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Technical Note

SLAB FORMWORK DESIGN

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Catatan Redaksi:

Perencanaan bekisting (*form work*) di Indonesia sering kali dilalaikan dan diserahkan kepada pelaksana/ mandor, padahal kegagalan bekisting akan menimbulkan masalah yang sangat rumit. Bekisting juga merupakan komponen biaya pelaksanaan struktur beton bertulang yang cukup besar. Makalah ini memaparkan praktek perencanaan bekisting untuk lantai di Romania, dimana perencanaan bekisting merupakan salah satu syarat untuk mendapatkan sertifikasi insinyur professional. Makalah ini adalah kelanjutan dari makalah *Wall Formwork Design*, yang dimuat dalam Dimensi Teknik Sipil, Vol. 6, no.2, September 2004.

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.

Note: Discussion is expected before June, 1st 2006. The proper discussion will be published in "Dimensi Teknik Sipil" volume 8, number 2, September 2006.

Table 1. Formwork Panel Nominal Dimensions [3]

Type of panel	Size		Components			Thickness of panel
	Length (mm)	Width (mm)	No. of studs	No. of traverse frames	No. of braces	
P1	2400	300	2	2	3	100 mm
P2	2400	400	3	2	6	
P3	2400	600	3	2	6	
P4	1200	300	2	2	1	
P5	1200	400	3	2	2	
P6	1200	600	3	2	2	
P7	600	300	2	2	-	
P8	600	400	3	2	-	

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.

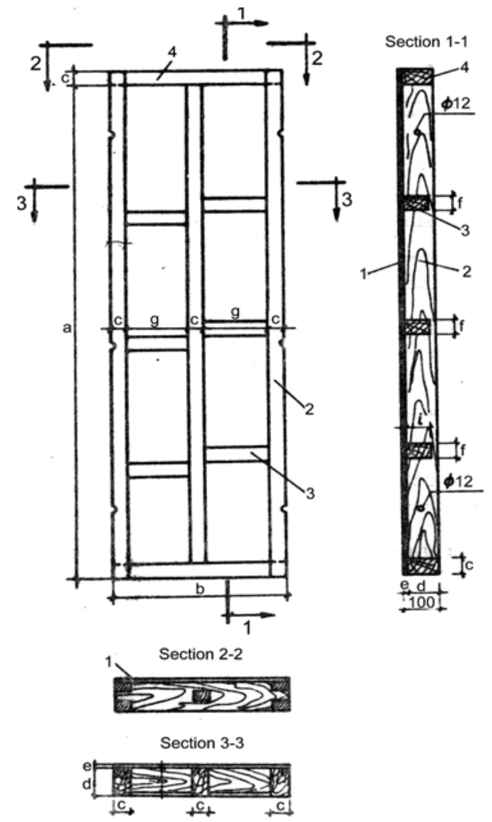


Figure 1. Typical Plywood Panel

Caption: 1. Plywood sheathing; 2. Batten (Stud); 3. Brace; 4. Transverse frame: e = 8; 15 mm, d = 92; 85 mm, c = 48 mm, i = 68 mm, f = 38 mm. [1, 2, 3]

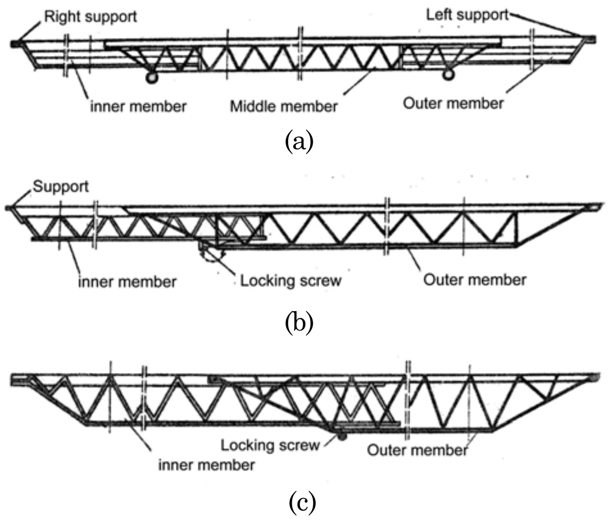


Figure 2. Typical Steel Telescopic Joists. a. Joist Length 1,8..3,0 m; b. Joist Length 3,0..5,0 m and c. Joist Length 3,6…6,0 m [1]

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]

