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Form Pressure Exerted by Self-Consolidating Concrete: Primary Factors and Prediction Models—Report

Reported by ACI Committee 237

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Form Pressure Exerted by Self-Consolidating Concrete: Primary Factors and Prediction Models—Report

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Form Pressure Exerted by Self-Consolidating Concrete: Primary Factors and Prediction Models—Report

Reported by ACI Committee 237

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Given the high flowability and relatively fast casting rate of self-consolidating concrete (SCC), such concrete can exert high form pressure. Accurate assessment of form pressure is necessary from safety and economic points of view. The maximum form pressure and pressure decay are dependent on the structural buildup of the concrete at rest following placement, as well as on the placement parameters. The structural buildup at rest is affected by the thixotropy of the mixture. This report presents information on key parameters, including constituent materials; mixture proportioning; and casting parameters such as the casting rate, concrete temperature, and reinforcement percentage, affecting thixotropy and SCC form pressure. Prediction models available for estimating SCC form pressure are presented. Findings from two round-robin field studies

conducted to validate these models are also discussed. This report should be of interest to concrete professionals, including concrete suppliers and formwork designers, because it covers: 1) the influence of SCC proportions and casting parameters on form pressure; 2) means to estimate formwork pressure with examples; and 3) techniques to measure formwork pressure in field applications.

Keywords: form pressure; lateral pressure; self-consolidating concrete; structural buildup at rest; thixotropy.

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CHAPTER 1—INTRODUCTION**1.1—Introduction**

Self-consolidating concrete (SCC) is highly flowable non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. SCC is designed to have a relatively low yield stress compared to conventional concrete to ensure high flowability without segregation. Yield stress corresponds to the critical shear stress value beyond which the material starts to flow. SCC can have slump flow values typically in the range of 22 to 30 in. (560 to 760 mm). Due to the high fluidity of SCC, formwork systems are often designed to sustain full hydrostatic pressure. Accurate estimation of form pressure for field application of SCC is necessary for the economical design of formwork and to ensure safety during and after casting. Field and laboratory investigations involving the measurement of lateral pressure exerted by SCC on formwork systems indicate that form pressure can be considerably lower than hydrostatic pressure (Assaad and Khayat 2005c; Assaad et al. 2003b; Billberg et al. 2014; Gardner et al. 2016). This is illustrated in Fig. 1.1 for SCC used for the rehabilitation of wall elements that measure 20 ft (6 m) in height, 23 ft (7 m) in length, and 7.5 in. (0.19 m) in width (Assaad 2004; Khayat et al. 2005b). The casting rate was approximately 21 ft/h (6.5 m/h). The pressure distribution envelopes exerted by a representative SCC mixture determined at the end of the placement and then after 1 and 3 hours are shown in Fig. 1.1 (left). The variations in the maximum lateral pressure with time for five different SCC mixtures that were proportioned with different thixotropic values are illustrated in Fig. 1.1 (right).

Form pressure is affected by structural buildup; structural buildup increases with rest time, hence reducing form pressure (Assaad et al. 2003b; Assaad and Khayat 2005c). The rate of structural buildup is dependent on the concrete mixture characteristics, including:

- (a) Binder constituent (Assaad et al. 2003b)
- (b) Type and dosage of chemical admixtures (Assaad et al. 2003b; Khayat and Assaad 2006)
- (c) Water-cementitious materials ratio (w/cm) (Khayat and Assaad 2006)
- (d) Maximum aggregate size and the total aggregate content (Assaad and Khayat 2005a)

For a given casting rate R , lower form pressure can be observed for concrete with a higher rate of structural buildup at rest (Assaad and Khayat 2007). The structural buildup of the concrete corresponds to an increase in shear strength when the material is left at rest due to flocculation—a physical effect that is reversible—as well as hydration of the cement-based materials, which is irreversible. At very early age, the flocculation component is dominant, and the structural buildup is reversible and can be broken down if the mixture is agitated. However, as hydration progresses with time, the structural buildup gradually becomes less reversible (Roussel et al. 2012). The placement of SCC mixtures with a high rate of structural buildup, at relatively low to moderate casting rates—for example, approximately 7 to

