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Performance Evaluation of Concealed Beams in Reinforced Concrete Slabs: A Focus on Load-Carrying Capacity and Deflection

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ABSTRACT

The utilization of hidden beams in large span reinforced concrete slab construction has gained attention as a potential solution to mitigate excessive deflection. However, the absence of explicit mention in standard civil engineering literature, codes, and standards raises questions regarding its effectiveness. This paper presents a performance-based analysis of two different cases of slab arrangements involving hidden beams, employing REVIT and ROBOT Structure software. The analysis considers dead and live load combinations in accordance with the design guidelines specified in BS8110. The results of the performance-based analysis demonstrate a significant 10% reduction in the span moment for slabs incorporating hidden beams, indicating their potential to reduce deflection. However, the differences observed in terms of support moment, deflection, and stress patterns within the slabs are not significant. These findings suggest that the presence of hidden beams yields only a slight but meaningful impact on reducing deflection. Considering the observed benefits, it is recommended to cautiously consider the use of hidden beams in large slab construction projects. However, additional research and analysis are necessary to assess other factors such as specific project requirements, cost implications, structural integrity, and construction feasibility. Further investigations should encompass a broader range of parameters, including different load combinations, variations in hidden beam width, and comprehensive cost analysis. By conducting thorough evaluations, a more comprehensive understanding of the effectiveness and feasibility of hidden beams in reducing deflection in large slab construction can be obtained, facilitating informed decision-making regarding their utilization.

Keywords: Deflection, Hidden beam, Performance and Reinforced concrete slab

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1 | INTRODUCTION

Beams are essential structural elements that transfer loads from slabs to supporting members in building construction. In wide concrete slabs, beams are commonly used to divide them into smaller panels. The dimensions of the required beams depend on various factors, including the span and the estimated load transmitted from the slab.

Hidden beams, also referred to as concealed beams, secret beams, wide-shallow beams, flat beam, or wide-band beams, have a width-to-depth ratio greater than 2. Typically, they are constructed with the same depth as the supporting slabs, within the slab's depth. These hidden beams involve placing additional longitudinal reinforcing bars in the slab along the line where the actual beam would be present or in the middle of large span slabs to mitigate excessive deflection, with or without the use of stirrups (Shuraim, 2012; Serna-Ros, et al., 2002; Lubell et al., 2009; Conforti et al., 2015; Conforti et al., 2017). Despite their growing popularity and usage, hidden beams are not explicitly mentioned in standard civil engineering literature, codes, and standards.

The concept of hidden beams aims to distribute loads imposed on the slab, reducing excessive stresses and enabling larger spans. While some information and documentation on hidden beams have emerged since the late 2000s, research on their performance remains limited. Further investigations are necessary, given the increasing popularity and usage of hidden beams in reinforced concrete constructions.

By conducting a comprehensive assessment of the load-carrying capacity and deflection behavior of concealed beams, this research aims to contribute to the understanding and performance evaluation of hidden beams in reinforced concrete slabs.

Ozbek et al. (2020) conducted an experimental investigation to examine the limitations of hidden beams. Fourteen half-scale specimens, including conventional T-beams and hidden beams, were subjected to four-point loading until failure. The test parameters included reinforcement ratio and slab thickness. The results revealed that hidden beams were capable of reaching reference strengths after experiencing excessive deformations, although in some cases they were unable to achieve these capacities.

Helou & Awad (2014) and Helou and Diab (2014) analyzed the structural impact of hidden beams in RC slabs. Numerical findings from these studies indicated that hidden beams were generally unnecessary and inadequate. Mahmad and Raviz (2017) used ANSYS to investigate the flexural behavior of RC slabs with concealed beams, reporting significantly higher deflections in slabs supported by hidden beams. Arakere and Doshi (2015) also examined the performance of slabs with concealed beams under seismic loading, finding greater displacement compared to slabs with normal beams. They recommended using normal beams for buildings subjected to seismic loading. However, Chetan and Hemant (2017) conducted research on the performance of concealed concrete beams and suggested the use of hidden beams instead of normal beams for earthquake-prone buildings. They reported that although slabs with concealed beams had lower stiffness, the base shear was significantly reduced due to the lower mass, thereby mitigating seismic forces. The authors also noted that in multi-storey structures with long span slabs, greater deflections were observed, and concealed beams could be implemented to reduce deflection and enhance slab stiffness.

