INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

Practical Implications of Structural Design of a Two-Span Rc Beam - Column Structure with Unequal Spans

Nwokoye Ogonna Samuel

Department of Civil Engineering Federal Polytechnic oko Nigeria

DOI: https://doi.org/10.51584/IJRIAS.2024.909044

Received: 04 September 2024; Accepted: 17 September 2024; Published: 21 October 2024

ABSTRACT

The structural design of reinforced concrete (RC) beam-column systems with unequal spans poses unique challenges, especially when one span is significantly longer than the other. This paper explores the practical implications of designing a two-span RC beam-column structure where one span is at least three times longer than the other. The study highlights the key considerations in terms of load distribution, deflection control, reinforcement detailing, and the potential for differential settlement and vibrations. This research draws on Eurocode standards for design, provides an analysis of various load cases, and discusses practical solutions for ensuring structural integrity and serviceability.

Keyword: Beam-Column, Reinforced, Concrete, Two-Span, Unequal

INTRODUCTION

Reinforced concrete (RC) beam-column systems are widely used in structural engineering due to their versatility and robustness. However, the design complexity increases significantly when dealing with unequal spans, especially when one span is substantially longer than the other. In such cases, the structural behavior under loads, deflection patterns, and reinforcement requirements vary considerably, necessitating careful consideration during the design process. This paper focuses on the practical implications of designing a two-span RC beam-column structure where one span is at least three times longer than the other. The goal is to provide insights into the challenges and solutions for ensuring safety, serviceability, and cost-effectiveness. Buildings such as classroom blocks where the architectural design usually takes the form of a classroom space like a hall which requires no intermediate columns and consequently a large span beam-column arrangement and adjacent to the classroom is usually the access corridor that link the several classroom in each floor. The corridor is usually of a much smaller span compared to the classroom and in most practical cases the classroom span is more than 3 times bigger. This paper will demonstrate the analysis of this type of structure.

Structural Behaviour of Unequal Span Beams

When designing a two-span RC beam with one span significantly longer than the other, the distribution of moments, shear forces, and deflections becomes non-uniform. The longer span tends to attract more load due to its greater flexibility, leading to higher bending moments and deflections compared to the shorter span. This discrepancy can result in several design challenges:

1. Unequal Load Distribution: The longer span will carry a disproportionate share of the total load, which increases bending moments and shear forces in that span. This can lead to excessive deflection and cracking if not properly designed.

2. Deflection Control: The deflection in the longer span can be a critical issue, especially for structures with strict serviceability requirements. Eurocode 2 recommends limiting deflections to prevent damage to non-structural elements and discomfort for occupants [1].

3. Differential Settlement: The unequal stiffness between spans can lead to differential settlement, particularly in structures built on non-homogeneous soil conditions. This differential movement can cause additional stress

in both the beams and the columns [2].

Design Considerations and Solutions

Designing a two-span RC beam-column structure with unequal spans involves addressing the challenges mentioned above through careful analysis and appropriate detailing. Some practical design considerations and solutions include:

Load and Moment Distribution

In structures with unequal spans, it is crucial to calculate the distribution of loads and moments accurately. Civilsoft analysis is a powerful tool for modelling such structures, allowing for the precise calculation of bending moments, shear forces, and deflections [3]. By understanding the load distribution, engineers can design reinforcement accordingly to resist the maximum moments and shear forces in each span.

Reinforcement Detailing

Reinforcement detailing must be tailored to address the differences in moment and shear force distribution between spans. For the longer span, increased reinforcement is required to handle the higher moments and prevent excessive cracking. Eurocode 2 provides guidelines on minimum and maximum reinforcement ratios, ensuring both safety and serviceability [4].

Longitudinal Reinforcement: The longer span requires more longitudinal reinforcement in the bottom layer to resist the increased tensile forces due to higher bending moments.

Shear Reinforcement: Additional shear reinforcement (stirrups) may be necessary in the longer span to resist higher shear forces. Eurocode 2 recommends spacing and diameter requirements for shear reinforcement based on the design shear force [5].

