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Theoretical Study on the Composite Floor Made of a Steel Space Frame and Concrete Slab

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Abstract. *This study investigates the structural behavior of composite roof systems consisting of a double-layer space frame topped with a concrete slab. The analysis focuses on the influence of joint spacing, connection types (fixed vs. bolted), and the addition of a concrete slab on the overall system performance. Twelve structural models were developed using ETABS (CSI) software, with an equal distribution between slab-incorporated and slab-free configurations. After performing numerical simulations, key parameters, including element cross-sectional areas, vertical deflections, and maximum displacements, were evaluated according to ACI 318 reinforced concrete and AISC steel design standards. The results indicate that incorporating a concrete slab into a space-frame system significantly reduces the maximum vertical deflection and allows for more efficient element sizing, especially in the top chord elements. Furthermore, models with fixed supports demonstrated greater overall stiffness and stability compared to models with pinned connections. The results confirm the critical role of slab integrity and joint stiffness in enhancing structural efficiency, improving material utilization, and ensuring compliance with contemporary design standards..*

Keywords - *Composite floor, Space frame, Concrete slab interaction, double layer grid, Cross-sectional area, Structural deflection, Parametric analysis*

INTRODUCTION

This research aims to evaluate the behavioral properties of a composite roof system, 25 m x 30 m (space frame double layer grid) and concrete slab. The model, as mentioned previously, was designed to monitor the system's response to vertical loads. A comprehensive study was conducted based on the analysis of three main components: the cross-sectional area of the structural components (HSS), the amount of vertical deflection due to loads, and the overall system response to a dead load and a live load of 1 kN/m².

After creating the numerical model using ETABS software, uses the finite element method (FEM) for its analysis. It is one of the global structural analysis and design software developed by CSI, dedicated to accurate and multiple calculations for the design and construction of composite structures (civil engineering) [1][2][3]. The model is designed and optimized by the latest international standards, namely the American Code for Reinforced Concrete (ACI 318) and the American Code for Steel Structures (AISC), to ensure the accuracy of the evaluation and the reliability of the results according to approved design methodologies [4][5][6]. The people trained in this profile should know about the business, computational tools, and statistical analysis and interpretation. Among the objectives of Information Science is to provide a means for making relevant information available to individuals, groups, and organizations involved with science and technology [7][8].

This study aims to compare the structural behavior of a system using pinned and fixed connections, as well as the presence and absence of a concrete slab, to analyze the effect of the slab on the performance of the composite system. The study also addresses the effect of joint spacing and the effect of all the aforementioned factors on the distribution of loads and the resulting deflection within the structure. This study, with dimensions of 25 x 30 meters, is of great practical importance in the field of civil engineering, as it provides results applicable to design and implementation projects.

METHODOLOGY

A computer simulation was conducted to study the effect of the presence or absence of concrete slabs, the effect of support types, external dimensions, and spacing between supports on the performance of structural systems in buildings. The simulations were conducted using ETABS, an advanced engineering software for structural analysis and modeling using the finite element method. This software is distinguished by its accuracy and flexibility in representing the structural behavior of various elements within a computer model.

The case in which the cross-section of the main structural member (25 x 30 m) was chosen as an intermediate case, representing a structural equilibrium between cases with small and large cross-sections, allowing for an accurate assessment of moderate structural behavior, the results of which can be generalized to large structural applications in buildings with moderate spans.

3.1 Modeling Scope and Setup

A total of 12 models were created, covering:
- Two joint conditions: pinned and fixed
- Two slab configurations: with and without concrete slab
- Three node spacing: 2.5 m, 3.0 m, and 3.75 m

3.2 Structural Configuration and Parameters

Double-layer grid (Top chord, Bottom chord, and Diagonal members)
Concrete slab thickness 80 mm

3.3 Loads and Boundary Conditions

Each model was subjected to equally distributed dead and live loads (1 kN dead and 1 kN live), representing service conditions for roofs. The limit conditions varied between pinned and fixed support types, consistent with the behavior of space frames in actual structures.

