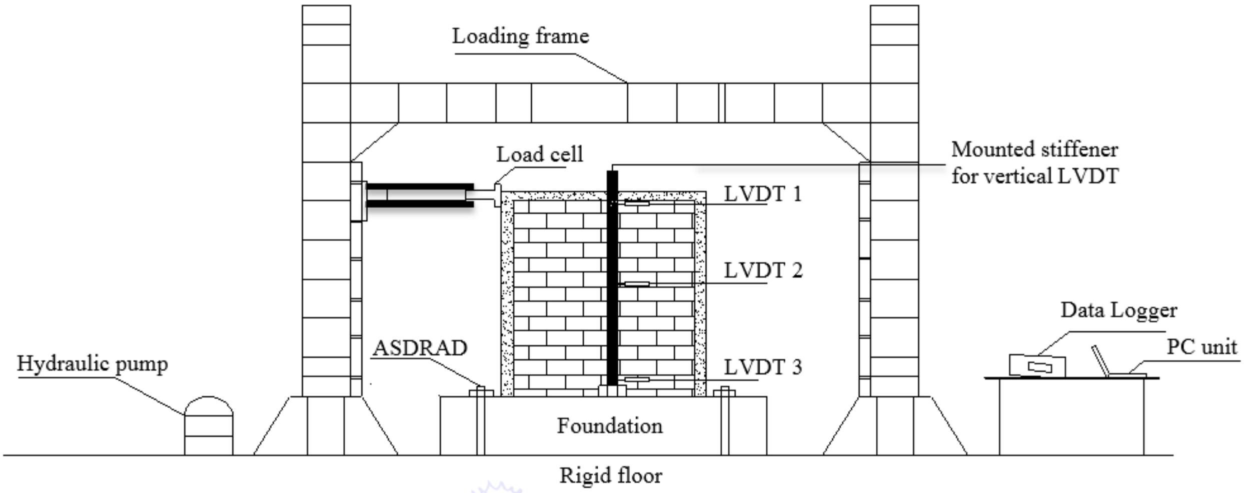
This research utilized the main building materials from local products, especially for concrete block and brick masonry. This research likewise investigated the structural performance of the walling system applied to non-engineered houses using local materials. These local masonry products, either hand- or machine-made (fabricated), are easily found in Indonesia, but they are produced from different material qualities. As a result, the production process produces random masonry quality in term of compressive strength and dimensions. For the best practice of a walling system, it is recommended to choose fabricated concrete blocks or brick masonry to produce better wall resistance. It should be noted that the modulus elasticity of a wall is directly affected by the compressive strength of masonry [16]. In this research, the compressive strength of concrete (f'_c) and the yield strength of steel bars (f_y) were 28 MPa and 240 MPa respectively.

Fig. 3 illustrates typical specimens constructed in this research for determining structural behaviour subjected to incremental lateral loads. The local material used for concrete blocks and brick masonry, specimen dimensions and details reinforcement were designed by considering the Indonesian National Standard [5]. The common dimension of tie-beams and tie-columns was 100x100 (mm) with a length of 1205 mm and height of 1130 mm. The tie-beams and tie-columns were reinforced with four longitudinal bars of 8 mm diameter and confined with a bar of 6 mm diameter giving a confinement pitch of 150 mm.

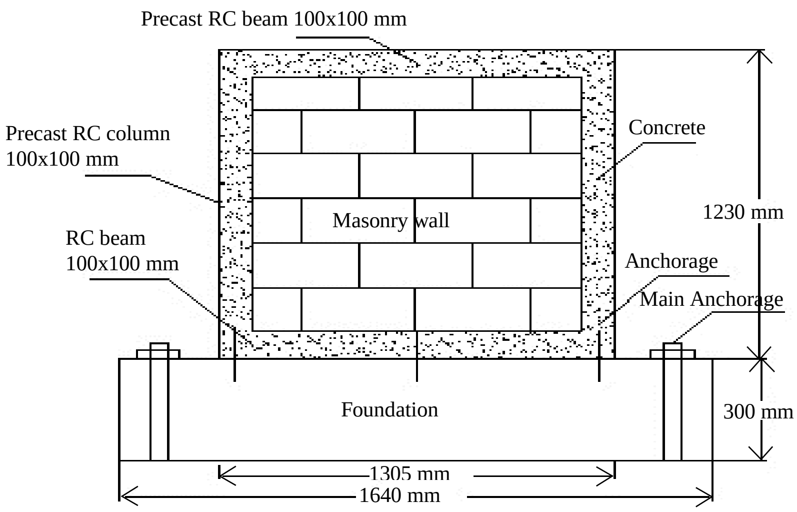
4.2 Loading arrangement and recorded data