Load (N/m^2)	*Telescopic joist 1,8...3,0 m*														
	Span of joist "D" in accordance with "d" distance between joists														
	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000
d (m)															
0.5	2.97	2.82	2.69	2.58	2.39	2.34	2.31	2.24	2.18	2.17	2.06	2.01	1.96	1.92	1.80
0.6	2.77	2.62	2.50	2.39	2.30	2.21	2.14	2.07	2.01	1.96	1.91	1.86	1.82		
0.7	2.60	2.46	2.34	2.24	2.15	2.07	2.00	1.94	1.88	1.83					
0.8	2.46	2.33	2.21	2.12	2.03	1.96	1.89	1.83							
0.9	2.34	2.21	2.10	2.01	1.93	1.86									
1.0	2.24	2.12	2.01	1.92	1.84										
1.1	2.15	2.03	1.93	1.84											
1.2	2.07	1.96	1.86												
	Telescopic joist 3,0...5,0 m														
d (m)															
0.5	5.00	4.93	4.68	4.47	4.29	4.13	3.98	3.85	3.74	3.63	3.53	3.44	3.36	3.28	3.21
0.6	4.83	4.55	4.32	4.13	3.96	3.80	3.67	3.55	3.44	3.34	3.25	3.17	3.09	3.02	
0.7	4.51	4.25	4.04	3.85	3.69	3.55	3.42	3.31	3.21	3.11	3.03				
0.8	4.23	4.01	3.80	3.63	3.47	3.34	3.22	3.11	3.02						
0.9	4.04	3.80	3.61	3.44	3.29	3.17	3.05								
1.0	3.85	3.63	3.44	3.28	3.14	3.02									
1.1	3.69	3.47	3.29	3.14											
1.2	3.55	3.34	3.16												
	Telescopic joist 3,6...6,0 m														
d (m)															
0.5	6.00	6.00	5.80	5.54	5.31	5.11	4.92	4.76	4.62	4.48	4.36	4.25	4.14	4.05	3.96
0.6	5.98	5.64	5.35	5.11	4.89	4.70	4.53	4.38	4.25	4.12	4.01	3.91	3.81	3.72	3.64
0.7	5.59	5.27	4.99	4.76	4.56	4.38	4.23	4.08	3.96	3.84	3.73	3.64			
0.8	5.27	4.96	4.70	4.48	4.29	4.12	3.97	3.84	3.72	3.61					
0.9	4.99	4.70	4.46	4.24	4.07	3.91	3.76	3.64							
1.0	4.76	4.48	4.25	4.05	3.87	3.72									
1.1	4.56	4.29	4.07	3.87	3.71										
1.2	4.38	4.12	3.91	3.72											

- **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.

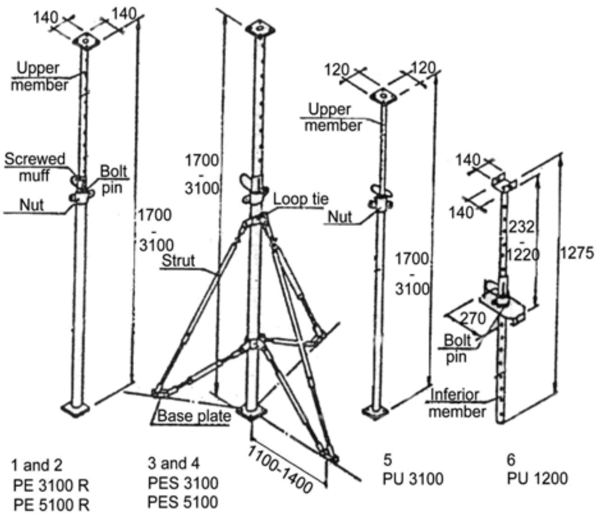


Figure 3. Typical Adjustable Steel Pipe Shore (Prop) [3]

Table 3. Allowable Axial Load "P" (daN) on Shore in Accordance With Length

Item name		Steel shore PE 3100 R	Steel shore PE 5100 R	Steel shore with spatial base PES 3100	Steel shore with spatial base PES 5100	Light steel telescopic shore PU 3100	Light steel telescopic shore PU 1200
H_{max} (mm)		3100	5100	3100	5100	3100	1220
H_{min} (mm)		1700	3100	1700	3100	1700	232
Load (N)	min	20000	18000	2000	18000	6000	3000
	max	45000	45000	45000	45000	12000	45000

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.