3.4 Analysis Outputs

The ETABS analysis provided the following primary outputs:
- Required hollow steel section sizes for each member type (top, bottom, diagonal)
- Maximum vertical displacement (UZ) at the base
- Allowable displacement verification per serviceability limit state (SLS)

RESULTS AND DISCUSSION

This study examined the effect of the presence of concrete slabs on the performance of space frame systems in buildings using a numerical analysis approach using ETABS. The case with a main member cross-section of 25 x 30 cm was chosen as an intermediate case, representing balanced structural behavior between the small and large cases.
5-1 Structural Modeling Considerations
The structural depth and module were selected according to the span-to-depth ratio for reinforced concrete systems, given by:

$$l/(d \quad) = 12 \pm 2 \qquad \ldots\ldots(4\text{-}1$$

Where:
: span length
: Total structural depth
This formula yielded a depth near 1.7 m for a 30 m span. The inclination angle between diagonals and chords was kept within 30°–60° to ensure optimal load distribution and structural efficiency.
After modeling and analyzing the models and extracting the results, several outputs were observed regarding the cross-sectional area and the maximum deflection, and comparing them with the permissible deflection found in the following tables:

Table 1. Composite space frames with diverse geometric parameters, choose HSS section.

CASE 25*30								
Dimension of floor (m)	**Depth (m)**	**Distance between two joints (m)**	**Angle (Deg.)**	**Type of joints**	**Situation space frame**	**Section (HSS) (mm)**		
						Top chord	**Diagonal member**	**Bottom chord**
25×30	1.7	2.5	53	pin	without slab concrete	**88.9*8**	**73*4.8**	**73*4.8**
					with slab concrete	**42.2*3.6**	**73*6.4**	**88.9*8**
			53	fixed	without slab concrete	**88.9*8**	**88.9*8**	**73*6.4**

					with slab concrete	**42.2*3.6**	**73*6.4**	**88.9*8**
		3	48	pin	without slab concrete	**88.9*8**	**88.9*8**	**73*6.4**
					with slab concrete	**42.2*3.6**	**73*6.4**	**101.6*8**
			48	fixed	without slab concrete	**88.9*8**	**88.9*8**	**73*6.4**
					With slab concrete	**42.2*3.6**	**73*6.4**	**101.6*8**
		3.75	42	pin	without slab concrete	**101.6*8**	**88.9*8**	**88.9*8**
					with slab concrete	**42.2*3.6**	**73*6.4**	**101.6*8**
			42	fixed	without slab concrete	**101.6*8**	**88.9*8**	**88.9*8**
					with slab concrete	**42.2*3.6**	**88.9*8**	**101.6*8**

