Civil Engineering Dimension, Vol. 6, No. 2, 101–108, September 2004
ISSN 1410-9530

Technical Note

WALL FORMWORK DESIGN

George Ilinoiu
Faculty of Civil, Industrial and Agricultural Constructions
Technical University of Civil Engineering of Bucharest
Bd. Lacul Tei, no. 124, sector 2, Bucharest, Romania
Telephone: 401-242.12.08 / 157; Fax: 401-242.07.81; e-mail: ilinoiug@hidro.utcb.ro

Catatan Redaksi:

Perencanaan bekisting (*Form Work*) merupakan bagian penting dalam pelaksanaan struktur beton bertulang, bila tidak direncanakan dengan baik, tidak jarang kegagalan bekisting menyebabkan masalah pelaksanaan yang cukup rumit. Bekisting juga menjadi komponen biaya struktur beton bertulang yang cukup besar. Makalah ini memaparkan perencanaan bekisting, yang di Romania, merupakan bagian persyaratan untuk mendapatkan sertifikasi Insinyur Profesional.

GENERAL CONSIDERATIONS

All concrete sections made with poured-in-place concrete require some temporary means of support for the fresh mixed concrete until it reaches the necessary hardening rate for strike off. Formwork is a temporary mould into which wet concrete and reinforcement is placed to form a particular desired shape with a predetermined strength. Depending on the complexity of the form, the relative cost of formwork to concrete can be as high as 75% of the total cost to produce the required member. A typical break-down of percentage costs could be as follows [1]:

- Concrete (materials 28%; labor 12%) = 40%;
- Reinforcement (materials 18%; labor 7%) = 25%;
- Formwork (materials 15%; labor 20%) = 35%.

The above breakdown shows that a building contractor will have to use an economic method of providing the necessary formwork if the contractor is to be competitive in tendering since this is the factor over which that company has most control.

PLYWOOD FORMWORK

Plywood is an ideal material for concrete forming. It produces smooth concrete surfaces and can be used repeatedly – 10 times up to 200 times or more for some overlaid panels.

Note: Discussion is expected before November, 1st 2004. The proper discussion will be published in "Dimensi Teknik Sipil" volume 7 number 1 March 2005.

The thinner panels can be bent easily for curved forms and liners. Plywood's excellent stiffness minimizes deflection during pouring. Its natural insulating qualities help provide more consistent curing conditions. The large panel size and lightweight reduce form construction and stripping time.

Plywood is made in panels consisting of odd numbers of veneers, each placed at right angles to the adjacent ply, which accounts for the physical properties that make it efficient in resisting bending, shear, and deflection.

Plywood sheet is the common material used for wall formwork but this material is vulnerable to edge and corner damage. The usual format is therefore to make wall forms as framed panels on a timber studwork principle with a plywood-facing sheet screwed to the studs so that it can be easily removed and reversed to obtain the maximum number of uses.

FORMWORK PRINCIPLES

The principles behind good formwork are based on the same basic frame theories used in the design and construction of permanent structural frames. Formwork must be able to withstand construction forces 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.

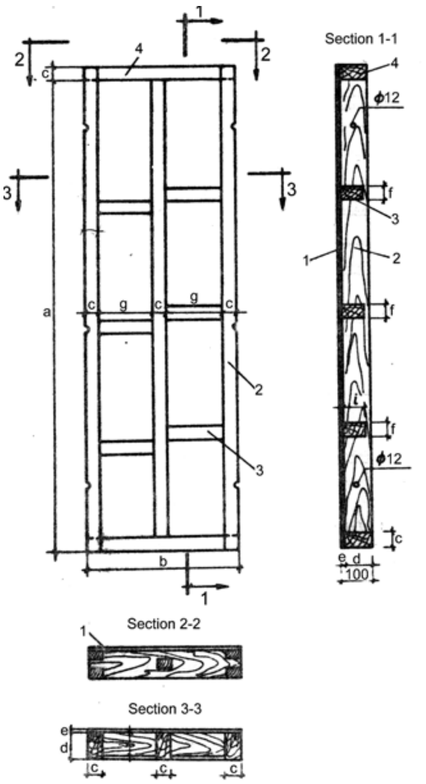


Figure 1. Typical plywood panel: 1. Plywood sheeting; 2. Batten; 3. Brace; 4. Transverse frame: e = 8; 15 mm, d = 92 ; 85 mm, c = 48 mm, i = 68 mm, f = 38 mm.

