Technical Note

SLAB FORMWORK DESIGN

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Catatan Redaksi:

Note from the Editor:
In Indonesia, although cost of formwork contributes significantly to the total reinforced concrete construction cost and formwork failure will result in a very complicated construction problem, formwork design is often neglected and left to the foreman to design. This paper presents slab formwork design practice in Romania, where formwork design is a requirement to obtain professional engineer certification. This paper is a continuation of previous paper “Wall Formwork Design” by the same author published in Dimensi Teknik Sipil, Vol. 6, no. 2, September 2004.

GENERAL CONSIDERATIONS

Although formwork is temporary in nature, the methods used in building formwork must adhere to code specifications [1] that apply to the particular material being used. Each component of the form must be able to support its load from two points of view: (1) strength, based on the physical properties of the material used, and (2) serviceability, the ability of the selected sections to resist the anticipated loads without exceeding deflection limits.

The usual format of a modular plywood panel, consists of framed plywood sheet screwed/nailed on a timber studwork (Figure 1). Plywood is a sheathing product made of several wood veneers with their grain lying (normal to one another) at right angles and firmly glued together under pressure, producing a panel that has uniform properties in both directions, an advantage regarding increased bending, shear, and deflection properties. [4]

When designing modular formwork for concrete, there is frequent intermixing of standard size units that have the following nominal dimensions, as shown in Table 1.

<table>
<thead>
<tr>
<th>Type of panel</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>No. of studs</th>
<th>No. of traverse frames</th>
<th>No. of braces</th>
<th>Thickness of panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2400</td>
<td>300</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>100 mm</td>
</tr>
<tr>
<td>P2</td>
<td>2400</td>
<td>400</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>2400</td>
<td>600</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>1200</td>
<td>300</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>P5</td>
<td>1200</td>
<td>400</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>1200</td>
<td>600</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>600</td>
<td>300</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>P8</td>
<td>600</td>
<td>400</td>
<td>3</td>
<td>2</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

SHORING MEMBERS

Shoring members support formwork and their contents, bearing loads and limiting their deflections. They can be divided into two major categories according to type and shape of concrete member that will be supported:

a. Horizontal shores (also known as joists) range from small units 1.8 m, to large members 9.0 m, used to carry much heavier loads, usually manufactured from wood or high-tensile steel, typical steel joists are illustrated in Figure 2. They are placed one along side another at allowable spans as specified in Table 2, and in accordance with bearing load imposed upon formwork.
Figure 1. Typical Plywood Panel

Caption: 1. Plywood sheathing; 2. Batten (Stud); 3. Brace; 4. Transverse frame: $e = 8$; $d = 92$; $85$ mm, $c = 48$ mm, $f = 38$ mm. [1, 2, 3]

Figure 2. Typical Steel Telescopic Joists. a. Joist Length 1.8…3.0 m; b. Joist Length 3.0…5.0 m and c. Joist Length 3.6…6.0 m [1]

b. Vertical shores (also known as props) support the horizontal shores (joists) from a firm base below. They may be manufactured of wood or steel, with various shapes, depending on the particular scope, typical adjustable steel pipe shores are illustrated in Figure 3.

- **Vertical wood shores** may be single wood posts, with wedges to adjust the height, double wood posts, two-piece adjustable posts, or T head shores.

Table 2. Allowable Spans “d” (m) Between Joists in Accordance With Length and Imposed Load [3]

