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STRUCTURAL EVALUATION OF THE MELATI HOSPITAL BUILDING AT SUNGAI PENUH CITY, INDONESIA

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ABSTRACT: Melati Hospital is one of the health buildings in Sungai Penuh City, Jambi Province, Indonesia. The building, which was previously the main maternity clinic, is going to be upgraded its status to a maternity hospital. Based on the field investigations, the concrete compressive strength (f'c) was 15.77 MPa, which did not meet the requirement in the Indonesian building codes. Therefore, a structural evaluation should be done on the building structure. Structural analysis was performed with ETABS v18 software using two methods, the open frame and the masonry infilled-frame methods. The performance of the building structure was evaluated in terms of the moment and shear capacities in columns and beams, as well as the inter-story drift in the existing building. The results obtained by modeling the structure as the open frame found that the capacity of the existing structure was not strong enough to resist the working loads, especially on the second-floor columns, beams, and inter-story drift that did not meet the permitted limit in the building codes. Meanwhile, the modeling of the structure used masonry infilled-frame, this hospital building structure is strong enough to withstand the working loads. From the results, it was found that the ability of this building to resist earthquake loads largely depends on the wall's contribution to withstand lateral loads. The masonry is a brittle material that is prone to crack or failure so the retrofitting of the masonry wall using ferrocement layers is highly recommended for this hospital building.

Keywords: Hospital building, Structural evaluation, Earthquake load, Structural elements capacity.

1. INTRODUCTION

Health is very important for humans to survive and do activities properly. To manifest good health in the community, not only medical personnel and good medical support equipment are needed but also a good structural building. So that the health building can function safely and its strength can ensure the safety of the humans in it [1]. In addition, Hospital buildings are the most important part when a disaster such as an earthquake occurs, so it is necessary to evaluate the strength of the building structure.

Presently, many methodologies have been developed to determine the feasibility of hospital buildings, such as an analytical study on the behavior of the hospital building under seismic load using a structural analysis program (ETABS, SAP) [2,3], visual rapid assessment and the application of jacketing repair methods [4], and also pushover analysis which is widely applied in various countries [5].

Furthermore, apart from developing methods for determining the feasibility of hospital buildings, several guidelines have been presented for restoration and strengthening reinforced masonry structures, such as the influence of strengthening with polypropylene bands (pp-bands) [6], the others using the method reinforced concrete monolithic slabs, with composite materials based on a finite element model in the SCAD Office [7] and using composite materials for retrofitting a certain number of masonry shear walls [8].

In Indonesia, building standards are always changing along with the development of science and the latest circumstances. An example is that in 2012, the regulation on earthquake-resistant buildings was contained in SNI 1726:2012 [9], but after 7 years, this regulation had changed along with research on the response to major earthquakes in Indonesia which damaged many buildings in Indonesia, so a new regulation was issued, namely SNI 1726:2019 [10].

The Melati Hospital building is one of the health buildings in Sungai Penuh City, Jambi Province, Indonesia, as shown in Fig.1. The building, which was previously the main clinic, needs to upgrade its status to a maternity hospital. This hospital was the first maternity hospital in Sungai Penuh City. This hospital building is a three-story building, and the construction uses reinforced concrete construction. The reason for choosing reinforced concrete construction is because of considering the function of the building, which is designed to have high strength against the influence of external loads that may occur [11]. This building was located in an earthquake-prone area and designed using the previous Indonesian building standard, SNI 1726:2012 [9]. The hammer test result of the building concrete compressive strength was quite low, which is 15.77 MPa. Therefore, a structural evaluation was carried out on the existing structure of the Melati Hospital building using the current Indonesian building standards [12]. The building structure was analyzed by considering the masonry infilled-frame, which is compared with the open frame method.

Fig.1 3D modeling of Melati Hospital building

2. RESEARCH SIGNIFICANCE

The study developed on evaluating the strength of building structural elements and providing structural strengthening solutions if structural elements fail to carry the working load using the latest SNI. In addition, this study needs to be carried out because the hospital is the most important part and must be declared safe in the event of an earthquake. This study can be a reference in evaluating the strength of the building structure and options for strengthening the building. Retrofitting solutions resulted from this study it is expected to be more economical, work easier, and fast work time compared other retrofitting options.