While existing literature has primarily focused on the performance of hidden beams under seismic loading, the present study aims to investigate the performance of hidden beams under dead and live loads, aligning with the design guidelines specified in BS 8110 (1997)

2 | METHODOLOGY

Modelling of Slab with Hidden Beams

To assess the performance of hidden beams under dead and live loads, the research employs a modeling and analysis approach using Revit and Robot Structures software. A 150mm thick slab, depicted in Figure 1, is created in Revit and subsequently exported to Robot Structures for detailed analysis

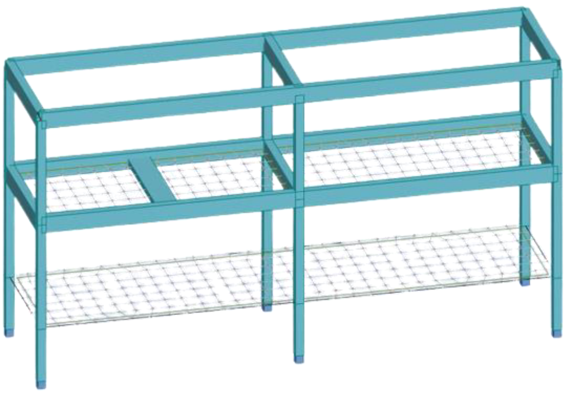

Figure 1: Slab and Beam arrangement for the Model

The study considered two cases:

Case 1:

A 7 x 3.5 m slab with a hidden beam measuring 150 x 600mm positioned at the mid span of the slab

Case 2:

A 7 x 3.5 m slab without any intermediary beam

The system is acted upon by a live load of 3.0 kN/m^2 and dead load of 22 kN/m^2 in addition to its own self weight. The periphery ledger beams have 450 x 230mm cross section while that of the supporting columns is 230 x 230mm, dead and live loads combination as recommended in BS 8110 (1997) is considered. Other design details are the compressive strength of 25 N/mm^2 and tensile strength of 460 N/mm^2 for concrete and rebar respectively.

3 | ANALYSIS AND RESULTS

Displacement in the Slabs

Figure 2 presents the displacement of the slabs under the influence of dead and live loads for the two cases examined. Upon observing the patterns and characteristics depicted in the figure, it becomes evident that the displacement of the slab in case 1 is comparable to that of case 2. This finding suggests that the presence of the hidden beam does not significantly impact the overall displacement of the slab. Interestingly, this result contradicts the findings reported by Chetan and Hemant (2017), who suggested that concealed beams could reduce slab deflection. It is important to note that the discrepancy in results may arise from variations in design parameters, slab dimensions, and load conditions between the current study and the research conducted by Chetan and Hemant (2017).

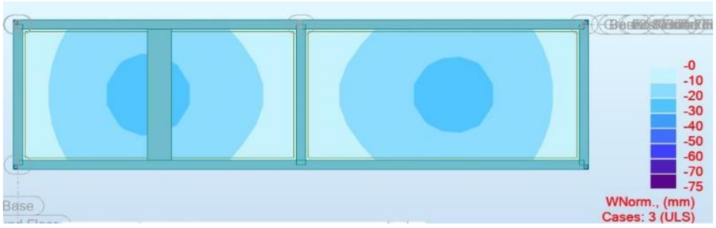

Figure 2: Displacement of Slabs under Dead and Live Loads for Cases 1 and 2.

Stress Distribution in the Slab

The stress distribution in the slab under dead and live loads is depicted in Figure 3 for both cases. It can be observed that the stress distribution patterns in both cases are remarkably similar, with the maximum stress values concentrated along the continuous edges of the slabs. This finding aligns with the results obtained by previous researchers and indicates consistent stress distribution behavior in slabs with and without hidden beams. This finding suggests that the hidden beam may not significantly alter the load-carrying capacity or structural behavior of the slab. Consequently, the effectiveness of hidden beams in enhancing the overall performance and strength of the slab is called into question

