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EFFECT OF BRICK MASONRY INFILLS TO SEISMIC CAPACITY OF INDONESIA MULTI-STORY RC BUILDING

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ABSTRACT: This paper discusses an analytical study on the effect of brick masonry infills to seismic capacity of the multi-story reinforced concrete (RC) structures by using the finite element computer codes called STructural Earthquake Response Analysis 3D (STERA 3D). A survived three-story RC building after the 2007 Sumatra earthquake was considered as an analytical model. The building was located in Padang city, West Sumatera, Indonesia. The model was analyzed for pushover and time history analyses. The pushover analysis was conducted followed UBC code and the recorded ground acceleration of 2009 West Sumatra earthquake was applied as input motion in time history analysis. The structural detail and material properties used in the analysis were collected from site investigated building after 2007 Sumatra earthquake. Two analytical RC building models were analyzed and compared in this study, i.e. bare RC frame model and brick masonry infilled RC frame model. The results of the analytical study were compared to the resume of the field observation after the earthquake for the considered building. The analytical results are clearly shown that the brick masonry infills may significantly improve the seismic capacity of the RC building. The RC building could be survived to large ground motion even the building was designed by applying the old Indonesia building code.

Keywords: RC building, Brick masonry, Seismic capacity, STERA 3D, Sumatra earthquake

1. INTRODUCTION

The successive M8.5 and M7.9 earthquakes have struck the south of Sumatra Island on September 12, 2007 (6:10 PM local time in Western Indonesia) and September 13, 2007 (6:49 AM local time in Western Indonesia) [1]. The epicenters of these earthquakes are marked in yellow and red stars in Fig.1. A location of the epicenter of the first event was approximately 30 kilometers off the coast southwest of Bengkulu city at the depth of about 30 kilometers. The second event was located about 225 kilometers off the northwest of the first event at the depth of 10 kilometers. These ground motions caused massive damaged of thousand houses and hundreds of RC building along the coastline in Bengkulu and West Sumatra provinces and Mentawai Islands [2]. One of the most affected city by the earthquakes was Padang city, West-Sumatera province, located approximately 180 kilometers from the epicenter of the second event.

Post-earthquake investigation of the damaged RC buildings caused by this 2007 Sumatra earthquake in Padang city, has been conducted and well-reported by Maidiawati and Sanada [3]. Their investigation has shown the interesting results about the effects of the brick masonry infills to the seismic capacity of the RC multi-story building. They found that two adjacent comparable tree-story RC buildings have differently behaved due to ground motion of the 2007 Sumatra earthquake. These RC buildings were Suka Fajar and Sutan Kasim buildings. The locations of these RC buildings are shown as two red-boxes in Fig. 2. These buildings were built in 1980. There was no detail information about the structural design of these RC building. However, it has been believed that the structure of these RC buildings was not designed to resist the strong ground motion such as 2007 Sumatra earthquake. The Suka Fajar building was used as a car's showroom, while the Sutan Kasim building as a company's office and car's tire dealer. Since Suka Fajar was occupied as the car shown room, most of the infills used tempered-glass. Contrast to Suka Fajar building, Sutan Kasim building used brick masonry as infills.

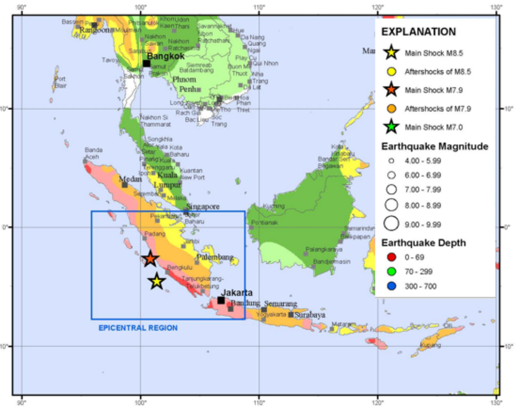


Fig. 1 Epicenters of the 2007 Sumatra Earthquake.

