Effect of concrete temperature and formwork width on variation pressure formwork of Self-Compacting Concrete

Amir Hosein Bakhtiarain
The Bsc. Student of Islamic Azad University, Hamedan branch
Email:bakhtiarian.amir.hosein@gmail.com
Morteza Askari
The faculty member of Islamic Azad University, Hamedan branch
Email: asgari.morteza@yahoo.com
0602-975
Presenter: Amir Hosein Bakhtiarain

Abstract

In this article two complete programs about effect of concrete temperature, formwork width, on lateral pressure formwork of Self-Compacting Concrete are discussed. For considering effect of concrete temperature concrete mixtures which are built under 10-30°c , are used and the result show that concrete temperature hasn't considerable effect on initial pressure (after casting finishing). But in time passing, pressure reduction is significant for surveying in formwork width effect, two columns with 200 and 920mm diameter, are applied

Key words: Self Compacting Concrete, Lateral pressure formwork, Concrete temperature , Section width.

1- Introduction

The design of formwork systems for vertically cast elements is controlled by the lateral Pressure developed by the flesh concrete. It is well established that concrete consistency, method of placement and consolidation, type of cement, temperature of concrete, maximum aggregate size, head of concrete, pore water pressure, rate of placement, and size and shape of the formwork have all marked effect on the development of lateral pressure [3-6-9].

Maxton (from Rodin [9]) studied the coupled effect of the casting rate and concrete temperature on the lateral pressure envelope for conventional concrete. Different series of low-slump concrete mixtures placed at casting rates varying between 0.6 and 2 m/h were investigated. The concrete temperature varied from 4.5 to 27$^{°C}$. Maximum lateral pressure was found to increase with the increase in the casting rate and/or decrease in concrete temperature. Irrespective of the tested parameters, the pressure envelope was reported to be hydrostatic from the free surface to a certain maximum value, and then remained constant until the bottom of the formwork.

For formwork design purposes, ACI Committee 622 [2] proposed the following design equations for column and wall elements, both of which take into account the rate of casting and concrete temperature:
For columns:

$$P_{max}= 7.19+ \frac{785R}{17.78+T} < 23.5H \text{ or } 143.7$$

For walls:

$$R<2.14 \text{ m/h: } P_{max}= 7.19 +\frac{785R}{17.78+T} < 23.5H \text{ or } 95.8$$

$$2.14<R<3 \text{ m/h: } P_{max}= 7.19 + \frac{1155}{17.78+T} + \frac{244R}{17.78+T} < 23.5H \text{ or } 95.8$$

$$R>3\text{m/h: } P_{max}= 23.5H< 95.8$$

Where P_{max}: maximum lateral pressure, KPa
R: rate of casting, m/h
T: concrete temperature, ˚C
H: head of concrete, m

2- effect of concrete temperature on formwork pressure

For investigation of effect of concrete temperature on lateral formwork pressure, experimental research of Assad [7] and his colleagues was used and described those below:

2-1- Materials

The ternary cement contained 6% silica fume, 22% fly ash, and 72% CSA Type 10 cement. The Type 30 cement, Type 10 cement, and fly ash had Blaine specific surface values of 600, 325, and 410m2/kg, respectively. The silica fume had a B.E.T specific surface of 20,250m2/kg. Continuously graded crushed limestone aggregate with nominal size of 10mm and well-graded siliceous sand were employed. The coarse aggregate and sand had fineness module of 6.4 and 2.5, bulk specific gravities of 2.71 and 2.69, and absorption values of 0.4% and 1.2%, respectively.
Polycarboxylate-based high-range water-reducing admixture (HRWRA) of 1.1 specific gravity and 27% solid content was used. A high molecularweight cellulosic-based material was employed for the VEA to enhance stability of mixtures proportioned with 0.40 w/cm.

