

Effect of Load Position and Concrete Compressive Strength on Reinforced Concrete Deep Cantilever Beams

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Abstract

This study focuses on the effects of load position and concrete compressive strength on the structural response of reinforced concrete deep cantilever beams. Three groups of specimens with compressive strengths of 26, 33, and 41 MPa were analyzed. To evaluate the effect of load position, the load was applied at five locations along the cantilever portion of the deep beam, namely 100%, 80%, 60%, 40%, and 20% of the cantilever length. The study used the Finite Element Method (FEM) in ETABS, with numerical results compared to theoretical calculations based on the STM method, as required by ACI 318-25. The results showed that moving the load position from the farthest point in the cantilever part to 20% of its length increases the beam load capacity and reduces the maximum deflection by about 34-55% and 83-95%, respectively. It was also found that increasing concrete compressive strength increases load capacity and reduces deflection under different loading cases. The STM method also proved to be conservative when compared with the FEM results by about 30-67%, depending on the loading case. The novelty of this study lies in evaluating the combined influence of load position and concrete compressive strength on reinforced concrete deep cantilever beams through a comparative STM–FEM framework.

Keywords: Deep cantilever beams, Reinforced concrete, Load position, Compressive strength, Finite element analysis, ETABS; Strut-and-Tie Model (STM), and ACI 318-25.

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1. Introduction

According to ACI 318-25, reinforced concrete deep beams are structural members loaded on one face and supported on the opposite face. ACI 318-25 describes the formation of compressive load-transfer paths in the form of compression struts between the loading and support regions[1]. Reinforced concrete beams can be classified as deep beams if one of the following two conditions is satisfied: first, the clear distance between supports does not exceed four times the overall depth of the reinforced concrete beam[2]. Second, the distance between concentrated loads and the support face does not exceed twice the overall depth of the reinforced concrete beam [3] and [4].

The Strut and Tie Modelling (STM) method is commonly used, along with other advanced analysis techniques, to ensure accurate and safe design, due

to the special structural behaviour of deep beams. This concept is not limited to deep beams but also includes all deep members, such as corbels and pile caps, which consist of compression struts that transfer loads from loading points to support points[5]. In contrast, the compression and tension elements meet at the nodes. This approach, known as the Strut and Tie Model (STM) [6] and [7], has made the code definition applicable to all deep members and is considered the most suitable method for simple, accurate, and safe analysis and design[8]. Studies have also shown that horizontally curved deep beams, such as circular beams, are consistent with this STM approach [9] and [10]. Despite its clear conservatism, STM has demonstrated its ability to accommodate horizontal curvature in deep structural members while maintaining flexibility and safety.

In other words, this method has shown tangible effectiveness despite the excessive conservatism it sometimes adopts, which aims to enhance safety levels even at the expense of economic cost. Reinforced concrete deep beams are more susceptible to severe shear forces due to their limited span-to-depth ratio. They are widely used in large construction projects that require high load-carrying capacity[11]. Because of their distinctive geometric characteristics, which differentiate them from conventional beams, they continue to attract significant attention and intensive scientific research. Reinforced concrete deep beams differ from conventional beams by their short span-to-depth ratio, which gives them a high capacity to carry heavy loads [12] and [13].

The short span also contributes to improving the structure's resistance to vibrations and foundation settlement, which is vital for structures subjected to dynamic loads such as stadiums and bridges [14] and [15]. When designing these beams, several factors must be considered, the most important being their exposure to very large shear forces. In addition, deep beams do not necessarily follow the same assumptions as conventional beams [16], such as the linear shear stress distribution or the assumption that plane sections remain plane after bending (Bernoulli's hypothesis) [17]. Therefore, engineers usually resort to more complex analysis methods, such as Finite Element Analysis (FEA) and STM [18] and [19].

Reinforcement elements are of great importance in the design of reinforced concrete deep beams, since shear forces cause complex internal stresses. These loads and stresses cannot be transferred safely, and catastrophic failure cannot be avoided except through a proper reinforcement system[20]. This means that it is necessary to use the main flexural reinforcement, together with web reinforcement of both horizontal and vertical types, to ensure the stability of the structural member [21] and [22]. Reinforced concrete deep beams exhibit unique structural behaviour due to differences in their resistance mechanisms and shear stress distributions. While these beams may fail under bending moments like conventional beams, the shear-resistance mechanisms become more complex as the applied forces increase.

This resistance is affected by several factors, including diagonal cracking, aggregate interlock,

and the compressive behaviour of the struts, ties, and nodes. Therefore, understanding and predicting the behaviour of these beams is essential to ensure the structure's efficiency and safety. Since the node lies within a complex region where opposing tension and compression forces intersect, failure may occur due to node cracking, strut crushing, or tie yielding under tension.