Deflection Control

To control deflection in the longer span, engineers can consider several strategies:

1. Increasing the Depth of the Beam: By increasing the depth of the beam, its stiffness is increased, thereby reducing deflection. However, this may not always be feasible due to architectural constraints.

2. Using High-Strength Concrete: High-strength concrete can increase the stiffness of the beam, reducing deflection and allowing for a slimmer beam profile.

3. Prestressing: Applying prestressing techniques can significantly reduce deflections by introducing a pre-compression force in the beam, counteracting the tensile forces from bending moments [6].

Addressing Differential Settlement

To mitigate differential settlement risks, it is essential to

1. Conduct a thorough geotechnical investigation to understand soil conditions and predict potential settlement.

2. Design foundations to accommodate different loads and settlements. Using flexible foundation designs, such as piles or rafts, can help distribute loads more evenly and reduce differential settlement [7].

Vibration Analysis

Longer spans are more susceptible to vibrations, especially under dynamic loads such as moving occupants or machinery. To address this, engineers must conduct a vibration analysis to ensure the natural frequencies of the structure do not coincide with the excitation frequencies. Additionally, damping mechanisms can be introduced to reduce the amplitude of vibrations and improve comfort and serviceability [8].

Case Study: Application of Design Principles

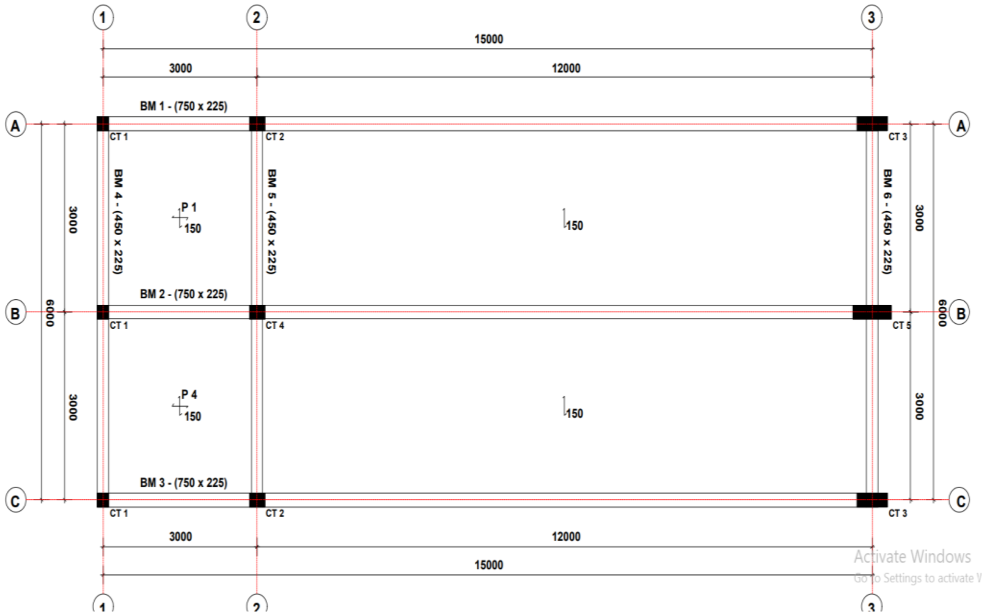
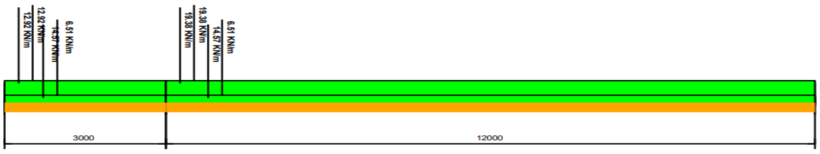
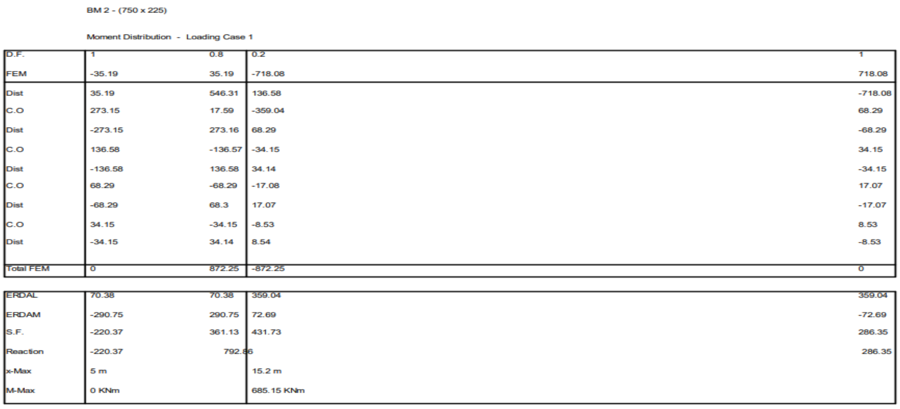