2-2- Mixture proportion

As summarized in Table 1, the investigated mixtures were prepared with 450 kg/m3 of binder content and w/cm of 0.40.The effect of concrete temperature on lateral pressure variations was evaluated by testing mixtures prepared at 10, 20, and 30 ± $2^{\circ C}$ for the TER-10, TER-20, and TER-30 mixtures, respectively. Ambient temperatures during the sampling and testing were 14, 20, and $27^{\circ C}$, respectively, to minimize heat loss of the tested concrete. The effect of using Type 30 cement and set accelerating admixture on the variations in lateral pressure was investigated, as they have marked effect on the rate of cement hydration. The dosage of the set accelerator was set at 1000 mL/100 kg of binder. The T30-20 and TER-20-ACCmixtures prepared with Type30 cement and set accelerating admixture, respectively, were proportioned at 20 ± 2$^{\circ C}$ and tested at 20$^{\circ C}$ ambient temperature. The VEA dosage was fixed at 260 mL/100 kg of binder, and the sand-to-total aggregate ratio remained constant at 0.46 for all tested mixtures. The HRWRA and AEA concentrations were adjusted to secure initial slump flow of 650 ± 15mm and air content of 6 ± 2%.

Table 1. Mixture proportions of evaluated SCC

temperature, ◦C	Mixture* codification	Ternary cement, kg/m3	Type 30 cement, kg/m3	Water, kg/m3 (w/cm = 0.40)	Sand (0-5 mm), kg/m3	Coarse aggregate, (5-10 mm), kg/m3	VEA, mL/ 100 kg of cement	Set-accelerator, mL/100 kg of cement	HRWRA L/m3	AEA, mL/ 100 kg of cement
10	TER-10	450	-	180	740	870	260	-	3.8	120
20	TER-20	450	-	180	740	870	260	-	3.8	120
30	TER-30	450	-	180	740	870	260	-	3.9	120
20	TER20-ACC	450	-	180	740	870	260	1000	3.7	135
20	T30-20	-	450	180	770	900	260	-	3.3	170

2.3. Instrumented column systems

Two experimental columns were used to determine the lateral pressure exerted by plastic concrete. The first column measures 2800mm in height and 200mm in diameter, and was used to evaluate pressure variations of the plastic concrete. The lateral pressure was determined using five pressure sensors mounted at 50, 250, 450, 850, and 1550mm from the base.

In order to enable the evaluation of pressure variation up to the hardening of the concrete, a shorter column measuring 1100mm in height and 200mm in diameter was used. Three pressure sensors similar to those employed in the former column were mounted at 50, 250, and 450mmfrom the base. Both experimental columns were made of PVC with a smooth inner face to minimize friction with the concrete.

2-4- Fabrication and testing program

The slump flow, concrete temperature, unit weight, air volume, L-box flow characteristics, surface settlement, and setting time were determined, and the results are summarized in Table 2.

Table 2. Properties of evaluated SCC mixtures

	TER-10	TER-20	TER-30	TER-20-ACC	T30-20
Slump flow, mm	655	665	645	645	640
Air content, %	6.5	4.3	5.9	4.5	6.2
Initial concrete temperature, ◦C	9.5	21.7	30.1	20.8	21.7
Unit weight, kg/m3	2230	2265	2190	2315	2335
h2/h1 of L-box test	0.84	0.81	0.85	0.82	0.85
Surface settlement, %	0.48	0.34	0.32	0.29	0.15
Initial set time, min	690	610	585	440	425
Final set time, min	780	705	660	480	470

2-5- Fresh concrete properties

All SCC mixtures had L-box blocking ratios (h2/h1) greater than 0.80 indicating adequate passing ability, and relatively low surface settlement (<0.5%). Surface settlement values are shown to decrease with the increase in the initial concrete temperature. The maximum surface settlement decreased from 0.48% to 0.34% and 0.32% for the TER-10, TER-20, and TER-30 mixtures cast at approximate temperatures of 10, 22, and 30◦C, respectively. The use of high early strength cement and set-accelerator are also shown to enhance the static stability of the plastic concrete. The mixtures prepared with set-accelerating admixture and Type 30 cement exhibited settlement values of 0.29% and 0.15%, respectively.

2-6- Lateral pressure envelope with respect to height

A typical diagram showing the distribution of lateral Pressure along the 2800-mm high experimental column for the TER-30 mixture is given in Fig.1. The slump flow values noted at various times are also indicated. Right after casting, the concrete is shown to develop lateral pressure close to the theoretical hydrostatic pressure. The hydrostatic pressure (P_{hyd}) is calculated as: $P_{hyd} = \rho \times g \times H$; where ρ, g, and H refer to the concrete unit weight, gravity constant, and head of concrete in the formwork, respectively. The relative pressures compared to P_{hyd} at the base of the column determined at end of casting and then after 1, 2, and 3 hours were 91%, 77%, 68%, and 61%, respectively.

