Dynamic Analysis of Partially Infilled RC Frames with Openings using Micro Modelling

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Abstract: *Masonry Infills (MI) can induce changes in the dynamic characteristics of RC frames due to its features and connection. In static analysis, the MI are treated as non-structural elements and only the contribution of its mass is considered whereas its structural parameters like strength and stiffness are generally ignored in practice, which leads to an unrealistic design. In this study, contribution of different configurations of partially infilled RC Frames with varying percentage of openings are analyzed. FE Analysis is carried out on partially infilled 2D RC Frames using micro modelling methods namely Gap Element and Link element. Natural frequency obtained from Shake Table tests are considered for validation of modal analysis results. Further the effect of openings provided at centre in partially infilled frames are studiedby varying the size of opening from 0% to 90%. Modal analysis is carried out on these models to obtain natural frequencies followed by Equivalent static and Response spectrum analyses for all the seismic zones as per IS 1893:(Part 1)-2016 to obtain base shear, displacements and storey drifts.*

Keywords:Shake Table, Link Element, Gap Element, Modal, Equivalent static, Response spectrum

1. INTRODUCTION

Structural Engineers have largely ignored the influence of MI when selecting the structural configuration. The design practice of neglecting the infill during the formulation of the mathematical model leads to significantimprecision in predicting the lateral stiffness, strength and ductility. Two types of micro modelling techniques are adopted namely Gap element and Link element. The shake table results of 2D RC frames with partially infilled is considered for the validation of the numerical model. FE analysis is carried out on bare frame and infilled frame with different percentage of openings.

2. BACKGROUND

A review of literature related to Micro modelling of Masonry Infilled RC frame has been carried out. Micro modelling includes two methods namely Gap element and Link element. For Gap element, Stiffness formula given in Dorji J &Thambiratnam D P (2009) has been considered. For Link element, details are considered from Achyutha H et.al (1986). Review on opening positions are contemplated from P G Asteris (2003). For validation of FE models, shake table test results are considered from Chethan K (2009).

3. MICRO MODELLING MEHTODS

3.1 Method I (Gap Element)

A new finite element technique developed by Dorji J (2009) has been used in this study to model the behavior of MI under lateral loads. In the present model the interface between the frame and the infill is provided with the Gap elements which have the capability to transfer the load to the infill masonry as shown in Figure 1.

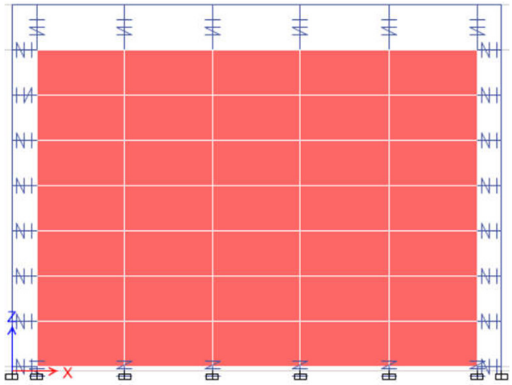

Figure -1: Micro modelling using Gap elements

3.2 Method II (Link Element)

This method proposed by Achyutha et.al (1986), is a simpler iterative finite element method of analysis of MI taking into consideration all the factors at the interface of infill and frame. The node connecting the infill is made of structural hinge so that no moment is transferred from the link elements to the infill as shown in Figure 2.

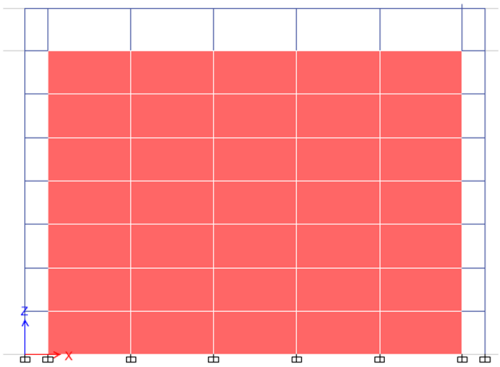

Figure -2: Micro modelling using Link elements

4. OBJECTIVES OF THE WORK

The following are main objectives,

- To study the micro modelling technique that can be incorporated in Finite Element analysis effectively to analyse the structural behaviour of partially infilled frames with openings.
- To validate the FE models by using the Natural frequency obtained from Shake Table test reported in the literature.
- FE Analysis involving Modal, Equivalent Static and Response Spectrum Analyses on various configurations of partially infilled 2D RC frames with openings.