In this research, the incremental lateral load was generally applied to the beam-column joint at each specimen. An exception to the loading arrangement, however, was given to the open frame where a vertical static load was added to the midspan of the beam member. The purpose of combining the horizontal and vertical loads applied to the open frame was basically to look for the effect of shear and flexure after achieving ultimate loads. This specimen model can be practically used for anticipating a wide wall opening used in an earthquake resistant building. The lateral load, therefore, was gradually increased to reach ultimate loads by utilizing small load increments in order to produce more accurate results. At each load step increase, the load-displacement response, mode failure and crack propagation were carefully recorded.

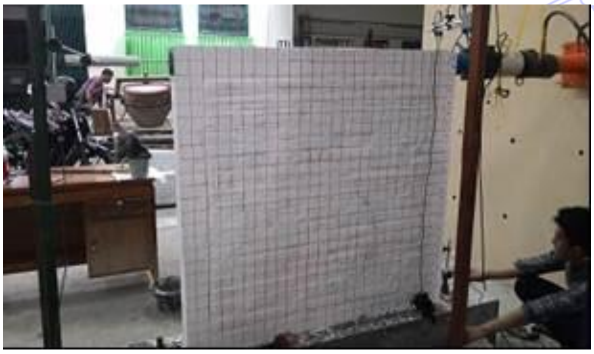
The loading arrangement used in this research was separated into two steps to test two group specimens consisting of intact (undamaged) and repaired specimens. Each load increment was automatically recorded by the data logger and stored in the PC unit. At the first step, lateral loads were applied to all intact specimens, and each specimen was incrementally loaded at the left beam-column joint until the ultimate load was reached. This latest condition caused the intact specimens to suffer over 70% damage. Further, at the second step, the repaired specimens were subsequently re-examined using the same loading arrangement.



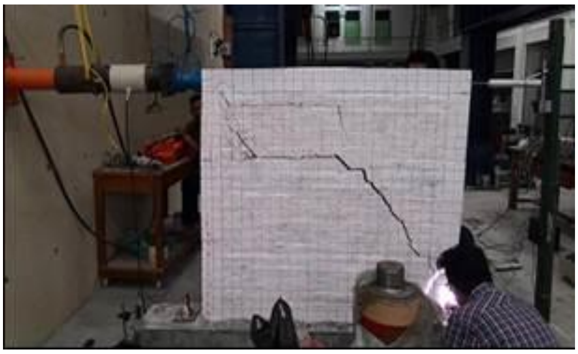
(a) Experimental setup at loading frame



(b) Anchorage system of typical specimens



(c) Experimental setup



(d) Observed tensile-diagonal crack (70% damage)

Fig. 3 Scenario of experimental setup and typical masonry walls

4.3 Retrofitting and strengthening techniques

Overall, damaged specimens were retrofitted and strengthened by using simple techniques and available local materials, such as cement mortar and wire mesh. Considering their failures, each damaged specimen was subsequently retrofitted with cement mortar, strengthened with wire mesh and plastered at both sides of each specimen. On-site retrofitting and strengthening techniques are constructed as follows: (a) portion of cracked masonry wall is removed first and rebuilt them in richer mortar afterward (non-shrinking mortar is preferable), (b) reinforcing wire mesh on both faces of the cracked wall is added and clamped it to the wall through spikes or bolts and then plastered it with mortar or micro-concrete or 1:3-4 cement–coarse sand plaster, and (c) neat cement slurry or epoxy like material can be injected into the cracks in walls, columns, and beams (if applicable). The main idea behind the use of a simple technique and local materials in this research is to help and encourage people to easily repair their damaged houses by themselves. It is believed that this technique is applicable and suitable in this region and is low-cost as well, rather than using other complicated treatments such as special materials and technologies.

In this research, masonry walls with and without plaster were experimentally tested having dimensions of 475x595x140 mm and 475x595x110 mm respectively. The compressive strength of both walls are 1.82 MPa and 2.56 MPa. Based on the empirical formula, the compressive strength is 2.18 MPa, which is comparable with the experimental results. This compressive strength was then accounted for the modulus of elasticity of masonry walls at 2215.61 MPa and 1783.06 MPa. In addition, the average strength of mortar is 6.5 MPa with ratio of 1:3-4 cement-coarse sand, which is sufficient for plastering the wall.

