PROGRESS REPORT

Submitted to the

READY-MIX CONCRETE RESEARCH FOUNDATION

AMERICAN CONCRETE INSTITUTE – CONCRETE RESEARCH AND EDUCATION FOUNDATION

on Self-Consolidating Concrete Formwork Pressure

for the period

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from

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<u>Task I. Capturing existing knowledge on formwork pressure exerted by SCC and make recommendations for current practice</u> (90% completed)

An extensive literature review undertaken to capture existing knowledge concerning formwork pressure exerted by SCC has been completed. This review addressed the following topics:

- Existing recommendations for formwork design. In this section, design recommendations and theoretical models proposed by various code regulations and researchers to predict formwork pressure are discussed, including recent recommendations for SCC.

- Relationship between form pressure and rheology of SCC. This section reviewed parameters affecting thixotropy and structural build-up of cement-based materials, evaluation methods, and relationship to the initial development of lateral pressure and its variation in time.

- Influence of various parameters affecting formwork pressure and thixotropy. These parameters were divided according to material properties, consistency level, placement conditions, and formwork characteristics.

- Lateral pressure measurement: Instruments and devices that have been used to monitor lateral pressure, including pressure transducers and pore water pressure sensors were discussed.

- Case studies. Well-documented case studies highlighting observations of formwork pressure measurements exerted by SCC were reviewed.

Interim recommendations summarizing current practice for formwork pressure exerted by SCC are under preparation. This work would constitute the remaining 10% of the scope of Task 1, which will be reported with the next progress report scheduled for May 2007.

The state-of-the-art report will be updated at the end of the project in order to integrate laboratory and field test results generated in this research, as well as any other relative information in the literature.

Task II. Devising portable apparatus for measuring and predicting lateral pressure and its initial rate of pressure drop in time (50% completed)

Work completed for Task II

Formwork pressure apparatuses have been developed in both Sherbrooke and Northwestern campuses. The aim of these devices is to monitoring the development of formwork pressure shortly after casting and the variation in the pressure envelope for plastic concrete. The first prototype was proposed by Khayat in 2003 and has been used in a series of experiments since, both in the laboratory and in the field.[1]

The device consists of a 1.2-m high pressure column that can be used to simulate concrete heads of up to 10 m due to air pressure introduced from the top of the column (Fig. 1). The column can be fabricated using rigid PVC or metal tubular sections. The testing protocol consists of placing the SCC continuously from the top of the column at a given casting rate up to 1 m in height. Air pressure is then gradually introduced from the top to simulate pressure increase due to concrete casting at a given rate of rise. The lateral stress is monitored using four pressure transducers of 20 mm in diameter, from Honeywell (Flush Diaphragm Millivolt Output Type Pressure Transducer), Fig 2. The sensors have 250-kPa capacity and are mounted at 920, 770, 620, and 420 mm from the top surface of the concrete. The sensors work using semiconductor gages on bending beams and can operate over a temperature range of –50 to +100 °C. The sensors are set flush with the inner surface of the instrumented column and sealed to prevent leakage during the overhead pressure application. The pressure transducers are properly calibrated mechanically at set intervals. This is validated using water prior to each use.

Fig. 1 – Sherbrooke pressure column enabling the measurement of form pressure of sections with up to 10 m in height

1. Khayat, K.H., and Assaad, J.J., "Measurement Systems for Determining Formwork Pressure of Highly Flowable Concrete," Materials and Structures, 2007 (in press).

Fig. 2 – Pressure transducer used for measuring lateral pressure

Work carried out in Task I consisted of reducing the height of the concrete inside the column to evaluate the possibility of decreasing the free height of the concrete in the pressure column without affecting the accuracy of the results. This is essential to render the pressure devise portable for laboratory and field use. Figure 3 illustrates the results of such an attempt where the variations of lateral pressure with height are compared for the same SCC mixtures used to initially fill the pressure column with 0.5 and 1 m of concrete before applying the overhead pressure to simulate a rate of rise of 10 m/h. The results indicate that the relationship between the maximum pressure vs. apparent concrete head can be similar when only 0.5 m of concrete is used to fill the pressure tube (Figs. 3 and 4).

