Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Effectiveness of Expanded Polystyrene (EPS) Core Reinforced Concrete Sandwich Panel (RCSP) Over Brick Infill Structure

Prasanna Adhikari [a], Kshitij Charana Shrestha [b], Sunita Ghimire [c]

[a] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] adhikari.prasanna11@gmail.com, [b] kshitij.shrestha@pcampus.edu.np, [c] ghimiresunitag@gmail.com

Abstract
This research investigates the seismic performance of Expanded Polystyrene (EPS) core Reinforced Concrete sandwich wall panel (RCSP) when used as structural walls and brick infill RC structural systems. The study specifically focuses on their suitability for construction in earthquake-prone regions like Nepal and compares their performance to that of brick infill walls. The research presents a comprehensive numerical validation of experimental findings on sandwich squat concrete walls without openings, comparing their seismic performance to RC frames with brick masonry infill. The study underscores significant enhancements in strength and stiffness of the EPS-RCSP system compared to RC-INFILL frames. While initial stiffness gains are observed with EPS-RCSP, its degradation in stiffness becomes more pronounced post a specific displacement and the energy dissipation capacity of EPS-RCSP surpasses that of RC-INFILL. The results indicate that the usage of EPS core RC sandwich wall panels significantly enhances the structural performance, making them a promising strategy for constructing buildings.

Keywords
Expanded Polystyrene, Reinforced Concrete Panel, Brick Infill, Energy Dissipation, Stiffness, Cyclic Analysis

1. Introduction

A load-carrying precast concrete sandwich panel (SP) is a structural or non-structural element consisting of two or more layers, typically made of high-strength materials, known as wythes and these wythes are separated by an intermediate core layer made of a lower-strength material. [1] The inclusion of intermediate cores in load-carrying precast concrete sandwich panels allows for the optimization of stiffness provided by the thin layers, while still maintaining a favorable strength to weight ratio. [2].By utilizing a lower-strength material for the core, the overall weight of the panel can be reduced without compromising its structural integrity. This optimization enables the panels to efficiently bear loads while minimizing the overall mass of the structure, which can have benefits in terms of construction, transportation, and energy efficiency. The combination of core and wythes properties in expanded polystyrene (EPS) reinforced concrete sandwich panel (RCSP) provides multiple benefits, including structural efficiency, versatility in utility and manufacturing, easy repair and erection, long-lasting performance with minimal maintenance, lightweight construction, economical production, high-quality standards, and excellent sound, moisture, thermal insulation, as well as resistance to weather and fire. [3] Due to their outstanding flexural and shear properties, sandwich composite structures are increasingly recognized as crucial components in contemporary lightweight construction. [4] The inherent lightweight nature of structural sandwich panels makes them well-suited as key structural elements in applications where minimizing weight is a priority. De souse et al presented the initial phase of an experimental study aiming to create a sustainable and versatile composite sandwich panel prototype for retrofitting older multi-storey RC frame buildings [5]. EPS-RCSP technology, with its efficiency, time-saving construction, cost reduction, and eco-friendliness, presents a compelling alternative to conventional bricks, addressing the need for sustainable materials in the face of global warming and the greenhouse effect [6].

2. Experimental Study Adopted for Numerical Validation

The University of Bologna and the Eucentre labs conducted an experimental campaign on five Planar Wall (PW) specimens to evaluate the seismic performance of reinforced concrete (RC) sandwich panels. The tests included cyclic horizontal loads with load reversals and a constant vertical load, with different vertical load values for each test. For a better understanding of the detailed experimental results, refer to Ricci et al. [7]. In this section, we will numerically validate panels without any opening as shown in Figure 1 and compare its seismic performance with that of RC brick infill structure.

