Experimental Validation of a One-Strut Model (OSM) for Infilled RC Concrete Frames

T.C. Nwofor

Department of Civil Engineering, University of Port Harcourt, P.M.B 5323 Port Harcourt, Rivers State, Nigeria

Abstract

In this study, the area of a diagonal strut used to replace the infill panel and also simulates the effects of the opening sizes in the infill panel using the one-strut model (OSM) for macro-modeling infill frames developed by the author in previous research is validated with an experimental approach where typical one bay one storey test frames were constructed and tested to obtain the load - displacement profiles. The results show that the macro-modeling technique, which makes use of a modified one-strut model used to replace the infilled panel gave lateral displacements results which when compared with two other models gave a close correlation with a calculated average error between the test frame and the one-strut models as 5.5% while an average error of 3.97% was achieved when we compare the results from the FE and one-strut structural models. Hence, there was close agreement between the outputs of the proposed one-strut model and the test models used for validation.

Keywords: *Experimental validation, one-strut model, test model, finite element model, lateral displacement.*

I. INTRODUCTION

It is very important now to study the influence of openings on the composite behavior of infilled frames and this has led to development of complex models with which the one-strut model (OSM) seems to be the simplest (Asteris and Tzamtzis, 2002; Syrmakezis and Asteris, 2001; Nwofor, 2011, Nwofor, 2012; Nwofor and Chinwah, 2012). An experimental study in which all these factors could be taken into account is difficult to implement for obvious reasons (Giannakas et al., 1987; Saneinejad and Hobbs, 1995; El-Dakhakkni, 2003; Asteris, 2003; Crisafulli and Carr, 2007). Thus, in most cases the use of finite element approach has been considered a most viable option in spite of its computational complexities and resource requirements. However, the major challenges in the development of the OSM is in deciding the value of the width of the equivalent strut on the one side and how to account for the effect of openings on the other. These problems were effectively addressed and resolved by the author in an earlier publication (Ephraim and Nwofor, 2015).

In this work, a single diagonal strut model, capable of predicting the shear strength of infilled frames with openings is validated based on structural modeling theory and experimental techniques.The main aim of this study was to obtain experimental data for the validation of the one- strut model proposed in earlier research by the author. The brick masonry infill panel consisted of different levels of openings ranging from fully in filled frame and bare frame configurations. The effects of opening sizes or solidity ratio on the strength, stiffness and drift of the infilled sway frames under load were investigated and the outputs compared with values established earlier based on the numerical analysis of one-strut and finite element models.

II. THEORETICAL FORMULATION

The application of the OSM encompasses the introduction of the width of the equivalent diagonal strut, expressed through the shear strength reduction factor (λ) and the solidity (β) ratio.

A. *Modified Area of Equivalent Strut*

In order to modify the equivalent diagonal area to account for openings, equation (1) , previously obtained by the author (Ephraim and Nwofor, 2015a,b) through regressional analysis relating the shear strength reduction factor (λ_m) to the opening area ratio (β) was adopted

$$\lambda_m = e^{0.06\beta} \qquad (1)$$

The equation was used to modify the area of the diagonal strut as follows

$$A_m = A\left(e^{0.06\beta}\right) \qquad (2)$$

B. *Analysis of the One-strut Model*

Once the geometric and material properties of the strut were calculated, the analysis of the infill frames was carried out using the stiffness matrix method in which the diagonal strut used to replace the infill frame was modeled as a pin-jointed bar element while the frame members were modeled as rigid jointed members. The typical infilled frame and the simplified diagonal strut model is shown in Figure 1, was analysed using STAAD. Pro computer software which is very efficient for analysis of this of skeletal structures of this nature.

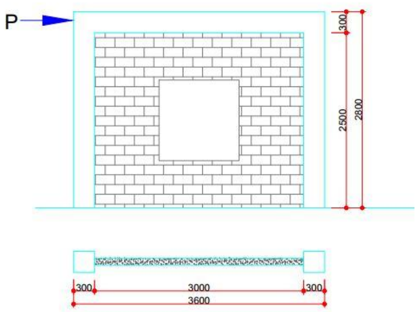


Figure 1: A Typical Infill and One-Strut Model under Consideration

C. The Finite Element Model

The main purpose of this analysis was to study the overall behavior of the structure and investigate the effect of infill walls on lateral load response of the structure. In order to advance the comparison with another reliable model, the FE micro model was executed using SAP 2000 version 8, a sophisticated software package for finite element modeling with capacity to model infill openings. Minor details that do not significantly affect the analysis were deliberately left out from the models for ease of analysis.

The results of the analysis by one-strut and finite element models for the various frames are presented in the Results section of this paper.

III. EXPERIMENTAL PROCEDURE

The experimental procedure consisted of testing single-bay, single-storey reinforced concrete frames infilled with one-quarter scale brick masonry at the Structural Engineering Laboratory of the Rivers State University of Science and Technology, Port Harcourt, Nigeria.