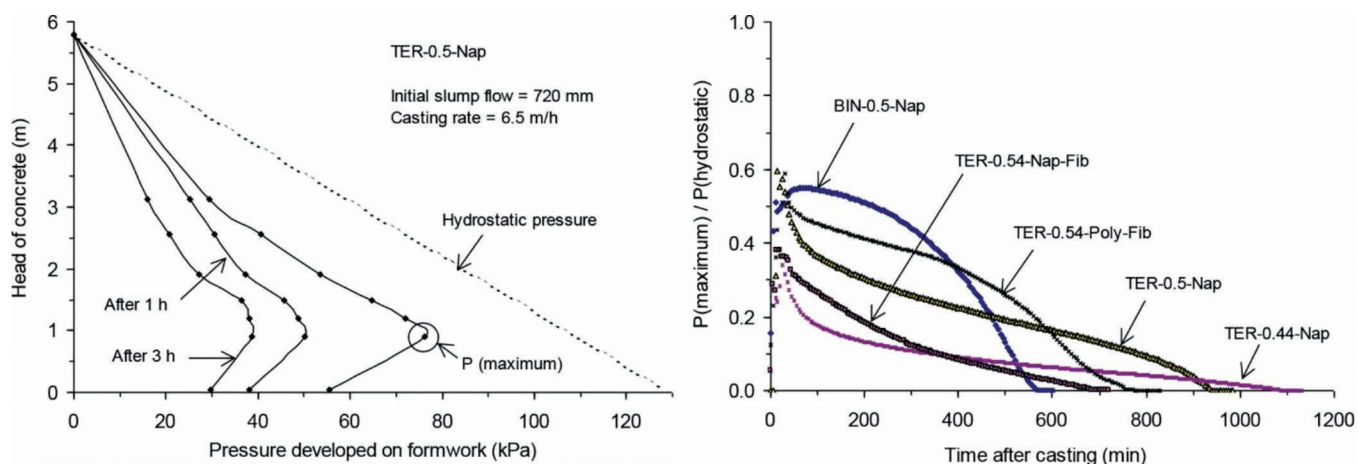


Fig. 1.1—Variations of lateral pressure with height (left) and $P(\text{maximum})/P(\text{hydrostatic})$ values for the five tested SCC mixtures (right) (Assaad 2004; Khayat et al. 2005b). (Note: 1 m = 3.3 ft; 1 kPa = 0.145 psi.)

16 ft/h (2 to 5 m/h)—can result in lateral pressures on the order of 50 to 60% of hydrostatic pressure (Khayat and Omran 2010b; Omran et al. 2014).

In addition to SCC mixture characteristics, form pressure is affected by the casting parameters, including:

- (a) Casting rate (Assaad and Khayat 2007)
- (b) Concrete temperature (Omran et al. 2014)
- (c) Waiting period between successive lifts (Omran et al. 2014)
- (d) Formwork material (Arslan et al. 2005; Omran and Khayat 2017a)
- (e) Minimum formwork dimension (Omran and Khayat 2017a)
- (f) Reinforcement percentage (Perrot et al. 2009).

The casting rate for SCC can vary by construction type (new construction or repair) and size of the member. Concrete temperature, casting rate, and waiting period between the successive lifts influence the structural buildup of SCC, thereby affecting the form pressure (Omran et al. 2014). Formwork materials and their dimensions (Omran and Khayat 2017a), reinforcement percentage (Omran and Khayat 2017b; Perrot et al. 2009), and the density (unit weight) of the SCC contribute to the net weight supported by the formwork and the resulting formwork pressure. Additionally, the form pressure is also affected by various other factors, such as the placement method used (pumping or chute) (Assaad and Khayat 2007), formwork leaks, tie placement, and nearby vibration (heavy traffic). As a result, jobsite controls or form-monitoring strategies (ACI SP-4 [2014] Chapters 11 and 12; ACI 347R-14 Chapter 5) should be employed by the contractor before, during, and after casting. Various theoretical and empirical models have been developed for the assessment of form pressure exerted by SCC, and some of the most prevalent models will be covered in this report.

1.2—Scope

The objective of this report is to provide detailed information to concrete professionals, including concrete suppliers and formwork contractors, with respect to the main SCC

mixture characteristics and casting parameters that influence form pressure. This report also presents the most prevalent models to estimate form pressure available to assess form pressure exerted by SCC, and the accuracy of these models are evaluated based on measurements collected from two round-robin field studies.

The development of factors of safety for use in formwork design, including those used for allowable stress design (ASD) and load and resistance factor design (LRFD) methodologies, is outside the scope of this report. The correction factors or safety factors will be dependent upon the capability of the ready mixed concrete producer to control the rheological parameters of the SCC mixture.

Additionally, test procedures for measuring thixotropy and other parameters needed for determining form pressure using these models are discussed. Details regarding the instrumentation needed for field measurement of form pressure and major round-robin field studies conducted to validate these models are presented.

Chapter 2 presents notation and definitions specific to this document. Chapter 3 describes the thixotropy of cement-based materials, test methods, and the effect of thixotropy on SCC form pressure. Chapters 4 and 5 identify the main material and casting parameters that influence form pressure characteristics, respectively. Chapter 6 presents the primary models available to estimate SCC form pressure. Chapter 7 discusses the results of two major round-robin field validation studies conducted in 2012 and 2014 to evaluate the suitability of various models to estimate SCC form pressure. Chapter 8 summarizes the key findings from this report.

1.3—Use of U.S. Customary Units in this report

In this document and in accordance with standard ACI and U.S. construction industry practice, lb is used as the unit abbreviation for either mass or force, as is evident in, for example, ACI 318-19 and ACI 347R-14. Two examples from ACI 318-19 are provided to help clarify this practice:

- (1) Mass: w_c = density of concrete, lb/ft³
- (2) Force: T_t = total test load, lb



CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

$IP\tau_{0rest}$	= yield stress at rest measured using inclined plane test setup, psi (Pa)
$IP\tau_{0rest}(t)$	= rate of gain in yield stress with time of rest measured using inclined plane test setup, psi/min (Pa/min)
$P_{hydrostatic}$	= equivalent hydrostatic pressure, psi (Pa)
P_{max}	= maximum lateral pressure exerted by concrete on formwork, psi (Pa)
$PV\tau_{0rest}$	= yield stress at rest measured using portable vane test setup, psi (Pa)
$PV\tau_{0rest}(t)$	= rate of gain in yield stress with time of rest measured using portable vane test setup, psi/min (Pa/min)
R	= casting rate, ft/h (m/h)
τ_{0rest}	= yield stress at rest, psi (Pa)
$\tau_{0rest}(t)$	= rate of gain in yield stress with time of rest; also referred to as A_{thix} , psi/min (Pa/min)
w_c	= density (unit weight) of concrete, lb/ft ³ (kg/m ³)
w/c	= water-cement ratio, by mass
w/cm	= water-cementitious materials ratio, by mass
w/p	= water-powder ratio, by mass; w/p is only used in mixtures containing a filler as a partial replacement of portland cement, such as limestone filler

