The Evaluation of Changes in Concrete Properties Due to Fabric Formwork

By

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Abstract

Fabric as a flexible formwork for concrete is an alternative giving builders, engineers, and architects the ability to form virtually any shape. This technique produces a superb concrete surface quality which requires no further touch up or finishing. Woven polyolefin fabrics are recommended for this application. A permeable woven fabric allows excess water from the concrete mix to bleed through the mold wall, and therefore reduce the water-cement ratio of the concrete mix. Due to the reduction in water-cement ratio, higher compressive strength in fabric formed concrete may be achieved, as also suggested by earlier research. The current research study was conducted to investigate and document the changes in concrete strength and overall quality due to use of commercially available woven polyolefin fabrics. Use of fabric formwork will contribute to decreased construction cost, construction waste, and greenhouse gas emissions. Two sets of tests were conducted as a part of this research study including comparison of compressive strength of fabric formed versus PVC formed concrete cylinders and comparison of behaviour of the fabric formed reinforced columns versus cardboard formed reinforced concrete columns. Variables in this research were limited to two types of fabric with different permeability (Geotex 104F and Geotex 315ST) and two types of concrete; concrete made with conventional Portland cement and no flyash herein called normal concrete (NC) and concrete with 30 percent flyash in its mix design (FAC).

The laboratory results revealed that fabric Geotex 315ST is an ideal geotextile for forming concrete. It was also found that the effects of fabric formwork on concrete quality in a large member are limited mostly to the surface zone and the core of the concrete remains the same as a conventionally formed concrete. Even though fabric formed cylinder tests showed an average of 15% increase in compressive strength of the concrete samples, compressive strength of the reinforced columns did not dramatically change when compared to the companion cardboard formed control columns. This research confirmed that fabric formwork is structurally safe alternative for forming reinforced concrete columns.

Acknowledgments

I would like to deeply thank my supervisors Dr. Dagmar Svecova, Prof. Mark West for having faith in me and for their leadership and guidance. Thanks also to the Cement Association of Canada (CAC) and Natural Sciences and Engineering Research Council (NSERC) for their financial support, Geotex Inc. for providing fabric samples, Mr. Morey McVey, Mr. Chad Klowak and Mr. Grant Whiteside from the McQuade Structures Laboratory of the University of Manitoba for their support and assistance during the fabrication and testing of experimental specimens.

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To the two dearest women in my life;

My mother and my wife.

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The following symbols are used in this thesis:

a	*Area of the affected concrete in fabric formed concrete specimens*
A	*Total area of the concrete in fabric formed concrete specimens*
A_g	*Gross cross-sectional area of concrete*
A_{st}	*Total area of longitudinal column reinforcement*
FAC	*Flyash concrete*
f'_c	*Specified compressive strength of concrete*
f_y	*Specified yield strength of steel reinforcement*
k	*Effective length factor for compression members*
l_u	*Unsupported column length*
M	*Moment at the end of the column (chapter 3)*
NC	*Normal concrete*
P_f	*Factored axial load*
P_{ro}	*Factored axial load resistance of a reinforced concrete column*
r	*Radius of gyration for the column cross-section*
R	*Rebound Value*
s	*Center-to-centre spacing of ties*
V	*Volume of the concrete (chapter 3)*

x	*Length of the mechanical press lever's handle (chapter 3)*
α_1	*Ratio of average stress in rectangular compression block to specified strength (CSA A23.3 Cl.10.1.7)*
β_1	*Ratio of depth of compression block to depth of neutral axis (CSA A23.3 Cl.10.1.7)*
ρ_c	*Density of concrete*
ρ_t	*Longitudinal steel reinforcement ratio (column)*
φ_c	*Resistance factor for concrete (CSA A23.3 Cl.8.4.2)*
φ_s	*Resistance factor for steel reinforcement*

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Chapter 1

Introduction

Fabric formwork, as a new concrete forming technique, provides technical advantages and new freedom to the architects, engineers and concrete formwork industry. Fabric-formed concrete members are easy to form, immaculate in finish (Figure 1), organic in form, and inexpensive to produce.

The surface finish of concrete formed in wood, steel or plastic molds generally has imperfections, often requiring further touch ups and costly treatments (Figure 2). Lumber and plywood used for conventional concrete forming are often used a few times and then sent to the landfill site. Creating curves and organic forms using conventional concrete forming is also time consuming, expensive and labour and material intensive. Fabric formwork can use a flexible woven nylon, polyolefin, polyester, polypropylene, polyamide, or polyethylene membrane (Koerner and Welsh 1980) instead of rigid conventional forms or panels. When fresh concrete is poured inside this membrane the fabric mold deflects into a repertoire of precise tension geometries.

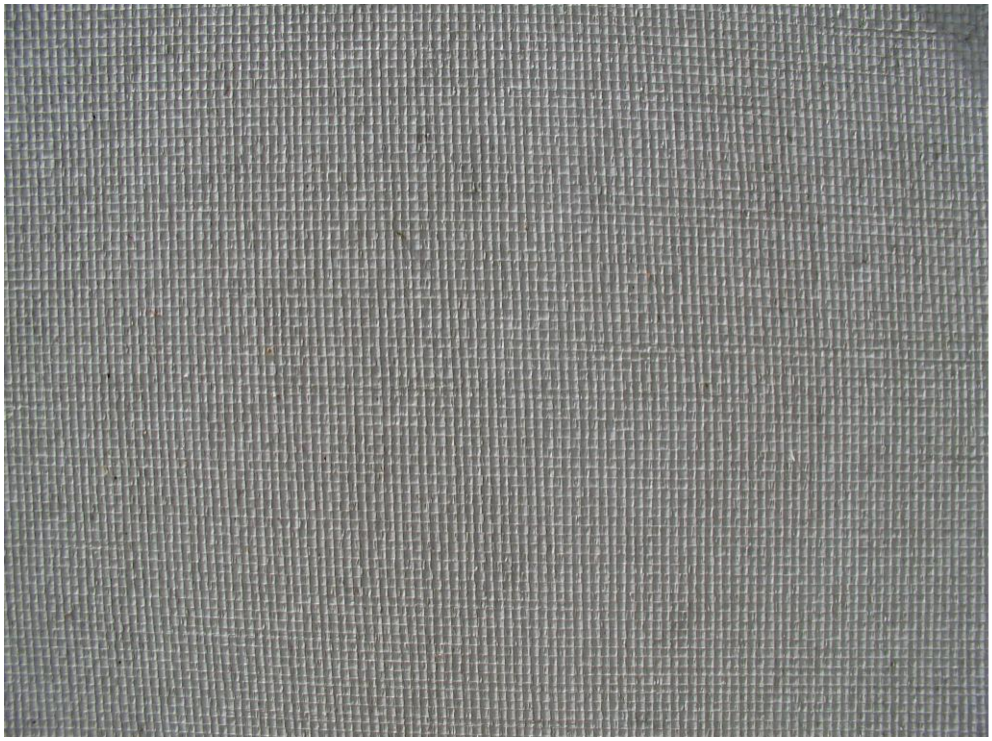


Figure 1: Close up view of the texture of a fabric formed concrete wall (C.A.S.T. 2008)

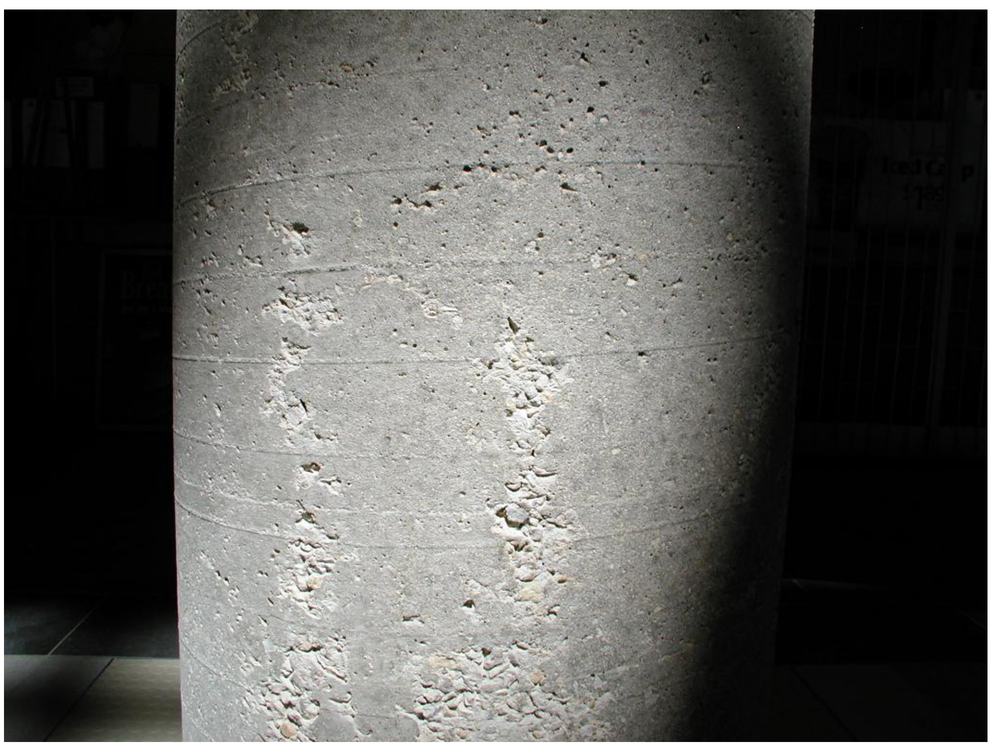


Figure 2: Bug holes and imperfections of a conventionally formed concrete column

Fabric formworks can be used to form columns, walls, beams, slabs and panels in both precast and in-situ construction. Fabric formwork can be simply built by construction connections and joints or can be sewn into any form, size, or shape on the job site or in the plant (Abdelgader et al. 2008). Fabric formwork is easy to use and build, very light and easy to transport, inexpensive as 1/10th of the cost of the conventional formwork, re-usable and therefore, environmentally friendly (West 2001). To provide a comparison base between the techniques, a cost analysis has been provided in Appendix A.

Although woven and non-woven fabric formworks are commercially available the effects of permeable fabrics on the quality of concrete has not been thoroughly investigated. This research is an experimental investigation of the change in concrete properties due to permeable fabric formwork using common and commercially available geotextile fabrics. Concrete close to the surface of a conventional formwork always has a higher water cement ratio than the core concrete (Malone 1999). Woven geotextiles used as forming membrane in fabric formwork technique have very small pores letting air bubbles and excess mix water bleed out, leaving a cement-rich paste at the surface of the concrete. This filtering action reduces the water cement ratio of the concrete at the surface zone and produces immaculate finishes unknown to other conventional methods of concrete construction. The low surface water/cement ratio in turn, makes the concrete more waterproof and causes less shrinkage and fewer cracks in the long term (Malone 1999).

1.1 Background and History

The first fabric formwork patents appear in the late 19th century. The first architectural and industrial use of fabric formwork was introduced in 1950s by Félix Candela who was famous for construction of reinforced concrete shells (Figure 3). Burlap fabric stretched over timber arches was the simple formwork he used to form ribbed, parabolic shells (Lee 2007).

Figure 3: Vault for a rural school in Tamaulipas, Mexico, designed by Felix Candela. (Faber 1963)

In the 1970's Spanish architect Miguel Fisac successfully used plastic sheets as formwork for textured wall panels. His technique was used to form architectural wall panels (Figure 4) in several buildings (Soler 1996).

Figure 4: Prefabricated cladding for a house formed with flexible formwork and white cement by Miguel Fisac (Arnardóttir and Merina 2008)

Further practical applications occurred in the mid 1960's with the introduction of fabric formwork for erosion control and pond liners (Figure 5). The efforts of E.W. Bindhoff (1982), B.A. Lamberton (1989), and others led to the first sustained commercial applications of fabric formworks.

Figure 5: River bank stabilization bags (Fabriform) installed in 1967 on the Allegheny Reservoir, New York (www.fabriform1.com 2009)

In the late 1980's a Japanese architect named Kenzo Unno, invented a system for fabric-shuttered walls (Chandler 2004). Around the same time, Richard Fearn, a builder and businessman in Canada, invented a number of fabric formwork techniques which developed into a series of foundation footing and column formwork products (www.fab-form.com 2009).

Also beginning in the mid 1980's, Mark West, architecture professor at the University of Manitoba invented a series of techniques for constructing fabric-formed walls, beams, columns, slabs, and panels. Research in the area of fabric formwork construction have been carried out at the Architectural Structures and Technology (C.A.S.T.) at the University of Manitoba, the first research centre dedicated to fabric formwork technology and education (C.A.S.T. 2008).

The first international conference on fabric formwork was held in summer 2008 in Winnipeg, Canada. At this conference the International Society of Fabric Forming (ISOFF) was formed. ISOFF has been created to communicate the work of researchers in fabric forming to manufacturers and concrete formwork industry (ISOFF 2008).

1.1.1 Previous Studies Using Permeable Rigid Formwork

In the civil engineering industry, two types of permeable formwork have been introduced, studied and used before. One technique is called permeable rigid formworks or drainage formliners and the other one is fabric formwork which is not a rigid mold.

Permeable rigid formworks or drainage formliners have an absorptive or permeable layer inside conventional rigid formwork (often a woven or nonwoven fabric) filtering air and water from the concrete at the mold surface. The surface of the concrete formed in permeable formworks is denser and stronger and has fewer imperfections than the same concrete formed in a conventional formwork without a drainage formliner (Malone 1999). Generally, with a conventional formwork, surface zone concrete has always more water than the concrete in the centre of the material mass. This high water-cement ratio at the surface, results in weaker and more permeable concrete (Reddi 1992). The bleeding phenomenon from a drainage formliner creates a filtering action which in turn, increases the concentration of fine aggregates close to the surface of concrete giving it a very fine finish and increased impermeability. X-ray radiographs have shown 10 percent higher cement to fine aggregate ratio in surface zone concrete cast in fabric formwork (Cron 1970). Marosszeky et al. (1993) reported a 70 percent increase in the strength of the surface concrete cast in permeable but rigid formworks as well as improved resistance to chloride ion penetration and a 100 percent increase in pull-off strength.

1.1.2 Previous Studies Using Fabric Formwork

Fabric formwork technique takes advantage of a non-rigid woven or non-woven fabric to form concrete. Bleeding characteristics of the available fabrics allow the extra water and air bubbles to bleed out from the formwork and reduce water-cement ratio at the surface of the concrete member. Koerner and Welsh (1980), reported a reduction in water-cement ratio of fabric formed concrete mats (made of woven nylon) used to control erosion and waves from 0.63 - 0.61 range down to 0.39 with no actual test on change in concrete compressive strength.

As seen in Table 1, Bindhoff et al. (1982) reported a 50 percent increase in cement grout compressive strength using the results from tests on cores from fabric formed pile jackets and companion specimens cast in conventional watertight molds. Bindhoff et al. used flyash in order to increase the waterproofing properties of underwater concrete. The work of Pildysh and Wilson (1983) found 50 to 100 percent increase in compressive strength of concrete due to fabric formwork. In their research, 152 by 305 mm (6 by 24 in.) hanging fabric socks were first vertically filled with grout under pressure and then a 152 by 305 mm (6 by 12 in.) test cylinder was cut out of the hardened mortar and compared to control conventionally formed samples. Pildysh and Wilson used 20 to 40 percent flyash was used in mortar mix design with only sand and no gravel.

Lamberton (1989) also showed a 50 percent increase in compressive strength in fabric formed concrete. In these tests, 139 by 305 mm (5.5 by 30 in.) fabric socks were cast vertically under 69 kPa injection pressure and then 152 by 305 mm (6 by 12 in.) cylinders were cut from the middle section of the hardened specimen. 5 to 10 percent stretch in the fabric used was considered when the initial 5.5 inch sock diameter was selected. Cement mortar was used to cast fabric formed cylinders using Portland cement and sand without of gravel.

Table 1: Previous studies using permeable fabric formwork

Authors	Year	Place	Mix Design	Flyash (%)	w/c Ratio	Type of Fabric	Test Type	Strength Increase Measured (%)
Eduardo W. Bindhoff	1982	USA	Grout	15	0.41 to 0.50	Woven Nylon	Does not clearly explain	50
Mikhail Pildysh & Ken Wilson	1983	Canada	Grout	25 to 40	0.46 to 0.65	Synthetic	6" by 24" fabric socks	50 to 100
Bruce A. Lamberton	1989	USA	Grout	No Flyash	0.65 to 0.72	Synthetic	6" by 24" fabric socks	50
Mahdi Al Awwadi Ghaib & Jaroslaw Gorski	2000	Poland	Concrete	No Flyash	0.57 to 0.83	Woven Poly-propylene	100 by 100 by 100 cubes (mm)	70
F. Delijani, M. West, D. Svecova	2010	Canada	Concrete	30	0.37	Polypropylene Geotextile	4" by 8" Cylinders	13 to 17

Ghaib and Gorski (2001) used four textile mattresses (made of woven polypropylene) filled with concrete mixes with different slump values. Total of 232 samples of 100 mm cubes were cut out from the hardened concrete mattress by electric saw and then compared to a series of 100 mm cubes control samples. Analysis of the compression strength tests showed up to 70 percent increase in compressive strength at the age of 28 days. It was found that the compressive strength of the concrete cast in fabric was a function of the pore size of the fabric used. In general, the compressive strength of fabric-formed concrete decreased as the pore sizes increased more than 0.35×10^{-3} m.

1.2 Objectives and Scope

The present research study was designed to re-evaluate the change in concrete properties due to fabric formwork and to evaluate the applicability of the ASTM standard for testing fabric formed cylinders.

The need for conducting such research became essential for several reasons: test methods used in former fabric formwork studies were not compatible with any specific standard testing method, all but one previous study used cement grout instead of concrete, and all previous studies used relatively high water cement ratio mix designs except Al Awwadi Ghaib et al. (2000). Although Awwadi Ghaib et al. (2000) used woven polypropylene fabric the specific type of fabric they used is unspecified.

Taking advantage of the work done in C.A.S.T. and years of using different types of available fabrics and geotextiles to form concrete, The Geotex 315ST geotextile (formerly named Propex 2006) was chosen for use in this research study. In full scale construction tests, Geotex 315ST showed good mechanical properties as a formwork fabric. It created a very good texture when exposed to cement mortar or fresh concrete. It is also one of the less expensive fabrics available among Geotex products. This geotextile is a woven “structural” fabric made of ultraviolet (UV) resistant polypropylene fibre with sufficiently high tensile strength in both warp (yarns running the length of the fabric) and weft (yarns running across the width of the fabric) weave directions.

Although mechanical properties and practical workability of Geotex 315ST were known to us, the change in overall quality of the concrete was undefined. The knowledge of change in concrete properties due to fabric formwork was limited to a few research studies available, claiming up to hundred percent increase in concrete’s compressive strength when cast in different types of fabrics (Bindhoff and King 1982). The need for conducting such research became essential when the methods used in former fabric formwork studies were not compatible with any specific standard testing method. The scope of this project is limited to two types of Geotex geotextile fabric and two types of concrete; Normal concrete (NC) and flyash concrete (FAC).

There are no ASTM or Canadian standards for forming fabric formed laboratory test cylinders, but the type of mold used in this research study provides some basis for testing and comparing the quality of concrete cast in fabric molds. Compared to the “sock” technique (Lamberton 1989) or the “mattress” technique (Ghaib and Gorski 2001) used in previous research testing, the test procedure proposed in this thesis is attempting to be close to conventional cylinder casting as recommended in ASTM C39/C39M-04a (2004). The method provides more practical comparisons for structural applications. Compressive strength of all cylindrical concrete specimens was determined on the basis of the standard test method (ASTM C39/C39M-04a 2004).

The mix design in this study was selected in order to simulate an everyday-use general concrete quality. Compressive strenght of 30 MPa (at 28 days) was selected as the average strength range to satisfy the above mentioed condition. The mix design used in this research (Table 2) was adopted from Mindess et al. (2003). Expected average 28 days compressive strength was 30 MPa with the slump value between 75 and 100 mm. The properties of the material were as follows:

- **Cement:** Type I (produced by Lafarge Canada)
- **Fine aggregate (Sand):** Average absorption capacity = 1.38% (as measured in the lab).
- **Coarse aggregate:** Maximum size = 19mm (3/4 in.), river gravel (round corners), average absorption capacity = 1.25% (as measured in the lab).

Table 2: Mix design for normal concrete

Material	Mix proportions [kg/m^3]
Water (kg)	147
Cement (kg)	400
Gravel (kg)	1023
Sand (kg)	693
Total (kg)	**2263**
w/c	**0.37**

Based on proportions expressed in Table 2, water-cement ratio in this mix design was found to be 0.37 which unlike former studies described in Table 1, is a relatively low. For flyash concrete, 30 percent of the cement in the ordinary concrete mix design was replaced with type C flyash (Table 3).

Table 3: Mix design for flyash concrete used

Material	Mix proportions [kg/m^3]
Water (kg)	147
Cement (kg)	280
Type C Flyash (kg)	120
Gravel (kg)	1023
Sand (kg)	693
Total (kg)	**2263**
w/cementitious materials	**0.37**

Chapter 2

Selection of Fabrics

2.1 Choice of Fabrics

Use of geosynthetics in civil engineering industry started as early as 1950's in the United States. More research and development on geotextiles was also conducted in the Netherlands, Britain and Germany (Bruun 2000). Geotextiles can be either woven or nonwoven fabrics. There are over 100 different applications for the use of geotextile fabrics in civil engineering industry (Suits 1991). The material used in the fabrication of geotextiles is normally a type of polymer. Polymers generally used in the geotextile industry consist of PE (Polyethylene or Polythene), PP (Polypropylene), PVC (Polyvinyl Chloride), PET (Polyethylene Terephthalate), PS (Polystyrene), PA (Nylons), and Cellulose (Bokuniewicz 2005).

Woven PP and PE are produced with high tensile strength and low elongations. They have high capability for filtration and distribution of load and manufactured from individually woven, ultraviolet (UV)-resistant Polypropylene fibers (Propex 2006). Geotextiles are produced as non-coated or coated using a layer of PE. Geotextiles are widely available in the market and their price rage varies between 1 to 1.6 Canadian dollar per square meter (10 to 15 Canadian cents per square foot) (Brock White Company 2009). The main use of Geotextiles is the stabilization of soil but some builders, architects and researchers have adopted them to be used as formwork for concrete.

In 1960 Felix Candela used burlap (jute) to form his concrete shells (Faber 1963). A decade later, Miguel Fisac used plastic sheets as fabric formwork and in 1980's Bindhoff (Bindhoff and King 1982) and Lamberton (Lamberton 1989) used Nylon fabrics. PE and PP woven fabrics became commercially available in mid 1980's. Use of PE and PP woven fabrics as formwork for concrete was introduced in late 1980's by Mark West and Richard Fearn more or less at the same time along with Kenzo Unno who used a plastic construction scaffolding netting as concrete formwork.

Specific brand name of Geotex geotextile was considered as the production line of choice in this research study for two reasons. This product was available in Winnipeg with a very low price of about one Canadian dollar per square meter (10 cents per square foot) (Brock White Company 2009) and has been used for projects at C.A.S.T. over the last couple of years. Of course, future studies could be conducted studying other products available worldwide, many of which share similar, if not identical, properties as those produced by Geotex.

In order to study specific effects on concrete strength and quality obtained by using commercially available woven polyolefin fabrics or geotextiles, it was necessary to form concrete cylinders using a variety of fabrics and concrete mix designs. A fabric used as concrete formwork must be strong enough to carry the hydrostatic pressure and the hoop tension imposed by wet concrete. In addition, it should be adequately porous to allow discharge (bleeding) of the excess mix water from the fresh concrete while preventing the loss of solid elements (fines) particularly cement and flyash particles (Lamberton 1989).

To reduce the number of samples to a manageable number, a test was designed to determine the bleeding characteristics of the woven fabrics available in the Geotex catalogue and hence their suitability for formwork. Fabrics with a tendency of allowing cement paste bleeding were not desirable. Nine types of available structural, woven fabrics were installed at the bottom of a wood box over separate openings. Plastic containers were placed underneath each fabric sample to collect the water and cement paste residue that would bleed through the fabric (Figure 6). All fabrics used in this research study are polypropylene woven monofilament calendered (a process in which rolls of textile are passed through pairs of hot rollers to give them a shiny surface) and stabilized to resist degradation due to ultraviolet exposure.

Fabric samples provided by Geotex Fabric Incorporation were available in 100 by 150 mm pieces. This, in turn, dictated the dimensions of the openings of the wood box. Nine available fabric samples were sandwiched between two 900 by 300 mm half inch ply-wood sheets. The samples were carefully attached by staples to the plywood and sealed with caulking in order to prevent cement paste bleeding out from the seams (Figure 7).

The surface of the plywood was fully covered with a waterproof tape (duct tape) in order to prevent plywood from absorbing any water from the concrete. This also helped the hardened concrete to be easily released from the box. The need for releasing the hardened concrete was considered so that the imprint of the fabrics created on surface zone of the concrete could be studied later on to evaluate the surface appearance of the castings(s).

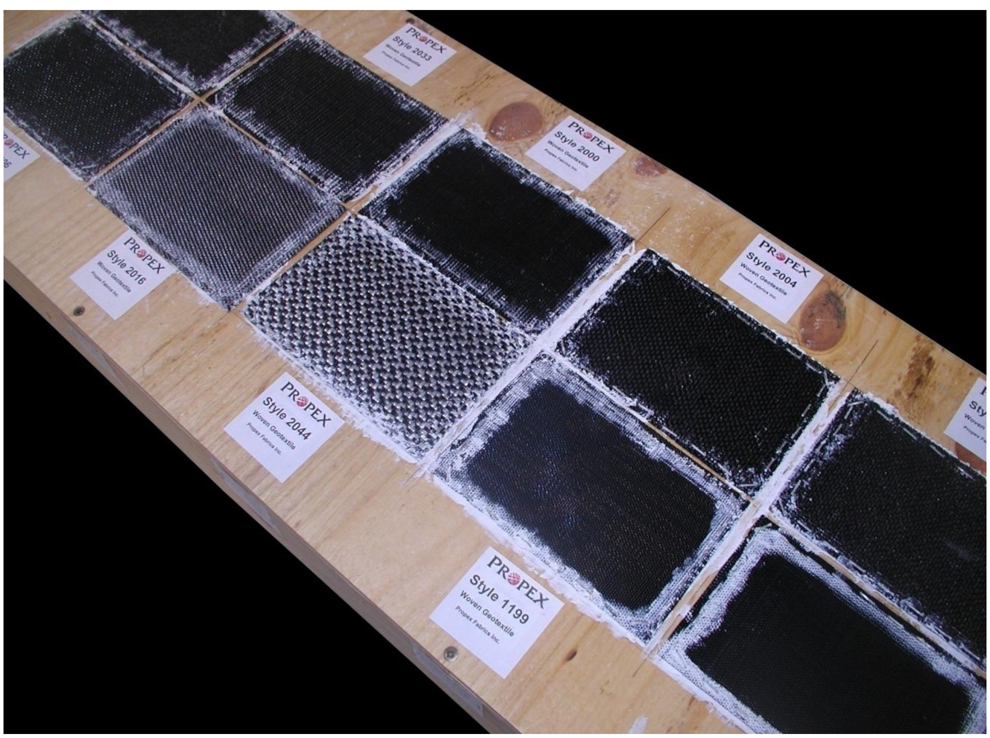


Figure 6: Installing fabric samples on plywood grid and sealing the corners

Labelled plastic containers were installed under the box (Figure 8) to collect bled water and cement paste. The weight of the empty plastic containers was recorded first and weighed again after the bleeding of the concrete had stopped; the difference was the weight of the bled water and cement paste. Collected bled materials were then left to dry and reweighed to determine the amount of water and cement in the paste respectively.

Figure 7: Top and bottom parts of the box test

2.2 Fabric Tests Using Normal Concrete

Fresh concrete was poured inside the box (Figure 9) and then vibrated. Some pressure (46 kg, using the available weights) was applied to accelerate the bleeding process (Figure 10).

Figure 8: Box made for Box Test using normal concrete

Figure 9: Filling the box with fresh concrete

As soon as the bleeding stopped, a comparison was made between individual fabrics using the weights of the collected water and cement paste that bled through each fabric (Figure 11).

Figure 10: Extra pressure on fresh concrete to accelerate the bleeding process

Figure 11: Collected bleed cement/water paste from fabrics tested with normal concrete in the box test

The amount of water and cement passed through each fabric sample were very close to each other. Therefore, to be able to choose suitable fabrics for future tests, we examined separately the amount of passed cement or water separately as well as the surface quality of the concrete.

As seen in Figure 12, the least amount of bleeding occurred with Geotex 315ST. Geotex 106F (previously known as Propex 1198) on the other hand, had the maximum bleeding ratio in both water and cement. Visual inspection of the hardened concrete taken out of the box concluded that Geotex 315ST had the best texture produced with the least amount of air holes and overall imperfections. Geotex 106F showed lack of fine aggregate on the surface and a porous surface (Figure 13).

