Nigerian Journal of Science and Engineering Infrastructure (NJSEI)

Volume 2, Issue 1 (2024), 1-10. Mahmud A. et al.

Concealed Beam in Reinforced Concrete Structures: A Performance-Based Analysis

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ABSTRACT

The use of hidden beams in reinforced concrete construction is seen as an effective method of reducing excessive deflection in large spans. However, despite its presumed advantages and growing usage, no mention of it in standard civil engineering literature, codes and standards. In this paper, performance-based analysis is carried out on three different cases of slab arrangement involving hidden beams using SAP2000. The process is performed under dead and live load combination and based on the design guidelines in BS8110. The result of the performance-based analysis shows a 4%, 2% and 11% decrease in deflection, stress distribution and area of bending steel reinforcement required for the case with hidden beam in comparison with the case without the hidden beam. This indicates that the presence of a hidden beam in a slab is significant. Thus, it is recommended for reducing excessive deflection in large spans, hidden beams can be introduced.

Keywords: Concealed beam, Performance, Reinforced concrete slab, SAP2000

INTRODUCTION

Beams are structural elements whose primary function is to transfer the loads from adjoining slabs to the supporting members. Where a concrete slab is very wide, beams are usually provided in between to convert them into smaller panels. The dimensions of the beam required will depend on factors which vary between the span and the estimated load transferred to the beams from the slab. A hidden beam also known as concealed beam, secret beam, wide-shallow beam, or wide-band beam is a beam whose width-to-depth ratio is greater than 2, though, in most cases it is usually

doi.org/10.61352/2024AT03

constructed having the same depth as the slab, in other words, it is provided within the depth of the supporting slabs. These hidden beams are constructed by placing additional longitudinal reinforcing bars in the slab along the line where the actual beam should have been present or in the middle of large span slabs where excessive deflection is feared and may involve stirrups or not (Shuraim, 2012; Serna-Ros, et al., 2002; Lubell et al., 2009; Conforti et al., 2015; Conforti et al., 2017). However, despite its growing popularity and usage, no mention of this type of beam in standard civil engineering literature, codes and standards. The idea of a hidden beam is to help disperse loads imposed on the slab thereby relieving the slab of excessive stresses and thus accommodating even larger spans.

Adequate information and documentation on hidden beams, especially concerning their performance, only started in late 2000, thus, research on the performance of these beams is still scanty and needs further investigations, especially with the growing popularity and usage in reinforced concrete constructions.

Ozbek et al., (2020) experimentally investigated the drawbacks of hidden beams. A total of fourteen half-scale specimens, including conventional T-beams and hidden beams, were tested for failure under four-point loading. Reinforcement ratio and slab thickness were adopted as test parameters. The results indicated that hidden beams were able to achieve reference strengths after excessive deformations or they occasionally could never achieve these capacities. Helou & Awad (2014); Helou and Diab (2014) investigated the structural influence of hidden beams in RC slabs. Numerical results from the investigations show that hidden beams are never adequate and are thus generally unnecessary. Mahmad and Raviz (2017) studied the flexural behaviour of RC slabs with concealed beams using ANSYS. They reported that the deflection of slabs supported with concealed beams was significantly more. Arakere and Doshi (2015) also studied the performance of slabs with concealed beams due to seismic loading. They reported that the displacement of a slab with concealed beam was greater compared to that with a normal beam. The researchers recommended normal beams for building under seismic loading. Contrary to previous researchers, Chetan and Hemant (2017) in their research on the performance of concealed concrete beams recommended the use of concealed beams ahead of normal beams for buildings during earthquake excitation. The authors reported that although the stiffness of the slab with concealed beams was less, the base shear was significantly lesser, since the lesser the mass, the lesser will be the seismic force. The authors also posit in their conclusion, that in multi-storey structures, if long-span slabs

doi.org/10.61352/2024AT03

are present, they tend to deflect more. Thus, concealed beams can be provided to decrease the deflection and increase the stiffness of the slab.

While the few available literature focused on the performance of hidden beams under seismic loading, the present study intends to investigate the performance of hidden beams under dead and live loads based on the design guidelines in BS 8110 (1997).

