Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Design project of the structure of a residential building in the city of Castellón street Paseo Ribalta n◦1

ANNEX N◦4: CONSTRUCTIVE PROCESS

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1. Purpose

The purpose of this annex is to design the type of falsework used during the construction of the slabs and calculate the necessary time of use of the falsework for each floor.

The calculation methodology is based on the chapters 33 and 34 of the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación* of J. Calavera, pages 715-754.

2. Necessity of using formwork

When the building is built quickly, each floor usually does not have enough resistance to support the upper one when it is constructed. Therefore, it is necessary to shim several floors so that the load of the floor under construction is distributed among several already hardened.

The reason for the use of this system is basically economic, since it reduces the number of girders and struts with respect to what would be necessary to always keep the slabs shingled to the ground. Moreover, the release of struts the lower floors allows masonry and finishing works to be started there.

3. Calculation hypothesis

- It is assumed that the consecutive lower floors, to which the load of the new slab is transmitted, they all have the same rigidity.
- The struts are considered as infinitely rigid with respect to the flexibility of the slabs.
- The struts of the ground floor rest on an infinitely rigid floor.
- The effects of retraction and creep can be neglected.
- The loads of the struts can be assimilated to loads uniformly distributed on the slabs.

4. Calculation of k_d

g – self-weight of the slab

k – characteristic coefficient of the load

n – number of the floor with falsework

d – number of the days of construction cycle per floor

d_1 – number of the days for the dismantling of the falsework from one floor and transfer it and assembly struts to the new upper floor

Table 4.1 Max coefficient of the load k, based on the table T-33.1 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Value of n	Max coefficient of the load, k
2	2,25
3	2,36
4	2,43

γ_{fg} – partial safety coefficient

γ_{fg} = 1,30 - if the quality control of the execution is intense

γ_{fg} = 1,35 - if the quality control of the execution is normal

γ_{fg} = 1,40 - if the quality control of the execution is reduced

In this project it is supposed that the quality control of the execution is normal so γ_{fg} = 1,35.

It is assumed that the weight of struts and formwork per m2 is of the order of 10% of the weight of the slab. It will be increased another 10% due to uncertainty hypothesis when more than one floor is shored. It is also necessary to consider some construction overload and it is adopted the value of $\frac{g}{n}$ where g is the own weight of the slab and n the number of floors with falsework.

This is equivalent to reducing the construction overhead proportionally to the number of plants.

P_{cd} - calculation load during construction

$$p_{cd} = \gamma_{fg} \cdot 1{,}1 \cdot 1{,}1 \cdot k \cdot g + \frac{g}{n} = k_d g$$

k_d – design coeffcient of the load

$$k_d = 1{,}21 \cdot \gamma_{fg} k + \frac{1}{n}$$

5. Solution 1: 2 shored floors without reshoring

The solution of 2 shored floors without reshoring was selected.

Table 5.1 Coefficient k_d for shored floor without reshoring with γ_{fg} = 1,35, based on the table T-33.4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

N◦ of the floors with falsework n	N◦ of the cycle of the construction from from the concreting of the floor			
	1		2	
	a)	b)	a)	b)
1	1,52	3,84	-	-
2	2,13	2,95	3,35	4,17