Due to the 2007 Sumatra earthquake, the Sutan

Kasim building had survived, while the Suka Fajar building collapsed. Maidiawati and Sanada [3] have also evaluated the seismic capacity of these RC buildings by using the Nakano's method [4] and the Japanese standard [5]. They concluded that the brick masonry infills has significantly contributed improve the seismic capacity of Sutan Kasim RC building. In their study, the seismic capacity was only considered the first-story of the buildings. The presence of the brick masonry infills in Sutan Kasim RC frame structure helped the building survive during the earthquake. More detail of this field observation and evaluation works has been clearly summarized in [3].

Fig. 2 Location of Evaluated RC Buildings.

(a) Suka Fajar Building (b) Sutan Kasim Building

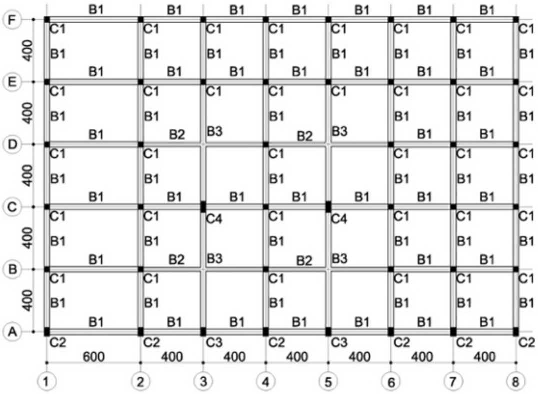
Fig. 3 Photos of Evaluated RC Buildings.

Obviously, several researchers have been focused on the investigation of effects and behaviors of the masonry infills to seismic performance, including the seismic capacity, of the RC structure. For instances, Tanjung and Maidiawati [6,7]; Maidiawati, Sanada, Konishi and Tanjung [8]; and Maidiawati and Sanada [9] have studied these effects through experimental works by testing the single-bay and single-story of RC frame structures subjected to lateral static loads. Their works have concluded that the masonry infill increases the lateral strength and stiffness of the RC frame structures, but reduce the structure's ductility. The comprehensive discussion of this topic has also been explained by Asteris [9], Barnaure and Stoica [10] in their research articles. They have discussed the failure modes and the mathematical model for the masonry infills in related to the seismic performance of the RC frame structure.

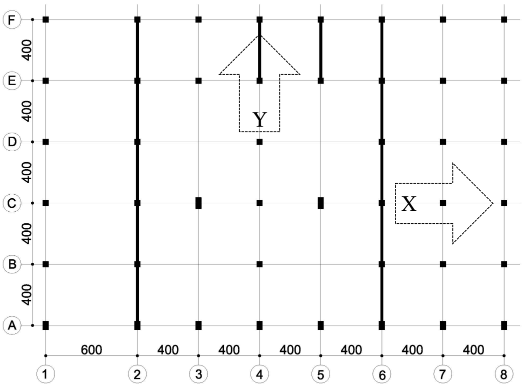
In this paper, an analytical study for defining the effects of brick masonry infills to the seismic capacity of the multi-story RC building is presented. For this analytical purpose, a survived Sutan Kasim building has been considered. The computer codes called STructural Earthquake Response Analysis 3D (STERA 3D) was used as an analytical tool [11,12]. These codes were developed by Professor Taiki Saito from Toyohashi University of Technology, Japan.

2. THE MATERIALS AND METHODS

Figure 4. shows the typical floor plan for all floors of the Sutan Kasim building according to detail site measurement. The notation C and B which is shown in Fig. 4a denotes the column and beam of the considered RC structure, respectively. The detail reinforcements arrangements for these columns and beams are given in Table 1 and Table 2, respectively. The location of the brick masonry infill walls is notated by the bold line in Fig.4b.



(a) Typical Floor Plan



(b) The Location of Brick Masonry Infill

Fig. 4 Floor Plan Used in the Analytical Model.