Fig 1.0 shows General arrangement of beams and columns for a part of the beam-slab-column RC structure



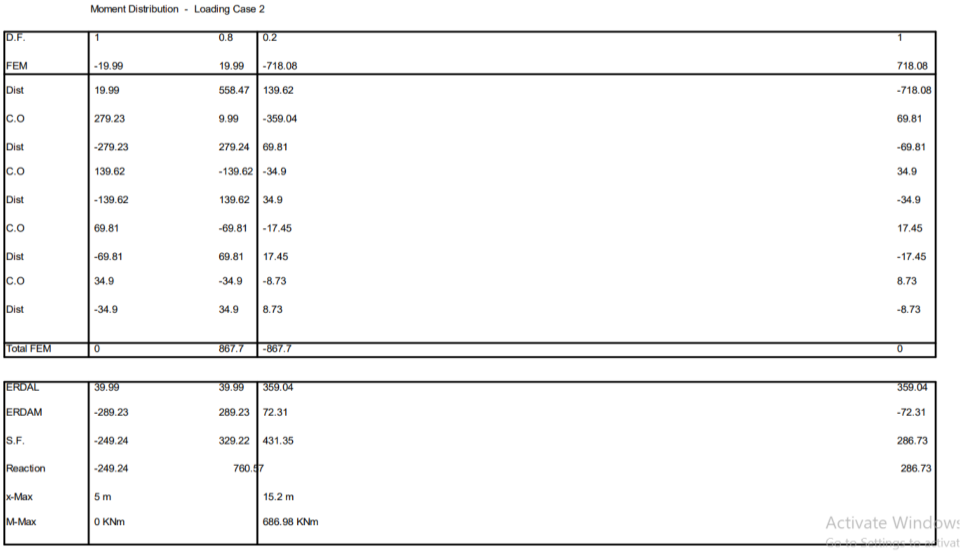


BM 2 - (750 x 225)

Moment Distribution - Loading Case 1

D.F.	1	0.8	0.2	1
FEM	-35.19	35.19	-718.08	718.08
Dist	35.19	546.31	136.58	-718.08
C.O	273.15	17.59	-359.04	68.29
Dist	-273.15	273.16	68.29	-68.29
C.O	136.58	-136.57	-34.15	34.15
Dist	-136.58	136.58	34.14	-34.15
C.O	68.29	-68.29	-17.08	17.07
Dist	-68.29	68.3	17.07	-17.07
C.O	34.15	-34.15	-8.53	8.53
Dist	-34.15	34.14	8.54	-8.53
Total FEM	0	872.25	-872.25	0

ERDAL	70.38	70.38	359.04	359.04
ERDAM	-290.75	290.75	72.69	-72.69
S.F.	-220.37	361.13	431.73	286.35
Reaction	-220.37	792.86		286.35
x-Max	5 m		15.2 m	
M-Max	0 KNm		685.15 KNm	

