Four Floor Building Fragility Analysis With Consideration of The Masonry Infilled Wall Contribution

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Abstract. Brick masonry confined with concrete frame is very common for non engineered or institutional building in developing countries. This typical building often seriously suffer from earthquake hit the region. This study aims to evaluate seismic performance of this type of building by developing fragility functions of the structure. Masonry wall is modelled as diagonal strut within the concrete frame. The masonry constituents and composite properties were determined for the model. The structure was subjected to incremental static lateral loading while pushover analysis was utilized to predict the re-sponse of the structure. As the damage states were defined from the spectral capacity curves, the fragility functions were develop for the structure. Based on this study, the seismic performance of the buildings can be determined rationally based on the resulting capacity curve: the infilled frame structure can resist maximum load of 20,3 × 103 kN and open frame is only able to withstand 15,2 × 103 kN. From the fragility curve, it can be concluded that the probability of the infilled frame to reach a certain damage state is lower than the open frame. The results confirm the beneficial effect of the ma-sonry wall to increase the seismic resistance of the building.

***Keywords**: Masonry infilled frame, equivalent diagonal strut, Pushover analysis, fragility curve, maximum base share.*

1. Introduction

In general, structural analysis considers a masonry infilled wall as a non-structural component that only affects the gravitational load on the beams that support it. From this background, structural planning in Indonesia assumes that the structure being reviewed is an open frame. These structures ignore the influence of the strength and stiffness of the infill wall behavior. Whereas in reality, a masonry infilled wall consists of brick and mortar components that interact with each other to produce strength and stiffness in the structure. Although the strength and stiffness values are strongly influenced by the quality of the constituent materials and the technicality of their manufacture [1].

Based on previous research, the comparison of the probability of collapse (collapse) in fill-walled structures shows a smaller value compared to the open frame structure model [2].

In this regard, this study provides a comprehensive structural analysis discussion that is structured from designing a macro model for infill walls to producing a capacity curve followed by a structural fragility curve. The fragility curve is able to provide a better prediction of structural damage. The fragility curve connects the conditional probabilities that give the probability that the structure will meet or exceed the level of damage specified for a given acceleration [3], [4].

2. Methods

2. 1. Modeling Stage

2. 1. 1. Open Frame Structure Modeling

The structural modeling here uses a masonry wall as a gravity load that is evenly distributed along the beams below. The buildings reviewed and analyzed in this research are the flat in Cilacap. This structural classification is included in the mid-rise irregular building group, due to the varying quality of materials, several sizes of beams and columns along with different plate placements on each floor.

Concrete modeling in this structural analysis uses [5] a nonlinear model with constant limiting values, while for steel a model is selected [6] with a hardening isotropic rule [7]

The grouping of structural elements with their dimensions and quality can be seen in table 1. The dimensions of the plate thickness are 140 mm for the floor plate and 120 mm for the roof.

Table 1. Classification of structural and dimensional elements

Element Classification	Beam		Column	
	Dimensions (mm)	Grade (Mpa)	Dimensions (mm)	Grade (Mpa)
a. Floor1,2,3				
1. Main type 1	300×400	f'c 28	300×400	f'c 30
2. Main type 2	300×500	f'c 28		
3. Main type 3	300×300	f'c 25		
4. Main type 4	300×600	f'c 24		
5. Main type 5	250×400	f'c 28		
6. Joist type 1	200×300	f'c 26	150×150	f'c 30
7. Joist type 2	300×400	f'c 24	150×300	f'c 30
8. Joist type 3	150×300	f'c 26		
9. Joist type4	150×250	f'c 28		
10. Joist type 5 (only on the 1st floor)	150×200	f'c 30		
b. Roof				
11. Main type 1	200×300	f'c 26	300×400	f'c 30
12. Main type 2	300×400	f'c 28		
13. Joist type 1	200×300	f'c 26	150×150	f'c 30
14. Joist type 2	150×250	f'c 28	150×300	f'c 30
15. Joist type 3	150×300	f'c 26		

2. 1. 2. Infill Walls Structure Modeling

This structural modeling considers that the wall components contribute to the strength and stiffness of the structure. This assumption can be represented by an approach in the form of a brick wall that behaves as a diagonal stretch, that is, modeling uses a single strat in the form of a diagonal element that behaves as a compression stress.