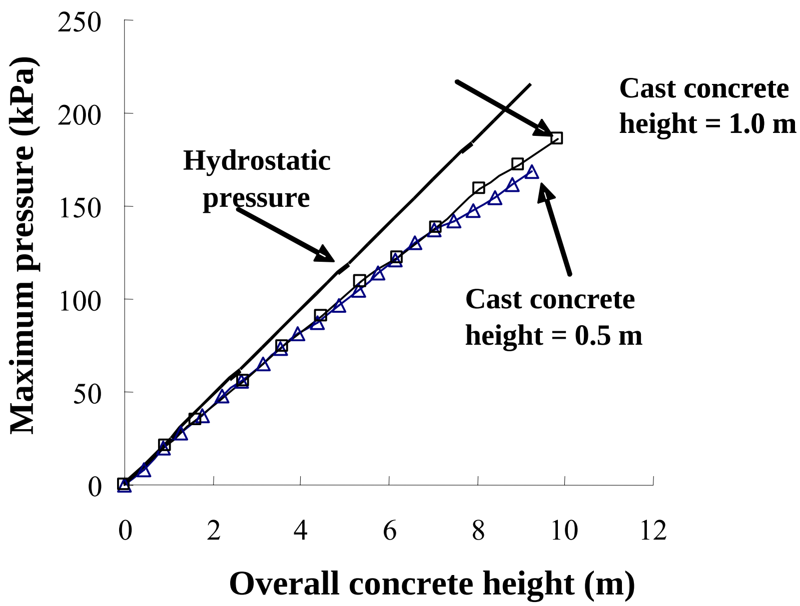


Fig. 3 – Relationship between maximum pressure and height of concrete using the Sherbrooke pressure column filled with 0.5 and 1.0 m of SCC

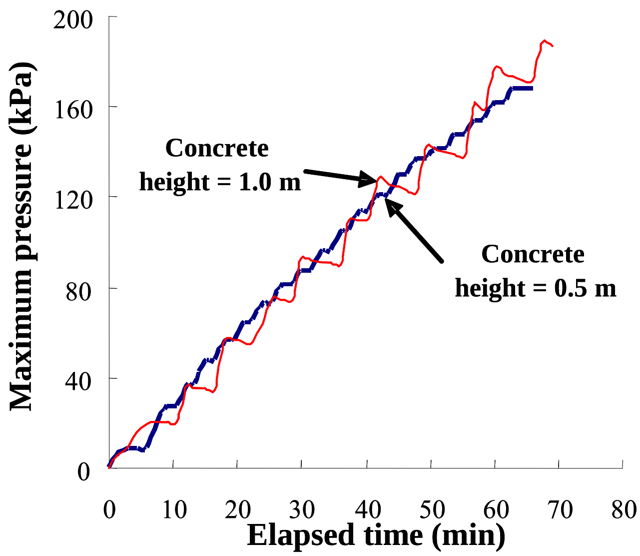
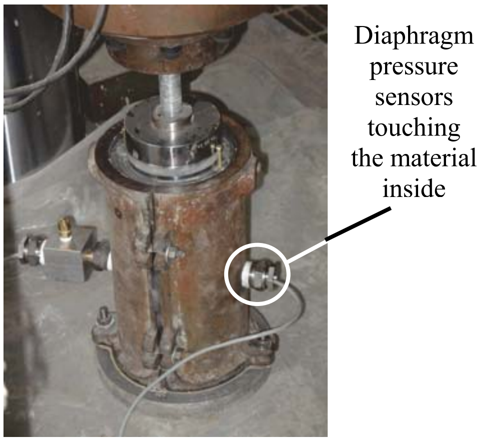


Fig. 4 – Relationship between maximum lateral pressure versus time using the Sherbrooke pressure column filled with 0.5 and 1.0 m SCC