2.2—Definitions

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

casting rate—vertical rate of concrete deposition into the formwork.

cohesion—ability of concrete to hold together due to the flocculation and hydration of the particles.

filling ability (unconfined flowability)—ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight.

flocculation—clustering of binder particles in cement paste at rest caused by interparticle forces, in part responsible for thixotropy, which results in an increase in yield stress.

lateral pressure cancelation—time corresponding to the time elapsed when the measured lateral pressure reaches zero.

passing ability (confined flowability)—ease with which concrete can pass among various obstacles and narrow spacing in the formwork without blockage.

pressure decay—decrease in the lateral pressure exerted by the concrete on the formwork with an increase in resting time.

rheology—science of deformation and flow of matter; evaluated using rheometers that enable one to relate variations in shear stress to shear rate.

shear thinning—decrease in viscosity with increasing shear rate during steady shear flow.

slump flow—measure of unconfined flow potential of a freshly mixed self-consolidating concrete; value is equal to

the average of two perpendicular diameters of the material measured to the nearest 1/2 in. (10 mm) after it is released from the slump cone and stops flowing.

stability—ability of a material to maintain the homogeneous distribution of its various constituents during its flow and setting.

structural breakdown—decrease in the viscosity when a constant shear rate is applied to the material at rest; decrease is due to the breakage of the flocculated particles and hydration products.

structural buildup—increase in shear stress when the material is left at rest due to flocculation and hydration.

yield stress—critical shear stress value below which an ideal plastic or viscoplastic material behaves like a solid (that is, will not flow); once the yield stress is exceeded, a plastic material yields (deforms plastically), while a viscoplastic material flows like a liquid.

yield stress at rest—represents static yield stress of the material—that is, minimum shear stress needed to initiate flow measured after a given time of rest.

CHAPTER 3—THIXOTROPY AND FORM PRESSURE

Understanding thixotropy is critical to the understanding of self-consolidating concrete (SCC) form pressure, and subsequent chapters of this report cite the effects of concrete materials and mixture proportioning as well as placement conditions (for example, temperature) on SCC thixotropy and form pressure. This chapter discusses the principles of thixotropy, methods available to measure it, and the relationship between thixotropy and form pressure. Refer to [ACI 238.2T](#) for further information on thixotropy.

3.1—Thixotropy

According to ACI 238.2T, thixotropy is a reversible, isothermal, time-dependent decrease in viscosity when a fluid is subjected to an increase in shear stress or shear rate; therefore, when the fluid is at rest, viscosity increases back to its original value. Thus, thixotropy can be considered as the continuous decrease of viscosity with time when there is an increase in shear stress or shear rate causing flow to occur, and the subsequent recovery of viscosity in time when the shearing is discontinued ([Mewis 1979](#); [Mewis and Wagner 2009](#)). Thixotropy should be distinguished from irreversible changes in viscosity. Such changes may be caused by hydration of the cementitious materials. Form pressure developed by SCC is a function of both the reversible structural changes due to thixotropy and the irreversible structural changes due to hydration ([Assaad and Khayat 2005c](#); [Assaad et al. 2003b](#)).

Thixotropy of cement-based materials is strongly dependent on the mixture characteristics, mixing, and casting parameters such as casting rate. [Tattersall and Banfill \(1983\)](#) reported that cement characteristics such as packing density, fineness, and chemical composition can significantly affect thixotropy. When a cement-based suspension is sheared, its network structure is broken and, with continued shearing, there is eventually an equilibrium state at which no addi-

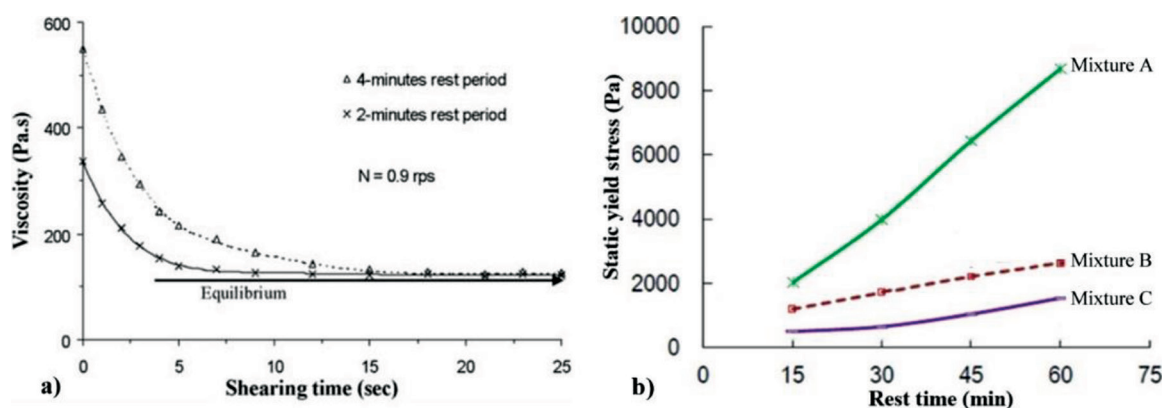


Fig. 3.1—Thixotropy in terms of: (a) structural breakdown measured as variation of viscosity with time for concrete after 2 and 4 minutes of rest (Assaad et al. 2003a); and (b) structural buildup for concretes with different degrees of thixotropy measured as variation of static yield stress with rest time (Omran et al. 2011). (Note: 1 Pa = 0.000145 psi.)

tional deflocculation happens in the paste. When shearing is stopped—that is, the suspension is at rest—the particles undergo reflocculation to form a network structure.

