Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 5, May 2024

Performance Based Analysis of The Structural Efficiency of Hidden Beams in Reinforced Concrete Structures

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***Abstract*: Hidden beams have a number of advantages to the drop beams but concern have arisen on their efficiency when used with solid slabs. They are not accounted for in the reviewed design standards and more study is needed to determine structural integrity of the structure if the hidden beams are to replace the drop beams in large spans where greater floor height clearance is required. This study involved the analysis and design of hidden beams in non- seismic regions like Kenya. It entailed modelling, analysis and design of twelve continuous slabs of a three- story moment resisting frame structure using ProtaStructure software. The Eurocodes design standards were used. Three models were employed; analysis of seven metre by six metres slabs with no partitioning beams, seven metre by six metre slabs with drop beams partitioning the slabs and seven metre by six metre slabs with hidden beams partitioning the slabs. The design of the beams was then generated and optimization carried out where the design proved insufficient. The study concluded that hidden beams cannot entirely replace the drop beams.**

***Keywords*: Hidden beams, drop beams, ProtaStructure software, Eurocode 2, Steel reinforcement**

1. INTRODUCTION

Concrete structures consist of slabs, beams, columns and the foundation. The purpose of the beams is to transfer loads from the slab to the column which then transfers to the foundation. Different codes and standards have been employed to offer guidance in design of these elements. The conventional traditional drop beam has been used and has proven efficient in transfer of loads. The depth of the beam is not limited to that of the slab and is calculated based on the span of the beam, the support conditions: cantilever, simply supported and continuous, structural systems: concrete highly stressed and concrete lightly stressed [1]. Circumstances have however arisen where architectural designs limit the use of the drop beams and necessitate the use of hidden beams.

Hidden beams are beams that have a depth that is equal to the thickness of the slab but have longitudinal bars and stirrups like a drop beam [2]. They have a depth that is lower than 350mm and a cross section that has a width over depth ratio greater than 2. Their provisions are mainly when there are large span slabs and the traditional drop beams cannot be used due to strict and rigid architectural considerations. They are beneficial since they save on floor height clearance leading to better aesthetics, simplify internal partitioning, save on materials, formwork and labour which means they are economically cheaper and free the way for horizontal electromechanical duct works [3]. They are mostly used with ribbed slabs and waffle slabs since the slabs have an added effective height of the concrete section [4].

A lot of discussions have however arisen on the efficiency of the hidden beams due to the reduced depth. In the study by [5], the reduced depth of hidden beams reduces the stiffness of the structure leading to reduced frequencies and renders the structure deficient under seismic excitation. The ductility of the beam is also altered due to the high reinforcement ratio at the column connection provided to compensate for the insufficient effective depth. Concerns have also arisen of the ability of hidden beams to overcome failure modes such as deflection. The design codes and standards have not included the design of hidden beams and have therefore not approved their use in reinforced concrete structures. There was limited study carried out directly on hidden beams prior to a study by [6] . In the article, the author states that some designers compromise the structural integrity of buildings by arranging reinforcements with similar strength to that of the adjacent slabs and claim they are reinforcement bars for hidden beam. On the contrary, a study by [7] concluded that hidden beams have less base shear than the normal beam and the lesser the mass the lesser the seismic force and therefore the hidden beam performs better during earthquake. There exists contradicting opinion on the use of the hidden beams in reinforced concrete structures and many Structural Engineers are therefore skeptical in employing hidden beams in their designs as more study is required before the hidden beams are conventionally used by all.

1. METHODOLOGY

The study involved the modelling, analysis and design of three-story structure using ProtaStructure software. Three models were generated consisting of twelve continuous slabs. Design details were: (1) 3- story moment resisting frame

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 5, May 2024

structure and a flat roof with access, (2) Floor height of 3000mm, (3) Slab height of 150mm, (4) 300*200 mm columns, (5) Floor slab permanent actions of 2.0 KN/m^2 and variable actions of 1.5 KN/ m^2, (6) Roof slab permanent actions 1.0 KN/m^2 and variable actions of 1.5 KN/ m^2, (7) f_{ck} = 25 KN/ m^2, (8) f_{yk} = 460 KN/ m^2 and, (10) Beam wall loads added to beams. Three models were analyzed and designed using ProtaStructure software using Eurocode's standards.

