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RESEARCH ARTICLE

Finite Element Analysis of Structural Concrete Insulated Panels Subjected to Dynamic Loadings

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Abstract

Human population is growing around the world day by day, necessitating highly sustainable and energy efficient building systems. In conventional building systems, significant amount of energy is consumed for providing thermal comfort to the occupants. Materials used for thermal insulation not only increase the cost of the buildings but also increase the dead weight. Structural concrete insulated panel system (SCIP) provide thermally efficient, light weight, and low-cost solution as compared to the conventional systems. SCIP system is new innovation in which, insulation material is placed between two layers of concrete. Due to low weight, it can be easily handled and transported to project sites. In present research, the performance of SCIP walls in a typical school double story building is examined by three-dimensional finite element analysis, using SAP2000. The response is evaluated by varying the thickness of the insulation layer in terms of safety and serviceability. The results show that the buildings incorporating SCIPs are capable to withstand high dynamic and earthquake loads and are significantly economical as compared to the conventional building systems.

Keywords: Conventional Building systems, SCIP, Finite element analysis, SAP2000, Dynamic loads, Economy.

1. Introduction

Conventional building materials have poor energy conservation capacity that not only increase the dead weight but also need a lot of time for construction [1]. Growing human population necessitates to develop techniques, which provide comfortable environment, are energy-efficient, light weight and have fast pace of construction [2]. Structural concrete insulated panel (SCIP) system is a new innovation, adapted in Pakistan after 2005 devastating earthquake. Throughout the world, it is used as a substitute for conventional building materials like brick masonry, wooden frames structures and concrete blocks [3]. SCIP is a light weight material and consists of insulation of varying thicknesses between two concrete layers: Owing to lesser weight, it is quite suitable in the areas, prone to high magnitude earthquakes. SCIPs need lesser manpower and time for installation than the conventional materials [4].

SCIPs can be manufactured in industry according to the requirement and specification for a particular project. Normally, the width and the length of such panels vary from 4ft (1.2 m) to 8ft (2.4 m), however, the length as high as 40ft (12 m) has also been used [5].

Several types of SCIPs have been developed all over the world. One of the important types is a precast sandwiched concrete insulated panel, which is in use since 1960. It consists of an outer layer of lightweight concrete with the insulation layer, made of polystyrene or polyurethane [6,7]. The material is reported to be highly successful in heat preservation than the conventional concrete. The combined effect of lightweight concrete and insulation layer controls the thermal conductivity more effectively and reduces the heating and cooling costs of the whole structure [8].

Three-dimensional modeling is an efficient way, the construction industry can benefit: It enables to identify the potential problems with designs and materials before they become realities saving millions of dollars. Several researchers have modeled design and materials for structural members: Some important works related to the current study are presented here:

Tomlinson et al. modeled non-pre-stressed precast concrete wall panels, using floating concrete studs and glass fiber reinforced polymer connectors. They concluded that the proposed mechanism can increase the ultimate load capacity of the members from 58% to 80% [9].

Lameiras et al. modeled SCIPs, using different softwares like SAP2000, ETAB, STAAD pro and FEMIX. By using FEMIX software, finite element meshes were developed for panels with varying thicknesses: Length of the panels was set as 8 m. In their study, it was assumed that the roof trusses transfer the load through wall onto the foundation. SCIP was designed by standard load combination of wind, earthquake, live and dead load as per ACI, UBC and other relative codes. They have reported that the stresses developed in the middle zone of the panel were extremely high and the calculated strengths were lesser than the produced stresses [10]. Hence, modeling and analysis indicates the risks, associated with a novel material/structure

Rizkalla et al. checked the load bearing capacity of SCIP by working on six precast panels of different thicknesses: The panels were designed and tested by using different combinations of vertical and lateral loads. All panels were tested in the laboratory by deploying different gravity and lateral load conditions: The structure consisted of a frame, braced on both sides. The vertical loads were applied on

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top of each corbel using hydraulic jack and the lateral loads were applied by the actuator connected spreader beam system that pushed and pulled the panel and simulated the wind pressure on suction. The panels were subjected to 0.7 times wind, 1.2 times dead and 0.5 times roof live loads. It was observed that the lateral deflection not only depended upon the thickness of panel but also on the shear transfer mechanism [11].