To obtain the appropriate loading for the models, the theory of dimensional analysis that involves incorporating the similitude requirements was employed in the experimentation in order determine the prediction and operating dimensionless parameters for modeling the real prototype behavior(Sabnis et al., 1983; Ephraim, 1999) of an infill wall depends on the magnitude of the racky loadQ, span L, thickness t, the modulus of elasticity E and Poisson's ratio ν,

Assuming the same material in prototype and model and neglecting Poisson's ratio distortion, the model load is

$$Q_M = Q_P / S_L^2 \quad (3)$$

Where S_L is the linear scale factor equal to 4 for 1:4 scale model adopted in this investigation. Therefore, the loading profile up to failure load obtained from the prototype that was analyzed using the proposed one-strut model would be divided by the square of the linear scale factor.

A. Model Materials Characteristics E, ν

The basic mechanical properties of masonry were obtained by tests carried out on masonry units. These mechanical properties are basic input parameters for the finite element micro and macro modeling of masonry infilled frame structure.

The mechanical strain gage was used during the experimentation which is limited to static measurement of strain, since its size and inertia rule out any reasonable frequency response, which is required in dynamic applications. The main disadvantage of this gage is the potential error induced when the gage is repositioned on structure for each strain reading. The error was minimized by having the operator that reads the gage develop a consistent technique. By measuring the compression load and the strains ε_y and ε_x, the values of modulus of elasticity (E) and Poissons ratio (ν) were obtained through the following basic relationships.

$$E = \frac{\sigma_y}{\varepsilon_x} \quad (4)$$

$$\nu = \frac{\varepsilon_x}{\varepsilon_y} \quad (5)$$

B. Test Set-up and Procedure

The main aim of the experimental program on the single bay, single storey infilled frame reinforced concrete frames with openings was to obtain a load displacement profile for each specimen in order to validate results from the FE micro model and the modified one-strut model considered in this study. Hence dial gauges (EL83-546, 25mm ravel x 0.01mm divisions) were acquired to measure the displacement profile as a result of the lateral in-plane loading. The general test set-up is shown in the Appendix. The lateral load was applied by a hydraulic jack at the level of the horizontal axis of the beam.