Fig. 1: Variations of lateral pressure envelope with time for the TER-30 mixture.

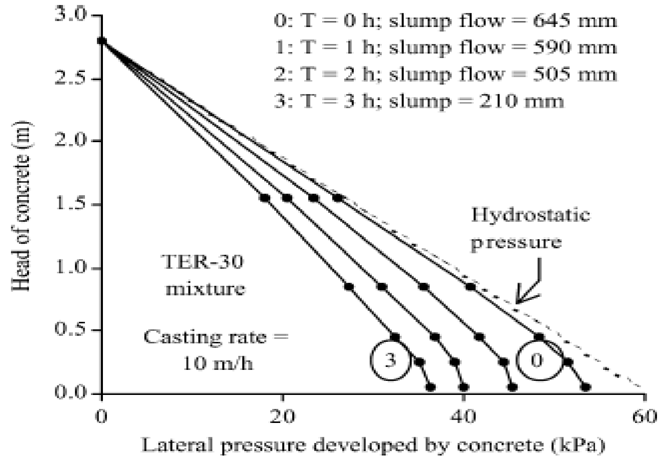
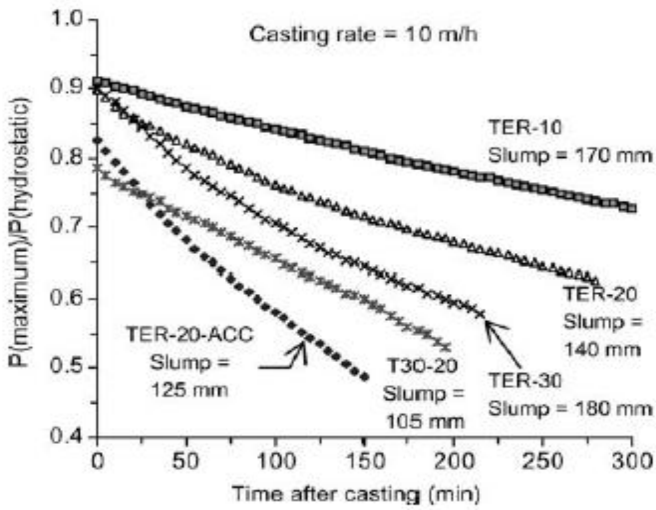


Fig. 2: Effect of concrete temperature, cement Type 30, and use of set-accelerating admixture on pressure variations determined at the bottom of the 2800-mm high column.



2-7- Effect of concrete temperature on variations in lateral pressure

Variations of the P(maximum)/P(hydrostatic) values measured along the 2800-mm column of the five SCC mixtures placed at 10 m/h are plotted in Fig.2. Slump values determined at the end of pressure monitoring are noted. Mixtures prepared with ternary cement at initial temperatures of 10, 22, and 30$^{\circ C}$ develop similar relative pressures of 91% at the end of casting. This indicates that concrete temperature has no significant effect on the development of initial pressure. The maximum initial pressure is rather affected by the degree of internal friction that depends on the coarse aggregate volume and mixture consistency. On the other hand, the rate of pressure drop with time is significantly affected by concrete temperature. For example, the time to reduce the relative pressure by 25% decreased from 400 to 250 and 160 minutes for the TER-10, TER-20, and TER-30 mixtures, respectively.

Alexandridis and Gardner [1] reported that concrete cast at higher initial temperature can exhibit higher cohesion through the formation of a gel structure. This can enable the plastic concrete to develop higher shear strength capable of carrying a greater fraction of the vertical load, thus resulting in increased rate of pressure drop with time. It is important to note that higher initial temperature can result in greater rate of loss in slump flow consistency, thus reducing the degree of lateral pressure. For example, slump values of 170 and 180mm were measured 5 and 3.5 hours after casting for the TER-10 and TER-30 mixtures, respectively.

