

Modal Analysis of RC Masonry Infill Model and Prototype Frames with Openings

Sushmitha M.^{1,*}, B.P. Annapurna², Bhagyashri P.³, Chethan K.⁴

Abstract

Modal evaluation is the technique of figuring out the inherent dynamic traits of the shape in phrases of herbal frequencies and mode shapes and the usage of them to create a mathematical version for its dynamic behavior. The dynamics of a structure is defined by frequency and position. Modal evaluation offers the records regarding to exceptional modes of vibration, exceptional form that may be taken up via way of means of the shape at some stage in vibration. These shapes during different modes are called mode shapes and all mode shapes have their corresponding natural frequencies. In this study, modal analysis on 3D-RC masonry infill (MI) model and prototype frames with openings are carried out. MI is modeled as equivalent diagonal strut which is a macro-modeling technique as per the formulation from IS 1893 (Part-1):2016. The natural frequencies obtained from modal analysis are compared with the time period formula from IS 1893 (Part-1):2016.

Keywords: Natural frequency, equivalent diagonal strut, macro-modeling, scale factor, mode shapes

INTRODUCTION

MI transforms the behavior of buildings from mainly frame action to mainly shear action. Also, the MI are capable of resisting the applied lateral seismic forces through axial compression along the diagonal. Discard of MI contribution results in a significant under-estimation of the lateral stiffness of the structure and thereby can result in an over estimation of the lateral forces.

A model is a representation of a real system. The parametric modeling simulation enables the operation of large amounts of building information, which makes it is possible to understand the structural behavior. The prototype is important to study the original design layout. The significant benefit of a prototype is that it simulates the real product. Prototyping is one of the ways to decrease design errors and reduce the failure factors in the preliminary design phase.

Modal analysis is carried out on both model and prototype of 3D RC MI frames with 0% to 100% openings to identify the dynamic characteristics and compare the same with IS codal provisions.

Background

B.S. Smith and C. Carter (1969) [1], Chethan K. et al. (2009) [2], Prabhu Raja et al. (2010) [3], P.G. Asteris et al. (2011) [4], P.B. Kulkarni et al. (2013) [5], F. Di Trapani et al. (2017) [6], Guang Yaung et al. (2019) [7] and many more have carried out studies on RC MI frames with equivalent diagonal strut. However, not many studies on the dynamic characteristics of model and prototype are carried out [8, 9].

*Author for Correspondence

Sushmitha M.

^{1,2,4}Department of Civil Engineering, University Visvesvaraya College of Engineering, Bangalore University, Bengaluru, Karnataka, India

³Department of Civil Engineering, Government Engineering College Ramanagara, Ramanagara, Bengaluru, Karnataka, India

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OBJECTIVES AND METHODOLOGY

The objectives of the study are:

1. To evaluate the dynamic response of 3D-RC MI model and prototype frames with openings using macro-modeling technique.
2. Development of prototype by using scaling laws.
3. Comparison of results with IS codal provisions.

The methodology to achieve the objectives are:

1. Development of prototype by increasing the dimensions in 1:4 scale by keeping same material property as that of model by following the Scale factor using Scaling Laws.
2. MI to be modeled as equivalent diagonal strut which a macro-modeling technique is using the formulation from IS 1893 (Part-1):2016.
3. Modal analysis is carried out on the model and prototype of 3D RC MI frames to obtain natural frequencies and mode shapes.
4. Comparison of natural frequencies obtained from modal analysis with IS 1893 (Part-1):2016 procedure for time period.

Modeling and Analysis

Modeling of 3D RC MI Model and Prototype Frames

To examine the structure for dynamic loading, it is obligatory to estimate the natural frequency of the structure. Many national and international codes state empirical formulae for estimating the natural frequency or the time period of the frames with and without infill. The majority of the formulae depend only on the height and base dimension of the structure lacking giving significance to the characteristics and location of masonry infill (MI). The concept of analyzing the masonry infill as equivalent diagonal strut has been suggested by many researchers which can be effectively used in the FE analysis to find the natural frequencies of the structures.