RESEARCH METHODOLOGY

Modelling of Slab with Hidden Beams in SAP2000

The concealed beam was modeled in SAP2000 using shell elements for the slab and frame elements for the beam, ensuring accurate representation of their interaction (CSI, 2021). Material properties of concrete (grade 25) and steel reinforcement (Y12) were defined following relevant codes and recommendations. A refined mesh around the beam captured stress concentrations, while fixed supports and applied dead and live loads simulated real-world conditions. A linear static analysis was performed to determine stresses, deflections, and reactions, with all procedures adhering to BS 8110 for design compliance. This detailed modeling approach laid the foundation for analyzing the structural behavior of the concealed beam system and validating its performance against engineering principles and code requirements. Thus to investigate the performance of hidden beams under dead and live loads and based on the design guidelines in BS8110 (1997), a 150mm thick slab as shown in Figure 1 is modelled and designed in SAP2000 (2021) considering three cases.

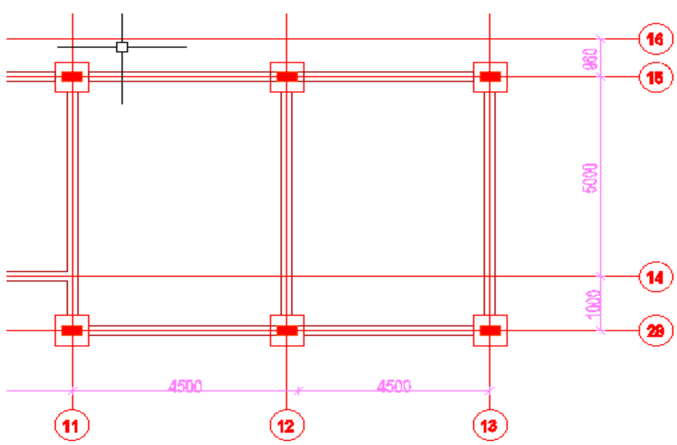

Figure 1: Slab and Beam arrangement for the Model

Case 1:

Slab with a 600x230mm dropdown beam (along gridline 12)

Case 2

Slab with a 150 x 450 mm hidden beam at the middle of the slab (along gridline 12)

Case 3

Slab without any intermediary beam

The system is acted upon by a live load of 2.0 kN/m^2 and a dead load of 5 kN/m^2 in addition to its self-weight. The slab thickness in all the cases is set to 150mm, the periphery ledger beams have 600x230mm cross-section while that of the supporting columns is 450x300mm, dead and live loads combination as recommended in BS8110 (1997) is considered. Other design details are the compressive strength of 25N/mm^2 and tensile strength of 460N/mm^2 for concrete and rebar, respectively.

RESULTS AND DISCUSSION

Deflection

The deflection of the slab under dead and live loads action is shown in Figure 2 for the three cases considered. It is obvious from the nature and patterns of the figures that the deflection of the slab for case 1 (Figure 2a) is less compared to cases 2 and 3 (Figures 2b and 2c) which show a similar pattern. However, it is observed that the deflection for case 2, especially at the edges, is quite lesser than that of case 3. Generally, a 4% decrease in deflection for case 2 in relation to case 3 is observed. The hidden beam acts like a stiffener, stiffening the slab and reducing its tendency to bend under load. Thus, as a result of the extra support, the slab bends less under load. This is crucial for maintaining a level surface, preventing bouncy floors and ensuring structural integrity. The ability of the hidden beam to handle higher loads or larger spans could allow for more open and airy spaces or reduce the need for additional support columns. This indicates that the hidden beam affects the deflection of the slab which is in agreement with the outcome of Chetan and Hemant (2017).

