Seismic performance of four-storey masonry infilled reinforced concrete frame building

By: ***Isyana Ratna*** **Hapsari**[1],
Senot **Sangadji**[2], **and** ***Stefanus Adi*** **Kristiawan**[2]

Scope of discussion

01 **Introduction** ☑

02 Modelling of the building

A. Open Frame
B. Infilled Frame

03 Seismic performance analysis

A. Non-linear static pushover analysis
B. Developing fragility curve

04 Conclusion

Research Introduction

Masonry infilled wall

Generally modelled as an open frame

Omitting the strength and stiffness contribution of the infilled wall

Only gives a gravitational load effect to the structure

A realistic analysis of structure

Reliable seismic performance within an acceptable limit

A macro model of masonry infilled wall in the form of an equivalent diagonal compression strut

The seismic performance evaluation

The seismic performance is assessed on the basis of the fragility curve

The fragility curve provides complete information on the probabilities of various levels of building damage due to various seismic intensities

Scope of discussion

01 Introduction

02 **Modelling of the building** ☑

A. Open Frame
B. Infilled Frame

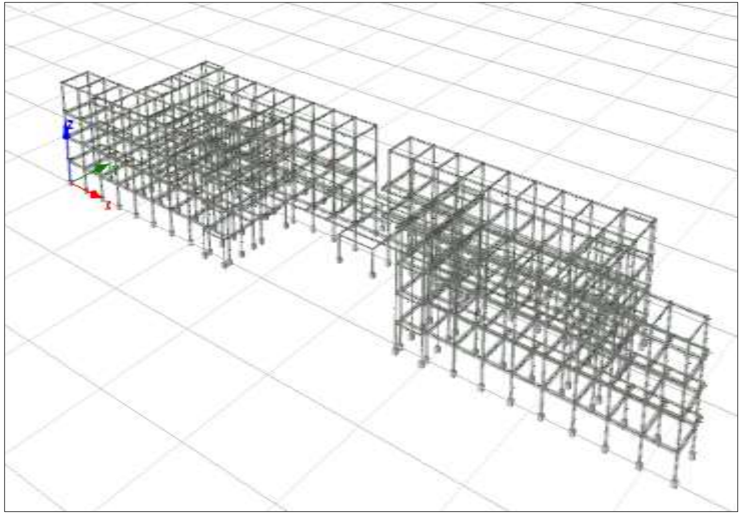
03 Seismic performance analysis

A. Non-linear static pushover analysis
B. Developing fragility curve

04 Conclusion

Open Frame Model

a. The building is a four-storey structure (residential purpose)
b. Classified to be the Mid Rise Irregular building group
c. The infilled wall is considered only to cause a gravitational load to the beam below it
d. The floor or rooftop load is calculated using tributary area method



Open Frame Model

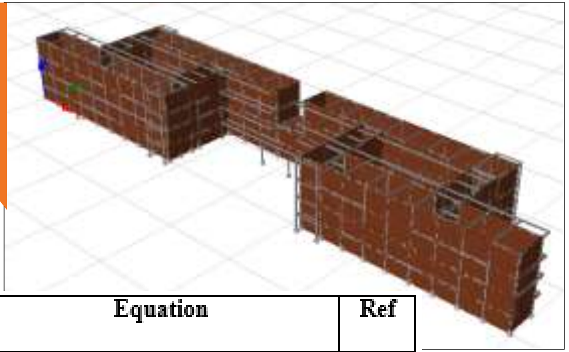
Table of Element Classes and Dimension

Element Classes	Beam size (mm^2)	Concrete compressive strength of beam (MPa)	Column size (mm^2)	Concrete compressive strength of column (MPa)	Slab thickness (mm)
a. 1,2,3 FLOOR					
1. Primary type 1	300 x 400	28	300 x 400	30	140
2. Primary type 2	300 x 500	28			
3. Primary type 3	300 x 300	25			
4. Primary type 4	300 x 600	24			
5. Primary type 5	250 x 400	28			
6. Secondary type 1	200 x 300	26	150 x 150	30	
7. Secondary type 2	300 x 400	24	150 x 300		
8. Secondary type 3	150 x 300	26			
9. Secondary type 4	150 x 250	28			
10. Secondary type 5 (only 1st floor)	150 x 200	30			
b. ROOF					
11. Primary type 1	200 x 300	26	300 x 400	30	120
12. Primary type 2	300 x 400	28			
13. Secondary type 1	200 x 300	26	150 x 150	30	
14. Secondary type 2	150 x 250	28	150 x 300		
15. Secondary type 3	150 x 300	26			