The model considered in this study is taken from Chethan K. et al. (2009) [2] as shown in Table 1 and parameters to find the width of equivalent diagonal strut for 3D RC MI model and prototype frames are as per the formulation from IS 1893(part-1):2016. MI are modeled as equivalent diagonal strut which is one of the macro-modeling techniques as follows.

- (a) End of diagonal strut shall be considered to be pin-jointed to RC frame
- (b) For URM infill walls without any openings W_{ds} of equivalent diagonal strut shall be taken as

$$W_{ds} = 0.175\alpha_h^{-0.4}L_{ds} \quad (1)$$

Table 1. Parameters to find equivalent diagonal strut for 3d RC Mi model and prototype.

Parameters	3D RC MI model	3D RC MI prototype
Bay-to-bay width in m	1.2	4.8
Floor-to-floor height in m	0.9	3.6
Breadth of beam/column, b in m	0.075	0.3
Depth of beam/column, d in m	0.1	0.6
Thickness of masonry infill, t in m	0.075	0.23
Height of masonry infill, h in m	0.8	3.0
Length of masonry infill, l in m	1.1	4.2
Height of column, h_{col} in m	0.9	3.6
Moment of Inertia of Beam/Column in m^4	6.25×10^{-6}	0.0054
Modulus of elasticity of concrete kN/m^2	2.5×10^{-7}	2.5×10^{-7}
Modulus of elasticity of masonry infill kN/m^2	14000	14000
Slope of the infill diagonal to the horizontal, θ in degrees	36.03	35.54
Width of equivalent diagonal Strut in m	0.142	0.548

where,

$$\alpha_h = h \left(\sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c h}} \right) \quad (2)$$

E_m = Modulus of elasticity of masonry infill

t = Thickness of masonry infill

h = Height of masonry infill

E_c = Modulus of elasticity of column

I_c = Moment of inertia of the column

θ = Slope of the infill diagonal to the horizontal

Macro-modeling of Prototype

The vital factor of the equivalent diagonal strut is their width, which affects the stiffness and strength. It is assumed that the material properties like cement, Poisson ratio and Elastic modules are similar for model and 1:4 scaled prototype frames. The dimensions of prototype are obtained by keeping material properties same for both model and prototype. Relating the natural frequency of the prototype and that of the model is obtained as follows:

$$f_m = \sqrt{S} f_p \quad (3)$$

Where, f_m = frequency of model

f_p = frequency of prototype

S = scale factor

The width of equivalent diagonal strut for 3D RC MI model and prototype frames are calculated as per IS Code 1893 (Part-1): 2016 are tabulated in Table 1. A typical 3D RC MI model and prototype frame with equivalent diagonal strut are shown in Figure 1 (a) and b), respectively.

Openings in Equivalent Diagonal Strut

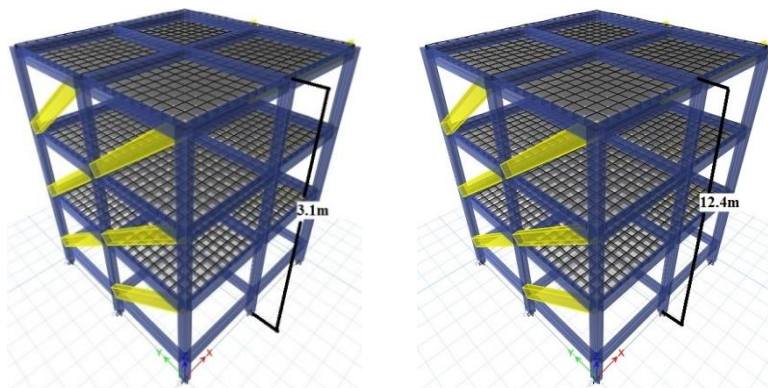
Study on infill walls with openings is mostly analytical as exact similarity to real cases, definite materials used, and definite types of openings cannot be simulated.

