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Cyclic Numerical Modeling of Confined Masonry Walls Using Equivalent Strut Model

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ABSTRACT: Confined masonry walls (CMWs) are generally used as a suitable type of lateral force resisting systems in earthquake prone regions. The RC confining members (tie-beams) in such walls are mainly used to provide integrity and increase the ductility of masonry buildings. Considering the inherent complexities of the structural behavior of masonry materials and interaction between tie-beams and walls, modeling and analysis of CMWs is one of the challenging problems in the analysis of buildings under lateral loads. Among the building analysis methods, macro-modeling methods have always been considered by researchers due to their proper accuracy and efficiency. The purpose of this study is to modify and verify a suitable macro-model based on the equivalent strut model (Crisafulli infill model) for the cyclic analysis of CMWs. To this end, first, by comparing the behavior of CMWs with infilled frames and identifying their similarities and differences and using the relationships available in the literature, the specifications and parameters of this model are modified for CMWs (with and without openings) as well as CMWs with interior tie-beams. Then, based on the available experimental results of several CMWs and a 3D confined masonry building, the accuracy of the equivalent strut-based model in estimating the lateral stiffness and shear capacity of the specimens is discussed. The results show that it is possible to predict reasonably the overall response of CMWs by the modified equivalent strut model.

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1- Introduction

In masonry buildings, structural walls are generally classified into three categories: unreinforced, confined and reinforced. A typical confined masonry wall consists of a masonry panel and reinforced concrete horizontal and vertical elements. In the construction of a confined masonry wall, first the masonry panels are constructed and then the vertical and horizontal ties are cast in place. The number of longitudinal rebars of the ties don't need to be calculated and their selection is based on the recommendations of the code regulations. Based on the laboratory researches on confined masonry walls [1], the mechanisms of in-plane failure of masonry panels and ties in a confined masonry wall can be generally divided into two categories of panel failures (including flexural failure, sliding shear failure and diagonal failure) and tie failures (including compressive, tensile and shear failures). Based on the laboratory response of confined masonry wall cases, researchers have proposed various behavioral models to simulate and predict their seismic behavior, most of which are presented as multilinear lateral load capacity curves. Recently, an extensive study [1] has been conducted on the conventional confined masonry walls in Iran and a comprehensive behavioral model has been proposed for their analysis. As it can be seen, the analytical models are used to analyze single confined masonry walls under lateral load and cannot be used directly for the nonlinear analysis of confined masonry buildings. During the last decades, due to the gradual change in the approach of some seismic design codes from traditional force-based design methods to performance-based design methods and displacement-based methods, attention to the nonlinear static or dynamic analysis methods of structures has become more essential. Among these, due to the inherent complexity of the behavior of masonry structures, their nonlinear analysis is of particular importance. In the field of nonlinear analysis of confined masonry walls, so far a simple and comprehensive model with sufficient accuracy for macro modeling and analysis of such structures under cyclic loads has not been presented. However, the equivalent strut method has been reviewed by several researchers and it has been observed that it is possible to use this approach to analyze the overall response of the confined masonry walls [2-5]. In this study, by comparing the behavior of confined walls with infilled frames and identifying their similarities and differences, one of the existing methods of infill cyclic static analysis (the Crisafulli multi-strut method [2]) is modified and suggested

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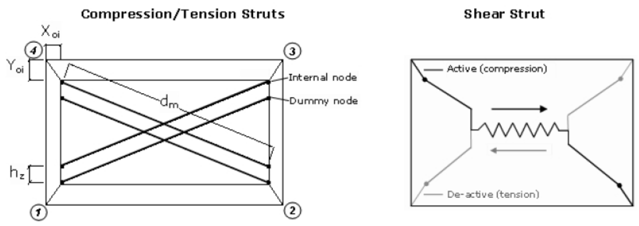

Fig. 1. Infill element struts configuration in Seismo-Struct Software [2016] [7]

