DETERMINATION OF CONCRETE PRESSURE IN ICF FORMWORKS

Introduction to the method
Here are given some useful indications for the determination of the concrete pressure inside the formworks that constitute the ICF constructive systems. The present research was conducted in collaboration with ICF ITALIA company, which made available resources and materials. The calculation method is taken from the "Guidelines for the implementation of structural concrete ..." (published in 2008 by the CSLP) and incorporates the contents of the DIN 18218/2008. The aforementioned documents state that, for the determination of concrete pressure, the following combined effects must be taken into account:
- the weight of formworks, reinforcing bars and concrete;
- the pressure exerted on formworks from concrete, in relation to its higher degree of consistency, in particular in the case of self-compacting concrete (SCC);
- the stresses exerted by: staff, materials, equipment, etc., including the static and dynamic effects caused by pouring concrete, its possible accumulations in the casting phase and its compaction;
- possible overload due to wind and snow.

The present assessment examines the thrust of concrete during pouring, and not the mobile loads deriving, for example, from the transit of the operators, materials, their possible accumulations, and from any construction site equipment. The lateral pressure of fresh concrete represents one of the actions to be taken into account for the structural design of ICF formworks, but it is not the only one.

In general the lateral pressure can be determined with the following relation:

\[ p = w \cdot h \]

where:
- \( p \) = lateral pressure (kN/m²);
- \( w \) = density of fresh concrete (kN/m³);
- \( h \) = height of the concrete, in fresh or plastic state, measured from the top of the casting (m), in the hypothesis that formworks have an inclination of ± 5 ° with respect to the vertical.

However, unlike other fluids, concrete is characterized by a gradual reduction of hydrostatic pressure due to the setting and hardening phenomena. The reports offered by CSLP Guidelines and shown by the examined scientific references, take into account these effects, in order to realistically determine the pressures acting on ICF formworks. Through the diagram in the following figure, taken from the Guidelines of the CSLP, it is possible to estimate the maximum pressure of fresh concrete (\( p_b \)) according to the relative height of hydrostatic pressure (\( h_0 \)), speed of casting raising and consistency of concrete.

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Diagram for the determination of concrete pressure
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The diagram makes explicit the pressure exerted on ICF formworks, according to the consistency of concrete, because the more fluid the material is, the greater the pressure imparted to the vertical structures.
In the two following diagrams, taken from the same guidelines, the trend of the lateral pressure is analyzed according to the pouring height, in case of ordinary concrete and self-compacting concrete:

As can be seen from the diagrams, in case of self-compacting concrete, the hydrostatic pressure starts from zero until reaching the maximum value at the pouring height \( h_p \). In this case, the maximum value of the pressure exerted by the concrete is therefore \( p_h = w \cdot h_p \).

In case of ordinary concrete, the behaviour of the fluid material is taken into account up to the hydrostatic height \( h_s \), where the pressure trend is \( p = w \cdot h \), while for \( h_s < h_p \) the pressure remains constant and equal to the maximum value \( p_h = w \cdot h_s \).

The trend of lateral pressures, according to the level of the concrete, is better clarified in DIN 18218, of which a brief summary is reported.

In DIN18218: 2008 the evaluation of the lateral pressure that the fresh concrete applies to the formworks is based on the following simplifying assumptions:
- a) the gross weight of fresh concrete is equal to 25 kN/m\(^3\);
- b) the casting time \( t_c \) must be between 5 and 20 hours;
- c) in case of deviation of the concrete temperature \( T_{c, Einbau} \), from the reference temperature \( T_{c, Rif} \) (equal to 15 °C), see section 5.3.2 of the standard, which introduces suitable corrective coefficients;
- d) fresh concrete is compacted with internal vibrators;
- e) the formwork is considered sealed;
- f) the raising speed of the casting (v) must not exceed 7.0 m/h;
- g) the concrete is introduced from above but the casting height must not exceed 10m.

The definition of pressure exerted by the concrete derives from the assumption of the mentioned boundary conditions, placed in relation to the six consistency classes identified by EC2: S1, S2, S3, S4, S5 and S6.

In the diagram, introduced in §4.3 of the examined DIN standard, the trend of pressures is fixed along the level of concrete \( H \) present inside the formwork.
The diagram is based on the experimental finding that the concrete does not behave like a perfect fluid and that’s why the pressure trend does not follow the hydrostatic line indicated in red, which culminates with the maximum value \( \sigma_h = w \cdot H \) (\( w \) = density of fresh concrete, \( H \) = height of the concrete), but it presents an envelope curve that can be represented with the constant line that develops starting from the hydrostatic height \( h_0 \).