The findings of the present parametric study using the finite-element method [4] lead to the following relationship for the infill wall stiffness reduction factor λ :

$$\lambda = 1 - 2\alpha_w^{0.54} + \alpha_w^{1.14} \quad (4)$$

Where,

α_w is the infill wall opening percentage (area of opening to the area of infill wall).



(a) 3D RC MI model.

(b) 3D RC MI prototype.

Figure 1. (a, b): 3D RC MI model and 3D RC MI prototype frames with equivalent diagonal strut.

The above λ co-efficient is used to find the width of equivalent diagonal strut with openings. The width of equivalent diagonal strut with 0% to 100% openings for 3D RC MI model and prototype frames are tabulated in Table 2.

MODE SHAPES

The mode shapes for bare frame, 3D RC MI model and prototype frames are shown in Figure 2–7 respectively.

Bare Frame Model

In-plane mode: 6.56 Hz, out-of-plane mode: 5.59 Hz

Bare Frame Prototype

in-plane Mode: 2.75 Hz, out-of-plane Mode: 1.86 Hz

3D RC MI Model without Openings

In-plane mode: 10.45 Hz, out-of-plane mode: 4.47 Hz

3D RC MI Prototype without Openings

In-plane mode: 5.16 Hz, out-of-plane mode: 1.68 Hz

3D RC MI Model with 5% Openings

In-plane mode: 9.85 Hz, out-of-plane mode: 4.48 Hz

3D RC MI Prototype with 5% Openings

In-plane mode: 4.67 Hz, out-of-plane mode: 1.69 Hz

Table 2. Width of equivalent diagonal strut with openings.

% openings	Width of equivalent diagonal strut for openings(mm)	
	3D RC MI model	3D RC MI prototype
0	142	548
5	90.5	348.5
10	70.5	272
20	45.7	175.9
30	29.8	114.5
40	18.8	71.8
50	11.1	42.7
60	5.8	22.3
70	2.3	9.3
80	0.3	1.4

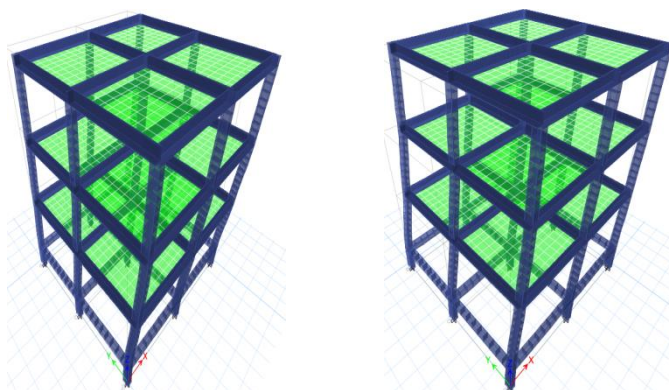


Figure 2. Bare frame model.

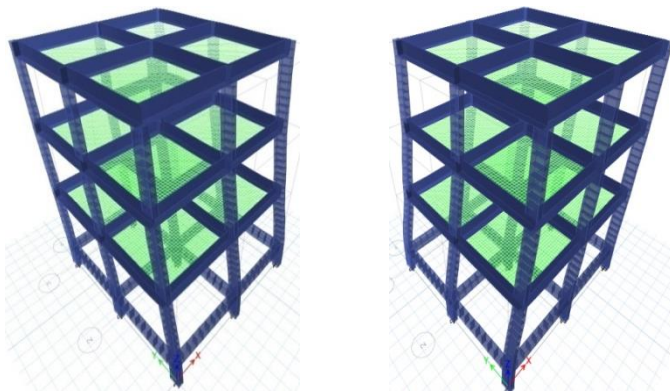


Figure 3. Bare frame prototype.