Infilled Frame Model

a. The infilled wall contributes to the strength and stiffness of the frame structure
b. A macro modelling of masonry infilled as an equivalent diagonal compression strut

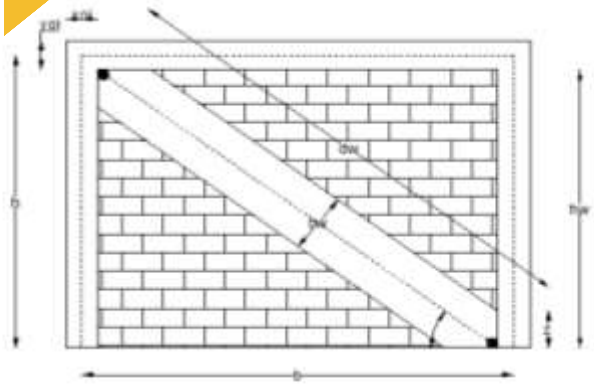
01 Infilled Frame Model



03 Geometrical Properties

Infilled Panel Model Parameters	Unit	Used Value	Equation	Ref
a. Panel Thickness, t_w	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)	[3]
c. Width of strut, b_{w1}	mm	varies	$b_w = 0.175\,(\lambda.\,h)^{-0.4}\, d_w$ (5)	[18, 19]
d. Strut Area 1, Am_1	mm²	varies	$Am_1 = bw_1 .\, t_{inf}$ (6)	
e. Strut Area 2, Am_2	%	70	$Am_2 = bw_{cracked}/bw_{uncracked}$ (7)	[3]
f. Strut Area Reduction Strain, (ε_1)		0.0006		[20]
g. Residual Strut Area Strain, (ε_2)		0.001		[20]
h. Equivalent Contact Length, h_z	mm	0	Diagonal Single strut	
i. Horizontal Offsets, x_{oi}	%	varies	$xoi = \frac{0.5 \text{ column width}}{\text{width of infill panel}}$ (8)	[15]
j. Vertical Offsets, y_{oi}	%	varies	$yoi = \frac{0.5 \text{ beam depth}}{\text{height of infill panel}}$ (9)	[15]

02 Macro modelling of masonry infilled



04 Mechanical Properties

Infilled Panel Model Parameters	Unit	Used Value	Equation	Ref
a. Elastic Young's Modulus, E_m	MPa	varies	$E_m = fm\theta / \varepsilon_m$ (1)	
b. Mean diagonal compressive strength, $fm\theta$	MPa	varies	$fm\theta = f_1 . sin^2\theta$ (2)	[3]
c. Tensile Strength, ft	MPa	0		[15]
d. Bond shear strength, τ_0	MPa	0.3		[15]
e. Coefficient of friction, μ		0.62		[16]
f. Maximum shear stress, τ_{max}	MPa	1		[15]
g. Strain at max stress, (ε_m)	MPa	0.0012		[15]
h. Ultimate strain, (ε_u)	MPa	0.024	$\varepsilon_u = 20 . \varepsilon_m$ (3)	[15]
i. Closing strain, (ε_{cl})	MPa	0.003		[15]
j. Specific Weight, W	N/mm^3	1.7E-005		