5. Results and Discussion

Conventional houses built in the earthquake prone area are enormously vulnerable to disasters, producing problems in for sustainable development [4]. Therefore, design consideration should meet the building function, priority scale and type of the building structure. Ensuring the long-term safety of the people in the region is an important task. The people, including building artisans, should be educated to learn earthquake resistant building technologies through demonstration accompanied by hands-on training. Improving people’s knowledge and skill of practical building design and construction are essential because the majority of structures in the quake-affected area, as in all rural and semi-rural areas of the country, including houses and infrastructure buildings, are built using the traditional system by local masons who play an additional role of engineer [1, 3, 6].

Over the last 100 years, confined masonry construction has emerged as a building technology that offers an alternative to both unreinforced masonry and RC frame constructions. In fact, confined masonry has features of both these technologies, and people have widely utilized it in their built houses. Confined masonry construction consists of masonry walls (made either of clay brick or concrete block units) and horizontal and vertical RC confining members built on both sides of the masonry wall panel [17]. Vertical (tie-columns or practical columns) and horizontal elements (tie-beams) are rigidly assembled in RC frame construction, except that they tend to have smaller cross-sections. To emphasize that confining elements are not beams and columns, the alternative terms horizontal ties and vertical ties could be used instead of tie-beams and tie-columns. The confining members are effective in enhancing the stability and integrity of masonry walls for in-plane and out-of-plane earthquake loads. Besides, the confining members also functioned to improve the strength and reduce the brittleness of masonry walls subjected to lateral loads, contributing to their improved seismic performance [18-19].

5.1 Observed strength of materials

Three different specimens comprising open frame, frame infill concrete blocks and frame infill masonry bricks were simultaneously investigated under lateral loads to define their structural behaviour. Table 2 presents the average compressive and tensile strengths of the materials used in this study. Longitudinal reinforcing steel and confinement utilized bars with a diameter of 8 mm and 6 mm respectively. The measured compressive strength of concrete and the tensile strength of steel used for beams and columns were greater than 28 MPa and 240 MPa as designed.

5.2 Strength, stiffness, and ductility

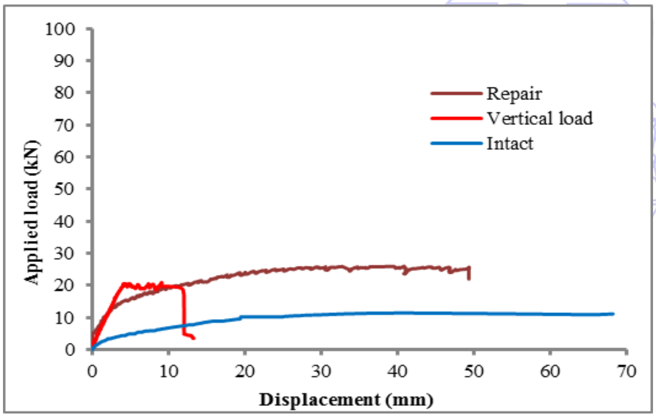
Based on the recorded data, the load-displacement responses of three different specimens for both the intact and repaired condition were plotted separately into three figures showing their displacement ductility at a certain condition (Fig. 4).

Referring to these plotted graphs, the displacement ductility with respect to the strength of every specimen in any condition can be instantaneously computed by considering the ratio between the ultimate and first yield displacements or $\mu_\delta = \delta_u/\delta_y$. Moreover, less or more ductile structure can be solely defined as dependent on the computed values of displacement ductility compared to the national standards of Indonesia for reinforced concrete structures [20].

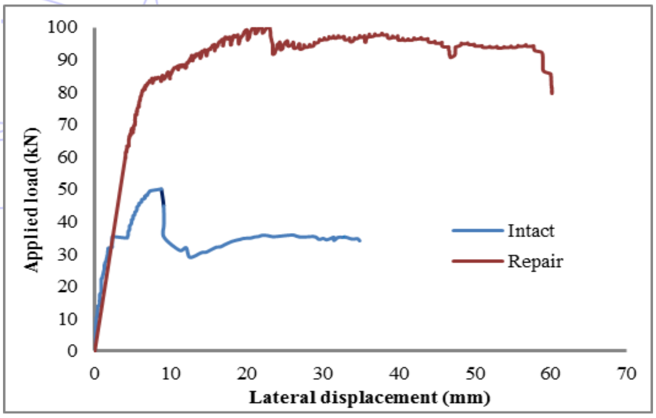
Table 2 Compressive and tensile strength of the used materials