Table 1. Panel nominal dimensions

Type of panel	Size		Components			Thickness of panel
	Length (mm)	Width (mm)	No. of spars	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	-	

Although formwork is temporary in nature, the methods used in building formwork must adhere to the code specifications 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;
(2) serviceability, the ability of the selected sections to resist the anticipated loads without exceeding deflection limits.

Typical deflection limits for the various components are usually [2]:

- Maximum deflection L/300 – for concrete that provides permanent finish;
- Maximum deflection L/200 – for concrete surfaces with finishing.

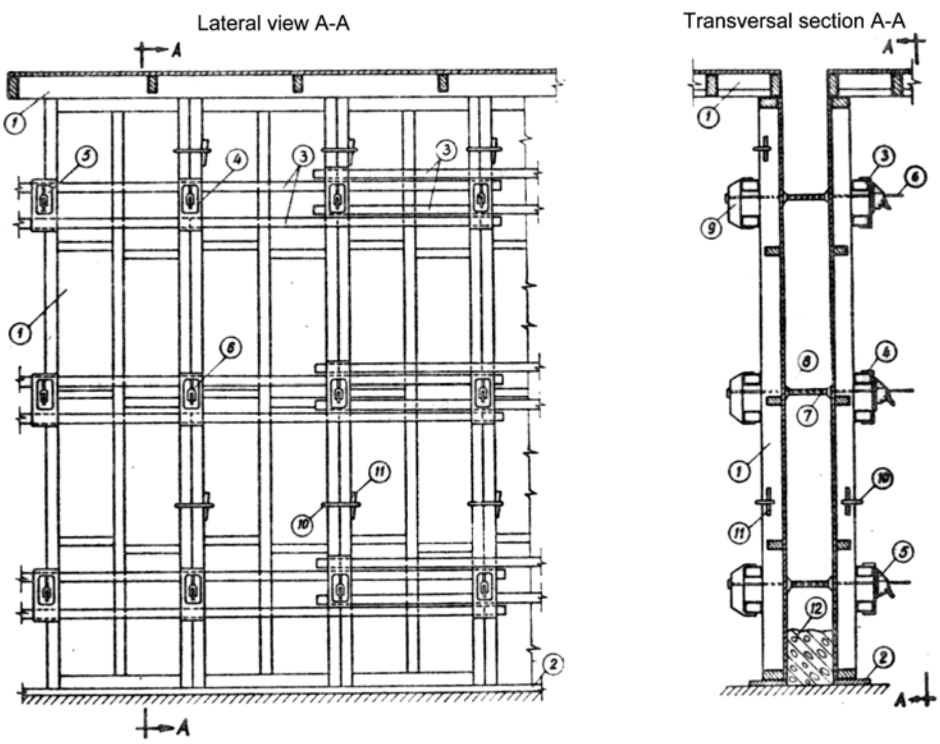


Figure 2. Plywood panels: 1. Plywood sheeting; 2. Wooden wedges; 3. Wale; 4. Plate washer; 5. Bolt (Nut); 6. Tie rod; 7. Pipe spacer; 8. Plastic cone; 9. Shoe; 10. Clamp; 11. Wedge; 12. Concrete kicker.

These limits ensure that the resulting concrete sections will be straight once the forms are removed.