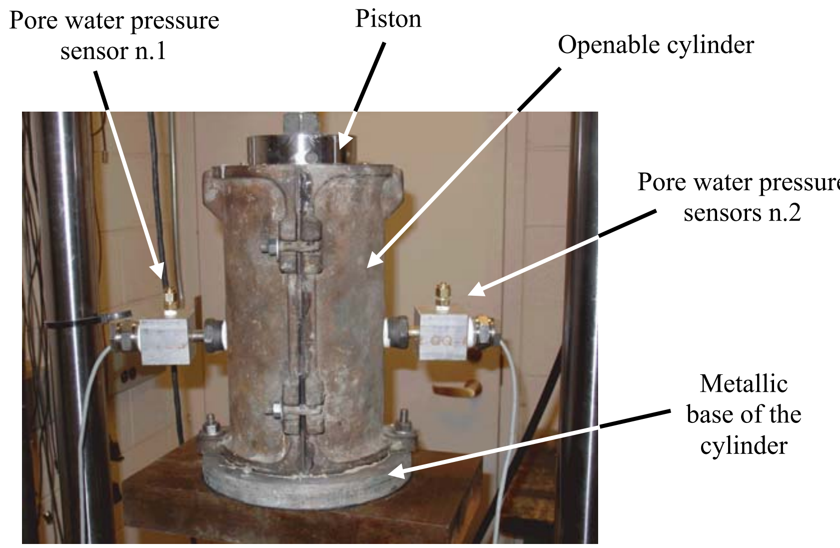
Figure 5 presents of a new design for two pressure tubes that will be used to develop a field-oriented device to evaluate formwork pressure. Both devices are currently under fabrication. The first model is circular in cross-section measuring 0.7 m in height and 0.2 m in diameter (Fig. 5-a). A pressure transducer set flush with concrete will be employed at 62.5 mm from the base. Another transducer will be set above the concrete level to determine the over pressure inside the tube at a distance of 625 mm from the base of the column. A rectangular column (Fig. 5-b) measuring 0.2 m in width and 0.4 m in length is also being fabricated and will have two pressure transducers at near the bottom (one in each side) and a third transducer near the top.

Northwestern University apparatus is composed of a cylinder-piston system. Similar to the device mentioned above, simulation of the vertical loads generated by SCC is performed by pressurizing the concrete in a cylindrical container. The pressurization is produced by direct surface contact between the piston and fresh SCC mixture. A laboratory mechanical testing system is used to impose and control the axial load. Different casting rates can be easily simulated by changing the rate at which the vertical load is applied. A wide range of casting heights can be simulated, with values largely covering practical ranges used in the construction field: from less than 1 m to several dozens of meters.

To record the horizontal pressures generated by the concrete during the pressurization, the cylinder was instrumented with two diaphragm pressure cells positioned at mid-height (Figure 5a,b). Each pressure cell had 400 kPa capacity and were calibrated prior to use. Measurements of total and pore water pressure were carried out: the former by a sensor directly touching the concrete surface (Figure 6); the latter by mean of a sensor in a chamber hydraulically connected to the concrete volume inside the formwork (Figure 7).



a)



b)