This concept is proposed with the aim of capturing the actual behavior of the infill walls against the column beams as the structural framework. Where the failure occurs when subjected to lateral loads is at the corner of the wall filler. The framework will support the wall at the end, and the wall will behave to resist excitation as a compressive force (meaning that the strata that is able to withstand the compressive force, is weak to the tensile force).

Macro modeling of this infill wall into a compressive diagonal stretch is an alternative analytical model [8], [9]. This study uses a single strut modeling (see Figure 1) to represent the behavior of the infill walls. Despite the simplicity of the mathematical formula, this modeling can still have an adequate impact on the stiffness value of brick wall panels due to lateral loads [10]. The compressive strength value of the charger wall uses previous research data [11] with the results of testing the compressive strength of brick walls without diagonal reinforcement of steel reinforcement on average yields 0.919 MPa.

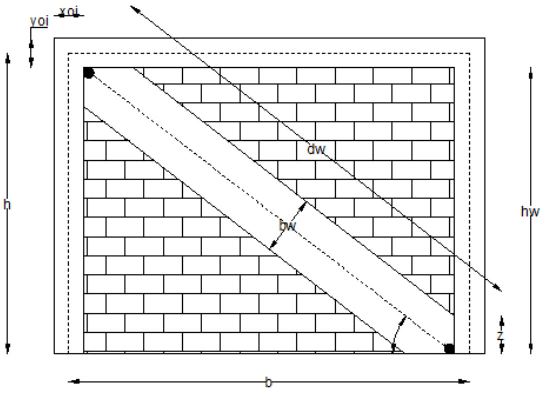

Figure 1. Illustration of geometric parameters of infill walls

Table 2 shows the recapitulation of the parameters of the infill wall modeling in the form of a single structure, starting from the values, formulas and references used. In this research, structural modeling and calculation using Seismostruct as finite element software.

Infill wall modeling is considered to be without openings by allocating the walls to the perimeter of the structure only. Meanwhile, to determine the performance of the structure against seismic loads, this study uses the Pushover non-linear static analysis method.

Table 2. Infill wall parameters, formulas and references used

Infill Wall Panel Parameters	Unit	Value	Formula/Reference	
1. Mechanical Properties				
a. Modulus of elasticity, E_m	MPa	varies	$E_m = f_1 / \varepsilon_m$	(1)
b. Average diagonal compressive strength, f_1	MPa	varies	$fm\theta = f_1.\ sin^2\theta$	(2)
c. Tensile strength, ft	MPa	0	[12]	
d. Shear strength, $\tau 0$	MPa	0,3	[12]	
e. Friction coefficient, μ		0,62	[13]	
f. Maximum shear stress, τ_{max}	MPa	1	[12]	
g. Maximum stress, (ε_m)	MPa	0,0012	[12]	
h. *Ultimate strain*, (ε_u)	MPa	0,024	$\varepsilon_u = 20.\varepsilon_m$	(3)
i. *Closing strain*, (ε_{cl})	MPa	0,003	[12]	
j. Specific gravity, W	N/mm^3	1,7E-005		
2.Empirical character				
a. *Starting Unloading Stiffness Factor*, (γ_{un})		1,7	[12]	
b. *Strain Reloading Factor*, (α_{re})		0,2	[12]	
c. *Strain Inflection Factor*, (α_{rh})		0,7	[12]	
d. *Complete Unloading Strain Factor*, (β_a)		2	[12]	
e. *Stress Inflection Factor*, (β_{ch})		0,9	[12]	
f. *Zero Stress Stiffness Factor*, (γ_{plu})		1	[12]	
g. *Reloading Stiffness Factor*, (γ_{plr})		1,1	[12]	
h. *Plastic Unloading Stiffness Factor*, e_{x1}		3	[12]	
i. *Repeated Cycle Strain Factor*, e_{x2}		1	[12]	
j. *Reduction Shear Factor*, (α_s)	MPa	1,43	[8]	
k. *Out-of-plane Failure Drift*	%	1	[14]	
l. *Proportion of stiffness assigned to shear*, γ_s	%	70	[12]	
3.*Geometrical Properties*				
a. Thickness, tw	mm	150		