3. STRUCTURAL ANALYSIS

3.1 Building Data

The three-story Melati Hospital building is made of reinforced concrete structures with a size of 28.16m in length and 13m in width. The yield strength of steel (fy) was 240 MPa and 400 MPa for plain and deformed steel reinforcements, respectively, while the compressive strength of the concrete (f'c) was 15.77 MPa. Fig.2 shows the layout of the building. The dimensions of the structural elements are:

1. Beam: B1, B3 (30 x 40) cm, B2 and RB (15 x 20) cm.
2. Tie Beam: S1 (40 x 60) cm and S2 (15 x 20) cm.
3. Column: K1 (35 x 35) cm, K2 and K3 (30 x 400) cm.
4. Slab thickness: 13 cm.

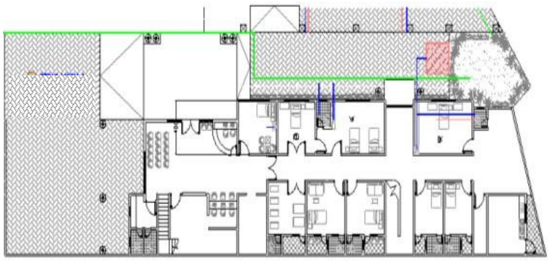


Fig.2 The layout of building

3.2 Structural Modeling

3.2.1 Structural modeling for open frame method

In the modeling of the open frame method, columns and beams are modeled as frame elements, while slabs are modeled as shell elements [13]. The modeling is carried out per the existing conditions of the Melati Hospital building, as shown in Fig.3.

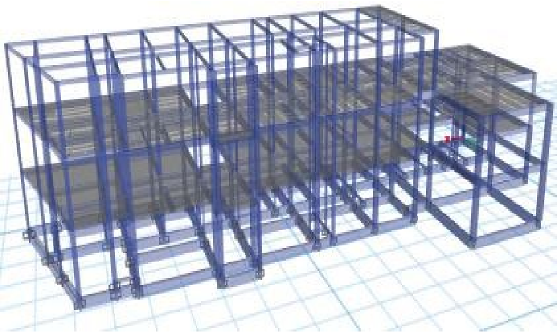


Fig.3 Modeling of building structures with an open frame method

3.2.2 Structural modeling for masonry infilled-frame method

Concerning the results obtained in the modeling of the open frame method, another analysis was carried out using the frame method with a filler wall [11]. In the modeling of the frame with filler walls, columns and beams are modeled as frame elements, slabs as shell elements, and walls as wall elements with masonry material [13]. The properties of the masonry walls are modeled according to Fig.4. Modeling of the masonry infilled-frame is carried outwith the definition:

1. The compressive strength (f'c) of plaster for the walls is 5.23 MPa.

2. Specific gravity of plaster is 2130 kg/m^3.
3. The compressive strength (f'c) of masonry is assumed 1 MPa.
4. Specific gravity of masonry is 1700 kg/m^3.

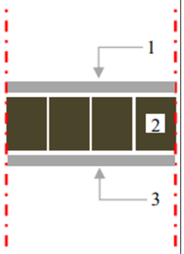
Layer Name	Distance (mm)	Thickness(mm)	Material	
1	62.5	25	Plaster	
2	0	100	Masonry	
3	-62.5	25	Plaster	

Fig.4 Properties of masonry walls

The result of modeling the masonry infilled-frame is shown in Fig.5.

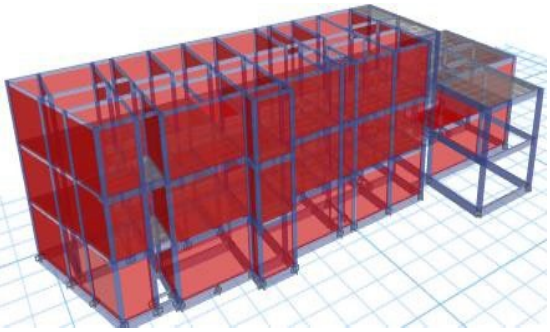


Fig.5 Structural modeling of masonry infilled-frame method

3.3 Loading Analysis

3.3.1 Dead loads

The dead loads on the building were calculated based on the Indonesian building standard, SNI 1727:2020 [14]. The dead loads acting on the building structure are shown in Table 1.