It is well known that a cantilever beam experiences high flexural stresses due to its single support. These high flexural stresses are considered the main cause of failure in this type of beam. Conventional shear also plays an important role in the failure of such beams, as mentioned earlier, because they have only one support. Therefore, shear failure is considered one of the most important and most dangerous types of failure in cantilever beams. However, the situation is different here because the focus is on deep cantilever beams, in which a compressive strut may fail, in addition to conventional shear failure or the usual flexural failure. Therefore, this study was necessary to identify the response of such members to flexural stresses and conventional shear on the one hand, and to the crushing of the compressive strut on the other hand. Although several studies have investigated reinforced concrete deep cantilever beams, limited attention has been given to the combined effects of load position and concrete compressive strength on their structural response, using both STM and FEM approaches[23]. Furthermore, a comprehensive comparison between STM predictions and nonlinear FEM results for different load positions remains insufficiently addressed in the literature. Therefore, the present study aims to fill this gap.

2. Finite Element Modelling with ETABS Software

The study used numerical analysis based on the Finite Element Method in ETABS to investigate the effects of changing load position (X) and concrete compressive strength (f'_c) on the structural behaviour of deep cantilever reinforced concrete beams, in terms of load capacity and maximum deflection. The study methodology included the analysis of three main groups of specimens considering concrete compressive strengths of 26, 33, and 41 MPa, where each group was represented by several loading cases through changing the load position along the cantilever part to values of 2, 4, 6, 8, and 10 m, i.e., 20, 40, 60, 80, and 100% of the

cantilever length (L), to investigate the influence of this parameter in detail, as shown in Fig. 1.

The design of all models was carried out in compliance with ACI 318-25 provisions. The geometric dimensions were kept constant for all specimens to ensure accurate comparison, with a height (h) of 5 m and a width (b_w) of 1 m. The same general properties of the member were adopted, and the numerical analysis was used to calculate ultimate load resistance and peak deflection. Then, a finite element size of 24 mm was adopted following a series of mesh sensitivity analyses. In order to reach the optimum size that achieves a balance between result accuracy and avoiding any waste of effort and time. A fixed boundary condition was assigned at the cantilever support. At the same time,

the external load was introduced as a concentrated force acting at different locations along the beam length. As for the reinforcement, it was arranged as a reinforcement mesh consisting of $\varnothing 12$ bars spaced at 300 mm in both orthogonal directions, with 8 main 25 mm bars at the top of the beam and 4 16 mm bars at the bottom. The Strut-and-Tie Method (STM) adopted in this study was implemented in accordance with the provisions of ACI 318M-25. The design and evaluation of struts, ties, and nodal zones were performed in accordance with the requirements specified in Chapter 23 of the code. Therefore, the analytical procedures and design assumptions are fully consistent with the current ACI 318M-25 provisions.

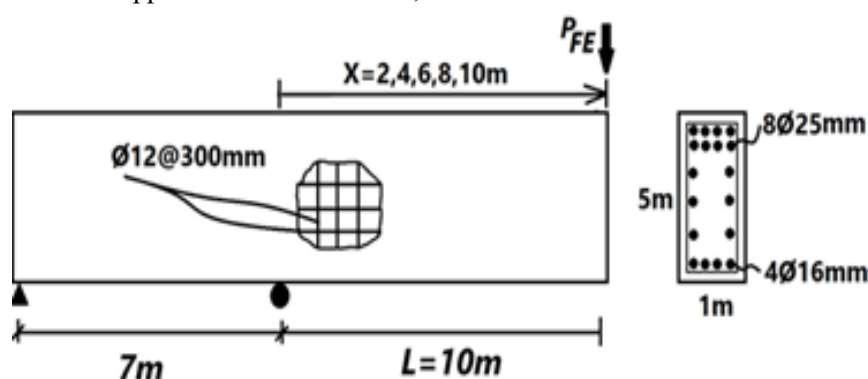


Fig. 1 Cantilever beam specimen details.

2.1 Verification of ETABS analysis results

The validity of the numerical analysis was confirmed by comparing it with the experimental results reported in Reference [25], Fig. 2, due to the scarcity of studies on the effect of changing the load position along the cantilever section of reinforced concrete deep beams. The comparison included the main structural parameters, namely the load capacity and the maximum deflection values. The numerical analysis was carried out using the ETABS finite element software, while maintaining the same geometry, material characteristics, boundary conditions, and loading scheme adopted in the reference investigation. The comparison demonstrated a satisfactory correlation between the experimental observations and numerical predictions, with differences within acceptable engineering limits and not exceeding 10%, as shown in Table 1. This agreement demonstrates ETABS's accuracy in representing the nonlinear behaviour of

deep beams. It should be noted that the reference specimens were classified as fully deep beams, and the results confirmed the software's accuracy and applicability in dealing with this type of structural member.