b. *Dimensionless relative stiffness*, λ_h			$\lambda_h = h \sqrt[4]{\frac{E_m\, t_w \sin(2\theta)}{4\, E_c\, I_c\, h_w}}$	(4)
c. Strat width, b_{w1}	mm	varies	$b_w = 0{,}175.\ (\lambda.\ h)^{-0.4}\ d_w$	(5)
d. Strat 1 area, Am_1	mm^2	varies	$Am_1 = bw_1.\ T_{inf} / 2$	(6)
e. Strat 2 area, Am_2	%	70	$Am_2 = bw_{cracked}/bw_{uncracked}$	(7)
f. *Strut Area Reduction Strain*, (ε_1)		0,0006	[15]	
g. *Residual Strut Area Strain*, (ε_2)		0,001	[15]	
h. Vertikal distance strat, h_z	mm	0	*strat tunggal diagonal*	
i. Horizontal distance between point, x_{oi}	%	varies	$xoi = \frac{0{,}5 \times lebar\ kolom}{panjang\ bersih\ panel}$	(8)
j. Vertikal distance between point, y_{oi}	%	varies	$yoi = \frac{0{,}5 \times tebal\ balok}{tinggi\ bersih\ panel}$	(9)

Figures 2 and 3 are the results of modeling of open frame structures and structures with infill walls carried out by SeismoStruct.

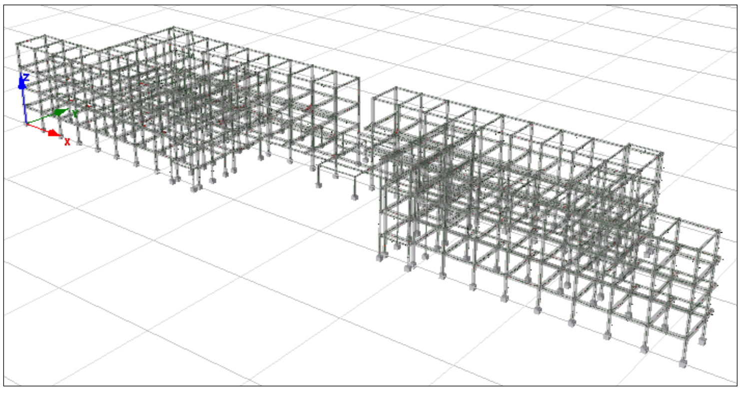

Figure 2. Modeling result of open frame structure

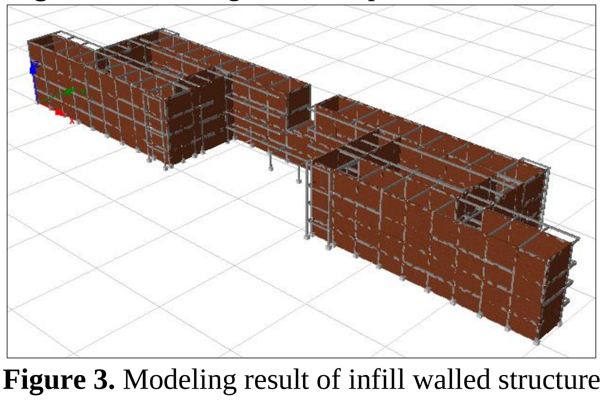

Figure 3. Modeling result of infill walled structure

2. 2. Fragility Analysis Stage

According to HAZUS MH-MR5, there are two basic components that must be met in determining the limit of structural damage, namely: the capacity curve and the fragility curve. Where the fragility curve represents the possibility of structural damage: structural systems, nonstructural components that are sensitive to deviation or acceleration [16].