FORMWORK LOADS

The basic consideration in formwork design is strength-the forms ability to support, without excessive deflections, all loads, and forces imposed during construction. Two types of problems arise in formwork design:

- Horizontal forms must support gravity loads based on the mass of the concrete, the construction crew and equipment, and the weight of the formwork itself;
- Vertical forms must primarily resist lateral pressures due to a particular height of plastic concrete. Wall and column forms are examples where lateral concrete pressures are a prime concern, while formwork, supporting a structural slab must be designed to sustain gravity loads.

The individual formwork panels and members may be limited to bending, shear, bearing, or deflection and all four should be checked against the allowable values prescribed by norms and specifications.

Two types of loads are considered in the design calculations:

(1) Vertical loads. Horizontal forms must support gravity loads based on the mass of the concrete, the work crew, and equipment, and the weight of the formwork itself;

(2) Horizontal loads. Vertical forms must primarily resist lateral pressures due to a particular height of plastic concrete.

FORMWORK PRESSURES

The pressure exerted by concrete on formwork is determined primarily by the following factors [3]

- Rate of concrete placement.
- Temperature of concrete.
- Weight of concrete.
- Method of concrete vibration.
- Depth of placement.

The lateral pressure exerted by plastic concrete on vertical formwork is rather complex in nature and is affected by several factors. The freshly placed concrete initially acts as a liquid, exerting fluid or hydrostatic pressure against the vertical form. Because hydrostatic pressure at any point in a liquid is the result of the weight of the fluid above, the density of the concrete mix influences the magnitude of the force acting on the form. Nevertheless, because fresh concrete is a composite material rather than a true liquid, the laws of hydrostatic pressure apply only approximately and only before the concrete begins to set.

The rate of placement also affects lateral pressure. The greater the height to which concrete is placed while the whole mass remains in the liquid stage, the greater the lateral pressure at the bottom of the form.

The temperatures of concrete and atmosphere affect the pressure because they affect the setting time. When these temperatures are low, greater heights can be placed before the concrete at the bottom begins to stiffen, and greater lateral pressures are therefore built up.

Vibration increases lateral pressures because the concrete is consolidated and acts as a fluid for the full depth of vibration. This may cause increases of up to 20% in pressures over those incurred by spading. Other factors that influence lateral pressure include the consistency or fluidity of the mix, the maximum aggregate size and the amount and location of reinforcement.

Romania norm C11-74 [4] specifies the following loads for formwork design:

1. **Vertical Loads**, include:
   a). The weight of the formwork itself and the scaffold:
      - for lumber in panels 750 daN/m^3
      - for lumber in shoring elements 600 daN/m^3
      - for plywood 850 daN/m^3
   b) The weight of fresh concrete:
      - normal weight (heavy) concrete:
        - plain 2400 daN/m^3
        - reinforced 2500 daN/m^3
      - lightweight concrete 700– 1900 daN/m^3 (depending on the type of aggregates used in the mix)
   c). The uniform distributed load of runways for concrete transport and impact loads of the crowding of crewmen:
      - for panel design 250 daN/m^2
      - for horizontal shoring (joists) of panels 150 daN/m^2
      - for vertical shoring elements (props, columns etc.) 100 daN/m^2
   d). The concentrated load form weight of work crews and transport equipment:

- for one crew member that carries loads 130 daN
- for wheel barrow concrete transport 280 daN

e) The load from the vibrating effect of the concrete compaction:120 daN/m^2

2. **Horizontal Loads**, include:

f) Static load from lateral pressures due to a particular height of plastic concrete (placed and compacted) according to the rate of placement (see Figure 3) on the panels surface.

Two factors that affect the maximum effective horizontal pressure are seen to be:
- rate of rise of the concrete in the forms;
- rate of setting (loss of fluidity).

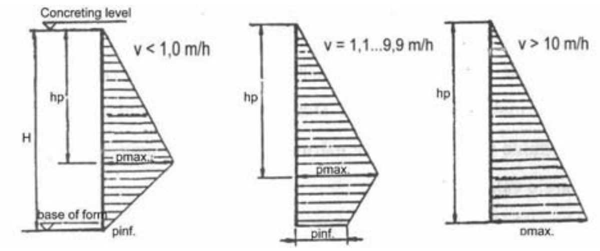


Figure 3. Lateral forces due to concrete acting on a wall form.