No	Material type	Experimental testing	
	Concrete	Average compressive strength (MPa)	
		Beam & column	Precast joint
1	Open frame	43.61	28.16
2	Frame infill concrete block	45.56	28.16
3	Frame infill masonry brick	31.82	35.97
	Steel	Average tensile strength (MPa)	
		Ø 8 mm	Ø 6 mm
4	Reinforcing steel	374.24	282.23
	Masonry	Average compressive strength (MPa)	
		Concrete block	Brick
5	Masonry wall	2.346	8.45

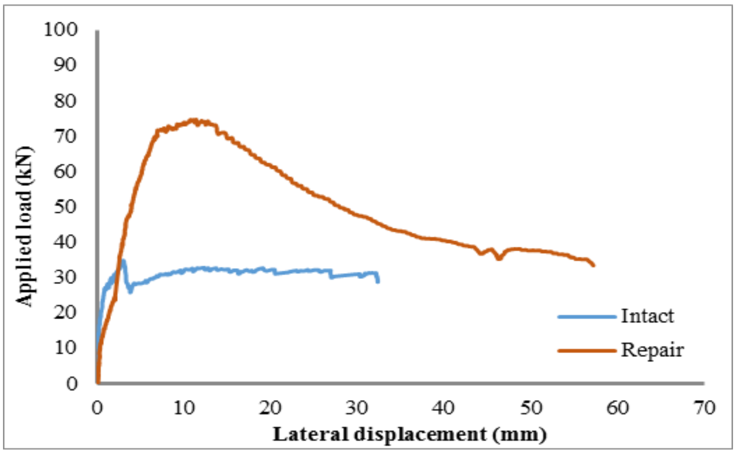
Fig. 4a depicts the only open frame that was laterally and vertically loaded, showing that the static vertical load was limited up to 20 kN whilst the lateral load was increased gradually to reach the ultimate load. Instead of the retrofitting technique applied to the damaged concrete, the RC frame was additionally strengthened using two bars with an 8 mm diameter that were installed diagonally at both sides, and these two bars were then welded to vertical reinforcements at the joint before re-concreting them (Table 3).



(a) Open/bare frame



(b) Frame infill concrete block



(c) Frame infill masonry brick

Fig. 4 Load-displacement relationships

For the RC frame was infill with wall masonry, the stiffness and strength of the frame significantly contributed to resist lateral loads because an effective strengthening technique utilizing wire mesh embedded in the plastered mortar was used in both sides of the frame and wall. In contrast, the RC frame infill with concrete blocks (Fig. 4b) was stiffer than that of clay masonry bricks (Fig. 4c) but produced walls with full ductility according to the Indonesian Standard [11] and achieved very close displacement ductility to the other wall types. Besides, the repaired specimen generally had greater strength compared to the intact once. The applied lateral loads reached the ultimate load when the displacement approximately achieved a quarter value. The intact specimens, however, were more brittle, resulting in less strength and ductility. The practical RC frame without masonry wall infill is a weak structure and produces less strength, stiffness, and ductility especially when the frame is applied to lateral loads.

Based on the experimental tests, it can be concluded that using simple retrofitting and strengthening techniques are more effective and less budget to repair non- and structural-components of non-engineered building. More importantly, these simple techniques contribute significantly to increase the strength, stiffness, and ductility of RC frame infill with masonry walls against earthquake lateral loads. In line with the research objective, this research assists the people who are living in the prone area of earthquake disaster to repair their damaged houses by themselves.

5.3 Damage and failure for infill wall masonry

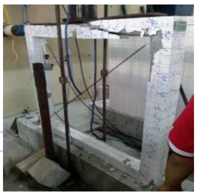
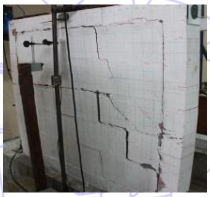
When the specimen reached the ultimate load, strain and displacement devices directly measured any changes of each load step. These phenomena are always experienced, not only for undamaged specimens but also for damaged specimens during experimental tests. Table 3 illustrates the comparison of deformed shapes and propagated cracks between undamaged and damage specimens after reaching ultimate loads. The deformed shapes show that the repaired specimens are stronger than the intact (undamaged) specimens.