<table>
<thead>
<tr>
<th>Load (N/m²)</th>
<th>Telescopic joist 1.8…3.0 m</th>
<th>Span of joist “D” in accordance with “d” distance between joists</th>
</tr>
</thead>
<tbody>
<tr>
<td>d (m)</td>
<td>2000</td>
<td>2500</td>
</tr>
<tr>
<td>0.5</td>
<td>2.97</td>
<td>2.82</td>
</tr>
<tr>
<td>0.6</td>
<td>2.77</td>
<td>2.62</td>
</tr>
<tr>
<td>0.7</td>
<td>2.60</td>
<td>2.46</td>
</tr>
<tr>
<td>0.8</td>
<td>2.46</td>
<td>2.33</td>
</tr>
<tr>
<td>0.9</td>
<td>2.34</td>
<td>2.21</td>
</tr>
<tr>
<td>1.0</td>
<td>2.24</td>
<td>2.12</td>
</tr>
<tr>
<td>1.1</td>
<td>2.15</td>
<td>2.03</td>
</tr>
<tr>
<td>1.2</td>
<td>2.07</td>
<td>1.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>d (m)</th>
<th>1.8…3.0 m</th>
<th>3.0…5.0 m</th>
<th>3.6…6.0 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>6.00</td>
<td>6.00</td>
<td>5.89</td>
</tr>
<tr>
<td>0.6</td>
<td>5.98</td>
<td>5.64</td>
<td>5.35</td>
</tr>
<tr>
<td>0.7</td>
<td>5.59</td>
<td>5.27</td>
<td>4.99</td>
</tr>
<tr>
<td>0.8</td>
<td>5.27</td>
<td>4.96</td>
<td>4.70</td>
</tr>
<tr>
<td>0.9</td>
<td>4.99</td>
<td>4.70</td>
<td>4.46</td>
</tr>
<tr>
<td>1.0</td>
<td>4.76</td>
<td>4.48</td>
<td>4.25</td>
</tr>
<tr>
<td>1.1</td>
<td>4.58</td>
<td>4.29</td>
<td>4.07</td>
</tr>
<tr>
<td>1.2</td>
<td>4.38</td>
<td>4.12</td>
<td>3.91</td>
</tr>
</tbody>
</table>
• Vertical metal shores may be adjustable pipe shores or shores made up of prefabricated steel tubing. Scaffold-type shoring, is usually assembled into towers by combining a number of units into a single shoring structure.

**Figure 3. Typical Adjustable Steel Pipe Shore (Prop) [3]**

Table 4. Types of Loads According to Weight of Material or Equipment [1]

<table>
<thead>
<tr>
<th>Item</th>
<th>Type load</th>
<th>Building material, equipment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Weight of the formwork itself and the scaffold</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>lumber in panels</td>
<td></td>
<td>7500 N/m²</td>
</tr>
<tr>
<td></td>
<td>lumber in shoring elements</td>
<td></td>
<td>6000 N/m²</td>
</tr>
<tr>
<td></td>
<td>plywood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>Weight of fresh concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>normal weight (heavy) concrete</td>
<td></td>
<td>2400 N/m²</td>
</tr>
<tr>
<td></td>
<td>reinforced concrete</td>
<td></td>
<td>2500 N/m²</td>
</tr>
<tr>
<td></td>
<td>lightweight concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Uniform distributed load of runways for concrete transport and impact loads of the crowding of crewmen</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>panel design</td>
<td></td>
<td>2500 N/m²</td>
</tr>
<tr>
<td></td>
<td>horizontal shoring (posts)</td>
<td></td>
<td>1500 N/m²</td>
</tr>
<tr>
<td></td>
<td>vertical shoring elements (e.g. props, columns)</td>
<td></td>
<td>1000 N/m²</td>
</tr>
<tr>
<td>d</td>
<td>Concentrated load from weight of work crews and transport equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>one crew member that carries loads</td>
<td></td>
<td>1300 N</td>
</tr>
<tr>
<td></td>
<td>wheelbarrow / buggies for concrete transport</td>
<td></td>
<td>2800 N</td>
</tr>
<tr>
<td>e</td>
<td>Load from the vibrating effect of the concrete compactor</td>
<td></td>
<td>1200 N/m²</td>
</tr>
</tbody>
</table>

Table 5. Combination of Loads According to Member Design [1, 3]