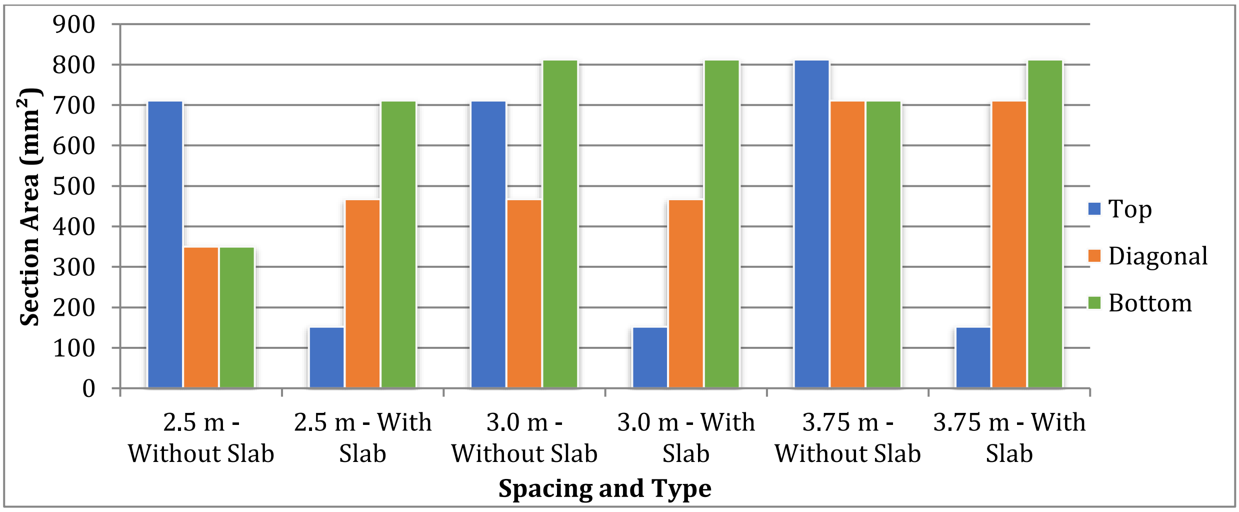

Figure 1. pinned support –section area comparison

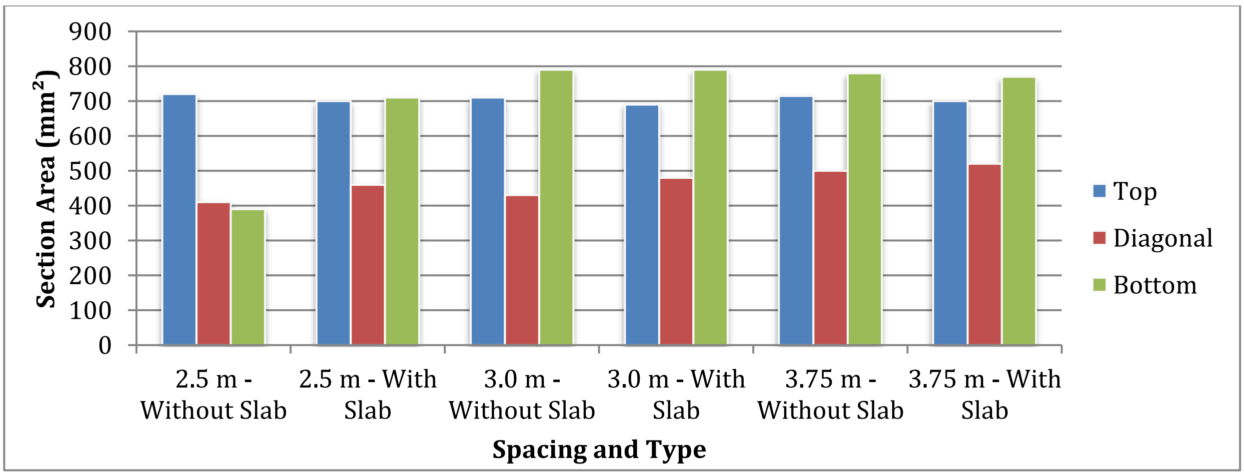

Figure 2. fixed support –section area comparison

The table 1. and diagram fig 1. and fig 2. show a comparative analysis of the required cross-sectional areas of the structural members (Top, Diagonal, Bottom) chord in the case of pinned and fixed support, at three different support spacing (2.5 m, 3.0 m, 3.75 m), and for both the presence and absence of a concrete slab. The results show that the required cross-sectional area of the top member decreases significantly when the concrete slab is present, especially at larger spacing, as a result of the slab's contribution to load-bearing and reducing the moments transferred to the steel frame. The values also show that the diagonal member is affected to a relatively lesser extent, while the requirements of the bottom member increase when the slab is present due to the redistribution of vertical forces within the system.

These results demonstrate the importance of incorporating a concrete slab in improving structural performance and reducing material consumption.

Deflection is a key indicator for assessing the stiffness of a structural system and its response to vertical loads.
In the following table, the types of fixed connections and restraints, the presence and absence of concrete slab, and the maximum displacement values under the influence of different distances are evaluated.

Table 2. Maximum displacement and comparison with the permissible code displacement

CASE (25*30)									
Dim. of floor (m)	**Depth (m)**	**Distance between two joints (m)**	**Angle (Deg.)**	**Type of joints**	**Situation space frame**	**Max Disp. (UZ) (mm)**	**Location max Disp.**	**Max Disp. (L/240)**	**Disp. check**
25×30	1	2.5	53	pin	without slab concrete	**8.995**	**Top**	**10.42**	**allowable**
					With slab concrete	**6.342**	**Top**	**10.42**	**allowable**
			53	fixed	without slab concrete	**7.91**	**Top**	**10.42**	**allowable**
					With slab concrete	**6.483**	**Top**	**10.42**	**allowable**
		3	48	pin	without slab concrete	**11.86**	**Base**	**12.5**	**allowable**
					With slab concrete	**10.78**	**Base**	**12.5**	**allowable**
			48	fixed	without slab concrete	**11.8**	**Base**	**12.5**	**allowable**
					With slab concrete	**9.785**	**Base**	**12.5**	**allowable**
		3.75	42	pin	without slab concrete	**14.59**	**Base**	**15.625**	**allowable**
					With slab concrete	**13.2**	**Top**	**15.625**	**allowable**
			42	fixed	without slab concrete	**14.45**	**Base**	**15.625**	**allowable**
					With slab concrete	**13.98**	**Top**	**15.625**	**allowable**

