Evaluation of Existing Equivalent Diagonal Strut Relationships for Masonry Infill Walls in Modeling Concrete Sandwich Panel Infills

Sajjad Bagheri[1], Mahdi Yazdani[2*], Seyed Jafar Hashemi[3]

[1, 2, 3] Department of Civil Engineering, Faculty of Engineering, Arak University, Arak, Iran

ABSTRACT

With the publication of the fifth edition of the Iranian Seismic Design Code (Standard No. 2800) and the introduction of specific provisions for modeling masonry infill walls based on the equivalent diagonal strut approach, evaluating the applicability of this approach to emerging systems, such as concrete sandwich panel (CSP) infill walls, has gained considerable importance. In the present study, the effective width of the equivalent diagonal strut was first determined for 32 concrete sandwich panel-infilled steel frame (CSP-ISF) specimens using experimental results and finite element simulations through an inverse analysis approach based on the equivalence of initial lateral stiffness. Subsequently, the relationship adopted in the fifth edition of Standard No. 2800, together with ten other widely used formulations for estimating the effective width of the equivalent diagonal strut, was statistically evaluated. The results indicated that, although the formulation adopted by Standard No. 2800 provides a more accurate estimation of the initial lateral stiffness of these systems compared with the other available relationships, it is still associated with considerable prediction errors. Therefore, the investigated relationships were re-evaluated after applying constant correction factors to improve their predictive accuracy. The results showed that the Durrani and Luo relationship, after applying a constant correction factor of 0.738, achieved the highest predictive accuracy among the modified relationships for the investigated database, with a mean absolute error and a maximum absolute error of 14% and 55%, respectively. Nevertheless, the remaining prediction errors highlight the need for developing dedicated relationships for CSP infill walls.

KEYWORDS

Infilled frame, Equivalent diagonal strut, Concrete sandwich panel, Statistical analysis, Inverse problem.

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* Corresponding Author: Email: m-yazdani@araku.ac.ir

1. Introduction

Although generally regarded as nonstructural components, infill walls can substantially increase the lateral stiffness and strength of building frames, thereby significantly affecting their seismic response [1-3]. Therefore, accounting for the contribution of infill walls in structural analysis can lead to more accurate predictions of structural response. In recent years, CSP infill walls have attracted increasing attention due to their rapid construction, consistent quality, and favorable thermal and acoustic performance [1].

The fifth edition of Standard No. 2800 provides codified provisions for incorporating the effects of masonry infill walls in structural analysis through the equivalent diagonal strut model and adopts the Mainstone (1974) relationship for determining the effective strut width [4]. Despite the widespread use of this approach, existing relationships for determining the effective strut width have been developed primarily based on the behavior of masonry infill walls, and their direct application to CSP infill walls involves uncertainty because of differences in layered configuration, composite material behavior, and mechanical properties. Accordingly, evaluating the performance of 11 commonly used relationships for determining the effective width of the equivalent diagonal strut, including the relationship adopted in the fifth edition of Standard No. 2800, through their ability to reproduce reference effective widths obtained from an inverse analysis approach based on initial lateral stiffness equivalence, and investigating the potential for improving their predictive performance through the application of constant correction factors constitute the primary objectives of this study.

2. Methodology

A database comprising 32 CSP-ISF specimens, derived from a numerical study based on experimental results, was used to evaluate the existing relationships [2]. The reference study investigated the effects of key geometric and mechanical parameters governing the lateral response of the system. The specimens were generated by varying one parameter at a time, and the ranges of the investigated parameters are presented in Table 1.

Table 1. Range of Geometric and Mechanical Parameters of Concrete Sandwich Panel-Infilled Steel Frames (CSP-ISFs)

Parameter	Range
Aspect Ratio	0.6, 1, 1.4, 2
Compressive strength of shotcrete	5, 10, 15, 20 MPa
Total shotcrete thickness	4, 7, 12 Cm
Frame bending stiffness	Weak, Standard, Strong

To determine the reference effective widths of the equivalent diagonal struts, an inverse analysis approach based on initial lateral stiffness equivalence was employed. First, the surrounding frame of each specimen was modeled in ETABS based on the reference specimen specifications, and its lateral stiffness was compared with that reported for the corresponding bare frame. After verifying the frame model, the CSP infill was replaced by an equivalent diagonal strut. In this model, the strut thickness and elastic modulus were defined based on the equivalent properties of the infill, while the strut-to-frame connections were modeled as pinned to permit axial force transfer along the strut. Given the composite nature of CSP, the mechanical properties of the strut were defined based on the properties of the shotcrete layers, while the effects of the remaining infill components were implicitly accounted for through the effective-width determination process. Subsequently, the effective strut width was independently varied for each specimen until the difference between the initial lateral stiffness of the frame with the equivalent strut and the reported stiffness of the corresponding CSP infilled frame was reduced to less than 3%. The initial lateral stiffness was calculated as the ratio of the lateral force applied at the top level of the frame to the corresponding displacement. This procedure was repeated independently for all 32 specimens, and the effective strut width corresponding to the stiffness-equivalence criterion was obtained as the reference value for evaluating the existing relationships. The inverse analysis procedure for determining the reference effective width is illustrated in Figure 6.

