The influence of tie beams on the reinforced concrete frame structural model

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ABSTRACT

The separation of "tie" beams from the frame model for independent calculation is commonly applied in reinforced concrete (RC) structural design coursework and even in graduation projects for civil engineering students. However, this approach does not accurately reflect the actual structural behavior of the building. The author recognizes that the impact of tie beams on the RC frame structure can be analyzed through three different models: (1) considering tie beams as simply supported beams and analyzing them separately, (2) modeling them as fixed-end beams, (3) integrating tie beams into the RC frame model for simultaneous analysis. This study employs Etabs and NConc (developed by NCal Solution) to perform structural analysis, reinforcement design, and result evaluation. From this analysis, the study aims to assess the appropriateness of modeling tie beams as part of the RC frame structure, ensuring consistency with both structural design calculations and actual construction practices where tie beams are present.

Keywords: *Tie Beam, Reinforced Concrete Beam, Tie Beam Model, Nconc, Reinforced Concrete Frame*

1. INTRODUCTION

Tie beams are a structural component in construction projects, serving to connect and reinforce columns, thereby increasing the stiffness and stability of the foundation system. Tie beams are typically located at or near the base of the ground floor columns, linking them to mitigate differential settlement and enhance the structure's load-bearing capacity. [3]

The functions of tie beams in design and construction are analyzed as follows:

- Reduce local differential settlement: Along with the beam and column systems, they form a load-bearing frame that distributes loads evenly to the foundation system, mitigating uneven settlement between columns. [2]

- Connect columns and foundations: They play a role in positioning and maintaining stable relative distances for column bases, preventing displacement from lateral forces. [2]

- Increase stiffness of the structural frame: Helps stabilize the column system and reduces deformation under applied loads.

- Maintain stability of masonry walls: Tie beams also help support and reduce cracking under wall loads, especially in weak soil conditions. [2]

Currently, the practice of separating tie beams from the frame model for independent calculation is commonly applied in RC structural design coursework and even in graduation projects for civil engineering students.

In theory, the influence of tie beams on the reinforced concrete frame system has been remarked as unnecessary for the following reasons:

- Tie beams only serve an auxiliary connection role between columns to reduce lateral displacement. Therefore, they may not need to be modeled if the project does not demand high precision in the internal force analysis results. [3]

- Omitting tie beams in the calculation model does not significantly affect the accuracy of the design results.. [6]

The influence of tie beams on the reinforced concrete frame system has also been remarked as necessary:

- Fully modeling all structural components, including tie beams, significantly increases the frame's stiffness. This will accurately reflect the structure's actual behavior when analyzed using software.

- Assuming a calculation model that omits tie beams can lead to inaccuracies in stress and internal forces within main load-bearing elements, such as columns and floor beams. [2]

- Under both elastic and plastic RC design principles, the inclusion of all structural members including tie beams is crucial to achieving design accuracy.

Consequently, the practice of isolating tie beams lacks sufficient documentation validating its accuracy in representing real structural behavior. Existing design codes provide no explicit requirement for modeling tie beams within RC frame load analysis. [10] This flexibility enables engineers to adopt different analytical approaches. Accordingly, this paper will analyze and compare different calculation models, considering the influence of tie beams on the RC frame structural model.

2. RESEARCH METHODOLOGY

2.1. Research approach and methodology

Theoretically, the separation of tie beams for independent calculation is executed in design projects as follows:

- Using the reaction forces calculated from the isolated tie beam and applying them as nodal loads at the columns, to avoid omitting the load transfer from the tie beam to the column.

- When the tie beam is omitted from the frame model, the effective length of the column increases, which consequently increases the required column reinforcement, tending toward a conservative design.

In student or preliminary analyses, the tie beam is often idealized as a simply supported or fixed-end beam. However, this simplification is inaccurate since tie beams are monolithically cast with reinforced concrete columns. Therefore, the connection of the tie beam to the column, when analyzed separately, can hardly satisfy the assumption of a pinned connection, nor even a fixed connection, within the context of the entire frame model.