Ukanwa et al. developed a 3-dimensional finite element model using 4-point bending test, for understanding the flexural behavior of the panels [12]. The model was prepared using ABAQUS 6.13. It is reported that the ultimate strength not only depends upon the material properties, but also on the length to thickness ratio. The length to thickness ratio of 25 resulted in a strength of 16.21 KN and a deflection of 20.21 mm against a strength of 34.4 KN and deflection of 8.51 mm for that of 13.33. It was also observed that the same thickness did not produce equal flexural strength but the parameter changed as a function of length to thickness ratio. Additionally, mid-point deflections were also noted down. The highest length to thickness ratio produced the highest deflection.

Khattak et al. checked the thermal efficiency of SCIP buildings; two buildings in Islamabad, the capital of Pakistan, were chosen as test case; one consisted of SCIP system and the other had conventional brick masonry wall system (9 inch or 22 cm) thick [13]. The energy efficiency was examined under similar wind and sunlight conditions. The thermal sensors were placed in both buildings for 72 hours without heating/air-conditioning in winter and summer sessions. It was observed that the U-values (Thermal transmittance) of SCIP walls were theoretically twelve times more energy efficient than those of brick masonry walls.

Pečur et al. have reported that the sandwich concrete insulated panel have many advantage over other SIPs [14]. SCIP have excellent thermal mass properties, outstanding sound insulation properties, faster construction time, are quickly assembled, require less trained labor, less affected by weather, require simplified construction process, easily handled on site, are fire resistant, high durable and need lesser HAVC expenditures during the life of the structures.

Qureshi et al. studied the comparison of cost and duration of construction among cold roll gauged steel (LGS), Structural concrete insulated panel (SCIP) and conventional reinforced concrete (RC) constructions. They have reported that the cost of LGS was almost half, while that of SCIP was almost 0.65 times that of the conventional RC construction. LGS took 27 days for completion, SCIP took 25 days, while RC structure took 52 days for the same structure [15].

Present study is intended to check the axial, shear and flexural strength of the SCIPs, using Finite Element Modeling in SAP2000 software. A two-story school building, constructed after the 2005 devastating earthquake in Pakistan, was chosen as the test case. The building was constructed using Pakistan Building Codes, developed for the earthquake prone regions of the country.

SAP2000 is a software, developed by the Computer and Structural Inc. (CSI), Berkeley California in USA [16]. It is intended for the design and analysis of structures such as buildings, towers, industrial plants, stadium, off shore structures, dams and many others. This software has the ability to generate complex models, which can be meshed with powerful in-built pattern. The software is integrated with essential dead, live, and dynamic loads as per ACI, AISC, Canadian and European codes. In this software, a number of features are present such as static and dynamic analysis, linear and nonlinear analysis, pushover analysis, 3-dimensional solid element modeling, efficient and stable solution algorithms, a number of constraints and a wide variety of load conditions and combinations. SAP2000 converts each object of the structure in one or more elements: Using the graphical user interface, a physical member can completely be defined in terms of its geometry, applied loads and material properties. Earthquakes of 2005 and 2019 in Himalayan region of Kashmir demonstrated that the conventional building materials like clayey bricks, and stones are not suitable owing to

their hostile seismic performance, which resulted in considerable loss of life and property. Present study intends to introduce novel materials and techniques, suitable for providing better seismic performance.

2. MATERIAL AND METHODS

2.1 Model and Loads

For this research, a two-story school building (actually made of brick masonry) was modeled using SAP 2000.