The FEM used in the current study performed a nonlinear static analysis (Pushover analysis), enabling accurate representation of the nonlinear behaviour of concrete and reinforcing steel, including crack development, post-cracking stiffness degradation, and reinforcement yielding. To ensure accurate analysis of the disturbed regions (D-zones), especially at support points and load application locations, a suitable finite element discretization was adopted through a mesh sensitivity study involving several element sizes and comparison of the resulting peak loads P_{FE} (the highest converged load attained during the nonlinear pushover analysis) and the corresponding deflections (Δ).

Table 1: Finite element verification.

No.	Parameter	Experimental [25]	Numerical	Difference
1	load capacity	998.7	998.7	9.5%
2	Maximum deflection	0.68	0.68	9.7%

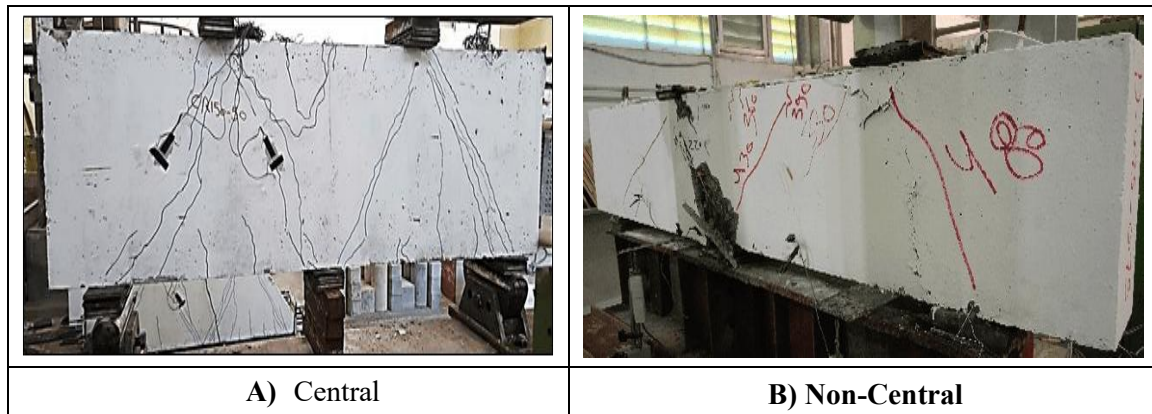


Fig. 2 Reference specimen used for verification of the ETABS model [25].

2.2 Material Characteristics

In the current research, numerical models of reinforced concrete beams were developed, using concrete and reinforcing steel as the primary structural materials to accurately represent the material properties of each test specimen. As shown in Table 2, the adopted material parameters included Poisson's ratio, the specified concrete compressive strength (f'_c), the tensile strength of concrete (f_t), the elastic moduli of concrete (E_c) and steel

reinforcement (E_s) and reinforcing steel (E_s), together with the yield strengths assigned to the flexural and shear reinforcement (f_y and f_{ys}). Concrete was modelled using nonlinear material properties capable of simulating cracking and compressive behaviour, while reinforcing steel was assumed to exhibit elastic-perfectly plastic behaviour. The adopted nonlinear material assumptions enabled realistic simulation of the structural response up to failure.

Table 2: Properties of the materials utilized.

Concrete				Reinforcing Steel		
f'_c (MPa)	E_c (MPa)	f_t (MPa)	Poisson's ratio (v)	f_{ys} (MPa)	f_y (MPa)	E_s (MPa)
26	23965	2.85	0.31	420	430	200000
33	26999	3.21				
41	30094	3.58				

2.3 Finite element study cases

A total of fifteen specimens were considered to perform a detailed assessment of the effect of changing the load position along the cantilever part, as illustrated in Table 3 and Fig. 3. The investigated specimens were divided into three principal groups according to the adopted concrete compressive strength level, with values of 26, 33, and 41 MPa for

the first, second, and third groups, respectively. To facilitate the analysis process, the study adopted a simplified designation system for the specimens, in which the letter (C) denotes the cantilever concrete beam, and the letter (D) denotes the deep beam. The compressive strength and load position are provided. A mesh size of 50 mm was selected after several trial analyses to ensure stable numerical results while maintaining reasonable computational

efficiency. The selected mesh produced consistent load-deflection responses and stress distributions throughout the numerical investigation.

Table 3: Finite element study cases.