The influence of rest time on thixotropy is shown in terms of the structural breakdown in Fig. 3.1(a) (Assaad et al. 2003a) and structural buildup in Fig. 3.1(b) (Omran et al. 2011). In Fig. 3.1(a), the concrete is subjected to a constant rotational velocity of 0.9 revolutions per second (rps) after leaving it to rest for 2 minutes. The application of the rotational velocity resulted in breakdown of the flocculated structure. Such breakdown with time indicates that the concrete is thixotropic. An equilibrium structure is achieved after approximately 10 seconds in Fig. 3.1(a), where a balance between flocculation and deflocculation is reached. When shearing is stopped, and the material is allowed to rest for 4 minutes, the material is then resheared at the same rotational velocity of 0.9 rps. The results in Fig. 3.1(a) show that the measured viscosity is initially higher, indicating reflocculation during the rest time, and eventually a decrease in the viscosity to the same equilibrium value, indicating the reversible behavior of thixotropy. During the rest time, the reflocculation of individual particles happens. In addition to the flocculation, hydration products can also form between particles, leading to a further increase in structural buildup (Khayat et al. 2002; Roussel et al. 2012). The longer the material is at rest, the more the structural buildup becomes significant, thus requiring higher stress to break down the structure. This increase in the structural buildup is measured in terms of the change in static yield stress with rest time in Fig. 3.1(b). The three mixtures shown in Fig. 3.1(b) exhibit different levels of thixotropic behavior in that all show an increase in static yield stress with time. SCC Mixture A has a higher thixotropy than Mixtures B and C, as it exhibits greater static yield stress values after rest periods of 15 to 60 minutes. The rheology test protocol for the determination of the static yield stress is presented in Section 3.2.

3.2—Thixotropy test methods

There are numerous test methods that can be used to quantify the thixotropy and structural buildup of concrete. These

experiments often consist of either conducting rheological tests at a constant shear rate, such as steady-state flow curves (Ghezal et al. 2002; Tattersall and Banfill 1983) and stress-growth tests (Assaad et al. 2003a), or using varied sheared rates such as hysteresis curves (Ish-Shalom and Greenberg 1960; Wallevik 2003) and breakdown area curves (Khayat et al. 2002). Steady-state flow, hysteresis, and breakdown area curves measure thixotropy in terms of the breakdown of the structure, whereas stress growth tests measure the structural buildup. The breakdown of the structure quantifies the reversible structural changes due to thixotropy, whereas the structural buildup measurements include both reversible structural changes due to thixotropy and the irreversible structural changes due to hydration. In this Report, emphasis is placed on structural buildup measurements as the form pressure estimation models (Khayat and Omran's [2010b] and Ovarlez and Roussel's [2007] models) described in Chapter 6 include the structural buildup as a parameter.

3.2.1 Structural buildup measurement—One of the ways of quantifying structural buildup is to measure the yield stress of the material at rest (τ_{0rest}). τ_{0rest} indicates the strength and number of interparticle bonds that are ruptured due to the applied shear or stress (Tattersall and Banfill 1983). The rheology test protocol for the determination of τ_{0rest} (also referred to as static yield stress and shear-growth yield stress) consists of applying a small rotational velocity (that is, 0.03 rps) to a vane immersed into fresh concrete (or mortar) and recording the variations of torque as a function of time, as shown in Fig. 3.2.1a. The shear-growth profile in Fig. 3.2.1a shows a linear-elastic region followed by a yielding moment where the torque exerted on the vane shaft reaches a maximum value corresponding to the beginning of flow. The maximum value during this profile corresponds to τ_{0rest} . The presence of such maximum torque response can be explained by the concept of structural deformation and breakdown of the bond in the flocculated system (Barnes 1997; Dzuy and Boger 1985). The calculation of τ_{0rest} from the measured maximum torque (T_{max}) requires knowledge of the geometry of the yield surface and shear stress distribution on the surface. Dzuy and Boger (1985) assumed that

the material is sheared along a localized cylindrical surface circumscribed by the vane, and this shear stress is uniformly distributed over this surface. Based on this assumption, a good approximation of τ_{0rest} can be calculated as per Eq. (3.2.1a). The details regarding the derivation and assumptions used for estimation can be found in [Koehler and Fowler \(2004\)](#).

$$\tau_{0rest} = \frac{T_{max}}{K} \quad (3.2.1a)$$

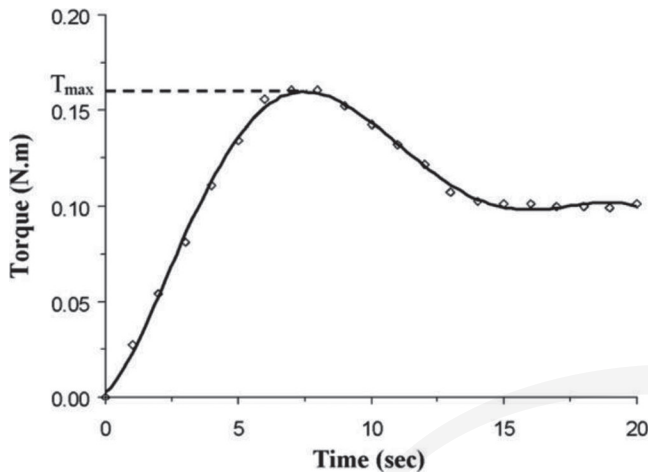


Fig. 3.2.1a—Typical torque-time profile for SCC with 26 in. (650 mm) slump flow at a constant rotational velocity of 0.03 rps ([Assaad et al. 2003a](#)). (Note: 1 N·m = 0.735 lb·ft.)

$$K = 2\pi r^2 H + \frac{4}{3}\pi r^3$$

where K is a constant and H and r are the height and radius of the vane.