The compressive strength of the existing concrete used in the considered structure was about 26.7 MPa [9]. Its compressive strength was obtained by conducting the non-destructive Schmidt Hammer test and the uniaxial compressive test on the cylinder concrete specimens taken by the core drill machine. All RC structures installed plain rebar with nominal yield tensile stress about 307 MPa for the longitudinal flexure and 240 MPa for shear reinforcements, respectively [3,9]. The compressive strength of the brick masonry is 4 MPa.

Table 1 Reinforced Arrangements of Columns

n	Column	C1	C2	C3	C4
1	B x D	350x350	350x550		350x700
	Main rebar	4ϕ22 4ϕ16	8ϕ22	10ϕ22	18ϕ22
	Hoop	2ϕ6@200			
2	B x D	350x350	350x550		350x700
	Main rebar	4ϕ22 4ϕ16		4ϕ22 6ϕ16	4ϕ22 14ϕ16
	Hoop	2ϕ6@200			
3	B x D	350x350	350x550		350x700
	Main rebar	8ϕ16			18ϕ16
	Hoop	2ϕ6@200			

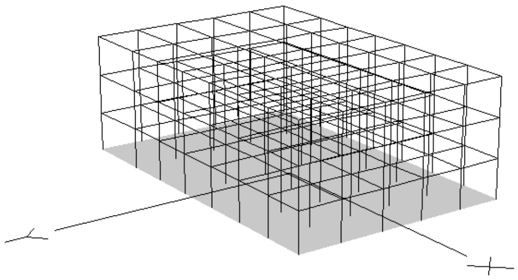
Unit: mm; n: story number

Table 2 Reinforced Arrangements of Beams

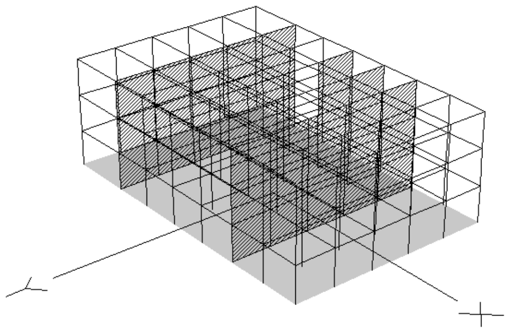
N	Beam	B1	B2	B3
2	B x D	350 x 550	250 x 420	350 x 720
	Main rebar	4ϕ16 4ϕ12	10ϕ16 2ϕ12	10ϕ12
	Stirrup	2ϕ6@100 (middle: 2ϕ6@150)		
3	B x D	300 x 450	250 x 420	350 x 720
	Main rebar	4ϕ16 4ϕ12	10ϕ16 2ϕ12	6ϕ22
	Stirrup	2ϕ6@100 (middle: 2ϕ6@150)		
R	B x D	300 x 450	250 x 420	300 x 550
	Main rebar	4ϕ16 4ϕ12		4ϕ22 4ϕ12
	Stirrup	2ϕ6@100 (middle: 2ϕ6@150)		

Unit: mm; n: story number

The STERA 3D computer codes were used to create the analytical models for the given floor plan shown in Fig 4. The STERA 3D is the computer codes based on the nonlinear finite element method which can be used to evaluate the seismic performance of the RC and Steel buildings. The STERA 3D computer codes have the capabilities to performs the elastic modal analysis, the nonlinear lateral static pushover and the nonlinear lateral static cyclic analysis and the nonlinear earthquake responses analyses. STERA 3D comes with the graphic user interface to create and to analyze the building model and then also to show the analysis results. To make the analysis more reliable, the beam is modeled as a line element with nonlinear bending and shear springs. The column is also modeled as a line element, however, considering the nonlinear interaction between axial force and bending moment. The interaction is furthermore expressed by the nonlinear axial springs for concrete and nonlinear multi springs for the reinforcements. The masonry infill is defined as a line element with nonlinear shear spring and vertical spring in the middle of the brick wall [11]. The final images of the analytical models for the bare frame and the bare frame with brick masonry infills models, respectively, are shown in Fig 5. As mentioned above, two types of analysis were performed on the models, i.e. the pushover and the time history analyses. The pushover analysis was conducted for maximum drift ratio 1/100 in X and Y directions, respectively.



