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Structural Analysis and Design of Beam Formwork Systems Using Fundamental Engineering Mechanics

Huu-Dien Nguyen

Long An University of Economics and Industry, Tan An 850000, Long An, Vietnam.

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[*] **Corresponding author:** Huu-Dien Nguyen, Long An University of Economics and Industry, Tan An 850000, Long An, Vietnam.

Abstract

The safety and efficiency of beam formwork are critical concerns in reinforced concrete construction, as failures can lead to severe consequences. While advanced Finite Element Method (FEM) software is available, a foundational understanding based on the mechanics of materials remains essential for verification and practical design. This paper details a systematic methodology for the design and verification of beam formwork systems, treating components as discrete structural elements. The analysis covers the side-panels and soffit (bottom) sheathing, their supporting members (studs, stringers), and the primary shoring system. A case study for a 350 mm x 700 mm beam is presented, where all components are subjected to checks for bending stress and deflection under the action of fresh concrete and construction loads. The results validate the proposed configuration: 25 mm thick film-coated plywood sheathing supported by 50 x 50 mm timber studs at 0.315 m (sides) and 50 x 50 mm timber stringers at 0.39 m (soffit), with the load ultimately transferred to adjustable steel props via 100 x 100 mm timber bearers. All calculated stresses and deflections were well within the allowable limits of the materials. The maximum load on a single steel prop was found to be 13.5 kN, which is safely below its 20 kN capacity. This work demonstrates that a principles-based mechanical analysis provides a reliable and transparent framework for ensuring the structural adequacy and safety of beam formwork systems.

Keywords

Beam Formwork; Structural Design; Construction Safety; Load Calculation; Timber Design; Concrete Pressure

1. Introduction

Beams are fundamental structural elements that transfer loads from slabs and walls to columns. The formwork system that supports freshly placed concrete for beams must be designed to withstand significant pressures and loads. An improper design can lead to excessive deflections, causing aesthetic and functional issues, or worse, catastrophic collapse [1]. Modern engineering often utilizes sophisticated FEM software for formwork analysis [2]. However, a hand-calculation approach based on standard structural mechanics is invaluable for initial design, quick checks, and understanding the fundamental load paths and failure mechanisms [3]. This approach effectively applies the core concept of FEM—discretizing a complex system into simpler, analyzable elements.

This paper focuses exclusively on the structural design of beam formwork. It outlines a comprehensive procedure to calculate loads and verify the capacity of each component, from the plywood sheathing to the supporting shoring.

2. Method and Analytical Model

2.1 Material Properties

The design utilized the following materials:

- **Sheathing:** 25 mm thick film-coated plywood.
    - Modulus of Elasticity (E) = 6,500 MPa
    - Allowable Bending Stress ([σ]) = 26 MPa
- **Timber Supports:** Group VI timber was used for secondary members.
    - Modulus of Elasticity (E) = 9,400 MPa
    - Allowable Bending Stress ([σ]) = 12 MPa
    - Sections: 50 x 50 mm for studs and stringers; 100 x 100 mm for bearers.
- **Steel Supports:** Hoa Phat adjustable steel props (Model K-102) with a safe working load of 20 kN were used.

2.2 Load Calculations and Assumptions

Loads were calculated in accordance with standard construction practices, incorporating appropriate load factors for safety [4].

Load factors are applied according to TCVN 2737:1995: $\gamma\_f = 1.2$ for dead loads (concrete self-weight, reinforcement), $\gamma\_f = 1.3$ for live loads (construction, vibration, pouring), and $\gamma\_f = 1.1$ for formwork self-weight

Reinforcement weight estimated as 0.5% of concrete volume × steel density (78.5 kN/m³) × depth = 0.005 × 78.5 × 0.7 = 0.275 kN/m².

Per TCVN 2737, construction live loads (pouring and vibration) are combined with concrete pressure as unfactored loads before applying load factors.

A) Loads on Side-Form (Vertical Loading)

The lateral pressure from fresh concrete governs the design of the side panels.