An example of the behaviour of concrete inside the formwork is also shown in the following diagram, extrapolated from chapter 7 of "Concrete Construction Engineering Handbook", by E. G. Navy.

![Diagram of concrete lateral pressure](image)

**Typical trend of lateral pressure of concrete**

The diagram contained in §4.3 of the DIN standard extends up to the height \( h_E = v \cdot t_E \), according to the speed of concrete pouring \( v \) and the setting time of concrete \( t_E \), in which there is the transition from fresh concrete to hardened concrete.

The maximum concrete pressure is set equal to the value \( \sigma_{h_{k, max}} \) in which each type of concrete (classified as F1, F2, F3, F4, F5 and F6), has a maximum value depending on the parameter \( v \) (pouring raising speed) and \( k_1 \).

The value \( k_1 \) is evaluated in relation to the setting time \( t_E \).

In tables 1 and 2 of §4.4 of the aforesaid standard, it is possible to determine the mentioned parameters.

<table>
<thead>
<tr>
<th>Konsistenzklasse</th>
<th>maximaler horizontaler Frischbetondruck bei Einbau gegen die Steigrichtung (von oben) ( \sigma_{h_{k, max}} ) kN/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>(5 \cdot v - 21) \cdot K1 ≥ 25</td>
</tr>
<tr>
<td>3</td>
<td>(10 \cdot v - 19) \cdot K1 ≥ 25</td>
</tr>
<tr>
<td>4</td>
<td>(14 \cdot v - 18) \cdot K1 ≥ 25</td>
</tr>
<tr>
<td>5</td>
<td>(17 \cdot v - 17) \cdot K1 ≥ 25</td>
</tr>
<tr>
<td>6</td>
<td>44 \cdot v \cdot K1 ≥ 30</td>
</tr>
<tr>
<td>7</td>
<td>62,5 \cdot v \cdot K1 ≥ 30</td>
</tr>
<tr>
<td>8</td>
<td>52,5 \cdot v \cdot K1 ≥ 30</td>
</tr>
</tbody>
</table>

*mit\( v \) Steiggeschwindigkeit (Betoniergeschwindigkeit) [m/h]

K1 Faktor zur Berücksichtigung des Erstarungsverhaltens nach Tabelle 2

**Determination of maximum horizontal pressure of concrete**
In the same diagram, in addition to $\sigma_{hk, \text{max}}$, the design value of the pressure appears, indicated with $\sigma_{hd, \text{max}} = \gamma_F \cdot \sigma_{hk, \text{max}}$ in which the characteristic value is multiplied by the partial safety factor $\gamma_F$, set equal to 1.5.

In both cases, the vertical line passing through the value of the maximum pressure intersects the diagram of the hydrostatic pressures, at height $h$. In conclusion, in the APPENDIX B of the standard, we offer a summary of the diagrams that express the progress of the concrete pressure as a function of $t_E$ setting time, consistency of concrete and concrete pouring speed.

### Pressure trend ($\sigma_{hk, \text{max}}$)

1. Elements that influence the determination of concrete pressure

In this section, the parameters, that affect the determination of concrete pressure and which may introduce variations compared with the basic assumptions with which it was possible to obtain the values in the diagrams above, are treated individually.

These parameters are described in the DIN18218: 2008 standard and in the CSLP guidelines in §4.2.
a) Temperature of fresh concrete
The temperature has influence on the setting time of concrete and also on the relative pressures, transmitted by fresh concrete to ICF formworks.

In particular, in §4.2 of the CSLP guidelines, it is specified that: "Within the permitted temperature range for concrete, before the installation, (5 ÷ 30 °C) it is possible to predict the effect of temperature over time setting: if the temperature is higher than 15 °C (but lower than 35 °C) for each degree of difference in more, the pressure $p_b$ and the hydrostatic height $h_s$ can be reduced by 3% up to a maximum of 30%, while if the temperature is lower than 15 °C (but more than 5 °C) the pressure $p_b$ and the hydrostatic height $h_s$ can be increased by 3% for each degree of difference.”