2.1. Model 1

Consists of 7000mm* 6000mm slabs. No beams are added to partition the slabs

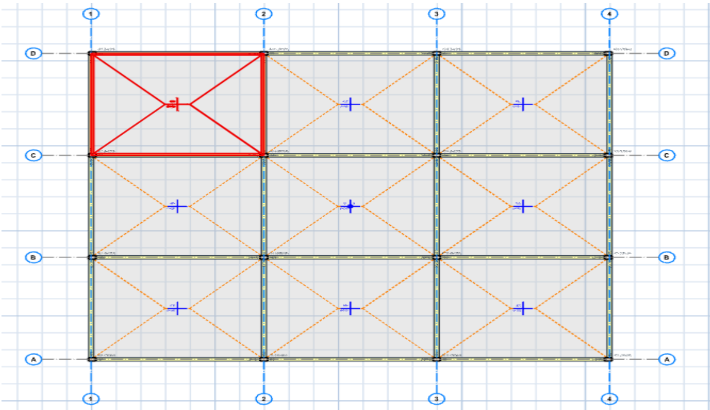

Figure 1: Model 1 layout

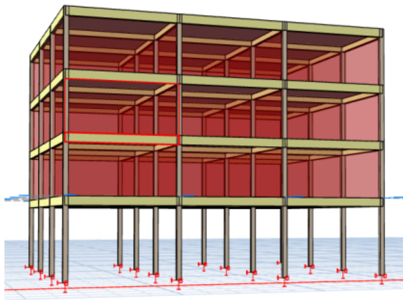

Figure 2: Model 1 3D model

2.2. Model 2

Consists of 7000mm*6000mm slabs. 200mm*450mm beams are added to partition the slabs.

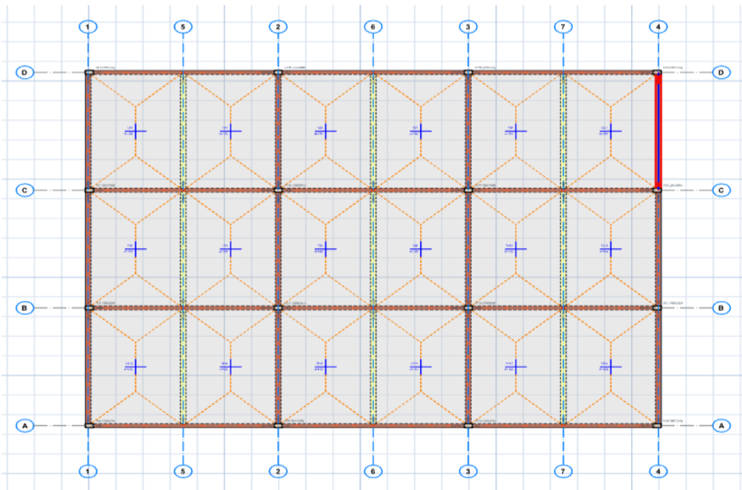

Figure 3:Model 2 layout

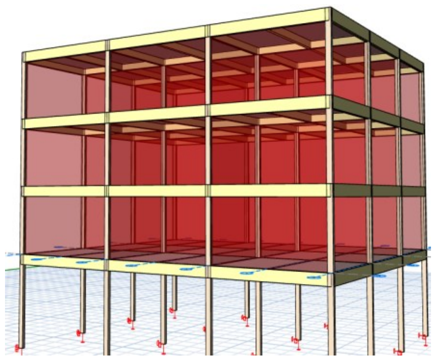

Figure 4: Model 2 3D model

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2.3. Model 3

Consists of 7000mm*6000mm slabs. 500mm*150mm hidden beams are added to partition the slabs.