This aligns with the actual construction process, where the tie beam is cast monolithically and acts integrally with the RC frame system. Therefore, separating the tie beam for independent calculation is unreasonable, given the simultaneous, collaborative behavior of the entire system

Computation and Modeling Guidelines: [12]

- Structural analysis should follow the principles of structural mechanics, with the finite element method (FEM) recommended for general cases.

- When modeling the structural system, it is necessary to consider the simultaneous action of the bar elements, with different degrees of freedom for each element..

- When building the finite element model, the size and configuration of elements should be chosen based on software capabilities while ensuring sufficient accuracy in determining internal forces along the column length.

- FEM-based analysis should be executed using specialized structural engineering software.

Accordingly, three analytical models are developed to assess the influence of tie beams on RC frame behavior:

- Model (1): The tie beam is analyzed independently as a simply supported beam, and its reaction forces are imposed on the RC frame.

- Model (2): The tie beam is modeled as a fixed-end beam, and its reaction forces are integrated into the RC frame analysis.

- Model (3): The tie beam is fully modeled within the RC frame to simulate concurrent interaction and load sharing.

2.2. Case Study Example

2.2.1. Input Data

A two-story reinforced concrete frame with 400×400 mm square columns.

The floor slab has a thickness of 120 mm; beams are 350×700 mm in section, constructed with concrete grade B30.

Concrete unit weight is taken as 25 kN/m³

Live load: 2 kN/m²

Finishing load: 1.01 kN/m²

Brick wall 200 mm thick, 4 m high, brick unit weight 15 kN/m³, mortar 18 kN/m³.

Frame span: 6 m; story height: 4 m.

Requirement: analyze the example using the three models described above.

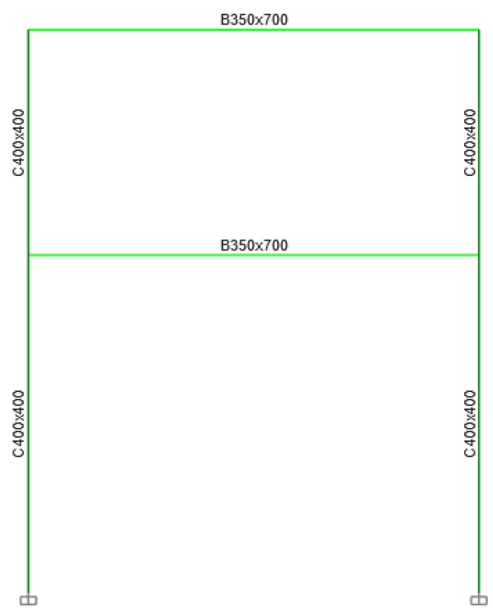


Figure 1. Model RC frame (no tie beam)

2.2.2. Applied loads

- Self-weight of the structural element is automatically calculated by the software.

- Finishing load:

$g_{finishing\ load}$ = 1.01 (kN/m²) × 6 m = 6.06 kN/m

- The self-weight of a 120 mm thick slab can be estimated as follows:

$g_s = 25\ (kN/m^3) \times 0.12m \times 6m = 18\ kN/m^2$

- Load of a 4 m brick wall:

$g_{brick\ wall} = (15\ (kN/m^3) \times 0.2m + 18\ (kN/m^3) \times 0.03m \times 2) \times 4m = 14.16\ (kN/m)$

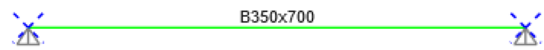
- Live load applied to the tie beam:

$q_{k,t} = 2 \times 6 = 12\ kN/m$

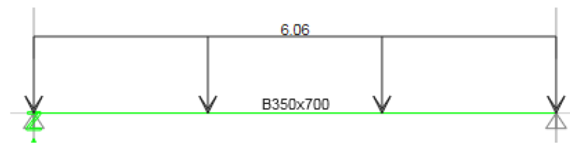
Software used for analysis: Etabs v22 by CSI (USA), NConc by Ncal Solution (Vietnam) [7]