Fig. 5 – Instrumented cylinder

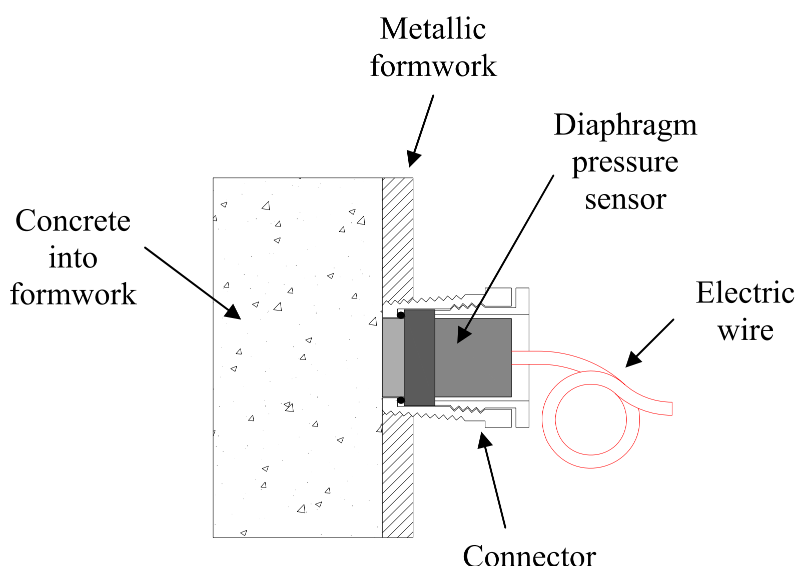


Fig. 6 – Measurement of the total pressure: the sensor touches the concrete

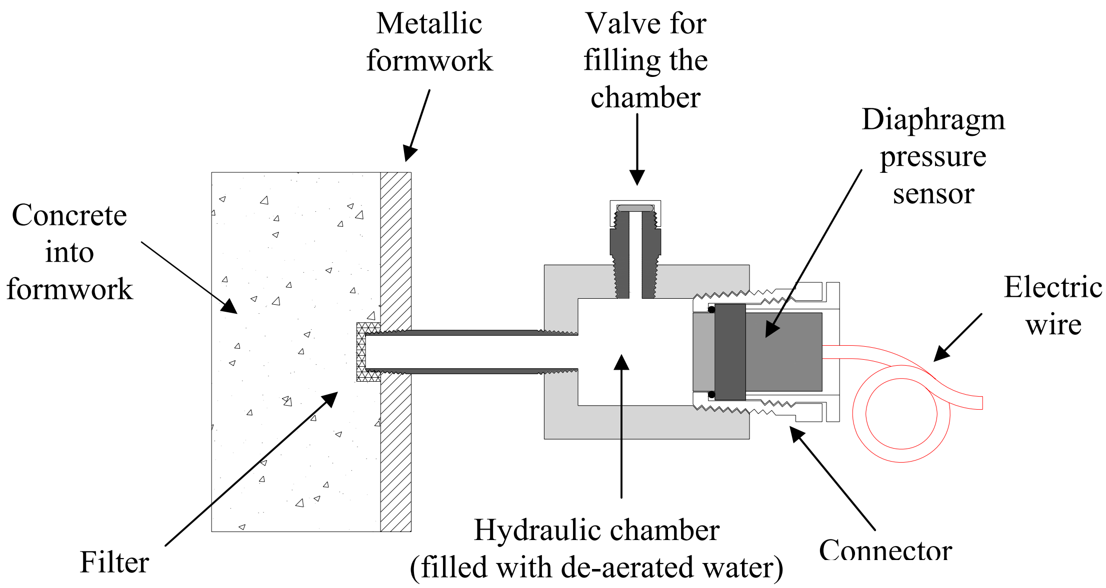


Fig. 7 – Measurement of the pore water pressure: the hydraulic connection

In addition to fabrication of the device, work in this task also consisted of using the cylinder-piston apparatus to simulate columns heights measuring 14 m. Simulation of different casting rates was also performed. Mixtures were designed using four different water/binder (w/b) ratios and different binder compositions were used to evaluate the sensitivity of the apparatus. Figure 7 shows a simulation conducted with the apparatus for an SCC concrete cast at a rate of 7 m/h. Difference between the recorded peak values of the lateral pressure P_w and the vertical pressure P_v (hydrostatic) is clear. Mixtures containing 30% Class F fly ash were tested and a significant reductions in the lateral pressure was found when a lower w/b ratio was reduced.