Table 1 Dead loads on the building structure

Loads	Load value
Floor coverings	48 kg/m^2
Floor plaster	42 kg/m^2
Plafond	20 kg/m^2
Rainwater	50 kg/m^2

3.3.2 Live loads

The live loads calculated based on SNI 1727:2020 must be the maximum load expected to occur due to the occupancy and the use of the building [14], but it must not be less than the minimum load set. The live loads on the building are based on the floor plan.

1.	Patient room	= 1.92 kN/m^2.
2.	Lobby/corridor	= 4.79 kN/m^2.
3.	Lobby above the 1st floor	= 3.83 kN/m^2.
4.	Operating room/laboratory	= 2.87 kN/m^2.

3.3.3 Earthquake load

The response spectrum is used as an analysis of dynamic earthquake loads. The response spectrum earthquake load is calculated based on SNI 1726:2019 [10]. Based on the design spectral acceleration parameter values for soft soil in the hospital building location, the value of spectral design S_{D1} and S_{DS} are 0.663g and 1.459g, respectively. Fig.6 shows the response spectrum for Sungai Penuh City with soft soil conditions.

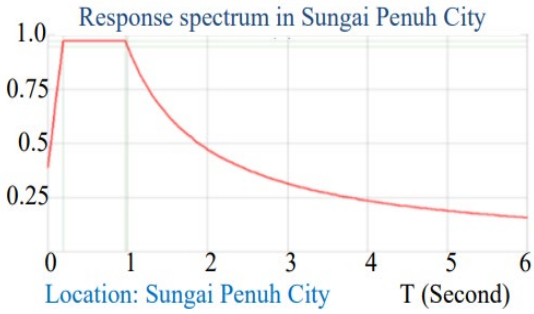


Fig.6 Earthquake response spectrum design

3.3.4 Load combination

Based on SNI 1726:2019, to simulate the direct effect of the random earthquake plan on the structure of the building, the effect of earthquake loading in the main direction determinant must be considered to be 100% effective and must be considered to occur together with the effect of deep earthquake loads with a perpendicular direction to the main direction of the load, with an effectiveness of only 30% [10]. The load combination is as follows:

1. 1.4 DL
2. 1.2 DL + 1.6 LL
3. 1.2 DL + 1.0 LL ± 1.0 EQx ± 0.3 Eqy
4. 1.2 DL + 1.0 LL ± 0.3 EQx ± 1.0 Eqy
5. 0.9 DL ± 1.0 EQx ± 0.3 Eqy
6. 0.9 DL ± 0.3 EQx ± 1.0 EQy

Where DL is dead load, LL is live load, EQX is X-directional earthquake load, and EQY is Y-direction earthquake load.

3.3.5 Building priority factors (Ie) and response modification coefficient (R)

Based on SNI 1726:2019, the earthquake reduction factor (R) is 8 for the frame structure of the special moment-bearing frame system (SRPMK), and the building importance factor (Ie) is 1.5 for risk category IV [10]. The response spectrum data are inputted into the structural modeling and scale factor (SF) calculations were performed using Eq. (1).

$$SF = G.I_e / R \tag{1}$$

Where G is the acceleration of gravity, Ie is the building priority factor, and R is the building response modification coefficient.

4. RESULTS AND DISCUSSION

4.1 Cross-Sectional Capacity for Open Frame Method

4.1.1 Column capacity

To determine the cross-sectional capacity of the building structure, it is necessary to review the cross- sectional capacity of the columns and beams in Melati Hospital building. The review of the structural elements is grouped by dimensions, type, and position of those columns and beams. From the results of the structural analysis, it will be known the cross- sectional capacity of the structural elements such as beam moment capacity, beam shear capacity, column interaction diagrams, and column shear capacity [15]. The results of this cross-sectional capacity will determine whether the cross-section can withstand the working loads. The cross-sectional capacity of the column can be obtained with the P-M interaction diagram and shear capacity results.

The calculation results of the interaction diagram of the first-floor, second floor, third-floor columns of the building are shown in Fig.7.