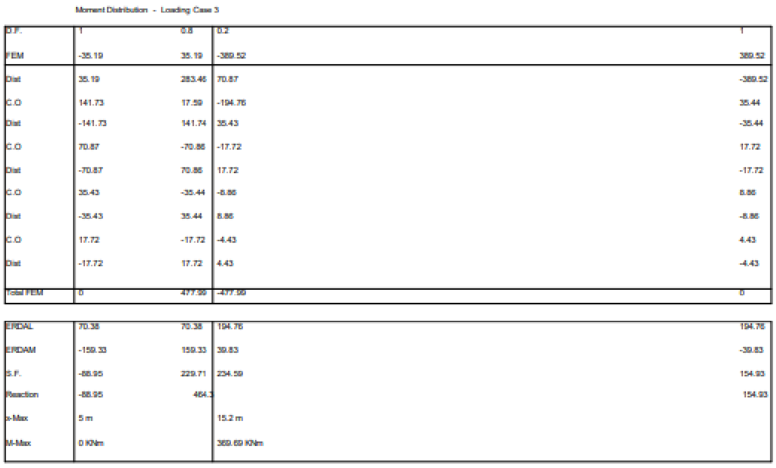


Moment Distribution - Loading Case 2

D.F.	1	0.8	0.2	1
FEM	-19.99	19.99	-718.08	718.08
Dist	19.99	558.47	139.62	-718.08
C.O	279.23	9.99	-359.04	69.81
Dist	-279.23	279.24	69.81	-69.81
C.O	139.62	-139.62	-34.9	34.9
Dist	-139.62	139.62	34.9	-34.9
C.O	69.81	-69.81	-17.45	17.45
Dist	-69.81	69.81	17.45	-17.45
C.O	34.9	-34.9	-8.73	8.73
Dist	-34.9	34.9	8.73	-8.73
Total FEM	0	867.7	-867.7	0

ERDAL	39.99	39.99	359.04	359.04
ERDAM	-289.23	289.23	72.31	-72.31
S.F.	-249.24	329.22	431.35	286.73
Reaction	-249.24	760.57		286.73
x-Max	5 m		15.2 m	
M-Max	0 KNm		686.98 KNm	

Table 1.0 shows bending moment distribution for beam-2



Moment Distribution - Loading Case 3

D.F.	1	0.8	0.2	1
FEM	-35.19	35.19	-389.52	389.52
Dist	35.19	283.46	70.87	-389.52
C.O	141.73	17.59	-194.76	35.44
Dist	-141.73	141.74	35.43	-35.44
C.O	70.87	-70.86	-17.72	17.72
Dist	-70.87	70.86	17.72	-17.72
C.O	35.43	-35.44	-8.86	8.86
Dist	-35.43	35.44	8.86	-8.86
C.O	17.72	-17.72	-4.43	4.43
Dist	-17.72	17.72	4.43	-4.43
Total FEM	0	477.99	-477.99	0

ERDAL	70.38	70.38	194.76	194.76
ERDAM	-159.33	159.33	39.83	-39.83
S.F.	-88.95	229.71	234.59	154.93
Reaction	-88.95	464.3		154.93
x-Max	5 m		15.2 m	
M-Max	0 KNm		369.69 KNm	