5.4 Structural behaviour comparison

It has been observed that poor performance of under-reinforced masonry and non-ductile reinforced concrete frame construction probably caused high human and economic losses after severe earthquakes. In the test, due to the static vertical and incremental lateral loads, both beam and column components of the intact and repaired open frames buckled accordingly. In contrast, the repaired beam component incidentally suffered wide and long diagonal cracks at the precast joints causing collapse of that component (Table 3). The highest specimen strength was reached by repaired specimen type 2 where the damaged RC frame infill with concrete blocks was retrofitted and strengthened with wire mesh and plastered with mortar, producing greater structural behaviour compared to the case with the RC frame infill with brick masonry. The type 2 specimen experienced light damage at the tension corner of the bottom side, and no other damage was found. Theoretically, when the precast RC frame infill with a masonry wall is loaded laterally, a diagonal crack then occurs. Specimen type 3 showed this condition where large diagonal crack damage occurred along the diagonal tension crack. The displacement ductility of specimen types 2 and 3 (Fig. 4b and Fig. 4c) are very close to each other and both specimens have ductile structures resulting in great structural behaviour for withstanding lateral loads due to earthquake ground motion.

Even though the significant contribution of infill walls to the lateral stiffness and strength of RC frame structures is already predictable, however, a couple of structural engineers have for a long time frequently ignored their influence. In fact, infill panels are generally considered as architectural, non-structural elements and designed according to specified criteria such as fire resistance, thermal comfort, and sound proofing. For this reason, lack of knowledge relating to the composite behavior of infilled frames and deficiency in practical methods for predicting stiffness, strength, and ductility of the structural element should be well-paid attention. It should be noted that ignoring the infill walls produces in the substantial inaccuracy of computing the lateral stiffness and critically causes a certain element in lower part of the structure overloaded. It has been observed that the contribution of infill walls to the lateral stiffness, strength, and ductility of frames has proven an important factor in a building design but again it is still debatable. As a result of the interaction complexity between infill wall and RC frame, it produces a great number of unknown parameters and the structure behavior remains poorly understood [21]. It should be noted that the combination of weight, stiffness and weakness against tensile forces makes traditional masonry buildings highly vulnerable to earthquakes. Earthquake ground motion generates additional loading and develops shear stresses resulting damage to structural elements. Since masonry, which can be stressed relatively high in compression, is weak in withstanding bending and shear, collapse is often the result. Given this reason, masonry has, for a long time, been considered unsuitable in earthquake resisting constructions except the masonry uses strong mortar, high strength masonry, added reinforcement, improved detailing and the introduction of good anchorage between masonry walls and floor and roofs having enhancement the resistance of masonry to seismic stress. Unfortunately, there are no universally accepted design guidelines regarding infilled frames. Consequently, most of the current design codes including the Indonesian National Standard do not contain detail-design guidelines for this type of structure.

Table 3 Comparison of deformed shapes and propagated cracks

Specimen	Deformed shape and propagated crack	
	Intact (undamaged)	Repair
	Observed	Observed
Type-1 (open/bare frame)		
Type-2 (frame infill with concrete block)		
Type-3 (frame infill with masonry brick)		

6. Conclusions

A simple retrofitting and strengthening technique applied to precast reinforced concrete for a non-engineered building subjected to lateral loads is presented in this paper based on the experimental tests. Specimen type 1 produces less strength and ductility when subjected to the combination of a static vertical load and an incremental horizontal load due to the stiffness of the open frame not contributing significantly. The concrete block masonry, as well as the precast system, provides a great contribution to the RC frame infill with concrete block masonry (specimen type 2), resulting in better structural behaviour when compared to specimen type 3 due to wall material characteristics. Confining members functioned effectively to improve the strength and reduce the brittleness of masonry walls subjected to lateral loads, contributing to their improved seismic performance. Plastering at both sides of each specimen increases its stiffness and contributes a significant displacement reduction. In general, the repaired specimen contributed significantly to strength, stiffness, and ductility, compared to the intact once. The precast reinforced concrete frame provides good structural behaviour against incremental lateral loads.

Acknowledgements

The author would like to acknowledge the Directorate General of Higher Education, Ministry of Research and Technology and Higher Education, which granted a multi-year research project under the Grant Competition Scheme (2014-2016), and the Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia, which supported utilization of all experimental devices. The author wishes to express special thanks to both research assistants, Mr. Rico Pratama and Mr. Aditya Wangga, who helped in setting up experimental tests and recording data.

References

[1] T. Boen, "Earthquake resistant design of a non-engineered building in Indonesia," Proc. Workshop of the EQTAP-IV, EDM Press, Dec. 2001, pp. 1-34.