Group	Specimen	Load Position X (m)	Compressive Strength (f'_c) MPa
Group A	CD26-2	2	26
	CD26-4	4	
	CD26-6	6	
	CD26-8	8	
	CD26-10	10	
Group B	CD33-2	2	33
	CD33-4	4	
	CD33-6	6	
	CD33-8	8	
	CD33-10	10	
Group C	CD41-2	2	41
	CD41-4	4	
	CD41-6	6	
	CD41-8	8	
	CD41-10	10	

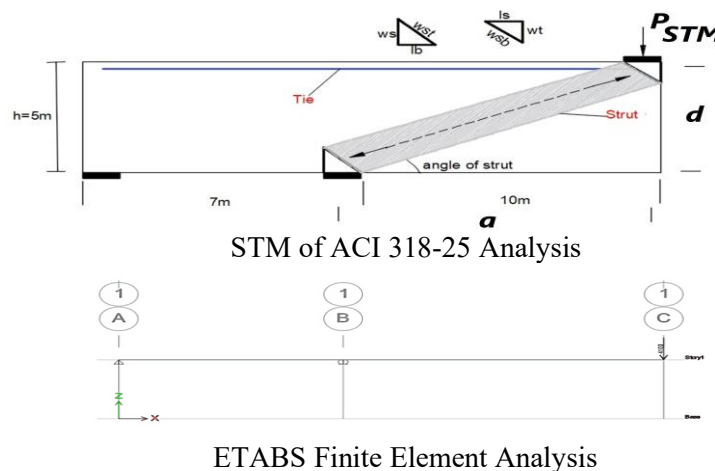


Fig. 3 Analysis of Specimens

3. Effect of changing load Position

Changing the load position along the length of the cantilever part of the deep beam modifies the shear span-to-effective depth ratio (a/d) of the deep beam Fig. 3. Variations in the a/d ratio alter the inclination angle of the strut-and-tie mechanism, and accordingly, the values of the vertical and horizontal components of the strut change. Here, the strut represents the main compressive load-transfer path through which the applied load is transmitted toward the support. If the angle increases, that is, if the applied load is shifted toward the support region, the vertical component of the strut increases, which makes the beam have a higher load-carrying capacity. On the other hand, if the angle decreases, the strut's vertical contribution to the compression

force decreases, and therefore its resistance decreases. At the same time, from a flexural point of view, if the angle increases, the flexural stresses decrease because the moment arm decreases; conversely, when the angle decreases, the moment arm increases, the bending moments increase, and the beam resistance decreases.

3.1 Effect of Changing Load Position When the Compressive Strength is 26 MPa (Group A)

The obtained results indicated that the structural behaviour of deep beams is significantly affected by changes in load position along the cantilever portion. At a concrete compressive strength of 26 MPa, the highest load capacity of 5500 kN was recorded when the load was applied near the support at a distance of

$X=2$ m. As the load moved away from the support, this value gradually decreased until it reached 4100 kN at a distance of $X=10$ m, representing a reduction of about 25% of the maximum load capacity Fig. 4.

This behaviour is attributed to the elongation of the load transfer path and the reduction in the efficiency of forming the direct compressive strut, which, in turn, leads to a decrease in arching action. A large increase in the maximum deflection at the

free end was also observed as the applied load was relocated farther from the support. The deflection increased from 7.734 mm at $X=2$ m to 47.075 mm at $X=10$ m, that is, an increase of about six times (500–510%), as shown in Fig. 5. This can be explained by the moment effects resulting from the increase in the lever arm, which leads to a reduction in the effective stiffness of the structural member and an increase in deformations.

Table 4: Numerical Results for all specimens.

Group	Specimen	Load Position X (m)	Compressive Strength (f'_c) MPa	Load Capacity P_{FE} (kN)	Maximum Deflection Δ (mm)	ACI 318-25 P_{STM} (kN)	P_{FE}/P_{STM}
Group A	CD26-2	2	26	5500	7.734	3800	1.447
	CD26-4	4		5400	18.391	2850	1.894
	CD26-6	6		5350	31.300	2100	2.547
	CD26-8	8		5200	44.678	1700	3.058
	CD26-10	10		4100	47.075	1450	2.827
Group B	CD33-2	2	33	6050	7.551	4200	1.440
	CD33-4	4		5900	17.836	3600	1.638
	CD33-6	6		5500	28.562	2650	2.075
	CD33-8	8		5200	39.658	2150	2.418
	CD33-10	10		4300	43.824	1840	2.336
Group C	CD41-2	2	41	6800	2.245	4750	1.431
	CD41-4	4		6700	17.234	4500	1.488
	CD41-6	6		6500	30.749	3300	1.969
	CD41-8	8		5500	37.632	2650	2.059
	CD41-10	10		4400	40.573	2280	1.929

3.2 Effect of Changing Load Position When the Compressive Strength is 33 MPa (Group B)

It was found that changing the position of the concentrated load on the cantilever section clearly affects its structural behaviour, with the maximum load capacity of 6050 kN achieved when the load was placed near the support at a distance of $X=2$ m. As the load position was gradually moved until it reached $X=10$ m, this capacity decreased to 4300 kN, that is, by a reduction of about 29%, as shown in Fig. 4. This reduction is mainly due to the decrease in the efficiency of forming the direct compressive strut, which weakens the arching action, in addition to the increase in the length of the load transfer path.