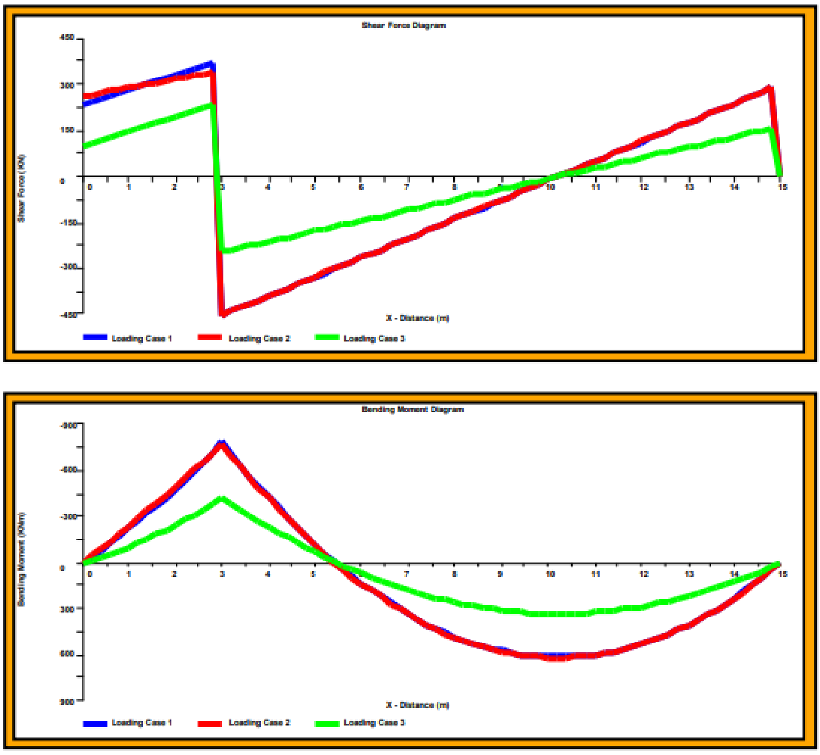


Fig 2.0 shows bending moment and shear force diagrams for the beam-2

A case study of a two-span RC beam-column structure with one span of 12 m and another of 3m was analyzed using Civilsoft. The analysis demonstrated that the longer span attracted significantly higher bending moments. Reinforcement detailing was adjusted accordingly, with the longer span receiving more longitudinal and shear reinforcement to meet Eurocode 2 requirements. Deflection checks confirmed that increasing the beam depth and using high-strength concrete effectively controlled deflection within acceptable limit. From fig2.0, showing the bending moment diagram, the maximum interior support moment for the longer span is -686.98kNm. On the other hand, the entire shorter span is under negative hogging bending moment which reduced graphically to zero at the end span where the column is in tension due to the monolithic nature of the frame and the continuity effect of the bending of the shorter span of the beam

Determination of longitudinal reinforcements for the RC members: Support reinforcement for the interior support. M_{max} =686.98kNm, b=225mm, F_{ck}=25N/mm^2, h=750mm, d=707m

K = *M / bd2fck* = 686.98E6 / (225x707x707x410x25) = 0.0288

z = 671.5 As = 686.98E6 / (0.87x410x671.5) = 2,868 *mm2*

Provide 6Y25T (A_{sprov}= 2940mm^2)

Check for deflection:

Basic span/ effective depth ratio= 26,

$M/bd2$=686.98E6/(225x707^2) = 6.108

Fs = 5fyAsreq/8Asprov = 5*410*2868/(8*2940)

Fs=249.974

Modification factor=0.834

Allowable span/effective depth ratio=basic span/effective depth ratio x modification factor

Allowable span/effective depth ratio=26*0.834= 21.68

Actual span/effective depth ratio= 12,000/707 = 16.97

Allowable ratio is greater than actual ratio hence deflection requirement is satisfied

Interior column type 4:

Axial load =723.2kN, Column Moment= 35.99kN, d/h=0.809, N/bhfck=0.04286

M/bh^2fck=0.0948, Asreq= 1399.39mm

As prov.= 1884mm^2, Provide 6Y20

Pad foundation for the interior column type 4

Base thickness =350mm, width of pad=1700mm

Effective depth d=288mm, length= 1700mm

Momentx=61.31kNm

As req= 567.44mm2

As prov= 754mm2

Provide Y12@150mm c/c

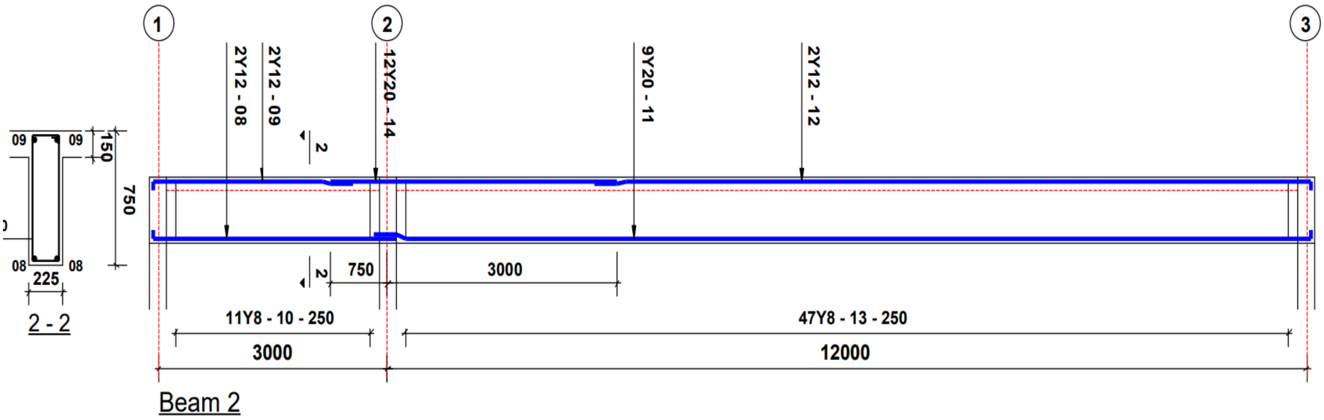


FIG 3.0 detailing of the beam-2 Showing both longitudinal reinforcements and shear reinforcements