[2] S. Brzev, Earthquake-resistant confined masonry construction, Kanpur: NICEE Press, Indian Institute of Technology, 2007.

[3] D. Kusumastuti, K. S. Pribadi, and R. Rildova, "Reducing the earthquake vulnerability of non-engineered buildings: case study of retrofitting of a school building in Indonesia," Proc. the 14th World Conference on Earthquake Engineering, NICEE Press, Oct. 2008, pp. 1-8.

[4] M. Teguh, "Earthquake resistant construction practices in Indonesia: a reconnaissance on vulnerable built-conventional houses for sustainable development," Proc. The 3rd International Conference on Sustainable Built Environment (ICSBE) in collaboration with the Fourth International Seminar on Tropical Eco-Settlement (ISTEcS), FCEP Press, Oct. 2014, pp. 9–24.

[5] BSN, Procedure of earthquake resistance for a building structure and non-building (SNI 1726-2012), Jakarta: BSN Press, 2012.

[6] A. S. Arya, T. Boen, and Y. Ishiyama, Guideline for earthquake resistant non-engineered construction, Paris: UNESCO Press, 2014.

[7] A. S. Arya, "Non-engineered construction in developing countries: an approach toward earthquake risk reduction," Proc. The 12th World Conference on Earthquake Engineering, NICEE Press, Feb. 2000, pp. 2824–2846.

[8] V. P. Jadhao and P. S. Pajgade, "Influence of masonry infill walls on seismic performance of RC framed structures: a comparison of AAC and conventional brick infill," International Journal of Engineering and Advanced Technology, vol. 2, no. 4, pp. 148-153, April 2013.

[9] M. Teguh and L. Makrup, "Model design of an earthquake resistant precast non-engineered house and development of retrofitting method on post-earthquake damage," Research Report No. 1305/K5/KM/2014, Directorate General of Higher Education, Ministry of Education and Culture of Indonesia, UII Press, Sept. 2014.

[10] M. Pasca and L. Liberatore, "Predicting models for the evaluation of out-of-plane ultimate load carrying capacity of masonry infill walls," WIT Transactions on the Built Environment, vol. 152, pp. 83-94, 2015.

[11] R. J. Frosch, "Seismic rehabilitation using precast infill walls," Ph.D. dissertation, University of Texas at Austin, p. 224, 1996.

[12] P. A. Teeuwen, "Lateral behavior of steel frames with discretely connected precast concrete infill panels," Ph.D. dissertation, Eindhoven University of Technology, The Netherlands, p. 195, 2009.

[13] M. Teguh, "Sharing experiences and lessons learned in a disaster management system in Indonesia," Asian Transaction on Engineering, vol. 1, no. 5, pp. 35-44, November 2011.

[14] S. Aaleti and S. Sritharan, "Performance verification of the PreWEC concept and development of seismic design guidelines," Research Report No. ISU-CCEE Report 02/11, Iowa State University Press, Nov. 2011.

[15] P. Negro and G. Toniolo, "Design guidelines for connections of precast structures under seismic actions," JRC Scientific and Policy Report, European Union Press, Nov. 2012.

[16] F. Christy, D. Tensing, and M. Shanthi, "Experimental study on axial compressive strength and elastic modulus of the clay and fly ash brick masonry," Journal of Civil Engineering and Construction Technology, vol. 4, no. 4, pp. 134-141, April 2013.

[17] Akmaluddin, R. S. Saftaningtyas, R. Rawiana, and Z. Gazalba, "Hybrid reinforced concrete frame building with pumice brick masonry infill under static lateral loading," International Journal of Engineering & Technology, vol. 2, no. 8, pp. 1482-1491, August 2012.

[18] N. Mojsilovis, "Tensile strength of clay block: an experimental study," Construction and Building Materials, vol. 25, no. 11, pp. 4156-4164, 2011.

[19] M. Corradi, A. Borri, and A. Vignoli, "Experimental study on the determination of strength of masonry walls," Construction and Building Materials, vol. 17, no. 5, pp. 325-337, 2003.

[20] BSN, Structural concrete requirement for buildings (SNI 2847-2013), Jakarta: BSN Press, 2013.

[21] A. Bourzam, T. Goto, and M. Miyajima, "Shear capacity prediction of confined masonry walls subjected to cyclic lateral loading," Structural Eng./Earthquake Eng., JSCE, vol. 25, no. 2, pp. 47s-59s, 2008.