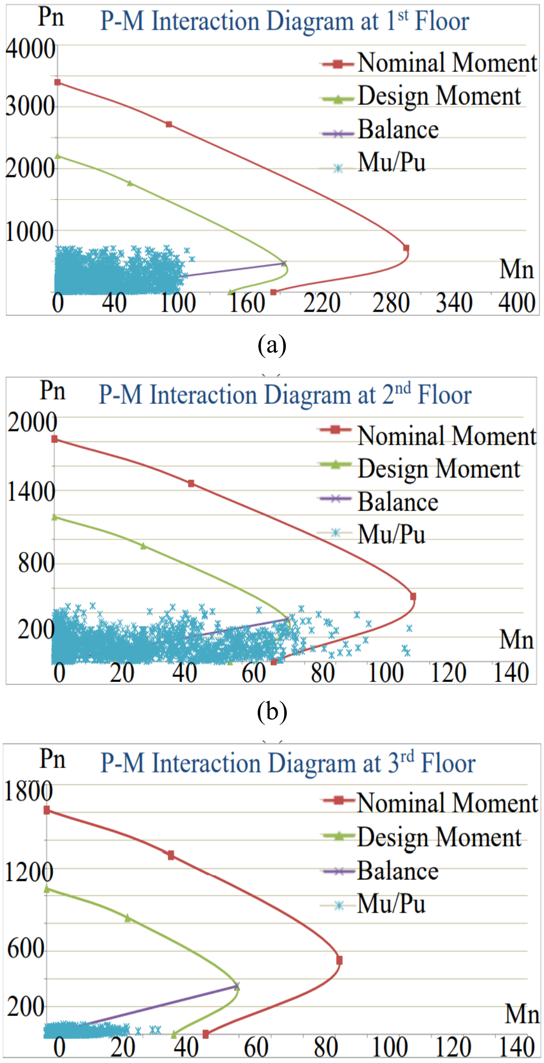
From Fig.7, it is identified that the columns on the 1st and 3rd floors are still strongly carrying the working loads on the structure because the moment and axial do not cross the permitted limit in the P-M interaction diagram. Meanwhile, the column on the 2nd floor is not strong enough to carry the working load because there is a moment and axial that passes the line permit limit in the P-M interaction diagram. The shear capacity of the building columns is shown in Table 2. It can be recognized that the column can withstand the shear forces acting on the structure.

Table 2 Column shear capacity for open frame method

Story	Dimension (mm)	ϕ (mm)	Space (mm)	ϕVn (kN)	Vu (kN)	Desc.
1	350 x 350	10	100	141.5	60.9	OK
2	300 x 300	10	100	112.2	59.4	OK
3	300 x 300	10	100	112.2	11.3	OK

4.1.2 Beam capacity

The cross-sectional capacity of the beam can be determined by comparing the moment capacity and shear plan with the working moment and shear ultimate [15].



(a)

(b)

(c)

Fig.7 P-M interaction diagram at 1st floor (a), 2nd floor (b), 3rd floor (c) for open frame method

Table 3 Beam flexural capacity for open frame method

Type	Dimension (mm)	Comp. rebar	Tensile Rebar	ϕMn (kNm)	Mu (kNm)	Desc.
S1	400 x 600	6D19	8D19	378.86	77.23	OK
S2	150 x 200	2D10	2D10	7.28	3.86	OK
B21	300 x 400	6D13	6D13	84.05	107.61	NOT OK
B22	150 x 200	2D10	2D10	7.278	6.1	OK
B31	300 x 400	6D13	6D13	84.05	109.08	NOT OK
B32	150 x 200	2D10	2D10	7.28	3.9	OK
RB	150 x 200	2D13	2D13	11.48	11.15	OK

Table 4 Beam shear capacity for open frame method

Type	Dimension (mm)	Comp. rebar	Tensil rebar	Vr (KN)	Vu (kN)	Desc.
S1	400 x 600	6D19	8D19	269.53	77.23	OK
S2	150 x 200	2D10	2D10	53.58	7.72	OK
B21	300 x 400	6D13	4D13	151.08	112.03	OK
B22	150 x 200	2D10	2D10	38.31	11.35	OK
B31	300 x 400	6D13	4D13	151.08	103.47	OK
B32	150 x 200	2D10	2D10	38.31	10.81	OK
RB	150 x 200	2D13	2D13	82.84	16.48	OK

Table 3 shows that the beams flexural capacity of the building structure is unable to withstand the loads acting on the structure. Meanwhile, the beam has enough capacity to resist the shear forces acting on the structure, as shown in Table 4.