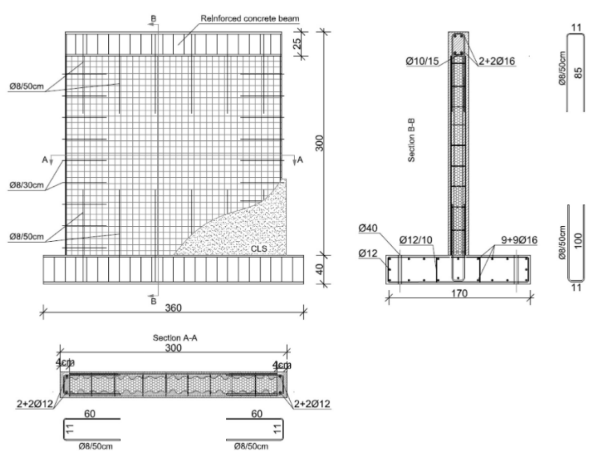

Figure 1: Reinforcement layout: solid sandwich panel [7]

The study includes five planar walls made of a 3m x 3m square panel. Three panels (PW1, PW2, and PW3) have no openings, while the other two panels (PW4 and PW5) have a central 1m x 1m opening. The total thickness is 18 cm, comprising two external 4 cm-thick shotcrete layers and a central expanded polystyrene core of 10 cm thickness. The panels are connected to the foundation and beam using U-shaped Ø 8 mm anchor rods spaced at 50 cm intervals and the two concrete layers are connected with each other using Ø 8 mm anchor rods spaced at 30 cm intervals . Ricci et al.'s study, as stated in their research findings [7], determined that the seismic performance of the tested panels, regarding factors like stiffness, strength, and ductility, closely resembled that of traditional RC shear walls with comparable geometric and mechanical attributes.

3. Finite Element Modeling

To construct the finite element (FE) models, we employed two distinct element types available in the DIANA element library. The initial element selected was an 8-noded linear solid brick element, specifically the HEX24L, chosen to emulate the characteristics of concrete. The second element of choice was a 2-noded, 1-D truss bar element known as L2TRU, utilized to model the reinforcement present within the concrete elements. The base beam's bottom surface was completely constrained in all directions, preventing any movement or rotation. To simulate the impact of steel bracing used to prevent lateral buckling and out-of-plane motion, a tying method was employed. This involved restricting in-plane displacement, with the loaded node serving as the master node and the top of the beam as the slave face.

Regarding loading, three types were applied: the structure's self-weight, vertical compression on the beam, and monotonic pushover loading. Vertical compression loads of 50 kN, 100 kN, and 250 kN, matching the test specimens, were applied to the beam's top face. Additionally, a controlled lateral pushover load was gradually applied at a tie-beam node, increasing by 1 mm per load step.

The analysis followed a specific sequence: first, self-weight and vertical compression loads were applied, and then the pushover lateral load was gradually introduced. This loading sequence enabled a comprehensive exploration of the structural behavior and response under various load conditions.

Mechanical parameters used for material modelling of concrete, reinforcement and wire mesh were acquired from experimental tests conducted [7] and all parameters are presented in Table1.Total strain-based crack model with a smeared approach for fracture energy was used to represent concrete in their nonlinear stages. For stirrups, embedded type reinforcement was employed and bond-slip type reinforcement was utilized for longitudinal reinforcement.The nonlinear behavior of both types of reinforcement was represented by Von Mises plasticity model.

Figure 2 illustrates the solid model's geometry for the Sandwich wall panel within the DIANA software. The representation closely mirrors the experimental setup, incorporating the beam, wall, and foundation as shown in the experiment. To replicate the experimental conditions from Ricci et al. (2013) [7], an axial load of 50 kN, 100kN and 250kN are applied to the top of the beam.