It was also observed, as shown in Fig. 5, that when the load moved away from the support, a noticeable increase was recorded in the maximum deflection value at the free end, where the deflection increased by about 480%, rising from 7.551 mm at $X=2$ m to 43.824 mm at $X=10$ m. This behaviour can be explained by the fact that, as the lever arm

increases, the bending moment increases, leading to a reduction in the beam's effective stiffness and a proportional increase in deformations.

3.3 Effect of Changing Load Position When the Compressive Strength is 41 MPa (Group C)

The results showed that changing the load position along the cantilever section can clearly affect the structural behaviour of the beams. When the load was applied at a distance of $X=2$ m, the highest load capacity value of 6800 kN was recorded. This value gradually decreased as the load moved toward the free end, reaching 4400 kN at a distance of $X=10$ m, as shown in Fig. 4. This reduction is estimated at 35%. This is due to an increase in the load transfer distance and a reduction in the efficiency of direct compression strut formation, leading to a weakening of arching action within the structural member. Also, as shown in Fig. 5, a large increase in the maximum deflection at the free end occurred. At a distance of $X=2$ m, the deflection value was 2.245 mm, whereas at a distance of $X=10$ m, a deflection of 40.573 mm

was recorded; that is, the increase ranged between 1700% and 1800%. This behaviour is explained by

the increasing effects of shear and flexure as the moment arm increases.

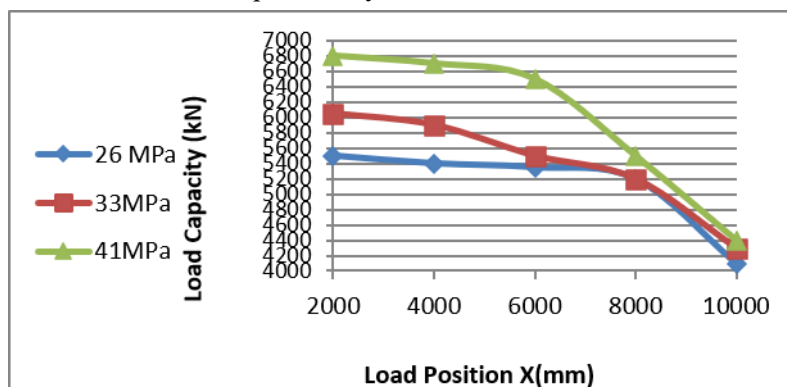


Fig. 4 Effect of load position on the ultimate load capacity of reinforced concrete deep cantilever beams.

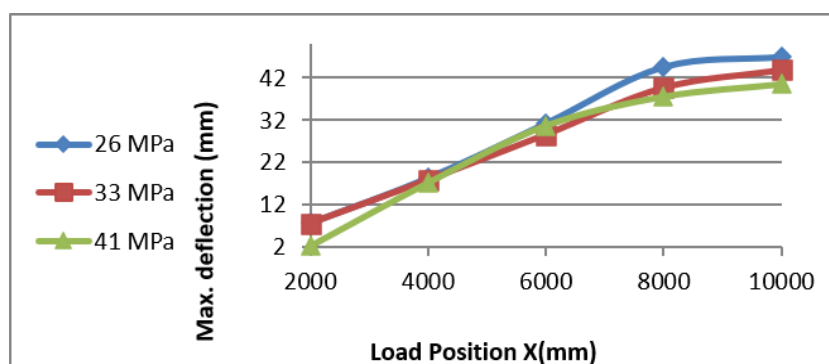


Fig. 5 Effect of load position on the Maximum deflection of reinforced concrete deep cantilever beams.

3.4 Effect of Increasing the Compressive Strength of Concrete

The results are presented in Figs. (6–10) show that raising the concrete compressive strength from 26 MPa to 33 MPa and subsequently to 41 MPa (i.e., by 58%) resulted in a consistent enhancement of load-carrying capacity for all investigated models. However, the degree of this improvement depends greatly on the load position. When the load is close to the support at a distance of ($X = 2$), the load capacity increases by approximately 24%, rising from 5500 to 6050 kN and then to 6800 kN. In contrast, this effect becomes less pronounced as the loading distance increases. For example, at a distance of $X = 10$ m, the capacity increased from 4100 kN to 4300 kN, then to 4400 kN, a relatively slight increase of about 7%.