4.1.3 Inter story drift

According to SNI 1726:2019, the determination of inter-story drift (Δ) must be calculated as the difference in the drift at the center of mass above and below the level under review [10,16]. Tables 5 and 6 show the results of the building inter-story drift for X and Y-directions.

Table 5 Inter story drift in X-direction for open frame method

Story	H_{SX} (mm)	H (mm)	∂_e (mm)	Δ mm	Δ_i (mm)	Δper (mm)	Desc.
3	12	4000	33.9	124.3	19.58	40	OK
2	8	4000	28.56	104.7	59.39	40	NOT OK
1	4	4000	12.26	45.32	45.32	40	NOT OK
Base	0	4000	0	0	0	40	OK

Table 6 Inter story drift in Y-direction for open frame method

Story	H_{SX} (mm)	H (mm)	∂e (mm)	Δ (mm)	Δ_i (mm)	Δperm (mm)	Desc.
3	12	4000	40.38	148.05	-4.65	40	OK
2	8	4000	41.65	152.7	87.74	40	NOT OK
1	4	4000	17.72	64.96	64.96	40	NOT OK
Base	0	4000	0	0	0	40	OK

Based on Tables 5 and 6, it can be seen that the inter-story drift in X and Y directions does not meet the permitted limit as required on the SNI 1726:2019 [10].

4.2 Cross-Sectional Capacity for Masonry Infilled-Frame Method

4.2.1 Column capacity

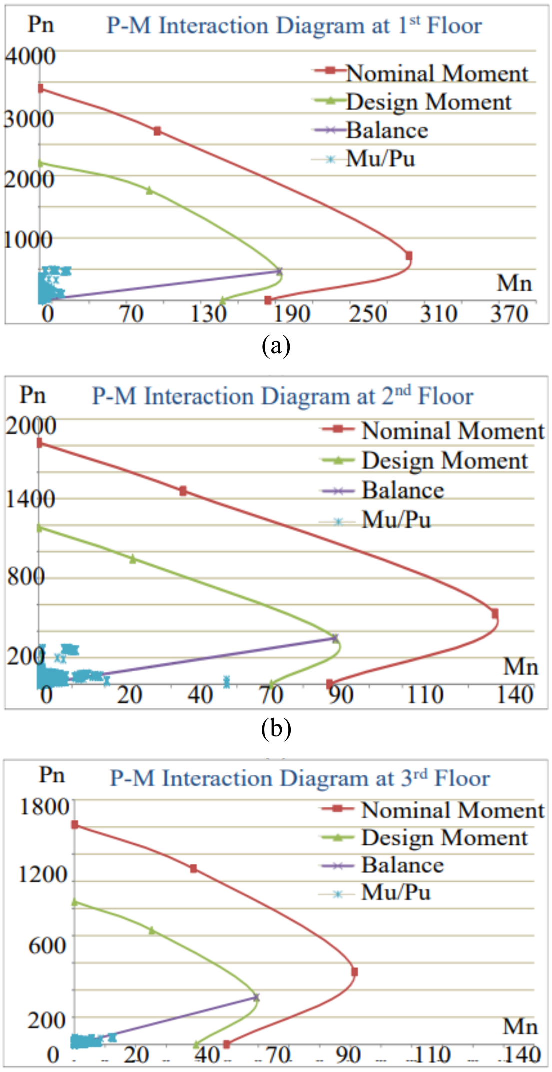
The cross-sectional capacity for masonry infilled- frame [17] can be seen on the diagram of the P-M interaction, as shown in Fig.8.

As seen in the figure, the first, second, and third floor columns are strong enough to carry the working loads because the axial moment and compression force do not pass through the design of the axial compression moment line.

The calculation results of column shear capacity for masonry infilled-frame are shown in Table 7. It shows that the columns of the building are able to withstand the shear forces acting on the structure.

Table 7 Column shear capacity for masonry infilled-frame method

Story	Dimension (mm)	Diameter (mm)	Space (mm)	ϕVn (kN)	Vu (kN)	Desc.
1	350 x 350	10	100	141.5	10.16	OK
2	300 x 300	10	100	112.2	9.28	OK
3	300 x 300	10	100	112.2	2.77	OK



(a)

(b)

(c)

Fig.8 P-M interaction diagram at 1st floor (a), 2nd floor (b), and 3rd floor (c) for masonry-infilled frame method.