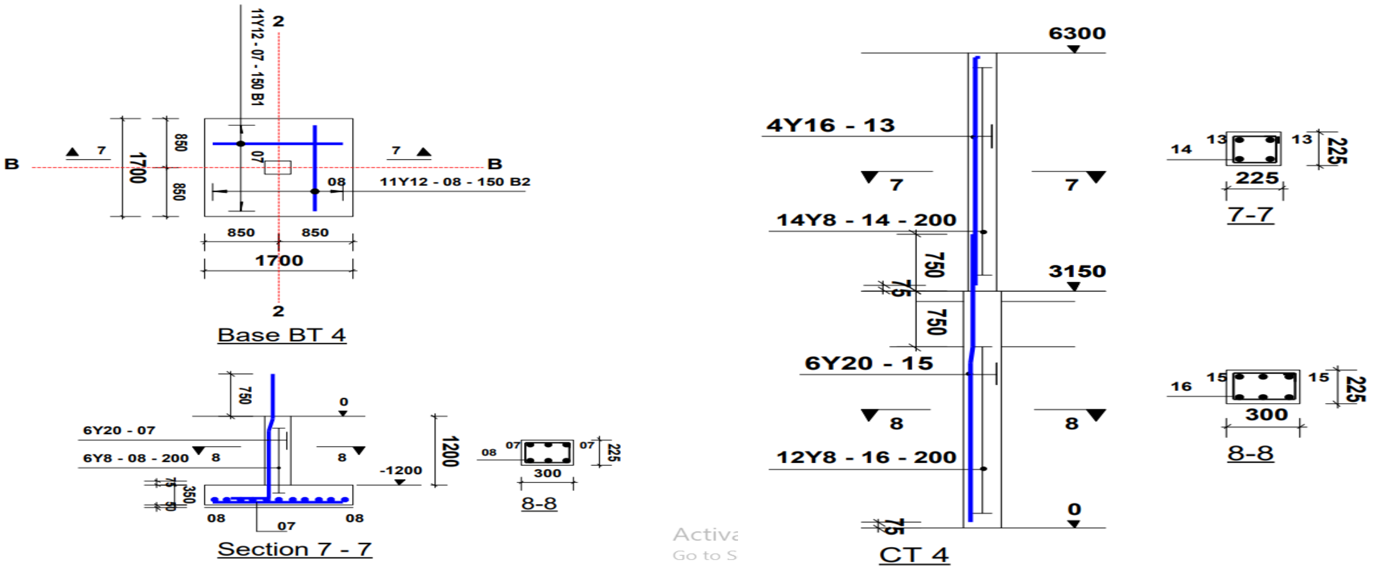


Fig 4.0 shows Column and Column base details

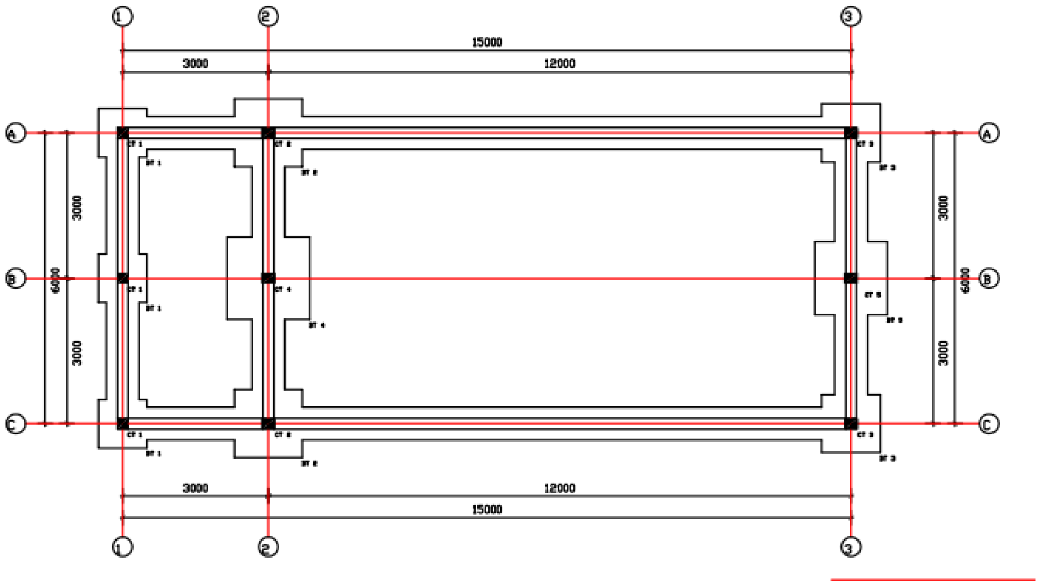


Fig 5.0 foundation layout for the section of the frame structure

DISCUSSION OF RESULTS

From fig 2.0, showing the bending moment diagram and the column. 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 the interior columns and the end column to the longer span are both critical columns though the axial load for the end column is smaller but the column design moment is 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 686.98kNm which is bigger that the maximum span bending moment 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.

CONCLUSION

Designing a two-span RC beam-column structure where one span is substantially longer than the other requires careful consideration of load distribution, deflection control, reinforcement detailing, and potential differential settlement. By applying advanced analysis software like Civilsoft, following Eurocode guidelines, and incorporating practical design strategies, engineers can ensure these structures are safe, functional, and economical. Future research could explore the impact of varying load patterns and more complex structural forms to further enhance design approaches for unequal span structures.

REFERENCES

1. EN 1992-1-1: Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. CEN, Brussels, 2004.
2. Bowles, J. E. (1996). "Foundation Analysis and Design." McGraw-Hill.
3. Zienkiewicz, O. C., Taylor, R. L., & Zhu, J. Z. (2005). "The Finite Element Method: Its Basis and Fundamentals." Elsevier Butterworth-Heinemann.
4. EN 1992-1-1: Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. CEN, Brussels, 2004.
5. Park, R., & Paulay, T. (1975). "Reinforced Concrete Structures." John Wiley & Sons.
6. Nilson, A. H., Darwin, D., & Dolan, C. W. (2010). "Design of Concrete Structures." McGraw-Hill.
7. Tomlinson, M. J., & Woodward, J. (2014). "Pile Design and Construction Practice." CRC Press.
8. Clough, R. W., & Penzien, J. (2003). "Dynamics of Structures." McGraw-Hil