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

Item	Type load	*Building material, equipment*	*Value*	
a	Weight of the formwork itself and the scaffold	lumber in panels	7500 N/m³	
		lumber in shoring elements	6000 N/m³	
		plywood	8500 N/m³	
b	Weight of fresh concrete	normal weight (heavy) concrete	plain	24000 N/m³
			reinforced	25000 N/m³
		lightweight concrete	7000–19000N/m³	
:c	Uniform distributed load of runways for concrete transport and impact loads of the crowding of crewmen	panel design	2500 N/m²	
		horizontal shoring (joists) of panels	1500 N/m²	
		vertical shoring elements (e.g. props, columns)	1000 N/m²	
d	Concentrated load form weight of work crews and transport equipment:	one crew member that carries loads	1300 N	
		wheel barrow/ buggies for concrete transport	2800 N	
e	Load from the vibrating effect of the concrete compaction:		1200 N/m²	

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

Item name	Combination of loads	
	Strength	Deflection
Slab and arch forms and horizontal props (joists)	a + b + c + d	a + b
Vertical props for slabs	a + b + c	a + b
Column forms with the maximum edge of 30 cm and walls of maximum 10 cm width	f + g	f
Column forms and walls with larger values	f	f
Lateral faces of forms for beams and arches	f	f
Bottom of beams	a + b + e	a + b
Centers and scaffolds < 6 m	a + b + c (e)	a + b
Centers and scaffolds > 6 m	a + b + c (e) + h	a + b

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 (15) 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 crewmembers.
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 by 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.

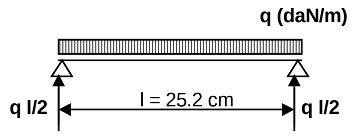
Plywood Panel Design

Recommended standard thickness of plywood (δ_{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.

Table 6. Properties of form Material

PROPERTIES OF FORM	Material		Value
Allowable bending stress (σa)	lumber		12 N/mm^2
Allowable bending stress (σa)	plywood	When the face grain is parallel to the span	13 N/mm^2
		When the face grain is perpendicular to the span	5 N/mm^2
Allowable bending stress of steel (σa)			210 N/mm^2
Modulus of elasticity	lumber		10.000 N/mm^2
	plywood		7.000 N/mm^2
	steel		210.000 N/mm^2
Allowable bending deflection limitations	architectural concrete		L maximum clear span/300
	concrete surfaces with finishing		L maximum clear span/200
Allowable tolerances	length and width of panel		+ 2 mm
	thickness of panel		- 5 mm
	length of diagonals of panel		± 5 mm

a. For 30 cm width panel:



Reactions for a simple beam with a uniformly distributed load
q = uniformly distributed load pre unit length (ml) [Nml]

Verification for bending stress:
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 (25.2 cm)
The maximum bending moment that will occur at the center of the beam, will be calculated as follows:
M = ql^2/8
The applied bending stress must not exceed the allowable bending design stress:

$$\sigma_e \leq \sigma_a$$

Where:
σ_e = applied bending stress;
σ_a = allowable bending design stress;
M = bending moment [Nmm];
I = moment of inertia of the cross section [mm^4];
W = section modulus of the cross- section [mm^3]

$$\sigma_e = M\frac{y}{I} = \frac{M}{W} \leq \sigma_a$$

M = q x l^2/8;
W= b x h^2/6
h = 8 or 15 mm

Verification for deflection:
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:

$$f_e = \frac{5}{384} x \frac{qxl^4}{ExI}$$

The applied deflection must not exceed the allowable design deflection:

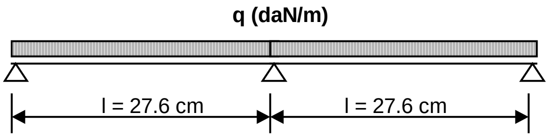
$$f_e \leq f_a$$

Where:
f_e = applied deflection;
f_a = allowable design deflection;
I = moment of inertia of the cross section [mm^4];
E = modulus of elasticity [N/mm^2]

$$f_e = \frac{5}{384} x \frac{qxl^4}{ExI} \leq f_a = \frac{l}{200}$$

I = bxh^3/12 (mm^4)
h = 8 or 15 mm
E = 7000 (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]

Verification for bending stress: 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: $M = ql^2/10$ The applied bending stress must not exceed the allowable bending design stress: $\sigma_e \leq \sigma_a$ Where: σ_e = applied bending stress; σ_a = allowable bending design stress; M = bending moment [Nmm]; I = moment of inertia of the cross section [mm^4]; W = section modulus of the cross- section [mm^3]. $\sigma_e = M\frac{y}{I} = \frac{M}{W} \leq \sigma_a$ $M = q \times l^2/10$; $W = b \times h^2/6$ h = 8 or 15 mm	**Verification for deflection**: 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: $f_e = 0.005x\frac{qxl^4}{ExI}$ The applied deflection must not exceed the allowable design deflection: $f_e \leq f_a$ Where: f_e = applied deflection; f_a = allowable design deflection; I = moment of inertia of the cross section [mm^4]; E = modulus of elasticity [N/mm^2]. $f_e = 0.005x\frac{qxl^4}{ExI} \leq f_a = \frac{l}{200}$ $I = bxh^3/12$ (mm^4) h = 8 or 15 mm E = 7000 (N/mm^2)