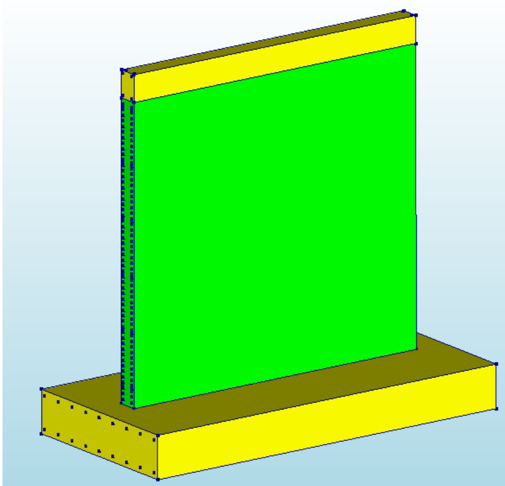

Figure 2: Geometry detail of Sandwich wall panel

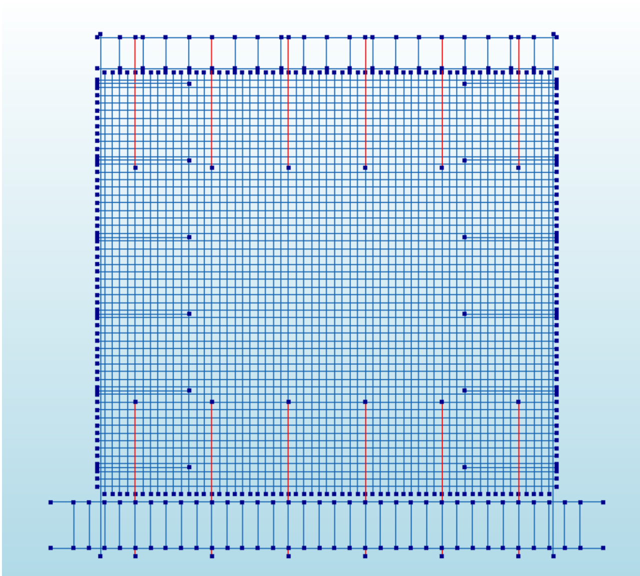

Figure 3: Reinforcement layout of Sandwich wall panel

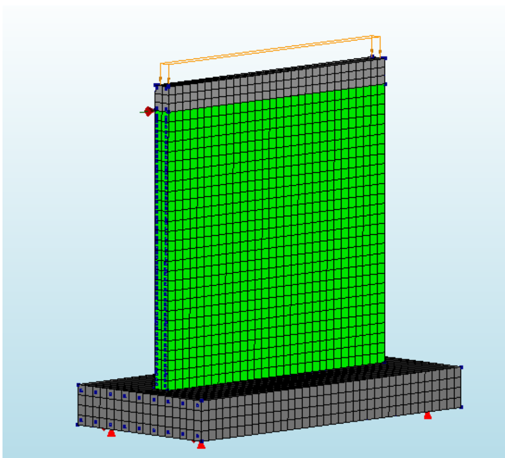

Figure 4: Meshing and Boundary conditions in DIANA

For the frame's reinforcement, the model adheres to the experimental specifications, as depicted in Figure 3. Figure 4 showcases the meshing, loading application, and boundary support conditions. The mesh size is maintained at 100mm.

Table 1: Mechanical parameters used for material modelling [7]

Material Properties	Value	Unit
Concrete in Beam and Foundation		
- Specific Gravity	2.4	t/m^3
- Young,s Modulus	31.447	GPa
- Poisson's Ratio	0.2	
- Ultimate Tensile Strength	1.79	MPa
- Ultimate Compressive Strength	26	MPa
- Tensile Fracture Energy	0.0488	N/mm
- Compressive Fracture Energy	23.5	N/mm
Concrete wall		
- Specific Gravity	2.4	t/m^3
- Young,s Modulus	31.447	GPa
- Poisson's Ratio	0.2	
- Ultimate Compressive Strength	26	MPa
- Tensile Fracture Energy	0.0488	N/mm
- Compressive Fracture Energy	23.5	N/mm
- Longitudinal and Shear bars		
- Specific Gravity	7.855	t/m^3
- Young,s Modulus	206	GPa
- Poisson's Ratio	0.3	
- Yield Stress	450	MPa
- Failure Tensile Stress	610	MPa
- Failure Strain	22	%
- Wire Mesh		
- Specific Gravity	7.855	t/m^3
- Young,s Modulus	206	GPa
- Poisson's Ratio	0.3	
- Yield Stress	450	MPa
- Failure Tensile Stress	720	MPa
- Failure Strain	10	%

4. Numerical validation of experimental results

The results of the quasi-static nonlinear pushover analysis were compared with the experimental findings. The analysis employed a displacement-controlled approach, utilizing the regular Newton-Raphson iteration method with a step size of 1 mm. A displacement-based convergence criterion of 0.01 was implemented.The outcomes of the numerical analysis, as illustrated in Figure 5, 6, and 7, reveal a remarkable resemblance to the experimental results. Figure 5, 6, and 7 exhibits both the monotonic pushover curve and the hysteresis envelope derived from both numerical and experimental analyses, showcasing a close alignment between the two sets of data.The numerical trajectory closely mirrors the experimental one, signifying a strong correlation and confirming the accuracy of the numerical simulation concerning the experimental data.