In the model, the brick masonry was replaced with SCIPs. The structure consisted of walls of SCIP with thickness ranging from 5 to 9 inches (12.5 cm to 22.5 cm), ASTM A572-50 cold formed steel for trusses, a 4000 psi (28 MPa) concrete for footings and a 3000 psi (20 MPa) concrete for beams, columns and SCIP and A615Gr60 steel reinforcement for beams and columns. The user interface for specifying concrete properties is shown in Figure 1.

The Finite Element modeling of the building was performed in SAP2000 under different load combinations. To study the behavior, seismic and serviceability state analysis were conducted using the codes [17,18].

Figure 1 Material properties for concrete

As mentioned above, a two-story school building constructed after the 2005 earthquake was chosen as case study. The plans of the floors are shown in Figure 2 and Figure 3. The structural components of the building are modeled as per details given in Table 1. The FEM of the building is shown in Figure 4. The load cases, types and details are provided in Table 2.

The FEM consists of shell and frame element to represent the structural components. Appropriate FEM techniques were employed to model the components, as given in Table 1. The columns and the trusses are modeled as frame elements. The SCIP is modeled as multi-layer shell element. Isolated footing is used for column and spread footing is used for plinth beam. SCIPs are fixed to the beams.

The meshes of SCIP consist of flat shell eight nodes for modelling the internal and external concrete layers, as well as the connectors. The mesh coincides with the middle surface of SCIPs. It is assumed that

bond between materials (Concrete and insulation layer) is perfect [10].

Time history analysis was performed using UBC 97 to evaluate the response of the building under seismic load [19]. Dynamic loads were decided as per seismic and wind data of the region. The parameters of seismic zone 4 were used for the earthquake analysis. Wind load was applied in accordance with ASCE 7-10. The wind speed of 60 mph (90 Km/h) was applied with the exposure type B. The snow load was chosen as 0.33 lb/in² (2 kN/m²), in accordance with regional weather data.

Figure 2. Ground floor plan

Figure 3. First Floor plan

Table 1. Structural components

Structural Component	Designation
Column	Finite element
Beam	Finite element
Truss	Finite element
Slab	Shell element
Sandwich panel wall	Shell layer element

Figure 4. Finite Element Model

Table 2. Load cases

LOAD CASES NAME	LOAD CASE TYPE	DETAILS
DL	Dead	Self-weight of structural component. Using self-weight of slab + water tank load + walls + trusses component
LL	Live	60lb/in ² (40 N/cm ²)
SNOW	Snow	0.33 lb/in ² (2 kN/m ²)
WX	Wind in x direction	Static loading in according with ASCE 7-10
WY	Wind in y direction	
ESX	Earthquake load in X direction	Equivalent static load
ESY	Earthquake load in Y direction	
ERX	Earthquake in X direction	Time History Analysis using UBC97
ERY	Earthquake in Y direction	

The load combinations are shown in Table 3: The RCC and steel design load combinations were selected as per ACI 318-02 [20] and LRFD-93 [21](for cold formed steel components) respectively. The service load combinations are based on UBC97-31 recommendations [22].