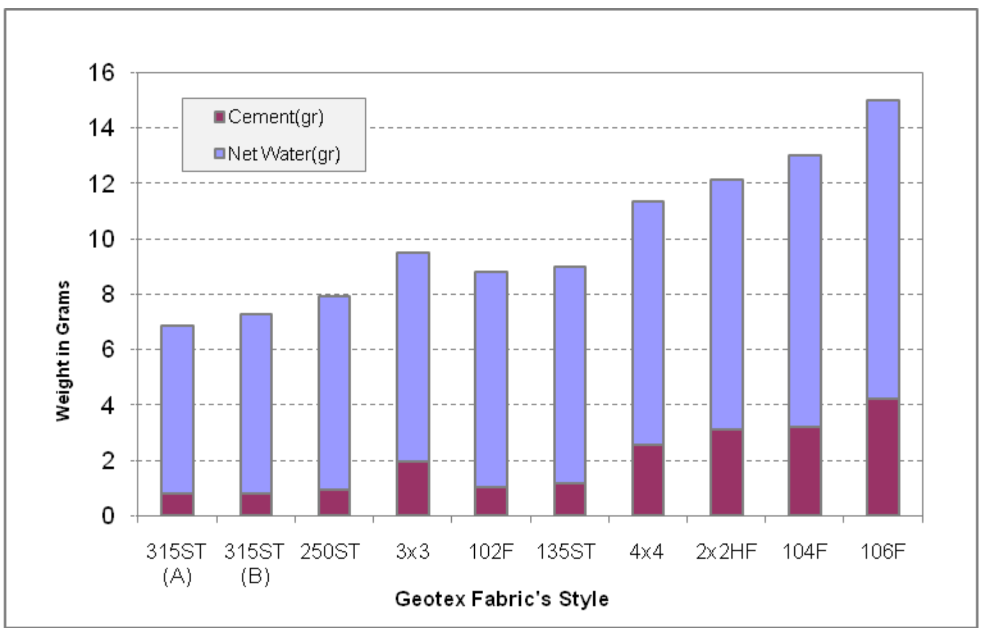


Figure 12: Results from normal concrete box test

Since selecting two types of fabric representing the least and the most bleeding was the target, two fabrics of Geotex style 315ST and 104F (previously named Propex 1199) were selected. Geotex 104F was selected instead of Geotex 106F because it bled less cementitious material while it had large amount of bleed water. Table 4 and Table 5 provide the mechanical properties of both selected fabrics in detail.

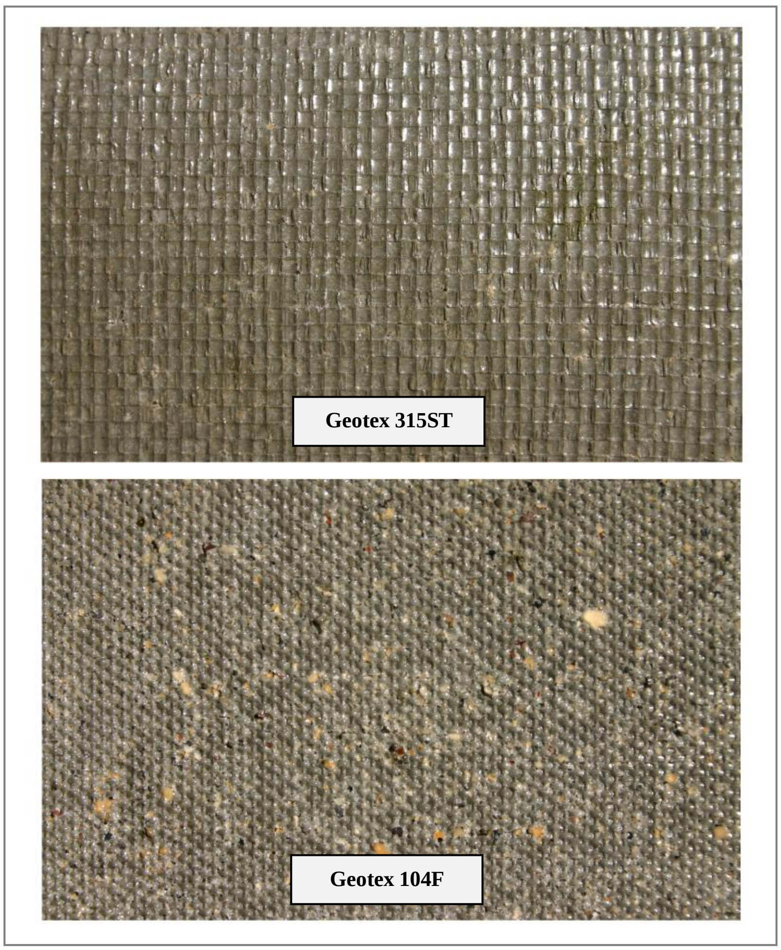


Figure 13: Comparison between the textures produced by different fabrics

Table 4: Mechanical properties of Geotex 104F (Propex 2006)

Property	Test Method	Minimum Average Roll Value [English]	Minimum Average Roll Value [Metric]
Grab Tensile	ASTM-D-4632	370/250 lbs	1.64/1.11 kN
Grab Elongation	ASTM-D-4632	16%	16%
Mullen Burst	ASTM-D-3786	480 psi	3300 kPa
Puncture	ASTM-D-4833	120 lbs	0.533 kN
Trapezoidal Tear	ASTM-D-4533	100/60 lbs	0.445/0.265 kN
UV Resistance	ASTM-D-4355	90 % at 500 hr	90 % at 500 hr
AOS (max. average roll values)	ASTM-D-4751	70 sieve	0.212 mm
Permittivity	ASTM-D-4491	0.3 sec^{-1}	0.3 sec^{-1}
Flow Rate	ASTM-D-4491	22 $gal/min/ft^2$	895 $L/min/m^2$
% Open Area	CWO-22125	5%	5%

Table 5: Mechanical properties of Geotex 315ST (Propex 2006)

Property	Test Method	Minimum Average Roll Value [English]	Minimum Average Roll Value [Metric]
Grab Tensile	ASTM-D-4632	315 lbs	1.40 kN
Grab Elongation	ASTM-D-4632	15%	15%
Wide Width Tensile	ASTM-D-4595	175/175 lbs/in	30.7/30.7 kN/m
Wide Width Elongation	ASTM-D-4595	15/8 %	15/8 %
Mullen Burst	ASTM-D-3786	675 psi	4650 kPa
Puncture	ASTM-D-4833	150 lbs	0.667 kN
Trapezoidal Tear	ASTM-D-4533	120 lbs	0.533 kN
UV Resistance	ASTM-D-4355	70 % at 500 hr	70 % at 500 hr
AOS (max. average roll values)	ASTM-D-4751	40 sieve	0.425 mm
Permittivity	ASTM-D-4491	0.05 sec^{-1}	0.05 sec^{-1}
Flow Rate	ASTM-D-4491	4 $gal/min/ft^2$	160 $L/min/m^2$

2.3 Fabric Tests Using 30% Flyash Concrete

There are reports on fine additives such as Silica fume having the tendency to clog filter fabrics associated with permeable rigid formworks or drainage formliners (Malone 1999). Mixes of normal concrete on the other hand, have not shown any significant blockage in the formwork liner (Nolan et al. 1995). Generally, particles of a typical silica fume are smaller than 1 micron (Malhotra and Carette 1982) while the average diameter of a typical cement particle is approximately 10 μm (Kosmatka et al. 1995). The size of the spherical particles of the fly ash ranges between 10 and 100 micron (FHWA 2003).
Herein, another experiment was conducted to observe if flyash particles are able to clog the pores of the fabrics used in this research study. Using the two selected fabrics from the first box test, a second box was made and new experiment (Figure 14) was conducted with 30% type C flyash added to the mix design.

Similar to the first box test, bled water and cement paste from the fabrics were collected in containers and weighed in wet and dry form to measure the amount of water and cementitious materials bled through the two fabrics. Since only 6 pieces of fabric were installed in this box (three samples of Geotex 315ST and three samples of Geotex 104F), individual samples had a larger area exposed to the fresh concrete. Therefore, before deriving the results, corrections were applied to the areas to make the results consistent with the first box test results.

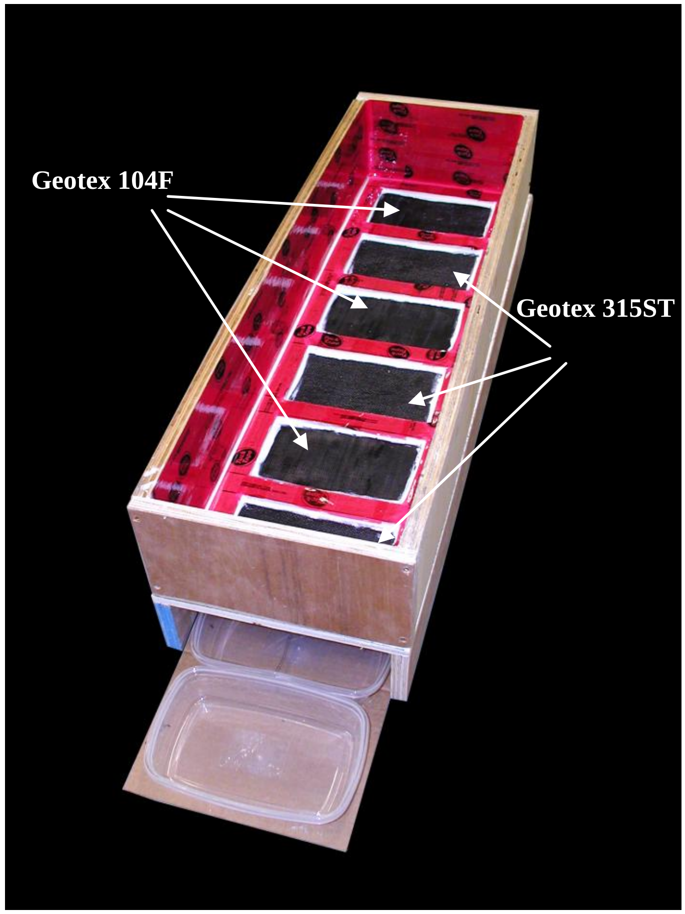


Figure 14: Box made for Box Test 2

2.4 Results

As seen in Figure 15, each fabric bled almost the same amount of cementitious material when exposed to normal concrete and flyash concrete. Both fabrics bled less water when exposed to flyash concrete meaning that some clogging happened when cementitious paste tried to pass through the fabric. It is hypothesized that this is caused by the increase in the amount of very fine particles in the flyash mix.

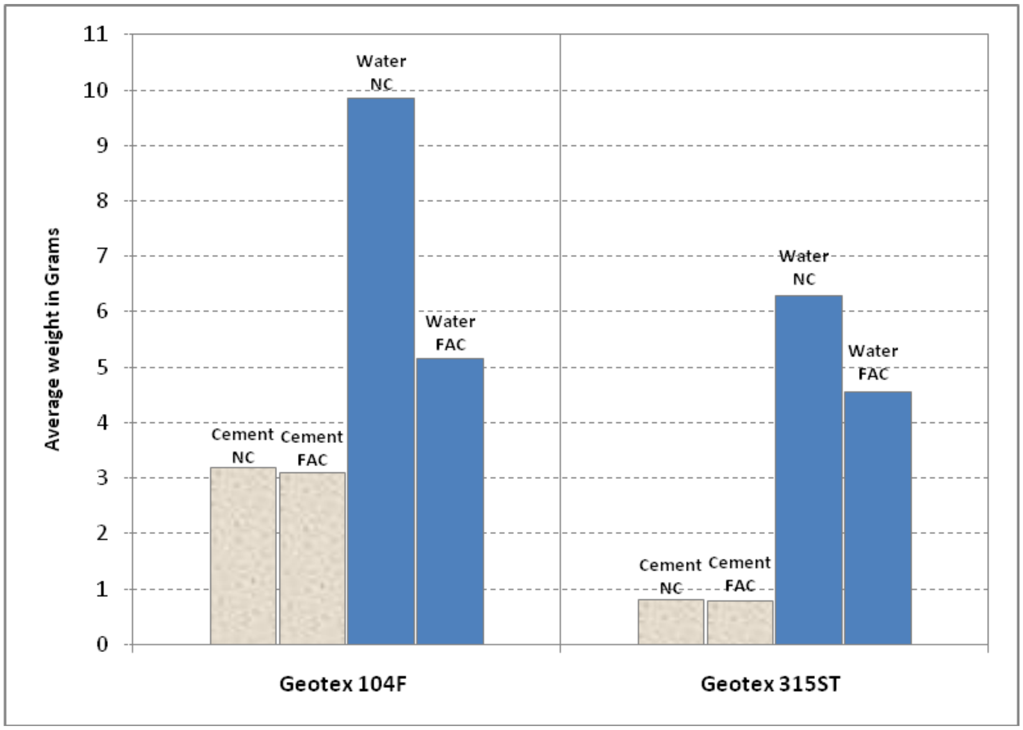
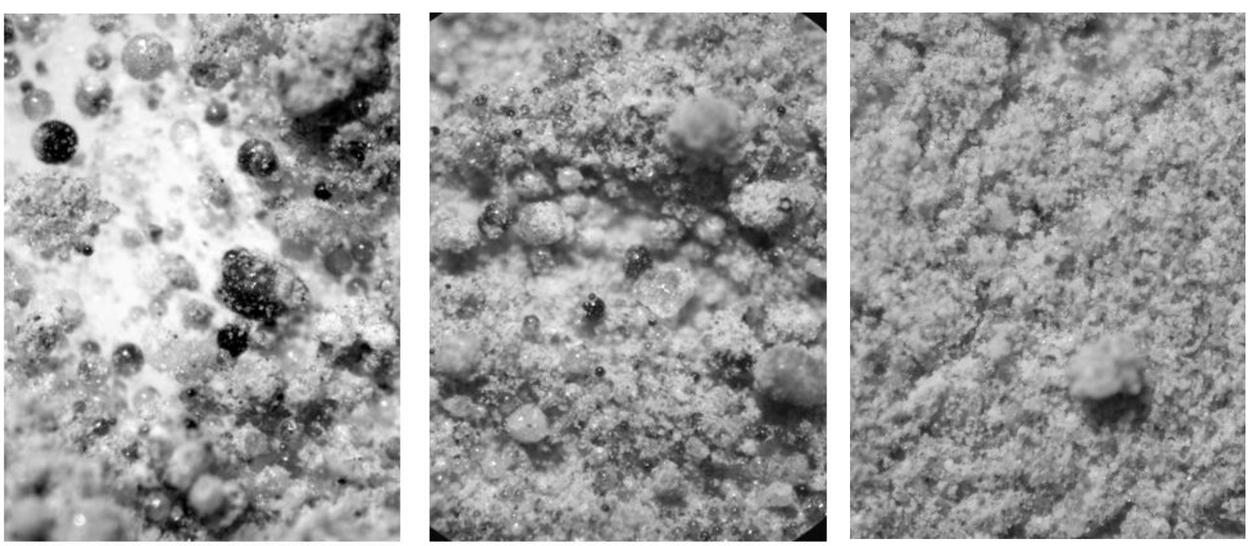


Figure 15: The effect of flyash on the amount of bled water and cementitious material

In order to investigate characteristics of collected dried cementitious material from this experiment, dry bled paste powder was examined under a stereoscopic zoom microscope (Nikon SMZ800) using maximum magnification of 378x to observe if flyash bled through the fabrics. Dried passed cementitious material was set under the microscope and the visual results were compared to both pure flyash and pure cement. Based on observations, Geotex 315ST did not bleed any flyash at all while Geotex 104F which has larger pores let a small amount of flyash bleed out (Figure 16). As seen in Figure 15, Geotex

315ST bled much less cementitious material compared to Geotex 104F which is caused by the size of its openings and their potential clogging by flyash particles.

Additionally, when exposed to flyash concrete, Geotex 104F bled much less water comparing to the time when normal concrete was used. Since the amount of passed cementitious material that passed through each fabric in both normal and flyash concrete was constant, the amount of bleeding water became a definitive factor in this comparison test. When flyash concrete was used, Geotex 104F showed about 48% reduction in amount of bled water (from 9.85 gr down to 5.15 gr) compared to water bled from normal concrete. While Geotex 315ST showed only 27% reduction in bled water (from 6.28 gr to 4.56 gr) due to clogging effect. This indicates that Geotex 104F is susceptible to clogging when flyash concrete is used. Compared to its use with normal concrete, Geotex 104F looses less water and air bubbles when exposed to flyash concrete. Consequently, when flyash concrete is the concrete of choice, use of textile with smaller openings is recommended.



a) Pure Flyash with different sizes of flyash beads

b) Material bled from Geotex 104F showing some flyash beads along with the fine aggregates (mostly cement)

c) Material bled from Geotex 315ST with almost no flyash beads

Figure 16: Microscopic pictures comparing bleed-dried cementitious material from different fabrics to pure flyash

Chapter 3

Placing and Handling of Fabric Formed Concrete

3.1 Depth of Bleeding Effect

Mix water bleeding through the fabric pores is the major cause affecting concrete quality cast in fabric or permeable formworks. Investigations on permeable formwork liners have shown that the effect of bleeding is limited only to a few tens of millimetres of the surface of the concrete (Malone 1999). In the present study, fabric formed concrete cylinders were cast with diameters varying from 100 mm in increments of 50 mm, to 250 mm to study if there was any change in cement or fine aggregate concentration close to the surface of the specimens in order to study the depth of the fabric formwork's effect on the concrete as a function of diameter of the cylinders.

Molds were first made and cylinders were cast using a 30 MPa normal concrete. Hardened samples were all vertically cut in half, polished and sections of the specimens were studied visually and using a microscope. In all sizes, no visual concentration of cement/fine aggregates was seen and all sections had the same texture throughout. The presence of sectional large aggregates in the visual field made visual determination difficult. No relationship between the size of the cylinder and the bleeding depth could be determined in this test.

3.2 Fabrication of Fabric Molds

A simple formwork was designed and built to form concrete cylinders using fabric. In order to do so, the fabric needed to be cut to size. Woven geotextiles can be cut using scissors or a knife edge though edge fraying may occur. To avoid edge frying, fabric pieces were cut using a soldering gun. A blade-shaped tip and an aluminum straight edge were used to be able to follow straight lines when cutting (Figure 17 and Figure 18). By using a soldering gun to cut the fabric by melting, the fraying problem was completely avoided and sharp, straight edges were provided for the fabric samples. Cut fabrics were then sandwiched and bolted between two pieces of plywood. Plywood pieces were made wide enough to support and hold the fabric in between and resist the possible tension created in the fabric mold due to the hoop pressure created by the fresh concrete.

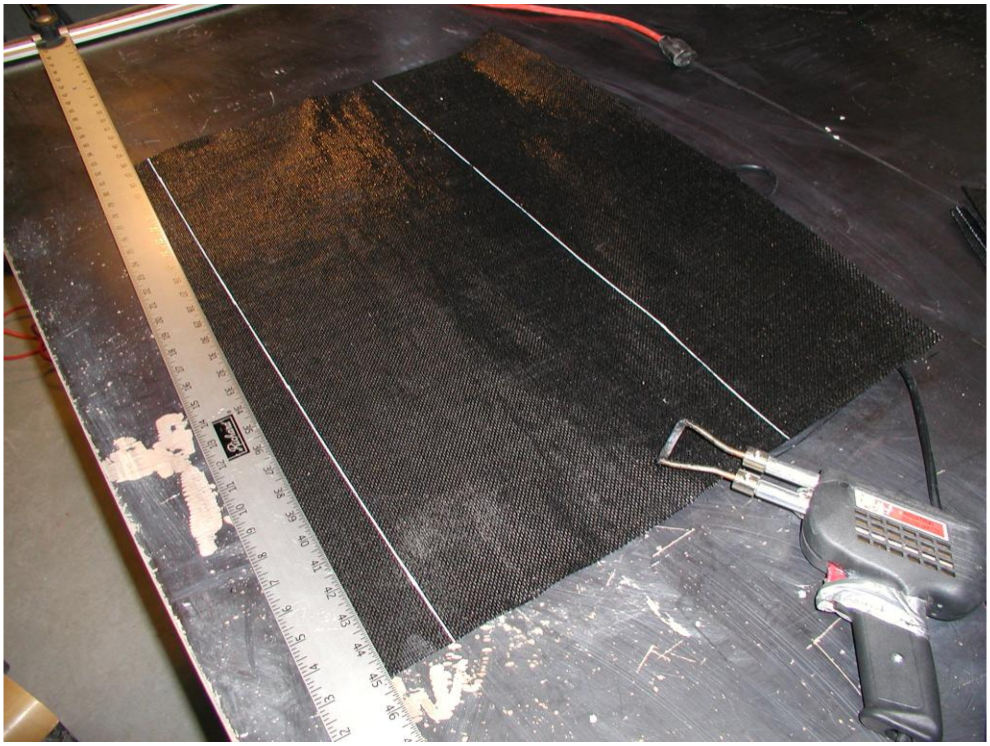


Figure 17: Tools used to cut fabric

Figure 18: Soldering gun with the blade-shaped tip melting fabric and providing straight edge

The height of the cut fabric and the plywood pieces were the same as the height of the desired 305 mm (12 in.) concrete cylinder (Figure 19). The length of the fabric piece was also measured to have enough room in between the plywood pieces and to create the necessary diameter for the hardened concrete cylinder. A wood base and two supports were also added to the forms to avoid possible movements of the mold during the casting (Figure 20).

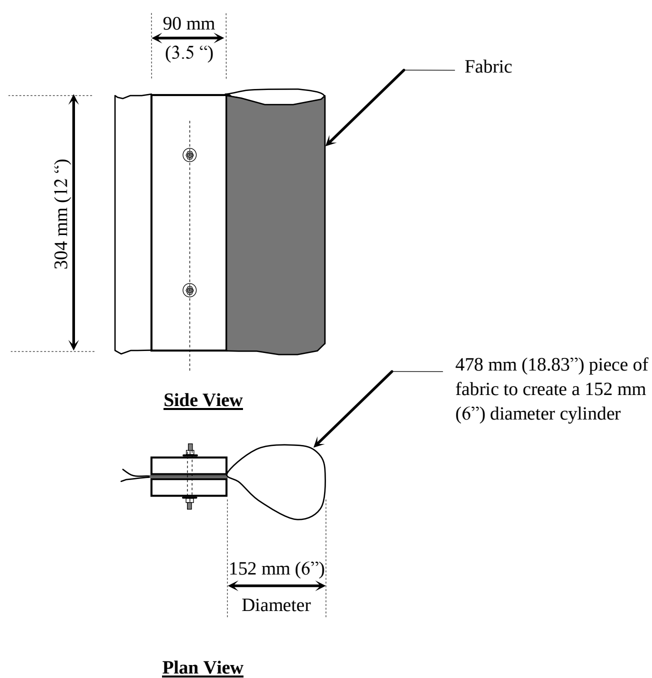


Figure 19: Details of fabric mold for concrete cylinders

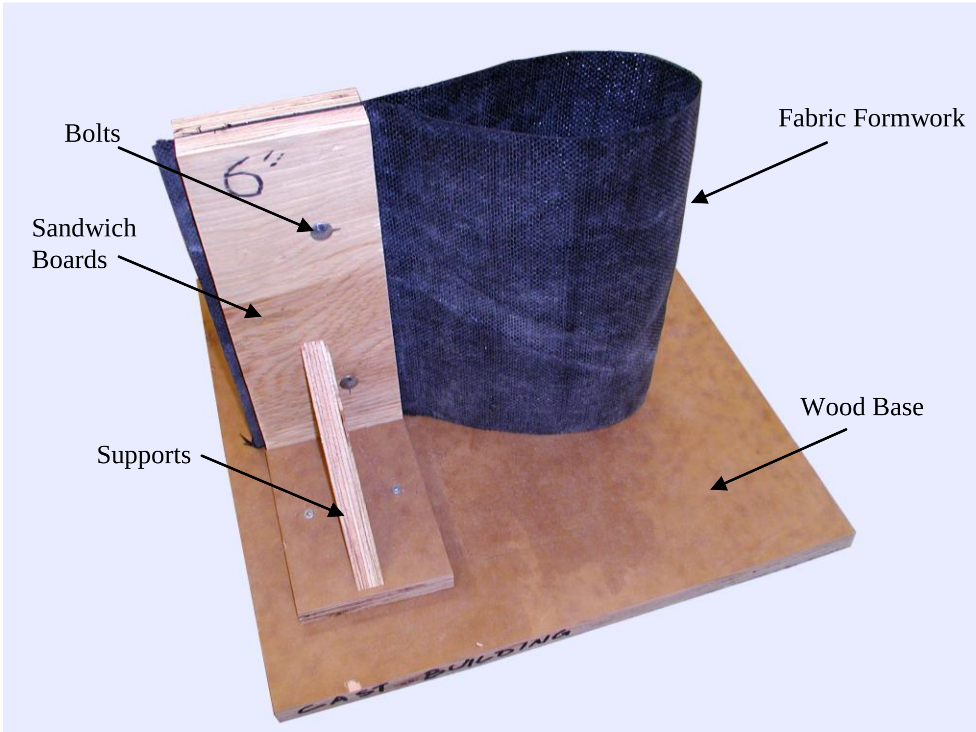


Figure 20: Actual fabric formwork for 152 by 305 mm (6 by 12 in.) concrete cylinders

The bottom of the fabric forms could be left free as is done in commercial applications of the fabric-formed column molds (Fab-Form Industries Ltd. 2009). The bottom of the fabric mold need only be held by hand when the first scoop of fresh concrete is placed inside the mold, after which the rest of the concrete can be poured in with no problem. Tapping the walls of the fabric formwork acts as vibration and helps start the bleeding of the air bubbles and water from the concrete. In order to comply with the existing cylinder casting standard (ASTM C39/C39M-04a 2004), when pouring, samples were compacted in three layers using the standard compacting rod (Figure 21). Although an empty fabric form does not have any specific shape, the hydrostatic pressure created by the fresh concrete forms a perfect cylinder once it is poured inside the fabric mold (Figure 22). Figure 23 shows the bleed water within the first 45 minutes after casting.

Figure 21: Compacting fresh concrete using the standard rod

Figure 22: Fabric mold filled with fresh concrete

Figure 23: Bleed clear water from the walls of a 152 mm (6 in.) diameter fabric-formed concrete cylinder

When it was time for specimens to be taken out of their molds, the bolts were removed. Since polyethylene and polypropylene fabrics do not create any adhesion between the fabric and hardened concrete, there is no need for releasing oils and the fabric could be easily stripped off from the surface of the hardened concrete (Figure 24 and Figure 25).

3.3 Bleeding Tests

The relationship between bled volume of water and height in a concrete column was studied to see the effect of position along the height of the column on the amount of bleeding.

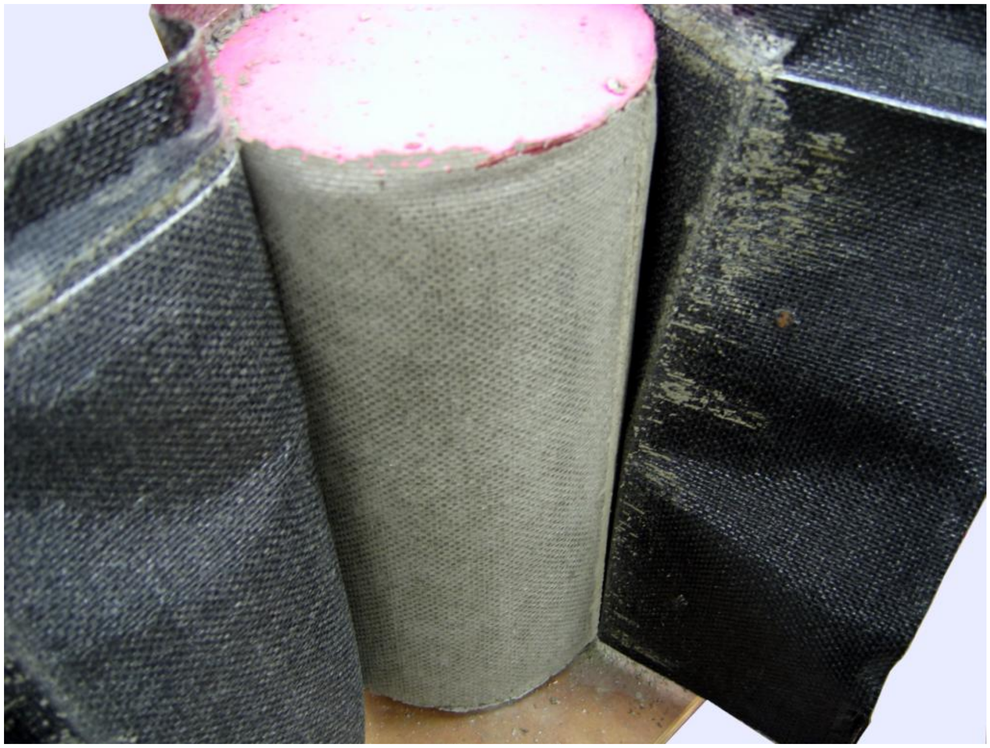


Figure 24: Stripping fabric from a fabric formed concrete cylinder

Figure 25: Reusable fabric form parts; the base, sandwich boards, bolts, and the fabric itself

It could be hypothesized that the amount of bleeding along the height of a fabric formed column varies as a function of location along the column's height (Figure 26). In order to establish this relationship, pressure applied to the bottom and middle of the columns due to self-weight of normal density concrete was simulated by using a mechanical press.

The mechanical press apparatus was designed and fabricated in the laboratory and calculations shown in Appendix B were made to find the load necessary to simulate the pressure at various heights along a 3 meters tall column's length and apply it to both PVC and fabric formed specimens using an adjustable lever handle. HSS 38 by 38 mm steel square and L shape profiles were used to build the apparatus. As shown in Figure 27, each mechanical press apparatus was designed to have two handles in order to pressurize two cylinders at the same time.

A set of 54 samples of 152 by 305 mm (6 by 12 in.) were made and tested to investigate an assumed linear relationship between height of a column and the bleeding ratio. This series of samples (Table 6) were cast and the bleeding water was measured to find if the bleeding ratio along the height of a column.

