UTILIZING EXPERIMENTAL DATA IN COMPARATIVE EVALUATION OF SEISMIC TECHNIQUES FOR COMPOSITE STEEL–CONCRETE WALL WITH CENTRAL OPENINGS

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ABSTRACT
Building on previous experimental research, this study employs the displacement coefficient method (DCM) in the SAP2000 framework. It integrates the N2 method as outlined in Eurocode 8 to assess the seismic performance of composite steel–concrete shear walls with a central opening (CSRSW–CO). Data from experimental evaluations of scale models at a 1:3 ratio is used, and the seismic performance of these walls under seismic loads, with a specific aim to estimate the target displacement under considered seismic loading, is assessed. Dual application of the DCM and N2 method provides a comprehensive analysis regime. This approach enables an in-depth examination of how each method predicts and enhances the seismic performance of composite shear walls, emphasizing the unique challenges posed by central openings. The study not only compares the effectiveness and applicability of these methods in contemporary seismic design practices but also aims to refine the calculation of target displacements, improving the predictive precision and structural integrity of buildings with intricate wall systems. The results of the analysis indicate the estimation of the target displacement being 74 mm for the N2 method and 76 mm by the DCM; these lie at the ductile zone of the capacity curve. The analytical test initially agrees with the experimental test, with the elastic region considered, but is differing under higher displacements. This indicates that it is rather important to exercise caution and utmost precision especially when conducting numerical analysis.
Keywords: earthquake engineering, composite steel–concrete shear walls, central openings, SAP2000, numerical analysis.

1 INTRODUCTION

The study investigates the seismic performance of composite steel–concrete shear walls with central openings [1]; the SAP2000 framework analytical framework is applied to the case study. Employing displacement-based performance design, our findings align with capacity curves used in practice [2] and those generated by ATENA software. Using SAP2000 uniquely pushed these walls to displacements of 600 mm – not to suggest routine capability at this level but to assess their performance limits and ductility under extreme seismic loads. This methodology, incorporating both the N2 method from Eurocode 8 [3] and the displacement coefficient method (DCM) from FEMA 440 [4, p. 440], provides a comprehensive view of the structural behaviour under stress. The study specifically addresses the seismic conditions of a building based on 0.12 g reference peak ground acceleration, type 1 response spectrum, C soil class with a 1.5 behaviour factor, ensuring that our findings are relevant and applicable to local architectural and engineering practices.

In recent decades, the architectural requirements for high-rise buildings in seismic zones have markedly increased. These buildings often have complex configurations that pose challenges to seismic structural design [5]. Mid to high-rise structures in these areas typically rely on structural reinforced concrete shear walls for resistance against lateral forces. These walls are crucial as they not only support the building’s stability but also possess the ability to undergo considerable deformations, efficiently absorbing and dissipating seismic energy

WIT Transactions on The Built Environment, Vol 217,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ERES250041

during earthquakes. This deformation capacity is essential for maintaining the structural integrity and safety of buildings in earthquake-prone regions.

2 EXPERIMENTAL SPECIMENS AND MATERIAL PROPERTIES

The data obtained from the experiment performed by researchers at Politechnica University Timisoara [1] consisted of a hybrid steel–concrete reinforced shear wall with central openings and structural steel profiles partially embedded on the wall's edges (CSRCW-21–CO). Experimental specimens have dimensions of 3000 mm in height, 1000 mm in width, and 100 mm in thickness. These specimens were constructed at a reduced scale of 1:3 and replicate a three-storey, single-bay structural shear wall typically found in low-rise multi-storey buildings (Fig. 1(a)). The openings considered simulate standard architectural doors, typically measuring 900 mm wide and 2,100 mm high, scaled down to 300 mm by 700 mm at a 1:3 ratio. Specimens were erected on heavily reinforced foundation beams measuring 1,500 mm long, 400 mm high, and 350 mm wide. The walls featured partially embedded I-shaped steel profiles at their edges, constructed from welded steel plates. These profiles were connected to the wall panels using headed shear studs (13 mm in diameter and 75 mm in length, welded with specialized equipment) and rectangular perforated steel plates (5 mm thickness) spaced every 120 mm. All welds had a thickness of 3 mm. Fig. 2(b) illustrates the horizontal cross-section of the profile.