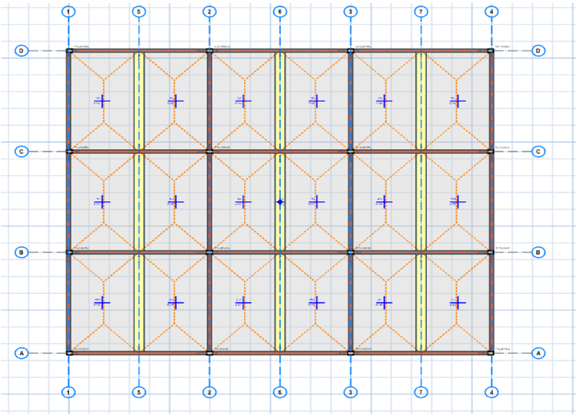

Figure 5: Model 3 layout

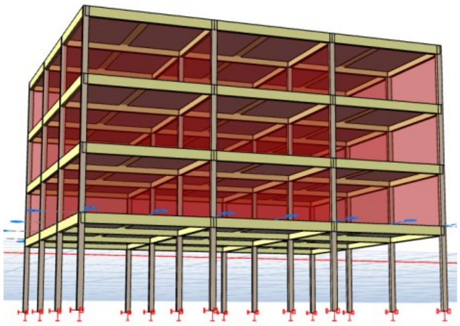

Figure 6: Model 3 3D model

2. RESULTS AND DISCUSSION

Model 1: The slabs failed in deflection with effective span to depth ratio, L/d of 49.54 greater than the allowable of 34.09. The section was therefore insufficient.

Model 2: The drop beams passed in deflection with the first span of the beam having L/d of 15.04 which was less than the allowable 36.94. The area of steel reinforcement provided was 2T16 bottom and top bars with area of steel reinforcement of 403mm^2 which was greater than the area of steel reinforcement required at the tension zone which was 331.09mm^2, 153.26mm^2 and 331.9mm^2

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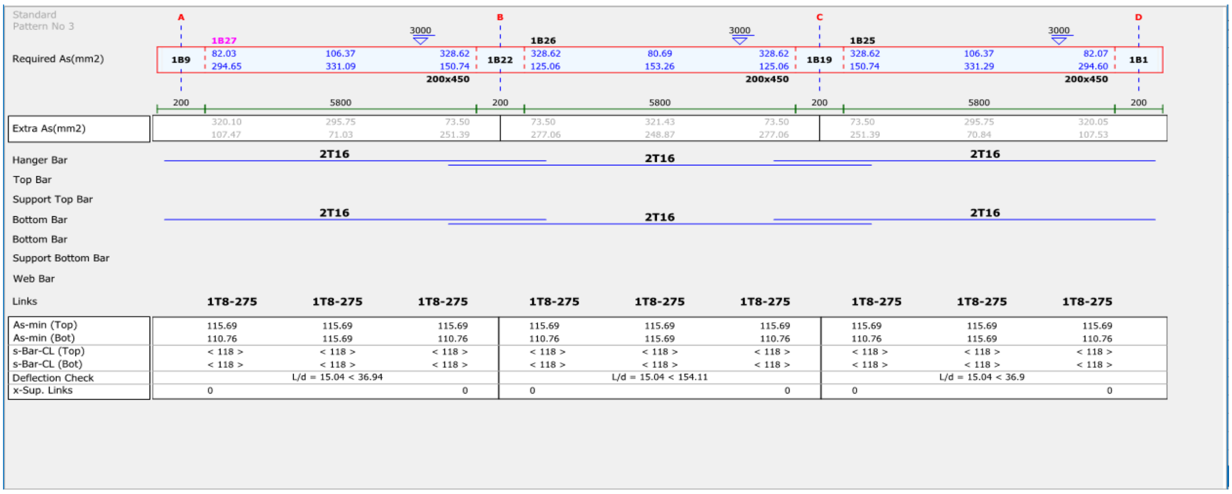

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Figure 7: Drop beam design

Model 3: The hidden beam failed in deflection with the first and third section of the beam having L/d of 63.49 which was greater than the allowable of 18.59 and the middle section having L/d of 60.61 which was greater than the allowable of 40.04. There was also high reinforcement ratio at the support of 3T32 which still did not attain the minimum area of steel reinforcement required. The area of steel reinforcement required at the tension zone was 2030.96mm, 477.12mm and 2031.03mm and at the compression zone was 10,750.78mm^2, 112.57mm^2, 10,751.34mm^2. The area of steel reinforcement provided at the tension zone was 1965mm^2, 805mm^2 and 1965mm^2 and at the compression zone was1258mm^2, 805mm^2, 1258mm^2. The area of steel reinforcement provided was therefore proven insufficient for the outer spans of the beams and efforts to optimize the sections failed.

