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Structural Design Considerations for a three-span Beam-Column RC Structure with a significantly longer middle span

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ABSTRACT : *Designing a reinforced concrete (RC) beam-column structure with three spans, where the middle span is at least three times longer than the adjacent spans, poses significant engineering challenges. This structural configuration leads to non-uniform load distribution, increased bending moments, shear forces, and deflections, particularly in the longer middle span. This paper explores the typical structural design considerations for such a configuration, focusing on load distribution, reinforcement detailing, deflection control, potential issues related to differential settlement, and the impacts of dynamic loading. By adhering to Eurocode standards and employing advanced structural analysis tools, this study provides insights and recommendations for ensuring the* safety, serviceability, and durability of three-span beam-column RC structures with unequal spans.

KEYWORDS: *Three-Span, beam-column, Structure*

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I. INTRODUCTION

Reinforced concrete (RC) structures are commonly used in building construction due to their strength, durability, and flexibility in design. However, when designing multi-span RC beam-column structures with significantly unequal spans, particularly when the middle span is considerably longer than the adjacent spans, unique structural challenges arise. The longer middle span attracts more load, resulting in higher bending moments, shear forces, and deflections. These factors necessitate careful structural analysis and design to ensure that safety and serviceability criteria are met. This paper examines the typical structural design considerations for a three-span RC beam-column structure where the middle span is at least three times longer than the other spans, providing practical insights for engineers.

A. Structural Behavior of Unequal Span Three-Span Beams

In a three-span beam-column structure with a longer middle span, the load distribution is highly uneven. The middle span, being more flexible, tends to attract more load, leading to increased bending moments and deflections. This non-uniformity presents several design challenges:

(i) Increased Bending Moments and Shear Forces

The longer middle span is subject to higher bending moments and shear forces compared to the shorter adjacent spans. This can lead to excessive deflection and cracking if not properly designed [1].

(ii) Deflection Control:

Controlling deflection in the longer middle span is crucial for maintaining serviceability. Eurocode 2 specifies deflection limits to prevent damage to non-structural elements and discomfort for building occupants [2].

(iii) Differential Settlement and Dynamic Effects

The difference in span lengths can lead to differential settlement, especially if the structure is built on variable soil conditions. Additionally, longer spans are more susceptible to dynamic effects, such as vibrations from wind or traffic loads, which can impact the overall stability of the structure [3].

II. METHODOLOGY

A. Design Considerations for a Three-Span Beam-Column RC Structure

Designing a three-span RC beam-column structure with a significantly longer middle span requires careful consideration of several key factors:

a. Load and Moment Distribution

Accurate calculation of load distribution and internal forces is essential for designing RC structures with unequal spans. CIVILSOFT is a valuable tool for modelling such structures, providing detailed information on bending moments, shear forces, and deflections [4]. Understanding these factors allows engineers to optimize reinforcement placement and adjust beam depths to ensure adequate strength and stiffness.

b. Reinforcement Detailing

Reinforcement detailing must be tailored to accommodate the differences in load distribution between spans:

(i)Longitudinal Reinforcement: The longer middle span requires additional longitudinal reinforcement to resist the higher tensile forces resulting from increased bending moments. Eurocode 2 provides guidelines on the minimum and maximum reinforcement ratios to ensure adequate strength and ductility [5].

(ii)Shear Reinforcement: The increased shear forces in the longer middle span necessitate additional shear reinforcement, such as closely spaced stirrups. Eurocode 2 outlines specific requirements for shear reinforcement spacing and diameter based on the design shear forces [6].

(iii)Continuous Reinforcement Detailing: It is critical to ensure that reinforcement is continuous across the spans, particularly at support points where moments can be significant. Proper anchorage and lap lengths should be provided to maintain structural integrity and avoid sudden failure [7].

c. Deflection Control

Deflection control in the longer middle span is vital for maintaining structural integrity and serviceability. Several strategies can be employed to minimize deflection:

(i)Increasing Beam Depth: A deeper beam section increases stiffness, thereby reducing deflection. However, this may not always be feasible due to architectural constraints and cost considerations.

(ii)Using High-Strength Concrete: High-strength concrete enhances stiffness and reduces deflection, allowing for slimmer beam profiles and potentially lowering material costs [8].

d. Addressing Differential Settlement

Differential settlement can occur in structures with unequal spans, particularly if built on heterogeneous soil conditions. Mitigating differential settlement requires:

(i)Geotechnical Investigation: A thorough investigation of soil conditions helps predict potential settlement and informs foundation design [10].