3. DISCUSSION AND COMPARATIVE EVALUATION OF RESULTS

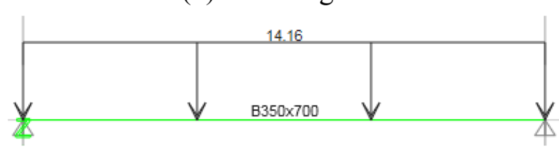
3.1. Model (1): Tie beam 350×700 mm modeled as a simply supported beam with two supports



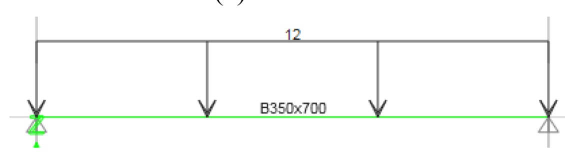
(a) Structural model of the tie beam with two simply supports



(b) Finishing load



(c) Wall load



(d) Live load

Figure 2. Structural model and applied loads on the tie beam for the model (1)

Reaction forces from the supports:

Table 1: Reaction forces – Model (1)

Load Cases	Left support	Right support
Self-weight	FZ = 24.5 kN	FZ = 24.5 kN
Wall load	FZ = 57.6 kN	FZ = 57.6 kN
Finishing load	FZ = 24.0 kN	FZ = 24.0 kN
Live load	FZ = 60.0 kN	FZ = 60.0 kN

These values can be manually verified; for example, the self-weight reaction at each support is:

FZ = 0.35 m × 0.7 m × 25 kN/m³ × 8 m / 2 = 24.5 kN

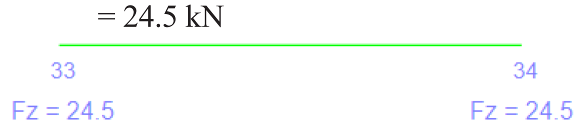
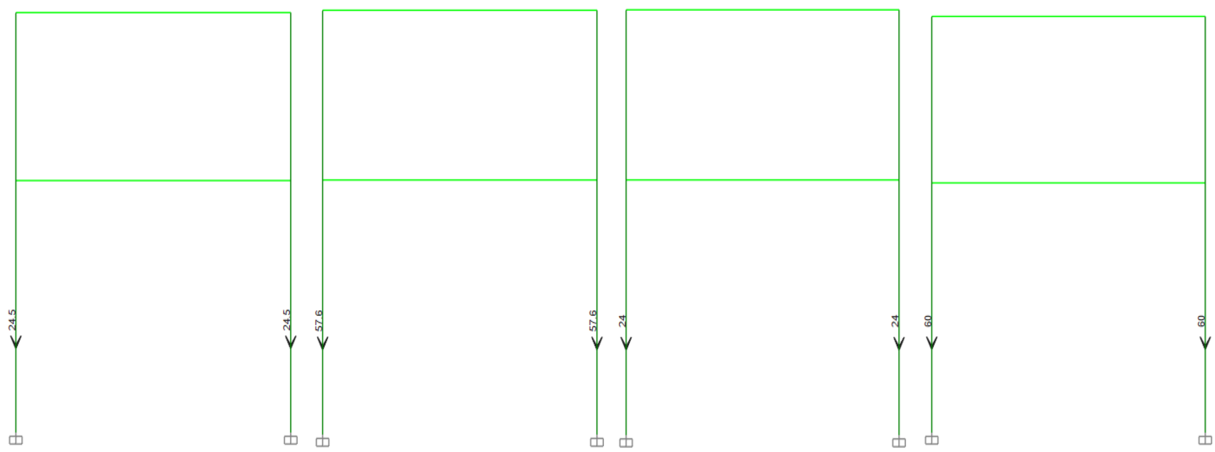


Figure 3. Reaction forces from Etabs – Model (1)

Assign loads to the RC frame:



(a) Self-weight (b) Wall load (c) Finishing load (d) Live load

Figure 4. Structural frame model assign load to the tie beam for model (1)

3.2. Model (2): Tie beam 350×700 modeled as a beam with two fixed-end supports

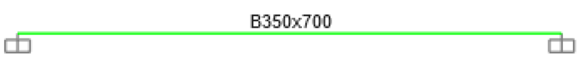


Figure 5. Structural model of the tie beam with two fixed-end supports

Loads are taken similarly to the Model (1)