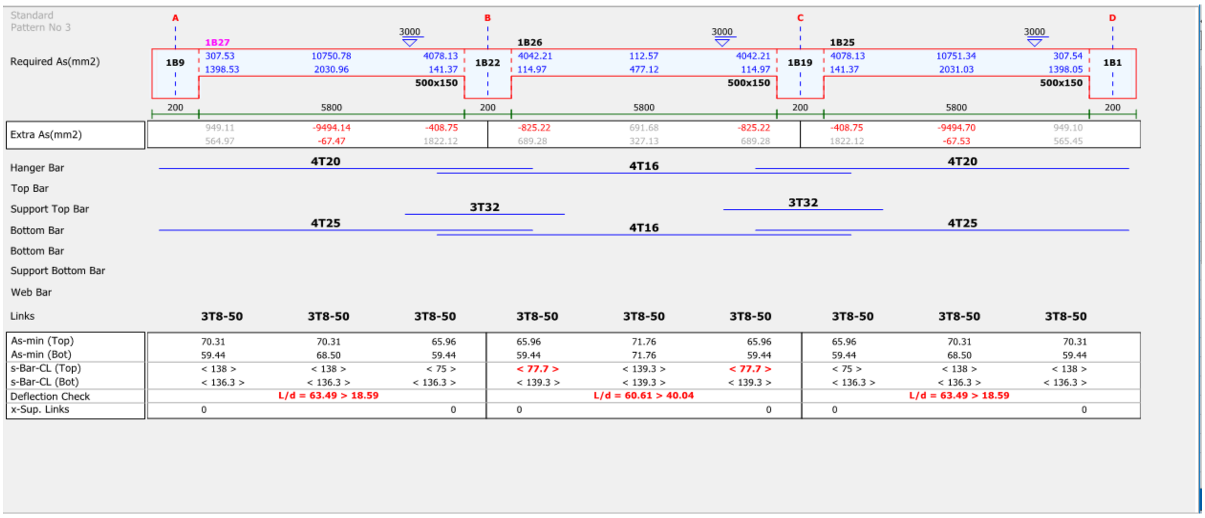

Figure 8: Hidden beam design

3. CONCLUSION AND RECOMMENDATIONS

The analysis and design generated show that the hidden beams cannot completely replace the drop beams despite their advantages compared to them. The hidden beams are susceptible to failure by deflection and even though they may not reach the ultimate limit state in non-seismic regions, they will go beyond the serviceability limit state. High reinforcement ratio was also observed at the support rendering the beam susceptible due to reduced ductility. It would therefore not be safe to completely eliminate the drop beams and replace with hidden beams in the design.

In circumstances with long slab spans, other design criteria can be employed. This would include:

I. Using one-way ribbed slabs or two-way ribbed slabs (waffle slabs)- suitable for long spans with relatively low live loads. They are lighter than the solid slabs and have a higher effective depth hence able to withstand the long spans without internal beams [8]

II. Use of flat slabs- they are a two- way concrete slabs that do not have beams and transfer the loads directly to the columns. They are employed mainly due to architectural considerations where long span slabs are needed. They are susceptible to punching shear failure which is minimized by use of drop panels or column heads or through increasing the thickness of the slab [9] In

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the study by [10], flat slabs proved to be more economical in multi- story building than the grid slab system and conventional slabs with less maximum displacement, maximum force and maximum bending than the grid slab system.

III. Use of steel-concrete composite beams with precast hollow- core slabs- suitable for long span structures due to its high bending capacity, lightweight, good ductility and quick construction [11]

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