<table>
<thead>
<tr>
<th>Item name</th>
<th>Combination of loads</th>
<th>Strength</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab and arch forms and horizontal props (posts)</td>
<td>a + b + c + d</td>
<td>a + b</td>
<td></td>
</tr>
<tr>
<td>Vertical props for slabs</td>
<td>a + b + c</td>
<td>a + b</td>
<td></td>
</tr>
<tr>
<td>Column forms with the maximum edge of 30 cm and walls of maximum 10 cm width</td>
<td>f + g</td>
<td>f</td>
<td></td>
</tr>
<tr>
<td>Column forms and walls with larger values</td>
<td>f</td>
<td>f</td>
<td></td>
</tr>
<tr>
<td>Lateral faces of forms for beams and arches</td>
<td>f</td>
<td>f</td>
<td></td>
</tr>
<tr>
<td>Bottom of beams</td>
<td>a + b + e</td>
<td>a + b</td>
<td></td>
</tr>
<tr>
<td>Centers and scaffolds &lt; 6 m</td>
<td>a + b + c (e)</td>
<td>a + b</td>
<td></td>
</tr>
<tr>
<td>Centers and scaffolds &gt; 6 m</td>
<td>a + b + c (e) + h</td>
<td>a + b</td>
<td></td>
</tr>
</tbody>
</table>

**FORMWORK PRINCIPLES AND LOADS ON CONCRETE SLABS**

The principles behind good formwork are based on the same basic frame theories used in the design and construction of structural frames. Formwork must be able to withstand loads that, in many respects, can be more severe than those experienced by the completed structure. It is imperative that each component of the formwork be erected according to the formwork drawings to ensure that all construction loads are safely supported.

For the design of formwork, the loads on concrete slabs (Table 4) must be taken into account differently, in combination, according to Table 5.

The design of formwork components will be made according to the following characteristics: type of material used, nature of the load, number of reuses, moisture conditions and deflection limitations.

**SLAB FORMWORK AND SHORING SYSTEM DESIGN**

Formwork must be checked to ensure that they withstand bending and shear, and that deflection will not exceed the specified value according to surface finishing.

**Evaluation of Loads**

1. Weight of 8 (1.5) mm panel sheathing.
2. Weight of fresh concrete (h_{slab}).
3. Uniform distributed load of runways for concrete transport and impact loads of the crowding of crew members.
4. Concentrated load weight of work crews and transport equipment.
5. Load from the vibrating effect of concrete consolidation.
Note 1: The loads on plywood are usually considered as being uniformly distributed over the entire surface of the plywood. The concentrated load “d” can be transformed in a uniform distributed load, by dividing it to the span “l”.

Note 2: This design recommends three basic span conditions for computing the uniform load capacity of plywood panels. The span may be single span, two-spans or three–span according to the panel’s width.

Plywood Panel Design

Recommended standard thickness of plywood ($\delta_{\text{panel}}$), 8 or 15 mm. When calculating the allowable pressure of concrete on plywood as limited by the allowable unit stress deflection of the plywood, use the clear span between supports.

| Note 1: The loads on plywood are usually considered as being uniformly distributed over the entire surface of the plywood. The concentrated load “d” can be transformed in a uniform distributed load, by dividing it to the span “l”.

Table 6. Properties of form Material

<table>
<thead>
<tr>
<th>PROPERTIES OF FORM</th>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable bending stress ((\sigma_a))</td>
<td>lumber</td>
<td>12 N/mm²</td>
</tr>
<tr>
<td>Allowable bending stress ((\sigma_a))</td>
<td>plywood</td>
<td>When the face grain is parallel to the span</td>
</tr>
<tr>
<td>Allowable bending stress ((\sigma_a))</td>
<td>plywood</td>
<td>When the face grain is perpendicular to the span</td>
</tr>
<tr>
<td>Allowable bending stress of steel ((\sigma_a))</td>
<td>lumber</td>
<td>210 N/mm²</td>
</tr>
<tr>
<td>Allowable bending stress of steel ((\sigma_a))</td>
<td>plywood</td>
<td>7.000 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>lumber</td>
<td>10.000 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>plywood</td>
<td>7.000 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>steel</td>
<td>210.000 N/mm²</td>
</tr>
<tr>
<td>Allowable bending deflection limitations</td>
<td>architectural concrete</td>
<td>L maximum clear span/300</td>
</tr>
<tr>
<td>Allowable bending deflection limitations</td>
<td>concrete surfaces with finishing</td>
<td>L maximum clear span/200</td>
</tr>
<tr>
<td>Allowable tolerances</td>
<td>length and width of panel</td>
<td>± 2 mm</td>
</tr>
<tr>
<td>Allowable tolerances</td>
<td>thickness of panel</td>
<td>± 5 mm</td>
</tr>
<tr>
<td>Allowable tolerances</td>
<td>length of diagonals of panel</td>
<td>± 5 mm</td>
</tr>
</tbody>
</table>

a. For 30 cm width panel:

Reactions for a simple beam with a uniformly distributed load

\(q = \text{uniformly distributed load per unit length (mL)} [\text{N/m}]\)

Verification for bending stress:
The calculation is made for a width of b=1m.
\(q = (a + b + c) \times 1.00 + d/1 (\text{N/ml})\)
Where: \(l = \text{span between supports (25.2 cm)}\)
The maximum bending moment that will occur at the center of the beam, will be calculated as follows:
\(M = q l^2/8, \sigma_e \leq \sigma_a\)
The applied bending stress must not exceed the allowable bending design stress:
\(\sigma_e \leq \sigma_a\)
Where:
\(\sigma_e = \text{applied bending stress}; \sigma_a = \text{allowable bending design stress}; M = \text{bending moment [Nmm]}; I = \text{moment of inertia of the cross section [mm}^4\]; W = \text{section modulus of the cross- section [mm}^3\]; \sigma_e = M I/W \leq \sigma_a\)
\(M = q x P/8; W = b x h^3/6; h = 8 \text{ or } 15 \text{ mm}\)

Verification for deflection:
The calculation is made for a width of b=1m.
\(q = (a + b) \times 1.00 \text{ m (N/ml)}\)
For a rectangular beam subjected to bending the applied deflection \(f\) can be calculated form the following equation:
\(f_e = 5 x q x l^4 \times E / 384 I\)
The applied deflection must not exceed the allowable design deflection:
\(f_e \leq f_a\)
Where:
\(f_e = \text{applied deflection}; f_a = \text{allowable design deflection}; I = \text{moment of inertia of the cross section [mm}^4\]; E = \text{modulus of elasticity [N/mm}^2\]; f_e = 5 x q x l^4 / 384 E I \leq f_a = l / 200\)
\(I = b x h^3/12 \text{ (mm}^3\); \(h = 8 \text{ or } 15 \text{ mm}\)
\(E = 7000 \text{ (N/mm}^2\)
b. For 60 cm width panel:

Reactions for a simple beam with a uniformly distributed load spanning over three or more equally spaced supports. q = uniformly distributed load pre unit length (ml) [Nml]

<table>
<thead>
<tr>
<th>Verification for bending stress:</th>
<th>Verification for deflection:</th>
</tr>
</thead>
</table>
| The calculation is made for a width of b=1m. q = (a + b + c) x 1.00 + d/l (N/ml) Where: l = span between supports (27,6 cm) The maximum bending moment that will occur at the center of the beam, will be calculated as follows: M = q*l²/16 The applied bending stress must not exceed the allowable bending design stress: σₑ ≤ σₐ Where: σₑ = applied bending stress; σₐ = allowable bending design stress; M = bending moment [Nmm]; I = moment of inertia of the cross section [mm⁴]; W = section modulus of the cross- section [mm³]. σₑ = M * v = M / W ≤ σₐ  
M = q x l²/10; W= b x h²/6  
h = 8 or 15 mm |
| The calculation is made for a width of b=1m. q = (a + b) x 1.00 m (N/ml) For a rectangular beam subjected to bending the applied deflection f can be calculated form the following equation: fₑ = 0.005 x q*l⁴ / E*I  
The applied deflection must not exceed the allowable design deflection: fₑ ≤ fₐ Where: fₑ = applied deflection; fₐ = allowable design deflection; I = moment of inertia of the cross section [mm³]; E = modulus of elasticity [N/mm²]. fₑ = 0.005 x q*l⁴ / E*I ≤ fₑ = l / 200  
I= b*h²/12 (mm⁴)  
h = 8 or 15 mm  
E = 7000 (N/mm²) |

Horizontal Steel Telescopic Joist Design

Loads: q = a + b  (N/m²)
From Table 2, according to the type of joist used, the load “q” and the span of the joist “D” the spacing “d” of joists under paneling is given.
q = uniformly distributed load pre unit length (ml) [Nml]

Technical note: If the value “d” is not a common measure of the standard panel length, the joists will be placed at equidistance, but not more than “dmax” for Table 2.