- Fresh Concrete Pressure: $q_{1tt} = \gamma * H * n1 = 25\ \text{kN/m}^3 * 0.7\ \text{m} * 1.3 = 22.75\ \text{kN/m}^2$
- Concrete Vibration Load: $q_{2tt} = 2\ \text{kN/m}^2 * 1.3 = 2.6\ \text{kN/m}^2$
- Concrete Pouring Load: $q_{3tt} = 4\ \text{kN/m}^2 * 1.3 = 5.2\ \text{kN/m}^2$
- **Total Lateral Load, q_{lat} = 30.55 kN/m²**

B) Loads on Soffit-Form (Vertical Loading)

The soffit supports the entire weight of the beam.

- Concrete Self-Weight: $q_{1tt} = 25\ \text{kN/m}^3 * 0.7\ \text{m} * 1.2 = 21\ \text{kN/m}^2$
- Reinforcement Weight: $q_{2tt} = 1.0\ \text{kN/m}^3 * 0.7\ \text{m} * 1.2 \approx 0.084\ \text{kN/m}^2$
- Formwork Self-Weight: $q_{3tt} = 6\ \text{kN/m}^3 * 0.025\ \text{m} * 1.1 = 0.165\ \text{kN/m}^2$
- Construction Live Load: $q_{4tt} = 2.5\ \text{kN/m}^2 * 1.3 = 3.25\ \text{kN/m}^2$
- Concrete Pouring Load: $q_{5tt} = 4\ \text{kN/m}^2 * 1.3 = 5.2\ \text{kN/m}^2$
- Concrete Vibration Load: $q_{6tt} = 2\ \text{kN/m}^2 * 1.3 = 2.6\ \text{kN/m}^2$
- **Total Vertical Load, q_{vert}= 32.3 kN/m²**

2.3 Case Study: Design of a 350 mm x 700 mm Beam Formwork

2.3.1 Side-Form Design

- **Plywood Sheathing:** Modeled as a continuous beam over multiple supports (vertical studs). With a stud spacing of L = 0.315 m: (Fig.1)
    - $M_{max} = (q_{lat} * L^2) / 8 = (30.55 * 0.315^2) / 8 = 0.38$ kN.m/m
    - Section Modulus, $W = (b * h^2)/6 = (1 * 0.025^2)/6 = 1.04 \times 10^{-4}\ \text{m}^3$
    - Bending Stress, σ = M / W = 0.38 / 1.04e-4 = 3.65 MPa < [26 MPa] **(OK)**
    - Moment of Inertia, $I = (1 * 0.025^3)/12 = 1.30 \times 10^{-6}\ \text{m}^4$
    - Deflection, $f = (q_{lat} * L^4) / (185 * E * I) = 0.19$ mm < [L/400 = 0.79 mm] **(OK)**

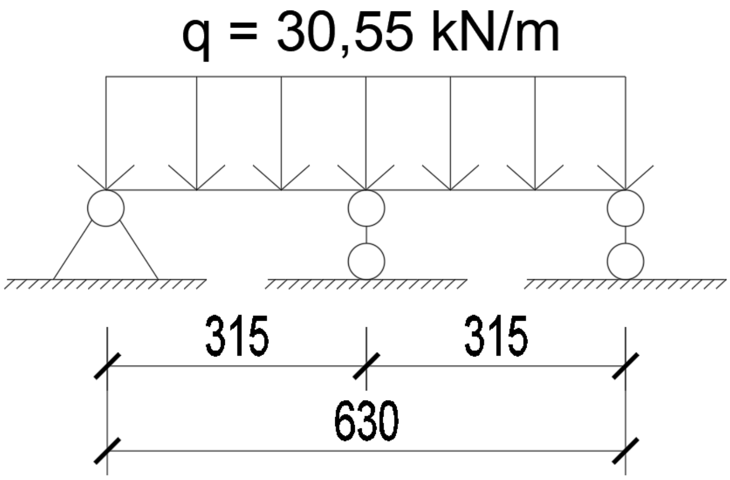

Figure 1. Calculation diagram for beam side-panel sheathing.