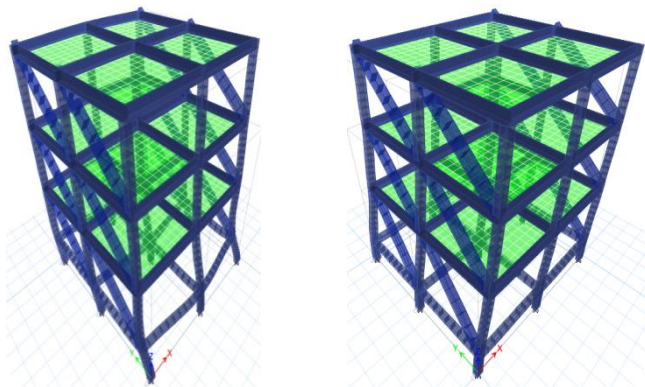


Figure 4. 3D RC MI model without openings.

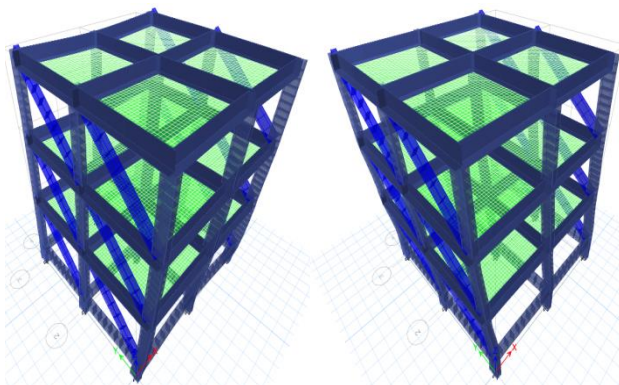


Figure 5. 3D RC MI model without openings.

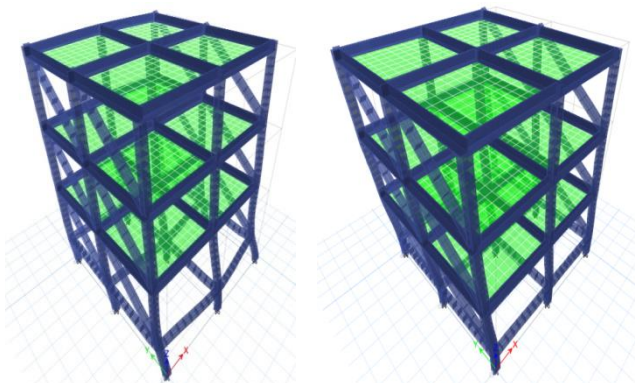


Figure 6. 3D RC MI model with 5% openings.

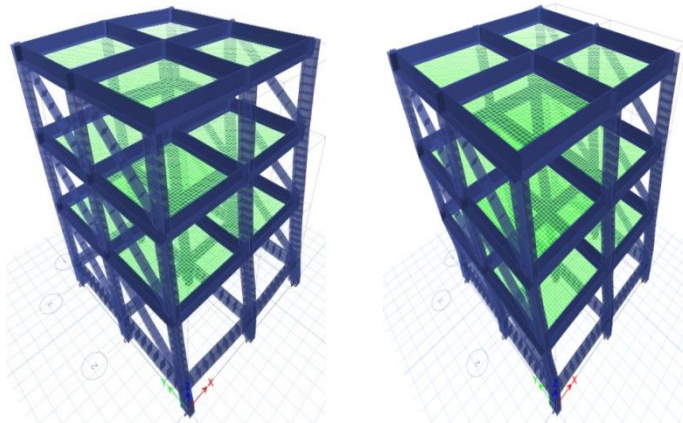


Figure 7. 3D RC MI prototype with 5% openings.

Table 3. Natural frequency (Hz) for both bare frame (Bf) and 3d RC Mi model and prototype frames.