Batten (Stud) Design
The design will be made in the most unfavorable situation; this will be, the design of the central stud of the 60 cm width plywood panel.

Loads:
For verification for bending stress:
q = (a + b + c) x 1.00 + d/l (N/ml)
For verification of deflection:
q = (a + b) x 1.00 m (N/ml)
a. For panel with \( L = 1.20 \text{ m} \) and spacing between joists \( d = 1.20 \text{ m} \)

\[
P = \text{concentrated load due to work crews and transport equipment [N]}
\]
\[
q = \text{uniformly distributed load per unit length (ml) [Nml]}
\]

**Verification for bending stress:**

\[
\sigma_v = \frac{M}{W} \leq \sigma_{\text{ult}} = 12 \text{ N/mm}^2
\]
\[
M = \text{bending moment [Nmm]};
\]
\[
W = \text{section modulus of the cross section [mm}^3\text{]}
\]
\[
M = \frac{qL^2}{8} + \frac{P_xL}{4}
\]
\[
W = \frac{b h^2}{6} = \frac{4.8 \times 8.5^2}{6}
\]
\[
h = \text{thickness of stud 85 or 92 mm}
\]

**Verification for deflection:**

\[
f_v = \frac{5}{384} \frac{qLt^4}{EI} \leq f_{\text{ult}} = \frac{l}{200}
\]
\[
f_v = \text{applied deflection};
\]
\[
f_{\text{ult}} = \text{allowable design deflection};
\]
\[
I = \text{moment of inertia of the cross section [mm}^4\text{]};
\]
\[
E = \text{modulus of elasticity [N/mm}^2\text{]}
\]
\[
I = \frac{b h^3}{12} \text{ (mm}^4\text{)}
\]
\[
b = 48 \text{ mm}, h = 85 \text{ mm}
\]
\[
E = 10000 \text{ (N/mm}^2\text{)}
\]

b. For panel with \( L = 2.40 \text{ m} \) and spacing between joists \( d = 1.20 \text{ m} \)

\[
P = \text{concentrated load due to work crews and transport equipment [N]}
\]
\[
q = \text{uniformly distributed load per unit length (ml) [Nml]}
\]

**Verification for bending stress:**

\[
\sigma_v = \frac{M}{W} \leq \sigma_{\text{ult}} = 12 \text{ N/mm}^2
\]
\[
M = \text{bending moment [Nmm]};
\]
\[
W = \text{section modulus of the cross section [mm}^3\text{]}
\]
\[
M = \frac{qL^2}{8} + 0.203 \times \frac{P_xL}{4}
\]
\[
W = \frac{b h^2}{6} = \frac{4.8 \times 8.5^2}{6}
\]
\[
h = \text{thickness of stud 85 or 92 mm}
\]

**Verification for deflection:**

\[
f_v = \frac{0.005}{384} \frac{qLt^4}{EI} \leq f_{\text{ult}} = \frac{l}{200}
\]
\[
f_v = \text{applied deflection};
\]
\[
f_{\text{ult}} = \text{allowable design deflection};
\]
\[
I = \text{moment of inertia of the cross section [mm}^4\text{]};
\]
\[
E = \text{modulus of elasticity [N/mm}^2\text{]}
\]
\[
I = \frac{b h^3}{12} \text{ (mm}^4\text{)}
\]
\[
b = 48 \text{ mm}, h = 85 \text{ mm}
\]
\[
E = 10000 \text{ (N/mm}^2\text{)}
\]
**Steel Pipe Shore Design**

![Diagram of Steel Pipe Shore Design](image)

The design will be made for the most loaded shore.

\[ P = (a + b + c)dx \frac{D}{2} (N) \]

Where:
- \( d \) = spacing of joists support under the paneling (m);
- \( D \) = span of telescopic steel joist (m);
- \( P \) = concentrated load due to work crews and transport equipment [N]

The type of steel pipe shore will be chosen if:

\[ P_a = P_{max} - \frac{(P_{max} - P_{min})}{H_{story}} \leq P (N) \]

**REFERENCES**