The first depends on the size of form or forms being filled vs. the rate at which the concrete is placed. The second depends on a number of factors, of which the most significant is the temperature. The time of setting for concrete according with NE 012-99 [5] is when the temperature of concrete is 10^o…30^o C is 35…40 min and for t < 10^o C is 50…70 min according to the grade of cement used (32,5 or 42,5).

The effect of pressure in compacting the lower fluid layers by forcing out mixing water (bleeding) has led to the belief that for very rapid rates of rise there is a maximum pressure which cannot be exceeded. It will usually be more economical to control the rate of rise than to try to provide form strength to resist such high pressures.

The rate of placement the relation between the height of the form H and the time period needed for the casting of the whole element. The rate of pour is expressed in meters of concrete poured per hour.

The hydrostatic lateral pressure is given by the following equation:

$$p = \rho . H \tag{1}$$

Where:

p – lateral pressure [daN/m^2]
ρ_b – unit weight of fresh concrete [daN/m^2]
H – height of plastic concrete above height considered [m]

The position of the maximum pressure (Fig. 3) is determined with the following equation:

$$h_p = \lambda_1 x H \tag{2}$$

Where: λ_1 – has the value according to Table 2.

The value of the maximum pressure p_{max} is determined with the following equation:

$$p_{max} = \lambda_1 . \lambda_2 . \lambda_3 . \lambda_4 . H . \rho_b \text{ (daN/m}^2\text{)} \tag{3}$$

Where:
H – the height of the poured concrete (m);
ρ_b – density of fresh concrete (kg/m^3).

Table 2. Relation between rate of concrete pour, concrete workability, section of element and concrete temperature

Characteristics		λ_1	λ_2	λ_3	λ_4
Rate of concrete pour (m/hour)	≤ 1	0.55			
	2	0.65			
	3	0.75			
	4	0.85			
	6	0.90			
	8	0.95			
	≥ 10	1.00			
Workability of concrete, slump (cm)	≤ 1		0.85		
	1…4		0.95		
	5…9		1.00		
	10…15		1.05		
	≥ 15		1.10		
Minimum section of element (cm)	≤ 15			0.90	
	16…54			0.95	
	≥ 55			1.00	
Concrete temperature (°C)	≤ 5				1.00
	6…24				0.95
	≥ 25				0.90

The minimum pressure p_{inf} is determined with the following equation:

$$p_{inf} = \alpha . p_{max} \text{ (daN/m}^2\text{)} \tag{4}$$

Where: α - has the value according to Table 3.

Table 3. Coefficient α according to rate of concrete placement.

Rate of placement (m/hour)	< 1	2	3	4	6	8	≥10
α	0	0.25	0.45	0.70	0.80	0.90	1.00

g) Dynamic load from lateral pressures due to impact of falling concrete during placement:
- for a capacity of the transport equipment:
  0,2 m^3 ....200 kg/m^2
  0,2...0,7 m^3....................400 kg/m^2
  0,7 m^3............................600 kg/m^2
- for placement with chutes and hoppers: 200 kg/m^2
- for placement with concrete pumps: 600 kg/m^2

h) Wind forces on wall forms that will be taken into account only for bracings, scaffolds, and centres 700 daN/m²

For the design of the size and deflections of component elements of the formwork, the loads will be taken into account differently, according to the Table 4.

Table 4. Combination of loads

Item name	Loads	
	Strength	Deflection
Slab and arch forms and horizontal props (beams)	a + b + c + d	a + b
Vertical props for floors	a + b + c	a + b
Column forms with the maximum face of 30 cm and walls of maximum 10 cm thickness	f + g	f
Column forms and walls with bigger values	f	f
Lateral faces of forms for beams and arches	f	f
Bottom of beams	a + b + e	a + b
Centres and scaffolds < 6 m	a + b + c (e)	a + b
Centres and scaffolds > 6 m	a + b + c (e) + h	a + b

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;
- Deflection limitations.