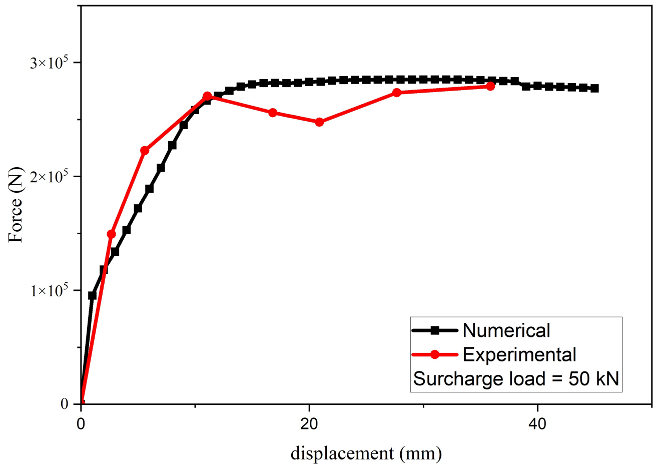

Figure 5: Pushover curve comparison between experimental and numerical analysis for 50 kN Surcharge load

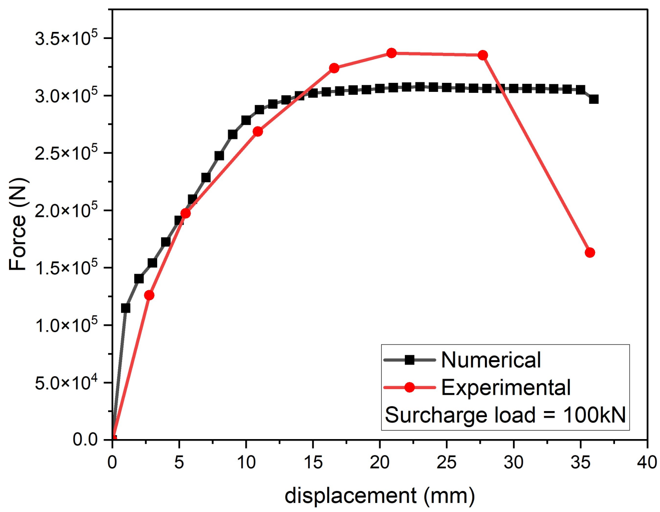

Figure 6: Pushover curve comparison between experimental and numerical analysis for 100 kN Surcharge load

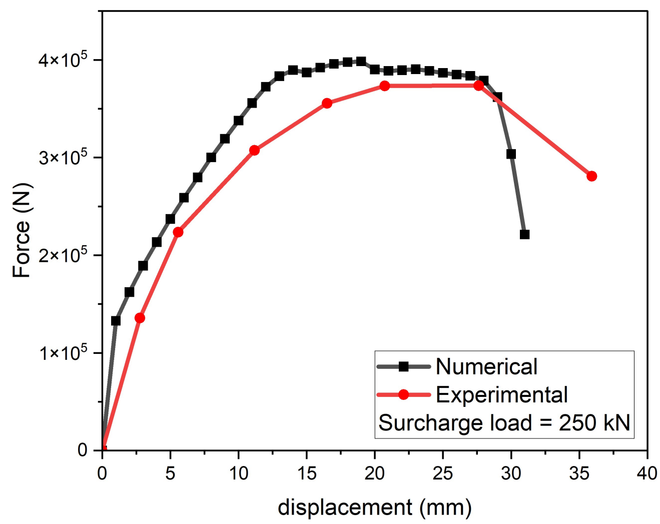

Figure 7: Pushover curve comparison between experimental and numerical analysis for 250 kN Surcharge load

5. Representative Structures for case study

5.1 RC-INFILL Structure

With the help of the previous study, the RC frame system of bay length 3m*3m c/c is taken from the Model M1 of Uprety & Suwal [8] and the structural properties are shown in Table 2. The frame detail is shown in Figure 8 and arrangement of reinforcement in figure 9.