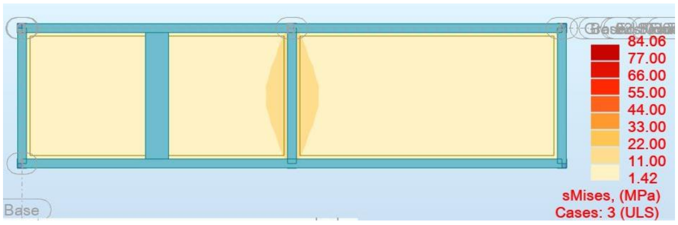

Figure 3: Stress distribution in the slab under dead and live loads for both cases

Span Moment in the Slab

The bending moment developed at the bottom of the slabs is considered and presented in Figure 4 for both cases. A similar pattern is observed, with the maximum bending moment occurring at the middle. However, in case 2, the bottom reinforcement experiences a more pronounced bending moment. A closer examination of the exact values of the bending moment in Figure 6 reveals a significant difference of up to 10% between the two cases. This finding aligns with the work of Chetan and Hemant (2017), who suggested that the presence of a hidden beam in the slab has a positive and considerable effect on the bending moment. Implication: The observed difference in the bending moment between the cases indicates that the presence of a hidden beam in the slab can have a significant impact on the structural behavior and load-carrying capacity. This implies that the use of hidden beams may be beneficial in enhancing the structural performance of slabs under loading conditions.

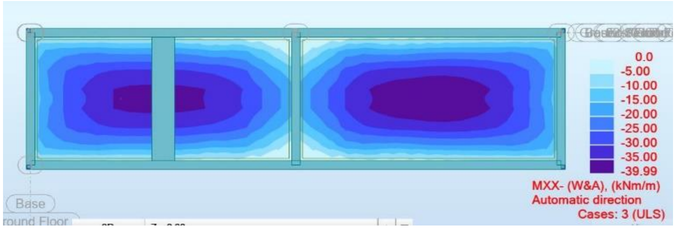

Figure 4: Bending Moment Distribution at the Bottom of Slabs for Cases 1 and 2 under Dead and Live Loads.

Figure 5: Comparison of Bending Moment Values between Cases 1 and 2

Support moments in the Slabs

Figure 6 displays the maximum support moments for the two considered cases. The observed pattern in both cases is similar, suggesting that the presence of a hidden beam in slab construction does not have a significant effect on the support moments developed. This finding implies that the addition of a hidden beam may not be necessary for altering the support moment distribution in the slab.

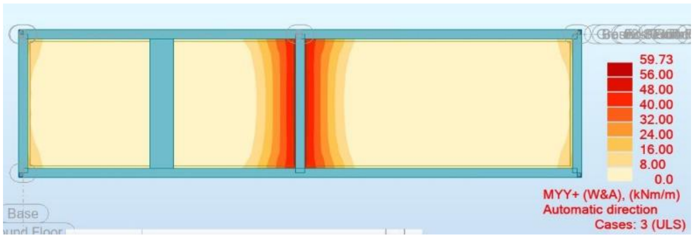

Figure 6: Comparison of Maximum Support Moments for Cases with and without Hidden Beam

4 | CONCLUSION AND RECOMMENDATIONS

Based on the analysis and findings of this study, the following conclusions can be drawn:

1. The presence of a hidden beam in reinforced concrete slabs did not significantly affect the displacement and stress distribution patterns in the slabs under dead and live loads.
2. However, a notable difference was observed in the bending moment at the bottom of the slabs, with the case without a hidden beam exhibiting higher bending moments compared to the case with a hidden beam.
3. The difference in bending moments indicates that the presence of a hidden beam can potentially reduce the span moment in slabs by up to 10%, suggesting its potential effectiveness in reducing excessive deflection in large span constructions.

Based on the findings of this study, the following recommendations are made:

1. The use of hidden beams in reinforced concrete slabs can be considered as a viable option for reducing excessive deflection in large span constructions.
2. Further studies should be conducted to determine the optimum width and placement of hidden beams in slabs to achieve the most effective utilization.
3. Cost-benefit analysis should be conducted to assess the economic feasibility of incorporating hidden beams in construction projects.
4. Design guidelines and standards should be updated to include provisions for hidden beams, considering their potential benefits in enhancing the structural performance of reinforced concrete slabs.

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