This means that a temperature of concrete greater than 15 °C favors the hardening process of concrete and speeds up the reduction of lateral thrust against formworks.

b) Concrete retarding additives
Concrete additives affect the pressure of the material, as they induce a change in consistency or setting time.

In fact, the use of retarding additives leads to an increase in the pressure of fresh concrete $p_b$ and the respective $h_s$, equal to the rates shown in the diagram in Figure 4-4 of the CSLP guidelines and shown below.

![Diagram](image.png)

Coefficients to increase pressure and hydrostatic height, thanks to the effect of retarding additives

2. Description of the calculation sheet for the determination of the concrete pressure inside ICF formworks
The calculation method, proposed for the determination of concrete pressure is based on the considerations indicated in the previous paragraphs and in particular on the following hypotheses:

a) the gross weight of the fresh concrete is 25 kN / m$^3$;

b) the casting time $t_E$ of concrete in the formwork cannot be exceeded and can be assumed equal to $t_E = 5h, 7h, 10h, 15h, 20h$;

c) the pouring setting temperature of the $T_{c, Einbau}$ and the reference temperature of the concrete at pouring time $T_{c, Rif}$ must be equal to 15 °C;

d) fresh concrete must be compacted with internal vibrators;

e) the formwork is considered sealed;

f) the pouring raising speed $v$ is at any point at most 7.0 m / h;

g) the consistency class can not be higher than F4 (ie slump S4);

h) the concrete is introduced from above by a height not exceeding 10m.

Under those hypotheses, the following parameters are assumed:

- Concrete consistency class F4
- Setting time $t_g$ 10 h
- Pouring speed 0.7 m/h
- Pouring height 4 m
With these values, the maximum (theoretical) pressure of concrete can therefore be determined if it has a hydrostatic behaviour (dashed blue line of the following diagram):

\[ \sigma_h = w \cdot h = 25 \text{ kN/m}^2 \cdot 4 \text{ m} = 100 \text{ kN/m}^2 \]

Instead, to determine the trend of the actual concrete pressure (red line of the following diagram), the value of the maximum pressure \( \sigma_{h, \text{max}} \) must be related to the quantities, that are indicated in §4.4 of the DIN 18218 standard below.

\[
\sigma_{h,k, \text{max}} = (17 \cdot 0.7 + 17) \cdot 1.70 = 49.13 \text{ kN/m}^2
\]

The maximum design pressure is obtained by increasing the determined value \( \sigma_{h,k, \text{max}} \) with the safety factor \( \gamma_F \) equal to 1.5:

\[
\sigma_{h,d, \text{max}} = \gamma_F \cdot \sigma_{h,k, \text{max}} = 1.5 \cdot 49.13 = 73.70 \text{ kN/m}^2
\]

The hydrostatic height \( h_s \) is then determined by the intersection of the straight line \( x = 49.13 \) and the hydrostatic straight line passing through the points:

\[
A = (0, H) \quad \text{and} \quad B = (\sigma_h, 0) \quad \text{that become} \quad A = (0.4) \quad \text{and} \quad B = (100.0)
\]

The line in question is therefore:

\[
y = (-x + 100) / 25
\]

From which:

\[
h_s = H - y = 4 \text{ m} - 2.03 = 1.97 \text{ m}
\]

The following diagram shows all the parameters obtained in the analysis.
The above diagram is obtained through the use of the proposed calculation sheet and leads to the same results determined manually, in accordance with the standards indicated (DIN18218: 2008 and Guidelines for the implementation of structural concrete of the CSLP).

3. Conclusions

The calculation method proposed allows to determine the pressure of fresh concrete, acting on ICF formworks and taking into account the variables that influence the phenomenon, in compliance with the industry standards and scientific evidence existing at international level.

With the hypotheses described in the previous example, or in the case of "ordinary" concrete and castings, the value of lateral pressure assumes an order of magnitude of 50kN/m² (corresponding to about 5000kg/m²).

The ICF formworks withstand these pressure values in order to allow the casting safely and inevitably possess additional resistance reserves, that are inherent in the sizing of the same.

It is therefore legitimate to believe that the huge "containment" action permanently induced by ICF formworks on concrete walls, may cause "stabilizing" effects on the walls themselves. On these arguments, experimental investigations are being carried out on real-sized walls, which are built using the ICFITALIA constructive system.

NOTE. The method above described and the resulting calculations, although they are the result of careful evaluations, must be verified by the user, relieving the author of any responsibility.