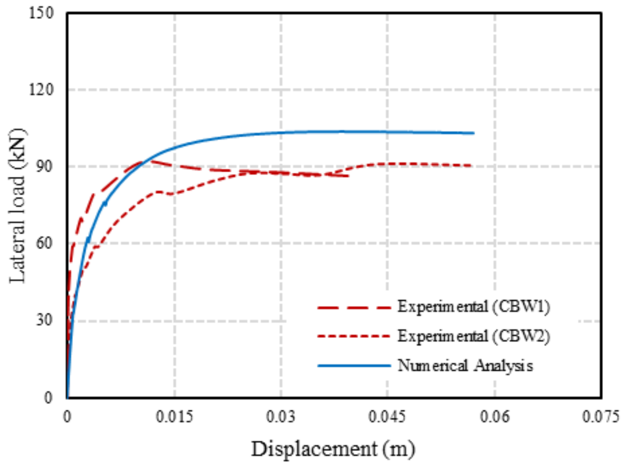

Fig. 2. Comparison of laboratory capacity curves and numerical analysis results for CBW1 and CBW2

to analyze the confined masonry walls with and without openings as well as the confined masonry walls with middle ties around openings. Following, the details of this method are introduced under the title of equivalent strut and how to estimate and modify its parameters and finally, the accuracy of the modified model is discussed with the results of some experiments performed on confined masonry walls with and without openings, as well as a three-dimensional confined masonry building.

2- Methodology

The confined masonry wall system can be considered as a masonry infilled frame with weak surrounding concrete ties, provided that the specific panel and ties failure mechanisms are well predicted and applied in the equivalent strut numerical model. The Crisafulli equivalent strut model [2] has been implemented by Blandon [6] in SeismoStruct software [7] for behavioral modeling of masonry infills. The purpose of this research is to develop and validate the macro model method based on the equivalent strut model of Crisafulli for the nonlinear analysis of confined masonry walls, in such a way that the effect of the presence of the opening and its surrounding ties in the numerical modeling of the masonry wall, as well as the middle ties in the masonry walls, can be considered. In the Crisafulli model, as shown in Figure 1, four-node infill elements are used to model the compressive behavior of the masonry wall. In this model, each masonry wall panel consists of six main elements; four compression struts and two shear springs. When loading, a pair of parallel compression diagonal struts with a shear spring are activated in the direction in which the load is applied. In the model developed herein for the confined masonry system, the shear springs are eliminated and therefore, the strength and stiffness of the system depend only on the limited compressive strength of the diagonal struts.

3- Results and Discussion

In order to have comprehensive numerical modeling, in addition to validating the method for the analysis of solid confined masonry walls, this process should be utilized for confined masonry walls with openings. In the first step, it is tried to model the confined brick walls tested in Iran. The samples are two specimens of similar solid confined brick walls CBW1 and CBW2, which have been tested by Tasnimi [8] in the laboratory under a quasi-static (cyclic) lateral loading and the results are available to us. Then, the adopted modeling is also utilized for the analysis of some other confined solid brick walls and with openings tested abroad. These numerically examined laboratory samples are as follows:

- A confined clay brick wall with window opening (CLY P W), a confined clay brick wall with door opening (CLY P D) and a solid confined clay brick wall (CLY S CTRL) under gravity and lateral loading tested by El-Diasiti et al. [9];
- Two specimens of confined brick walls with horizontal and vertical ties surrounding the opening (with middle ties) under lateral cyclic load and permanent gravity load were tested by Singal and Ray [10].

Finally, based on the laboratory response of a specimen of confined brick buildings tested in Iran, the validity of this method for numerical modeling of confined masonry buildings is also investigated. This specimen has one room on each floor which has been tested on a scale of 1:2 by Hajesmaeili [11] under cyclic lateral loading.