Table 6: Series of tests studying changes in bleeding/strength of a fabric formed concrete column through its height

Mold Type	**Geotex 315ST**			**Geotex 104F**			**PVC Mold**		
Pressure Applied	No	Yes		No	Yes		No	Yes	
Height of Column	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Number of Cylinders [Normal Concrete]	3	3	3	3	3	3	3	3	3
Number of Cylinders [Flyash Concrete]	3	3	3	3	3	3	3	3	3

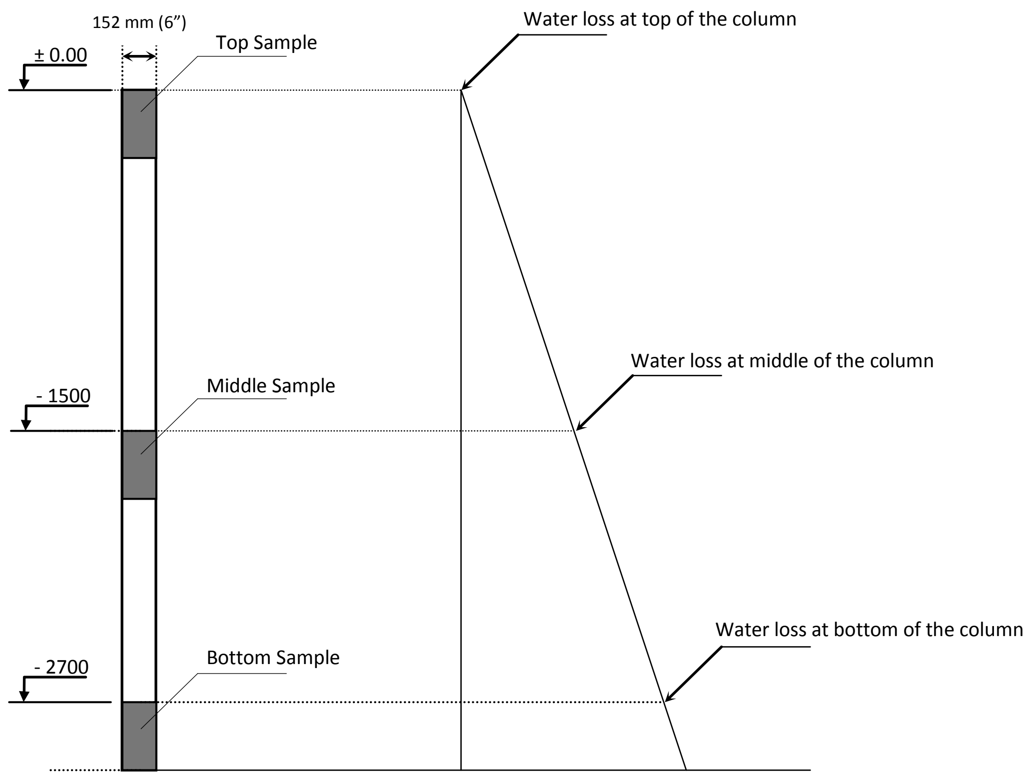


Figure 26: Assumed linear relationship between the height of a column and the water loss of the fresh concrete

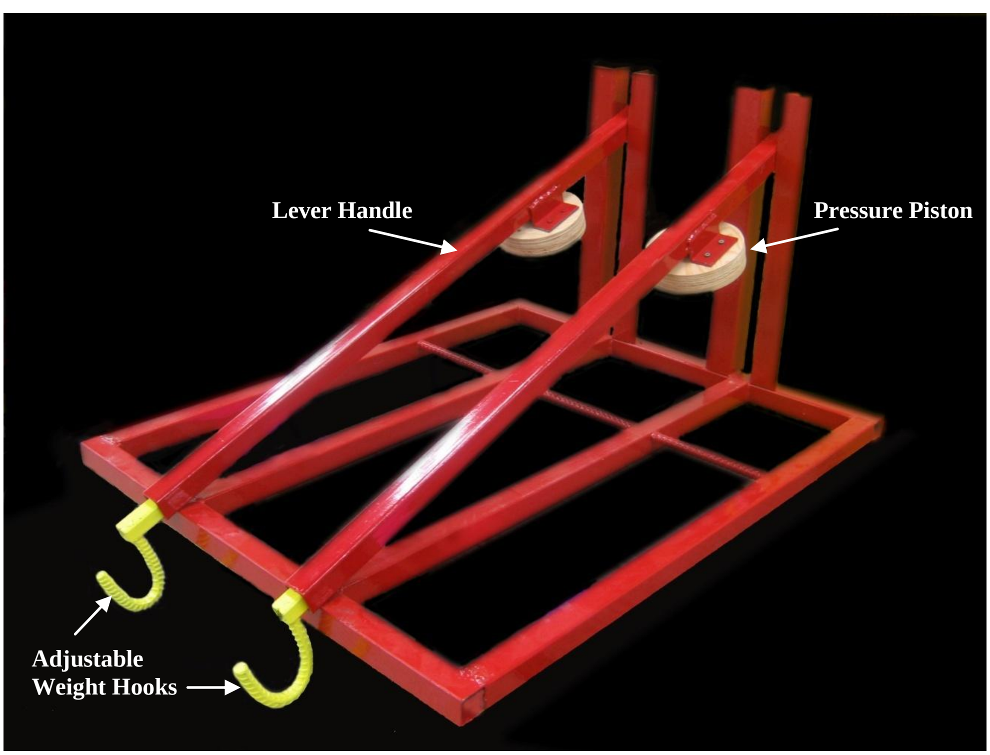


Figure 27: Finished Press machine

The variables in this test were fabrics Geotex 104F and 315ST in both pressured and unpressured molds, 30 MPa concrete with and without flyash (Type C) and plastic (PVC) molded samples as control specimens in pressured and unpressured molds. Fresh concrete was first poured and compacted into the fabric and PVC (control) molds. Lever handles were then slowly brought down and wooden pistons were adjusted over the top of the fresh concrete sample. A circular plastic sheet was cut and put in between the concrete and the piston in order to block any possible water absorption by the wooden pistons and to ease the release of the piston from the hardened concrete. Calculated weights were gently hung on the adjusted hooks (Figure 28) and bleeding water collection started immediately afterwards.

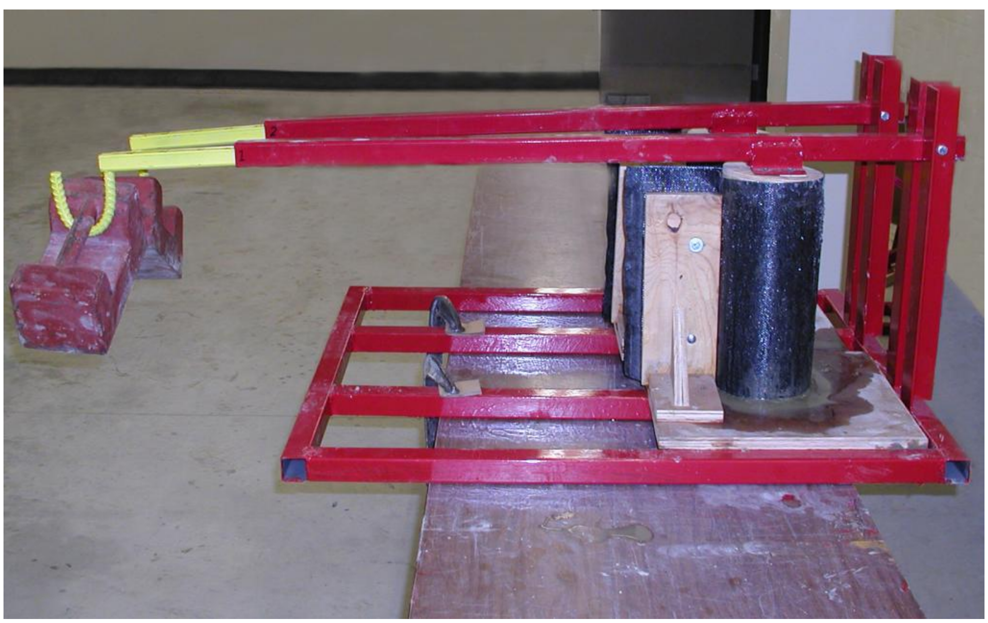


Figure 28: Bleeding test in progress

Bled water was carefully and constantly collected using absorbent paper sheets, as shown in Figure 29. These wet papers were kept in plastic bags in order to avoid water evaporation during the test. Following the test plastic bags were weighed full and empty and values were recorded. Paper sheets were then dried in the oven of 24 hours at 50°C and then weighed to find the amount of the water bled from each specimen.

Generally, bleeding liquid from the fabric formwork was thick and cloudy for the first few minutes and then it became very clear. The heavier loads initiated the bleeding process sooner. When higher pressures were applied to the specimens, bleeding volume was larger but the bleeding time was shorter.

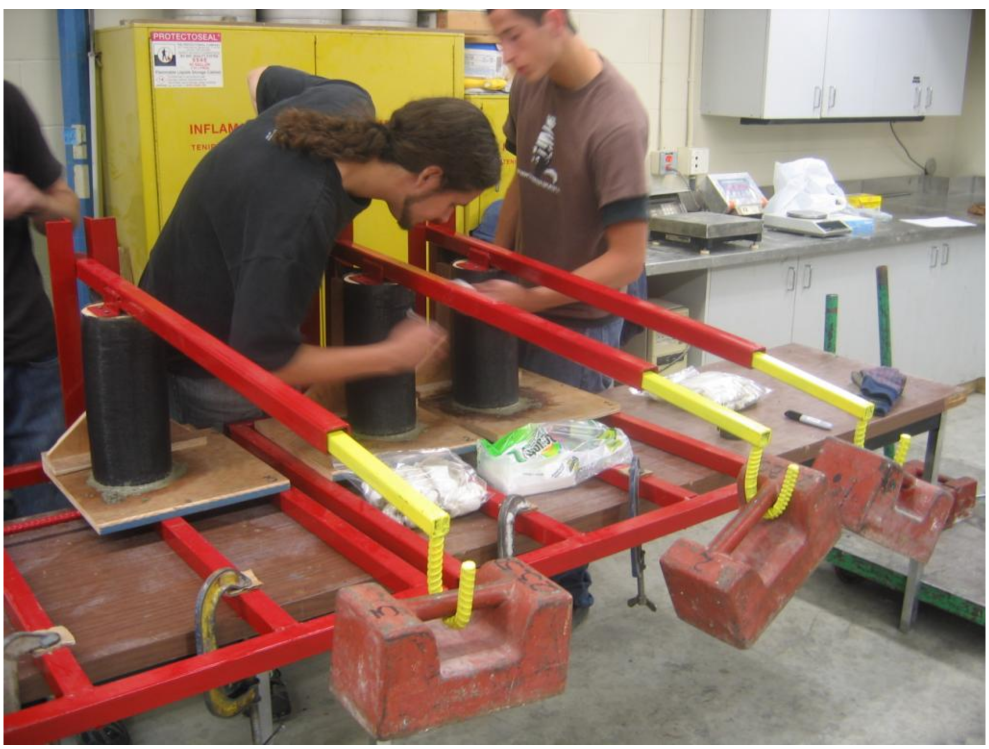


Figure 29: Collection of bleeding water during the bleeding test

3.4 Test Results

Figure 30 shows the relationship between the height of the column and the amount of water bled through the fabric. The results show linear relationship between pressure that corresponds to a point at specific height of a column and bled water. Geotex 104F which was the more porous fabric (see Table 2 and 3) led to a higher water loss. Greater bleeding causes a greater reduction in the water cement ratio and therefore the potential for increased compressive strength in the concrete. 152 by 305 mm (6 by 12 in.) cylinders were tested following the existing standard (ASTM C39/C39M-04a 2004).

Compared to normal concrete, using the bottom-point cylinders, flyash concrete gained more strength than the normal concrete in both fabrics. When normal concrete was used, again, comparing bottom-point cylinders, Geotex 104F gained about 110% extra strength compared to the samples formed by Geotex 315ST. As for flyash concrete in the bottom-point cylinders, fabrics behaved the opposite way, Geotex 315ST gained about 7% extra strength than 104F. As seen in Figure 31, the concrete strength also increases linearly from top to bottom of column. It is important to note that this linear relationship between strength gains towards the bottom of concrete column is not limited to fabric-formed concrete. Similar results were found by Maynard and Davis (1974) and in this study that used PVC molds (Figure 32). This increase in compressive strength is due to due to self weight of the fresh concrete and extra compaction at the bottom of all conventionally and fabric formed columns and due to higher density concrete formed in that section.

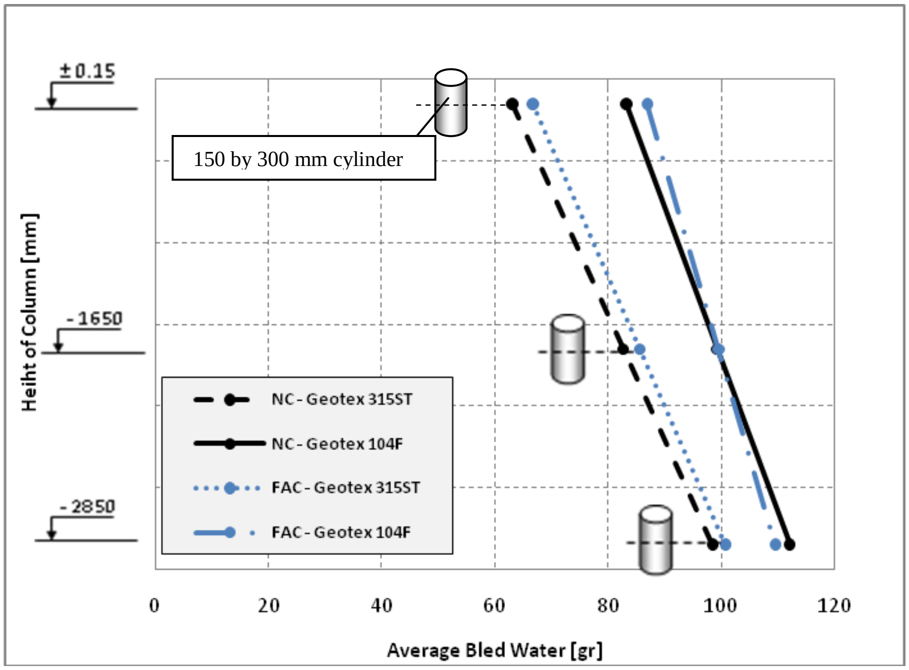


Figure 30: Average water loss through fabric formed cylinders

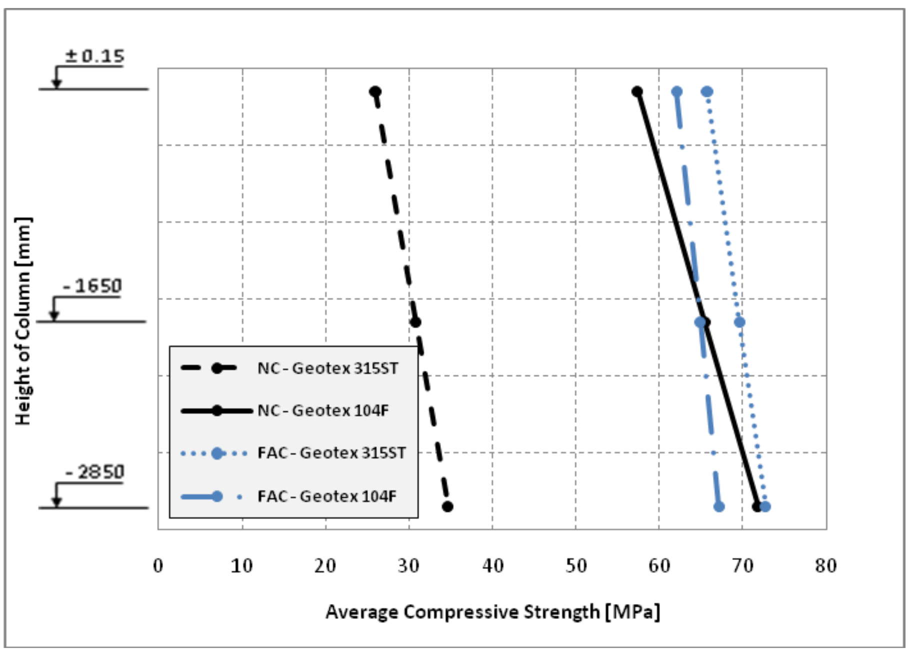


Figure 31: Average rate of strength increase with depth in fabric formed concrete

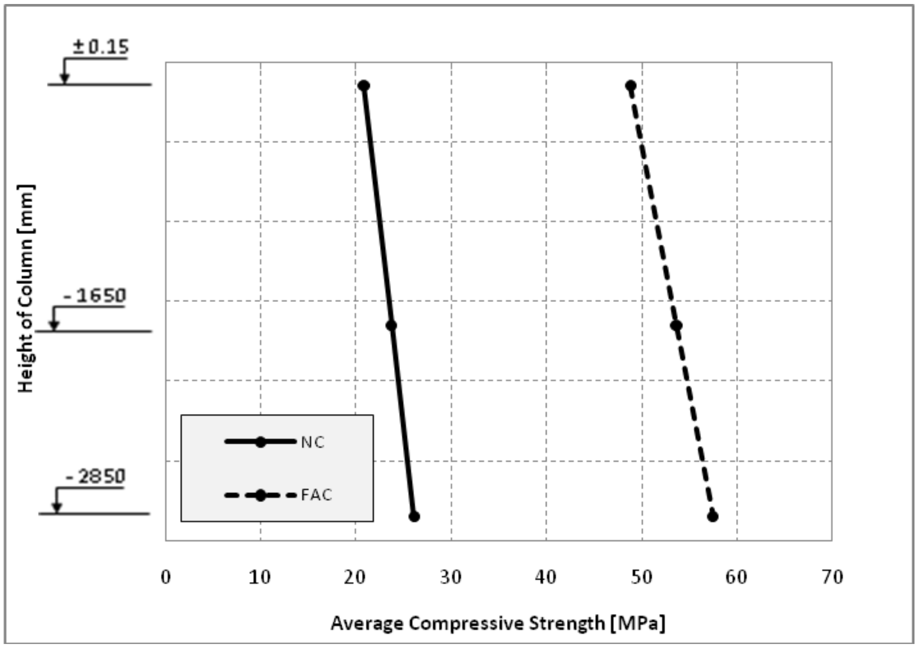


Figure 32: Average rate of strength increase with depth in PVC concrete

3.5 Finish Effect of Vibration on Concrete Surface

In another test, the change in quality of the surface due to vibration was also studied. A series of six 152 mm (6 in.) by 305 mm (12 in.) cylinders were made by Geotex 315ST and Geotex 104F. Molds were cast using a commercial flyash concrete (Lafarge, with 125 mm of slump), following the Canadian code requirements (Kosmatka, et al. 1995). Samples were vibrated for about eight seconds using an electric concrete internal vibrator. Fabric formworks were removed after 24 hours. The less porous fabric Geotex 315ST produced a much better surface finish due to less fine aggregates and cement bleeding through the fabric pores. Geotex 104F, on the other hand, did not provide a uniform texture and created some color variation on the surface which may have been due to excessive fine aggregate escape from the surface of the fabric mold. Bleeding water from Geotex 104F was cloudier than that produced by Geotex 315ST, indicating a greater concentration of fine particles through the fabric's pores. Based on this test, if a concrete surface finish is required, Geotex 315ST is recommended.

Chapter 4

Strength Tests

Concrete cylinders were cast in the two fabric types and in watertight PVC molds, and tested for compression strength at the ages of 3, 7, 14 and 28 days. The difference in overall strength between fabric-formed cylinders and PVC cast cylinders was then used to gauge the effects of formwork on the strength of concrete.

Since no relationship between diameter of the specimen and the bleeding depth could be determined in the tests reported in Chapter 3, 101 by 203 mm (4 by 8 in.) cylinders were chosen for further tests. This allowed for fresh concrete to be produced in a single batch in the laboratory, more precise control over the mix design and the accuracy of the aggregate weight percentages. Large aggregates were separately and thoroughly washed in order to reduce the amount of dust and dirt and create a homogenous concrete. In this experiment, a total of 36 cylinders were cast using normal concrete: 12 cylinders by Geotex 315ST, 12 by Geotex 104F and, 12 by PVC control molds. The same number of flyash concrete cylinders was made for a total of 72 specimen cylinders. All cylinders were cured in a humidity/temperature controlled curing room before testing for compressive strength.

4.1 Casting and Testing Concrete Cylinders with Fabric Formwork

Both fabric-formed and PVC formed control cylinders were cast in a vertical position (Figure 33) and compacted using the standard placement and vibration procedures (Kosmatka, et al. 1995). The bottom of each fabric formed cylinder was protected by a plastic sheet in order to prevent water absorption from the wood base, simulating the same condition as in the PVC molds (Figure 34). All PVC and fabric-formed specimens were cast using the same batch of fresh concrete made on premises. The same mix

Figure 33: Fabric formwork shown from above

Figure 34: Fabric-formed concrete cylinders

designs were adopted as in earlier tests (Chapter 2, Table 1 and Table 4). Aggregates were washed thoroughly and precise scaling was employed when weighing the aggregates. A 100 litre pan concrete mixer was used to mix the fresh concrete.

When the concrete was ready it was brought to the molds by wheel barrow for casting. Cylinders right after casting are shown in Figure 35. When casting the normal concrete, ambient temperature of the laboratory was recorded as 22 degree Celsius and the slump of the fresh concrete measured as 90 mm. For the flyash concrete, the temperature was recorded as 24 degree Celsius and the slump value was measured as 85 mm.

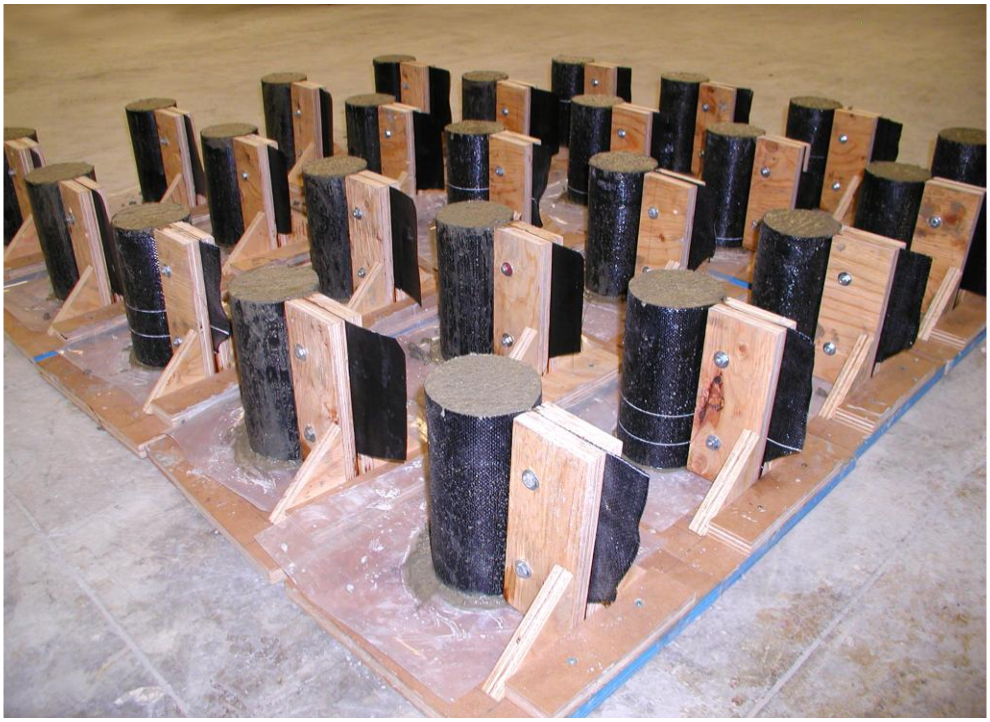


Figure 35: Fabric-formed cylinders after casting

Two hours after casting, all specimens were covered with plastic sheets (Figure 36) and left in place for 24 hours. Sandwich boards, bolts and fabric forms were carefully taken off the fabric formed specimens after the first day. PVC cast hardened concrete cylinders were removed from the PVC molds after one day using air pressure. All specimens were then transferred to a curing room in order to maintain uniform curing conditions before testing. The temperature of the curing room was recorded as 20 degree Celsius and relative humidity as 100 percent.

When visually inspected, the surface of the specimens formed with fabric had a finely textured surface imprint. Unlike PVC formed samples, no large aggregate or bug holes were visible on the concrete surface. Figure 37 shows three cylinders cast from left to right, Geotex 104F, PVC and Geotex 315ST.

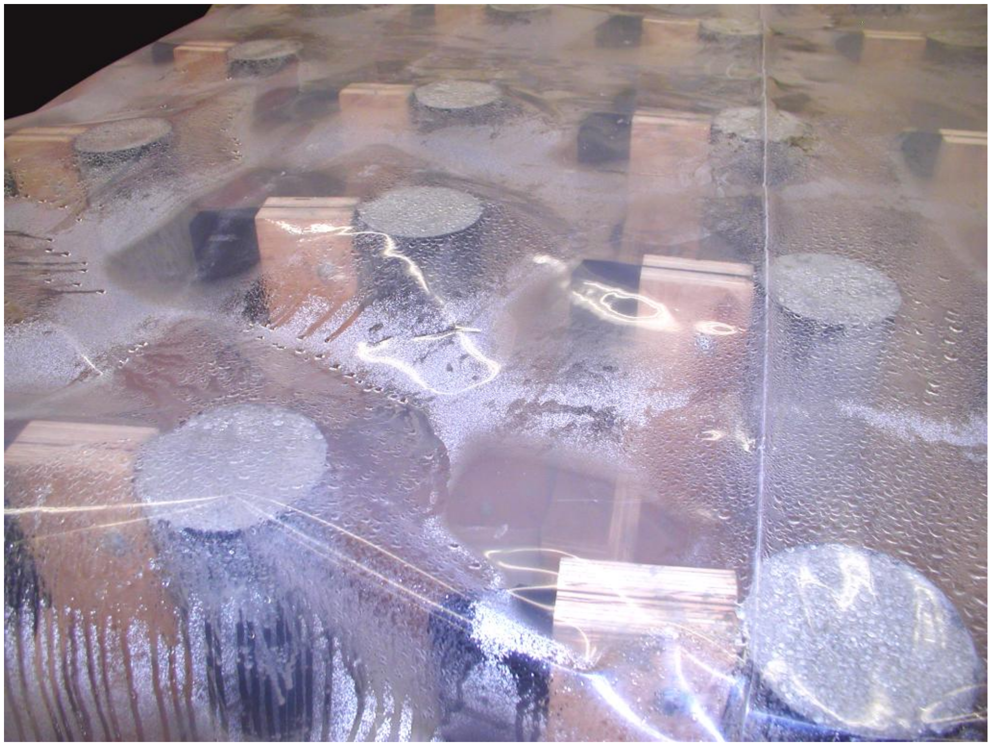


Figure 36: Cylinders curing

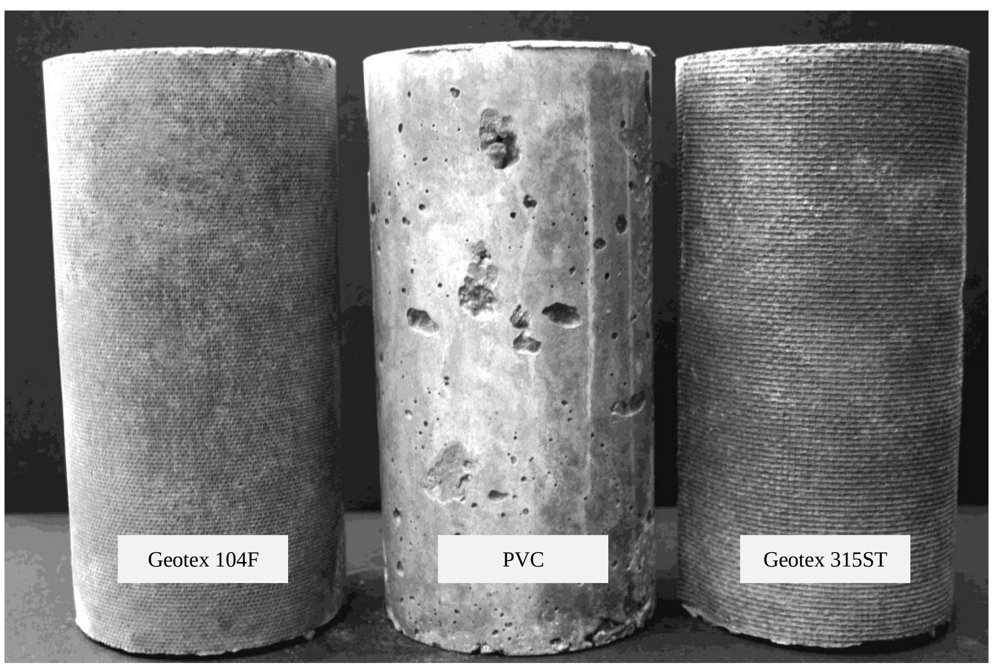


Figure 37: The effect of mold on quality of quality of concrete finish

Due to flexibility of the fabric forms, final hardened cylinders had minimal variation in diameter (1 to 4 mm). In order to consider the difference between the diameters of the fabric formed specimens and companion control samples, the diameter of each fabric formed cylinder was measured at three points and then the average diameter value was used to find the actual area of each cylinder. The average variation in diameter between fabric formed cylinders and PVC formed cylinders was less than one percent. Cylinders were tested for compressive strength at the ages of 3, 7, 14 and 28 days.