05 Empirical Properties

Infilled Panel Model Parameters	Unit	Used Value	Equation	Ref
a. Starting Unloading Stiffness Factor, (γ_{un})		1.7		[15]
b. Strain Reloading Factor, (α_{re})		0.2		[15]
c. Strain Inflection Factor, (α_{ch})		0.7		[15]
d. Complete Unloading Strain Factor, (β_a)		2		[15]
e. Stress Inflection Factor, (β_{ch})		0.9		[15]
f. Zero Stress Stiffness Factor, (γ_{plu})		1		[15]
g. Reloading Stiffness Factor, (γ_{plr})		1.1		[15]
h. Plastic Unloading Stiffness Factor, e_{x1}		3		[15]
i. Repeated Cycle Strain Factor, e_{x2}		1		[15]
j. Reduction Shear Factor, (α_s)	MPa	1.43		[3]
k. Out-of-plane Failure Drift	%	1		[17]
l. Proportion of stiffness assigned to shear, γ_s	%	70		[15]

Scope of discussion

01 Introduction

02 Modelling of the building

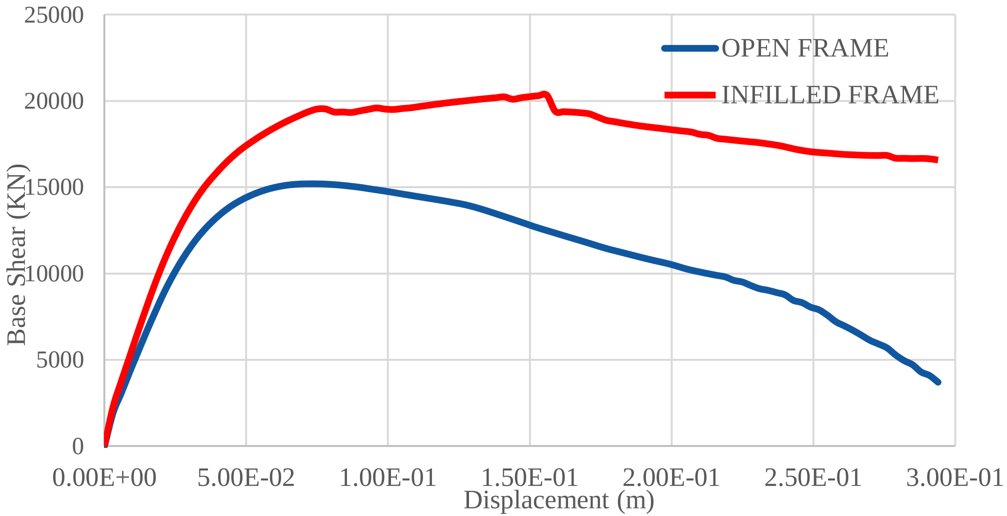
A. Open Frame
B. Infilled Frame

03 **Seismic performance analysis** ☑

A. Non-linear static pushover analysis
B. Developing fragility curve

04 Conclusion

Seismic performance analysis



Capacity Curve

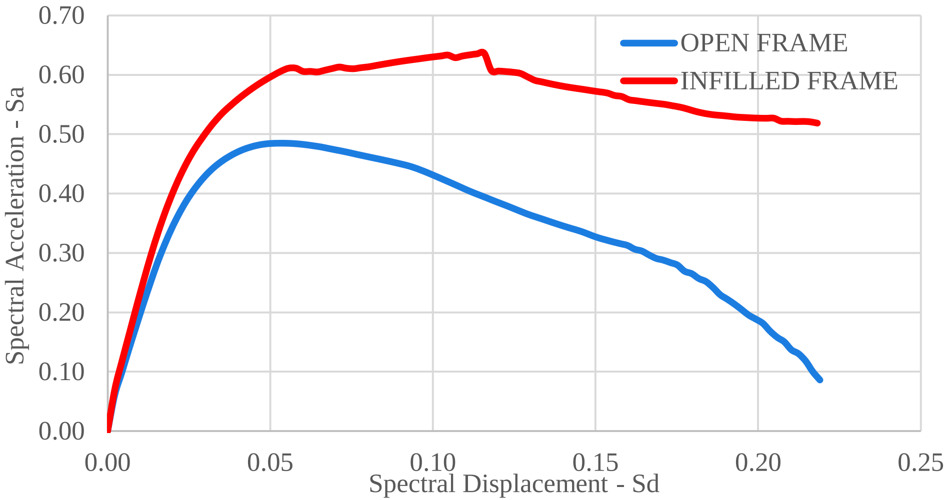
Using a non-linear static pushover analysis