The T30-20 and TER-20-ACC mixtures developed the lowest initial relative pressures of 78% and 83%, respectively, compared to 91% for those cast at 10 to 30$^{\circ C}$ initial temperatures and placed at similar casting rates of 10 m/h (Fig. 2). The incorporation of set-accelerating admixture in the TER-20-ACC mixture resulted in the highest rate of pressure drop with time; the elapsed period required to reduce the relative pressure by 25% was 88 minutes. The increased rate of cement hydration due to the incorporation of set-accelerating admixture can lead to greater cohesiveness, and hence sharper rate of drop in lateral pressure.[4]

3- effect of section width on formwork pressure

For investigation of effect of concrete temperature on lateral formwork pressure, experimental research of Khayat[8] and his colleagues was used and described those below:

3-1- Materials

A ternary cement made with approximately 6% silica fume, 22% Class F fly ash, and 72% Type 10 cement was used. A continuously graded crushed limestone aggregate with nominal size of 10 mm and well-graded siliceous sand were employed. The sand had a fineness modulus of 2.5. The bulk specific gravities of the aggregate and sand were 2.72 and 2.69, and their absorptions were 0.4% and 1.2%, respectively. A naphthalene-based high-range water reducer (HRWR) with solid content of 41% and specific gravity of 1.21 was used. A liquid-based polysaccharide was used for the viscosity-modifying admixture (VMA) to enhance stability of the plastic concrete. A synthetic detergent-based air-entraining admixture (AEA) and a carboxylic acid-based water-reducing admixture were incorporated.

3-2- Mixture proportion

For the SCC mixture used in this study, a proven mixture prepared using 490 kg/m^3 of binder, 0.38 w/cm, and 0.44 sand to-coarse aggregate ratio was used. The VMA was incorporated at a dosage of 1325 mL/100 kg of water, and the HRWR dosage was adjusted at 6 L/m^3 to secure initial slump flow of 650 mm. A dosage of 150 mL/100 kg of cementitious materials of the AEA was used. The unit weight and air content were 2280 kg/m 3 and 6.1%, respectively.

3-3- Instrumented formworks

As already mentioned, two experimental formworks were used. The first measured 2100 mm in height and 200 mm in diameter. The PVC tube had a wall thickness of 10 mm and a smooth inner face to minimize friction during and after concrete placement. The stress in the diaphragm caused by concrete lateral pressure was determined using five pressure sensors mounted at 850, 1250, 1650, 1850, and 2050 nun from the top. The monitoring of pressure distribution was stopped once the concrete had an approximate slump consistency of 100 mm. The second column consisted of a sonotube of 3600 mm in height and 920 mm in diameter. The column was adequately braced and reinforced. The lateral pressure was determined using two pressure sensors located at 2050 and 2880 mm from the top.

The monitoring of pressure distribution was stopped once the concrete had an approximate slump consistency of 100 mm. The second column consisted of a sonotube of 3600 mm in height and 920 mm in diameter. The column was adequately braced and reinforced. The lateral pressure was determined using two pressure sensors located at 2050 and 2880 mm from the top. In this case, the lateral pressure was monitored until the hardening of the concrete.

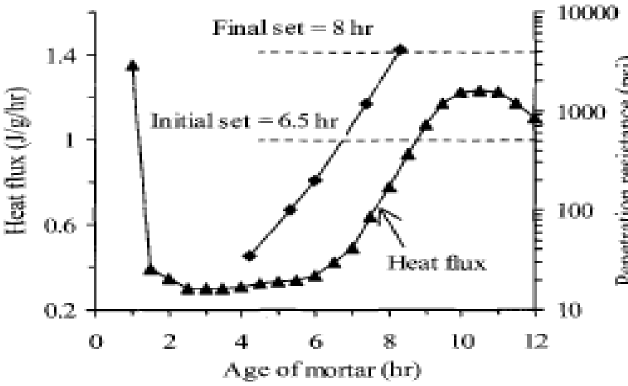
3-4- Fabrication and testing program

Ready-mixed concrete was delivered to the experimental site. The ambient and concrete temperatures were 16 and $19^{\circ C}$ respectively. The slump flow, air content, JRing and Lbox flow characteristics, and surface settlement were determined for the SCC. The measurement corresponds to the mean diameter of the spread concrete at the end of flow. The JRing spread values was 600 mm and for Lbox test the measure was 0.81 and maximum surface settlement was 0.34%.

The concrete was directly discharged from the mixing truck into the formwork from the top at the desired pouring rate without stoppage or vibration. In the case of the 3600-ram high column, the concrete was placed at a rate of rise of 10m/hr. For the 2100-ram high column, the formwork pressure was evaluated twice; once using a rate of placement of 10m/hr and then at 25 m/hr for a second column. The slump flow values determined upon the arrival on site of the concrete and after 1 and 2 hours were 650, 635, and 450 mm, respectively. After 3 and 3.5 hours, slump consistencies of 180 and 65 mm were measured, respectively.