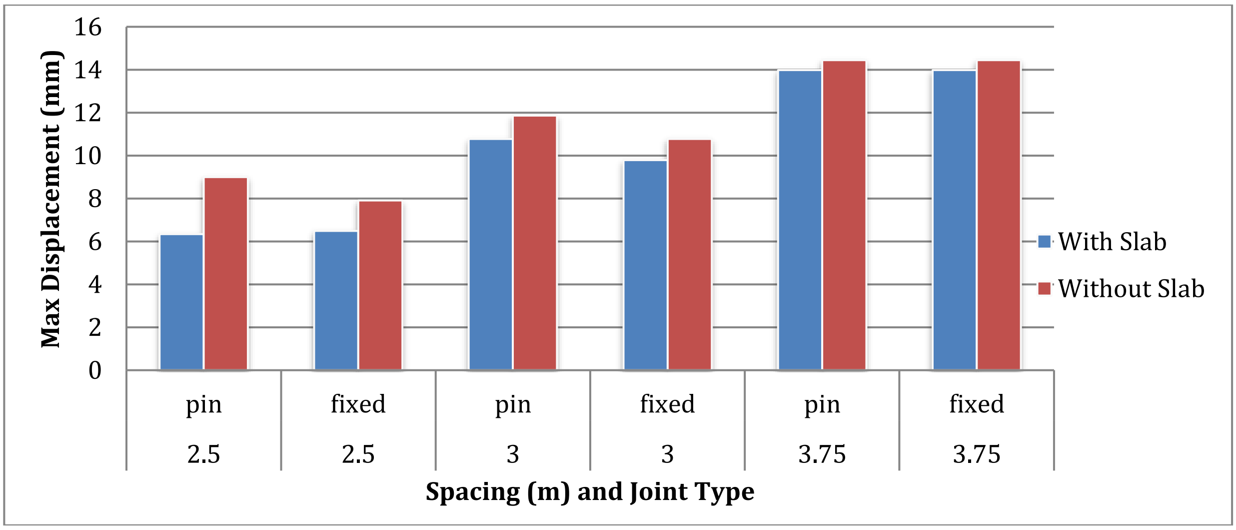

Figure 3. Effect of Slab Concrete and Support Type on Maximum Vertical Displacement

The presence of the concrete slab has been shown to significantly reduce the maximum displacement in all cases when comparing the vertical displacement values for three span lengths (2.5 m, 3.0 m, and 3.75 m), different types of supports (fixed and pinned), and slab conditions (with and without slab). This is because the presence of the concrete slab contributes to enhancing the overall stiffness of the composite system, thus improving the load distribution between the various structural elements, and increasing the overall performance efficiency of the composite structural system [9][10].

The presence of the concrete slab increases the stiffness of the system and improves load sharing among different components of the structural system, to many efficiency criteria, and enhances the performance of the structural system as a whole, composite system [11][12].

When the span length increased from 2.5 m to 3.75 m, a significant increase in deflection values was observed for all studied configurations, demonstrating a direct correlation between them. This is consistent with conventional curvature theory, which claims that the cubed length of the opening is directly proportional to the amount of deflection [13][14].

Overall, the results showed that the use of fixed supports with concrete slabs effectively and significantly reduces deflection (vertical displacement) in composite space frame (double layer grid) systems, enhancing the structural system's ability to resist vertical loads and increasing its operational efficiency [15][16].

Conclusion

Results from analyzing twelve numerical models indicated that incorporating concrete slabs into the composite system improves the system's overall stiffness and its resistance to vertical load-induced deformations, which consequently lowers vertical displacement. The use of fixed supports aids in the prevention of frame rotation, which helps to minimize deformations and increases structural performance efficiency, thus serving as a more appropriate and effective engineering substitute to pinned supports.

The results revealed a clear axial geometric relationship between the supports concerning the deformation behavior of the structural system. According to common engineering principles that relate the degree of displacement to the size of the opening, the deformation is directly proportional to the distance between the supports.

In order to improve service performance and reduce deflection, it is recommended to shorten the distance between supports or improve the structural system by using concrete slabs and rigid connections.

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