Output:
Capacity Curve

a. setting the target displacement of 0.294 m (2% of the height)
b. the iteration is carried out as much as 98 steps
c. the lateral load is performed on the weak est axis of the structure (y-axis)

a. Maximum lateral load infilled frame = 20. 3x103 kN and open frame = 15.2x103 k N
b. Increase 33%

Seismic performance analysis



Spectrum Capacity Curve

Developing fragility curve

a. Converting the capacity curve into a spectrum capacity curve

Formula using *ATC-40*:

$$Sa = \frac{V/W}{\alpha 1} \quad ; \quad Sd = \frac{\Delta roof}{PF1 \times Øroof1}$$

Where:

$$PF1 = \left[\frac{\sum_{i=1}^{N} (wi.Øi1)/g}{\sum_{i=1}^{N} (wi.Øi1^2)/g} \right] \quad ; \quad \alpha 1 = \frac{\left[\sum_{i=1}^{N} (wi.Øi1)/g\right]^2}{\left[\sum_{i=1}^{N} (wi)/g\right]\left[\sum_{i=1}^{N} (wi.Øi1^2)/g\right]}$$

Seismic performance analysis

Determining the damage states

1 **Inter-story drift in *HAZUS-MH MR5* method**

Model Building Type		Structural Damage States			
		Slight	Moderate	Extensive	Complete
Low-Rise Buildings – High – Code Design Level					
W1, W2		0.004	0.012	0.040	0.100
S1		0.006	0.012	0.030	0.080
C1, S2		0.005	0.010	0.030	0.080
C2		0.004	0.010	0.030	0.080
S3, S4, PC1, PC2, RM1, RM2		0.004	0.008	0.024	0.070
Low-Rise Buildings – Moderate – Code Design Level					
W1, W2		0.004	0.010	0.031	0.075
S1		0.006	0.010	0.024	0.060
C1, S2		0.005	0.009	0.023	0.060
C2		0.004	0.008	0.023	0.060
S3, S4, PC1, PC2, RM1, RM2		0.004	0.007	0.019	0.053
Low-Rise (LR) Buildings – Low – Code Design Level					
W1, W2		0.004	0.010	0.031	0.075
S1		0.006	0.010	0.020	0.050
C1, S2		0.005	0.008	0.020	0.050
C2		0.004	0.008	0.020	0.050
S3, S4, PC1, PC2, RM1, RM2		0.004	0.006	0.016	0.044
S5, C3, URM		0.003	0.006	0.015	0.035
Low-Rise (LR) Buildings – Pre – Code Design Level					
W1, W2		0.003	0.008	0.025	0.060
S1		0.005	0.008	0.016	0.040
C1, S2		0.004	0.006	0.016	0.040
C2		0.003	0.006	0.016	0.040
S3, S4, PC1, PC2, RM1, RM2		0.003	0.005	0.013	0.035
S5, C3, URM		0.002	0.005	0.012	0.028
Mid – Rise Buildings					
All	Mid-Rise Building Types	2/3 * LR	2/3 * LR	2/3 * LR	2/3 * LR
High – Rise Buildings					
All	Mid-Rise Building Types	1/2 * LR	1/2 * LR	1/2 * LR	1/2 * LR

2 **Inter-story drift in *ATC-40* method**

Interstory Drift Limit	Performance Level (Damage States)			
	IO	DC	LS	SS*
Maximum total drift	0.01	0.01-0.02	0.02	$0.33 \frac{V_i}{P_i}$

3 **Maximum base shear by Silva et al**

- Limit state 1 (LS1): top displacement at 75% of the maximum base shear capacity is achieved
- Limit state 2 (LS2): top displacement at the maximum base shear capacity is achieved
- Limit state 3(collapse)-(LS3): top displacement when the base shear capacity decreases 20%

Seismic performance analysis

Establishing the fragility curve

Determining the standard deviation of the total uncertainty (β_{ds}) i.e: the uncertainty of structural capacity (β_C), spectrum demand (β_d) & damage limit value of the structure ($\beta_{M(ds)}$).