The initial and final setting times were determined in the laboratory at $20^{\circ C}$ in compliance with ASTM C403 and are given in Fig.3. The adiabatic temperature was also evaluated in an adiabatic calorimeter on mortar obtained by sieving fresh concrete through a 4.75-mm sieve. The heat evolved was determined by deriving the temperature rise as a function of time. The time between the initial contact of cement with water and that corresponding to the beginning of the acceleration of temperature rise was 6 hours, as also shown in Fig.3.

Fig 3: Variations of hydration and stiffening kinetics with time.



3-5- Lateral pressure variations

The variations of the lateral pressure envelope determined on the 2100-ram high column along with the consistency are plotted in Fig.4. Immediately after filling the formwork, the concrete is shown to act as a fluid exerting almost hydrostatic head. However, a gradual decrease in lateral pressure takes place with time. The relative pressures at the base of the column determined initially and after 1, 2 and 3 hours were 98%, 89%, 83% and 76% of hydrostatic pressure, respectively.

3-6- Results of the section width Influence on formwork

The effect of column diameter (200 vs. 920 mm) on changes in lateral pressure is illustrated in Fig.5 by plotting the variations of the P(measured)/P(hydrostatic) values calculated at 2050 mm from the top of the formworks as a function of time. It is important to mention that both columns were cast on the job site at the same casting rate of 10 m/hr. Initially, the mixture placed in the larger column exhibited slightly greater pressure of 99% of hydrostatic pressure compared to 96% for the 200-mm diameter column. However, the rate of drop in pressure was significantly different. In the case of the former concrete placed in the 920-mm diameter column, the time required to reduce lateral pressure by 5% of the hydrostatic value was 20 minutes, resulting in a slope of 5.3 kPa/hr. Conversely, for the 200-mm diameter column, this period was 38 minutes resulting in a slope of 3.3kPa/hr. In general, the rate of drop in lateral pressure of plastic concrete depends on the degree of thixotropy or shear recovery [9]. This phenomenon causes a build-up of the structure and an increase in cohesiveness soon after the material is left standing at rest without any shearing action. In the case of the 200-mm diameter column, the arching effect can be relatively more pronounced than that resulting from the 920-ram diameter column.

Fig 3: Variations of hydration and stiffening kinetics with time.

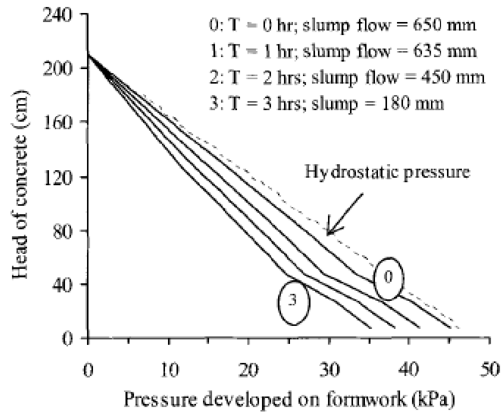
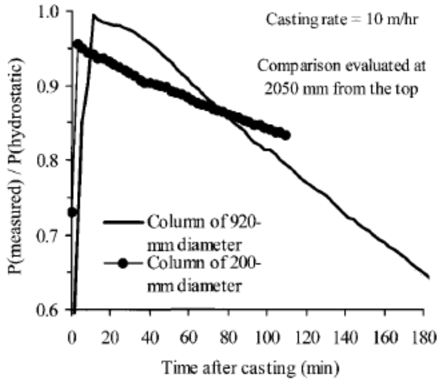


Fig. 5: Effect of the section width on lateral pressure.



4- CONCLUSIONS

- Variations in fresh concrete temperature have limited effect on the maximum lateral pressure developed by SCC at the time of casting. However, the rate of pressure drop with time increases with the concrete temperature that promotes faster development of cohesion.
- The use of Type 30 cement or set-accelerating admixture can lead to 10% reduction in the initial pressure and accelerate the rate of pressure drop by two folds compared to similar concrete prepared with a ternary cement.
- The scale effect had an influence on the rate of drop in lateral pressure of SCC with time; however, no appreciable difference in the maximum initial pressure was observed.
- Immediately after casting, the SCC placed in the 200-ram diameter column was found to exert slightly less pressure than that cast in the 920-ram column. This can be due to an arching effect in the relatively restricted section.

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