5. METHODOLOGY

The methodology includes;

- Exploring literature on micro modelling techniques on 2D RC infilled Frames
- Two methods in micro modelling are adopted namely Gap Element and Link Element to perform FE analysis on partially Infilled 2D RC frames with openings
- The validation of the FE models is done using Natural frequency obtained from Shake table test carried out on 2D RC frame models with different configuration of MI at Earthquake Engineering and Vibration Research Centre (EVRC), CPRI, Bangalore
- The modal analysis on 2D RC infilled frames with openings at center of infill varying from 0% to 90% are carried out to get the Natural frequencies and mode shapes for the two types of micro modelling techniques.
- Equivalent Static and Response Spectrum analyses are carried out on all the models for all the seismic zones as per IS 1893(Part-1): 2016 to obtain base shear, displacement and storey drift.

6. 2D RC MODELS CONSIDER FOR ANALYSIS

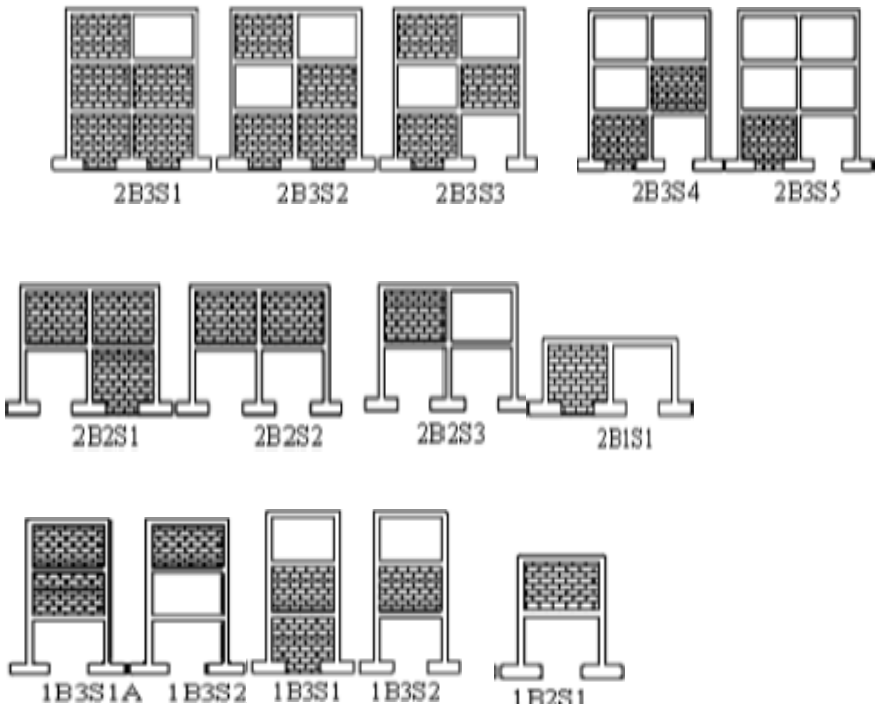

Figure-3: 2D RC Partially infilled frame

The models shown in the Figure 3 are considered for the analysis. Material and sectional properties are tabulated Table 1 and Table 2 respectively

Table -1: Material Properties

Properties	Beam link / ColumnLink	Masonry	M25
Density	1 x 10^{-5}kN/m^3	19.2 kN/m^3	25 kN/m^3
Modulus of Elasticity	534 N/mm^2	14000N/mm^2	25000 N/ mm^2