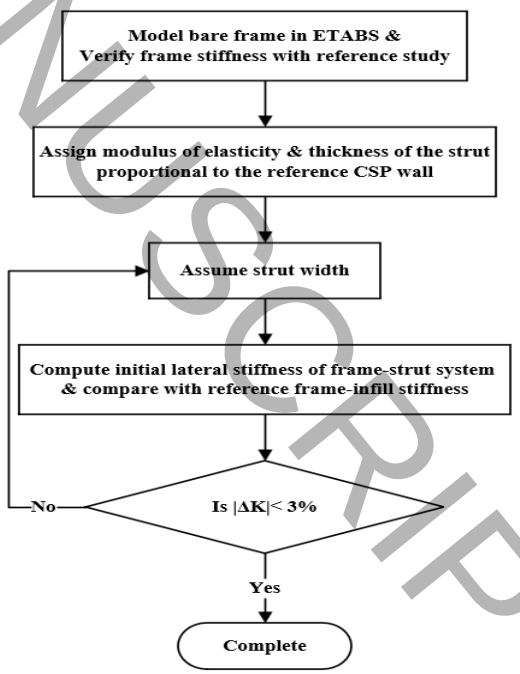

Figure 1. Inverse problem solution flowchart for CSP strut width based on initial lateral stiffness

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3. Discussion and Results

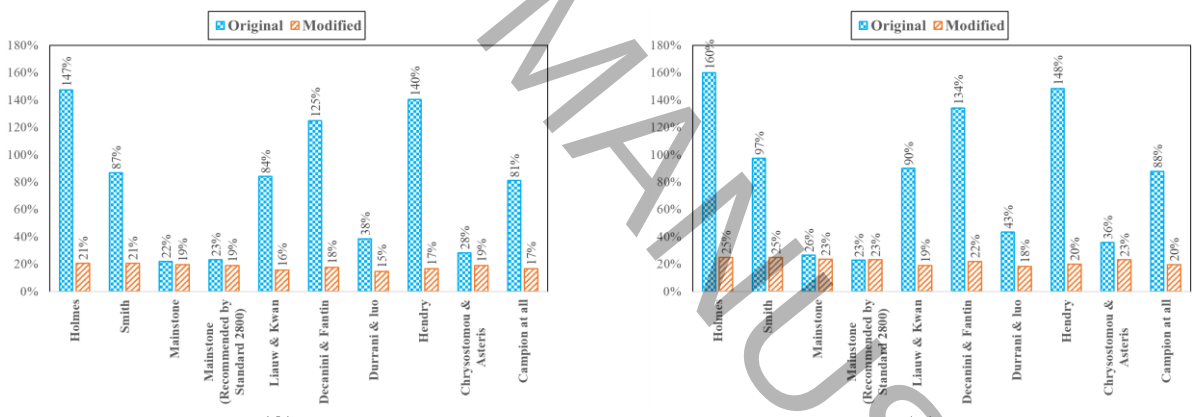
The reference effective widths obtained from the inverse analysis were used to evaluate 11 commonly used relationships for determining the effective width of the equivalent diagonal strut. Prediction errors before and after applying the correction factors were evaluated using the selected statistical indices, with the results presented in Figure 2. The results obtained are limited to the database and the specifications and modeling conditions investigated in this study.

Among the original relationships considered in this study, the Mainstone (1974) [5] relationship, adopted in the fifth edition of Standard No. 2800, showed the best overall performance. Nevertheless, its prediction error remained considerable. To examine the potential for improving the performance of the existing relationships, a constant correction factor was determined for each relationship based on the mean ratio of the predicted effective width for each specimen to the corresponding reference value obtained from the inverse analysis. This factor brings the mean error of each relationship in the database close to zero. Among the modified relationships, the Durrani and Luo [6] relationship, with a correction factor of 0.738, exhibited the best overall performance across the selected statistical indices.

4. Conclusions

In this study, 11 commonly used relationships for determining the effective width of the equivalent diagonal strut, which were primarily developed for masonry infill walls, were evaluated for CSP infill walls. The reference effective widths were determined using an inverse analysis approach based on initial lateral stiffness equivalence and used as the basis for evaluating the investigated relationships. The results showed that the Mainstone (1974) relationship, adopted in the fifth edition of Standard No. 2800, performed better than the other available relationships in estimating the effective strut width of CSP-ISFs; however, direct application of the existing relationships still resulted in considerable errors.

Then, a constant correction factor was determined for each relationship, with the Durrani and Luo relationship, using a correction factor of 0.738, showing the best performance for the investigated database. Despite the improved performance after correction, the remaining considerable errors indicate that structural differences between CSP and masonry infill walls limit the direct applicability of the existing relationships. Therefore, dedicated relationships based on the geometric and mechanical characteristics of CSP infill walls are needed to achieve more accurate predictions.



(A) **(B)**

Figure 2. Statistical Error Indices for Original and Modified Equivalent Diagonal Strut Relationships: (a) MAE, (b) RMSE

5. References

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