The change in concrete yield stress with resting time can also be used to determine the degree of structural buildup and is expressed as the rate of gain in yield stress with the time of rest ($\tau_{0rest}(t)$). The portable vane test is a simplified and manual version of the aforementioned test and consists of determining the minimum torque needed to shear the mortar or concrete after a certain period of rest. A torque wrench is attached to the vane shaft and twisted to shear the tested materials at a constant speed of 10 to 15 seconds per quarter turn at the specified rest times. The peak torque value (T_{max} ; Fig. 3.2.1a) needed to break down the inter-structural bonds and, thus, overcoming the yield stress of the material is noted. The sheared surface corresponds to a cylindrical surface of the interface between the outer diameter of the vane and sheared test sample. To prevent the entire sample from rotating in case of a plug flow of the test sample, a square container is used for the sample holder ([Omran et al. 2011](#)). The portable vane shown in Fig. 3.2.1b has four vanes of different sizes to determine yield stress at different times of rest. The variations of yield stress at rest measured using the portable vane ($PV\tau_{0rest}$) for SCC mixtures with slump flow values between 24 and 28 in. (600 and 720 mm) were determined using four vanes of different sizes (Fig. 3.2.1b). The results in Fig. 3.2.1c show that the $PV\tau_{0rest}$ increased

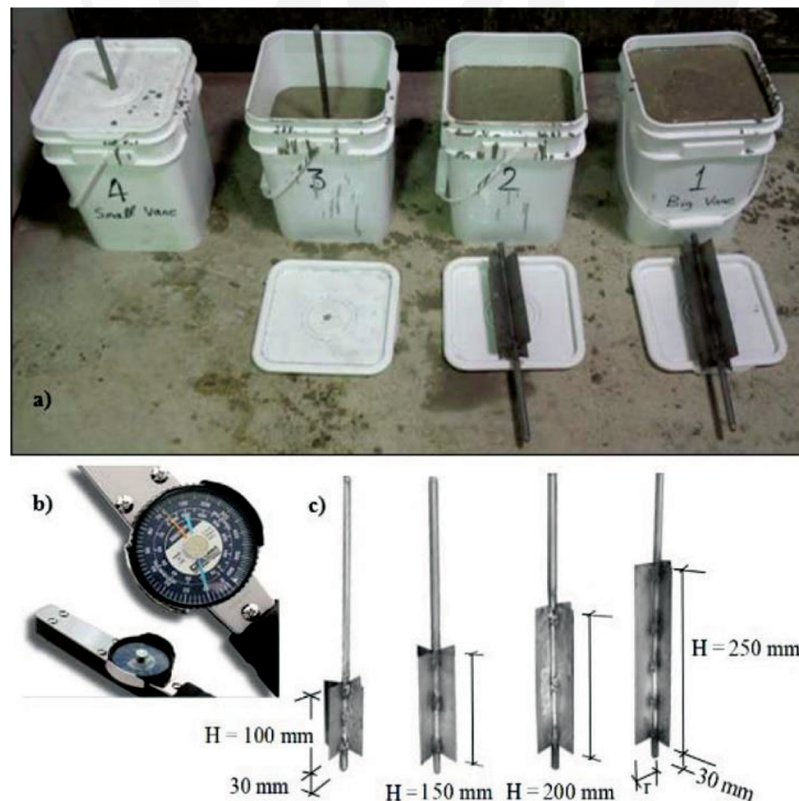


Fig. 3.2.1b—Portable vane test setup: (a) square containers; (b) torque meter; and (c) vanes of different sizes ([Omran et al. 2011](#)). (Note: 1 mm = 0.394 in.)

in a linear fashion over 60 minutes of rest. Thixotropy can be quantified as the slope of each line ($\tau_{0rest}(t)$), as well as the multiplication of τ_{0rest} and $\tau_{0rest}(t)$. A single size of vane can also be used with a sample of different heights; refer to portable vane test (Omran et al. 2011) for further information about the portable vane test method.

For the purpose of form pressure prediction, it is recommended that the measurement of thixotropy is done as soon as practical after the completion of mixing and agitation. It

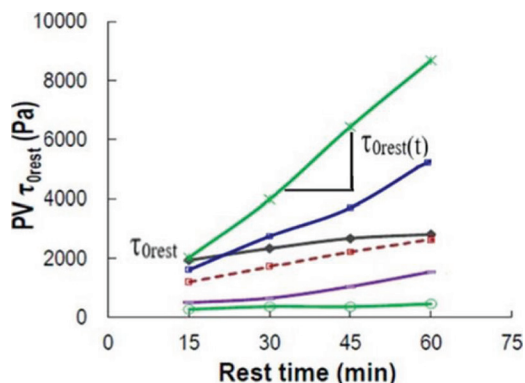


Fig. 3.2.1c—Typical variations of yield stress as a function of rest time for SCC mixtures determined using portable vane test (Omran et al. 2011). (Note: 1 Pa = 0.000145 psi.)

is recommended to perform at least three static yield tests to determine thixotropy by using 30- to 60-minute rest times to ensure that the rate of increase in static yield stress is linear, as indicated in Fig. 3.2.1c.