This indicates that the effect of concrete strength decreases when flexural behavior becomes dominant over shear behavior in the structure. The increase in load capacity is attributed to the high efficiency of internal force transfer within the STM, where the

performance of the struts and nodes depends directly on the material's compressive properties. As for the deflection, the maximum deflection values at failure loads generally decrease with increasing concrete strength at the same load position. At $X=2$ m, the deflection decreased from 7.734 mm to 7.551 mm and then to 2.245 mm, i.e., 71%, which reflects a noticeable improvement in stiffness. Similarly, the deflection at $X=10$ m decreased from 47.075 mm to 43.824 mm and then to 40.573 mm (14%). However, the values remained very high because of the dominance of flexural effects.

Moreover, the theoretical results of STM (P_{STM}) indicate a continuous increase with the rise in concrete strength, as the predicted values rose from 3800 kN to 4200 kN and subsequently reached 4750 kN at ($X = 2$ m), i.e. 25%, which confirms the existence of a clear direct relationship between concrete compressive strength and the performance of the strut-and-node system. However, this effect diminishes at large load distances, where flexural requirements and the cantilever action govern the

overall structural response. The comparison between STM and FEM indicates that STM can be effectively used during preliminary design stages due to its simplicity and reasonable accuracy. In contrast,

FEM provides a more detailed representation of stress distribution, cracking behaviour, and deformation patterns.

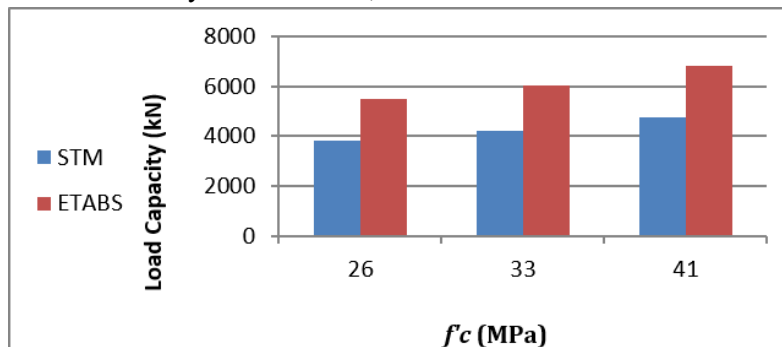


Fig. 6 P_{FE} and P_{STM} comparison when Load Position X = 2 m.

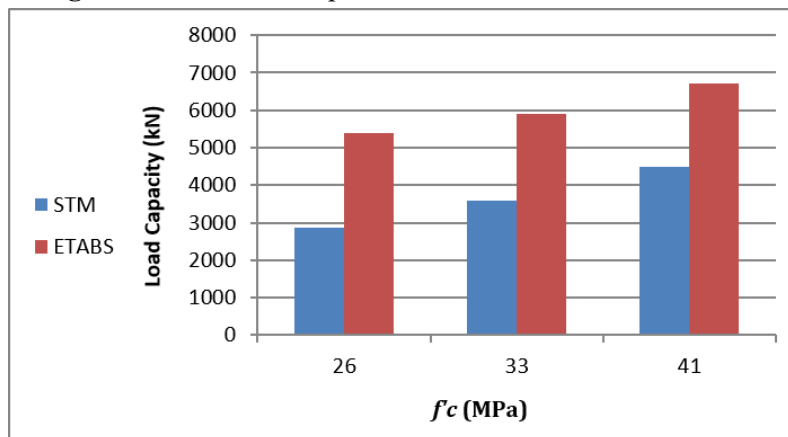


Fig. 7 P_{FE} and P_{STM} comparison when Load Position X=5m.