(ii)Flexible Foundation Design: Adopting flexible foundation designs, such as piles or rafts, can help distribute loads more evenly and reduce differential settlement. Additionally, designing foundations to accommodate differential movements can prevent structural distress [11].

e. Dynamic Effects and Vibration Control

Longer spans are more susceptible to dynamic effects, such as vibrations from wind, traffic, or mechanical equipment. To address these issues:

(i)Conduct Vibration Analysis: Performing a vibration analysis ensures that the natural frequencies of the structure do not coincide with excitation frequencies, thereby preventing resonance [12].

(ii)Introduce Damping Mechanisms: Damping mechanisms, such as tuned mass dampers or viscous dampers, can be introduced to reduce vibration amplitude and improve occupant comfort and serviceability [13].4. Case Study: Application of Design Principles

B. Case study

A case study was conducted on a three-span RC beam-column structure with a middle span measuring 12 meters and adjacent spans of 3 meters each. CIVILSOFT Software was used to model the structure and assess its behaviour under load conditions, including dead load and live load. The analysis revealed that the middle span experienced bending moments approximately four times greater than those in the adjacent spans, corroborating theoretical predictions. Based on the analysis, reinforcement detailing was adjusted to address the increased moments and shear forces in the middle span. Additional longitudinal reinforcement was provided to resist higher tensile forces, and closely spaced stirrups were included to manage increased shear forces. Deflection checks indicated that increasing the beam depth and using high-strength concrete effectively controlled deflection within acceptable limits, ensuring compliance with Eurocode 2 requirements [14].

C. Design calculations: first floor beam-2, dimension 750mmx225mm, Span 2

Span moment =499.95kNm, cover= 25mm and fy=410N/mm^2, length of Span= 12,000mm, bw=225mm

Effective width of flange bf=225+(12000*0.7)/5=1905mm

Effective depth d=750-25-16/2-8= 709mm, $A_s = \frac{M}{0.87 f_y Z}$

Z=(d(0.5+$\sqrt{0.25 - \frac{k}{0.9}}$)) Z=673.55mm. hence As req= 1905mm^2

Provide 10Y16B as the span reinforcement. As prov. = 2010mm^2

a. Check for deflection

As required= 1905mm2 A_s prov. = 2010mm^2

Basic span/effective depth ratio= 26, d=709mm, M/bd^2 = 499.95x1000000/ (225x709^2) =4.42

Fs=(5xfyxAsreq)/(8xAsprov.), fs=242.95N/mm^2, modification factor= 55+((477-fs)/(120x(0.9+(m/bd^2)))

Modification factor= 0.916, Allowable span/effective depth ratio= basic span/effective depth ratio x modification factor, allowable span/effective depth ratio = 26x0.916= 23.83

Actual span/effective depth rato =16.92. since allowable ratio> actual ratio, deflection requirement is satisfied