Table 3. Load combinations

No	RC design load combination	Service load combination	Steel design load combination
1	1.4DL	DL	1.4DL
2	1.2 DL +1.6 LL	DL+ LL	1.2 DL +1.6 LL
3	1.3 DL + 0.5 LL+1.1EX	DL+LL+EX	1.3DL + 0.5LL + 1.1EX
4	1.3 DL + 0.5 LL -1.1EX	DL +LL-EX	1.3 DL + 0.5LL-1.1EX
5	1.3 DL + 0.5LL+1.1EY	DL+LL+EY	1.3 DL +0.55 LL+EY
6	1.3 DL+0.55LL-1.1EY	DL+LL-EY	1.3 DL+0.55LL-1.1EY
7	0.99 DL + 1.1 EX	DL+EX	0.99 DL+1.1EX
8	0.99DL-1.1EX	DL -EX	0.99 DL -1.1 EX
9	0.99 DL+1.1EY	DL +EY	0.99DL +EY
10	0.99 DL-1.1EY	DL - EY	0.99DL -1.1 EY
11	1.2DL+1.0LL+1.6WL	DL+LL+W	1.2 DL+1.0LL+1.6W
12	1.2DL+1.0LL-1.6WL	DL+LL-W	1.2DL+1.0LL-1.6W
13	0.99DL+1.6 WL	DL+WL	DL+WL
14	0.99DL-1.6WL	DL-WL	0.99 DL-1.6WL
15	1.2 DL+1.6 LL +0.5 SL	DL+LL+SL	DL+1.6LL+0.5SL
16	1.2DL+1.0LL+WL+0.5SL	DL+LL+W+SL	1.2 DL+1.0LL+WL+0.5SL

2.2 Structural component capacity

The axial, flexural and shear capacities were calculated in accordance with ACI 318-02 and are presented in Table 4.

Table 4. Structural Component capacity

Element	Bending in(Nm)	k- Shear Capacity	Compression capacity K/in	Tension capacity
	+ve -ve	K/in (KN/cm)	(KN/cm)	(K/in) (KN/cm)
Wall	53 (6)	53 (6)	27 (47)	196 (340)
Wall joint	104	104	42.4	208
				40

	(12)	(12)	(74)	(360)	(70)
Footing	128	-	19.55	-	-
	(15)		(34)		
Footing	128	128	58	586	48
wall	(15)	(15)	(100)	(1000)	(84)

The serviceability limit state was checked through allowable compressive stress in concrete, cracking stress in concrete, and the allowable tensile stresses in steel in accordance with the following formulae [23]:

$$f_{cr} = 7.5\sqrt{f'_c} \text{ (Psi) or } 0.62\sqrt{f'_c} \text{ (MPa)}$$

$$f_a = 0.45f'_c$$

In the above equations, f_{cr} is the cracking stress, f'_c is the compressive strength and f_a is the allowable compressive stress in concrete. The cracking stress in concrete comes out to be 410 psi (**2.8 MPa**), the allowable compressive stress in concrete is 1350 psi (**9.4 MPa**) and the allowable tensile stresses for Grade 60 and Grade 80 steels are 16 ksi (**112.0 MPa**) and 31 ksi (**220 MPa**) respectively.

3. Results and discussion

Different components of the structure, subjected to above mentioned loading combinations were analyzed. The capacity of the panels was checked against the ultimate and serviceability limits. The results and the discussion are provided in the following sections.

3.1 Ultimate membrane forces

The ultimate membrane forces acting on the walls are shown in Figures 5-14. The ultimate forces are designated as F11, F22, F12, M11 and M22.

Figure 5. Resultant F11 of wall (COMB ENVP-MAX)

Figure 6. Resultant F11 of wall (COMB ENVP MIN)

Figure 7. Resultant F22 of wall (COMB ENVP - MAX)

Figure 8. Resultant F22 of wall (COMB ENVP - MIN)

3.2 Axial force

The compressive and tensile load capacities of 7 in. wall thickness of SCIP are mentioned in Table 4, and are 196 kips/inch (34.3 KN/cm) and 19 kips/inch (3.3 KN/cm), respectively. The results as obtained by the FEM using software SAP2000 with a delineation range between 0 to 19 and 0 to -196 are shown in Figures 5, 6, 7 and 8. The analysis show that all the tensile and compressive forces are well within the limit capacity of structure. It can be concluded that the building is safe against axial forces.

3.3 Shear force

As per results given in Table 4, the shear force capacity of the SCIP is 27 kips/inch (47.3 KN/cm). By using SAP2000, the maximum shear forces acting on the structure at different points are shown in Figures 9 and 10. For shear forces, the delineation range was set between 27 and -27. From the figures, it is clearly evident that all shear forces are in limit of the capacity of structure. From this result, it can be concluded that the building is safe against shear forces.