4.2 Density

Samples were tested at 3, 7, 14 and 28 days using a compression testing machine at the University of Manitoba structures laboratory. Strength gains of fabric formed cylinders were compared to PVC formed cylinders. The densities of all cylinders were determined before testing in order to study the relationship between type of mold and the effect on density and strength of the hardened concrete. As seen in Figure 38 and Figure 39, regardless of type of concrete, fabric formed cylinders gained higher densities. When normal concrete was used, Geotex 104F gained higher density while Geotex 315ST shows higher density when flyash concrete is used. Compared to PVC-formed companion control samples, fabric-formed concrete cylinders showed an average of 2 percent higher overall density when normal concrete was used and 3.3 percent higher density when flyash concrete was used. This might be due to air and water loss through the porous mold wall. Studies suggest that increase in density of concrete can result in increase in compressive strength of concrete (Mather 1965).

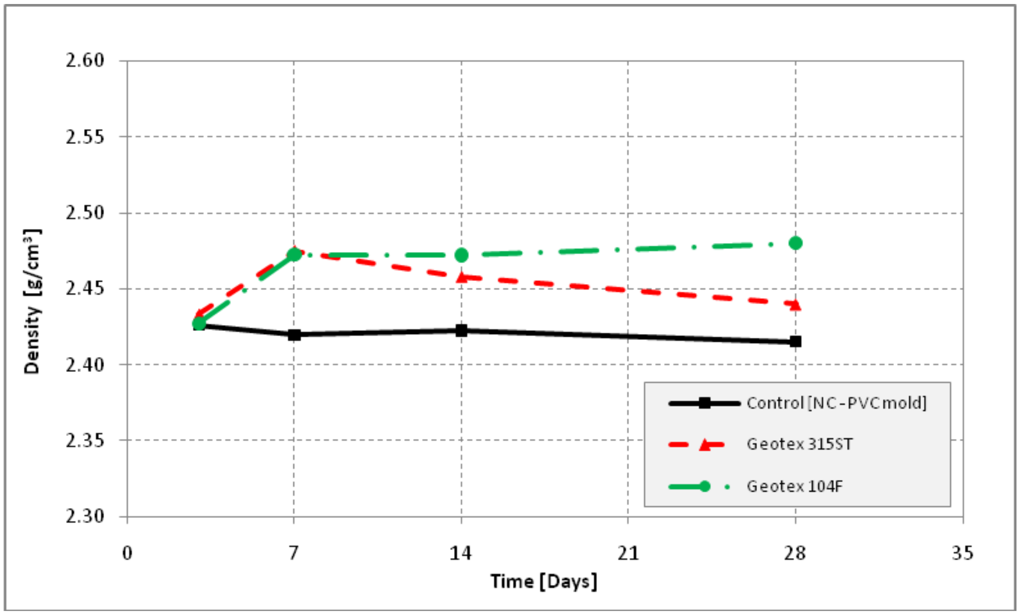


Figure 38: Average density of normal concrete cylinders

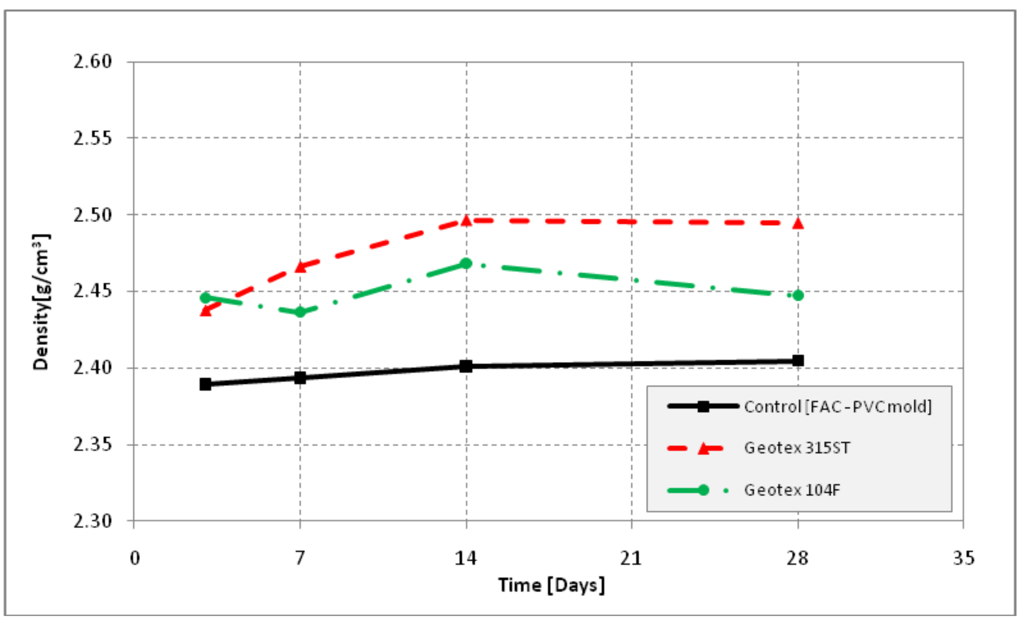


Figure 39: Average density of flyash concrete cylinders

4.3 Strength Test Results

Figures 40 and 41 show strength for normal and flyash concrete respectively. The fabric formed normal concrete had about 19% higher strength at three days for both fabrics compared to PVC mold. After 28 days, Geotex 315ST cast normal concrete gained 13.4% of strength, while Geotex 104F gained 16.7% of strength. This can be clearly seen in Figure 40.

As seen in Figure 41, the fabric formed flyash concrete had a 28% higher strength at three days for both fabrics compared to PVC mold. After 28 days, samples formed with Geotex 315ST gained 16.2% extra strength compared to the control PVC samples, while Geotex 104F gained 12.7% of strength. Flyash samples gained higher overall strength compared to normal concrete.

In both normal and flyash concrete the difference between strength increase due to fabric formwork remained almost the same. Comparison of concrete strength gain between the two fabric used revealed only 3% difference. Considering the fact that the two fabrics that were chosen represented a wide range of pore sizes in available woven geotextiles, it can be suggested that within limits, the final strength of a fabric formed cylinder may not be dramatically affected by the type of fabric used.

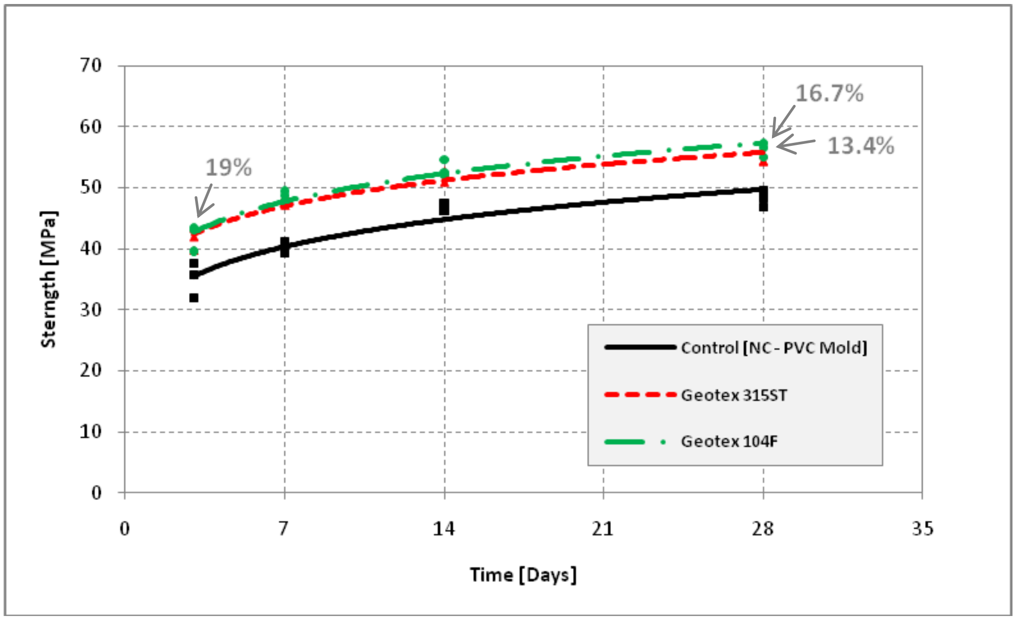


Figure 40: Strength gain of normal concrete

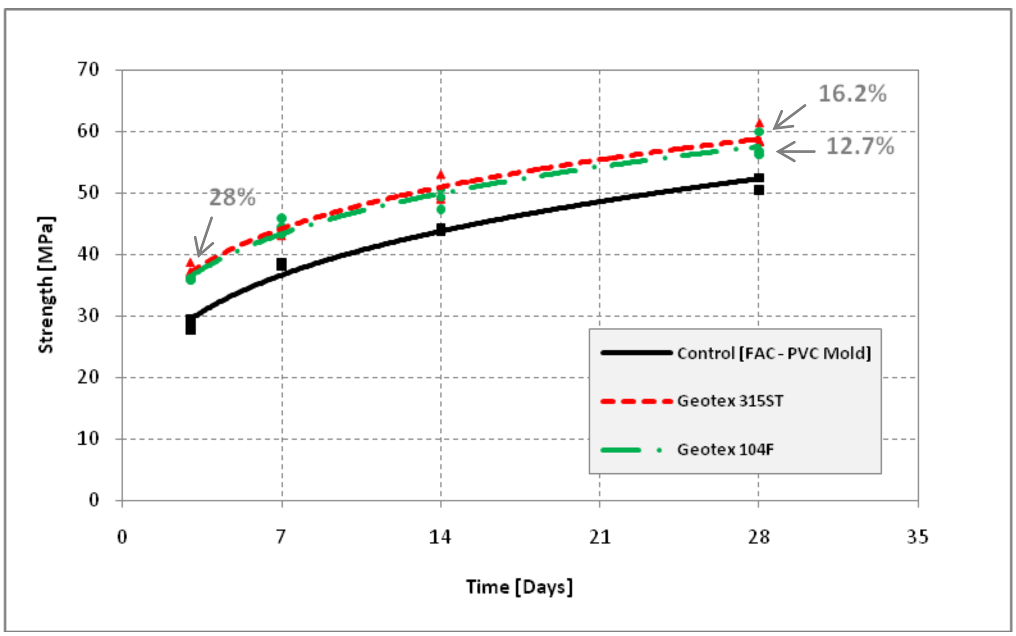


Figure 41: Strength gain of flyash concrete

Chapter 5

Column Tests

In order to evaluate the effect of fabric formwork on structural behaviour of a column, full size fabric-formed and conventionally formed reinforced concrete columns were designed and tested to failure under concentric axial load. The variables in these tests were two types of formwork; permeable fabric versus cardboard and two types of concrete; Flyash concrete and normal concrete. The fabric of choice was Geotex 315ST due to its better surface finish.

5.1 Column Specifications and Design

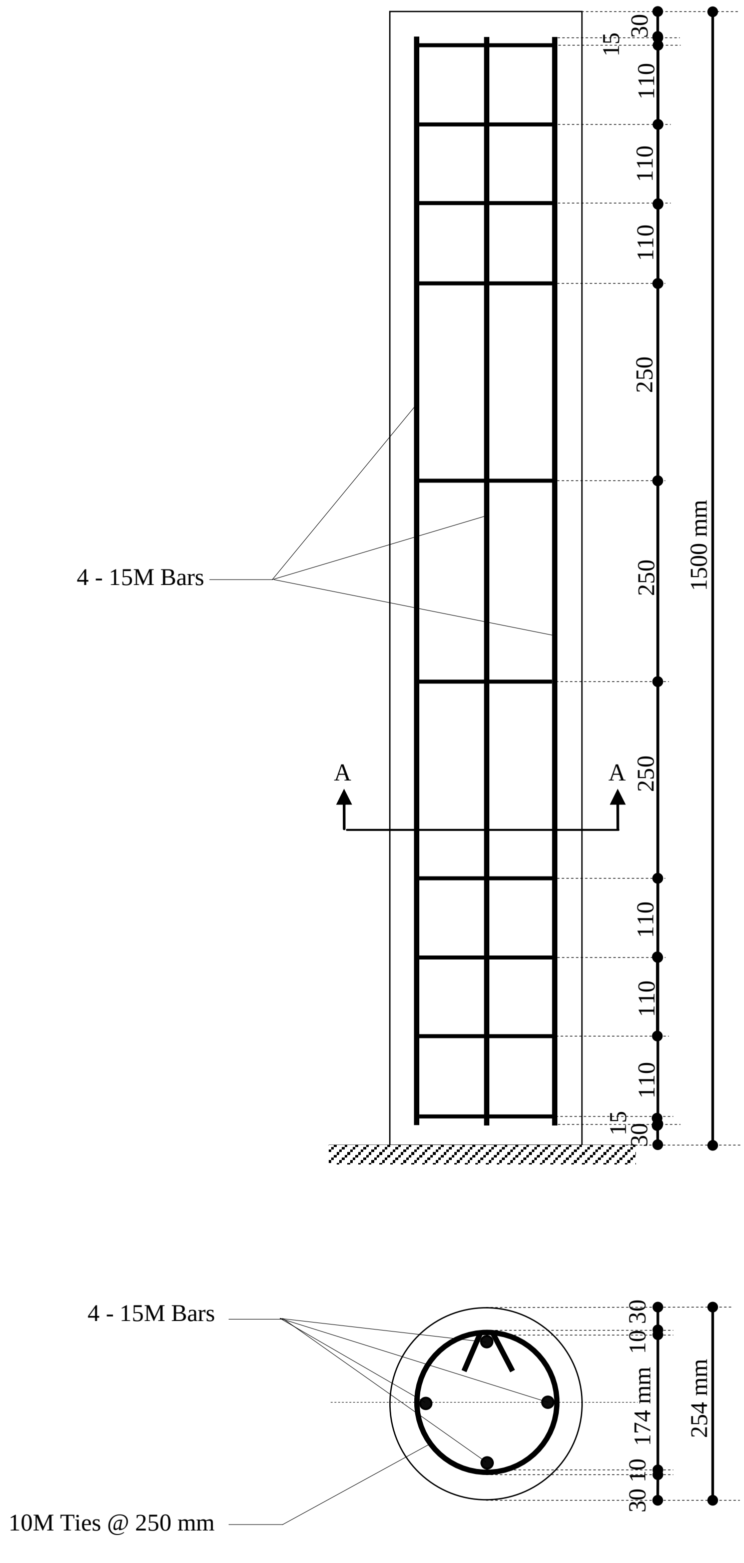
A total of six column specimens were tested to failure by applying a concentric axial load. Table 7 lists the specifications of the columns tested. FF stands for fabric formed columns, CT for cardboard tube formwork, NC for normal concrete and, FAC for flyash concrete. The design of the columns was limited by the capabilities of the available testing equipment. The detailed design of the column can be found in Appendix D.

Table 7: Specifications of the concrete columns tested

Column	Dimension [mm]	Type of Formwork	Type of Concrete
FF-NC-1	254 x 1500	Fabric (Geotex 315ST)	Normal
CT-NC-1	255 x 1500	Cardboard Tube	Normal
FF-NC-2	254 x 1500	Fabric (Geotex 315ST)	Normal
CT-NC-2	255 x 1500	Cardboard Tube	Normal
FF-FAC	254 x 1500	Fabric (Geotex 315ST)	Flyash
CT-FAC	255 x 1500	Cardboard Tube	Flyash

All columns had 254 mm radius and the column height was limited to 1500 mm. Based on calculations, four 15M bars were considered as the longitudinal bars, tie size was selected as 10M and tie spacing (*s*) was calculated as 250 mm (center to centre) and tie hooks, were set as 135 degrees. Arrangement and configuration of the reinforcement in the column has been shown in Figure 42.

The reason for repeated normal concrete specimen in Table 7 is the fact that the first try to form fabric formed column FF-NC-1 was not entirely successful. The column formed in a bulgy shape and there was a concern that the shape will affect the test results. A second column (FF-NC-2) with a corrected formwork was cast to provide a straight column for testing.



Section A-A

Figure 42: Column reinforcement details

5.2 Column Casting

5.2.1 Formwork

Two types of formwork were used; Cardboard tubes and Geotex 315ST. 254 mm (10 in.) inside diameter cardboard column formwork was employed because it is a widely used conventional formwork in today's North American construction industry .The cardboard forms used did not come with a non absorbent plastic inside layer and therefore provided some water absorption from the fresh concrete.

From the available fabric types Geotex 315ST was selected because it provides a better concrete finish. Both the control cardboard and fabric formed columns were cast simultaneously using the same concrete batch. The columns were cast using normal concrete and flyash concrete. Total of 6 columns were cast. As shown in Figure 43, the formwork was essentially the same as that used to cast the earlier cylinder specimens. The formwork was made of a single, rectangular, piece of fabric sandwiched between two vertical pieces of 38 x 89 mm lumber (2" by 4"). The fabric was first fitted to create the proper diameter and stapled to the lumber pieces.

After that, the wooden pieces were bolted together in four locations along the length of the formwork to make the closure of the formwork as a cylindrical vessel. Figure 44 shows the finished formwork set up for both cardboard and fabric formworks. Both formworks were supported in a vertical position by diagonal braces in two directions for lateral support. Plastic spacers (PVC chairs) were installed beneath the reinforcement cages in order to create a 30 mm space between the longitudinal bars and ties and the bottom of the columns. The cages were centered and then fixed to the wood floor using handmade aluminum braces in order to avoid possible movements of the reinforcement cage during the casting as shown in Figure 45.

The cover distance between both fabric and cardboard formworks was maintained by using plastic wheel spacers on the longitudinal bars. These spacers were also used to keep the reinforcement cage in the centre of the formwork during casting as shown in Figure 46.

5.2.2 Concrete

For these tests commercial 25 MPa concrete was ordered from a local ready mix concrete plant and delivered to the laboratory. An aggregate size of 5 to 20 mm, a slump of 90 mm, and an air content of 5 to 8% was specified.

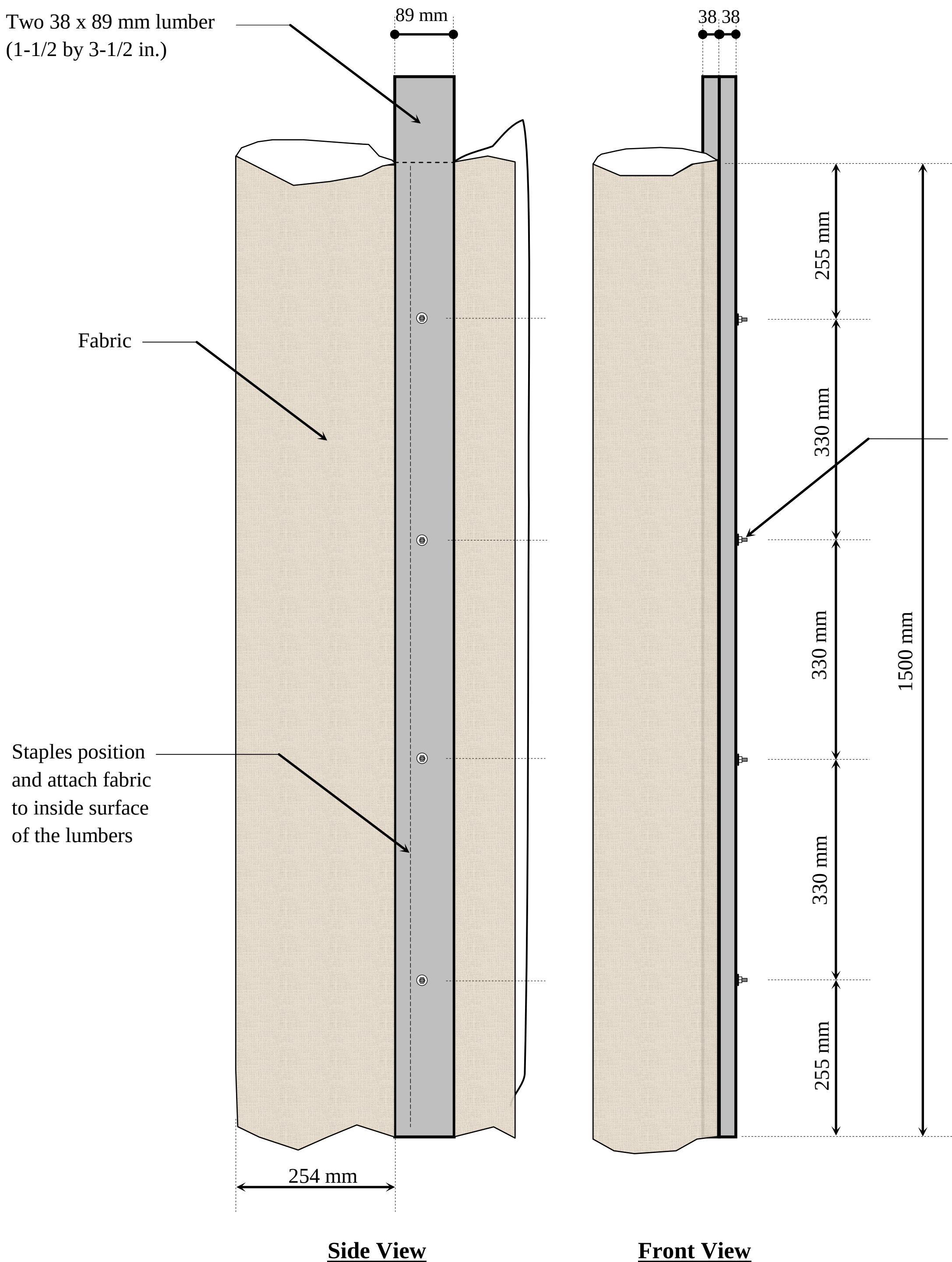


Figure 43: Configuration of the fabric formwork for reinforced concrete column

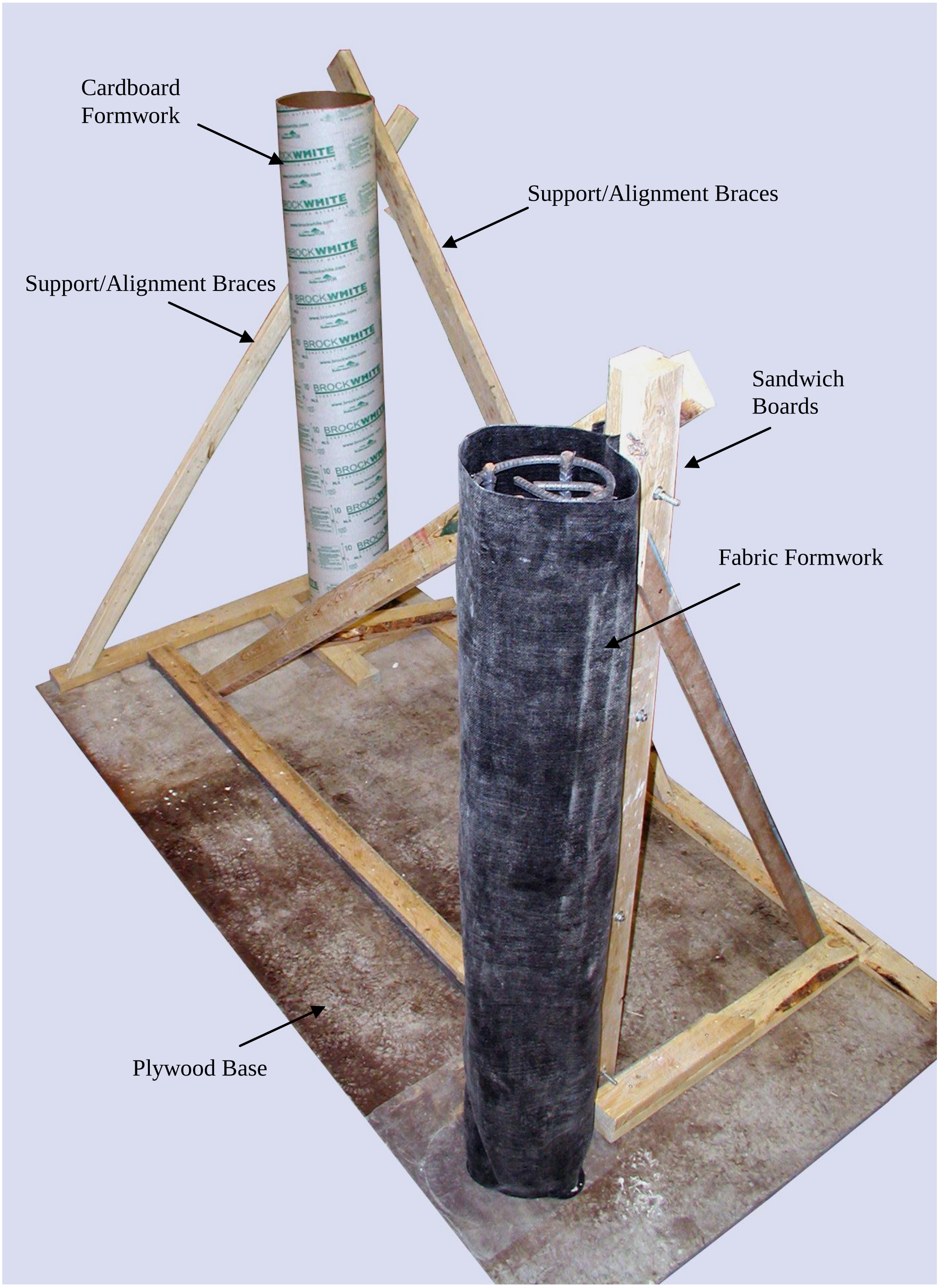


Figure 44: Setup for reinforced concrete columns formed with fabric and cardboard

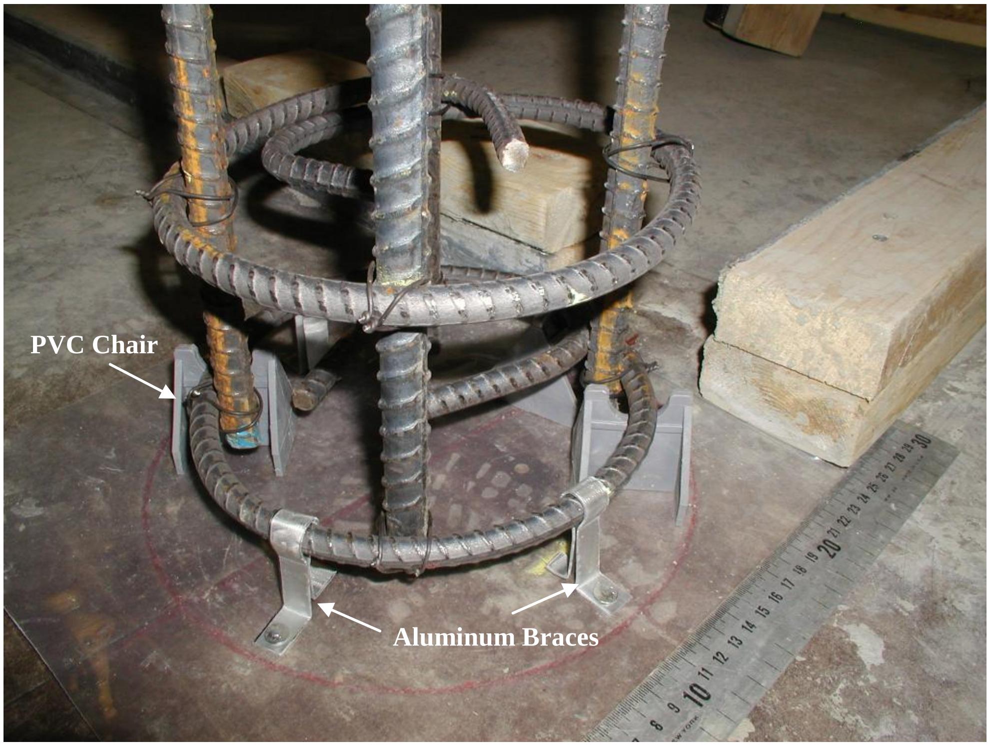


Figure 45: Details of the bottom of the column

Figure 46: Reinforcement cage

When the concrete was delivered, the slump value was measured and fifteen 101 by 203 mm (4 by 8 in.) PVC control compressive strength test specimens were cast. Fresh concrete was transferred by hand directly from the truck mixer's discharge chute to buckets and then into the forms as demonstrated in Figure 47. Each specimen was vibrated both inside and outside, using a portable electric internal vibrator at 5 to 15 second intervals. In case of fabric formwork, hand tapping the mold wall was also used to vibrate the concrete and help the bleeding of the air bubbles and extra water from the concrete. All columns and companion cylinders were cured in the same manner. Forms were stripped after one day, after which the columns, as well as the control samples were cured for another 3 days using wet burlap and plastic sheets as vapour barrier cover.

Figure 47: casting of column in fabric formwork

Unlike in the cardboard formed columns, no sign of color variation was observed in fabric formed columns. No imperfections such as bug holes or the appearance of large aggregates were seen on the fabric-formed concrete surface. Such column could be easily used as exposed concrete structural members with no necessity for expensive patch ups, epoxy coatings or paintings or architectural veneers.

5.3 Test Setup and Instrumentation

Cured, ready-to-test columns were instrumented at mid-height and top end to measure the longitudinal and circumferential strains under the axial load. To measure circumferential strains, two strain gauges were installed on mid-height of each column, 750 mm from the top end with a 180 degree interval. The concrete surface was first scrubbed with a grinder before the installation of the strain gauges. Voids were then filled with epoxy. After about one hour, extra epoxy was removed by sanding the surface down. Strain gauges were then attached to the smooth void-free concrete surface using adhesive. Strain gauges were tested for correct resistance after installation using a volt meter. Wires were soldered to the strain gauges and then covered with a protective film of acrylic coating to protect them from possible damage before testing. Except the first two columns (FF-NC-1 and CT-NC-1) which had pi-gauges only on mid-height, a total of eight Pi-gauges were installed on each column. Four Pi-gauges were placed on mid-height and four at the top end of each column to measure the displacement over the initial 200 mm length of the pi-gauges as shown in Figure 48. A Data Acquisition System (DAQ) was used to record the information gathered from 11 channels coming from the column instrumentations and testing machine (8 channels for the Pi-gauges, 2 channels for the strain gauges and one channel for the load applied to the columns by the machine). Strain and Pi-gauges were all tested for proper resistance and calibration just before every test session.