Reaction from the supports:

Table 2: Reaction forces – Model (2)

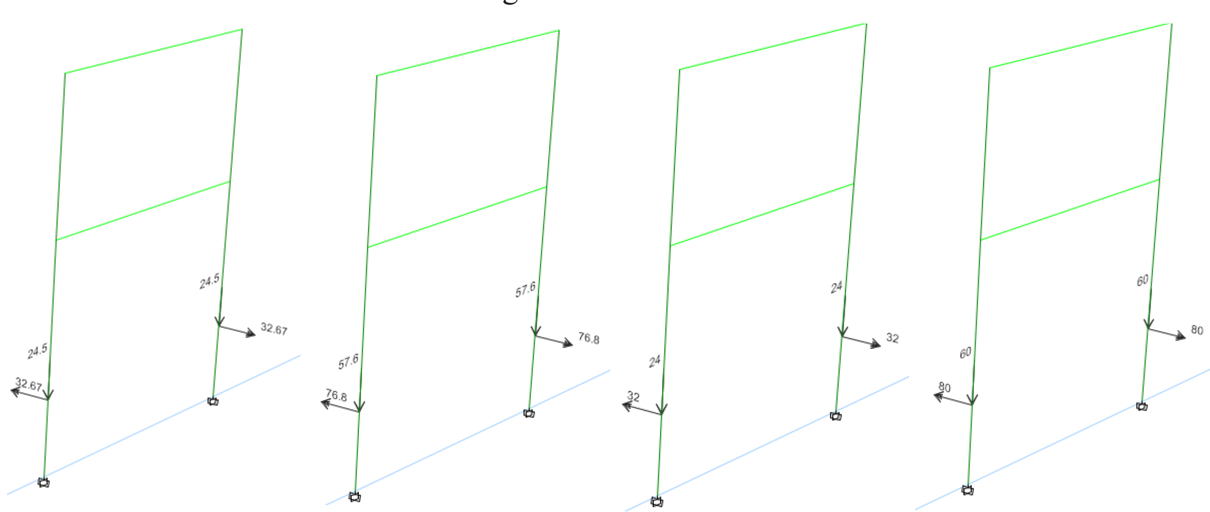
Load Cases	Left support	Right support
Self-weight	FZ = 24.5 kN, M = -32.67 kNm	FZ = 24.5 kN, M = -32.67 kNm
Wall load	FZ = 57.6 kN, M = -76.8 kNm	FZ = 57.6 kN, M = -76.8 kNm
Finishing load	FZ = 24.0 kN, M = -32 kNm	FZ = 24.0 kN, M = -32 kNm
Live load	FZ = 60.0 kN, M = -80 kNm	FZ = 60.0 kN, M = -80 kNm

These values can be manually verified; for example, the self-weight reaction at each support is:

$$FZ = 0.35\ m \times 0.7\ m \times 25\ kN/m^3 \times 8\ m / 2 = 24.5\ kN$$

$$M = -\ 0.35\ m \times 0.7\ m \times 25\ kN/m^3 \times 8^2/12 = -32.67\ kN.m$$

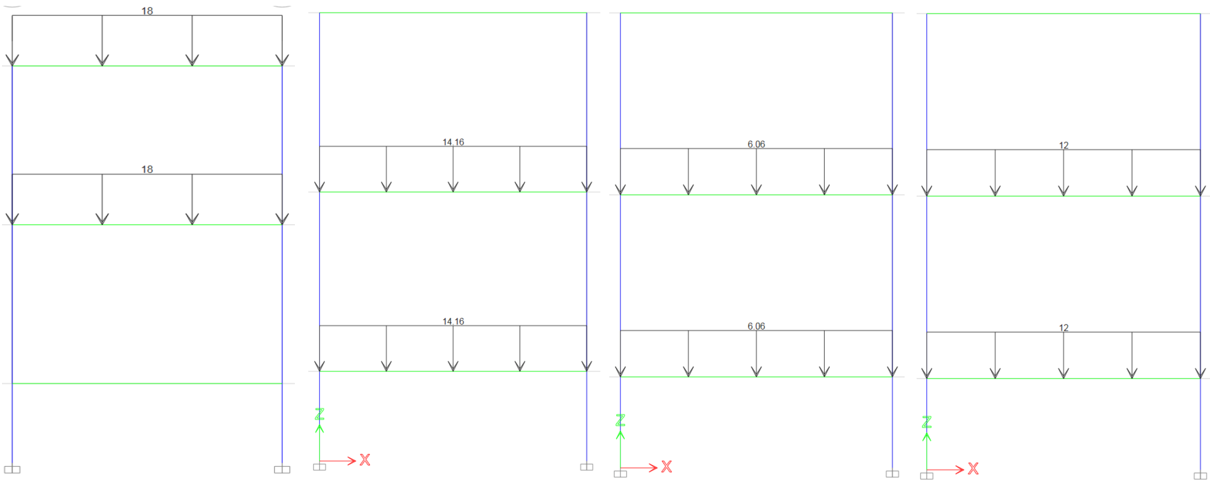
Assign loads to the RC frame:



(a) Self-weight (b) Wall load (c) Finishing load (d) Live load

Figure 6. Structural frame model assign load to the tie beam for model (2)

3.3. Model (3): Modeling tie beams within the RC frame for simultaneous action



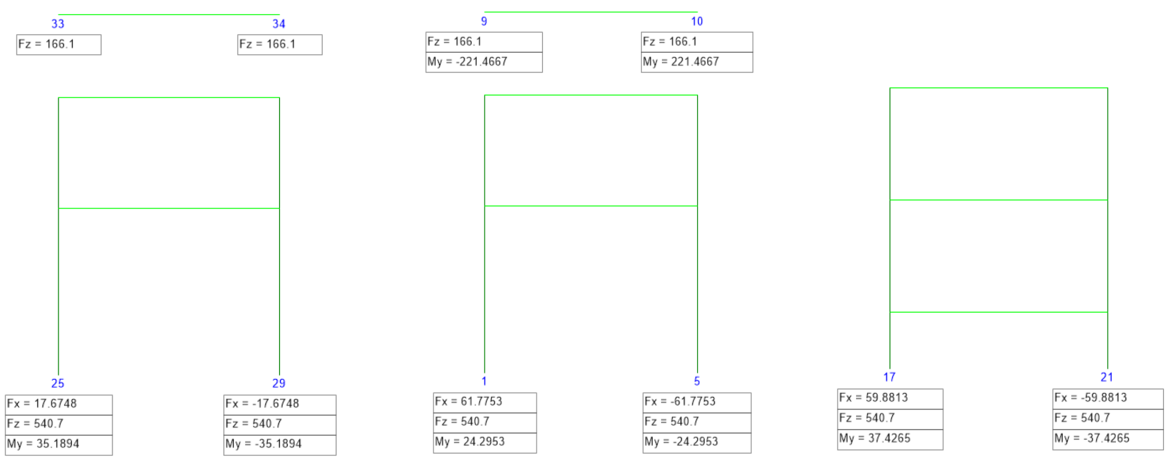
(a) Self-weight (b) Wall load (c) Finishing load (d) Live load

Figure 7. Structural frame model assign load to the tie beam for model (3)

3.4. Comparative results

The un-factored load combination was used for easier comparison, including: Dead load + Live load + Wall load + Finishing load.