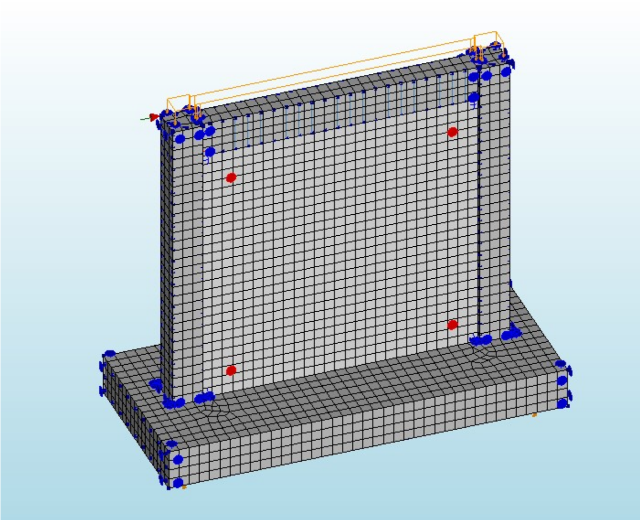

Figure 8: Meshing and Boundary condition of RC-INFILL

Table 2: Structural properties and section specifications [8]

Items	Beam	Column
Size	230*350 mm	300*300 mm
Longitudinal Reinforcement	3 @ 16 mm-Top 3 @ 16 mm-Bottom	8@ 16 mm
Transverse Reinforcement	2LVS 8 mm dia @125 mm c/c	8 mm dia @125 mm c/c

Note: c/c = center to center spacing.

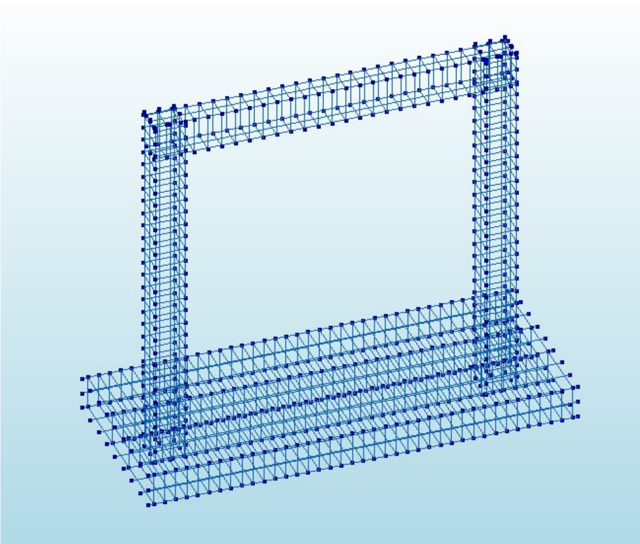

Figure 9: Arrangement of rebars

In the equivalent RC-INFILL frame model, most of the elements closely resemble those found in the EPS Panel model, except for the interface between the concrete and masonry units. To define this interface, a Coulomb friction model is employed. The mechanical properties governing this interface are sourced from [9].

Table 3 summarizes the specific values used for modeling the RC interface, encompassing parameters such as the normal stiffness modulus, shear stiffness modulus, tensile strength, friction angle, and dilatancy angle. These parameters are integral in characterizing the behavior of the interface between the concrete and masonry units within the RC-INFILL frame model.