5.4 Companion Control Cylinders

A compression testing machine was used to test the companion 101 by 203 mm (4 by 8 in.) concrete cylinders at the ages of 3, 7, 14, 28 and 56 days. All cured columns and the concrete cylinders were taken out of their molds simultaneously and were kept in the laboratory till testing. Figure 49 provides the data concluded from the cylinder compression tests. Both batches were specified to reach compressive strength of 25 MPa at 28 days but as the results show, the flyash concrete gained more compressive strength compared to the normal concrete. As seen in Figure 49, average compressive strength of the flyash sample at 28 days was measured as 39.2 MPa while the normal concrete specimens had average compression strength of 27 and 28.30 MPa. The actual compressive strength in both concretes was used to estimate the actual maximum axial load capacity of the columns.

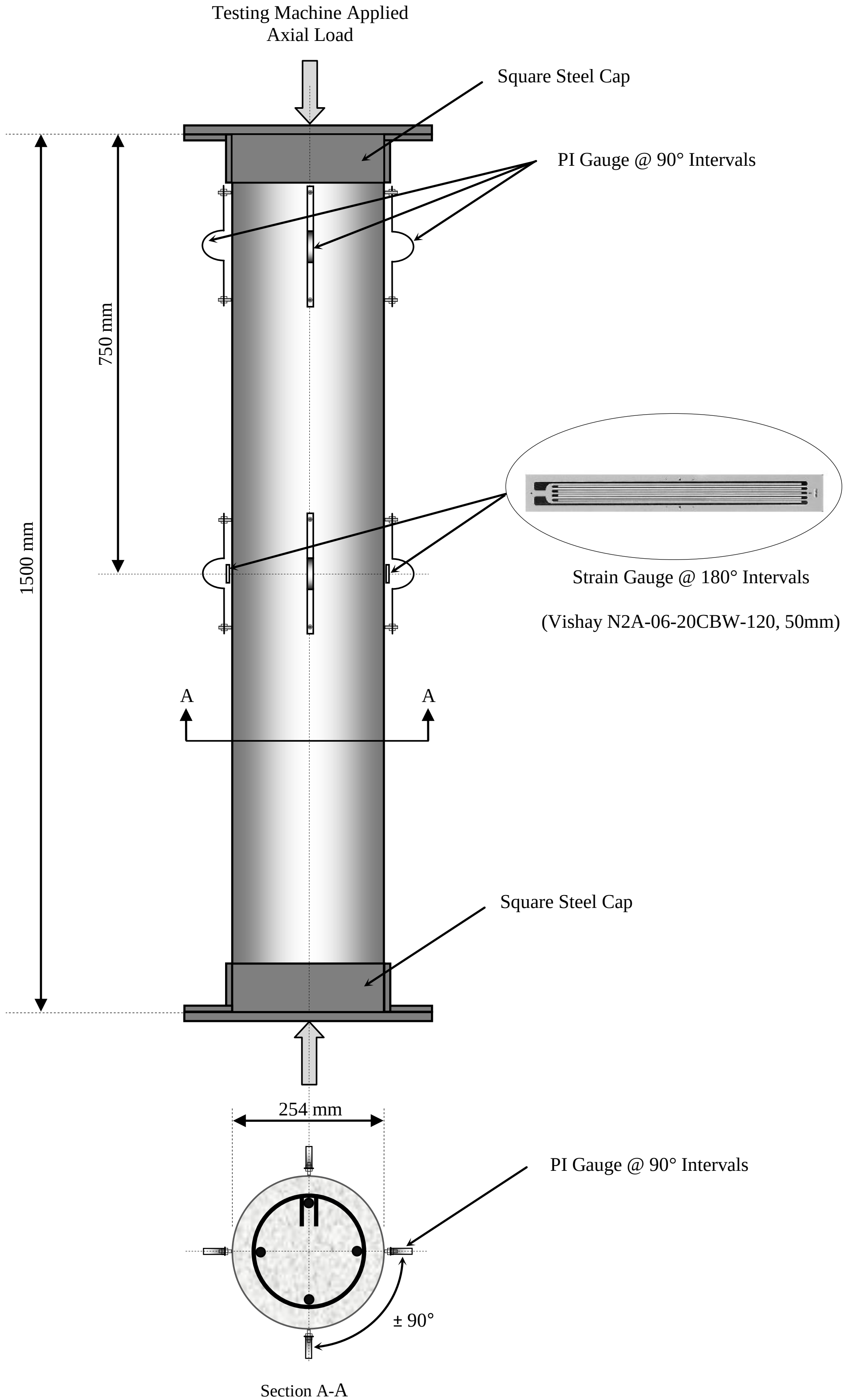


Figure 48: Configuration of the instrumentation of the concrete columns

5.5 Schmidt Hammer Tests

A rebound test was also used as a non destructive method to study the strength of the hardened concrete along their lengths. A Schmidt concrete test hammer (Proceq N/NR) was used in this research study. A grid of four vertical lines and 14 circumferential lines were drawn on the column surfaces. The grid lines provided locations to use the hammer at 14, 21, 28 and 56 days. Based on the manufacturer's manual, a Schmidt hammer may be used to evaluate the pressure resistance of an equivalent cylinder between 14 - 56 days (Proceq 2002).

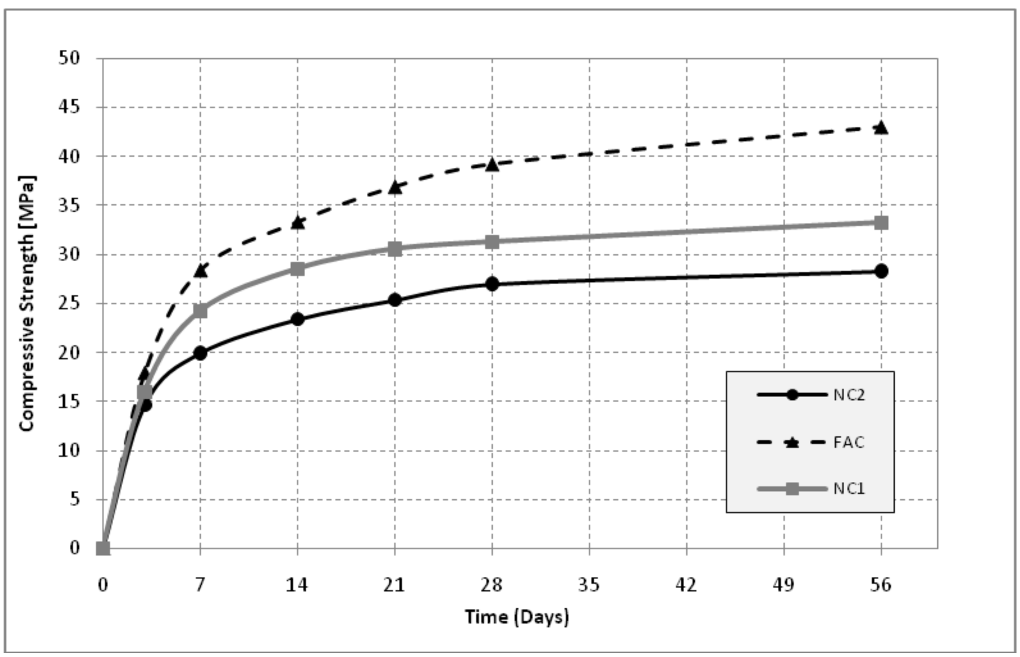


Figure 49: Concrete strength gain with time

Instructions for preparation of the concrete surface were carefully followed before and during the use of the hammer. Each assigned point was tested for 8 impact readings. Following the manufacturer's manual, the impact points were spaced at least 20 mm apart. The mean value of the 8 rebound values (R) was then calculated. Conversion curves were used to find the corresponding compressive strength of the average R values. For comparison purposes, only 28 day readings are provided in Figure 50. Charts showing the change in compressive strength along the height of the column for all columns have been provided in Appendix C.

As seen in the chart, all columns formed with fabric showed more surface strength than those formed with cardboard. When normal concrete is used, the difference between the compressive strength of the specimens cast in cardboard versus fabric formwork at the bottom of the column is between 12 and 15%. The difference between the formworks when using flyash concrete has minimal significance (5% difference). This is an indication of flyash particles possibly clogging fabric pores and therefore, reducing the amount of water bleeding and eventually resulting in less increase in compressive strength. In addition, regardless of the formwork type and referring to the results obtained from Schmidt hammer tests, the top end of the columns always proved to be weaker than other sections of the column. A phenomenon that appeared in both cardboard and fabric formed columns due to less compaction and less concrete density at top end of each column.

Compression strength test results from Schmidt hammer test have been compared to those from cylinder test for both normal and flyash concrete. As seen in Figures 51, 52 and 53, there are some fluctuations between the results obtained from Schmidt hammer and the PVC formed cylinders. The filled markers in the graph represent the bottom of the column, while the empty ones represent the top of the column.

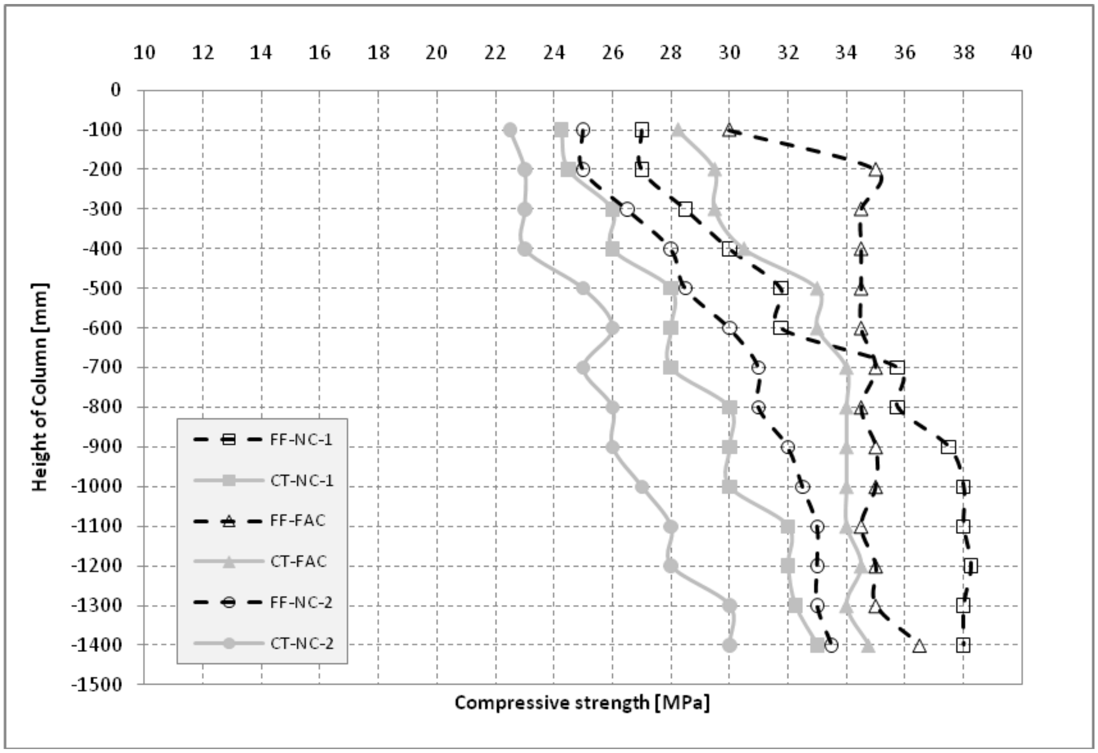


Figure 50: Results from the Rebound tests showing the variation of strength through the height of the columns at the age of 28 days

As seen in Figure 51, compared to results from cylinder tests fabric formed column has gained an average of 21.8% extra strength at the bottom of the column while the bottom of the cardboard formed column shows almost the same results as the cylinders. At the top of the column, both cardboard and fabric formed columns showed an average of 28% less strength compared to the cylinder test results. As seen in Figure 52, cylinder test results for flyash concrete show more compressive strength than both top and bottom readings of the Schmidt hammer.

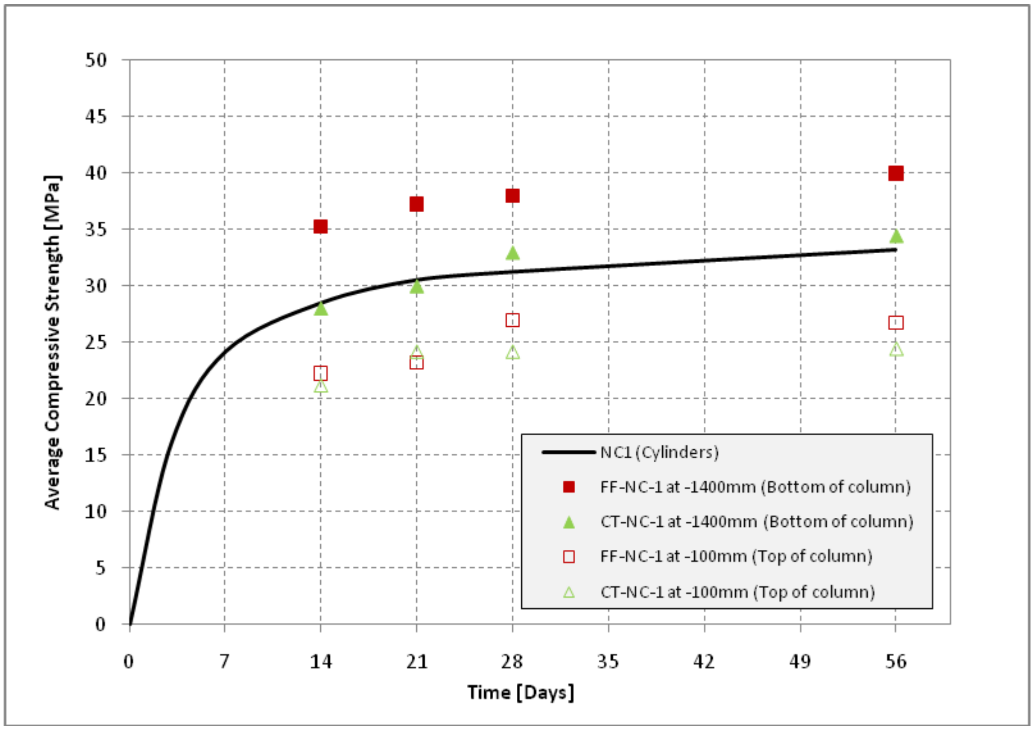


Figure 51: Normal concrete cylinders compared to Schmidt hammer results (Columns FF-NC-1 & CT-NC-1)

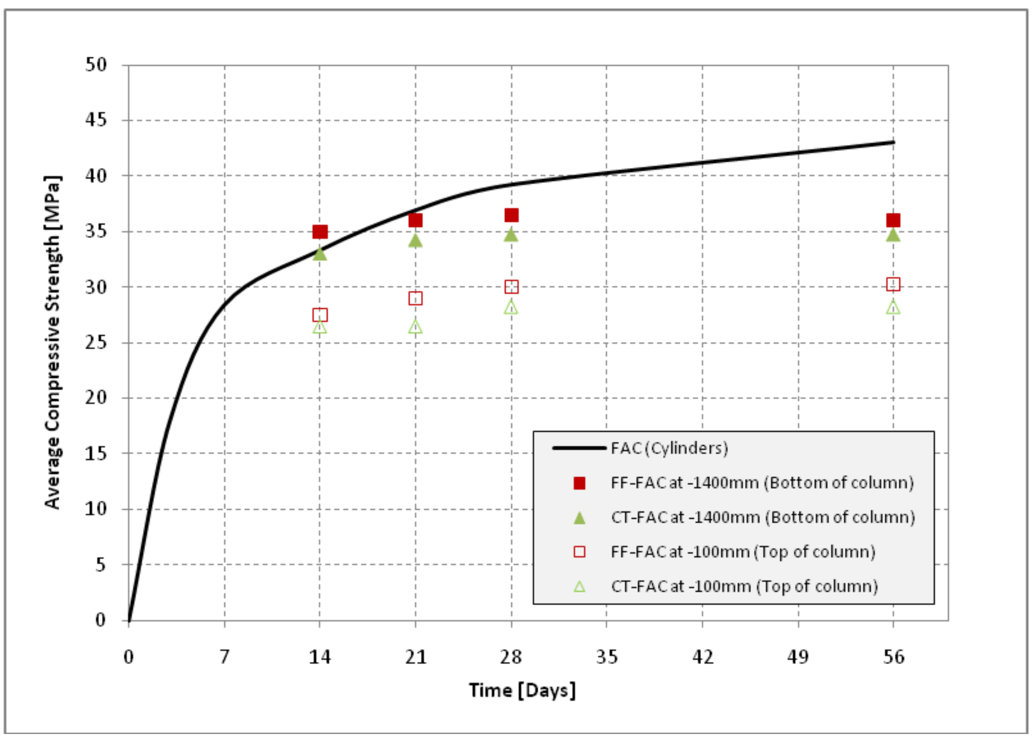


Figure 52: Flyash concrete cylinders compared to Schmidt hammer results (Columns FF-FAC & CT-FAC)

The difference between the readings of the Schmidt hammer at different ages stays constant but for some reason does not follow the strength indicated from cylinder tests. For the second set of normal concrete columns and cylinders, it can be seen in Figure 53 that compared to results from cylinder tests, fabric formed column has gained an average of 28% extra strength at the bottom of the column while cardboard formed column shows 14% difference. Schmidt hammer reading from the top of the columns shows 15% less compressive strength for cardboard formed columns and 6% less for fabric formed columns.

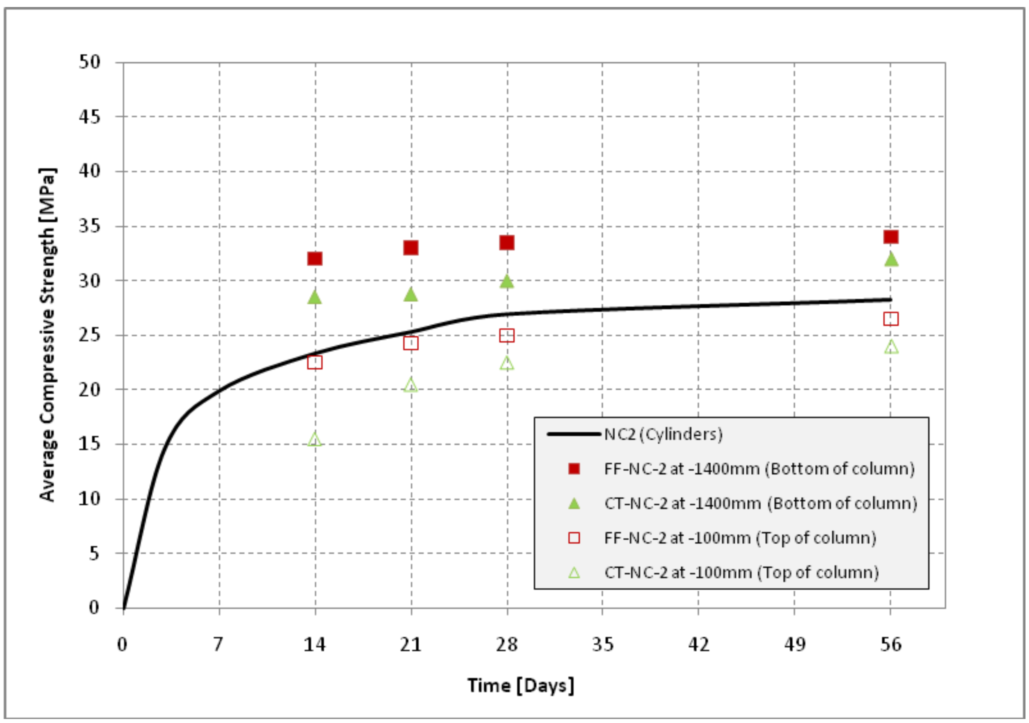


Figure 53: Normal concrete cylinders compared to Schmidt hammer results (Columns FF-NC-2 & CT-NC-2)

It is clear from the comparisons that for normal concrete the strength data from Schmidt hammer and from the cylinder test is comparable. Schmidt hammer is usually used to evaluate concrete strength of existing structures and it was shown in the previous figures that the strength is evaluated accurately. The method seems to be less accurate for the flyash concrete.

5.6 Column Compression Tests

All columns were cured for at least 56 days before testing. Columns were oriented in vertical position in the testing machine and axial load was applied to the specimens with a load rate of 50 kN per minute until failure.

Two 280 by 280 mm (11 by 11 in.) custom made steel caps were made using a square base plate and four pieces of steel L-profiles welded vertically to the base plate as shown in Figure 54. Steel caps were made to confine the levelling grout on both ends of each column so that the axial load was evenly distributed over the column sections. No lateral supports were used to support the caps or columns.

Sika Grout 212 HP was used to level top and bottom of each column. Each column was first brought to the loading position, then lifted vertically using straps and cross head of the loading machine for about two feet. While the column was hung in the air, the steel cap was filled with 10-20 mm of the grout mixture.

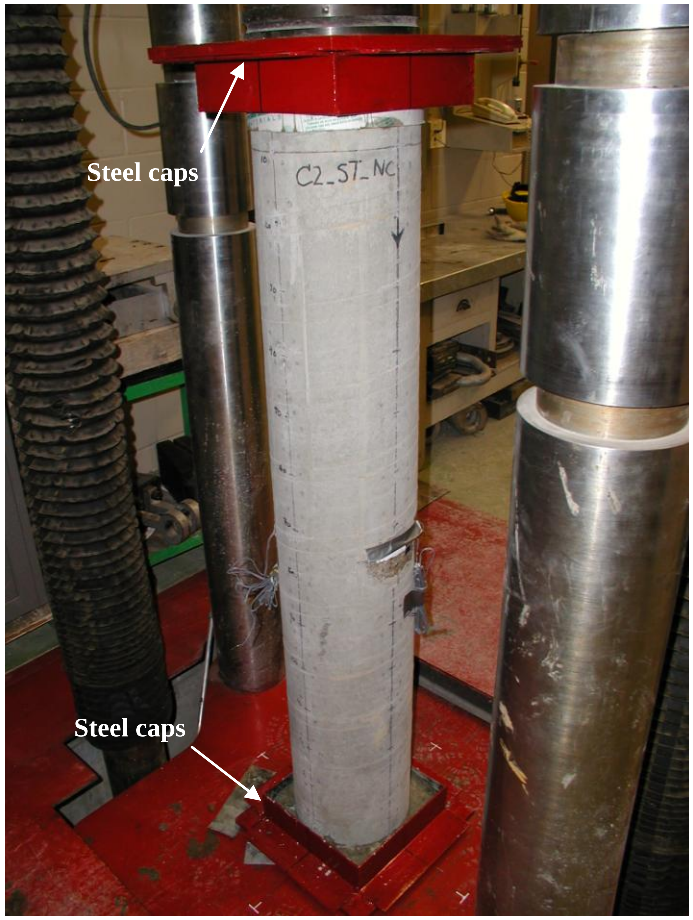


Figure 54: Columns test setup

The column was then slowly brought down to sit in the centre of the cap. After levelling the columns in a vertical position, specimen was left in place for 48 hours prior to testing day to let the grout gain its proper strength. To cap the top end of the column, a 75 mm circular cardboard mold was cut and used as a collar to retain the fresh grout in place when grouting the top end. First the collar was installed on top of the column, leaving only small room for the levelling grout. Then, grout mix was poured on top of the concrete. Steel cap was immediately placed on the fresh grout and levelled. A slight engagement of the machine's load piston also helped the cap being fixed in position until the grout set.

Due to the hand-made construction of the fabric molds, the columns cast by fabric formwork, did not have a completely uniform diameter along their lengths, making for a slight undulation along their sides. This slightly uneven surface did not allow the direct use of a carpenter's level for alignment and vertical positioning. Once the columns were brought down to sit in the fresh grout inside the caps, they were aligned using two Theodolites and then fixed in place using the machine load piston. To achieve more accuracy in alignment when testing both types of the columns, they were pre-loaded to obtain some data readings and then using the data from the strain and pi gauges, further adjustments were applied to centre the columns under the loading piston.

5.7 Test Results

5.7.1 Failure Patterns

In order to be able to better observe behaviour and the failure pattern of the columns, all tests were videotaped. The failure pattern of the columns was a factor to be investigated in this phase of the study. Based on observations of the two cardboard and two fabric-formed column tested, the failure of the cardboard formed column started with crushing on top and then spalling till failure. Cardboard-formed columns presented a typical gradual failure with no sign of brittleness, no longitudinal cracks and no flaking. On the other hand, fabric-formed columns started with crushing on top and development of longitudinal cracks at the same time along with spalling. Also, some flaking and relative sudden failure of outside surface was observed. Photographs of these column failures are shown in Figure 65 (page 82).

5.7.2 Compressive Strength

Compressive strength as given by the control cylinder tests at the age of 56 days was used to recalculate the theoretical expected maximum axial load of the steel reinforced column specimens. Table 8 provides a summary of the specifications of the tested columns and the obtained results. It can be noted that the formwork type had no bearing on the strength of either the normal or flyash concrete columns.

As seen in Table 8, the first two columns (FF-NC-1 and CT-NC-1), normal concrete columns formed with fabric and cardboard, withstood 1850 kN and 2200 kN of axial load, respectively. Maximum axial load of flyash specimen (FF-FAC and CT-FAC) was 2271 kN for fabric formed column and 2165 kN for cardboard formed column. As shown in Figure 55, for the last two columns (FF-NC-2 and CT-NC-2), normal concrete columns formed with fabric and cardboard carried 1703 kN and 1744 kN of axial load, respectively.

Table 8: Specifications and the obtained results from the four reinforced column specimens tested

Column	Formwork	Concrete type	f'c @ 56 days [MPa]	Age of concrete at testing [Days]	Theoretical max. load [kN]*	Experimental max. load [kN]	Experimental max. load/Theoretical
FF-NC-1	Fabric	Normal	31.27	85	1742	1850	1.06
CT-NC-1	Cardboard Tube	Normal	31.27	79	1611	2200	1.37
FF-NC-2	Fabric	Normal	26.99	69	1447	1703	1.18
CT-NC-2	Cardboard Tube	Normal	26.99	73	1424	1744	1.22
FF-FAC	Fabric	Flyash	39.21	88	2015	2271	1.13
CT-FAC	Cardboard Tube	Flyash	39.21	82	2008	2165	1.08

*Theoretical max load of columns of the same batch are different due to variable sectional area of the fabric formed columns.

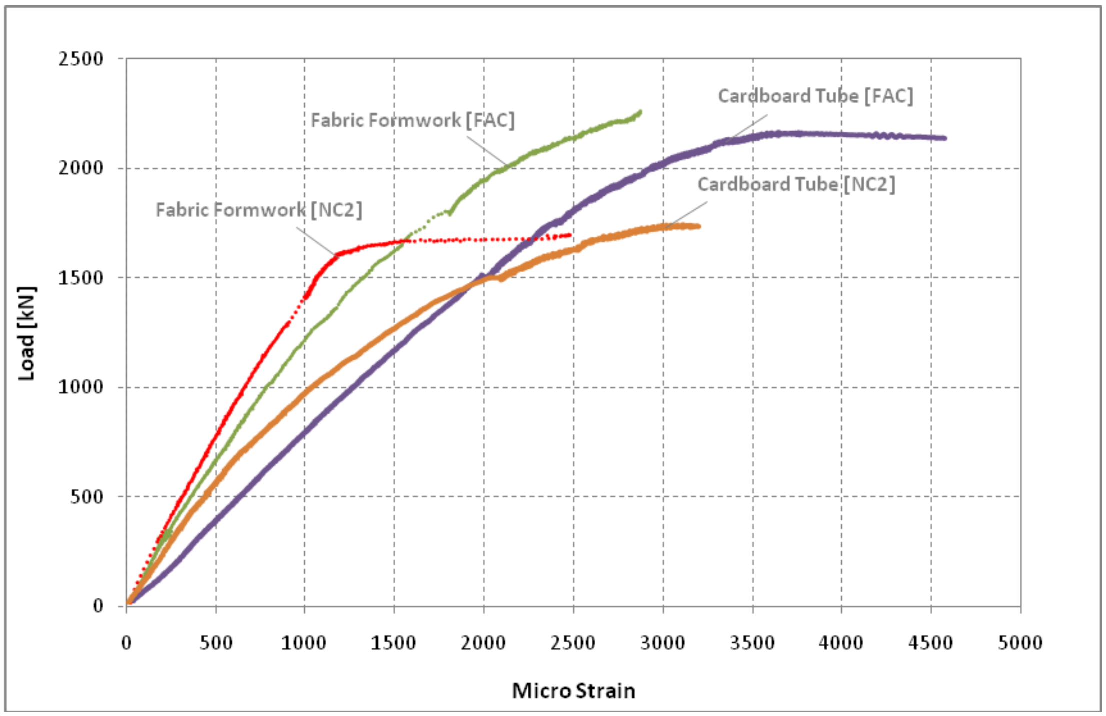


Figure 55: Maximum axial load of fabric-formed versus cardboard-formed steel reinforced concrete columns (Normal and flyash concrete)

The first normal concrete fabric formed column (FF-NC-1) became bulgy and uneven due to improperly installed fabric. This made it more challenging to centre the sample in testing machine. This fabric formed column failed at 1850 kN that is 15.9% lower compared to the companion cardboard formed column CT-NC-1. For this reason, another set of two columns were cast using normal concrete (FF-NC-2 and CT-NC-2). The maximum strain values plotted in Figure 55 are provided in Table 9 for all the columns tested. Regardless of the location of the pi-gauges, these strain values are the highest recorded values in the concrete at the time of failure of the column.