As an alternative to a rheometer, Khayat et al. (2010) developed an inclined plane test setup for measuring τ_{0rest} and $\tau_{0rest}(t)$. The inclined plane test setup consists of a movable plate whose inclination (θ) can be adjusted as shown in Fig. 3.2.1d. To measure τ_{0rest} for mortar or SCC, the sample is placed on the movable plate and is slowly lifted. Details regarding the volume and placement of the sample can be found in Khayat et al. (2010).

Depending on the value of θ , the gravitational (F_g) and frictional (F_k) forces acting on the sample along the inclined plane vary as shown in Fig. 3.2.1e. In the case of a solid sample, at a critical value of θ , the sample would begin to slide downward, and this sliding initiates when F_g is equal to F_k . However, for fresh mortar or SCC samples, if F_k is high enough to prevent sliding of the entire sample (achieved by increasing the roughness of the surface by covering it with sandpaper), shearing of the top layer occurs, resulting in the flow of the material, as shown in Fig. 3.2.1e(b). The critical angle (α) at which shearing happens and the vertical height to which the plate is lifted is used for estimation of τ_{0rest} , as shown in Eq. (3.2.1b). The test is conducted on samples

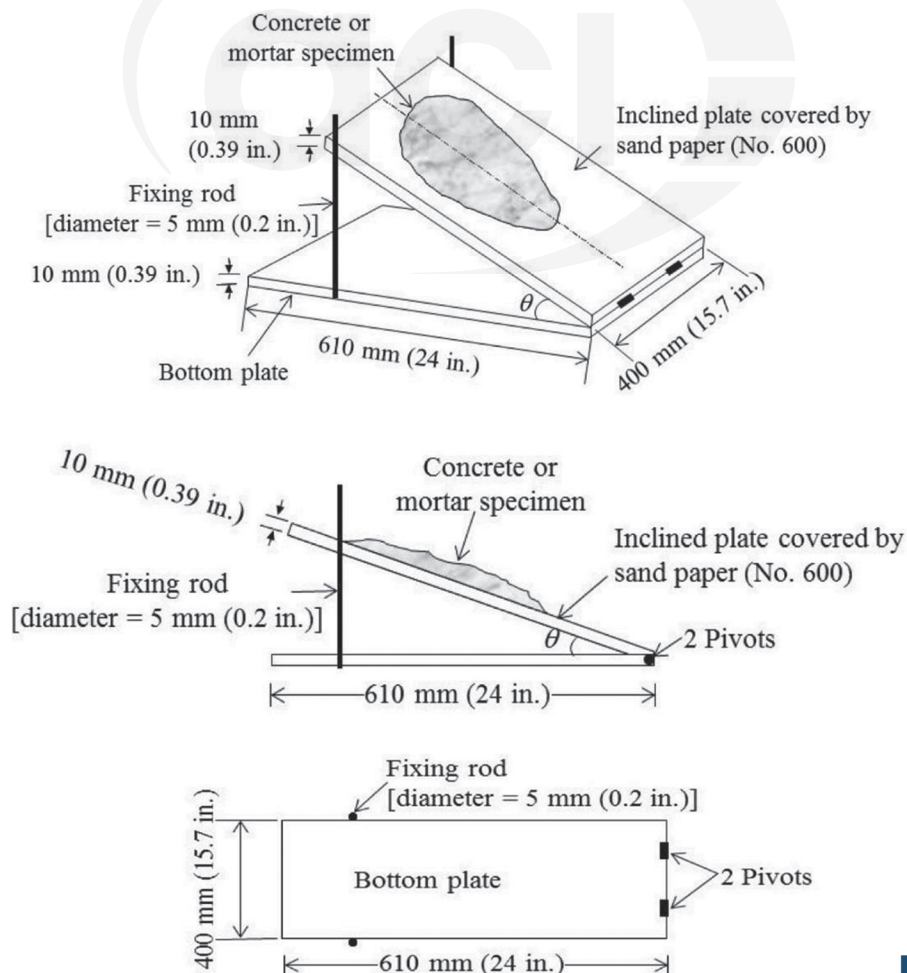


Fig. 3.2.1d—Schematic of the inclined plane test (Khayat et al. 2010).