Table 3: Interface properties used in RC-INFILL frame structure [9]

Parameter	Value	Unit
Normal Stiffness Modulus-Z	3.00E + 12	N/m^3
Shear Stiffness Modulus-X	3.00E + 10	N/m^3
Tensile Strength	1.00E -07	N/m^3
Friction Angle	30	degree
Dilatancy Angle	0.00	degree

5.2 EPS-RCSP Structure

The EPS-RCSP configuration employed in this study utilized the same bay length as the conventional RC frame. The EPS-RCSP panel was specifically designed to mimic real-world connections between slabs and the structural elements of a building, as discussed in Carbonari's work [10]. These simulated connections involved reinforced ends, which entailed a complete concrete section covering the panel's width over the support line. This concrete section incorporated four 12 mm diameter steel bars and six U-shaped bars with an 8 mm diameter, as depicted in Figures 10 and 11.

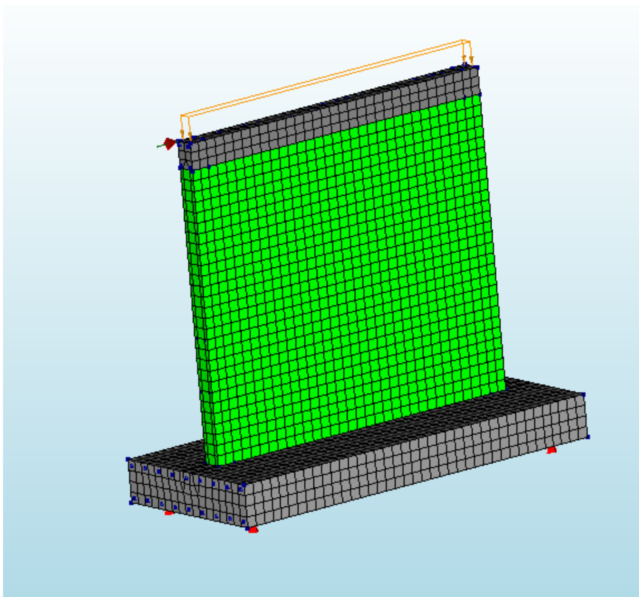

Figure 10: Meshing and Boundary condition of EPS-RCSP

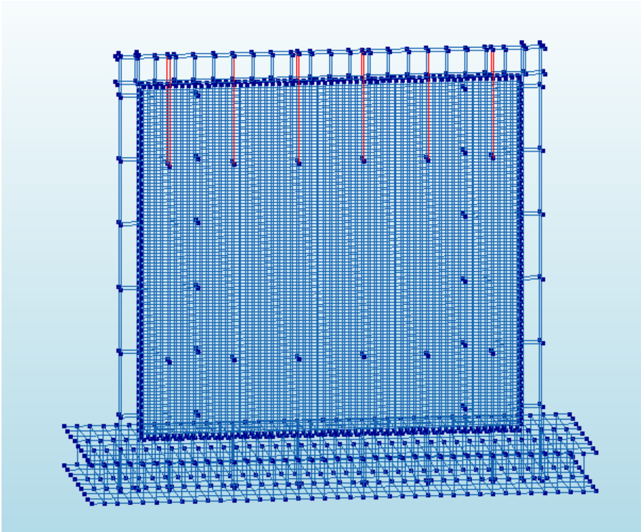

Figure 11: Meshing and Boundary condition

The wire mesh configuration, reinforcement of beams and foundations, and the connections between walls and beams, foundations and walls remained consistent with the verification method employed earlier in the study.

In this configuration, EPS-RCSP was employed with strengthened ends designed to mimic the typical connections found in real-world structures between slabs and the beams or walls that make up a building's structural framework as described by carbonari et al. [10]. These reinforced ends consisted of a full-section concrete component that spanned the width of the panel along the support line. This concrete section included four steel bars, each with a diameter of 12 mm, and six U-shaped bars, each with a diameter of 8 mm.

The arrangement of the wire mesh, the reinforcement of beams, the reinforcement of foundations, and the connections between walls and beams, as well as between foundations and walls, remained consistent with those used in the verification process described above.The FE modeling strategy of wall specimens validated earlier was used to model a representative EPS Panel.

6. Results and Discussions

Cyclic analysis was performed and various aspects such as, hysteresis curves, force-displacement envelopes, energy dissipation, and stiffness degradation were studied. The findings and insights obtained from these analyses shed light on the behavior and performance of the structures, providing valuable information for understanding their structural response.