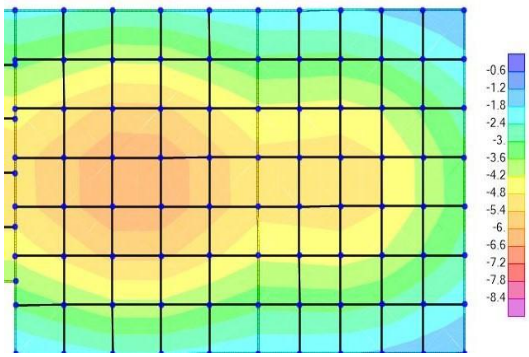

Fig. 2a: With Drop Down Beam

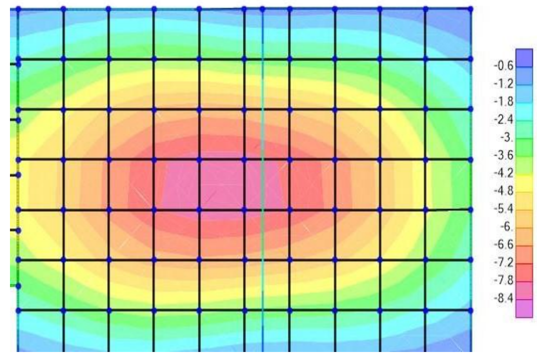

Fig. 2b: With Hidden Beam

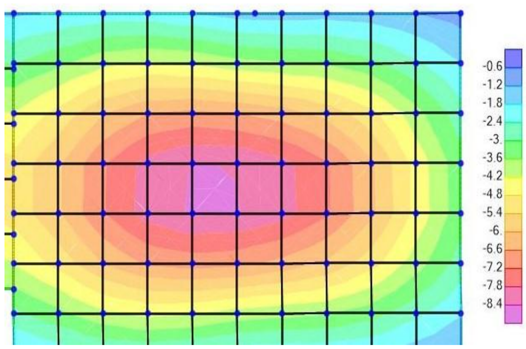

Fig. 2c: Without Beam

Stress Distribution

The stress distribution in the slab due to dead and live loads is shown in Figure 3 for all cases. The nature and pattern of stress distribution for cases 2 and 3 are very much similar, having maximum values along the edges of the slab. A 2% difference in the values of maximum stress is observed, thus indicating that the hidden beam has very little effect on the stress distribution of the slab. However, a significant stress distribution and pattern is observed in case 1. In this case, the stresses are maximum along the edges and along the dropdown beam with a maximum value far less compared to cases 2 and 3. This is because the beam shares the burden with the slab, spreading the weight more evenly across its surface thus reducing the stress on any one point and preventing cracks. This indicates that slabs are less likely to become uneven or bouncy, enhancing comfort and safety for those using the space.

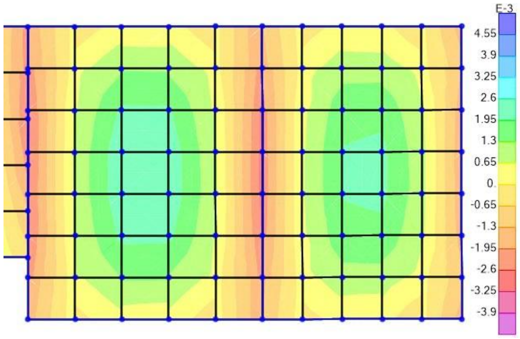

Fig. 3a: With Drop Down Beam

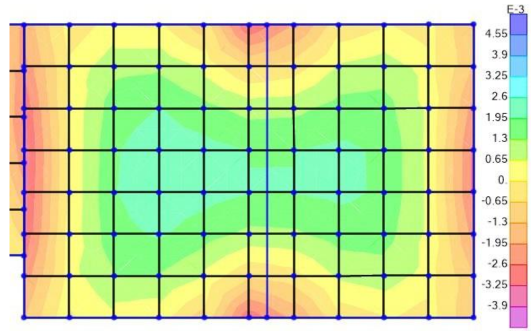

Fig. 3b: With Hidden Beam

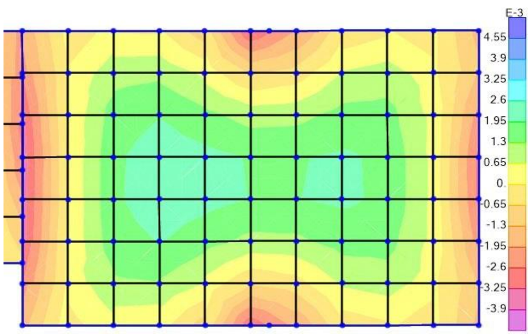

Fig. 3c: Without Beam

Area of Bending Steel Reinforcement Required

The area of bending steel reinforcement required to satisfy flexure and deflection is considered and presented in Figure 4 for all cases. Again a similar pattern is observed for cases 2 and 3, maximum values are observed at the edges for top reinforcement and the middle for bottom reinforcement as is expected. A significant difference in the area of steel reinforcement required of up to 11% is observed between cases 2 and 3. This further confirms the work of Chetan and Hemant (2017) who poised that the presence of a hidden beam in the slab has a positive effect and is considered significant. This indicates that in some cases, the hidden beam could potentially allow for thinner slabs or less reinforcement usage, leading to cost savings.