Then, in order to evaluate the numerical modeling method, the capacity and hysteresis curves obtained from numerical modeling and the existing laboratory response of these two cases are compared with each other in Figures 2 and 3. The capacity ratio of the numerical model to the average laboratory capacity of the two cases in Figure 2 is 1.14. Furthermore, the experimental and numerical hysteresis

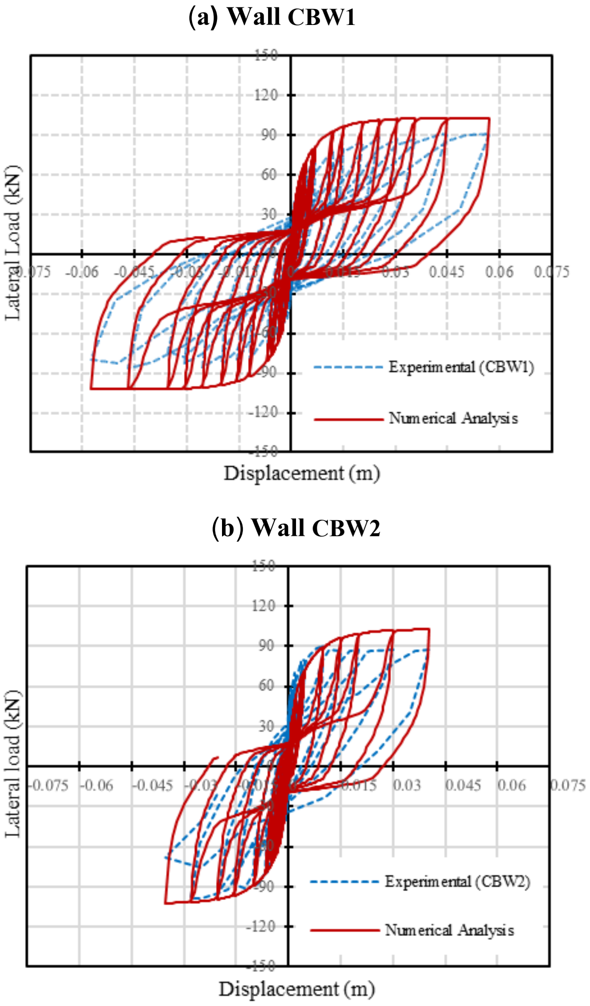

Fig. 3. Comparison of laboratory hysteresis curves and numerical analysis results for CBW1 and CBW2

curves of the specimens are shown in Figure 3 which indicate a relatively good correlation between them.

4- Conclusions

In this study, by reviewing the macro methods and models presented in the literature in the field of analysis of masonry structures and infilled frames, and considering the behavioral similarity of confined masonry walls and infills in concrete frames, the Crisafulli infill macro model was selected. Investigation of laboratory results performed on confined masonry walls shows that among the failure modes of masonry infill panels, often only two modes of failure of diagonal sliding shear and diagonal tension occur in such walls. Therefore, using the existing relationships for confined masonry walls, the specifications and parameters of the considered macro model method, which is equivalent strut method, were modified and investigated to analyze confined masonry walls (with and without openings) as well as the confined walls with middle ties around the openings. The results of the analysis of the walls and the three-dimensional confined building show that the Crisafulli model with the proposed modifications in this research, is able to predict the overall behavior of the cases studied in this research. The ratio of the capacity of the numerical model to the laboratory capacity in the considered specimens varies between 0.86 to 1.14. Due to the complexity of confined masonry walls behavior, this ratio is considered to be a relatively good accuracy for a simplified macro model. In the case of confined walls with openings, it was observed that reducing the initial strength and stiffness of confined masonry panels due to the existence of openings using the relation proposed by Alchar is a suitable and simple approach to predict the overall response of confined masonry walls with openings. Finally, it seems that the use of the equivalent strut macro model method modified in this study can be suitable for the rapid cyclic static analysis of walls of confined masonry structures that requires a trade-off between accuracy and efficiency, as well as performance-based seismic design applications. However, in order to increase the accuracy of the method used, the values of the selected parameters should be examined and corrected with the help of more laboratory test results and more comprehensive statistical methods.

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