(a) Bare Frame Model



(b) Frame with Brick Masonry Infill Model

Fig. 5 3D Analytical Models.

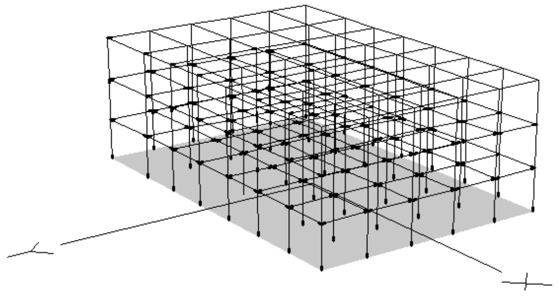
Table 3 Matrix of the Analytical Study

Analytical Works	Codes
Bare Frame Model	
Pushover X-direction	PO-X-WO
Pushover Y-direction	PO-Y-WO
Time History Analysis	EQ-WO
Bare Frame with Infills Model	
Pushover X-direction	PO-X-MW
Pushover Y-direction	PO-Y-MW
Time History Analysis	EQ-MW

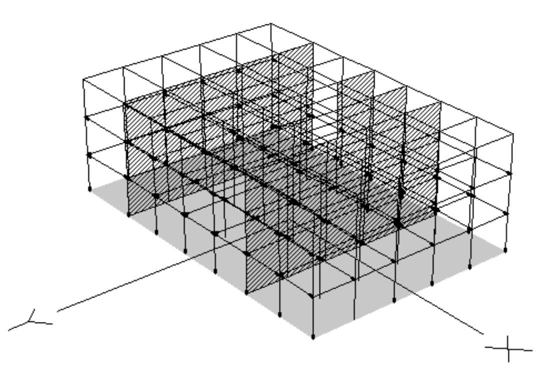
For the time history analysis, the input ground motions with a maximum acceleration of about 320 gals for 60 seconds' excitation was applied. The maximum acceleration of 320 gals was applied in according to the reported peak ground motion on the coastline of Padang city caused by the 2007 Sumatra earthquake [1]. These input ground motions were generated from the recorded ground motion of 2009 West Sumatra earthquake which was recorded by seismograph installed at Singkarak Hydro Electric Power Plant [13]. The works of the analytical study described in this paper thus following an analytical matrix as is tabulated in Table 3.

3. NUMERICAL RESULTS & DISCUSSION

Figure 7. shows the comparison of the post-images of the analytical models between the RC frame structure and RC frame structure with brick masonry infills. In STERA 3D, the damages on the structural components of the RC building is defined by the ductility of its structural components. When the ductility in a range of one to five denotes its structural components experience light to moderate damage, while for ductility great than five denotes severe damage. The comparison of these damage structural components is tabulated in Table 4. The presence of the brick masonry infill can reduce the damage of the columns up to 17% and beam almost 50%. As we have been presumed, the analytical results show the presence of the brick masonry infill can reduce the number of the damaged structural components.



(a) Bare RC Frame.



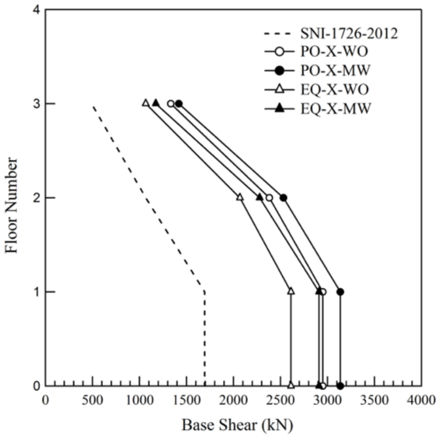
(b) Bare RC Frame with Brick Masonry Infill.

Fig. 7 Post-images of the Analytical Models.