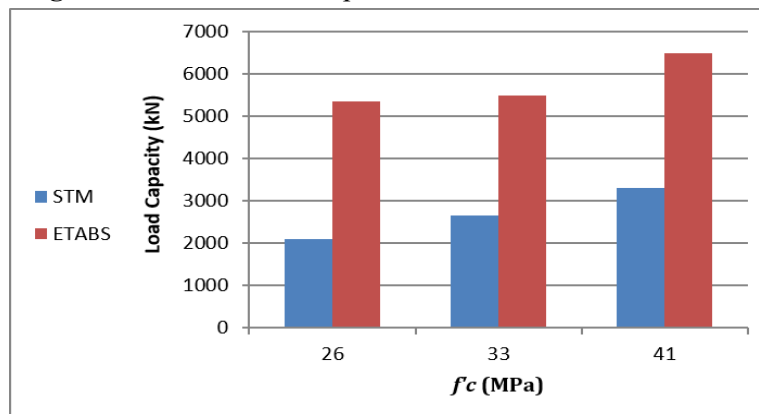


Fig. 8 P_{FE} and P_{STM} comparison when Load Position X = 6 m

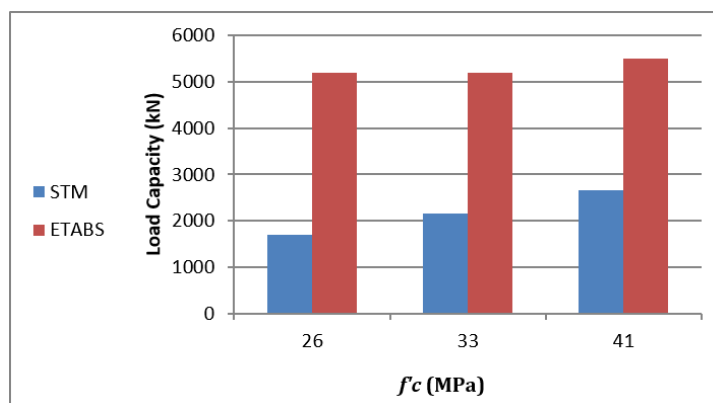


Fig. 9 P_{FE} and P_{STM} comparison when Load Position $X = 8$ m

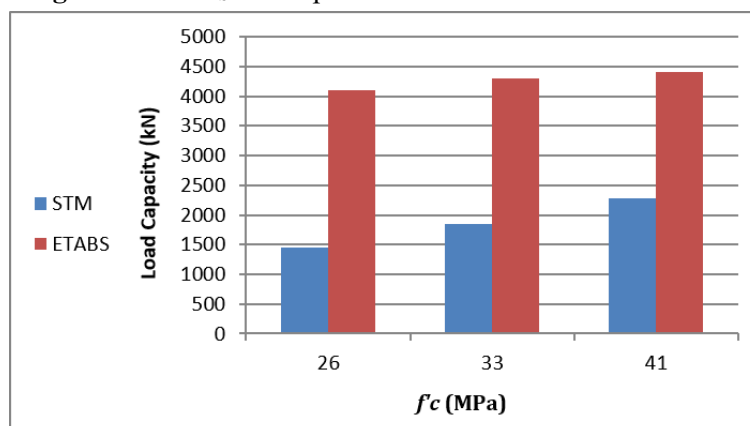


Fig. 10 P_{FE} and P_{STM} comparison when Load Position $X=10$ m

4. Discussion

The results clearly show that the load position is one of the most important factors affecting the structural behaviour of reinforced concrete deep cantilever beams. For all levels of concrete compressive strength, it was found that moving the load away from the support toward the free end continuously reduces the maximum load capacity. The reduction in ultimate load capacity with increasing load eccentricity can be attributed to increased bending effects and modifications to the internal load-transfer mechanism. As the load moves toward the free end, the compression strut becomes less efficient, leading to lower load-carrying capacity and larger deflections. For example, the load capacity decreased from 5500 kN at $X=2$ m to 4100 kN at $X=10$ m for a strength of 26 MPa, from 6050 kN to 4300 kN for 33 MPa, and from 6800 kN to 4400 kN for 41 MPa.

This percentage ranges between 25% and 35%, depending on the concrete's strength. Here, the location of the load becomes clear, and how it affects the mechanism by which internal forces are transferred through this behaviour. When the load is near the support, the STM method is used to create direct compression elements. Consequently, the

bending effect will be stronger. Conversely, as the distance from the load increases, the load transfer path lengthens, thereby decreasing the STM's efficiency and increasing the effect of bending moments on the structure's response.

The results clearly showed that the maximum deflection occurs at the free end as the load placement distance increases; thus, when the load was placed at $x = 10$ m, the deflection reached its maximum. When the load was placed at $x = 2$ m, the lowest deflection was recorded. For example, when the concrete strength was taken as 41 MPa, the deflection increased from 2.245 mm to 40.573 mm. This significant increase indicates a reduction in the effective stiffness of the structural element as a result of the increasing flexural moments caused by the longer moment arm.

The percentage ranges between 25% and 35%. This percentage depends on the concrete strength. In this case, the load location becomes apparent, as well as how it affects the organization of the mechanism by which the internal force is transferred through this behavior. When the load is near the support, the STM approach becomes active, forming

direct compression members that strengthen the arching effect. In contrast, as the distance to the load location increases, the load-transfer path lengthens, thereby decreasing the STM's efficiency. At the same time, the effect of bending moments on the structural response begins to increase.

The results clearly showed that the maximum deflection occurs at the free end as the distance to the load increases. When the load was placed at a distance of $x = 10$ m, the highest deflection value was recorded, whereas when it was placed at a distance of $x = 2$ m, the lowest deflection value was recorded. For example, when a concrete strength of 41 MPa was considered, the deflection increased from 2.24 mm to 40.57 mm.

An increase in load capacity was also observed at all loading points with increasing compressive strength, through improved nodal action and compressive struts. However, this effect diminishes at larger loading distances, where flexural behaviour becomes dominant, indicating that the load-transfer mechanism within the structural element directly affects the extent to which increased concrete strength is effective.