Horizontal Steel Telescopic Joist Design

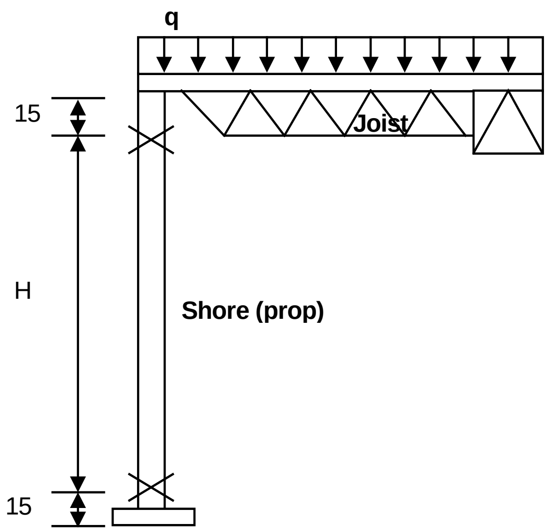


Figure 4. Typical View of Joist and Prop

Requirement: Spacing of joists under paneling "d" (m).

Loads: q = a + b (N/m^2)
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.

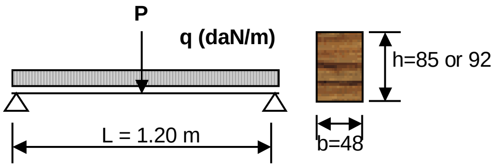
Batten (Stud) Design

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)

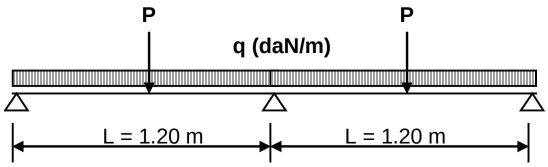
a. For panel with L = 1.20 m and spacing between joists d = 1.20 m



P = concentrated load do to work crews and transport equipment [N]
q = uniformly distributed load pre unit length (ml) [Nml]

Verification for bending stress:	Verification for deflection:
$\sigma_e = \frac{M_x}{W} \le \sigma_a = 12$ N/mm² M = bending moment [Nmm]; W = section modulus of the cross section [mm³] $M = \frac{qxL^2}{8} + \frac{PxL}{4}$ $W = \frac{bxh^2}{6} = \frac{4{,}8x8{,}5^2}{6}$ h = thickness of stud 85 or 92 mm	$f_e = \frac{5}{384} x \frac{qxl^4}{ExI} \le f_a = \frac{l}{200}$ f_e = applied deflection; f_a = allowable design deflection; I = moment of inertia of the cross section [mm⁴]; E = modulus of elasticity [N/mm²] $I = \frac{bxh^3}{12}$ (mm⁴) b = 48 mm, h = 85 mm E = 10000 (N/mm²)

b. For panel with L = 2.40 m and spacing between joists d = 1.20 m



P = concentrated load do to work crews and transport equipment [N]
q = uniformly distributed load pre unit length (ml) [Nml]

Verification for bending stress:	Verification for deflection:
$\sigma_e = \frac{M}{W} \le \sigma_a = 12$ N/mm² M = bending moment [Nmm]; W = section modulus of the cross section [mm³] $M = \frac{qxL^2}{8} + 0{,}203x\frac{PxL}{4}$ $W = \frac{bxh^2}{6} = \frac{4{,}8x8{,}5^2}{6}$ h = thickness of stud 85 or 92 mm	$f_e = 0{,}005x\frac{qxl^4}{ExI} \le f_a = \frac{l}{200}$ f_e = applied deflection; f_a = allowable design deflection; I = moment of inertia of the cross section [mm⁴]; E = modulus of elasticity [N/mm²] $I = \frac{bxh^3}{12}$ (mm⁴) b=48 mm, h = 85 mm E = 10000 (N/mm²)

Steel Pipe Shore Design

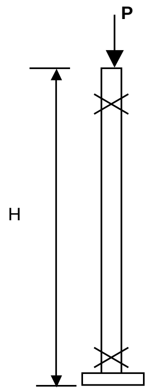


Figure 5. Schematic View of Prop (Shore)

The design will be made for the most loaded shore.

$$P = (a + b + c)xdx\frac{D}{2}\ (N)$$

Where:

d = spacing of joists support under the paneling (m);

D = span of telescopic steel joist (m);

P = concentrated load do to work crews and transport equipment [N]

The type of steel pipe shore will be chosen if:

$$P_a = P_{max} - \frac{(P_{max} - P_{min})x(H_{story} - H)}{(H_{max} - H_{min})} \geq P\ (N)$$

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