The columns were instrumented to measure both longitudinal and circumferential strains. Available readings for individual columns at all pi-gauge locations are provided in Appendix E. Column FF-NC-1 and CT-NC-1 had instrumentation only in the mid-height section. The rest of the columns were instrumented both at the top and mid-height point of the column.

Figure 56 to 59 depict the strains in the middle, while Figures 60 to 63 depict the strains at the top of the column. Each figure represents one location either North, South, East of West and strains of that location in each column were plotted in the same graph for comparison.

Table 9: Strain values for columns tested

Column	Formwork	Concrete type	Experimental max. failure load (kN)	Maximum strain at failure load (μs)	Location of pi-gauges on the column
FF-NC-1	Fabric	Normal	1850	-1114.39	Middle
CT-NC-1	Cardboard Tube	Normal	2200	-1946.67	Middle
FF-NC-2	Fabric	Normal	1703	-2479.81	Top
CT-NC-2	Cardboard Tube	Normal	1744	-2355.73	Top
FF-FAC	Fabric	Flyash	2271	-2673.10	Top
CT-FAC	Cardboard Tube	Flyash	2165	-3657.22	Top

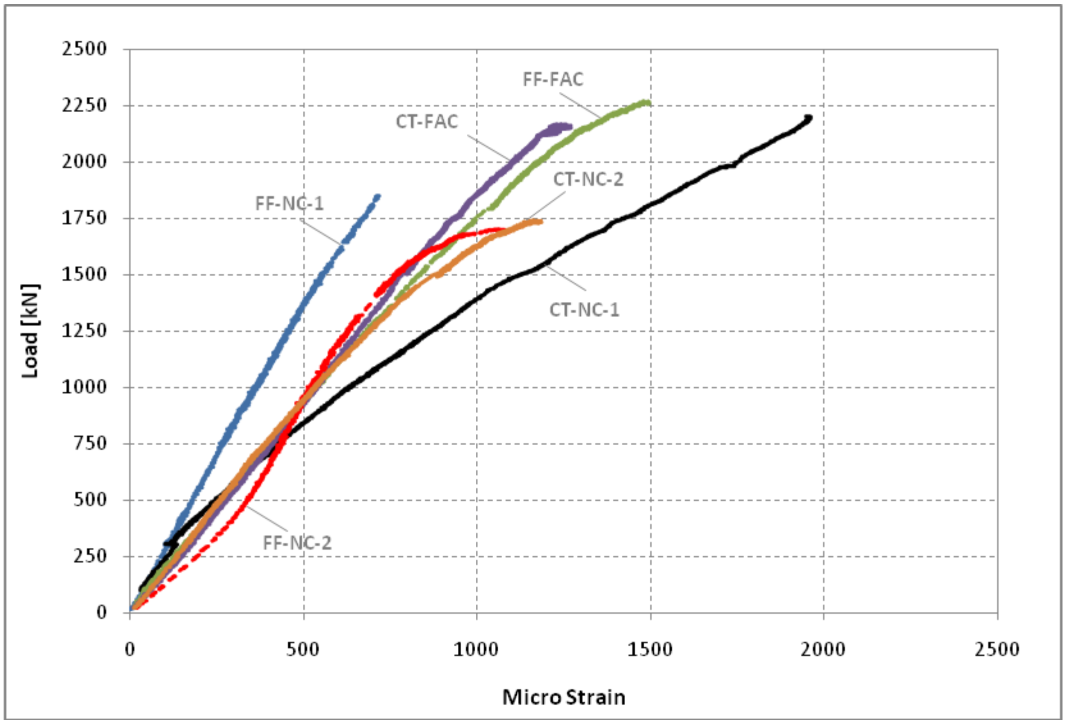


Figure 56: Readings from North pi-gauges at the middle of all columns

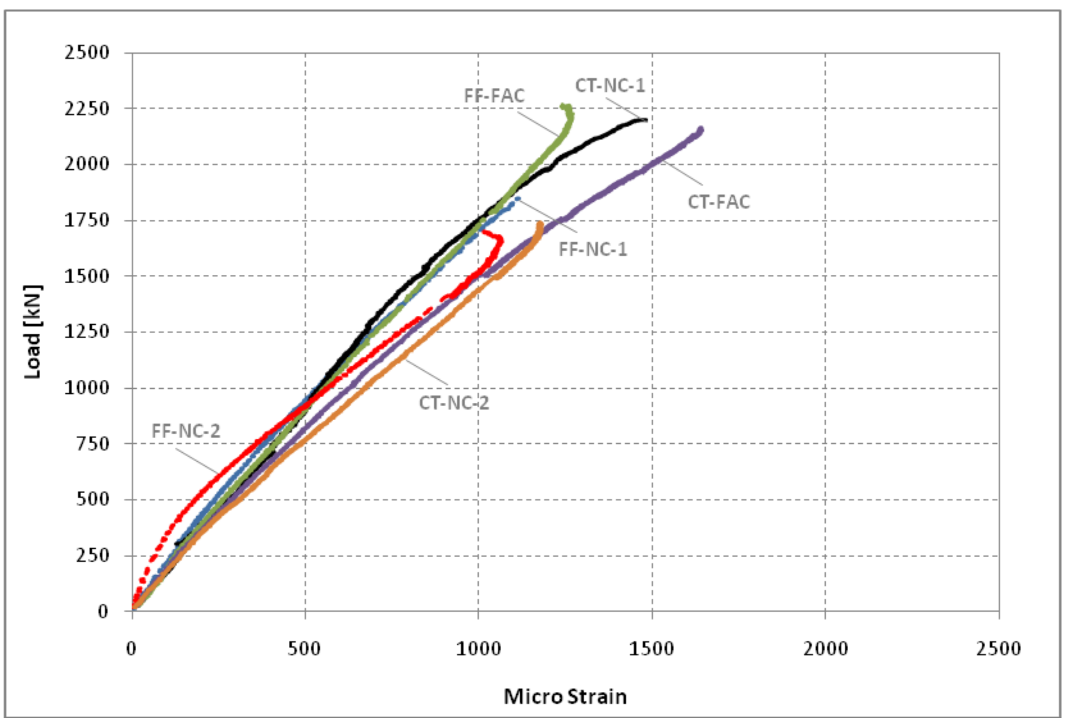


Figure 57: Readings from South pi-gauges at the middle of all columns

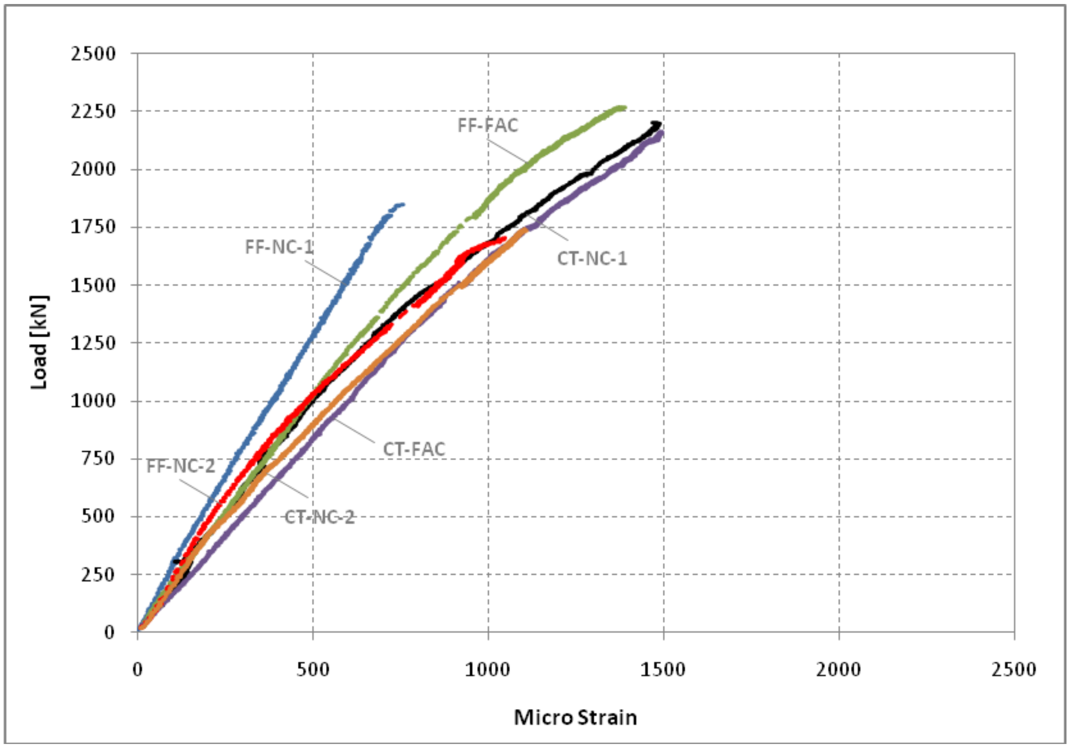


Figure 59: Readings from West pi-gauges at the middle of all columns

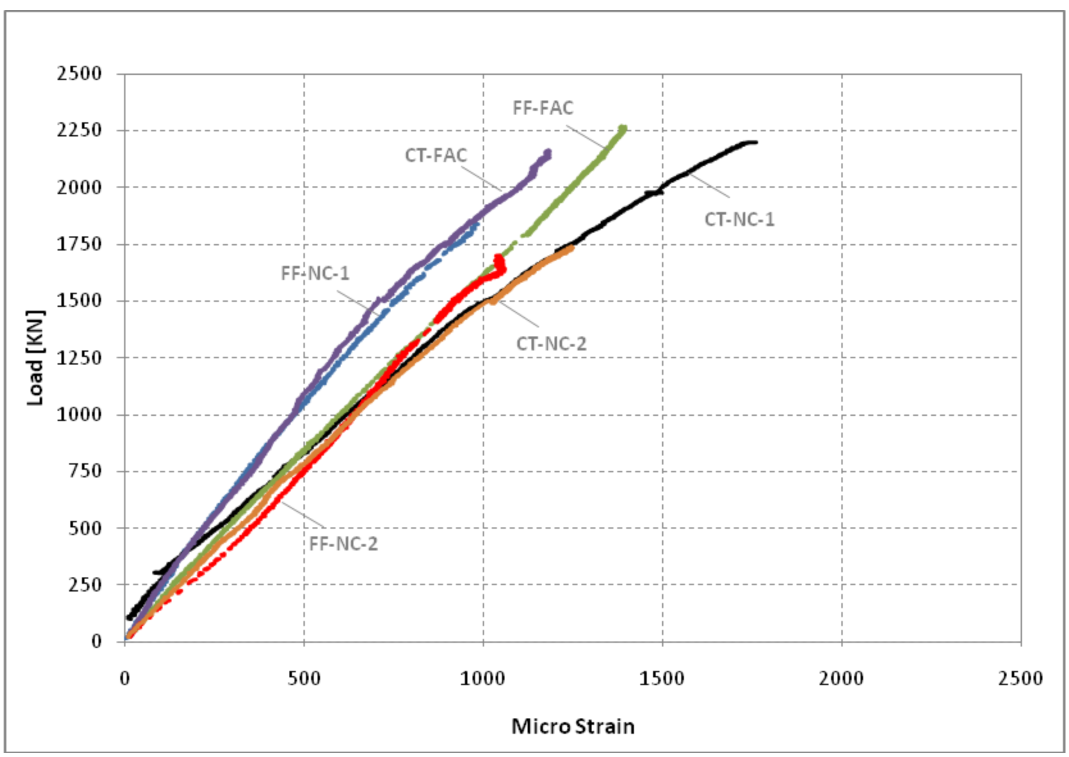


Figure 58: Readings from East pi-gauges at the middle of all columns

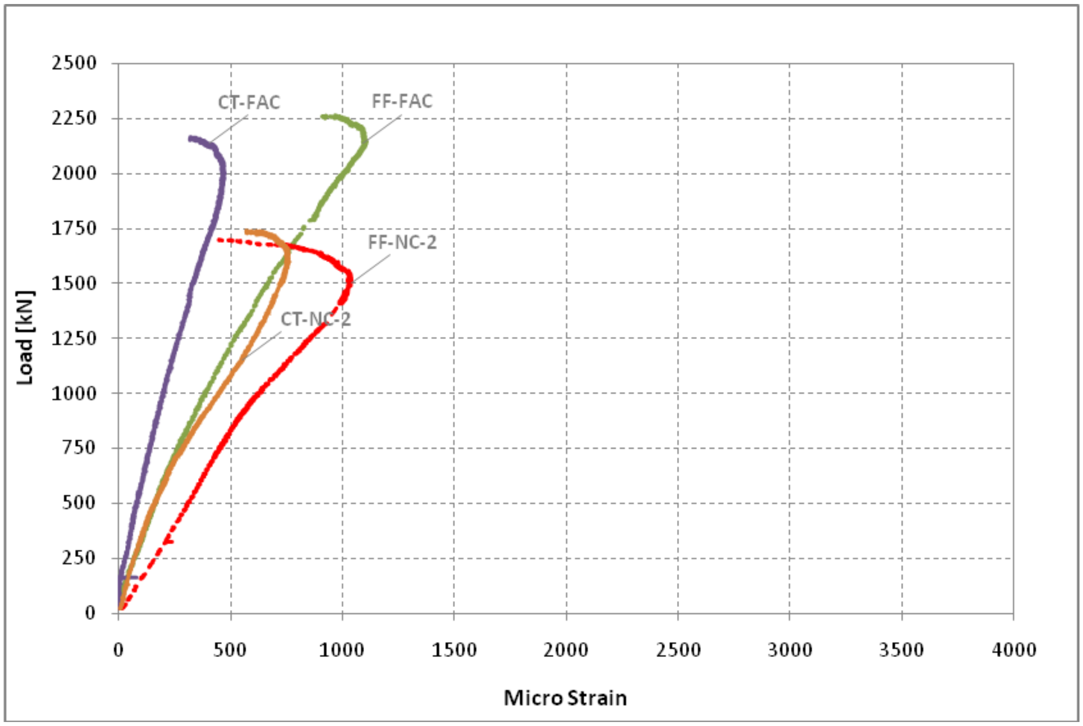


Figure 60: Readings from North pi-gauges at the top of all columns

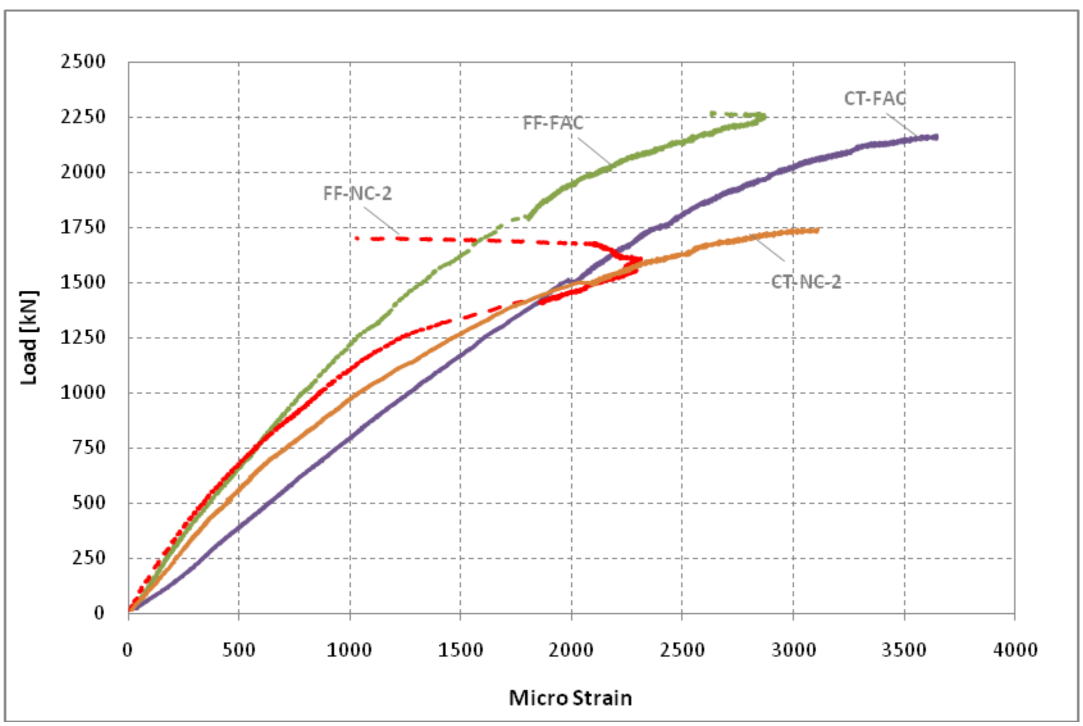


Figure 61: Readings from South pi-gauges at the top of all columns

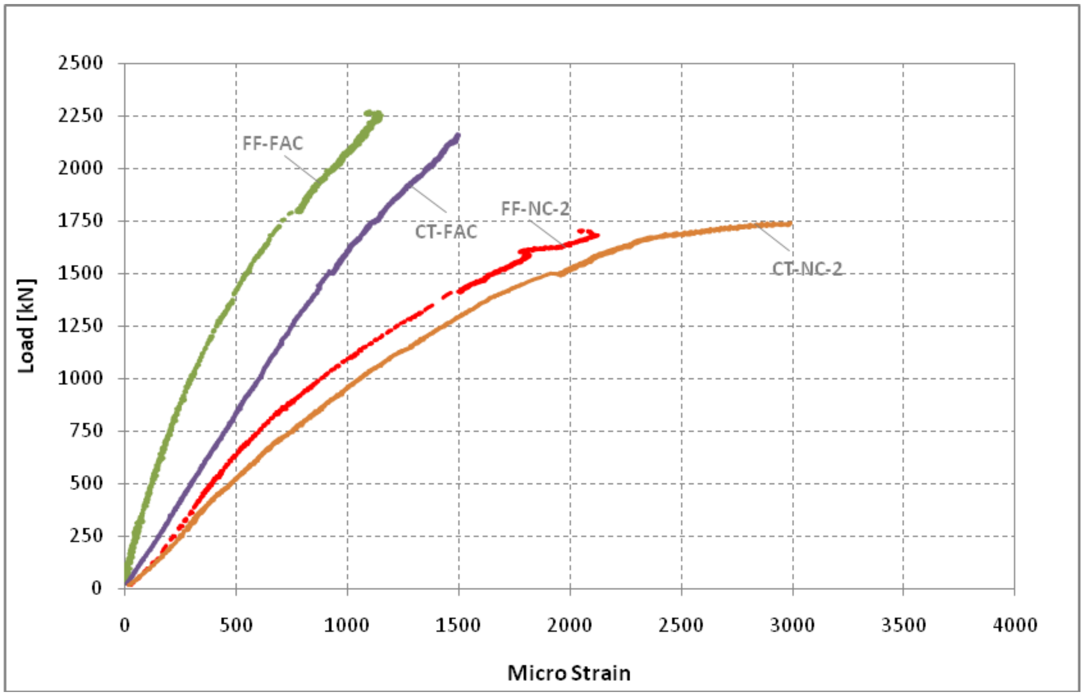


Figure 62: Readings from West pi-gauges at the top of all columns

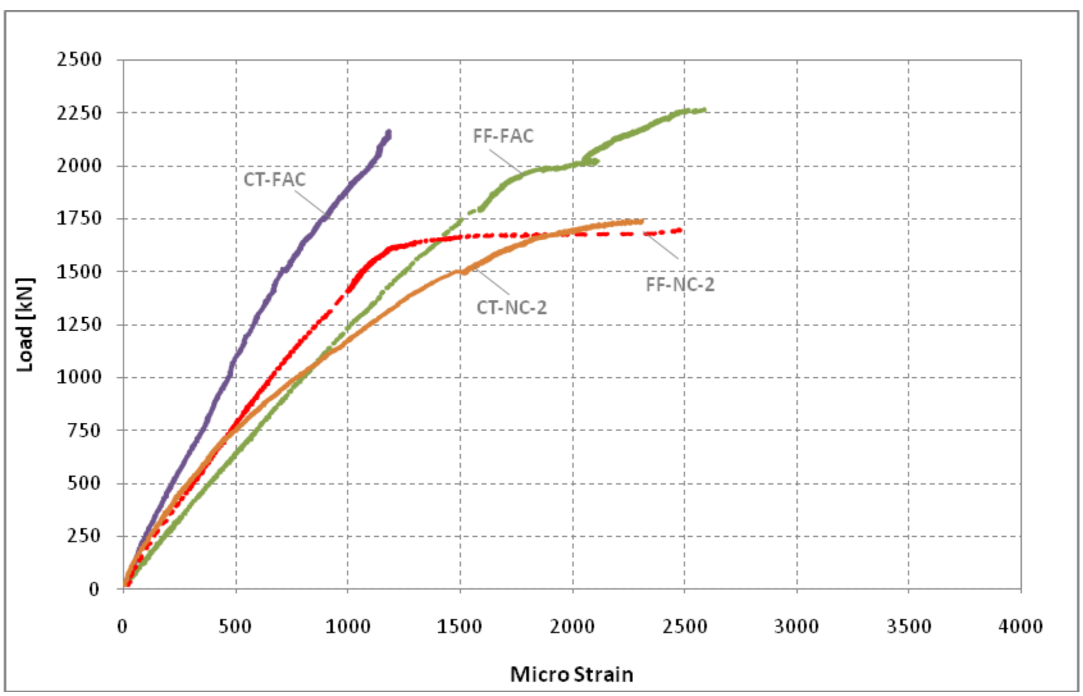


Figure 63: Readings from East pi-gauges at the top of all columns

As seen in Figure 60 which represents the readings from North pi-gauges at the top of all columns, a trend of reverse strain close to the failure load is observed. This means that as columns were starting to crush at another location, the surrounding concrete was experiencing some tension. Figure 61 represents readings from South pi-gauges at the top of all columns. As seen in this figure, columns undergo much larger strain values as high as 3600 micro strain at the load of about 2150 kN in case of column CT-FAC. Strain values read from the south pi-gauge of column FF-NC-2 change direction from compression to tension close to the failure load. This has been caused by the uneven failure of the column at top. As seen in Figure 64, the opposite side of the column across from the south pi-gauge has failed in compression and caused some tension in south-top-zone of the column. Figure 62 which represents the readings from West pi-gauges at the top of all columns shows the highest strain in column CT-NC-2 as 3000 micro strain at the corresponding load of 1750 kN. A similar trend is observed in Figure 63 from the values taken from top-East pi-gauges. Column FF-FAC carries 2700 micro strain at the load of 2250 kN. As seen in all top pi-gauge curves, except column CT-NC-2, regardless of the formwork type, flyash concrete experienced more strain than normal concrete. As seen in Figure 65, all six columns failed at the top. This type of failure in columns has been documented before in research conducted by Bazant and Kwon (1994) which found that regardless of the cross sectional size of the column, the fracture mechanism stayed the same. The reason for the top end failure is that the top end of a vertically cast member will always have less compressive strength than the lower parts of the member, due to increased pressure and compaction towards the bottom of the mold (Maynard and Davis 1974). This holds true regardless of the formwork used.

Flaking and surface concrete delamination observed in the failure of both fabric-formed columns also confirms that the surface of the concrete cast in fabric formwork was more brittle than concrete cast in conventional formwork. The change in Poisson's ratio was also studied when these columns were tested. The value was derived from dividing the average value of the data from two circumferential strain gauges placed at 180° apart from one another, by their corresponding axial pi-gauges. Both flyash and normal concrete fabric formed columns, proved to have lower Poisson's ratio value which is another indication of brittleness and less surface deformation in the fabric-formed specimens. It is necessary to mention that it is nearly impossible to form a perfectly straight column using handmade fabric column formwork, so very small values of eccentricity in loading condition may occur. Since small values of the eccentricity do not create large moment values at end portion of the columns, the effects of small eccentricities can be neglected (Bazant and Kwon 1994).

Figure 64: Column FF-NC-2 after failure

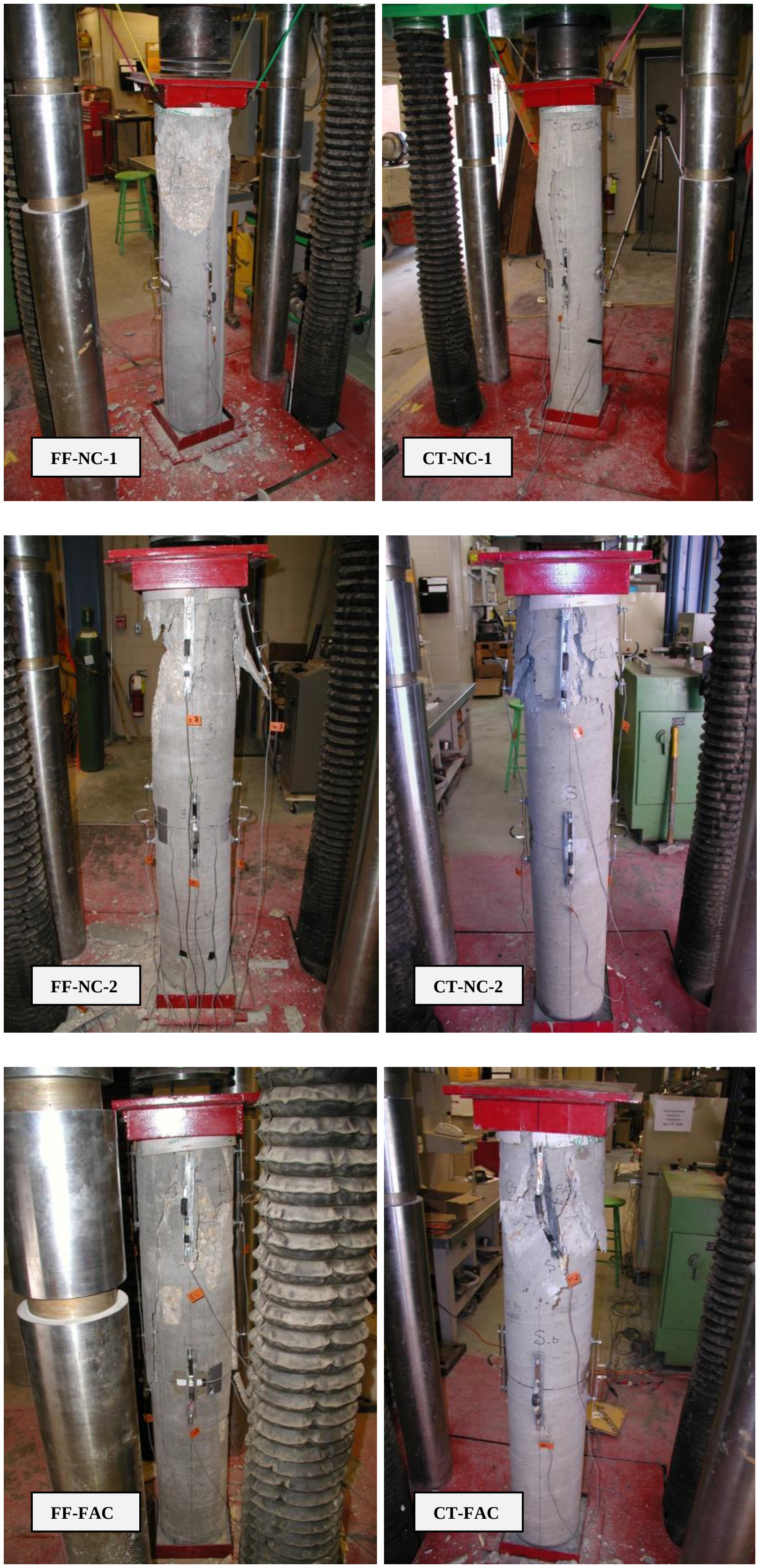


Figure 65: All columns after failure

In each concrete type, both fabric-formed columns withstood the same axial load level as the cardboard formwork control samples. All samples failed at the top portion. At the extreme top portion of a concrete column, a permeable fabric mold does not loose appreciably more water than a conventional formwork or a cardboard tube. Therefore, in columns cast with the similar type of concrete, regardless of formwork material, strength of the concrete at top zone always remains the same and constitutes the area of weakest concrete in ach column.

This test proved that use of a well designed permeable fabric formwork for casting steel reinforced concrete column is safe while it provides several advantages such as improved surface finish, lower material costs and the possibility of creating organic concrete forms with lower cost than conventional formworks. Concrete produced with fabric formwork is structurally capable of bearing the same loads as conventionally formed concrete.

5.8 Lessons Learned About Fabric Formwork

Our first attempt of casting a concrete column using fabric formwork was not quite successful. The column was bulgy at some points and it did not have constant diameter along its length while cardboard molds that are industrially manufactured are perfectly symmetrical tubes and form perfectly symmetrical columns. The reason for this problem was that the fabric was sandwiched between the boards using bolts and when the concrete was poured inside the mold, the hoop tension created by the liquid concrete pulled the fabric out between the bolts (Figure 66). Areas supported by bolts resisted the pressure while parts away from bolts deformed creating bulges along the length of the hardened concrete column, as shown in Figure 67.