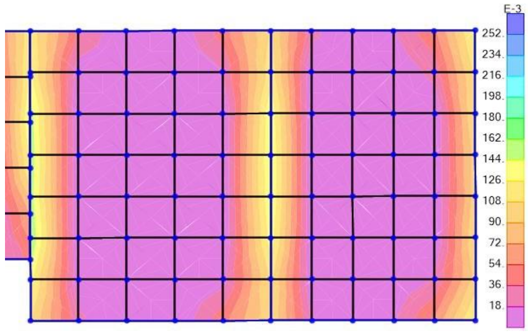

Figure 4a: With Drop Down Beam

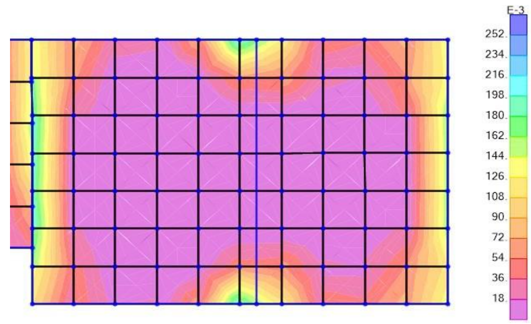

Figure 4b: With Hidden Beam

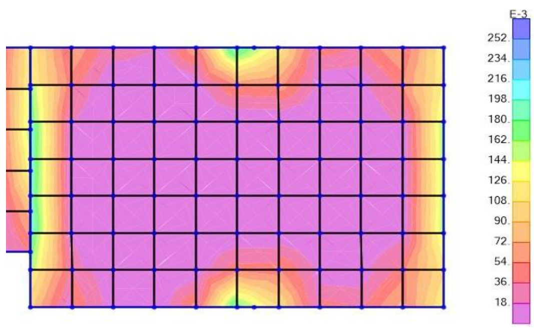

Figure 4c: Without Beam

Validation

To complement the visual insights from SAP2000, we'll now delve into the mathematical principles underpinning the concealed beam's behavior. This section demonstrates how analytical calculations corroborate the observed reductions in deflection and stress, solidifying our understanding of its structural benefits. Thus we calculate:

1. Calculate Moment of Inertia (I):

i. Plain slab:

For a slab thickness (h) of 150 mm and a width (b) of 1000 mm.

$I\_slab = (bh^3)/12 = (1000 \text{ mm} * 150 \text{ mm}^3)/12 = 2.81 * 10^{\wedge}9 \text{ mm}^4$

ii. Slab with concealed beam:

For a hidden beam depth (hb) of 150 mm.

a. $I\_beam = (hb^3)/12 = (450 \text{ mm} * 150 \text{ mm}^3)/12 = 1.27 * 10^9 \text{ mm}^4$

b. $\text{Total } I = I\_slab + I\_beam = 4.08 * 10^9 \text{ mm}^4$

2. Calculate Bending Stress (σ):

i. For a given bending moment (M):

$\sigma\_slab = M*y/I\_slab$

$\sigma\_beamed\_slab = M*y/ (I\_slab + I\_beam)$

σ_beamed_slab will be significantly lower than σ_slab due to the increased I.

3. Calculate Deflection (δ):

i. Using a simplified formula for a simply supported beam with a uniformly distributed load (w):

$\delta\_slab = 5wL^4/384EI\_slab$

$\delta\_beamed\_slab = 5wL^4/384E\ (I\_slab + I\_beam)$

δ_beamed_slab will be smaller than δ_slab due to the greater EI.

It can be seen also from this mathematical expression that the concealed beam significantly increases the slab's moment of inertia, leading to reduced stresses and deflections. The mathematical calculations demonstrate the beam's effectiveness in enhancing structural performance.

CONCLUSION

Performance-based analysis was performed on a hidden beam in a reinforced concrete slab, the result of the both numerical and analytical analysis show a significant reduction in the stress distribution and deflection required in the slab with respect to slabs with and without a hidden beam. Consequently, a hidden beam can be used to achieve reductions in stress distribution and deflection in large spans. Further investigations should be conducted to determine the optimum width of the hidden beam in slab construction and also the cost analysis, this will provide a holistic investigation of the hidden beam for the most effective utilization.

Conflict of Interest

The authors declare to conflict of interest

Authors' contribution

M. A. is responsible for the analysis and final write-up, H. A. is responsible for the conceptualization and initial drafting, and M. Y. S. is responsible for proofreading and validation.

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