- **Vertical Studs (50x50mm Timber):** Modeled as a continuous beam over supports (ties/bracing). With a support spacing of 0.39m and a tributary width of 0.315 m: (Fig. 2)
    - $q_{stud} = q_{lat}$* 0.315 m = 30.55 * 0.315 = 9.62 kN/m
    - M_{max} = (q_{stud}* L^2) / 10 = (9.62 * 0.39^2) / 10 = 0.15 kN.m
    - W_{timber} = (0.05 * 0.05^2)/6 = 2.08 x 10^{-5} m^3
    - σ = M / W = 0.15 / 2.08e-5 = 7.20 MPa < [12 MPa] **(OK)**
    - Deflection check was also satisfactory.

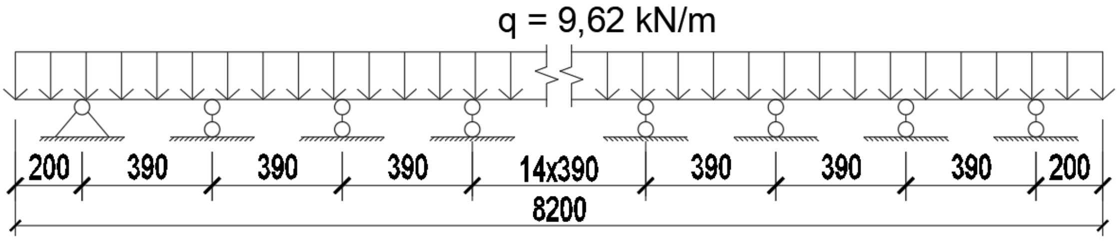

Figure 2. Calculation diagram for vertical studs (secondary members) supporting the side-panel.

2.3.2 Soffit-Form Design

- **Plywood Sheathing:** Modeled as a continuous beam over supports (longitudinal stringers). With a stringer spacing of L = 0.2 m:
    - $q_{ply} = q_{vert}$* 1 m = 32.3 kN/m
    - The moment was calculated considering continuous support, found to be M_{max} = 0.09 kN.m/m
    - σ = 0.09 / 1.04e-4 = 0.87 MPa << [26 MPa] **(OK)**
    - Deflection was negligible.
- **Longitudinal Stringers (50x50mm Timber):** Modeled as a continuous beam over supports (transverse bearers). With a bearer spacing of L = 0.39m and a tributary width of 0.175 m:
    - $q_{stringer} = q_{vert}$* 0.175 m = 32.3 * 0.175 = 5.65 kN/m
    - M_{max} = ($q_{stringer}$* L^2) / 10 = (5.65 * 0.39^2) / 10 = 0.09 kN.m
    - σ = 0.09 / 2.08e-5 = 4.32 MPa < [12 MPa] **(OK)**
    - Deflection was satisfactory.
- **Transverse Bearers (100x100mm Timber):** Modeled as a simply supported beam spanning between steel props (span = 1.2 m), subjected to point loads from stringers.
    - The critical point load was calculated as P = 2.2 kN.
    - M_{max} = P * a = 2.2 kN * 0.5 m = 1.1 kN.m (for a specific loading scenario).
    - W_{bearer} = (0.1 * 0.1^2)/6 = 1.67 x 10^{-4} m^3

- $\sigma = M / W = 1.1 / 1.67e\text{-}4 = 6.59$ MPa < [12 MPa] **(OK)**
- Deflection was also within allowable limits.

2.3.3 Shoring System Design (Fig. 3)

The total load on one steel prop was calculated by summing the reactions from the bearers and the diagonal bracing forces from the side-forms.