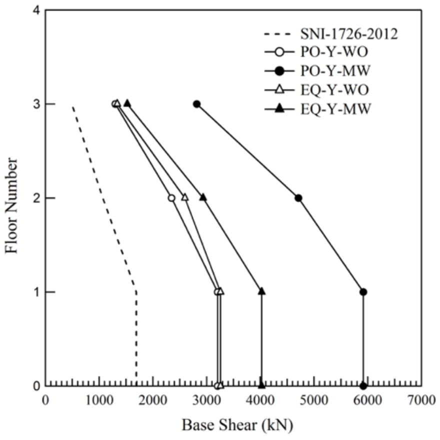
The comparison of analytical results in the term of base shear of the models, including the comparison with the requirement base shear design following Indonesia RC building code SNI-1726-2012 [14], is shown in Fig. 8. Noting that for the time history analysis, the North-South and East-West directions coincide with X and Y directions of the building, respectively.

Table 4 The Damage of Structural Components

Components	Percentage of Damage	
	Moderate	Severe
	Bare RC Frame	
Column	67%	0%
Beam	56%	18%
	Bare RC Frame with Brick Masonry Infill	
Column	40%	0%
Beam	8%	0%



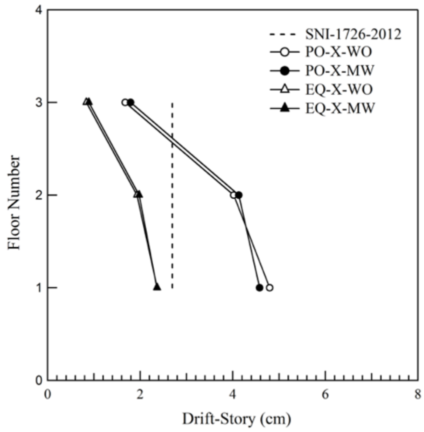
(a) X-direction



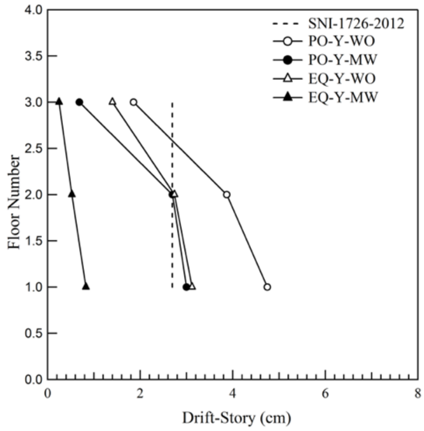
(b) Y-direction

Fig. 8 Comparison of the Base Shear.

The minimum requirement of the base shear design was evaluated based on seismic site parameters where the building was constructed. These parameters are the soil specification is the medium soil; the maximum spectral response acceleration at short periods S_S is 1,35; the maximum spectral acceleration at a period of 1 second S_1 is 0,599; the acceleration-based site coefficient F_a is 1,0; the velocity-based site coefficient F_v is 1,3; the maximum spectral acceleration at short periods adjusted for site class S_{MS} is 1,35; the maximum spectral acceleration at a 1 second period adjusted for site class S_{M1} is 0,779; the design spectral response acceleration at short periods S_{DS} is 0,9; and the design spectral response acceleration at a period of 1 second S_{D1} is 0,519. The above seismic site parameters were defined by Indonesia Seismic Design Map [15]. The importance factor I is 1,0, and response modification coefficient R is 8. These analytical results show that the presence of the brick masonry infills seems to have given a significant contribution for increasing the base shear, especially in Y-direction. Obviously, all base shears of the analytical models greater than minimum requirement by Indonesia code SNI-1726-2012 [14].



(a) X- direction



(b) Y-direction

Fig. 9 Comparison of the Inter-Story Drift.

The analytical results of the inter-story drift for the analytical models are given in Fig. 9. Refer to SNI-1726-2012 [14], in the case of RC frame structure, with or without brick masonry infills, the inter-story drift is limited to 1% of the inter-floor height and then divided by 1,3.