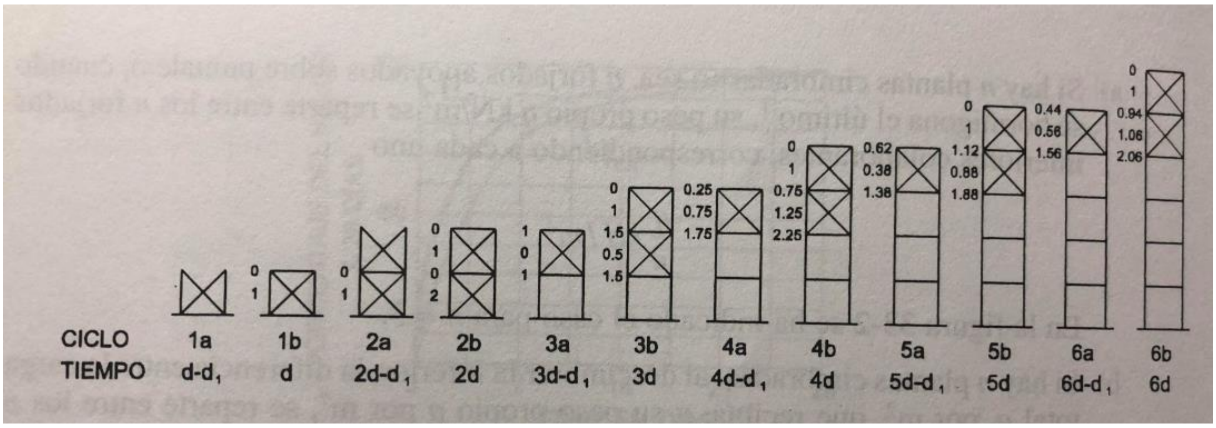

Figure 5.1 Diagram of cycle and time for the construction of the floors for Solution 1, figure 33-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle a - form removal from the lower floor

Cycle b - concreting the upper floor

6. Determination of the critical calculation load

In the process of design of the building, it is usually assumed that the characteristic load during construction does not exceed the characteristic load of the project, that is, the normal use foreseen in the building.

p_{cd} - calculation load during construction

p_d – calculation total load of project (permanent loads and live loads)

γ_{gl} – partial safety coefficient live load

If $p_{cd} \leq p_d$ the phase of construction is more favorable than the phase of normal service of the structure and the normal service phase is the critical one in the live of the slab.

p_d for the ground floor consists of:

g=7,5 kN/m^2 – self-weight of the slab

g_1=0,44 kN/m^2 – dead load of the floor layers

g_2=1 kN/m^2 – dead load of partition wall

q=3 kN/m^2 – live load

$$p_d = \gamma_{gf} \cdot (g + g_1 + g_2) + \gamma_{gf} \cdot q = 1{,}35 \cdot (7{,}5 + 0{,}44 + 1) + 1{,}5 \cdot 3 = 17{,}57\ \frac{kN}{m^2}$$

$$p_{cd} = k_d \cdot g$$

The most unfavorable value of k_d for the solution of 2 shored floors without reshoring is during the second cycle in the phase b of concreting and it is k_d=4,17

$$\mathrm{p}_{cd} = 4{,}17 \cdot 7{,}5 = 31{,}28\ \mathrm{kN}/m^2$$

$$\mathrm{p}_{cd} > p_d$$

$$31{,}28 > 17{,}57$$

Therefore, the phase of construction is a critical phase and it is necessary to change the solution of 2 shored floors without reshoring for the other with lower coeffcient k_d.

7. Solution 2: 2 shored floors with 2 reshored floors

A solution of great interest is the one that consists of carrying out the reshoring operation, which consists of form removal on certain floors freeing of corresponding punctual loads and redistributing the loads between the slabs, and then propping up again, ensuring the contact between struts and slab, so that these struts collaborate in future load increases. The following figure shows the scheme of the operation. In each operation cycle, the first phase is to reshore the lower floor plan (operation a). Afterwards, the shoring of the lowest reshored floor is dismantled and moved to its new location in the new floor under construction (operation a'), and then it is concreted (operation b).

It was decided to calculated solution 2 which is 2 shored floors with 2 reshored floors.