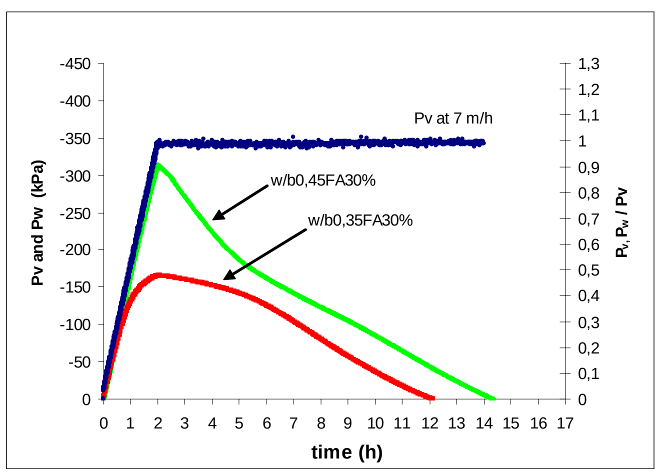
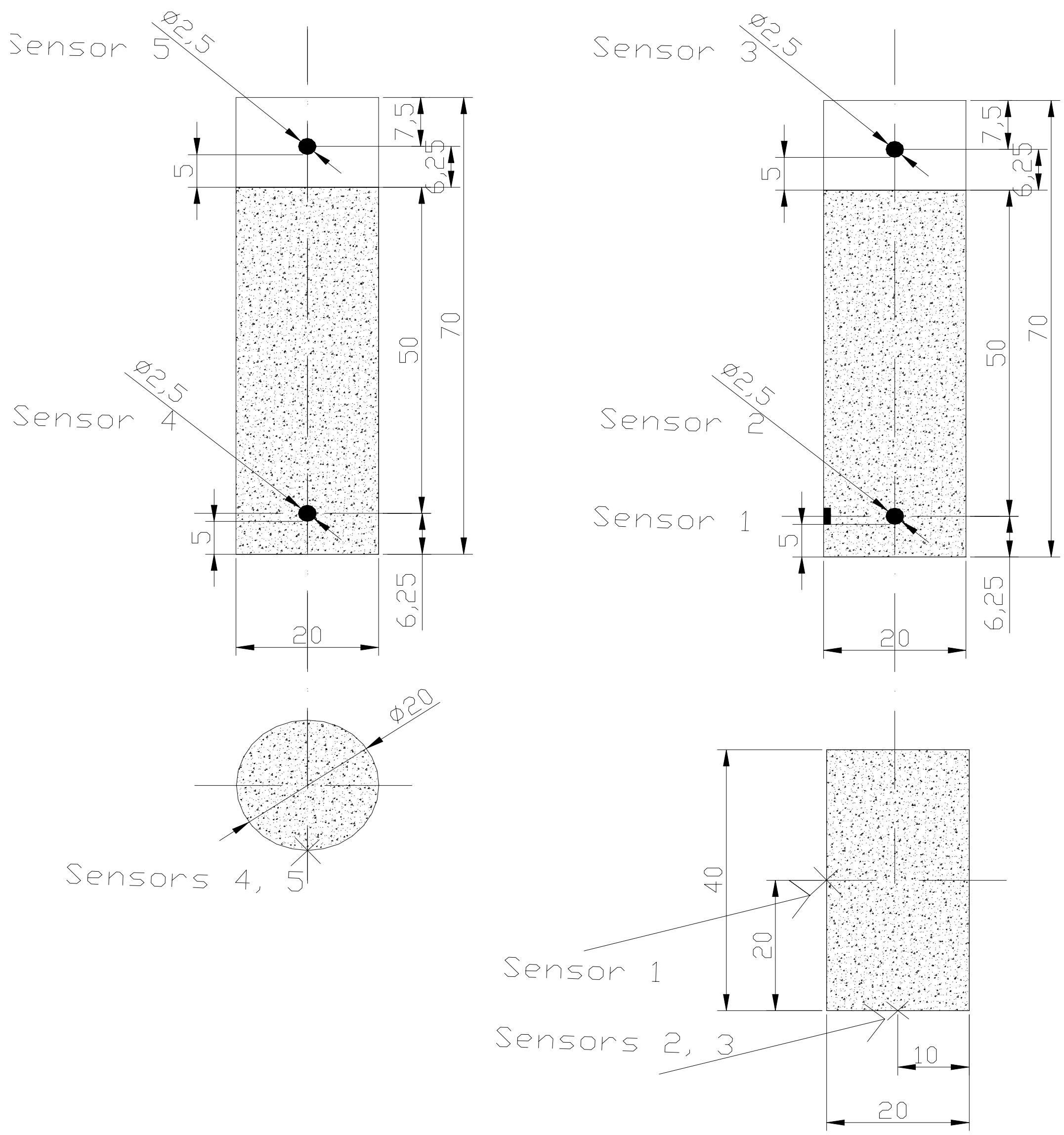


Fig. 7 – SCC mixtures containing Fly Ash: effect of the w/b on formwork pressure at the casting rate of 7 m/h

On-going work for Task II

The two pressure columns under construction at Sherbrooke will be filled with SCC to variable heights of 0.25, 0.35, and 0.5 m (instead of 1 m of the initial model) to facilitate handling. The magnitude of the pressure response will be determined for each test set up and concrete sample height at two placement rates of 5 and 10 m/h. SCC mixtures with various compositions shown in Table 1 will be used for validating the results. The main variables include slump flow (500 to 720 mm), paste volume (330 to 400 L/m^3), and *W/CM* (0.37 to 0.47).