2. 2. 1. Converting Capacity Curves to Capacity Spectrum Curves

Seismostruct output in performing structural analysis using the Pushover method is a capacity curve. Meanwhile, to obtain the fragility curve, it must first have a capacity spectrum curve. The formula used to convert the capacity curve (based on shear force - displacement) into a capacity spectrum curve (based on spectral acceleration - spectral displacement) based on ATC-40 [17] is as follows:

$$Sa = \frac{V/W}{\alpha 1} \quad (10)$$

$$Sd = \frac{\Delta roof}{PF1 \times \emptyset roof1} \quad (11)$$

The formula for getting the PF1 value is as follows:

$$PF1 = \left[\frac{\sum_{i=1}^{N} (wi.\emptyset i1)/g}{\sum_{i=1}^{N} (wi.\emptyset i1^2)/g}\right] \quad (12)$$

$$\alpha 1 = \frac{\left[\sum_{i=1}^{N} (wi.\emptyset i1)/g\right]^2}{\left[\sum_{i=1}^{N} (wi)/g\right]\left[\sum_{i=1}^{N} (wi.\emptyset i1^2)/g\right]} \quad (13)$$

Explanation :

Sa	= spectral acceleration,
Sd	= spectral displacement,
$PF1$	= first mode capital participation,
$\alpha 1$	= the mode mass coefficient of the first mode,
$\emptyset i1$	= amplitude of the first Pushover result for the i-th floor,
V	= base shear,
W	= weight of structure,
$\Delta roof$	= floor displacement,
$((wi))/g$	= mass on floor -i.

2. 2. 2. Determination of Damage Limits

There are several ways to determine the limit of structural damage, such as the deviation ratio between floors, maximum bottom shear force, displacement at melting (dy) and ultimate displacement (du), the level of material strain, etc. [18], [19].

This study will analyze the structural fragility using the maximum base shear force in determining the limit of damage. Based on research [19], the condition of structural damage can be divided into several levels according to the definition below:

a. Condition 1 (LS1): roof displacement at 75% of the maximum basic shear force is achieved
b. Condition 2 (LS2): roof displacement at the maximum base shear force capacity is reached
c. Condition 3 (collapse) - (LS3): displacement of the roof when the base shear force decreases by 20%

2. 2. 3. Creation of Structural Fragility Curves

Determine in advance the standard deviation of irregularity (β). The standard deviation of total uncertainty (βds) will be influenced by 3 standard deviations, namely: standard deviation of structural capacity uncertainty (βc), standard deviation of required spectrum uncertainty (βd) where βd = 0.45 (short period) and βd = 0.5 (long period), and the standard deviation of the uncertainty of the structural damage limit value (βM (ds)).

The mathematical equation that explains the relationship between the standard deviation value of uncertainty as a form of total standard deviation (βds) is as follows:

$$\beta_c = \sqrt{\ln(\frac{s^2}{m^2}+1)} \quad (14)$$

$$(\beta_{ds}) = \sqrt{[(CONV[\beta_c,\beta_d])]^2 + [\beta_{M(ds)}]^2} \quad (15)$$

Explanation :

m = the average of the spectral acceleration capacity of the observed structure,
s = standard deviation of the specified spectral parameters of the structure.

Creation of a fragility curve using the formula [20] as follows:

$$P\ (ds|S_a\ \text{atau Sd}) = \Phi\left(\frac{1}{\beta_{ds}}\right)\ln\left(\frac{\text{Sa atau Sd}}{\text{Sa.ds atau Sd.ds}}\right) \qquad (16)$$

Explanation :

Φ = standard normal cumulative distribution function,

Sa.ds or Sd.ds = the acceleration or spectral displacement required to obtain certain damage conditions.

3. Results and Discussion

The capacity curve is obtained when first setting the target structure displacement = 0.294 m and iteration is carried out as many as 98 repetitions. The comparison between the capacity curve resulting from the analysis of the open frame structure and the infilled wall structure can be seen in Figure 4 by referring to the analysis review only on the y-axis as the weak axis.