III. RESULTS AND DISCUSSION

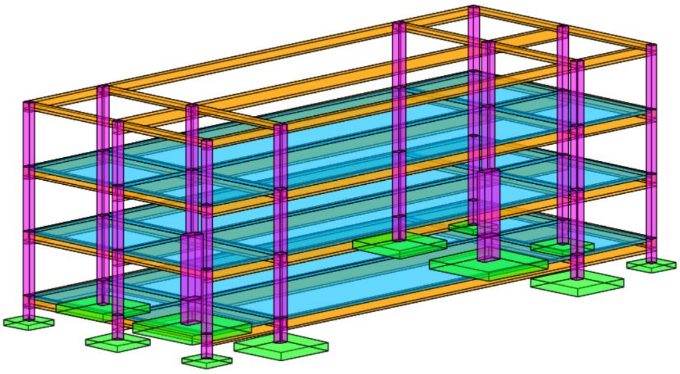


Fig 1 showing the 3D modelling of the three-span beam-column structure

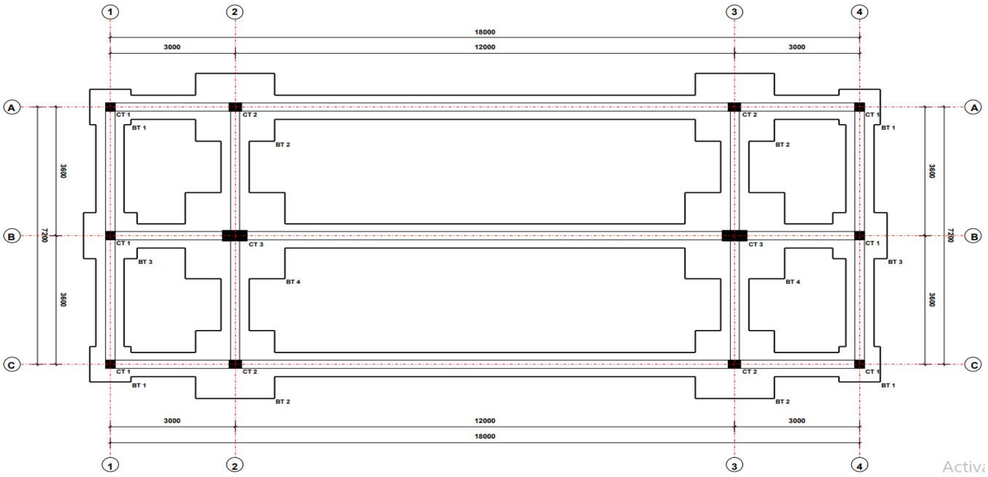
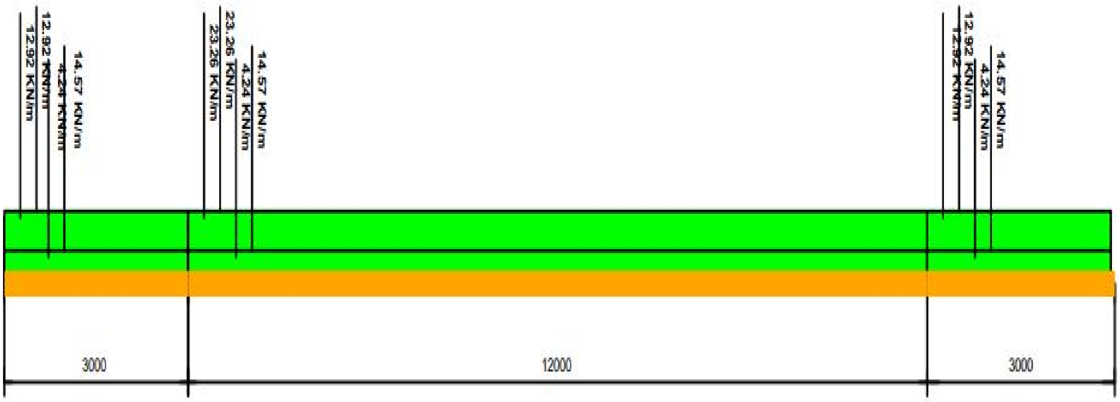


Fig 2 shows foundation layout for the frame on gridline-B



BM 2 - (750 x 225)

Moment Distribution - Loading Case 1

D.F.	1	0.8	0.2	0.2	0.8	1
FEM	-33.49	33.49	-783.96	783.96	-33.49	33.49
Dist	33.49	600.38	150.09	-150.09	-600.38	-33.49
C.O	300.19	16.75	-75.04	75.04	-16.75	-300.19
Dist	-300.19	46.63	11.66	-11.66	-46.63	300.19
C.O	23.32	-150.1	-5.83	5.83	150.1	-23.32
Dist	-23.32	124.74	31.19	-31.19	-124.74	23.32
C.O	62.37	-11.66	-15.6	15.6	11.66	-62.37
Dist	-62.37	21.81	5.45	-5.45	-21.81	62.37
C.O	10.9	-31.18	-2.72	2.72	31.18	-10.9
Dist	-10.9	27.12	6.78	-6.78	-27.12	10.9
Total FEM	0	679.11	-679.11	679.11	-679.11	0

ERDAL	66.98	66.98	391.98	391.98	66.98	66.98
ERDAM	-226.37	226.37	0	0	226.37	-226.37
S.F.	-159.39	293.35	391.98	391.98	293.35	-159.39
Reaction	-159.39	685.33		685.33		-159.39
x-Max	5 m		14 m		23 m	
M-Max	0 KNm		496.91 KNm		0.18 KNm	

Table 1 shows the bending moment distribution, shear force and reactions for beam-2 on gridline-B