Table -2: Sectional Properties

Type of structure	2D RC Frame
No. of storeys	1 to 3
No. of bays	1 to 2
Storey height (mm)	900
Bay width (mm)	1200
Beam (mm)	75 x 100
Column (mm)	75 x 100
Infill Thickness (mm)	75

7. FE ANALYSIS

FE Analysis is carried out on 2D RC Partially Infilled Frames with openings at Centre, using Gap and Link element method. FE analysis involving modal, equivalent static and response spectrum analyses are performed and the results of natural frequencies, displacements and storey drifts are tabulated and discussed.

8. MODAL ANALYSIS

Natural Frequency obtained from shake table test for all the models of 2D RC frames with MI including Bare frames and frequency calculated as per IS 1893-2016(part 1) are compared with natural frequency obtained from Modal Analysis adoptingmicro modelling methods i.e Gap Element and Link Element as shown in Table 3 and Figure 4.

Table -3: Natural Frequency (Hz) from Shake Table Test, IS 1893-2016 (Part 1), Gap and Link Element

2D RC Frames	Shake TableTest	IS 1893-2016	Gap Element	Link Element
1B2S1	16.50	6.76	19.677	20.79
1B3S1	34.00	4.50	32.45	29.04
1B3S2	20.75	4.50	17.95	17.67
1B3S1A	12.75	4.50	13.64	14.58
1B3S2A	11.25	4.50	10.78	11.15
2B1S1	**	19.12	97.07	85.08
2B2S1	35.00	9.56	36.25	36.69
2B2S2	15.00	9.56	15.36	18.49
2B2S3	15.50	9.56	16.39	20.8
2B3S1	36.00	6.37	32.04	30
2B3S2	30.00	6.37	30.35	26.98
2B3S3	26.25	6.37	26.75	24.23
2B3S4	25.75	6.37	24.36	25.65
2B3S5	19.25	6.37	17.13	18.27