The results of the STM confirmed a direct relationship between concrete strength and the efficiency of the struts and nodes. Although this model significantly underestimated the load capacity, especially as the load moved away from the support, it successfully simulated the general behavioural pattern. Nevertheless, the model remains a useful tool for identifying the main load-transfer paths and for providing conservative design estimates.

In conclusion, the results confirm that controlling the load position is a key variable in enhancing structural performance. While moving the load toward the free end reduces strength and increases deformation, bringing it closer to the support significantly increases capacity and reduces deflection. Accordingly, increasing the concrete compressive strength alone is not as effective as improving the load position.

From the standpoint of structural mechanics, the behaviour of deep beams is governed by the development of compression struts, which may undergo abrupt brittle crushing under high stresses. This mode of failure differs fundamentally from flexural failure, which is characterized by ductility.

Therefore, understanding the effect of load position on the formation of these struts is vital for safe and efficient design.

The load capacity increases with increasing concrete strength across all loading cases, due to improved performance of the nodes and compression members. This effect gradually decreases as the load is placed farther from the support, because flexural behaviour becomes stronger and starts to govern. Accordingly, the load-transfer mechanism within the structural member directly affects the effectiveness of the increased strength.

The results of the Strut-and-Tie Models (STM) confirmed a strong correlation between concrete compressive strength and strut-and-node mechanism performance. Although the STM noticeably reduced load capacity as the load moved away from the support, it successfully simulated the general behaviour pattern. Therefore, the model remains a useful tool for providing safe design and identifying the main load-transfer paths.

The results showed that controlling the load position is a key factor in improving structural performance. While moving the load toward the free end reduces strength and increases deformation, bringing it closer to the support increases load-carrying capacity and reduces deformation. Based on this, increasing the concrete compressive strength alone is not as effective as improving the load position and its influence. From the perspective of structural mechanics, the behaviour of deep beams is governed by the formation of compression struts, which may suddenly undergo brittle crushing under high stresses. This failure mode differs fundamentally from flexural failure, which is characterized by ductility. Therefore, understanding the effect of load position on the formation of these struts is highly important for safe and efficient design. The findings of this study apply to structural elements such as bridge pier caps, transfer girders, corbels, offshore structures, and heavily loaded industrial members where deep cantilever action is commonly encountered.

5. Conclusion

From the study results and the provisions specified in ACI 318-25, it is clear that both the concrete compressive strength and the load position affect the behaviour of reinforced deep cantilever beams. However, the study showed that the load position is

the most influential variable affecting both deflection and load-carrying capacity. The following is a summary of the main findings obtained:

1. The behaviour of reinforced concrete deep cantilever beams is significantly affected by both the load location and the compressive strength. However, the load location was the more influential variable. Moving the load toward the free end reduces the load capacity. It increases deformation, whereas bringing it closer to the support enhances load capacity and reduces deflection. Depending on the concrete strength, the percentage reduction in load capacity ranged between 25% and 35%. The load decreased from 5500 kN at $X = 2$ m to 4100 kN at $X = 10$ m (25%) in the group with $f'_c = 26$ MPa, from 6050 kN to 4300 kN (29%) in the group with $f'_c = 33$ MPa, and from 6800 kN to 4400 kN (35%) in the group with $f'_c = 41$ MPa.
2. As the load location moved further from the support point, the deflection increased; the lowest values were recorded near the support, and the highest values at the free end. The deformation in the group of $f'_c = 26$ MPa increased by about 500–510%, that is, about six times, from 7.734 mm at $X = 2$ m to 47.075 mm at $X = 10$ m. It increased by 480% in the group of $f'_c = 33$ MPa, from 7.551 mm to 43.82 mm, and by about 1700–1810% in the group of $f'_c = 41$ MPa, from 2.245 mm to 40.573 mm. Due to the increased flexural effect with increasing arm moment, this rise reduced the effective stiffness.
3. By forming effective direct-compressive struts, placing the load near the support enhances arching action. In contrast, as the load distance increases, the (a/d) ratio rises, and the arching action becomes weaker.
4. Increasing concrete strength improved load capacity across all loading cases. However, the load location significantly affected the magnitude of this improvement. The load capacity increased from 5500 kN to 6050 kN, then to 6800 kN, at f'_c from 26 to 41 MPa (i.e., by 58%). In contrast, the increase was only 7% at $X = 10$ m, rising from 4100 kN to 4300 kN, then to 4400 kN. This indicates that when flexural behaviour becomes stronger than shear behaviour, the influence of compressive strength decreases. Likewise, the deflection decreased by

71%, from 7.734 mm to 2.245 mm, at apparent PFE/PSTM ratios ranging from 1.431 to 3.058 across all cases, indicating that the STM results per ACI 318-25 were conservative and provided a safe limit for design purposes.

5. The influence of load position was found to be more significant than the increase in concrete compressive strength in affecting the ultimate load capacity and deformation behaviour of deep cantilever beams.

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