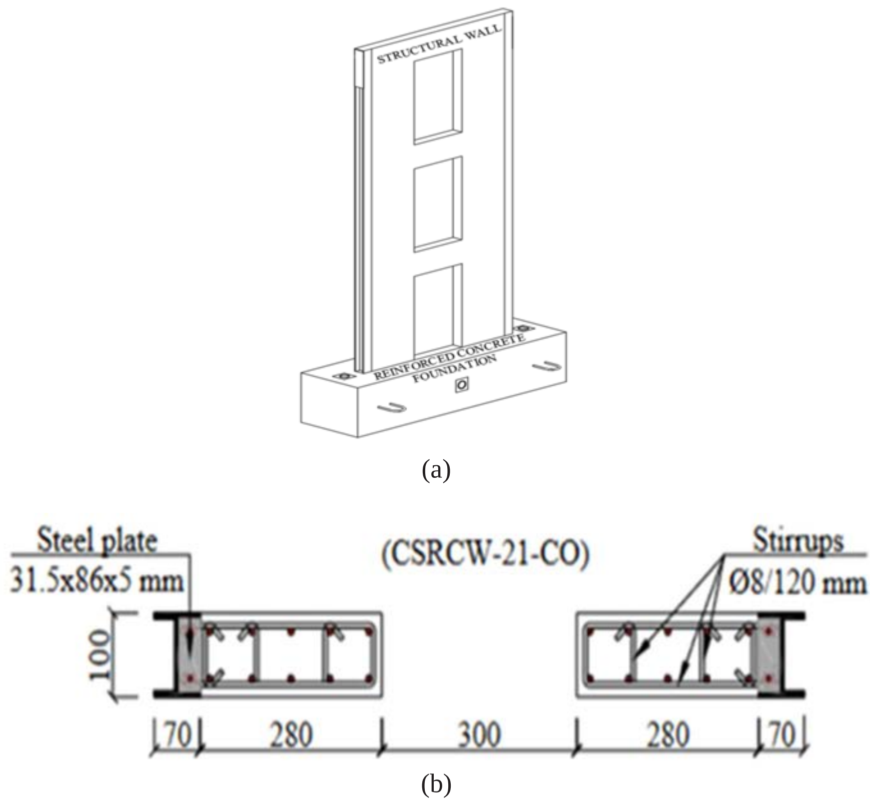


Figure 1: (a) CSRCW perspective view; and (b) Horizontal cross-section view (previously published).

In the experimental model, Eurocode guidelines were applied. The CSRCW structure consisted of concrete with a strength of C30/37; Fig. 2 represents behaviour profiles for the steel reinforcement and their steel profiles.

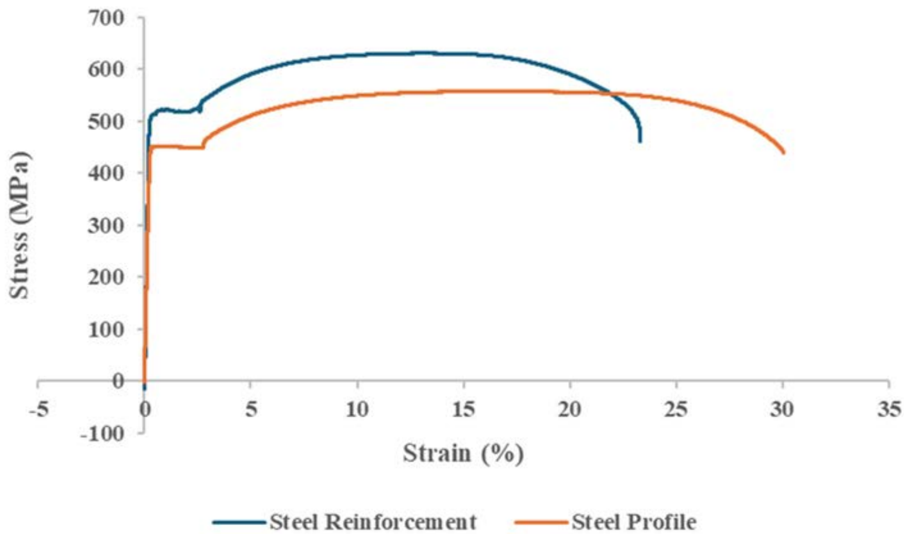


Figure 2: Strain–stress curve for steel reinforcement and profiles for the steel.