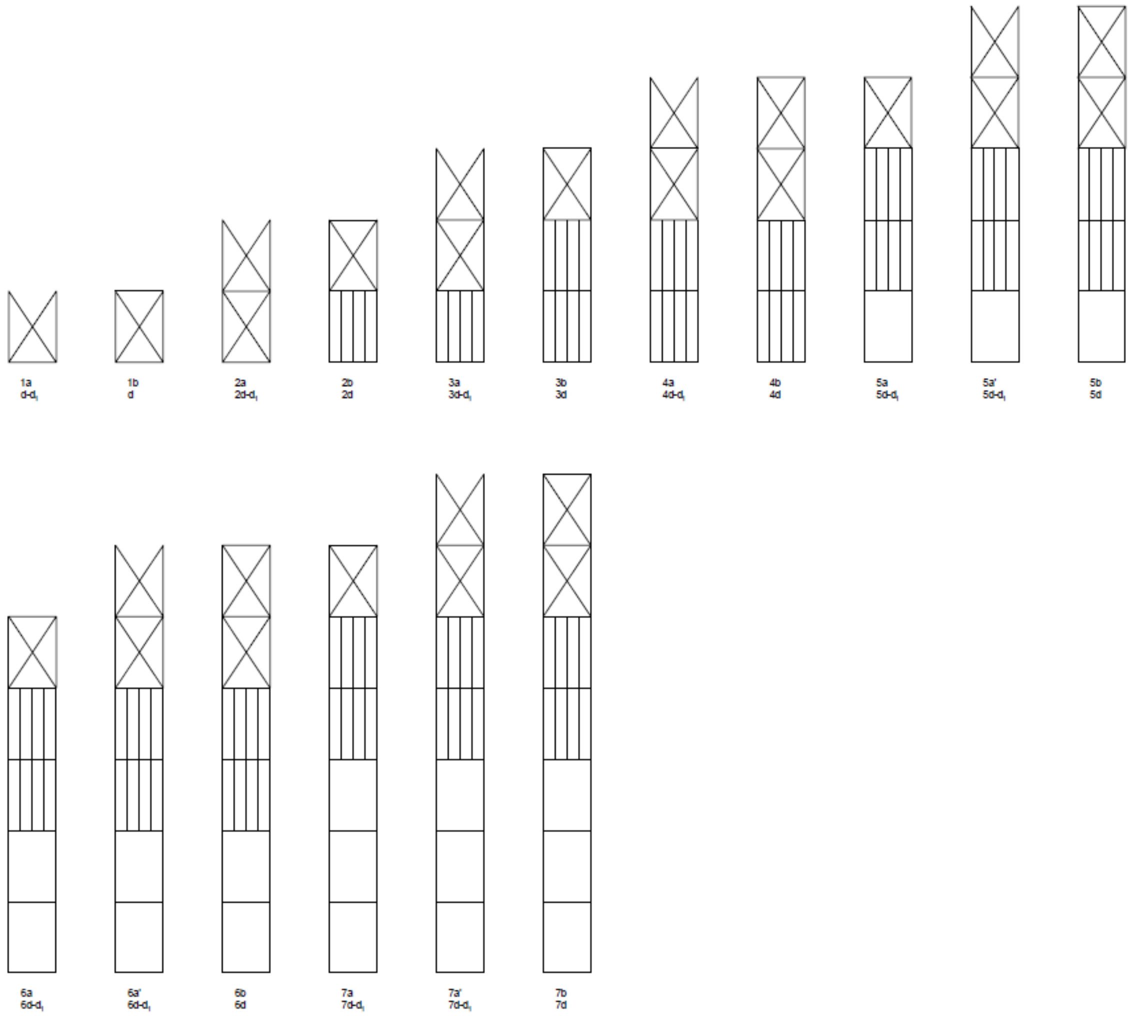

Figure 7.1 Diagram of cycle and time for the construction of the floors for Solution 2

Table 5.1 Coefficient k_d for 2 shored floors with 2 reshored floors with γ_{fg} = 1,35 , based on the table T-33.5 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

	Construction Cycle							
	1		2		3		4	
Slabs	a	b	a	b	a	b	a	b
1	0.00	0.00	1.52	1.52	1.52	1.52	1.89	2.30
2	1.50	1.31	2.25	2.25	1.89	2.30	1.89	2.30
3	0.75	0.75	2.30	2.30	1.89	2.30	1.89	2.30
4	1.47	1.88	2.30	2.30	1.89	2.30	1.89	2.30
5	1.07	1.47	2.30	2.30	1.89	2.30	1.89	2.30
6	1.26	1.66	2.60	2.65	1.89	2.30	1.89	2.30
7	1.16	1.57	2.55	2.55	1.89	2.30	1.89	2.30