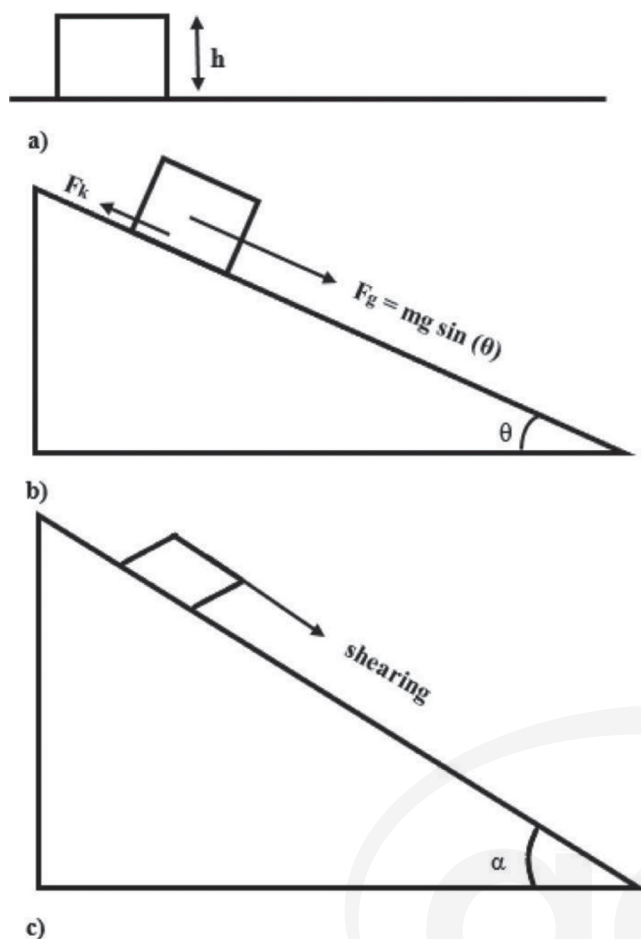


Fig. 3.2.1e—(a) SCC sample at zero inclination; (b) forces acting along the inclined plane on mass m at inclination angle θ ; and (c) shearing of the sample indicating flow initiation at critical angle α (Khayat et al. 2010).

subjected to different rest times to measure $\tau_{0rest}(t)$ and results of yield stress at rest obtained using the inclined plane test for SCC mixtures with different mixture compositions and slump flow values ranging between 22 and 28 in. (560 and 720 mm) are shown in Fig. 3.2.1f.

$$IP\tau_{0rest} = \rho g h \sin \alpha \quad (3.2.1b)$$

where h is the thickness of the spread of SCC at the horizontal position; ρ is SCC density; α is the critical angle at which shearing of the sample occurs; and g is the acceleration due to gravity.

Amziane et al. (2008) developed an alternative approach known as the plate test for measuring τ_{0rest} and $\tau_{0rest}(t)$ for thixotropic materials. The schematic of the plate test setup is shown in Fig. 3.2.1g. The test setup consists of a plate attached below a balance and is partly immersed in SCC. The plate is covered with sandpaper with an average roughness of 0.008 in. (200 μ m) to prevent slippage between the plate and the SCC; this roughness corresponds to a grit size of 70 or a U.S. mesh of 60. The apparent mass of the plate is monitored over time. The plate remains static during the test, and the change in apparent mass is attributed to mobilization

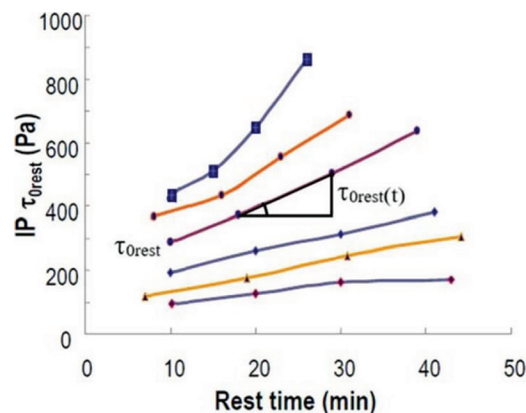


Fig. 3.2.1f—Yield stress variation with rest time for SCC mixtures measured using inclined plane test; SCC had different mixture compositions and slump flow values of 22 to 28 in. (560 to 720 mm) (Khayat et al. 2010). (Note: 1 Pa = 0.000145 psi.)

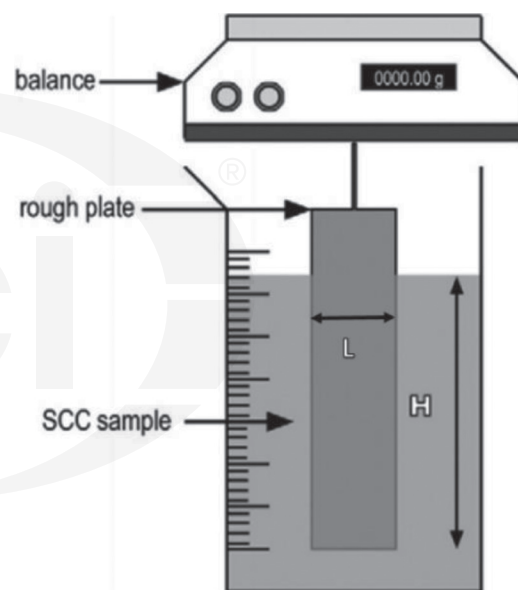


Fig. 3.2.1g—Schematic of plate test setup (Perrot et al. 2009).

of shear stress on the plate due to the slight deformation in the test material (mortar or concrete) under its own weight, which includes deformation due to settlement, segregation, bleeding, and evaporation of the test material. This deformation is limited at early age but sufficient to reach a critical value inducing material yielding. As a result, the mobilized shear stress can be considered τ_{0rest} . The dimensions of the plate are 0.1 in. (3 mm) thick, 3 in. (75 mm) wide and 4 in. (100 mm) long, and the concrete is placed to a height of 8 in. (200 mm) in a vessel made of smooth polyvinyl chloride (PVC) and has dimensions of 8 in. (200 mm) diameter and 8 in. (200 mm) in height. These dimensions are chosen such that the vessel is large enough compared to the size of the plate so that material can be assumed to be homogenous. To avoid losses due to evaporation and its influence on the apparent mass measured, an oil film is added on the top surface

the material. $\tau_{0rest}(t)$ is calculated from apparent mass evolution ($\Delta M(t)$) using Eq. (3.2.1c).

$$\tau_{0rest}(t) = \frac{g\Delta M(t)}{2S} \quad (3.2.1c)$$

where S is the area of the immersed surface—that is, plate width (L) times the immersed height (H).