Note - ** Denotes that shake table test result are not available for that model

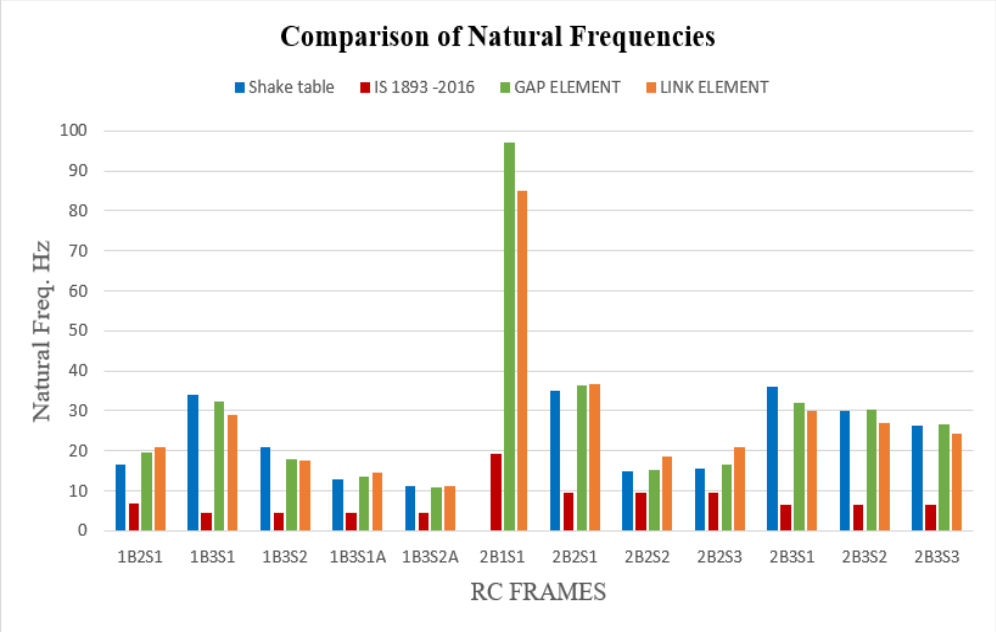

Figure -4: Comparison of Natural frequencies

- Natural Frequency obtained from IS 1893-2016 (part I) code does not match with the Frequency obtained from Shake Table test and Modal analysis results for Gap and Link Element highlighting the shortfall of IS code.
- Frequency from Micro modelling method i.e Gap and Link element method closely matches with the shake table test results; hence these two methods can be effectively adopted for FE analysis of partially infilled RC Frames.
- Natural Frequency will be same irrespective the Number of bays for all the 2D MI RC frames.

Modal analysis is carried out on all the 2D RC Frames with MI using micro modelling methods i.e Gap and Link element with openings at centreand increasing the percentage of opening from 0 to 90% including Bare frames. The results of Natural frequencies are tabulated in the Table 4 and Table 5.

Table4: Natural Frequency (Hz) with centre opening using lo Gap element

% opening	0	5	10	20	30	40	50	60	70	80	90
1B2S1	19.68	19.92	21.34	21.89	22.30	22.40	22.15	21.52	21.18	25.07	22.94
1B3S1	32.46	32.20	31.77	30.63	28.55	25.40	21.52	18.39	15.70	14.63	14.88
1B3S2	17.95	18.08	18.20	18.37	18.33	17.89	16.99	15.94	14.79	14.34	14.72
1B3S1A	13.64	13.92	14.14	14.39	14.54	14.21	13.80	13.11	12.80	13.01	14.10
1B3S2A	10.79	7.99	8.10	8.34	8.58	8.80	9.01	9.18	9.37	9.64	10.34
2B1S1	97.07	95.55	93.67	86.49	76.48	65.62	55.30	48.92	45.33	43.10	44.72
2B2S1	36.25	36.13	36.06	35.08	32.93	29.77	26.05	23.11	20.97	20.41	21.46
2B2S2	15.36	18.55	18.83	19.42	19.96	20.36	20.49	20.33	20.03	20.20	21.47
2B2S3	16.39	21.42	21.64	22.03	22.28	22.31	21.99	21.50	21.09	21.17	21.89
2B3S1	32.04	31.65	31.51	30.43	28.24	24.67	20.79	17.25	14.85	13.77	13.96
2B3S2	30.35	29.98	29.75	28.63	26.47	23.13	19.68	16.66	14.73	13.88	14.05
2B3S3	26.75	26.36	26.21	25.25	23.48	20.75	17.98	15.61	14.20	13.70	14.03
2B3S4	24.36	27.56	27.30	26.26	24.68	22.00	19.24	16.79	15.17	14.41	14.28
2B3S5	17.13	18.71	18.65	18.43	18.07	17.43	16.63	15.73	15.00	14.57	14.38

Table 5: Natural Frequency (Hz) with Centre Opening using Link Element

% opening	0	5	10	20	30	40	50	60	70	80	90
1B2S1	20.79	21.07	21.36	21.94	22.41	22.70	22.92	22.42	21.63	21.49	22.35
1B3S1	29.04	32.20	31.77	30.63	28.55	25.40	21.52	18.39	15.70	14.63	14.88
1B3S2	17.68	17.79	17.91	18.13	18.13	17.74	16.45	15.52	14.68	14.35	14.45
1B3S1A	14.58	13.77	13.95	14.35	14.54	14.28	14.44	13.75	13.21	13.23	14.03
1B3S2A	11.15	11.32	11.46	11.84	12.13	12.48	12.61	12.76	12.99	13.38	14.18
2B1S1	85.09	84.11	83.16	80.22	75.40	68.29	59.50	53.21	46.33	45.29	43.42
2B2S1	36.69	36.69	36.69	36.23	34.73	32.00	29.73	25.73	22.22	20.88	21.65
2B2S2	18.49	19.32	19.60	20.19	20.72	21.06	21.51	21.23	20.58	20.47	21.63
2B2S3	20.80	21.94	22.14	22.52	22.76	22.72	22.75	22.12	21.42	21.32	21.97
2B3S1	30.00	29.90	29.87	29.34	27.80	24.82	21.55	19.14	15.59	14.11	14.29
2B3S2	26.98	26.90	26.88	26.48	25.20	22.70	20.03	18.11	15.33	14.19	14.33
2B3S3	24.23	24.17	24.16	23.83	22.75	20.68	18.45	16.88	14.70	13.96	14.31
2B3S4	25.65	25.47	25.32	24.75	23.69	21.72	19.57	17.88	15.58	14.61	14.44
2B3S5	18.27	18.22	18.18	18.04	17.79	17.37	16.81	16.23	15.26	14.73	14.48