From the Figure 7.1 it can be seen that for 2 shored floors with 2 reshored floors the biggest coefficient k_d for γ_{fg} = 1,35 k_d=2,30 for the ground floor and floor 1,2,3,4. For utility roof k_d=2,65 and for roof of staircase k_d=2,55

The same determination of a critical load that was done for the Solution 1 will be done for the Solution 2.

Ground floor

$$p_d = \gamma_{gf} \cdot (g + g_1 + g_2) + \gamma_{gf} \cdot q = 1{,}35 \cdot (7{,}5 + 0{,}44 + 1) + 1{,}5 \cdot 3 = 18{,}57\ \frac{kN}{m^2}$$

$$p_{cd} = k_d \cdot g = 2{,}30 \cdot 7{,}50 = 17{,}25\ \frac{kN}{m^2}$$

$$\mathrm{p}_{cd} \leq p_d$$

$$17{,}25 \leq 18{,}57$$

Floor 1,2,3,4

p_d for the Floor 1,2,3,4 consists of:

g=7,5 kN/m^2 – self-weight of the slab

g_1=0,76 kN/m^2 – dead load of the floor layers

g_2=1 kN/m^2 – dead load of partition wall

q=2 kN/m^2 – live load

$$p_d = \gamma_{gf} \cdot (g + g_1 + g_2) + \gamma_{gf} \cdot q = 1{,}35 \cdot (7{,}5 + 0{,}76 + 1) + 1{,}5 \cdot 2 = 17{,}50\ \frac{kN}{m^2}$$

$$p_{cd} = k_d \cdot g = 2{,}30 \cdot 7{,}50 = 17{,}25\ \frac{kN}{m^2}$$

$$\mathrm{p}_{cd} \leq p_d$$

$$17{,}25 \leq 17{,}50$$

Utility Roof

p_d for the Utility Roof consists of:

g=7,5 kN/m^2 – self-weight of the slab

g_1=3,36 kN/m^2 – dead load of the floor layers

g_2=1 kN/m^2 – dead load of partition wall

q=2 kN/m^2 – live load

$$p_d = \gamma_{gf} \cdot (g + g_1 + g_2) + \gamma_{gf} \cdot q = 1{,}35 \cdot (7{,}5 + 3{,}36 + 1) + 1{,}5 \cdot 2 = 20{,}01 \, \frac{kN}{m^2}$$

$$p_{cd} = k_d \cdot g = 2{,}60 \cdot 7{,}50 = 19{,}50 \, \frac{kN}{m^2}$$

$$p_{cd} \leq p_d$$

$$19{,}50 \leq 20{,}01$$

Roof of staircase

p_d for the Utility Roof consists of:

g=7,5 kN/m^2 – self-weight of the slab

g_1=3,04 kN/m^2 – dead load of the floor layers

g_2=1 kN/m^2 – dead load of partition wall

q=2 kN/m^2 – live load

$$p_d = \gamma_{gf} \cdot (g + g_1 + g_2) + \gamma_{gf} \cdot q = 1{,}35 \cdot (7{,}5 + 3{,}04 + 1) + 1{,}5 \cdot 2 = 19{,}58 \, \frac{kN}{m^2}$$

$$p_{cd} = k_d \cdot g = 2{,}55 \cdot 7{,}50 = 19{,}13 \, \frac{kN}{m^2}$$

$$p_{cd} \leq p_d$$

$$19.13 \leq 19{,}58$$

Therefore, the normal service phase is the critical one in the live of the slab for all floors so the solution 2 can be applied.

8. Calculation of the period of the form removal

The method of reference curves was applied. Established that the critical evolution of resistance is that of the resistance to traction or adherence, the knowledge of the curves of evolution of the tensile strength of concrete at different temperatures provides a method for calculating the term of form removal.