3 NUMERICAL ANALYSIS, FINDINGS AND DISCUSSION

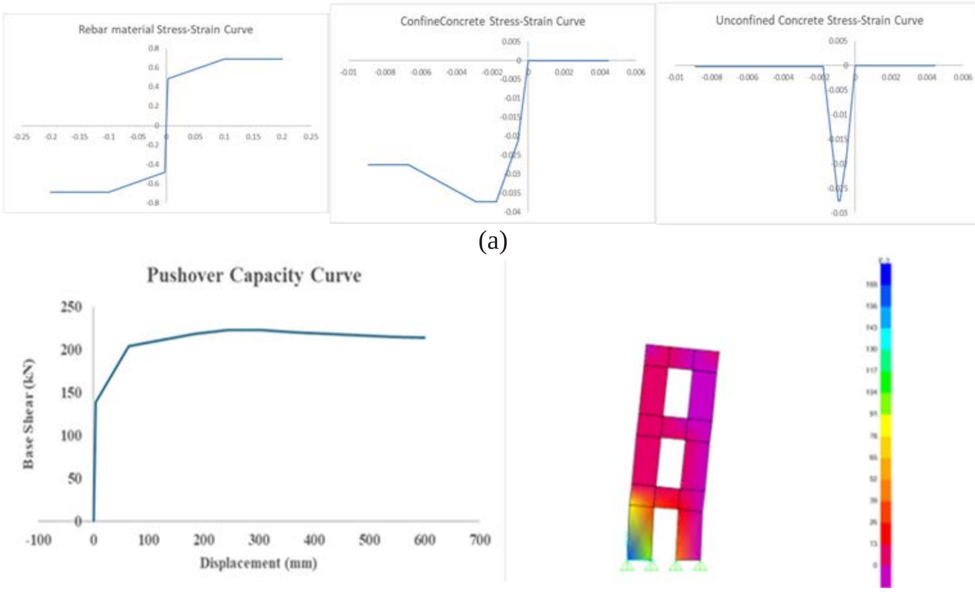
3.1 FEM analysis

SAP2000 was used to perform the numerical analysis of the specimen. The input parameters included reinforced concrete (RC) material with a strength class of C30/37, for the sections an unconfined reinforcement ratio of 0.3%, and boundary elements with 4% confined reinforcement were considered. Two types of materials were defined in the software: a uniaxial rebar material for the reinforcement and an isotropic material for the concrete. The walls were modelled as rigid diaphragms, and concentrated loads of 10 kN were applied at the joints. Custom material models were created to define the stress–strain behaviour, as shown in Fig. 3(a). Nonlinear behaviour of the walls was captured using the ‘layered nonlinear shell’ element, allowing separate definitions for the concrete and reinforcement layers.

Ground supports were modelled as fixed to replicate the rigid floor conditions used in the physical experiment. The numerical analysis produced displacement versus base shear capacity curves and shell layer strain distributions, shown in Figs 3(b) and 3(c), respectively. The point of maximum displacement was identified and considered in the analysis.

3.2 N2 method (Eurocode 8)

The N2 method, a variant of the capacity spectrum method included in Eurocode 8, which uses a displacement–acceleration format was adopted in the analysis. Pushover analysis of



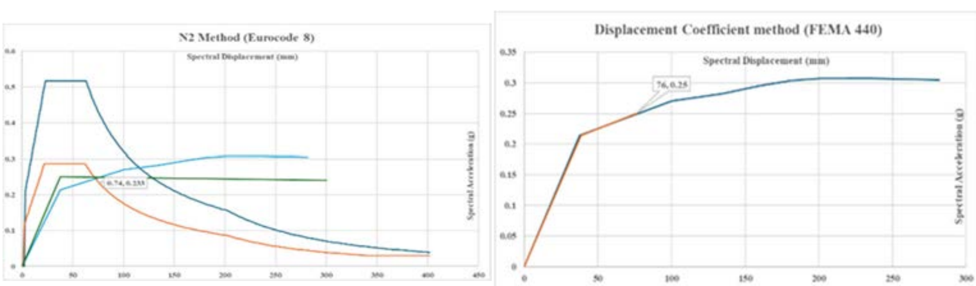
(b) (c)

Figure 3: (a) Nonlinear material stress–strain curves; (b) Capacity curve; and (c) Concrete membrane shell layer strain diagram.

the multi-degree-of-freedom (MDOF) system is conducted, converted into an equivalent single-degree-of-freedom (ESDOF) system, and approximating its behaviour by an idealized elastoplastic relationship characterized by the effective period T_e. The target displacement, $d*_{et}$ of this equivalent system is determined by the expression:

$$d_{et}^{*} = S_a(T_e)\left[\frac{T_e}{2\pi}\right]^2. \tag{1}$$

A detailed explanation of the methodology, including definitions and significance of the coefficients used, is provided in Lagaros and Fragiadakis [6]. The results obtained by applying the N2 method in this analysis are displayed in Fig. 4(a).



(a) (b)

Figure 4: (a) Demand and capacity spectra considering N2 method regime; and (b) FEMA 440 capacity versus demand spectra.