4.2.2 Beam capacity

Tables 8 and 9 show the flexural and shear capacity of the beams. These tables show that the beams in the building are able to withstand the working loads on the structure.

Table 8 Beam flexural capacity for masonry infilled-frame method

Beam Type	Dimension (mm)	Comp. Rebar	Tensile Rebar	ϕMn (kN)	Mu (kN)	Desc.
S1	400 x 600	6D19	8D19	378.8	46.7	OK
S2	150 x 200	2D10	2D10	7.3	3.9	OK
B21	300 x 400	6D13	6D13	84.1	49.2	OK
B22	150 x 200	2D10	2D10	7.3	1.9	OK
B31	300 x 400	6D13	6D13	84.1	67.3	OK
B32	150 x 200	2D10	2D10	7.3	3.2	OK
RB	150 x 200	2D13	2D13	11.5	4.9	OK

Table 9 Beam shear capacity for masonry infilled-frame method

Beam Type	Dimension (mm)	Comp Rebar	Tensile Rebar	Vr (kN)	Vu (kN)	Des
S1	400 x 600	6D19	6D19	269.5	39.5	OK
S2	150 x 200	2D10	2D10	53.6	7.7	OK
B21	300 x 400	6D13	4D13	151.1	44.8	OK
B22	150 x 200	2D10	2D10	38.3	5.2	OK
B31	300 x 400	6D13	4D13	151.1	53.8	OK
B32	150 x 200	2D10	2D10	38.3	5.1	OK
RB	150 x 200	2D13	2D13	82.8	5.9	OK

4.2.3 Inter story drift

The calculation results of the inter-story drift in the X and Y-directions on the retrofitted building are shown in Tables 10 and 11.

Table 10 Inter story drift in X-direction for masonry infilled-frame method.

Story	Hsx (mm)	H (mm)	∂e (mm)	Δ (mm)	Δi (mm)	Δpermit(mm)	Desc.
3	12	4000	0.61	2.24	0.3	40	OK
2	8	4000	0.53	1.94	3.98	40	OK
1	4	4000	1.61	5.92	5.92	40	OK
Base	0	4000	0	0	0	40	OK

Table 11 Inter story drift in Y-direction for masonryinfilled-frame method

St	Hsx (mm)	H (mm)	∂e (mm)	Δ (mm)	Δi (mm)	Δper (mm)	Desc.
3	12	4000	1.14	4.16	0.98	40	OK
2	8	4000	0.87	3.19	1.51	40	OK
1	4	4000	0.46	1.68	1.68	40	OK
Base	0	4000	0	0	0	40	OK

Tables 10 and 11 show that the inter-story drift that occurs in X and Y-directions has met the permitted limit according to Indonesian building standards.

From the structural analysis results of the two methods, it is identified that calculations with the open frame modeling method reveal that Melati Hospital building does not have strong enough capacity to resist the working loads, especially in the second-floor columns, beams, and inter-story drift. While the calculations with the masonry infilled-frame method [7], the structures of the hospital building are strong enough to withstand the working load based on the current Indonesian building standards. This result shows that the ability of Melati Hospital building to withstand earthquake loads is highly dependent on the contribution of the wall to resist the lateral loads so the connection of the walls to the columns and beams should be properly designed and constructed.

In addition, masonry is a material that is vulnerable and easy to experience failure (brittle), so strengthening the building wall is highly recommended by using the proper retrofitting method [18,19].

4.3 Retrofitting Building Wall Using Ferrocement Layer

Retrofitting is a set of operations done on part or all structures so that they can bear more loads and show better behavior characteristics [20,21]. One of the methods to retrofit the building walls is by using a ferrocement layer. The ferrocement layer is mortar containing woven wire mesh that was installed on a masonry wall (ferrocement layer retrofitting method). From the previous studies, it was found that retrofitting the building wall using a ferrocement layer increases the capacity of the wall [18-21]. An analysis was carried out using the ETABS v.18 programs for modeling and analysis of the building retrofitted using the ferrocement layer. The properties of masonry walls with the ferrocement layer are shown in Fig.9.