PROPERTIES OF FORM MATERIAL

Materials used for forms include lumber, plywood, plastics, steel, aluminum etc. Additional materials that are used include: nails, bolts, screws, ties, anchors etc.

Properties of form material are as follows:
- Allowable bending stress of lumber (σa) 120daN/cm²
- Allowable bending stress of plywood (σa)
  - When the face grain is parallel to the span 130 daN/cm²
  - When the face grain is perpendicular to the span 50 daN/cm²
- Allowable bending stress of steel (σa) 2100 daN/cm²
- Modulus of elasticity (E)
  - for lumber 100000daN/cm²
  - for plywood 70000 daN/cm²
  - for steel $2{,}1\times 10^6$ daN/cm²
- Allowable bending deflection limitations for the various modular panels are usually:
  - (L maximum clear span)/300 – for concrete surfaces exposed to view;
  - (L maximum clear span)/200 – for concrete surfaces with finishing.
- Allowable tolerances for panels:
  - for length and width of panel + 2 mm;
  - for thickness of panel - 5 mm;
  - for length of diagonals of panel ± 5 mm.

DESIGN EXAMPLE OF WALL AND SLAB FORMWORK AND SHORING SYSTEMS [6]

Symbols for cross section of rectangular beam

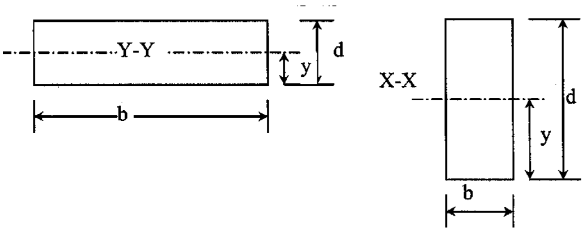


Table 5. Nomenclature

List of symbols	U.M.	Meaning
X-X or Y-Y		Neutral axes
b	[cm]	Width of beam face on which load or force is applied
d	[cm]	Depth or height of beam face parallel to the direction inn which the load or force is applied
δ	[cm]	Plywood thickness
h_{slab}	[cm]	Thickness of slab
M	[daNcm]	Bending moment
$I = bh^3/12$	[cm⁴]	Moment of inertia of the cross section of a beam
y	[cm]	Distance from neutral axes to most distant fiber of beam
σ_e	[daN/cm²]	Applied bending stress
σ_a	[daN/cm²]	Allowable bending design stress
$W = I/y = bh^2/6$	[cm³]	Section modulus of the cross-section
E	[daN/cm²]	Modulus of elasticity
P	[daN]	Concentrated load due to work crews and transport equipment
q	[daN/ml]	Uniformly distributed load per unit length (ml)

Initial Design Data:
- Member dimensions;
- Technology of concrete placement;
- Rate of concrete placement;
- Temperature of concrete;
- Workability of concrete (consistency);
- Story height H_{story};
- Thickness of slab h_{slab}.

Technical note: The design will be made for a wall with a thickness greater than 10 cm and respectively a column with the edge greater than 30 cm.

Loads

Static load from lateral pressures due to a particular height of plastic concrete (placed and compacted) according to the rate of placement on the panel's surface.

$$p_{max} = \lambda_1.\lambda_2.\lambda_3.\lambda_4.H.\rho_b \text{ (daN/m}^2\text{)}$$
$$p_{inf} = \alpha.P_{max} \text{ (daN/m}^2\text{)}$$
$$h_p = \lambda_1.H$$

Where:

λ_1 – coefficient according to work conditions.

H – the height of the poured concrete (level) (m).

ρ_b – density of fresh concrete (2400 kg/m³).

α – coefficient according to rate of pour.