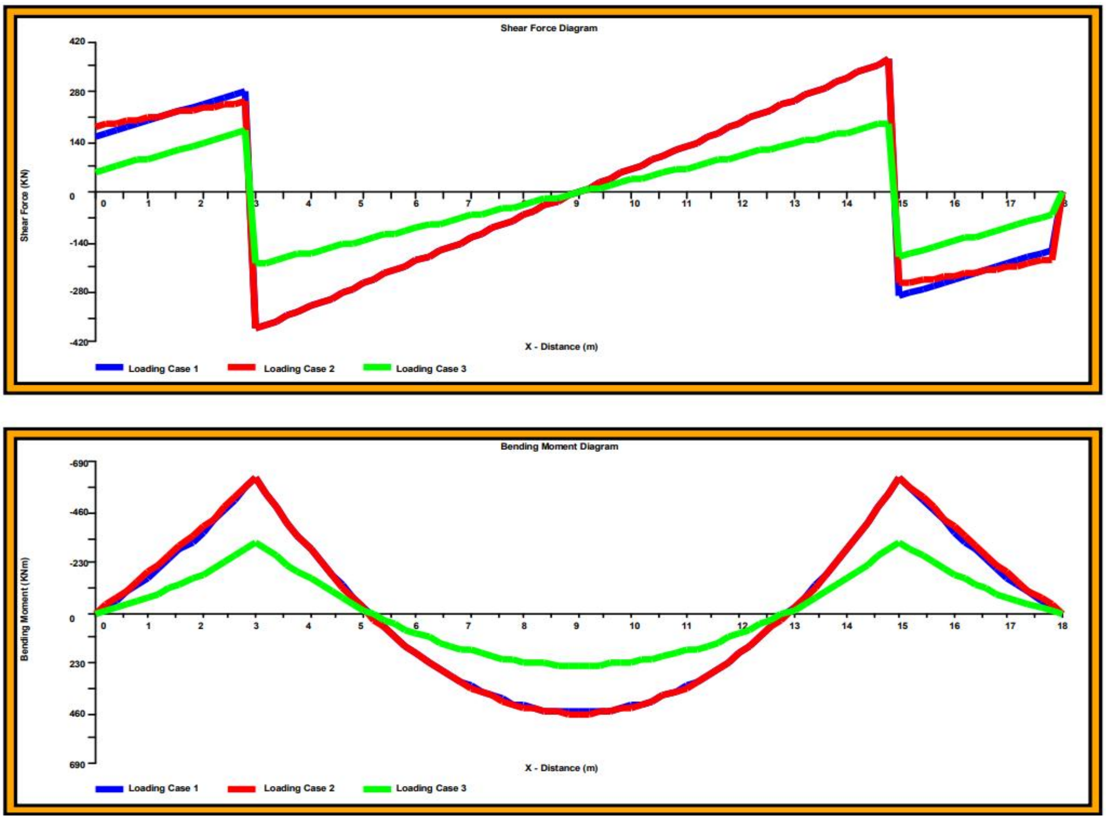


Fig.3: bending moment and shear force diagram for beam-2

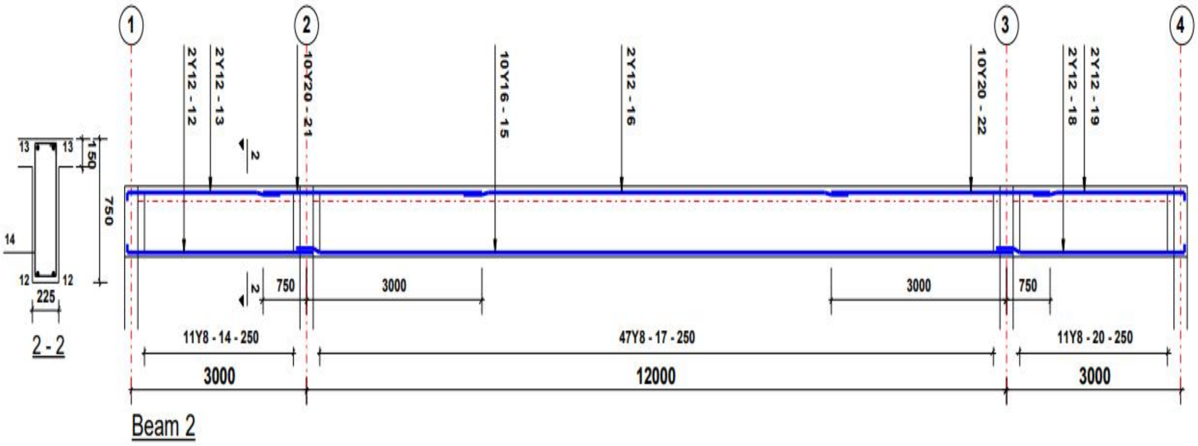


Fig 4: details of beam-2

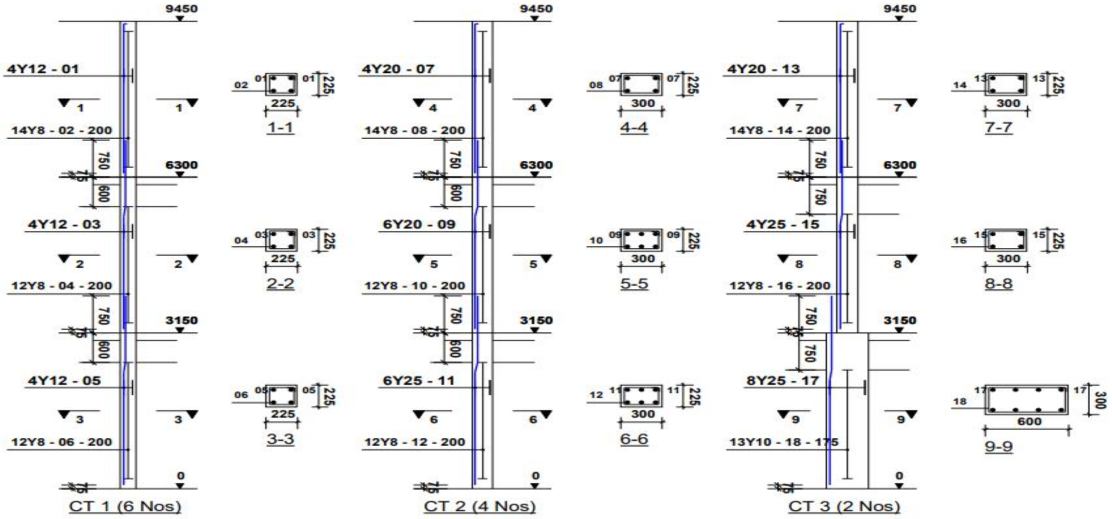


Fig 5: details of the frame columns

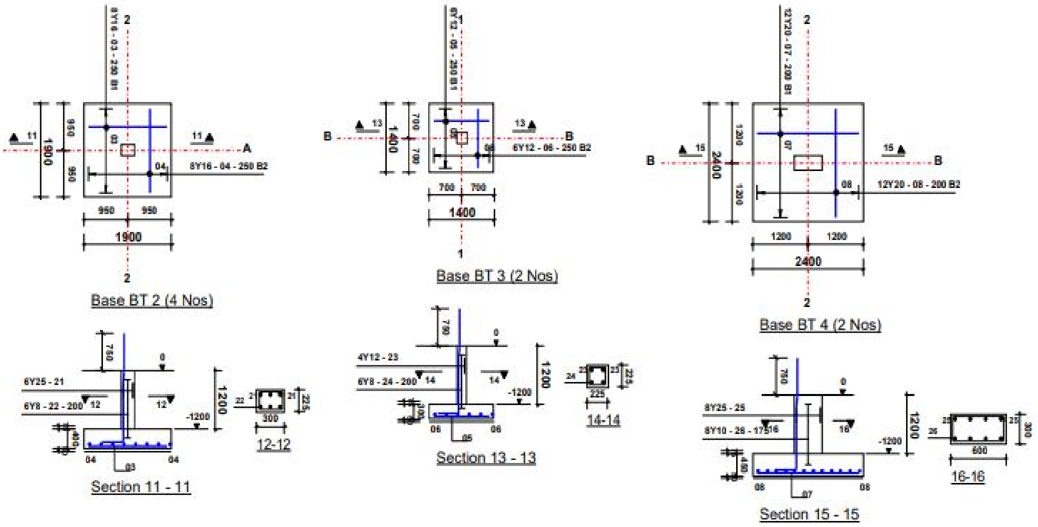


Fig 6: details of the pad foundation supporting the frame

B. Discussion of Result

From Fig 2, showing the bending moment diagram of the beam-2. The exterior column of the shorter span is actually in tension instead of the usual impression that columns are compression members. This is due to the interaction between the large bending in the longer span with the shorter span due to the monolithic nature of the solid slab-beam-column frame.

It is also observed that the entire shorter beam span is under negative hogging bending moment. This is also as a result of the continuity interaction between the much more large span sagging bending moments in the longer span. Both interior columns of the longer middle span are critical columns both the axial load and the column design moment are much higher which gave rise to deep column with heavy reinforcements. The most critical section of the beam is the connection of the longer span with the shorter span where we have biggest negative bending moment of 679.11kNm which is bigger than the maximum span bending moment of 499.95kNm hence the design for the top reinforcement to resist this negative bending moment is the most critical aspect of the design of this beam. The entire shorter span of the beam is designed for negative bending moment thereby providing adequate top reinforcement.

IV. CONCLUSION

Designing a three-span RC beam-column structure with a significantly longer middle span requires careful consideration of load distribution, deflection control, reinforcement detailing, and potential issues such as differential settlement and dynamic effects. By applying advanced analysis tools like CIVILSOFT, adhering to Eurocode guidelines, and incorporating practical design strategies, engineers can ensure that these structures are safe, functional, and cost-effective. Future research could explore the impact of varying load patterns, soil conditions, and dynamic effects to further enhance design approaches for unequal span structures.

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