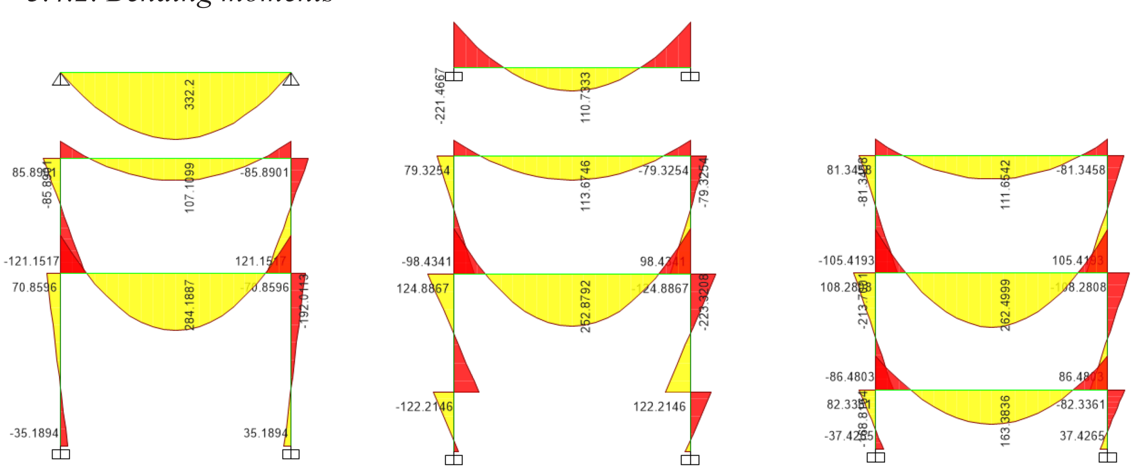
3.4.1. Reaction forces



(a) Model (1) (b) Model (2) (c) Model (3)

Figure 8. Comparison results of reaction forces of the 3 models

3.4.2. Bending moments



(a) Model (1) (b) Model (2) (c) Model (3)

Figure 9. Comparison results of bending moments of the 3 models

3.4.3. Axial forces

(a) Model (1) (b) Model (2) (c) Model (3)

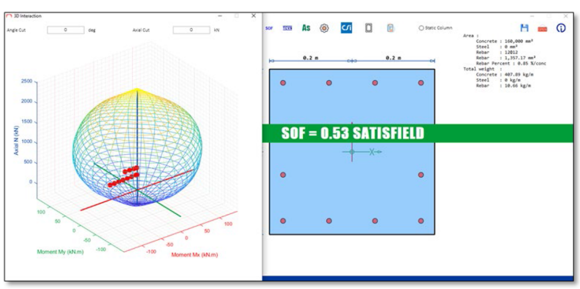
Figure 10. Comparison results of axial forces of the 3 models

3.4.4. Check the load-bearing capacity of the column

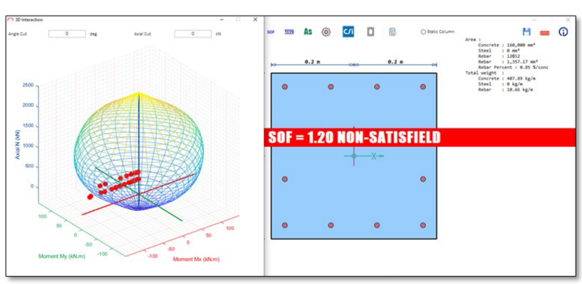
Software: NCONC v2.0 (Ncal Solution)

Applied standard: TCVN 5574:2018

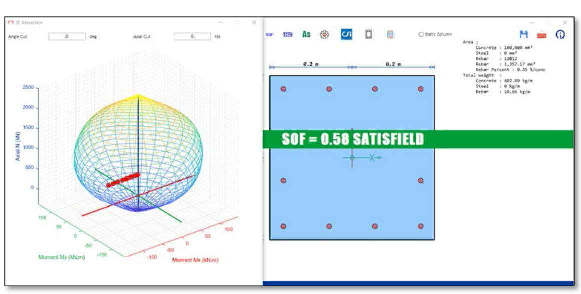
Reinforcement checked: 12d12, CB300-V



(a) Model (1)



(b) Model (2)



(c) Model (3)

Figure 11. Comparison results of check the load-bearing capacity of the 3 models

An important remark is that the commonly used internal-force combination method in Vietnam often selects the internal force with the largest absolute magnitude (either maximum or minimum) and take the corresponding internal forces (e.g., for columns: M_{max}, N_{tu}; M_{min}, N_{tu}; N_{max}, M_{tu}). However, in practice, an M–N force pair that is not individually critical (not a maximum/minimum for either M or N alone) may still govern the design when acting simultaneously. This is clearly observed when the interaction diagram method is applied to columns (or shear walls). The load-combination method helps engineers better control all considered combinations instead of only the max and min cases. [1] This demonstrates that column reinforcement design performed using the 3D interaction diagram generated by NConc software gives reliable results. [4].