To avoid such problem, another formwork was built but this time, the fabric was stapled to the sandwich boards along the length of the fabric. Staples were applied on a straight line, only a few millimetres apart from each other (though less staples would be probably also sufficient), providing a stitch line from top to bottom of the formwork. Orientation of the stitch line can be seen in Figure 43. Stapling provided an even distribution of the hoop forces along the height of the formwork and resulted in a uniform cylindrical geometry. The variation in diameter of the column along its length was dramatically reduced as demonstrated in Figure 68.

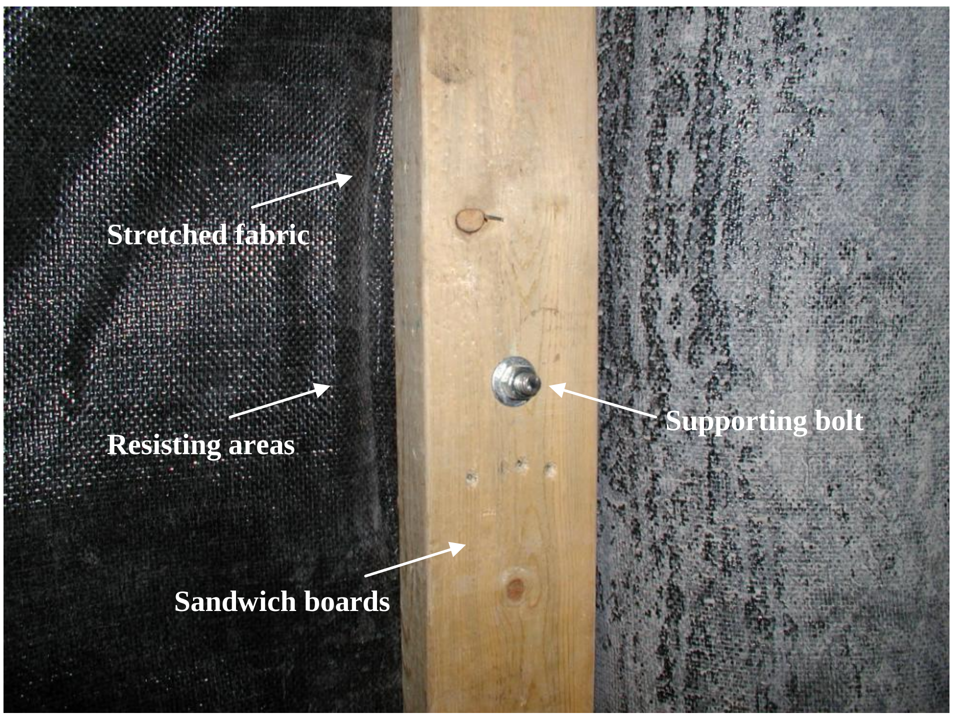


Figure 66: Tension created in fabric due to hoop pressure of the liquid concrete.

Figure 67: Bulged concrete column

Figure 68: Modified fabric formwork resulting in a straight column

When casting concrete columns in fabric formwork, extra attention must be paid to the initial concrete distribution at the bottom of the mold. In order to avoid problems, first scoops of the concrete must be vibrated by hand from outside to make sure fresh concrete has been evenly distributed inside the mold and the bottom of the fabric formwork tube does not rise up during this initial concrete placement. A video showing commercial practice for casting cylindrical fabric formed columns can be seen on the Fab-form web-site (http://www.fab-form.com/products/fasttube/fasttube_video.html).

Chapter 6

Summary and Conclusions

6.1 Summary

This thesis investigated the structural behaviour of fabric formed concrete. At the beginning comparison tests on small cylinders revealed that fabric formwork cast normal concrete can gain 13 to 17% strength, while flyash concrete gained 13 to 16% at 28 days. These strength gains had no effect on the ultimate strength observed in full size column tests.

As you increase diameter, area will grow much faster than the circumference will (Figure 69). The larger the diameter of the column, the less effect circumferential bleeding will proportionally have on the structural area of the column. Figure 70 shows the comparison between the affected perimeter concrete areas due to fabric formwork to the total sectional area in specimens with different diameters.

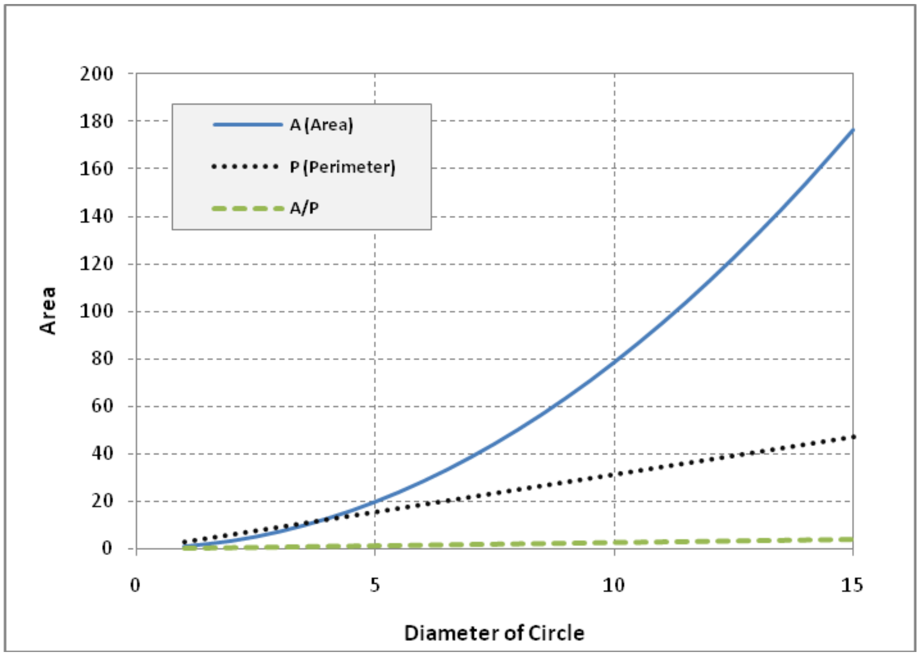


Figure 69: Relationship between area, perimeter and, diameter of a circle

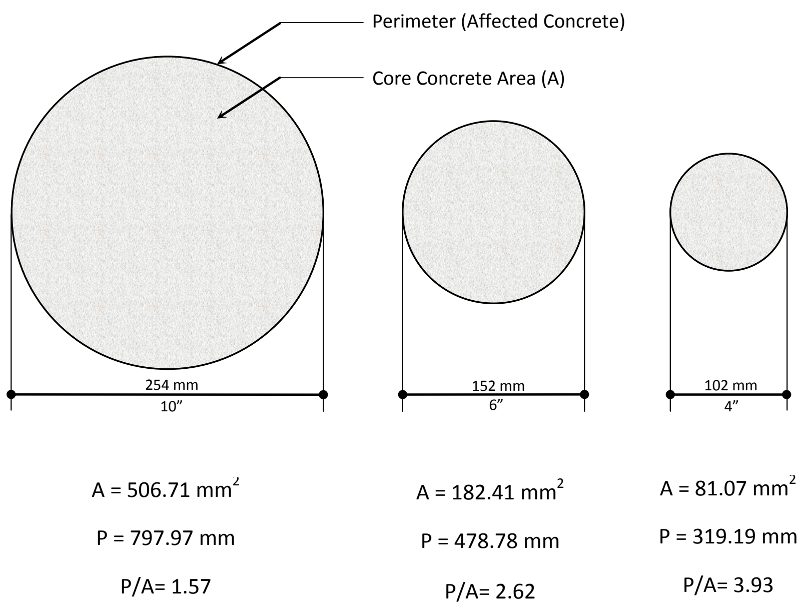


Figure 70: The effect of cross section size on strength

Since the depth effect of fabric formwork on concrete quality is not dependent on the diameter, the ratio of the affected area to the whole sectional area of the specimen is a definitive factor. As seen in the Figure 70, the larger the area of the member, the smaller the ratio of perimeter over area is. The smaller this ratio is the less effect the fabric formwork has on a member's concrete strength. This has been confirmed by cylinder and column tests in this thesis.

The smaller 101 by 203 mm (4 by 8 in.) fabric formed cylinders proved to gain an average of 15% extra compressive strength comparing to the conventionally molded control samples while some preliminary tests showed that 152 by 305mm (6 by 12 in.) cylinders gain an average of 10.3% extra compressive strength. The 254 mm (10 in.) diameter fabric formed flyash concrete column gained an extra 5% compressive strength compared to cardboard formed flyash column. In case of columns FF-NC-2 and CT-NC-2, the strength of fabric formed normal concrete column was decreased by 2% compared to cardboard tube formed column. A comparison of the test results shows that the growth in overall compressive strength in a concrete column due to fabric formwork diminishes as the diameter of the column increases.

6.2 Conclusions

The research presented in this thesis supports the following conclusions:

1. As shown by Schmidt hammer test results, permeable fabric formwork for concrete can enhance the quality and the hardness of the surface zone of the concrete.

2. Based on results of this research study, geotextile fabrics such as Geotex 315ST are suitable for forming fresh concrete. Mechanical properties and the optimal bleeding ratio, availability, price, as well as the fabric texture/imprint produced, make these products viable for use as concrete formwork.

3. Concrete texture produced by fabric formwork is without bug holes or honeycombs sometimes seen in conventionally formed concrete. No color variation was observed on the surface of the fabric formed columns. Very few imperfections or appearance of large aggregate was seen when fabric formwork was used. Such concrete could be used as the surface for exposed structural member with no or minimum additional work.

4. Even though fabric formed cylinder tests showed an average of 15% increase in compressive strength of the fabric formed reinforced columns did not change appreciably when compared to the companion cardboard formed control columns. The reason would be the fact that the ratio of the affected concrete area due to fabric formwork, reduces as the diameter of the specimen increases. Therefore, fabric formwork does not increase the overall compressive strength of a large/thick concrete member. Furthermore, compression failure in columns occurs at the top, where bleeding effect and strength advantage are minimum due to

minimal hydrostatic pressure. Ultimately, it can be concluded that fabric formwork is structurally safe alternative for forming reinforced concrete columns.

6.3 Suggestions for Future Studies

1. Permeable fabric formworks may require special handling during curing because their permeability can allow surface water evaporation unless protected, for example, by being wrapped in plastic sheeting. For this reason, there is a possibility that improper curing practices during construction may have an especially detrimental effect on concrete cast in permeable molds. Tests are needed on specimens cured in field conditions to study the susceptibility of concrete cast in permeable molds to strength loss due to improper curing practices.

2. This study did not use plasticizing admixtures. The effect of bleeding on plasticized concrete should be studied to gauge the effect of fluid loss in concretes with lower W/C rations. If fabric formwork helps bleed extra water and air bubbles out, it will also bleed the admixtures and chemicals added to the concrete mix, a phenomenon that may or may not affect the efficacy of the admixtures used in the mix design.

3. Due to the differences in W/C ratios and concrete strength in FF concrete, differences in qualities such as permeability and fire resistance of reinforced fabric-formed concrete members need to be studied.

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Appendices

Appendix A: Cost Analysis

Use of fabric formwork for concrete columns, would result in savings for project owners, builders and contractors. Since in this study comparison was made between cardboard and fabric formwork, a cost evaluation was adapted from the industry (Fab-Form Industries Ltd. 2009) to show the amount of savings when the two techniques are being employed. This case study reviews cost analysis of column forms for a project in Aldergrove, BC. As seen in Table A1 and A2, the analysis compares the overall cost of a non-permeable commercially available column fabric formwork called Fast-Tube™ (Figure A1) to conventional cardboard formworks and Geotex 315ST used in this thesis. As seen in Table A2, comparing to cardboard formwork, cost analysis shows 72.2% reduction in cost for Fast-Tube™ and 89.8% for Geotex 315ST.

Table A1: Project detail used for cost analysis

Project Details	mm	inch
Column diameter	254	10
Column height	1520	60
Number of columns	24	

Figure A1: Commercially available column fabric formwork called Fast-Tube™ (left) and conventional cardboard formworks (right) on a job site

Table A2: Project detail used for cost analysis

Item	Fast-Tube™	Cardboard	Geotex 315ST
Form purchase length m [ft]	36.56 [120]	2.44 [8]	78.64 [258] (Roll of 5.33m/17.5' width)
Total linear length required m [ft]	36.56 [120]	58.52 [192]	7.62 [25]
Waste per column [%]	0	38	0
Price per linear foot	$0.95	$1.69	$1.57 (per column/17.5 sqf)
Purchase price	$113.69	$323.76	$39.25
Volume of column forms m [ft^3]	0.023 [0.815]	1.89 [67]	0.023 [0.815]
Delivery cost	$ -	$26.32	$ -
Setup time [min/column]	same	same	?
Stripping time [min/column]	0.5	3	0.5
Stripping cost	$4.17	$25.00	$4.17
Disposal cost	$ -	$49.33	$ -
Total cost	**$117.86**	**$424.41**	**$43.42 ***

** Plus cutting and assembly time for handmade formed columns*

Table A3: General assumptions used for cost analysis of the project

General Assumptions	
Volume of column forms	Assumes every 2nd cardboard tube is nested inside the first
Delivery cost	\$0.01/m³ [\$0.39/ft³], local courier, 30 minute delivery
Disposal cost	\$0.04/m³[\$1.48/ft³], assumes full truckload pricing, stripped cardboard volume is 1/4 of original
Purchase price	Contractor price, Vancouver, BC for Fast-Tube™ and Winnipeg, MB for Geotex 315ST
Disposal	Fast-Tube used as an under-slab membrane, Geotex 315ST used as geotextile, cardboard goes to landfill
Geotex 315ST Specs.	Rolls of 418 sqm [4500 sqf], 1.07 by 1.52 m [3.5' by 5'] of fabric needed to form each column

Appendix B: Mechanical Press Apparatus Weight Calculations

1. Finding the necessary mass values 1500 mm from the top end of the column, considering total height of the column as 300 mm:

- Total height of concrete above the 305 mm (12 in.) tall sample at the middle of the column (Figure B1) equals:

$300cm - 150.00 = 150.00\ cm$

- Area of the 6" diameter cylinder:

$6'' \times 2.54 = 152\ mm$

$$Area = \frac{(\pi\ d^{\ 2})}{4} = \frac{(3.1415\ (152)^{\ 2})}{4} = 18145\ mm^2$$

- Volume of the concrete on top of the section:

$V = 18145\ mm^2 \times 1500\ mm = 27217500\ mm^3 = 0.0272\ m^3$

- Mass of the concrete:

If $\rho_c = \frac{Mass\ of\ Concrete}{Volume\ of\ Concrete}$

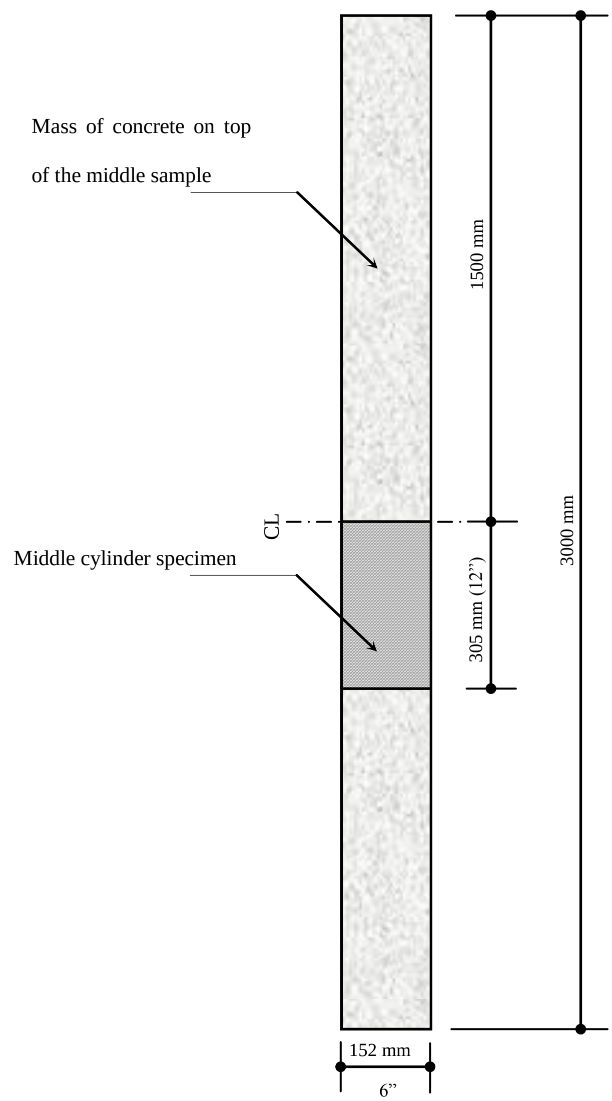

Figure B1: Position of the 6 by 12 inch middle concrete sample along the length of a 3 meter high concrete column

Considering ρ for concrete as 2300 kg/m^3 then:

$$M = \rho_c \times V = 2300\,kg/m^3 \times 0.0272\ m^3 = 62.56\,kg$$

Therefore, 63.02 kg of load needed to be applied on top of the middle cylinder to simulate the load of the concrete column at that point.

- Self weight of the lever handle including wooden piston and the hook (Figure B2):

$$4.67\ kg\ +\ 0.95\ kg\ =\ 5.62\ kg$$

- Reaction at point B, due to the self wight of the handle, wooden piston and hook only:

$$\circlearrowright + \sum MA = 0$$

$$-R_B \times 0.25 + 5.62\ \times 1.00\ \times \frac{1.00}{2} = 0 \quad \Rightarrow \quad R_B = 11.24\ kg$$

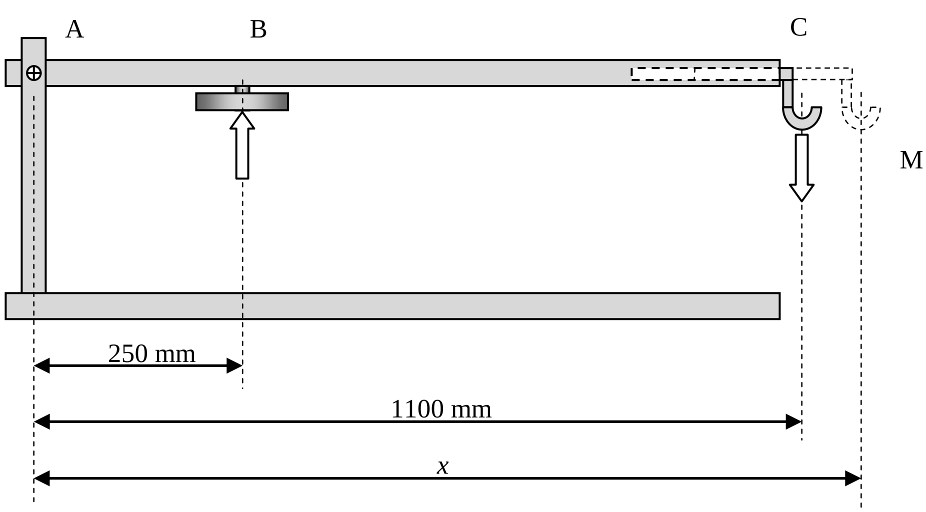

Figure B2: Press apparatus configurations and details

R_B equals the reaction at point *B* or at the wooden piston due to the weight of the piston and the steel lever handle alone. Therefore, necessary mass (M) hung on the one meter long lever handles equals:

$$1000\ mm \times M = 250\ mm\ (62.56 - 11.24) \Longrightarrow M = 12.83\ kg$$

Using a bucket of water as M= 12.83 kg hung on the hook, the lever would apply 62.56 kg of load on the fresh cast fabric formed concrete sample. This weight was applied on mid height samples to find the bleeding ratio of the middle point of a three meter high concrete column.

2. To find the necessary mass value on the bottom sample (Figure B3), following calculations were made. Considering the total height of the column as 300 mm:

- Total height of concrete above the 12" tall sample:

$$12'' = 305\ mm$$

$$3000\ mm - 305\ mm = 2695\ mm$$

- Area of the 6" diameter cylinder = $18241\ mm^2$

- Volume of the concrete:

$$V = 18241\ mm^2 \times 2695\ mm = 49159495\ cm^3 = 0.0492\ m^3$$

- Mass of the concrete equals:

$$M = \rho_c \times V = 2300\ kg/\ m^3 \times 0.0492\ m^3 = 113.16\ kg$$

- Total weight of the lever handle, wooden piston and the hook:

$$4.67\ kg\ +\ 0.95\ kg\ =\ 5.62\ kg$$

- Reaction at point B (R_B), due to the wight of the handle, including wooden piston and the hook only:

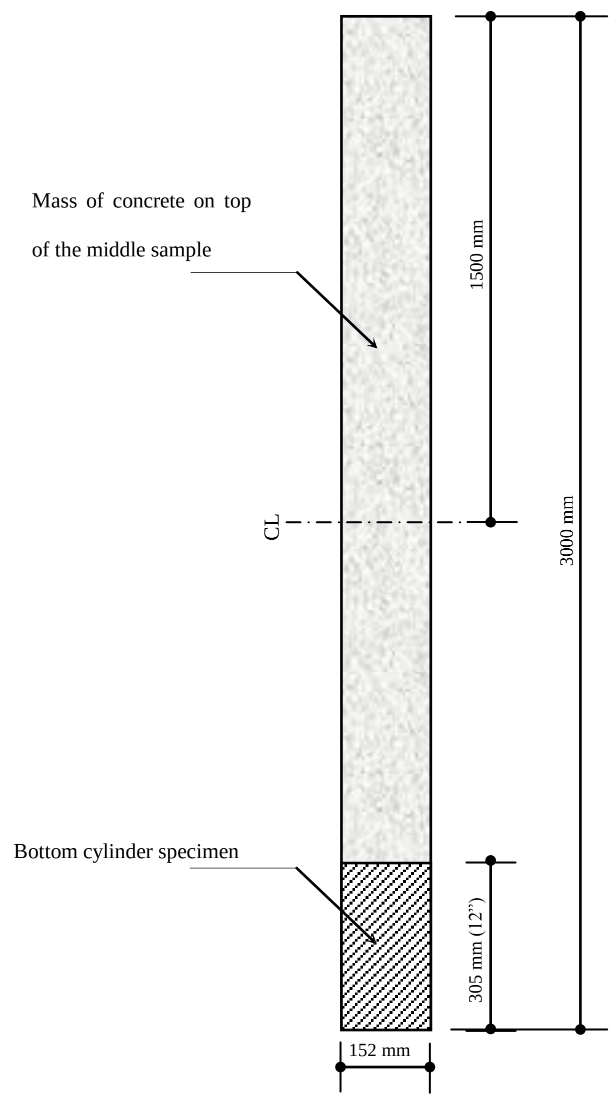

Figure B3: Position of the 6 (diameter) by 12 (height) inch bottom concrete samples along the length of a 3 meter high concrete column

$$\circlearrowright + \sum MA = 0$$

$$-R_B \times O.25 + 5.62 \times 1.00 \times \frac{1.00}{2} = 0 \quad \Rightarrow \quad R_B = 11.24\ kg$$

R_B equals the reaction at point *B* or at the wooden piston due to the weight of the piston and the steel lever handle alone. To find *"x"* (Figure B2) we have:

$$x \times 24\ kg = 250\ mm\ (113.16 - 11.24) \quad \Rightarrow \quad x = 1061\ mm$$

Using available fixed weights of 24 kg hung on to the hook, *"x"* is the total length needed on the lever's handle to create and apply 113.16 kg of load on our fresh cast fabric formed concrete sample.

Appendix C: Results from Rebound Tests (Schmidt Hammer Tests)