Layer Name	Distance (mm)	Thickness (mm)	Material
1	62.5	25	Plaster
2	50.5	1	Wire Mesh
3	0	100	Masonry
4	-50.5	1	Wire Mesh
5	-62.5	25	Plaster

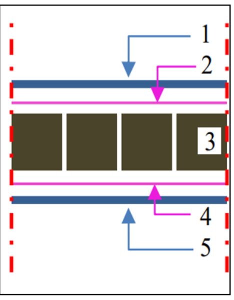


Fig.9 Properties of masonry walls using ferrocement layer

Retrofitting analysis with the ferrocement layer was carried out with the following material data:

1. The compressive strength for plaster (f'c) is 5.23MPa.

2. Specific gravity of plaster is 2130 kg/m^3.
3. The compressive strength for masonry (f'c) is 1MPa.
4. Specific gravity for masonry is 1700 kg/m^3.
5. Thickness of the wire mesh is 1 mm.

The effect of retrofitting on building walls can be obtained by comparing the response of building structures with and without retrofitting using the ferrocement layer. Fig.10 shows the location of the beams and columns which are reviewed to compare the building response before and after it were retrofitted**.**

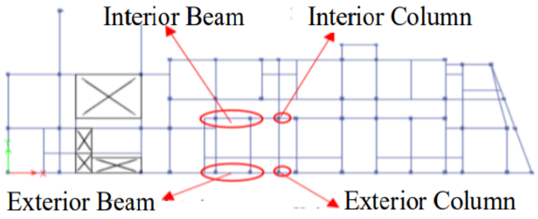


Fig.10 Location of beams and columns which is reviewed to compare the building response

Table 12 The comparison of internal forces on columns of the existing and retrofitted buildings

Position	Internal forces	Without retrofitting	With retrofitting	Reduct ratio
Interior	Moment (kNm)	0.688	0.575	16.4%
	Axial force (kN)	168.2	143.0	15%
	Shear force (kN)	0.053	0.050	4.74%
Exterior	Moment (kNm)	0.801	0.659	17.64%
	Axial force (kN)	156.4	132.3	15.41%
	Shear force (kN)	0.094	0.079	15.2%

Table 13 The comparison of internal forces on beams of the existing and retrofitted buildings

Position	Internal force	Without retrofitting	With retrofitting	Reduct ratio
Interior	Moment (kNm)	1.831	1.496	18.29%
	Shear force (kN)	4.612	4.389	4.84%
Exterior	Moment (kNm)	5.312	4.947	6.86%
	Shear force (kN)	10.522	10.249	2.59%

The comparison of the building response in term of the beams and columns internal forces is shown in Tables 12 and 13. From these tables, It can be seen that the retrofitting using the ferrocement layer reduce bending moment and shear force acting on columns and beams. The retrofitted column experienced a bending moment reduction of 16-17%, an axial force of 15-16%, and a shear force of up to 15%. While the beam had a bending moment reduction of 6-18% and a shear force of 2-5%. This proves that after being retrofitted with the ferrocement layer, the capacity of the building improves in which the presence of the ferrocement layer on the wall not only increases the capacity of the wall but it also reduces the internal forces of the structural elements such as columns and beams. In addition, the retrofitting wall using a ferrocement layer will prevent brittle damage to the wall when anearthquake occurs.

5. CONCLUSION

Based on the structural evaluation of Melati Hospital building, the following conclusions were drawn:

1. The compressive strength of concrete in the beam and column elements of Melati Hospital building is quite low, f'c = 15.77 MPa, lower than that required in Indonesian building standards (f'c = 17MPa).
2. The structural capacity of Melati Hospital building was not strong enough to resist the working loads, especially in the second-floor column, the beams, and the inter-story drift that was calculated with an open frame method. Whereas using modeling with the masonry wall infilled-frame method, this hospital structure is strong enough to withstand the working loads according to current Indonesian building standards.
3. The ability of Melati Hospital building to withstand earthquake loads is highly dependent on the contribution of the wall to resist the lateral loads so the connection of the walls to the columns and beams should be properly designed and constructed.
4. Retrofitting the walls of the building using ferrocement layers improves the capacity of the building by reducing the internal force on columns and beams. After retrofitting, the observed column had a moment reduction of 16-17%, an axial force of 15-16%, and a shear force of up to 15%, while the beam had a moment reduction of 6-18% and a shear force of 2-5%.

6. ACKNOWLEDGEMENTS

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