Equation:

$$\beta_C = \sqrt{ln(\frac{s^2}{m^2}+1)} \quad ; \quad (\beta_{ds}) = \sqrt{[(CONV[\beta_c,\beta_d])]^2+[\beta_{M(ds)}]^2}$$

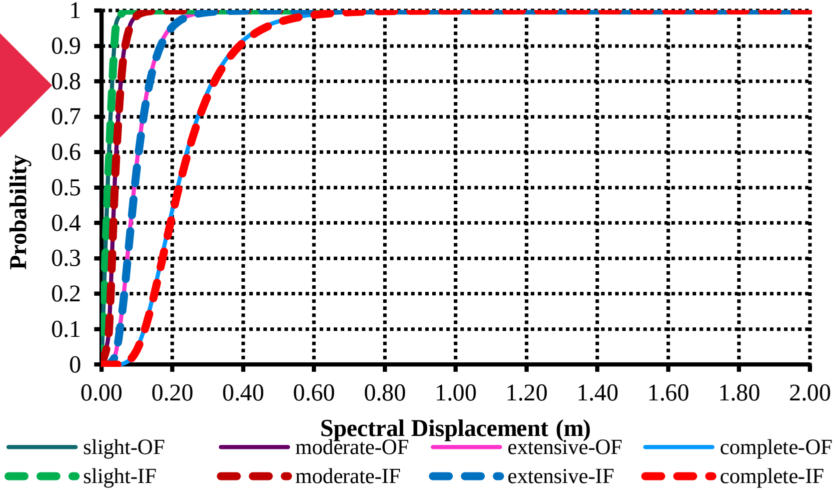
$$P\,(ds|S_a\ or\ Sd) = \Phi\left(\frac{1}{\beta_{ds}}\right) ln\left(\frac{Sa\ or\ Sd}{Sa.ds\ or\ Sd.ds}\right)$$

OPEN FRAME (HAZUS-MH MR5)					
Limit State	Sd (m)	$\beta_{M(ds)}$	β_C	β_d	β_{ds}
Slight	0.0184	0.4000	0.4672	0.4500	0.4519
Moderate	0.0368	0.4000	0.4672	0.4500	0.4519
Extensive	0.0920	0.4000	0.4672	0.4500	0.4519
Complete	0.2146	0.4000	0.4672	0.4500	0.4519
INFILLED FRAME (HAZUS-MH MR5)					
Limit State	Sd (m)	$\beta_{M(ds)}$	β_C	β_d	β_{ds}
Slight	0.0187	0.4000	0.4672	0.4500	0.4519
Moderate	0.0374	0.4000	0.4672	0.4500	0.4519
Extensive	0.0935	0.4000	0.4672	0.4500	0.4519
Complete	0.2183	0.4000	0.4672	0.4500	0.4519
OPEN FRAME (ATC 40)					
Limit State	Sd (m)	$\beta_{M(ds)}$	β_C	β_d	β_{ds}
IO	0.0920	0.4000	0.4672	0.4500	0.4519
LS	0.1840	0.4000	0.4672	0.4500	0.4519
SS	1.1812	0.4000	0.4672	0.4500	0.4519
INFILLED FRAME (ATC 40)					
Limit State	Sd (m)	$\beta_{M(ds)}$	β_C	β_d	β_{ds}
IO	0.0935	0.4000	0.4672	0.4500	0.4519
LS	0.1871	0.4000	0.4672	0.4500	0.4519
SS	1.6072	0.4000	0.4672	0.4500	0.4519