- As the percentage of opening increases the Natural frequency varies due to reduction in stiffness, highlighting the influence of MI.
- The Natural Frequency obtained for all the 2D RC Infilled Frames with openings using Gap Element closely matches with the natural frequency obtained using Link Element. Hence the link element can be effectively used for the analysis of 2D RC MI frames in any FE software where Gap element is not available.
- The influence of MI reduces drastically at 80% opening as the variation in Natural frequency is minimal.

9. STOREY DISPLACEMENT

The Response spectra for the different seismic zones as specified by the IS 1893(part 1):2016 are applied on 2D RC partially infilled frames for all the seismic zones. The Displacements and Storey Drifts obtained for 2B3S3 model from the Response Spectrum Analysis for Zone V and soft soil condition is tabulated Table 6 and plotted in the Figure 5.

Table-4: Storey Displacement (mm) for response spectrum analysis

% of Opening	Gap Element	Link Element
0%	0.058	0.062
5%	0.060	0.065
10%	0.062	0.068
20%	0.065	0.069
30%	0.072	0.074
40%	0.086	0.088
50%	0.116	0.109
60%	0.130	0.126
70%	0.172	0.165
80%	0.179	0.180
90%	0.180	0.181

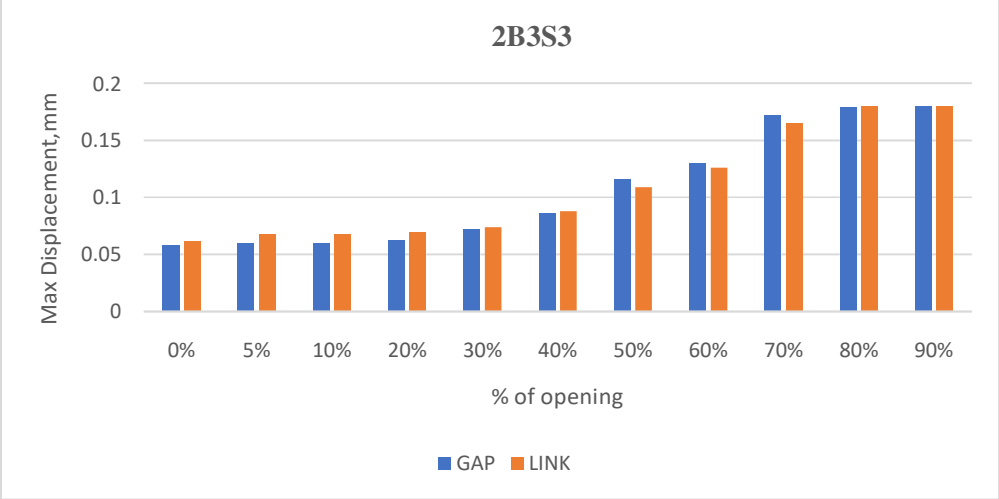

Figure -5: Displacement (mm) of 2B3S3 Frame with openings

- As the percentage of opening increases, the displacement increases due to the reduction in stiffness of the frames.
- It is observed that there is not much variation in displacement after 80% of opening indicating that influence of MI nullifies from 80% opening.