Model		IS 1893:2016 Model	3D RC MI Model	IS 1893:2016 Prototype	3D RC MI Prototype
BF	In-plane	5.71	6.56	2.02	2.75
	Out-of-plane	5.71	5.59	2.02	1.87
3D RC MI	In-plane	5.55	10.45	2.78	5.16
	Out-of-plane	5.71	4.47	2.02	1.68

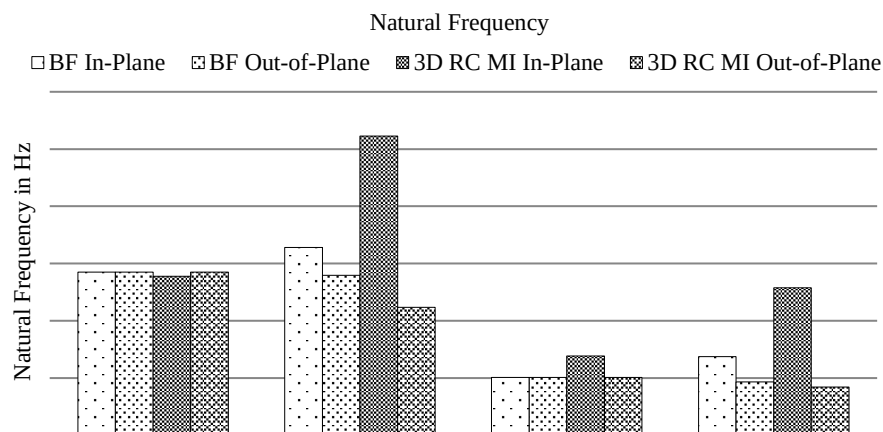


Figure 8. Natural frequency in (Hz) for both bare frame and 3D RC MI model and prototype.

RESULTS AND DISCUSSION

Natural Frequency

Modal Analysis is carried out on the 3D RC MI model and prototype frames with equivalent diagonal strut as per IS 1893 (Part-1): 2016.

Natural frequencies of 3D RC MI model and prototype frames obtained from modal analysis are tabulated in Table 3 in addition natural frequencies obtained from formulation in IS 1893:2016 code and graph are shown in Figure 8.

Natural frequency for only the bare frame model and Prototype results in the out-of-plane direction is matching with IS Code values highlighting the shortfall of IS Code in predicting the same.

In 3D RC MI frame, the natural frequency in in-plane direction is double the out-of-plane direction in both model and prototype showing the prominence of MI in RC frames.

Natural Frequency for Openings

The natural frequency of 3d RC Mi model and prototype frames in the in-plane and Out-of-Plane direction for 0% to 100% openings obtained from the modal analysis are tabulated in Table 4 and graphs are shown in Figure 9 and 10 respectively.

The natural frequency in the in-plane direction decreases as the percentage of openings increases due to reduction in stiffness of MI.

The influence of MI reduces drastically from 80% opening in in-plane direction nullifying the influence of the masonry

The natural frequency in the out-of-plane direction increases as the percentage of openings increases due to decrease in mass of the structure in the in-plane direction.

The natural frequency of the model has to be maintained square root times the scale factor of the natural frequency of the prototype as per scaling laws

Table 4. Natural frequency of 3d RC Mi model and prototype along in-plane and out-of-plane direction

% Openings	In-plane		Out-of-plane	
	<i>Model</i>	<i>Prototype</i>	<i>Model</i>	<i>Prototype</i>
0	10.45	5.16	4.47	1.68
5	9.85	4.61	4.48	1.69
10	9.47	4.42	4.50	1.70
20	8.74	3.98	4.53	1.72
30	7.95	3.66	4.56	1.73
40	7.25	3.36	4.62	1.75
50	7.15	3.11	4.62	1.77
60	6.89	2.92	4.65	1.79
70	6.63	2.79	4.76	1.81
80	6.41	2.71	4.92	1.83
BF	6.56	2.75	5.59	1.87