N_{prop}= ΣReactions ≈ 13.5 Kn

This load is less than the safe working load of the K-102 steel prop (20 kN). **(OK)**

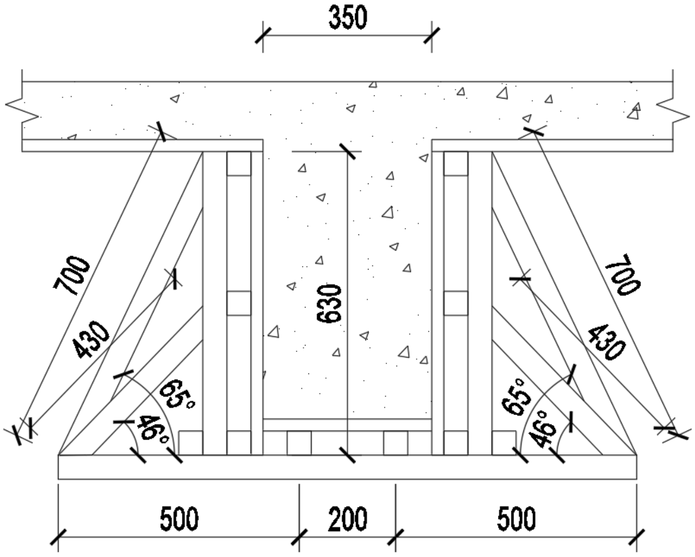

Figure 3. Overall bracing and shoring system for the beam, showing diagonal and vertical props.

3. Results and Discussion

The analysis confirms the structural adequacy of the proposed beam formwork system. All components passed the stress and deflection checks with significant safety margins. The governing design parameter for the plywood and timber members was often deflection rather than bending stress. The spacing of supports (0.315 m for side studs, 0.39m for soffit stringers and bearers) was proven to be efficient and safe. The load path from the concrete to the final support on the steel props was clearly defined and verified at each stage (Fig. 4)

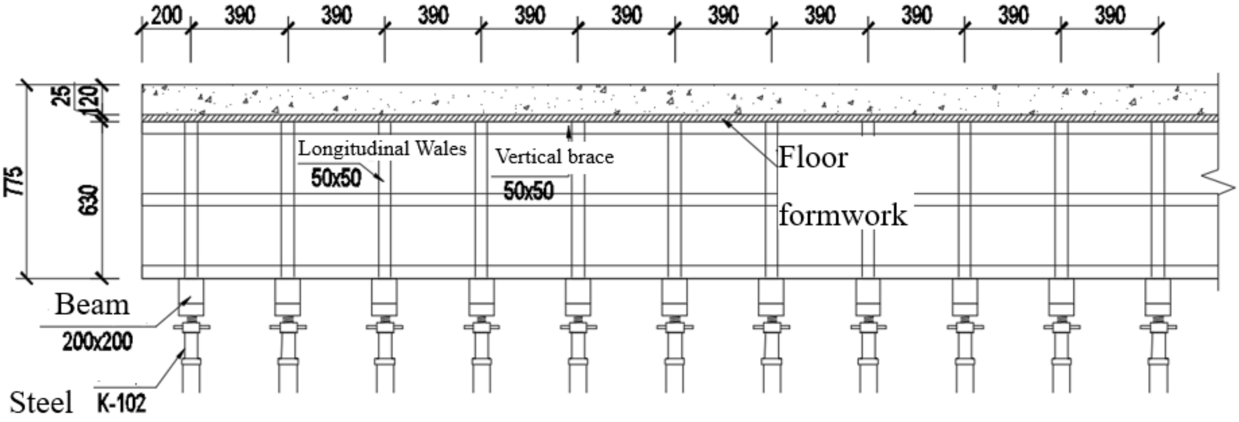

Figure 4. Side elevation view of the beam formwork assembly.

4. Conclusion

This study provides a validated, step-by-step methodology for the engineering design of beam formwork. By applying fundamental principles of structural mechanics, each component was systematically analyzed and verified.

This approach ensures safety, controls deflections, and provides engineers with a clear and reliable tool for formwork design, complementing the use of more complex FEM software. The success of this analysis for the case study beam demonstrates its practical applicability for similar construction projects.

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