The force-displacement envelopes of the push and pull directions of the structures are discussed. Figure 12 shows the force-displacement envelopes of EPS-RCSP, and RC -BARE FRAME. On the average force-displacement envelopes of the push and pull directions , EPS-RCSP resisted a peak load of 358.22 kN and RC-INFILL frame resisted a peak load of 244.75 kN. In comparison of RC-INFILLED frame, the strength of EPS-RCSP is increased by 46.36%.

Figure 13 shows the relationship between the accumulated dissipated energy and the no of cycle. EPS-RCSP is much higher than that of RC-INFILLED frame. The energy dissipation of EPS-RCSP is increased by 96.3% in 9th cycle compared to that of RC-INFILLED frame.

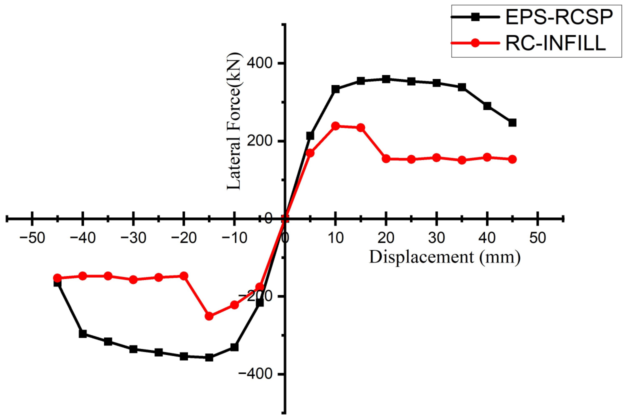

Figure 12: Hysteresis curve envelope

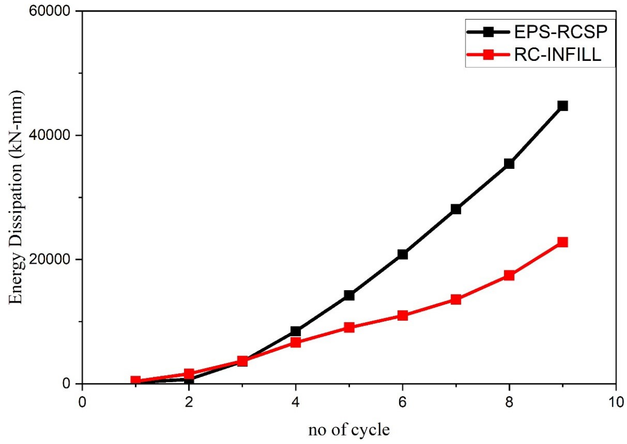

Figure 13: Energy dissipation vs no of cycle

The secant stiffness degradation evolution in figure 14 shows that all specimens present a continuous stiffness decrease with the increase of displacement. It can be seen that the presence of EPS-RCSP entails a significant enhancement of the in-plane stiffness when compared to the RC-INFILL frame

The EPS-RCSP and RC brick infill structures exhibit notable differences in their response to lateral loads. The EPS-RCSP demonstrates enhanced shear strength, uniform material distribution, and an efficient load path, resulting in consistent behavior and load distribution under lateral loads. Its superior energy dissipation capacity is attributed to controlled deformations and increased ductility, facilitated by wire mesh reinforcement and reinforced ends. In contrast, the RC brick infill structure may suffer from variations in brick quality, mortar strength, and alignment, leading to potential weak points and quicker strength degradation under lateral loads. While the EPS-RCSP initially benefits from higher stiffness and controlled deformation, prolonged loading may lead to more pronounced stiffness degradation comparable to traditional RC-INFILL.