The reference curves for Cement PA-350 with addiction of gravel in the medium humidity for medium temperature T=15◦C for the hardening period of concrete were used.

An average temperature T=15◦C during the period of hardening of concrete in average humidity is assumed and cement CEM II / A-S 32,5 is applied. The reference curve for these condition were used.

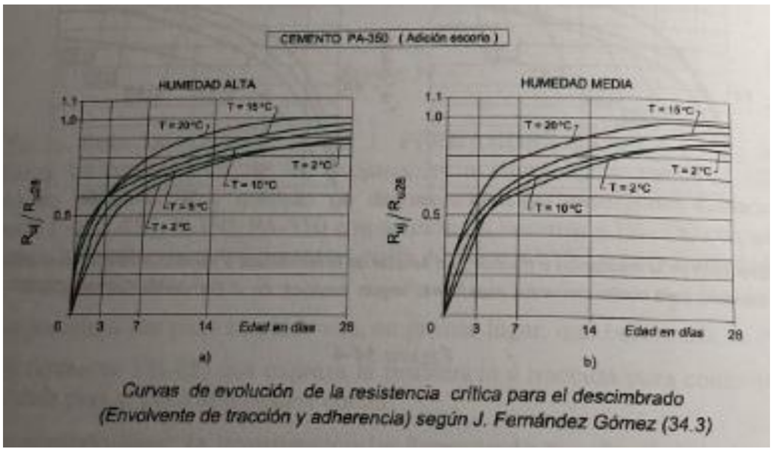

Figure 8.1 Reference curves, figure 34-7 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

According to table 5.1, the coefficients k_d are determined. It is assmued that the cycle is of d days for one floor and that it is necessary to have two days for the passage of struts from one floor to another (d_1=2).

Ground Floor

Table 8.1 Determination of the number of days for each cycle for ground floor, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	k_d·7.5	$\alpha = \frac{k_d \cdot 7{,}5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	0	0.00	0.00	0	0.00
	b	d	0	0.00	0.00	0	0.00
2	a	2d-2	1.52	11.40	0.61	5	3.50
	b	2d	1.52	11.40	0.61	5	2.50
3	a	3d-2	1.52	11.40	0.61	5	2.33
	b	3d	1.52	11.40	0.61	5	1.67
4	a	4d-2	1.89	14.18	0.76	10	3.00
	b	4d	2.3	17.25	0.93	25	6.25

The minimum age column has been obtained from the value α using the graph of Figure 8.1 b).

The cycle is therefore 7 days per floor, which also corresponds to the form removal from the ground floor.

First Floor

Table 8.2 Determination of the number of days for each cycle for first floor, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	$k_d \cdot 7.5$	$\alpha = \frac{k_d \cdot 7{,}5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	1.5	11.25	0.64	6	8.00
	b	d	1.31	9.83	0.56	4	4.00
2	a	2d-2	2.25	16.88	0.96	28	15.00
	b	2d	2.25	16.88	0.96	28	14.00
3	a	3d-2	1.89	14.18	0.81	12	4.67
	b	3d	2.3	17.25	0.99	43 (extrapolated)	14.33
4	a	4d-2	1.89	14.18	0.81	12	3.50
	b	4d	2.3	17.25	0.99	43 (extrapolated)	10.75

The cycle is therefore 15 days per floor, which also corresponds to the form removal from the first floor.

Second Floor

Table 8.3 Determination of the number of days for each cycle for second floor, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	$k_d \cdot 7.5$	$\alpha = \frac{k_d \cdot 7{,}5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	0.75	5.63	0.32	2	4.00
	b	d	0.75	5.63	0.32	2	2.00
2	a	2d-2	2.3	17.25	0.99	43 (extrapolated)	22.50
	b	2d	2.3	17.25	0.99	43 (extrapolated)	21.50
3	a	3d-2	1.89	14.18	0.81	12	4.67
	b	3d	2.3	17.25	0.99	43 (extrapolated)	14.33
4	a	4d-2	1.89	14.18	0.81	12	3.50
	b	4d	2.3	17.25	0.99	43 (extrapolated)	10.75

The cycle is therefore 23 days per floor, which also corresponds to the form removal from the second floor.