From Figure 4 it can be seen that the walled structure of the filler is able to accept a maximum lateral load of 20.3x103 kN and the open frame is able to accept lateral loads before the achievement of failure of 15.2x103 kN. This indicates that the infill walled structure is more resistant to lateral loads than the open frame. This is related to the effect of the inffll wall compressive strength modeled in the panel in the form of infill walls of = 0.919 MPa.

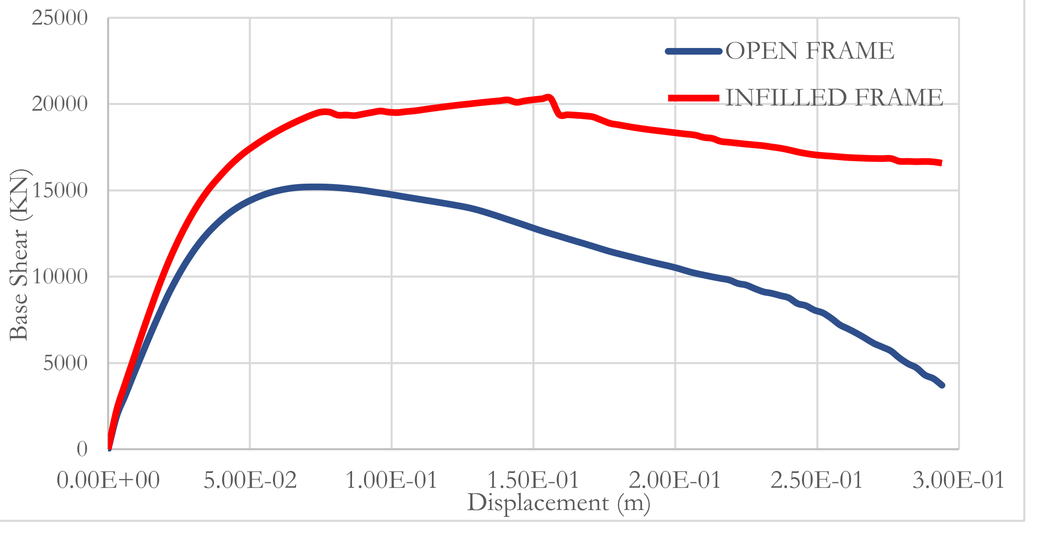

Figure 4. Comparison of the capacity curve of the open frame structure with the infilled wall

3.1 Fragility Analysis

From the Eigen value and the results of the Pushover analysis, we get: m = point mass and Øi1 = the form of the Pushover mode taken is usually based on the first mode of the building in the direction under review. This parameter is used in converting the capacity curve to a capacity spectrum curve.

The values for m and Øi1 above are then entered into equations no (12) and (13), so that α1 for the open frame = 0.80, PF1 = 1.37; and α1 for infilled wall structures = 0.81, PF1 = 1.36. The next step after getting α1 and PF1 numbers is to convert the resulting capacity curve into ADRS (Acceleration Displacement Response Spectrum) format, using equations (10) and (11) above.

To create a fragility curve, what must be done is to calculate the standard deviation of uncertainty (β). Based on the results of Eigen's analysis, this structure is included in the short-period structure (<3.5 seconds) because it has a period in the first mode of 0.36 seconds (open frame) and 0.31 seconds (filler walled structure), so the standard deviation required (βd) chosen = 0.45.