Figure 9. Resultant F12 of wall (COMB ENVP-MAX)

Figure 10. Resultant F12 of wall (COMB ENVP-MIN)

3.4 Bending Moment

The flexural capacity of 7-inch (17.8 cm) thick SCIP as mentioned in Table 4 is 53 kips-inch/inch (6 KN-m). By using software SAP2000, the maximum bending moment acting on the structure was checked with a delineation range between 53 and -53. The Figures 11, 12, 13 and 14 clearly show that all bending moments are within the limit capacity of SCIP. From this result, it is concluded that the building is safe vis-à-vis flexure.

Figure 11. Resultant M11 Diagram of SCIP wall (COMB ENVP MAX)

Figure 12. Resultant M11 Diagram of SCIP wall (COMB ENVP MIN)

Figure 13. Resultant M22 Diagram of SCIP wall (COMB ENVP MAX)

Figure 14. Resultants M22 Diagram of SCIP wall (COMB ENVP-MIN)

3.5 Comparison of different thickness of SCIP

For checking the effect of the wall thickness, SCIP was modeled with the wall thicknesses (insulation layer plus concrete) of 5, 6, 7 and 9 in (12.5, 15, 18, 22.5 cm, respectively). The thicknesses of the insulation layer were kept as 2, 3, 4 and 6 in. (5, 7.5, 10, and 15 cm, respectively) respectively with a concrete cover of 1.5 in (3.8 cm) on both sides. The detail of section is shown in Figure 15.

Figure 15. SCIP section

The axial stresses F11 and F22, the bending moments M11 and M22 and the shear forces F12, V13 and V23 were considered. The calculated results are shown in the Figures, ranging from 16 to 21.

Figure 16. Positive Moment as a function of insulation thickness

Figure 17. Negative Moment as a function of insulation thickness

Figure 20. Positive shear force as a function of insulation thickness

Figure 18. Positive axial force as a function of insulation thickness

Figure 21. Negative shear force as a function of insulation thickness

Figure 19. Negative axial force as a function of insulation thickness

Figure 16. shows that the positive moment M11 increases exponentially, the positive moment M22 increases logarithmically and positive moment M12 increases linearly as a function of wall thickness. Figure 17 shows that all the negative moments M11, M22 and M12 increase linearly as a function of wall thickness.

Figure 18 shows that the positive axial forces F11 increases linearly and F22 follows power law. Figure 19 shows that negative axial forces F11 and F22 increase linearly as a function of wall thickness.

Figure 20 shows that the positive shear forces F12 and V23 increase linearly and V13 adapts power law. Figure 21 shows that the negative shear forces F12 and V13 increase as a power function and V23 increases linearly as a function of wall thickness.

From the above discussion, it shows that the increased wall thickness increases the strength of the system in terms of axial forces, shear forces and bending moments. This should also result in reduced displacements, translations and rotations of the structure [4].

4. Conclusions

Based on the above study, the important conclusions are withdrawn as follows:

1. SCIPs are an excellent substitute of the conventional materials like bricks, concrete blocks and wooden frames.

2. The three-dimensional modeling confirms that the SCIP walls have a capacity to carry 45kips to 125kips per linear foot (**660 KN/m to 1800 KN/m**) of wall.
3. The composite system is capable to withstand 60 mph (**90 Km/h**) hurricane wind and 7.5 earthquake (Zone 4).
4. With increase in thickness of the insulation layer, the axial forces, shear stresses and the moments also increase.
5. Additionally, the poly Styrene foam could play very important role in sound insulation. The provision of the foam could also result in higher thermal mass and scaling. SCIPs reduce labor cost and skills for installation.
6. Together with the added structural performance, SCIPs are very beneficial materials for the construction in Himalayan regions, prone to extreme seismic loads and cold.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

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