Third Floor

Table 8.4 Determination of the number of days for each cycle for third floor, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	k_d·7.5	$\alpha = \frac{k_d \cdot 7,5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	1.47	11.03	0.63	6	8.00
	b	d	1.88	14.10	0.81	12	12.00
2	a	2d-2	2.3	17.25	0.99	43 (extrapolated)	22.50
	b	2d	2.3	17.25	0.99	43 (extrapolated)	21.50
3	a	3d-2	1.89	14.18	0.81	12	4.67
	b	3d	2.3	17.25	0.99	43 (extrapolated)	14.33
4	a	4d-2	1.89	14.18	0.81	12	3.50
	b	4d	2.3	17.25	0.99	43 (extrapolated)	10.75

The cycle is therefore 23 days per floor, which also corresponds to the form removal from the third floor.

Fourth Floor

Table 8.5 Determination of the number of days for each cycle for fourth floor, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	k_d·7.5	$\alpha = \frac{k_d \cdot 7,5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	1.07	8.03	0.46	2	4.00
	b	d	1.47	11.03	0.63	6	6.00
2	a	2d-2	2.3	17.25	0.99	43 (extrapolated)	22.50
	b	2d	2.3	17.25	0.99	43 (extrapolated)	21.50
3	a	3d-2	1.89	14.18	0.81	12	4.67
	b	3d	2.3	17.25	0.99	43 (extrapolated)	14.33
4	a	4d-2	1.89	14.18	0.81	12	3.50
	b	4d	2.3	17.25	0.99	43 (extrapolated)	10.75

The cycle is therefore 23 days per floor, which also corresponds to the form removal from the fourth floor.

Utility Roof

Table 8.6 Determination of the number of days for each cycle for utility roof, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	$k_d \cdot 7.5$	$\alpha = \frac{k_d \cdot 7,5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	1.26	9.45	0.47	2	4.00
	b	d	1.66	12.45	0.62	6	6.00
2	a	2d-2	2.6	19.50	0.97	33 (extrapolated)	17.50
	b	2d	2.65	19.88	0.99	43 (extrapolated)	21.50
3	a	3d-2	1.89	14.18	0.71	8	3.33
	b	3d	2.3	17.25	0.86	16	5.33
4	a	4d-2	1.89	14.18	0.71	8	2.50
	b	4d	2.3	17.25	0.86	16	4.00

The cycle is therefore 22 days per floor, which also corresponds to the form removal from the utility roof.

Roof of staircase

Table 8.7 Determination of the number of days for each cycle for roof of staircase, based on the table T.34-4 from the book *Cálculo, construcción, patología y rehabilitación de forjados de edificación*

Cycle	Phase	NOMINAL AGE	k_d	k_d·7.5	$\alpha = \frac{k_d \cdot 7{,}5}{p_{cd}}$	MINIMUM AGE [days]	d [days]
1	a	d-2	1.16	8.70	0.44	2	4.00
	b	d	1.57	11.78	0.60	6	6.00
2	a	2d-2	2.55	19.13	0.98	38 (extrapolated)	20.00
	b	2d	2.55	19.13	0.98	43 (extrapolated)	21.50
3	a	3d-2	1.89	14.18	0.72	8	3.33
	b	3d	2.55	19.13	0.98	43 (extrapolated)	14.33
4	a	4d-2	1.89	14.18	0.72	8	2.50
	b	4d	2.3	17.25	0.88	18	4.50

The cycle is therefore 22 days per floor, which also corresponds to the form removal from the roof staircase.

The total period of time of the constructive process is the sum of the cycles for all floors.

$$7 + 15 + 23 + 23 + 23 + 22 + 22 = 135\ days$$