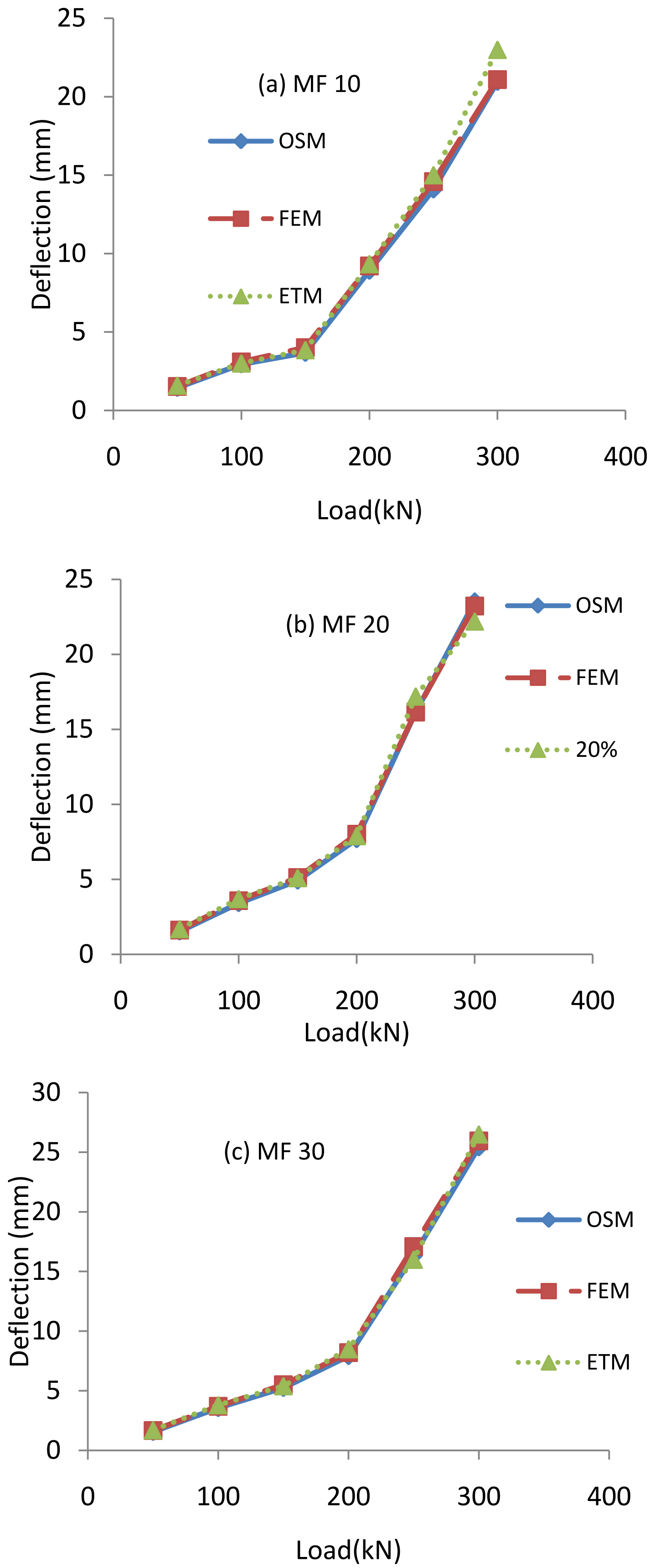
IV. RESULTS

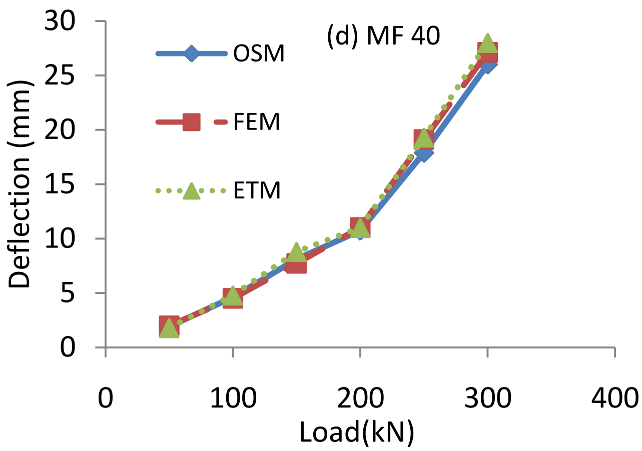
The extrapolated values to reflect the true prototype frames based on the similitude requirement established in the study is presented in Table 1. The comparative analysis of the experimental results with those from numerical analyses is shownwith graphical plots in Figure 2.

Table 1: Predicted (Extrapolated) Values of Deflection of the Prototype Frames

Model Loads (KN)	Model lateral Displacements (mm) MF 10	MF 20	MF 30	MF 40	MF 50
50	1.60	1.70	1.70	1.80	3.10
100	3.01	3.70	3.80	4.80	6.00
150	3.86	5.10	5.40	8.80	8.30
200	9.34	7.90	8.50	11.00	11.50
250	15.01	17.20	16.00	19.30	23.00
300	23.00	22.20	26.50	28.00	36.00

From Figure 2, it can be seen that lateral displacements from the three different models gave a close correlation with a calculated average error between the test frame and the one-strut models as 5.5% while an average error of 3.97% was achieved when we compare the results from the finite element model (FEM) and one-strut model (OSM)structural models. Hence, there was close agreement between the outputs of the proposed modified one-strut model and the experimentaltest models (ETM) used for validation, similar to the trend obtained in previous research (Ephraim and Nwofor, 2015a), underscoring the adequacy of the proposed model to reproduce the response of infill frames including those with openings.





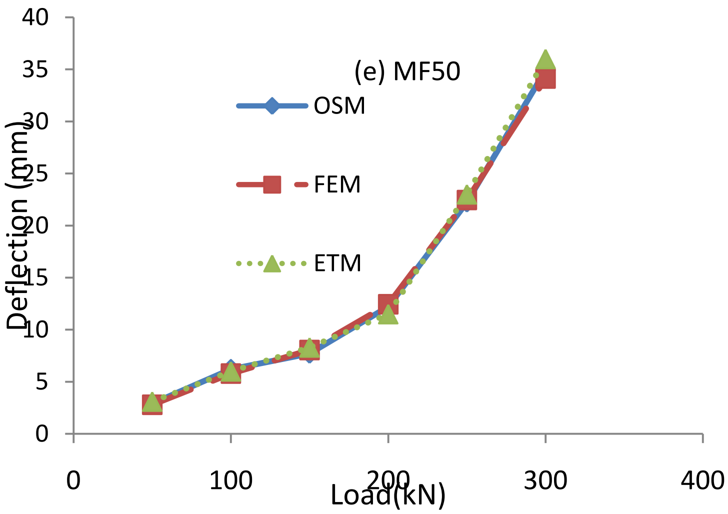


Figure 2:Variation of Deflection of Infilled Frames with Opening Ratio for Various Values of Applied Racky Load.

V. CONCLUSION

The following specific conclusion can be drawn, which are similar and compare favorably to previous research (Ephraim and Nwofor, 2015a).

1. The result obtained for lateral deflection in the test frame indicates that increase in opening generally leads to reduction of the lateral stiffness of the infill frame.
2. The shear strength reduction factor which varies exponentially with the opening ratio in the form $\lambda_m = e^{0.06\beta}$ has been further validated through the experimental test in this research.
3. A unique range of deflection 8-12.5; 13-23 and 21-32.5mm for load cases 200, 250 and 300 kN respectively was observed where the value for increasing lateral deflection was relatively gentle, however the lateral deflection obtained from the experimental test frames generally increased from gentle to rapid growth beyond 200 KN load.

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APPENDIX

Plate 1: Test Set-up and Instrumentation