3.4.5. General

Reaction forces: Model (2) and (3) show considerable similarity in reactions; However, Model (1) underestimates the lateral reaction forces transferred to the foundation. Consequently, the pile design based on this model would be unsafe as the actual lateral loads are significantly higher (nearly 3 times) than calculated, leading to the structure being unsafe.

Bending moment: Model (3) produces balanced moment results, whereas Model (1) shows no moment at this connection. For

Model (2), the bending moment is significantly larger, reaching nearly 1.5 times the reference value, and when checked with NCONC, the column fails completely. Primarily due to two factors: the excessively large effective column length in Model (2) and the significantly increased bending moment demand.

Axial force: All 3 models yield nearly equivalent axial forces. However, this factor does not determine reinforcement percentage, because it depends on the moments in the frame.

Construction Aspect: Model (1) cannot accurately represent the real structural behavior of the building, because during construction, the tie beam is cast monolithically. Therefore, modeling it as an isolated simply supported beam and applying its reactions to the frame is completely unreasonable, and it reflects an incorrect structural frame model.

4. CONCLUSION

The comparative evaluation of reaction forces, bending moments, axial forces, and column strength reveals the following:

Model (1) results in small lateral forces, causing danger to pile foundations.

Model (2) creates large moments at the column base, increasing the risk of failure.

Model (3) (modeling the tie beam with the frame) reflects construction reality more accurately and ensures structural safety compared to the other two models. Separating the tie beam for independent calculation is incorrect.

Therefore, this paper recommends using the integrated model (tie beam with frame) to optimize design and ensure structural safety.

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REFERENCES

[1] B.Q. Bao, *Design of Reinforced Concrete Structures according to TCVN 5574:2018*. Construction Publishing, 2020.

[2] Hoa Binh Corporation, "*Guidelines for Tie Beam Reinforcement Arrangement*" *Construction Blog*, https://hbcg.vn/news/1083-huongdancachbotrithepdakiengdanhchoban.html.

[3] N.D. Cong, *Practical Calculation of Reinforced Concrete Elements – 1,2*, Science and Technology Publishing, Hanoi, 2009.

[4] T.Q. Khang, "*Compare Csicol, Prokon, and Ncol column calculation software*," Journal of Science, Technology and Engineering Mien Tay Construction University, 8, 79-85, 2024.

[5] D.T.Q. Mai, *Reinforced Concrete – Theory and Design*. Construction Publishing, 2018.

[6] J.C. McCormac, *Design of Reinforced Concrete*, 9th ed. New York, NY, USA: Wiley, 2014.

[7] L.T. Nhan, "*Ncal Solution, Nconc*". https://www.ncal.com.vn/ph%E1%BA%A7n-m%E1%BB%81m/nconc.

[8] T.V. Tam, P.T. Tung, N.T. Ninh and P.N. Vuong, "*Programming software for load bearing capacity of reinforced concrete bi-axially loaded members with arbitrary cross-sections based on TCVN 5574:2018*," Journal of Science and Technology in Civil Engineering, 13(4V), 47-57, 2019. DOI: 10.31814/stce.nuce2019-13(4V)-05

[9] V.B. Tam, *Reinforced Concrete Structures – Basic Components*. Science and Technology Publishing, 2017.

[10] Ministry of Science and Technology, TCVN 2737:2023, "*Loads and Actions – Design Standard*", 2023.

[11] Ministry of Construction, TCVN 4453:1995, "*Monolithic concrete and reinforced concrete structure - Codes for construction, check and acceptance*", 1995.

[12] Ministry of Science and Technology, TCVN 5574:2018, "*Design of concrete and reinforced concrete structures*", 2018.