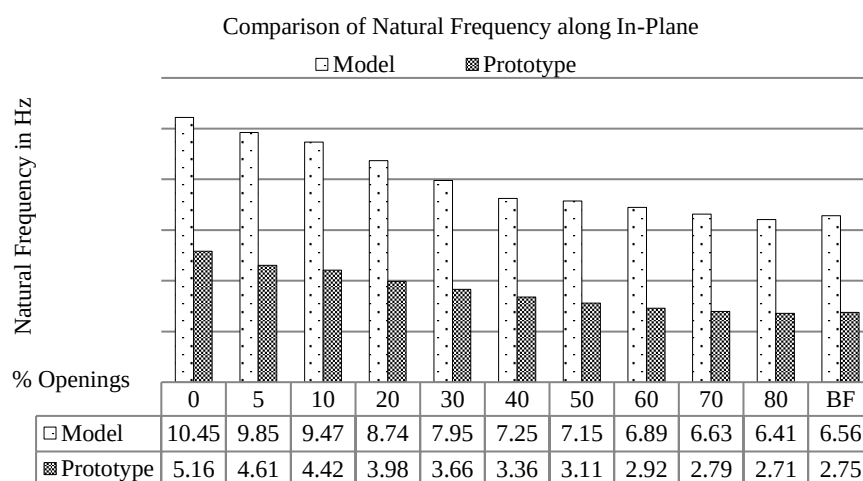


Figure 9. Natural frequency along in-plane direction.

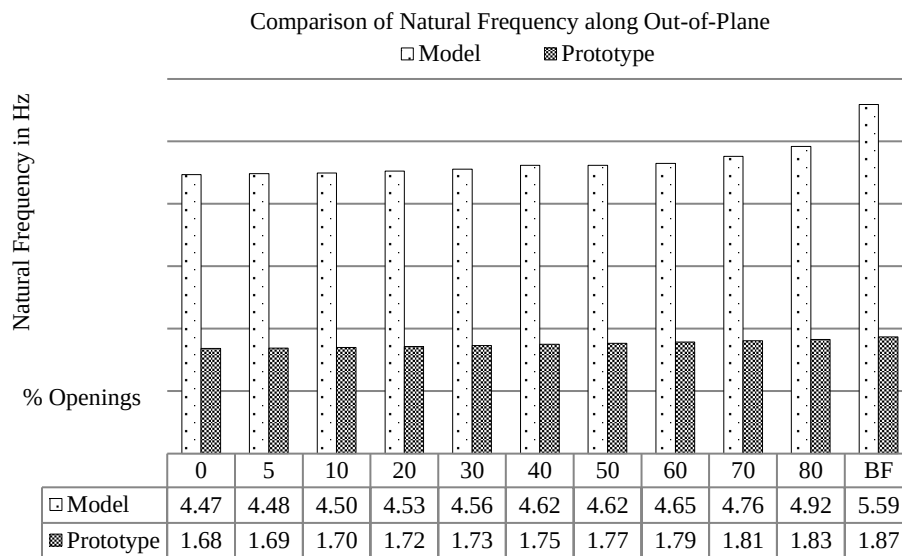


Figure 10. Natural frequency along out-of-plane direction.

CONCLUSIONS

The modal analysis is performed for 3D RC MI model and prototype with equivalent diagonal strut and the following are the major conclusions drawn.

Natural Frequency for only the bare frame model and Prototype results in the out-of-plane direction is matching with IS Code values highlighting the shortfall of IS Code in predicting the same.

In 3D RC MI frame, the natural frequency in in-plane direction is double the out-of-plane direction in both model and prototype showing the prominence of MI in RC frames.

The natural frequency in the in-plane direction decreases as the percentage of openings increases due to reduction in stiffness of MI.

The influence of MI reduces drastically from 80% opening in in-plane direction nullifying the influence of the masonry

The natural frequency in the out-of-plane direction increases as the percentage of openings increases due to decrease in mass of the structure in the in-plane direction.

The natural frequency of the model has to be maintained square root times the scale factor of the natural frequency of the prototype as per scaling laws.

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