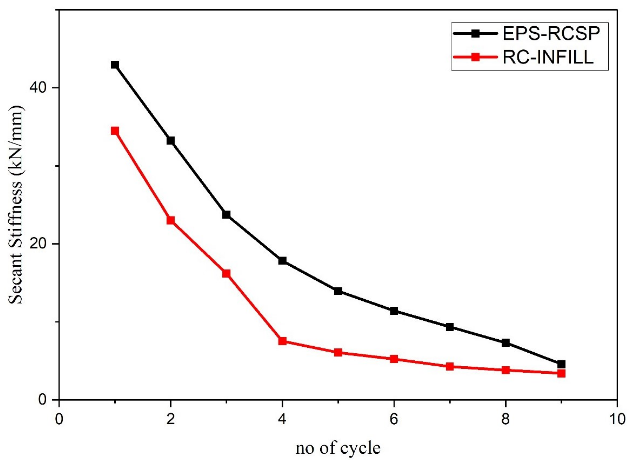

Figure 14: Secant stiffness vs no of cycle

7. Conclusions

This paper presents a numerical validation of experimental data related to a sandwich squat concrete wall without openings. The research aims to compare the seismic performance of this EPS-RCSP wall design with that of a reinforced concrete (RC) frame with brick masonry infill.From the conducted work, the following key findings can be summarized:

- On average, when considering both push and pull directions, the Reinforced concrete sandwich panel with expanded polystyrene (EPS-RCSP) exhibited 46.36% increase in lateral strength compared to the RC frame with brick masonry infill (RC-INFILL).
- The study observed a progressive reduction in lateral secant stiffness with increasing displacement for all specimens, indicating a continuous decline in stiffness. Notably, the presence of EPS-RCSP resulted in significantly higher in-plane stiffness during the initial cycles leading up to the peak load. Ultimately, both EPS-RCSP and RC-INFILL exhibited similar secant stiffness at the final displacement.
- In terms of the relationship between accumulated dissipated energy and the number of cycles, EPS-RCSP showed significantly higher energy dissipation compared to the RC-INFILL frame, with a notable 96.3 % increase in energy dissipation during the ninth cycle compared to the RC-INFILL frame.

In essence, the research findings indicate that the EPS-RCSP design offers enhanced strength and energy dissipation performance compared to the traditional RC frame with brick masonry infill, particularly under seismic loading conditions.

References

[1] Ehab Hamed. Modeling, analysis, and behavior of load-carrying precast concrete sandwich panels. *Journal of Structural Engineering*, 142(7):04016036, 2016.

[2] A Benayoune, A Aziz A Samad, DN Trikha, A Abdullah Abang Ali, and AA Ashrabov. Structural behaviour of eccentrically loaded precast sandwich panels. *Construction and building Materials*, 20(9):713–724, 2006.

[3] Adil Ahmad and Yogendra Singh. Flexural behavior of expanded polystyrene core reinforced concrete sandwich panels with different construction methods and end conditions. In *Structures*, volume 34, pages 2900–2911. Elsevier, 2021.

[4] Nahro Radi Husein, VC Agarwal, and Anupam Rawat. An experimental study on using lightweight web sandwich panel as a floor and a wall. *International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN*, 2278:3075, 2013.

[5] Christoph de Sousa, Joaquim AO Barros, and João R Correia. In-plane cyclic behaviour of rc frames strengthened with composite sandwich panels. *Engineering Structures*, 251:113529, 2022.

[6] Ankita Shirke, Swapnil Mangaonkar, Pranit Parad, Divyaraj More, and Yashwanthkumar Shetty. Comparison between eps construction and brick construction.

[7] Ilaria Ricci, Michele Palermo, Giada Gasparini, Stefano Silvestri, and Tomaso Trombetti. Results of pseudo-static tests with cyclic horizontal load on cast in situ sandwich squat concrete walls. *Engineering structures*, 54:131–149, 2013.

[8] Rupesh Uprety and Rajan Suwal. Bidirectional effect of earthquake on low-rise rc frames with and without the consideration of in-plane effect of unreinforced masonry infill. In *Structures*, volume 47, pages 648–664. Elsevier, 2023.

[9] Ojaswi Acharya, Aarosh Dahal, and Kshitij C Shrestha. Confined masonry in seismic regions: Application to a prototype building in nepal. In *Structures*, volume 47, pages 2281–2299. Elsevier, 2023.

[10] G Carbonari, SHP Cavalaro, MM Cansario, and A Aguado. Flexural behaviour of light-weight sandwich panels composed by concrete and eps. *Construction and Building Materials*, 35:792–799, 2012.