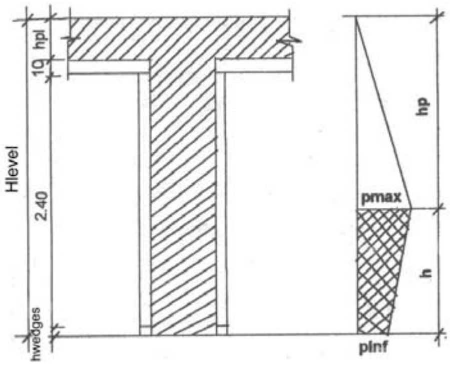


Figure 4. Pressure distribution of lateral face of panel

Technical note: The design will be made for a plywood sheet of 30 and 60 cm width respectively. If in the design just one of the above panels is used then the design will be made for that one.

The design will be made for a width of panel b = 1,00 m

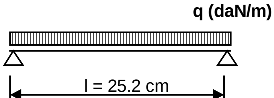
The load is considered uniformly distributed, with the value of:

$$q = f.1{,}00 = \left(\frac{p_{max} + p_{inf}}{2}\right)1{,}00\text{m (daN/ml)}$$

Design of Plywood Sheathing

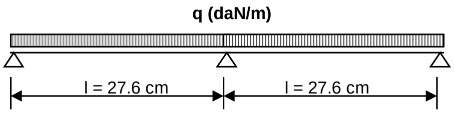
Verification of plywood panel

a. For 30 cm width panel:



Verification for bending stress:	Verification for deflection:
$\sigma_e = \frac{M}{W} \le \sigma_a$ = 130 daN/cm²	$f_e = \frac{5}{384} x \frac{q.l^4}{E.I} \le f_a = \frac{l}{200}$
M = q . l²/8;	$I = \frac{b.h^3}{12}$ (cm⁴)
W = b. h²/6	b=1.00m, h = 15 mm
b= 100 cm	E = 70000 (daN/cm²)
h = 8 or 15 mm	

b. For 60 cm width panel:



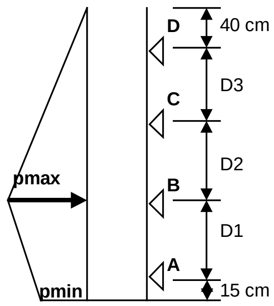
Verification for bending stress:	Verification for deflection:
$\sigma_e = \frac{M}{W} \le \sigma_a$ =130daN/cm²	$f_e = 0.005.\frac{qxl^4}{ExI} \le f_a = \frac{l}{200}$
M = q . l²/8;	$I = \frac{b.h^3}{12}$ (cm⁴)
W = b . h²/6	b=1.00m, h = 8 or 15 mm
h = 15 mm	E = 70000 (daN/cm²)

Design of Battens (Distances Between Wales)

The design will be made in the most least favorable situation, that is the design of the central span of the 60 cm width plywood panel.

The load is uniform distributed, with the value of:

$$q = f.0{,}276 = \left(\frac{p_{max} + p_{inf}}{2}\right)0{,}276\text{m daN/ml}$$



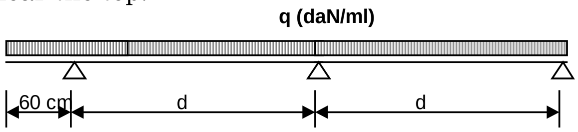
Verification for bending stress:	Verification for deflection:
$\sigma_e \le \sigma_a \Rightarrow \frac{q.D^2/8}{W} \le \sigma_a \Rightarrow$	$f_e \le f_a \Rightarrow 0.007.\frac{q.D^4}{E.I} \le \frac{D}{200} \Rightarrow$
$D = \sqrt{\frac{10.\sigma_a.W}{q}}$	$D = \sqrt[3]{\frac{E.I}{1{,}4.q}}$
σ_a = 120 (daN/cm²)	$I = \frac{b.h^3}{12}$ (cm⁴)
W = b . h² / 6	b=1.0 m; h = 15 mm.
b = 48 mm; h = 85 mm.	E = 100 000(daN/cm²)

The values will be chosen as follows: D1=D_{max}, the minimum value for "D" calculated for the verification of resistance and deformation, but not more than 60 cm.