8. STOREY DRIFT

Storey Drift is the lateral displacement of one level relative to the level above or below. The storey drift can be calculated by relative difference of design displacement between the top and bottom of a storey divided by the storey height. Storey drift of 1B3S1 for Zone V and soft soil condition is tabulated in the Table 6 and plotted in the Figure6.

Table-6: Storey drift of 1B3S1 with openings using Gap Element Method. (10^{-4})

% opening	Base	Storey 1	Storey 2	Storey 3
0	0	0.12	0.11	0.53
5	0	0.14	0.13	0.53
10	0	0.16	0.13	0.53
20	0	0.17	0.16	0.52
30	0	0.2	0.19	0.51
40	0	0.26	0.27	0.5
50	0	0.37	0.39	0.72
60	0	0.49	0.57	0.91
70	0	0.64	0.79	0.72
80	0	0.71	0.89	0.37
90	0	0.63	0.82	0.51

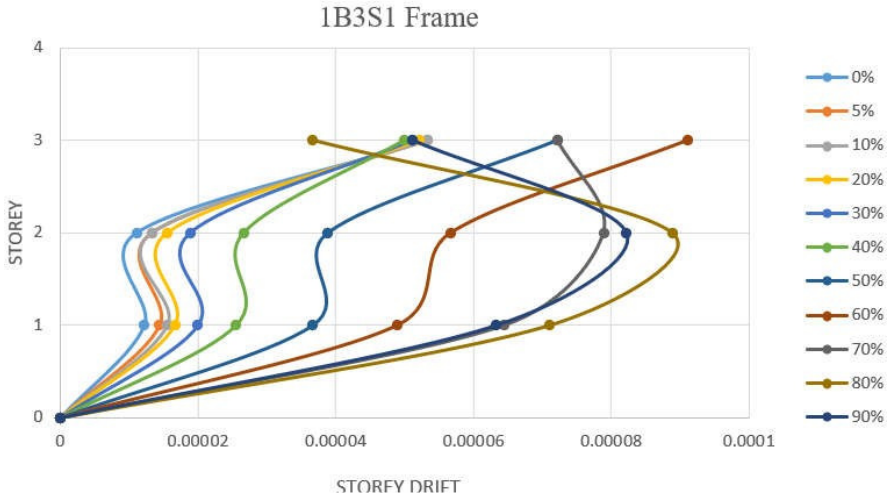

Figure - 6: Storey drift of 1B3S1 Frame with openings

- The storey drift is max at height h/2 from 70 % to 90% of opening and storey drift at 90% is same as bare frame.
- The storey drift is Maximum at the height h/2 from 0 % to 60 % of the partially infilled 2D RC models.
- It is observed that for all the cases of openings in 2D RC partially infilled frames the storey drift is within the permissible limit of 0.004h (h is storey height) as per IS 1893(Part I) – 2016.

9. CONCLUSIONS

1. Natural Frequency obtained from IS 1893-2016 (Part I) code does not match with the Frequency obtained from Shake Table test and Modal analysis results for Gap and Link elements highlighting the shortfall of IS code.
2. The reduction in the natural frequency is more, when the infill is removed in the lower floor as compared to the removal of infill in the upper floors.
3. Similarly, there is an increase in the natural frequency when the infill is removed from the upper floors as observed from 1B3S2A & 1B3S and 1B2S1 & 1B2S highlighting the contribution of infill mass being more in the upper floors as compared to the lower floors.
4. As the percentage of opening increases, the displacement increases due to the reduction in stiffness of the frames.
5. It is observed that there is not much variation in displacement after 80% of opening indicating that influence of MI nullifies from 80% opening.
6. Frequency from Micro modelling method i.e. Gap and Link element method closely matches with the shake table test results hence these two methods can be effectively adopted for FE analysis of partially infilled RC Frames with openings.

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