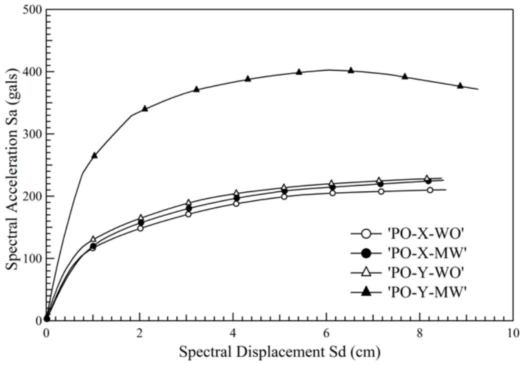
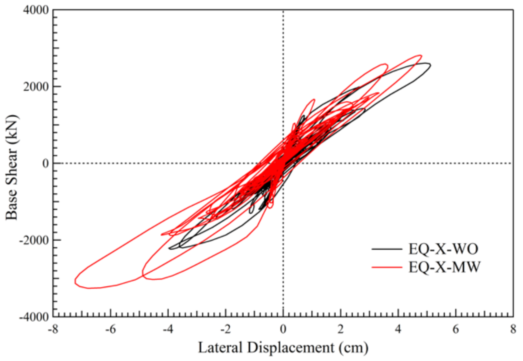
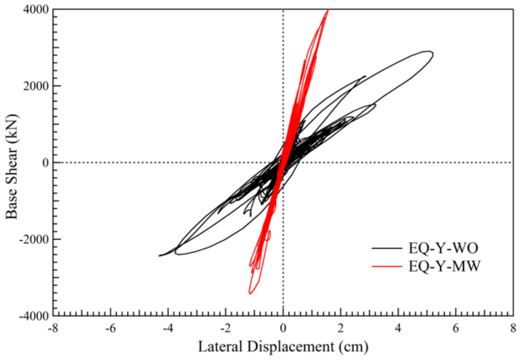


Fig. 10 Comparison of the Seismic Capacity.



(a) X-direction



Y-direction

Fig. 11 Seismic Response of the Structure.

All results of the pushover analysis passed the limitation of the inter-story drift of the current Indonesia code, while the results of the time history analysis still adequate the code. Again, the brick masonry infill shows it superior to increase the seismic performance of the RC structure by reducing the inter-story drifts of structures; see the comparison results for Y-direction in Fig. 9b.

Comparison of seismic capacity which is plotted based on the results of the pushover analyses of the analytical models is shown in Fig. 10. These graphs also clearly show the effect of the presence of the brick masonry infills on the seismic capacity of the RC frame building, i.e. have significantly increased the frame's seismic capacity. In this case, since the location of the brick masonry infills is parallel to the Y-direction, the increased of the seismic capacity is more observable in this direction.

A similar tendency regarding the effect of the brick masonry to the seismic capacity of the RC building is also shown by the graphs of the relation between base shear and the lateral displacement of the RC building as is shown in Fig 11. The lateral displacements in it figure were picked-up on the top of the building. The result of its comparison, again especially in Y-direction, confirms the effect of brick masonry infills can significantly improve the seismic capacity of the RC building. The stiffness of the RC frame is significantly raised due to the existence of the brick masonry infill, especially in Y-direction.

4. CONCLUSION

The analytical study to define the effects of brick masonry infill on the seismic capacity of the multi-storey RC building by using computer code STERA 3D has been presented in this paper. The survived tree-story RC building during the 2007 Sumatra earthquake was evaluated as an analytical model. The structural detail and the material properties used in the analysis were collected after the earthquake from the building site. To the analytical model, the pushover and time history analyses were applied. The pushover analysis followed the UBC method while for the time history analysis, the input motion generated from the 2009 West Sumatra earthquake was used. From the analytical results are clearly shown that the brick masonry infills may significantly improve the seismic capacity of the RC building. The evaluated RC building could be survived to large ground motion even though the building was designed by applying the old Indonesia building code.

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