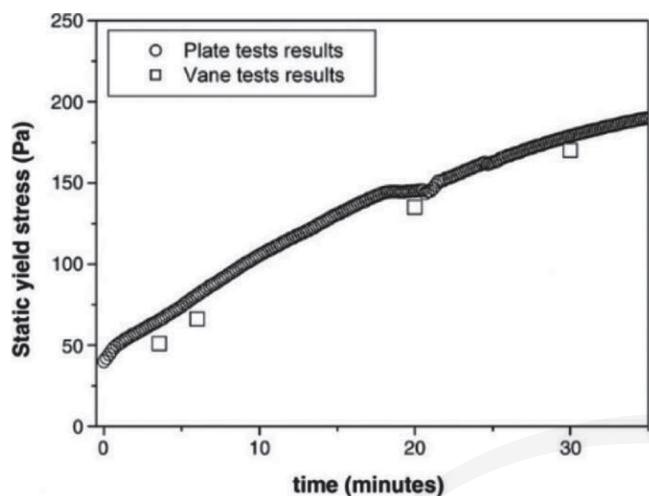


Fig. 3.2.1h—Comparison between calculated static yield stress values of SCC using the plate test and measured static yield stress values using a vane rheometer (Perrot et al. 2009). (Note: 1 Pa = 0.000145 psi.)

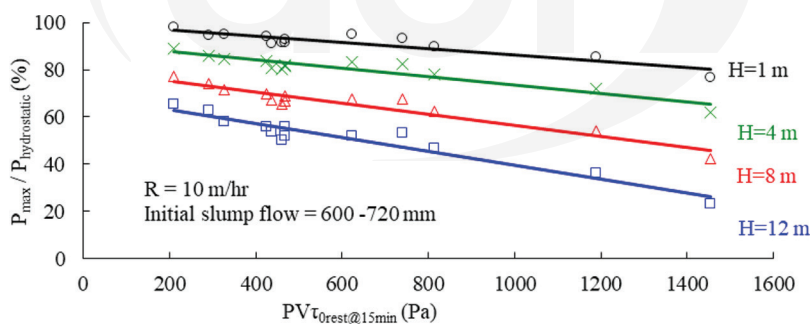


Fig. 3.3a—Variations of relative lateral pressure with $PV\tau_{0rest@15min}$ at different heights of placement (adapted from Khayat and Omran [2010b]). (Note: 1 m = 3.3 ft; 1 mm = 0.0394 in.; 1 Pa = 0.000145 psi.)

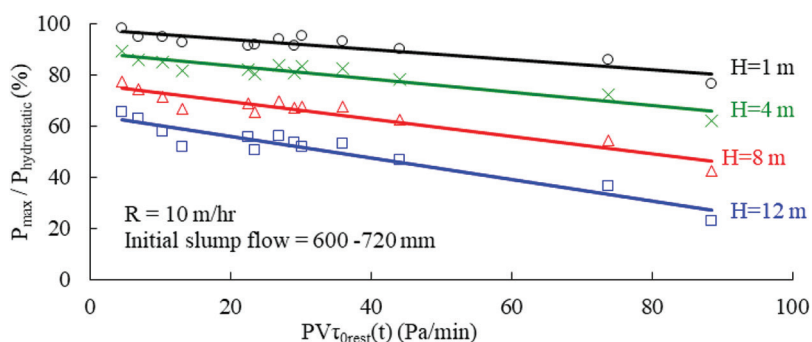


Fig. 3.3b—Variations of relative lateral pressure with $PV\tau_{0rest}(t)$ at different heights of placement (adapted from Khayat and Omran [2010b]). (Note: 1 m = 3.3 ft; 1 mm = 0.0394 in.; 1 Pa = 0.000145 psi.)

The comparison between the calculated yield stress values using the plate test and measured yield stress values using a vane rheometer for SCC with a water-cement ratio (w/c) of 0.47 is shown in Fig. 3.2.1h.

3.3—Influence of thixotropy on form pressure

Concrete that can exhibit a higher degree of thixotropy (that is, a higher rate of structural buildup) can develop greater cohesiveness soon after casting, thus acting as a cohesive body exerting less pressure than the full-hydrostatic pressure state. Khayat and Omran (2010b) evaluated the relationship between the form pressure characteristics and the structural buildup of SCC mixtures. The lateral pressure values were measured at different depths in the formwork—that is, 3.3, 13.1, 26.2, and 39.4 ft (1, 4, 8, and 12 m)—and the structural buildup of the mixtures were assessed by measuring τ_{0rest} after 15 minutes of rest ($\tau_{0rest@15min}$) and $\tau_{0rest}(t)$ using the portable vane test setup. Based on the results, a linear relationship (R^2 ranging from 0.82 to 0.92) was observed between the lateral pressure and structural buildup measured using different indexes—that is, $\tau_{0rest@15min}$, $\tau_{0rest}(t)$, $\tau_{0rest@15min} \times \tau_{0rest}(t)$ as shown in Fig. 3.3a, 3.3b, and 3.3c, respectively. Additionally, the lateral pressure decay during the first 60 minutes after casting and the pressure decay until reaching the pressure cancellation time (t_c) were correlated with the structural buildup as shown in Fig. 3.3d, 3.3e, and 3.3f.