Furthermore, for the value of βM (ds), 0.4 based on HAZUS-MH MR5 was taken. This value is used for all types of damage and forms structural boundaries. Meanwhile, the value of βc for Sd is 0.4672 (obtained from previous research that reviewed the same object, using the Pushover method, but the software for performing the analysis is different). This value is the value of structural variation based on the acceleration spectrum capacity which is set from 0.0 g to 2.0 g) [21]. The results of calculating the probability and dispersion of structures based on the achievement of the shear forces can be seen in table 3 below:

Table 3. Limitation of structural damage based on maximum shear force

OPEN FRAME STRUCTURE					
Condition	Sd (m)	βM (ds)	βC	βd	βds
LS 1	0,0217	0,4000	0,4672	0,4500	0,4519
LS 2	0,0526	0,4000	0,4672	0,4500	0,4519
LS 3	0,1188	0,4000	0,4672	0,4500	0,4519
INFILLED WALL STRUCTURE					
Condition	Sd (m)	βM (ds)	βC	βd	βds
LS 1	0,0270	0,4000	0,4672	0,4500	0,4519
LS 2	0,1158	0,4000	0,4672	0,4500	0,4519
LS 3	0,2183	0,4000	0,4672	0,4500	0,4519

The combination of the structural dispersion values above and the shear force values as a reference for obtaining the structural damage limit results in a fragility curve as shown in Figure 5.See the red line in figure 5 for an example of how to read the results on a probability curve based on the maximum shear force.

It aims to describe the comparative fragility conditions between structural models. When the structural response results in a displacement of 0.2 m, the probability that occurs at the level of breakdown condition 3 for the open frame is 87.54% while the infilled wall structure only shows 76.05%. This shows that the probability for the fragility of the structure at the same level of damage between open frame structures is greater than that of infill walled structures.

factors and maximum cement demand. Sand and gravel requirements are determined using grading zone graphs from the results of specific gravity measurements. In this study, Anadara granosa shell powder was substituted with cement by using a ratio of cement weight in the mixture. Mix design can be seen in Table 2. Concrete mix design with Anadara granosa shell waste as a partial replacement for cement. The process of mixing concrete materials is made with a value according to the results of the mix design. The process of making concrete is shown in Figure 4.3 and Figure 4.4.

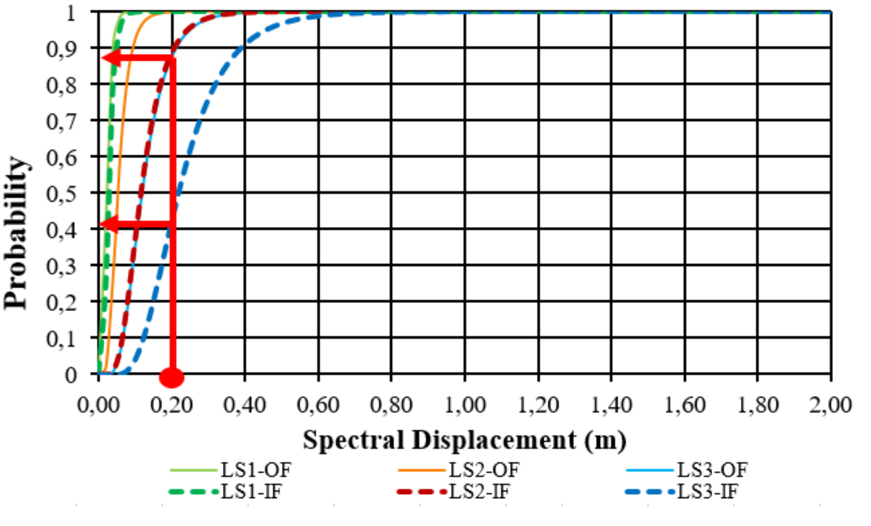

Figure 5. The fragility curve using the maximum shear force

4. Conclusion and Recommendation

a. The resulting capacity curve shows that the strength of the infilled wall structure is much greater than that of the open frame. And one of the parameters that greatly affects the strength of this infill wall is the compressive strength value of the brick panel.
b. From the structural friability curve it can be concluded that based on the spectral displacement, a larger displacement capacity implies lower friability.

c. In determining the limit of damage, it will be much more representative if we use the maximum shear strength as a reference.

5. Recommendation

For further research, the modeling of the infilled wall structure uses the actual assumption of the laying of the walls (adjusted to the actual conditions). In addition, it can be included in the assumption of the effect of openings such as windows and doors on the creation of a macro model of infill walled structures. It is suggested that the objective of the analysis results obtained is closer to the actual condition.

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