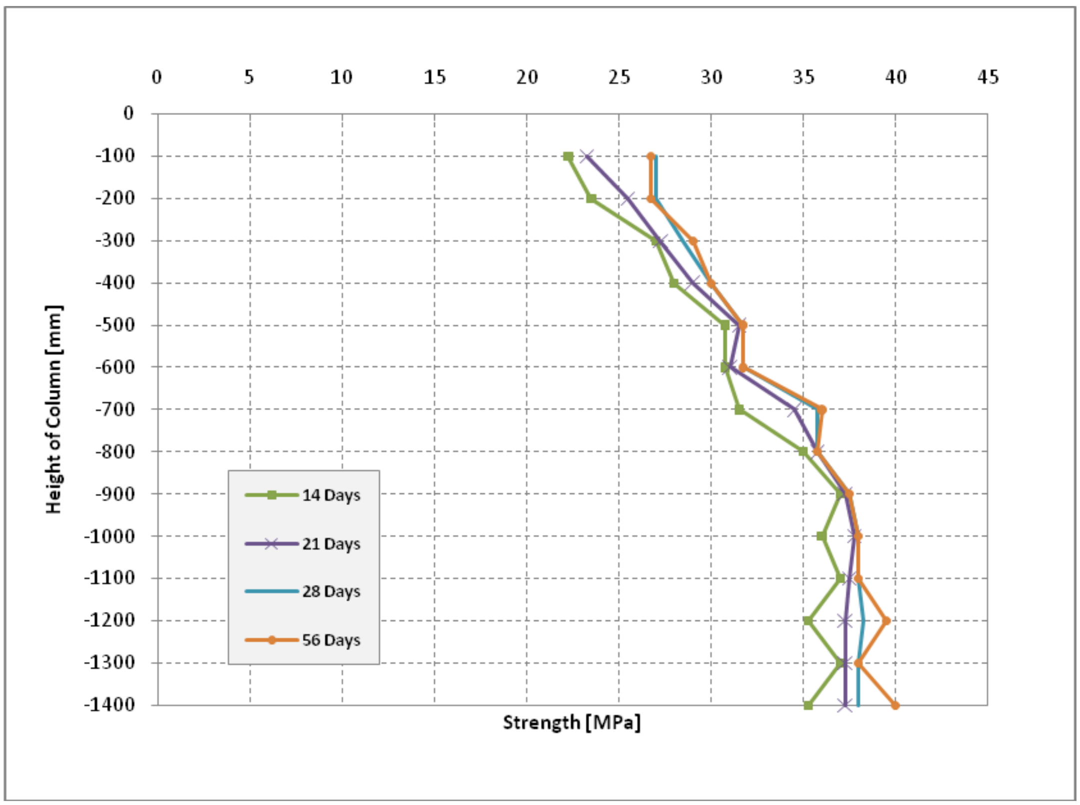

Figure C1: Column C1 – Fabric Formwork, Normal Concrete

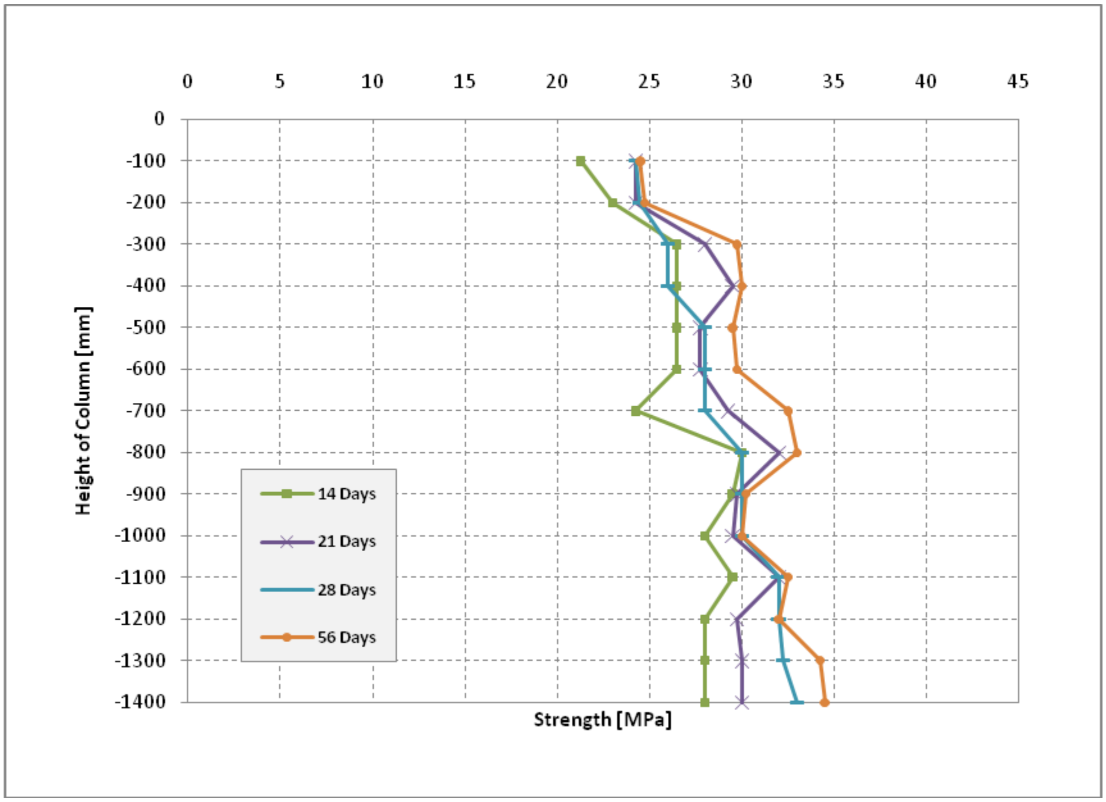

Figure C2: Column C2 – Cardboard Tube, Normal Concrete

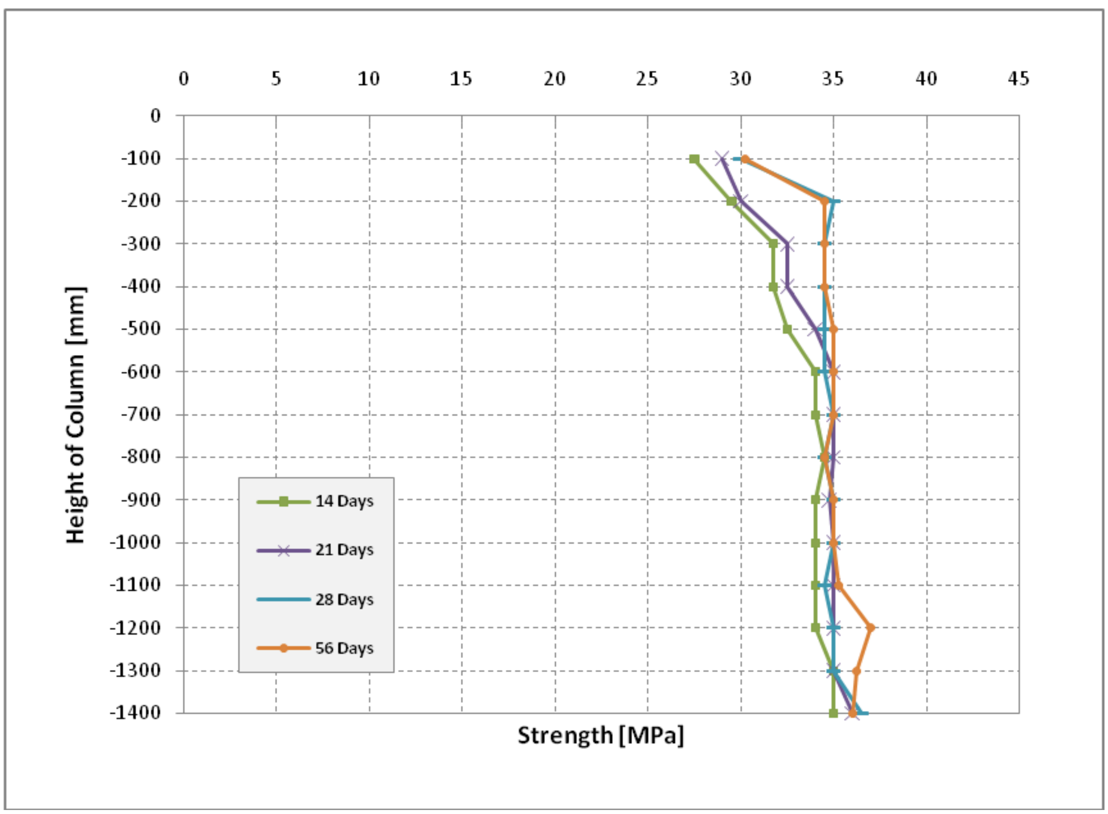

Figure C3: Column C3 – Fabric Formwork, Flyash Concrete

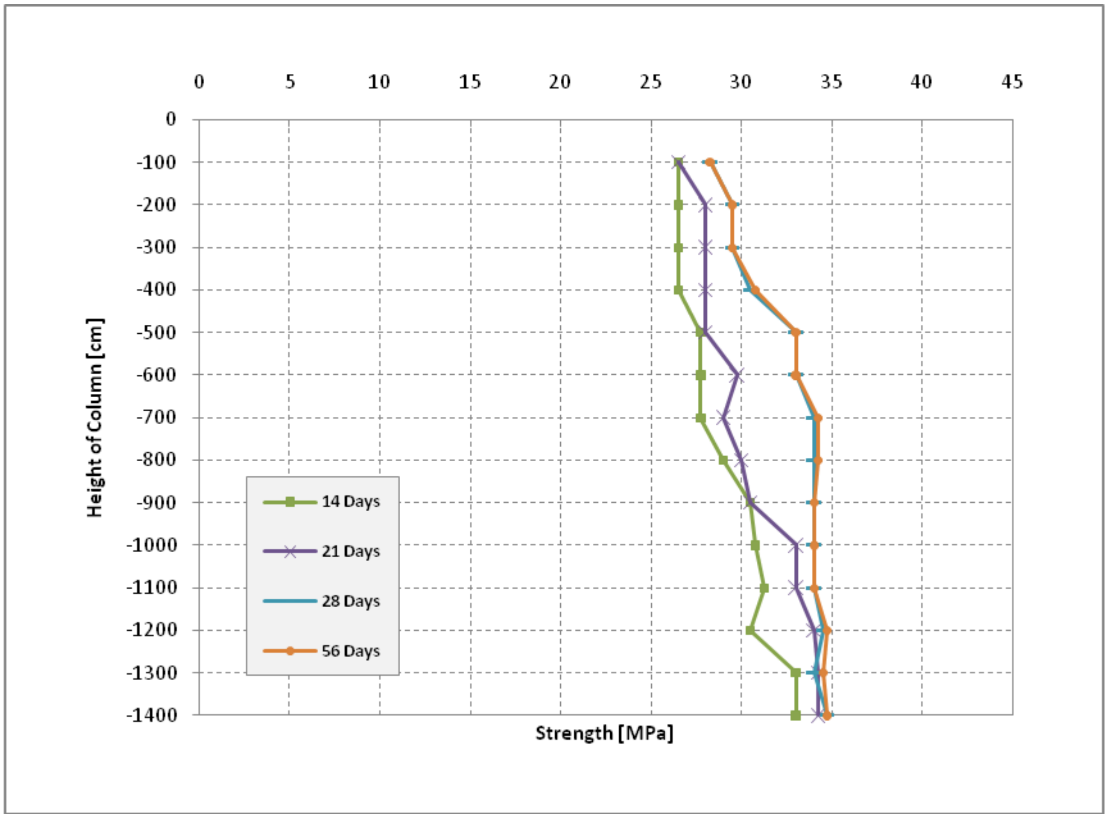

Figure C4: Column C4 – Cardboard Tube, Flyash Concrete

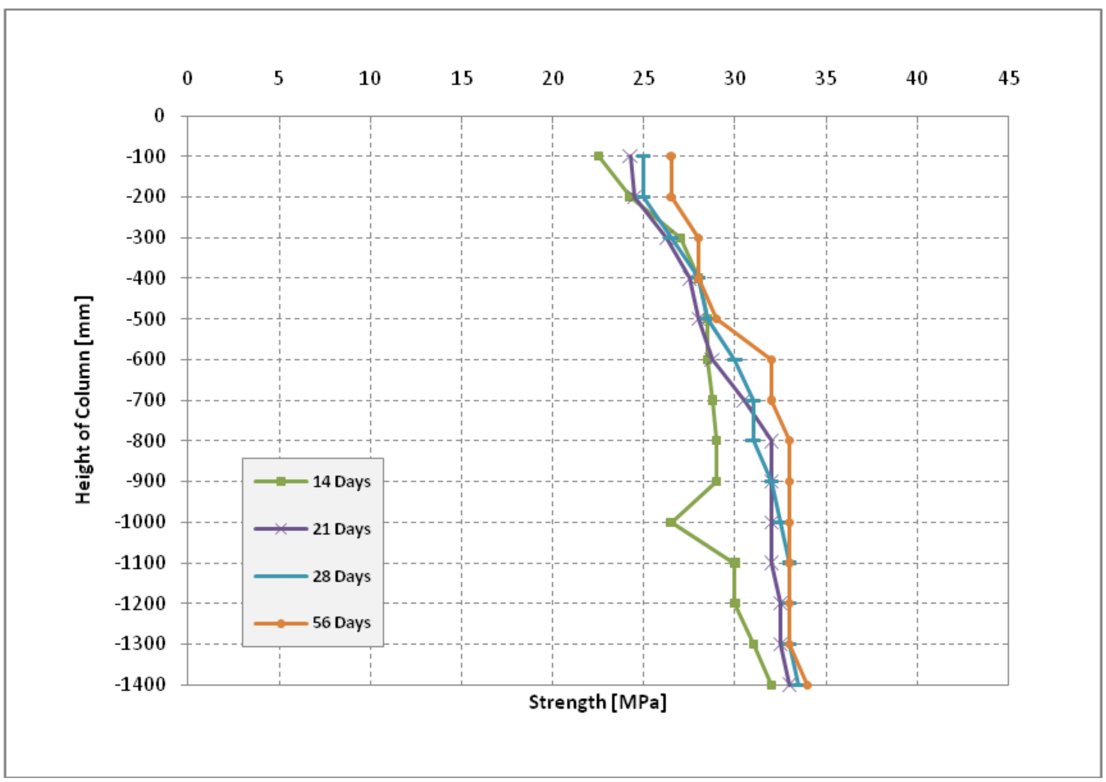

Figure C5: Column C5 – Fabric Formwork, Normal Concrete

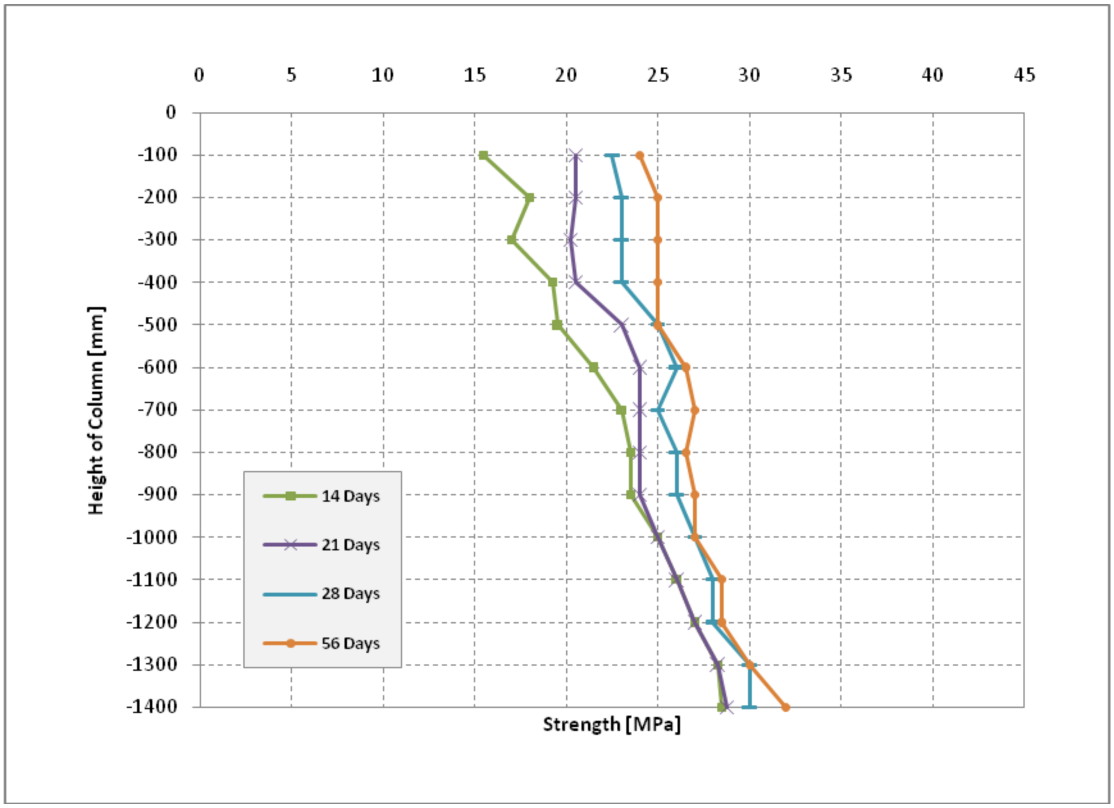

Figure C6: Column C6 – Cardboard Tube, Normal Concrete

Appendix D: Summary of Calculations and General Assumptions in Colum Design

Load eccentricity $= 0$

$f'_c = 25\ MPa$

$f_y = 400\ MPa$

$Diameter\ of\ the\ cross\ sectional\ area = 254\ mm = 10\ inches$

Therefore, concrete cross sectional area equals:

$$A_g = \frac{\pi d^2}{4} = \frac{\pi\ 254^2}{4} = 50670.75\ mm^2$$

Controlling Slenderness (CSA A23.3 Cl. 10.14.2):

$Radius\ of\ Gyration\ of\ circular\ columns\ (r) = 0.25D = 0.25\ (254) = 63.5\ mm$

Considering a pin-pin support, $k = 1\ and\ l_u = 1500\ mm,$

Therefore, the slenderness ratio equals:

$$\frac{kl_u}{r} = \frac{1 \times 1500}{63.5} = 23.62\ mm$$

In order to be able to ignore the slenderness effect, following condition should be satisfied (CSA A23.2 Eq. 10.15):

$$\frac{kl_u}{r} \leq \frac{25 - 10 \times (\frac{M_1}{M_2})}{\sqrt{\frac{P_f}{f'_c A_g}}}$$

Considering design load of $P_f = 600\ kN;$

If eccentricity equals zero; M_1 and M_2 (Moments at the ends of the columns) are both equal to zero:

$$23.62 \leq \frac{25 - 10 \times (\frac{0}{0})}{\sqrt{\frac{600 \times 1000}{25 \times 50670.75}}} = 36.33$$

Since the condition is satisfied, slenderness effect could be ignored.

Reinforcement Design

According to the CSA code (A23.3 Cl. 10.9.1 and 10.9.2), column reinforcement ratio (ρ_t) should be in the range from 1% to 8% of the cross sectional area. But since there is no lap splice region in the columns, the range will be limited between 1% to 4% (Brzev and Pao 2006) Also, according to A23.3 Cl. 10.9.3, minimum number of longitudinal bars for columns with circular ties shall be four. Assuming use of 4 Ø15 longitudinal bars:

$$Area\ of\ Reinforcement = A_{st} = 4 \times 200 = 800\ mm^2$$

Reinforcement ratio (A233 Cl.10.9) can be calculated as:

$$\rho_t = \frac{A_{st}}{A_g} = \frac{800\ mm^2}{50670.75\ mm^2} = 0.01579$$

Knowing that the reinforcement ratio is within the range:

$$0.01 \leq 0.01579 \leq 0.04$$

Therefore, 4 Ø15 steel bars could be selected as longitudinal bars.

Maximum Axial Load

Ratio of average stress in rectangular compression block to specified block (α_1) equals (A23.3 Eq. 10.1):

$$\alpha_1 = 0.85 - 0.0015\ f'_c \geq 0.67$$

Therefore:

$$\alpha_1 = 0.85 - 0.0015 \times 25 = 0.8125 \geq 0.67$$

Based on CSA A23 Eq. 10.10:

$$P_{ro} = \alpha_1 \varphi_C f'_c (A_g - A_{st}) + \varphi_s f_y A_{st}$$

Omitting the resistance factors of steel and concrete we can rewrite the equation as:

$$P_{ro} = \alpha_1 f'_c (A_g - A_{st}) + f_y A_{st}$$

Therefore, maximum factored axial load resistance of the reinforced column can be predicted as:

$$P_{ro} = \alpha_1 f'_c (A_g - A_{st}) + f_y A_{st} = 0.8125 \times 25\ (50670.75 - 800) + 400 \times 800$$

$$P_{ro} = 1332999.61\ \mathrm{N} = 1333\ \mathrm{KN}$$

Considering maximum capacity of the testing machine as 2670 kN, the calculated value of 1333 kN as the maximum predicted axial load capacity of the columns is within the safe margin (about 50% of the maximum load capacity of the testing machine).

Appendix E: All Columns Test Result Curves

Following graphs provide the results obtained from DAQ in each column test session. Figures E1 to E6 show the load versus strain curves for all columns at all available sensor attached to the specimen.

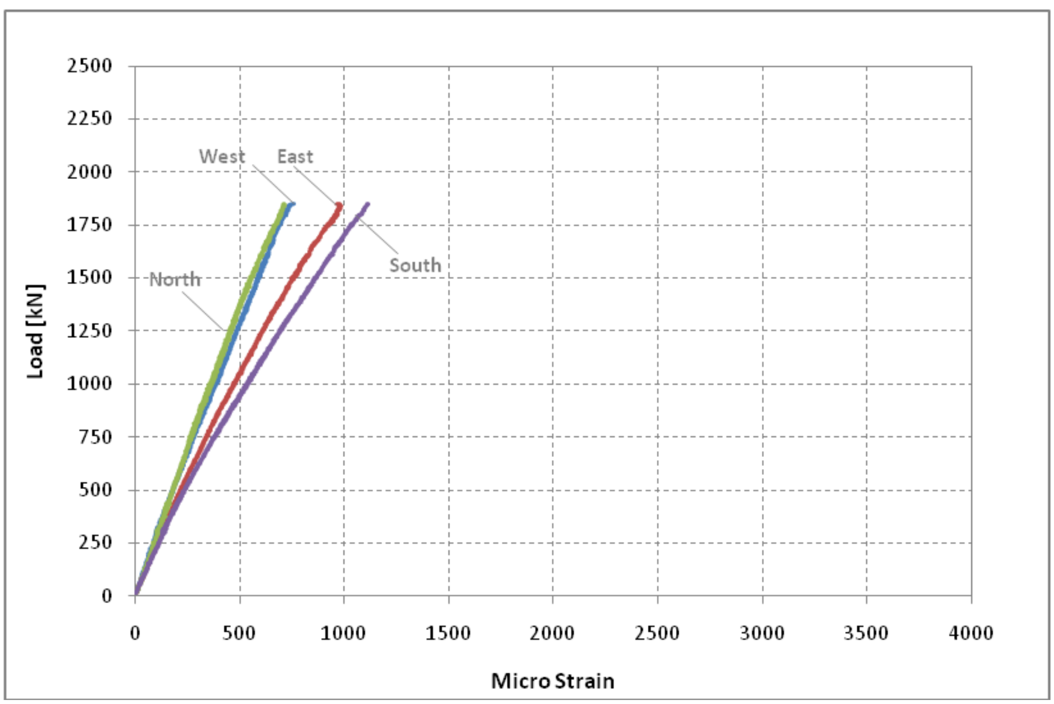

Figure E1: Column FF-NC-1, all pi-gauges

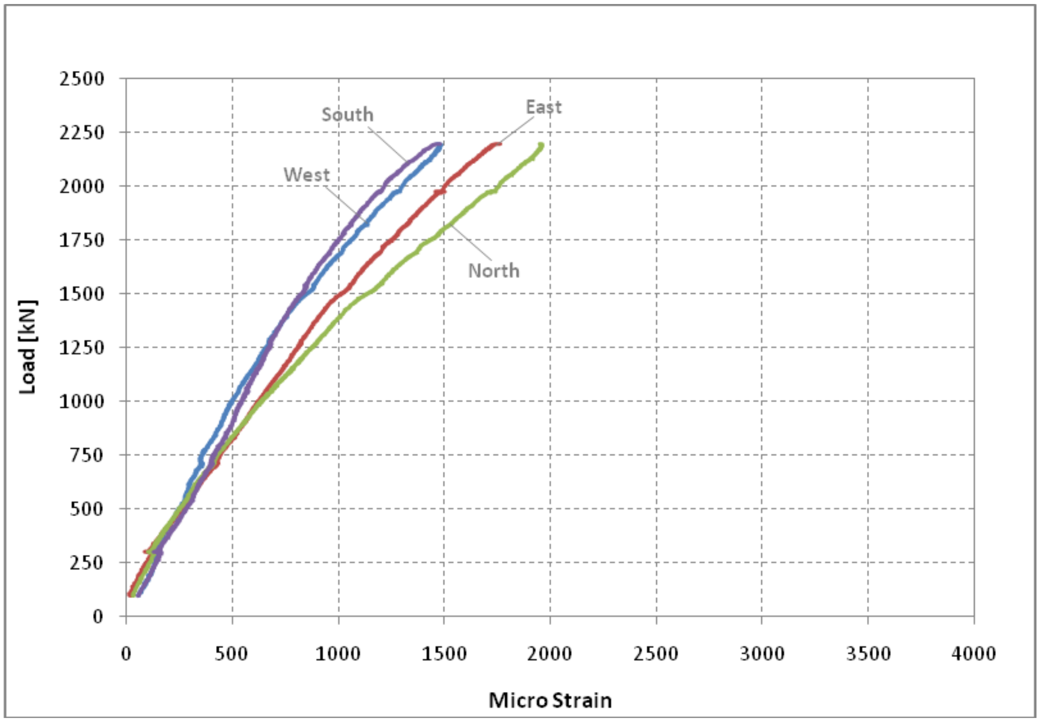

Figure E2: Column CT-NC-1, all pi-gauges

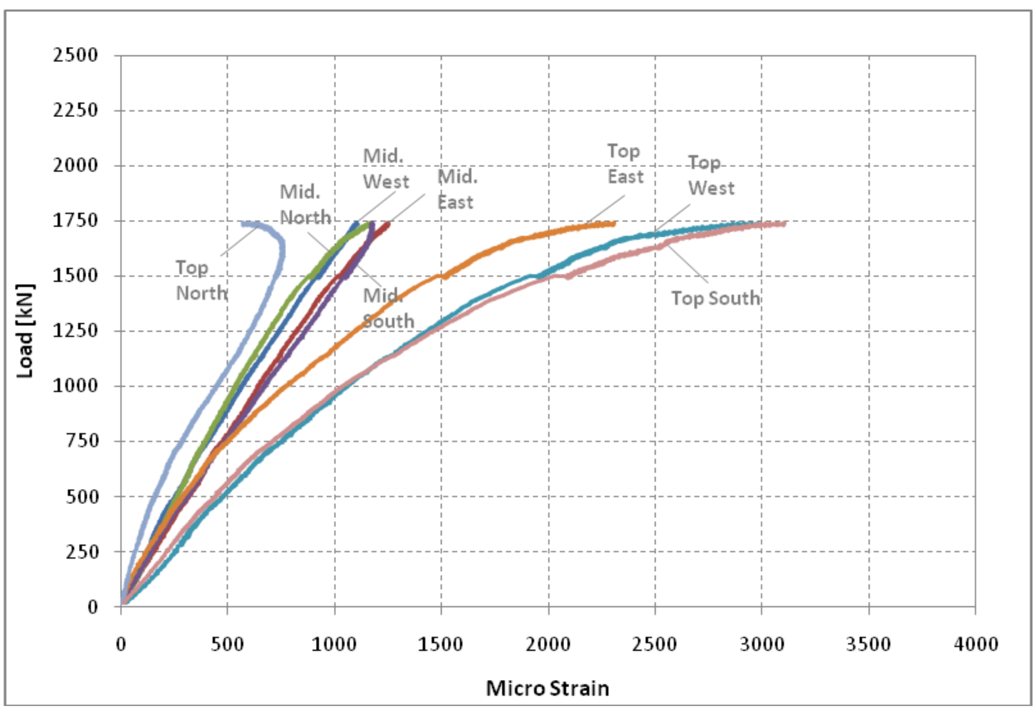

Figure E3: Column FF-FAC, all pi-gauges

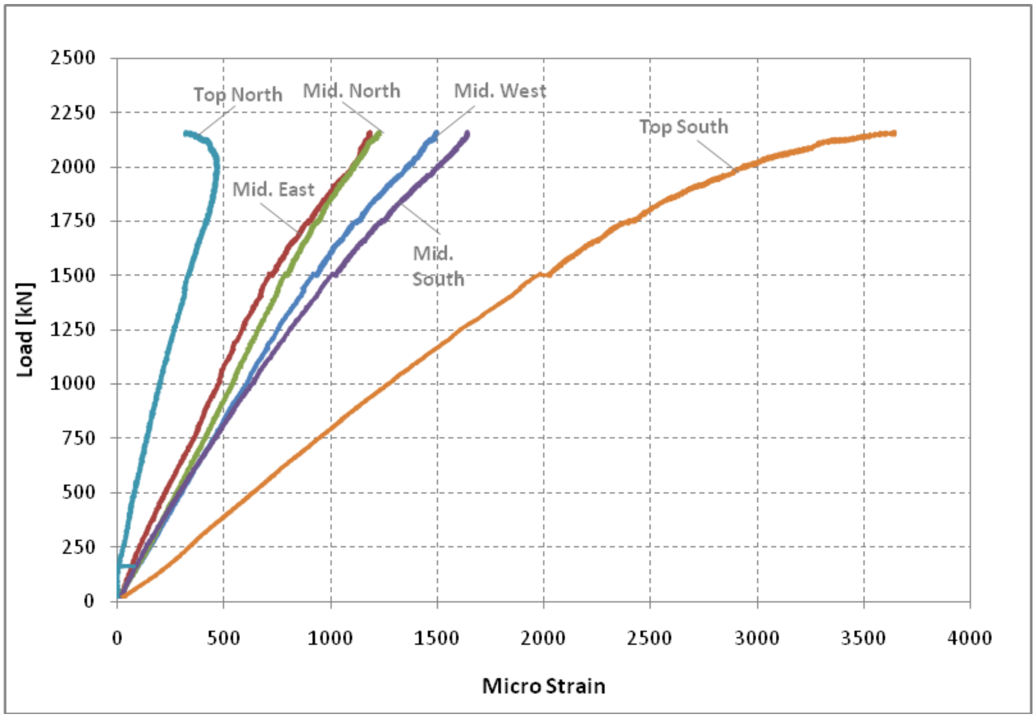

Figure E4: Column CT-FAC, all pi-gauges

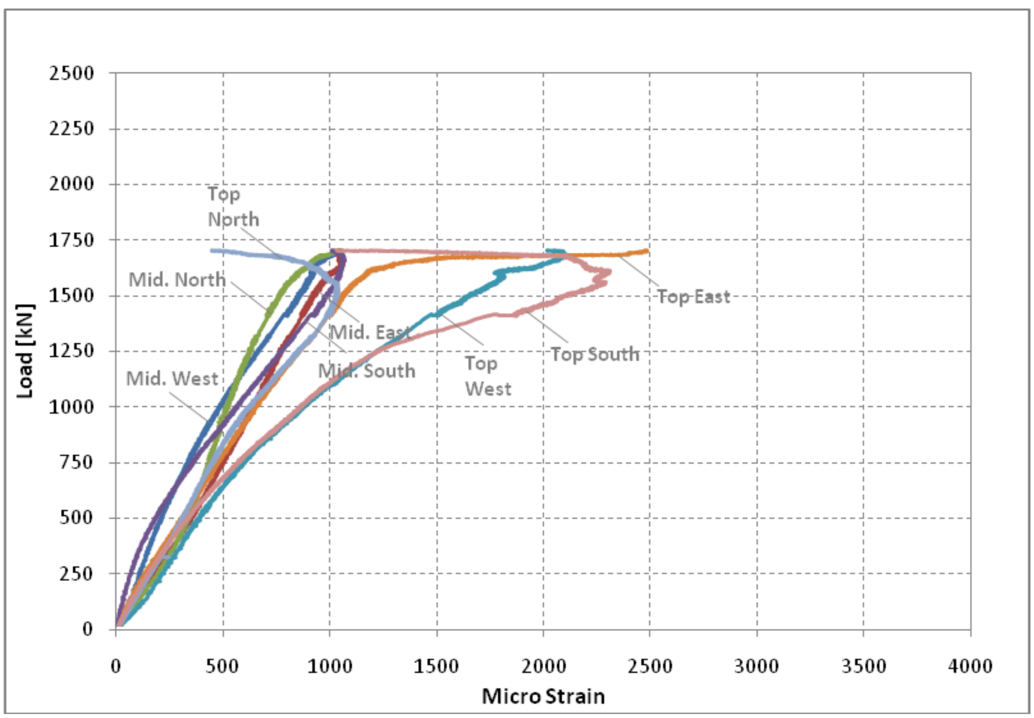

Figure E5: Column FF-NC-2, all pi-gauges

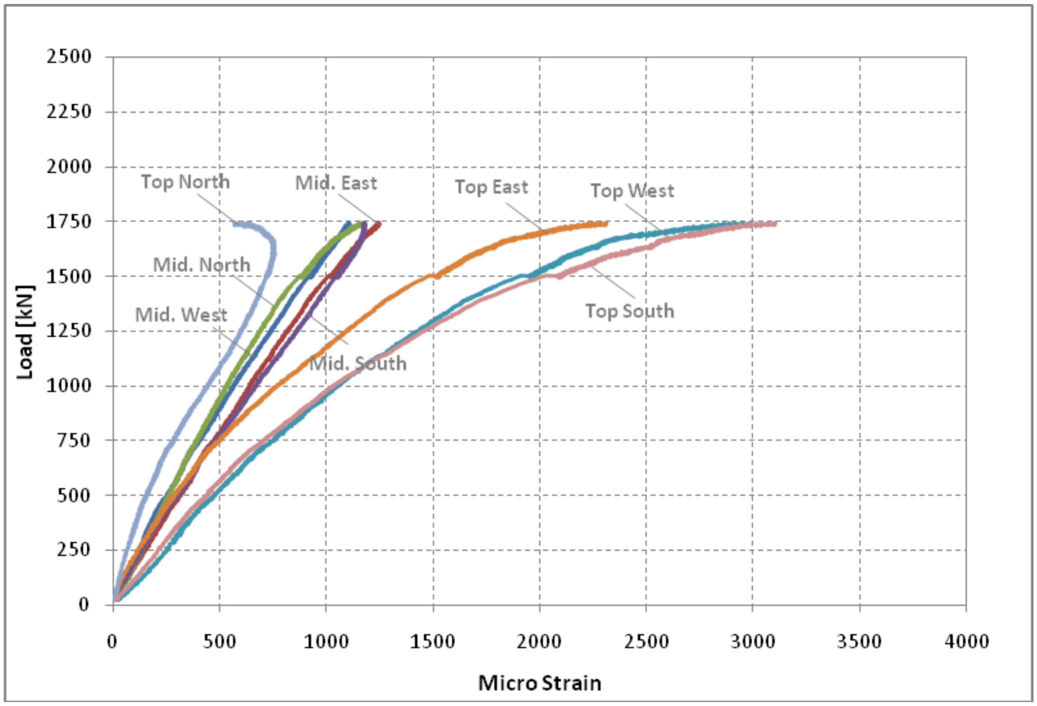

Figure E6: Column CT-NC-2, all pi-gauges