3.3 FEMA 440 DCM

For comparison purposes, FEMA 440 DCM expressed in eqn (2), was also used to estimate the target displacement.

$$d_t^* = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi}. \tag{2}$$

The FEMA 440 guideline provides a detailed explanation of the coefficients used. Fig. 4(b) shows the displacement values determined using this DCM.

3.4 Comparative assessment between numerical and experimental results

The comparative results, Fig. 5 show agreement between the SAP2000 and experimental curves in terms of initial stiffness and peak strength. In the numerical analysis, the numerical model was pushed up to 600 mm displacement, while the experimental tests were limited to approximately 80 mm displacement under cyclic loading.

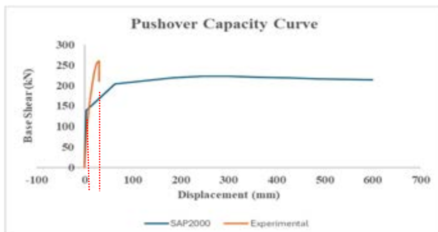


Figure 5: Comparative results between experimental and numerical findings.

4 CONCLUSIONS

The paper presents a comparative analysis of an experimental laboratory test against numerical results of composite steel–concrete shear walls with central openings. The SAP2000 software was the go-to software; the N2 method and the DCM were considered for the assessment and the results were compared to the results obtained from the experiment conducted at the Polytechnic University of Timisoara lab. Experimental tests involved scaled specimens constructed at a 1:3 ratio, enabling verification of the analytical approaches. Initial results showed that there is a good agreement in the first part of capacity curves, however the model needs further improvements to better align with test results. The goal of this study is to improve the modelling of shear walls implemented in complex building structures. The conclusions drawn from this comparative analysis are as follows:

1. Target displacement evaluation: 74 mm was estimated by N2 method, and 76 mm by the DCM. The values occurred in the ductile region, different from the experimental analysis which showed significant stiffness followed by a collapse at approximately 26 mm drift level.
2. Numerical vs. experimental comparison: Experimental stiffness between numerical and peak strength was initially similar but deviated under larger displacements. This was different in the numerical analysis.
3. Ductility limitation in experimental results: While initial stiffness and peak strength showed good agreement (Fig. 5), the experimental specimen exhibited limited ductility,

failing around 80 mm displacement under cyclic loading, compared to 600 mm in the numerical model. This reduced ductility is likely due to material degradation and localized damage effects not fully captured in the simulation.

4. Practical recommendations: To consider combining the two methods, consider other pushover methods for assessments of similar structures.
5. Future research direction: Further studies with larger specimens and various opening configurations are needed to validate and refine analytical methods, enhancing their reliability for seismic design.

REFERENCES

[1] Popescu, V.-Ș., Dan, D., Floruț, S.-C., Todea, V. & Stoian, V.A., Theoretical and experimental study of hybrid steel-concrete walls with openings subjected to seismic actions. *Proceedings of the 11th International Conference on Behaviour of Steel Structures in Seismic Areas*, (eds F.M. Mazzolani, V. Piluso, E. Nastri & A. Formisano), Lecture Notes in Civil Engineering, vol. 520, Springer Nature: Cham, Switzerland, pp. 139–149, 2024. https://doi.org/10.1007/978-3-031-62888-7_13.

[2] Todea, V., Dan, D., Stoian, V., Florut, S. & Popescu, D., Seismic behaviour of composite steel-concrete shear walls with central openings. *ce/papers*, **4**(2–4), pp. 1844–1848, 2021. https://doi.org/10.1002/cepa.1494.

[3] Fajfar, P., A practical nonlinear method for seismic performance evaluation. *Advanced Technology in Structural Engineering*, American Society of Civil Engineers: Philadelphia, USA, pp. 1–8, 2000. https://doi.org/10.1061/40492(2000)125.

[4] Federal Emergency Management Agency (FEMA), 356/November 2000 Pre-Standard and Commentary for the Seismic Rehabilitation of Buildings, 2000.

[5] Wang, Z., Pan, W. & Zhang, Z., High-rise modular buildings with innovative precast concrete shear walls as a lateral force resisting system. *Structures*, **26**, pp. 39–53, 2020. https://doi.org/10.1016/j.istruc.2020.04.006.

[6] Lagaros, N.D. & Fragiadakis, M., Evaluation of ASCE-41, ATC-40 and N2 static pushover methods based on optimally designed buildings. *Soil Dynamics and Earthquake Engineering*, **31**(1), pp. 77–90, 2011. https://www.sciencedirect.com/science/article/pii/S0267726110002113.