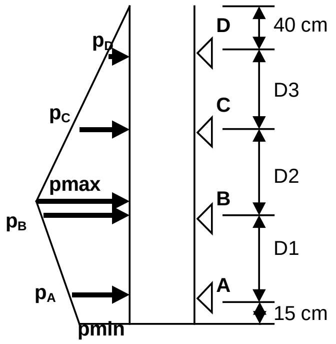
The values for D2 and D3 will respectively be 40% and 60% of the distance B-D remaining (where B-D = H story – 0,15 – 0,40 cm).

Design of Wales (Distances Between Ties)

The wall formwork design will be made according to the lateral pressure of fresh concrete; this may use the calculation to determine the spacing of wales. It will be assumed that the first tie will be as close to the bottom of the form as is practical, within 150…200 mm, and that the top tie will be at or near the top.



Where:
d – distance between ties;
D – distances between wales (vertical).



The values for p_A, p_B, p_C (daN/m²) will be calculated according to the known values p_{max} and p_{inf} (daN/ml).

The wale most stressed will be calculated (wale most near to the highest pressure point – point B), with the following equations:

$$q_A = p_A \cdot \frac{(0{,}15 + D1)}{2} \qquad \text{(daN/ml)}$$

$$q_B = p_B \cdot \frac{(D1 + D2)}{2} \qquad \text{(daN/ml)}$$

$$q_C = p_C \cdot \frac{(D2 + D3)}{2} \qquad \text{(daN/ml)}$$

$$q = \frac{(q_A + 2.q_B + q_C)}{4} \qquad \text{(daN/ml)}$$

Verification for bending stress:

$$\sigma_e \le \sigma_a \Rightarrow \frac{q.d^2/8}{W} \le \sigma_a \Rightarrow d = \sqrt{\frac{10.\sigma_a.W}{q}}$$

Wale (square shape pipe):
40 . 40 . 3,5 (W=5,73 cm³; I=11,50 cm⁴)
45 . 45 . 4 (W=8,25 cm³; I=18,60 cm⁴)
55 . 55 . 4 (W=12.9 cm³; I=35,60 cm⁴)

Verification of deflection:

$$f_e \le f_a \Rightarrow 0.007.\frac{qxd^4}{ExI} \le \frac{d}{200} \Rightarrow d = \sqrt[3]{\frac{E.I}{1{,}4.q}}$$

Where:
σ = 2100 (daN/cm²)
E = 2 100 000 (daN/cm²)

Technical note: dmax will be chosen as the minimum value resulted for both the verification of resistance and deflection. The distance d $\le$ dmax, will be adopted according to the formwork design plan, knowing that the tie will be put only between panels.

Tie Design

Only the most loaded tie will be calculated, that is the one placed nearest to point B (see figure). The tensile stress on the tie is: T = q.d (daN)
Where:
D - correct distance between ties, according to formwork design drawing.

$$A_a = \frac{T}{R_a}\text{; Ra = 2100 (daN/cm}^2\text{)}$$

The diameter of the tie will be chosen according to $A_a^e \ge A_a^{nec}$

REFRENCES

1. Ilinoiu, G., *Construction Engineering*. Conspress Publishing House, 2003, pp.9-26.

2. C140-71, *Concrete and reinforced concrete execution works*.

3. Peurifoy, R., Oberlender G. *Formwork for Concrete Structures*, McGraw-Hill, 1996.

4. C11-74, *Instructions regarding components and use of plywood for formwork*.

5. NE 012-1999, *Practice code for the execution of concrete, reinforced concrete and prestressed concrete works,* Part 1 – Concrete and reinforced concrete.

6. Teodorescu, M., Budan, C., and Ilinoiu, G., *Technology of Construction Works License Examination Guide,*

7. Technical University of Civil Engineering of Bucharest Publishing House, 1998.