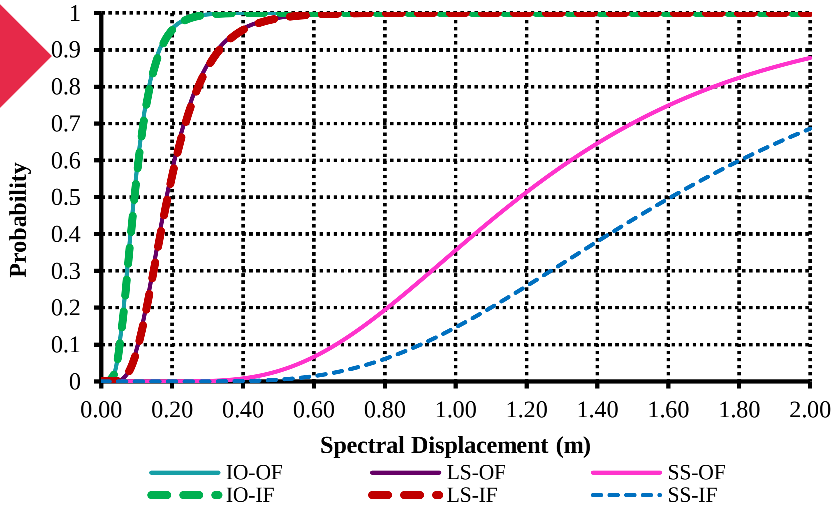
OPEN FRAME (Silva's Method)					
Limit State	Sd (m)	$\beta_{M(ds)}$	β_C	β_d	β_{ds}
LS1	0.0217	0.4000	0.4672	0.4500	0.4519
LS2	0.0526	0.4000	0.4672	0.4500	0.4519
LS3	0.1188	0.4000	0.4672	0.4500	0.4519
INFILLED FRAME (Silva's Method)					
Limit State	Sd (m)	$\beta_{M(ds)}$	β_C	β_d	β_{ds}
LS1	0.0270	0.4000	0.4672	0.4500	0.4519
LS2	0.1158	0.4000	0.4672	0.4500	0.4519
LS3	0.2183	0.4000	0.4672	0.4500	0.4519

The fragility curve

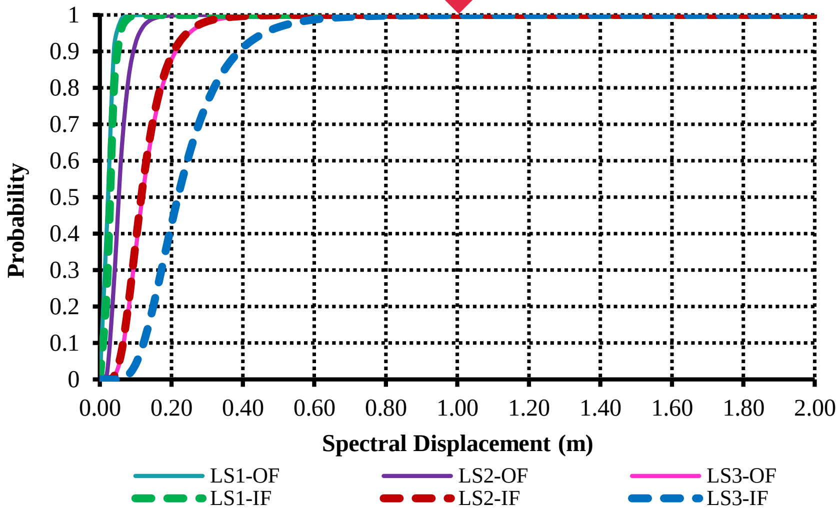
HAZUS



ATC-40



SILVA ET.AL



Scope of discussion

01 Introduction

02 Modelling of the building

A. Open Frame
B. Infilled Frame

03 Seismic performance analysis

A. Non-linear static pushover analysis
B. Developing fragility curve

04 **Conclusion** ☑

Research Conclusion

a. The capacity curve of the masonry infilled frame structure is increase 33% compared to the open frame structure
b. The Silva’s method capable to demonstrate the reduction of the probability of the masonry infilled wall structure to reach certain damage states for a given seismic intensity as compared to the open frame structure, because only this method specifies the damage states based on the magnitude of base shear while the other methods are based on the inter-story drift
c. From the fragility curve, the probability of the masonry infilled frame to reach a certain damage state is lower than that of the open frame. The results confirm the beneficial effect of the masonry infilled wall to increase the seismic resistance of the building

Thank you