(a) (b)

Fig. 8 – Second generation pressure column devices to evaluate formwork pressure of SCC with head of up to 10 m

Table 1 –SCC mixture compositions for validation of formwork pressure devices

Slump flow	720, 650, 600, 500 ± 10 mm					
Volume of paste	330, 400 L/m^3					
Cement type	GU (Type I)					
W/CM	0.37, 0.42, 0.47					
Sand-to-total aggregate (by volume)	0.5					
Sand (0-5 mm)	√	√	√	√	√	√
Coarse aggregate (MSA = 10 mm)	√	-	-	-	-	-
(MSA = 14 mm)	-	√	√	√	-	-
(MSA = 20 mm)	-	-	-	-	√	√

Results at Northwestern University indicate that the device is sensitive enough to measure changes by varying the mix composition and casting rate. The next phase at Northwestern University will focus on examining the repeatability of simulation. Experiments will be conducted with at least two of the SCC mixtures in Table 1. Each mix will be tested twice. This will also allow for a comparison of the two formwork simulation devices.

Task 3. Identifying the role of material constituents and mix design parameters affecting initial lateral pressure and its decay and relate to rheological parameters of cement paste (20% completed)

On-going work for Task 3

In order to identify the role of the material constituents on the lateral pressure, it is important to evaluate various mixture compositions. To date, all materials for this phase of the work has been ordered and obtained. In total, 8 different cements, 4 different superplasticizers, 2 different VMAs, 1 silica fume, and 2 different fly ashes have been acquired and evaluated.

Screening tests using the hysteresis loop test protocol is currently being conducted in order to determine compositional ranges of interest. Then, the ionic strength of the pore solutions of these compositions will be determined along with the zeta potential testing of the ingredients.

In parallel, work has been carried out on developing a test protocol to measure the ionic strength of the pore solution of the cements paste. A double filtration method will be used in order to exclude presence of large particle. The first filtration will be done with a qualitative filter paper, and the final filtration will be done with 0.45-micron paper (Figs. 9 and 10).

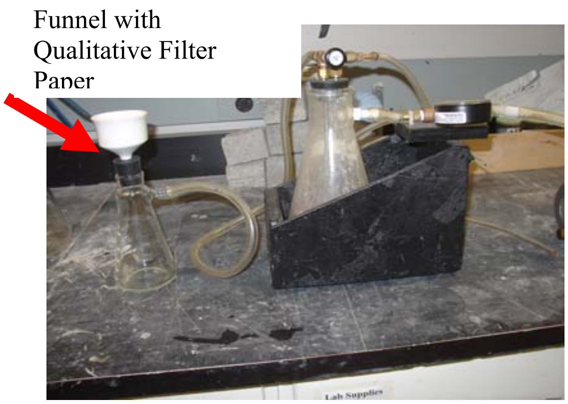


Figure 9: Primary filtration

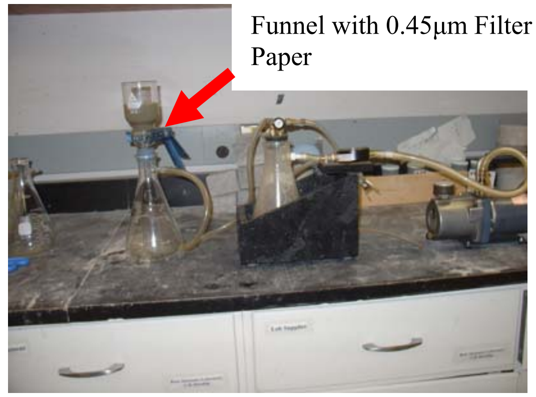


Figure 10: Secondary Filtration

In order to prevent any carbonation reactions, extraction of the pore solutions will be carried out in a glove box flushed continuously with nitrogen..

<u>Future work for Task 3</u>

Based on the results of the screening tests, the composition of the mixtures will be determined by using a factorial design method. This allows selecting compositions in an unbiased way, minimizing the number of mixtures, and determining the relative weights of ingredients. Complementary zeta potential measurements will be made in order to evaluate the effects of surface charges of the solid ingredients on thixotropy and rate of stiffening. The water/cement ratio and the superplasticizer dosage will be adjusted to achieve the desired fluidity level. The same fluidity level will be used for all mixtures.