

EVALUATION OF PUMPABILITY OF CONCRETE

K.D.N. Perera

178002L

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

December 2019

EVALUATION OF PUMPABILITY OF CONCRETE

Kurugamage Dilini Nuwanthika Perera

178002L

Thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

December 2019

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Masters under my supervision.

Name of the supervisor: Prof. S. M. A. Nanayakkara

Signature of the Supervisor:

Date:

DEDICATION

To my beloved parents, my loving husband and family for their overwhelming support and courage extended to me throughout this research project

And

To Prof. S. M. A. Nanayakkara, Dr. (Mrs.) M. T. P. Hettiarchchi and all of my dear teachers, who are the reasons behind my every successful step

ACKNOWLEDGEMENTS

My heartfelt gratitude goes to Prof S. M. A. Nanayakkara, my research supervisor for his expert guidance throughout the research project. Whenever, problems arose to achieve milestones and decisions had to be made, he confidently led me in the correct path.

The research project was funded by Siam City Cement (Lanka) Ltd. I am so grateful to Mr. Kalinda Dassanayake, the advisor for the research project from Siam City Cement (Lanka) Ltd; for providing all the necessary financial support and facilities for the experimental studies. The ICAR plus concrete rheometer was also provided by Siam City Cement (Lanka) Ltd.

I would like to acknowledge Prof. Asamoto for his generous advice and support for this project. He organized a diaphragm type pressure transducer and 20 strain gauges for the experiments at the time we needed. Those equipment played a major role in experiments conducted at the construction sites.

I warmly thank Dr. Takahashi for his kind advice and guidance. At some critical stages, his expert advice and recommendations were quite helpful for us to make decisions.

It was privilege to conduct research experiments at two high rise building projects with the support from Sanken Construction (Pvt) Ltd; who was the contractor of both construction sites. I would like to extend my gratitude to Ranjith San, Aruna San, Nalin San and Mr. Arshad for supporting my experimental studies. Furthermore, my special thanks goes to Rupasinghe San for providing us an altered pipe section in the pipe line circuit to fix the pressure transducer.

The dynamic data logger used to record data from pressure transducer and strain gauges was borrowed from structural Engineering Laboratory of Dept. of Civil Engineering at University of Ruhuna. My sincere thanks are to Dr. H. P. Sooriyaarachchi, Dr. N. H. Priyankara and Dr. K. S. Wanniyachchi of Dept. of Civil Engineering at University of Ruhuna for lending the data logger to use for the research experiments.

My special thanks goes to all the laboratory staff of Building Materials Laboratory and Structural Testing Laboratory; especially Mr. Leenus, Mr. Piyal and Mr. Lanka for the continuous support for my laboratory experiment.

I would also be pleased to acknowledge Dr. Damith Chathuranga, Mr. Janaka Basnayake and Mr. Uditha Roshan for their assistance in designing the bridge circuits for the strain gauges. Their technical support for the experimental investigations is much appreciated.

Last but not least, I am so much thankful to Mr. Tharanga Wickramasinghe for designing a laboratory apparatus (tribometer) as per my request.

Evaluation of Pumpability of Concrete

ABSTRACT

Current guidelines and practices at construction sites on concrete pumping has not been based on theoretical understanding of pipe flow of fresh concrete. In fact, only the slump value is monitored at construction sites, even-though any single point test is insufficient to represent flow curve properties of fresh concrete.

Based on flow curves of concrete and basic rheological properties, a theoretical model for horizontal straight flow has been developed and validated in previous studies. Yet, properties of concrete flow at horizontal and vertical bends, tapered sections and vertical lengths had to be investigated. In this research study, experimental investigations were carried out at two high rise building construction sites which included monitoring rheology of fresh concrete with ICAR plus concrete rheometer and pressure at some points of the concrete pumping pipe line with a pressure transducer and several strain gauges. In the horizontal straight section, theoretical pressure drop based on sheared plus plug flow condition could reasonably estimate the actual pressure drop with a 20% margin. Pressure drop at a horizontal bend was in between 0.5 to 1.7 bar while in a vertical bend it was around 6 bar. Pressure drop in the vertical straight length was equal to the pressure needed to overcome the self-weight only. Hence, concrete pumping pressure could be estimated within 20% margin.

Moreover, understanding on the influence of mix design parameters on concrete rheology is much useful for deciding the mix proportions of concrete at the mix design stage. A series of laboratory experiments were conducted at paste and mortar phases of concrete. Correct admixture concentration, increase of w/c ratio, decrease of fine aggregate volume concentration and round shape fine aggregates over angular shape found to be improving the rheological properties and hence the pumpability of concrete.

Key words: fresh concrete rheology, concrete pumping, concrete pipe flow

TABLE OF CONTENTS

Declaration	i
Dedication	ii
Acknowledgements	iii
Abstract	v
Table of Contents	vi
List of Figures	x
List of Tables	xiii
List of Abbreviations	xiii
CHAPTER 1: Introduction.....	1
1.1 Background	1
1.1.1 Current practices in Sri Lanka.....	2
1.1.2 Guidelines	3
1.1.3 Studies on concrete pumpability	6
1.2 Problem Statement.....	8
1.3 Objective.....	9
1.4 Research Plan	9
1.5 Guide to Thesis.....	10
1.5.1 Literature Review.....	10
1.5.2 Theoretical Investigation.....	10
1.5.3 Field Tests	11
1.5.4 Lab Experiments	11
1.5.5 Analysis and Conclusions	11
CHAPTER 2: Litratione review	12
2.1 Flow Characteristics	12
2.1.1 Behaviour of Suspensions	12

2.1.2	Shear Thinning Effect	12
2.1.3	Thixotropic Behaviour	13
2.2	Theoretical Understanding on Concrete Pipe Flow.....	13
2.2.1	Lubrication layer	14
2.2.2	Flow Curves	14
2.2.3	Theoretical model by Kaplan.....	15
2.3	Apparatus for Testing on Rheology of Concrete.....	16
2.3.1	Rheometers.....	16
2.3.2	Tribometers	18
2.4	Factors affecting Pumpability of Concrete.....	19
CHAPTER 3:	Theory of Concrete Pipe-Flow	22
3.1	Introduction	22
3.2	Flow curves of concrete.....	23
3.2.1	Flow curve of bulk concrete.....	26
3.2.2	Flow curve of lubrication layer	27
3.3	Mechanism of concrete pipe flow	29
3.4	Theoretical model for concrete pipe flow	32
CHAPTER 4:	Experimental Investigations	35
4.1	Introduction	35
4.2	Equipment	35
4.2.1	Rheological Measurements with ICAR plus Rheometer	35
4.2.2	Dynamic Data Logger – Kyowa Edx-100A.....	40
4.2.3	Diaphragm type Pressure Transducer	41
4.2.4	3-wire Strain Gauges.....	42
4.3	Evaluation of Concrete Pumping in High-rise Building Constructions	44
4.3.1	Procedure	47

4.4	Laboratory Experiments	49
4.4.1	Procedure of measurement of rheological properties.....	49
4.4.2	Rheometer Test	52
4.4.3	V funnel test	54
4.4.4	Flow Table Test.....	55
CHAPTER 5: Results and Analysis.....		57
5.1	Change of Fresh Concrete Properties and Influencing Factors	57
5.1.1	Discussion	60
5.1.2	Summary	62
5.2	Investigation on Pressure drops at horizontal and vertical bends and horizontal and vertical straight sections.....	63
5.2.1	Instrumentation	63
5.2.2	Procedure	66
5.2.3	Analysis of field data	67
5.2.4	Pressure variation in Horizontal Straight pipe Section	70
5.2.5	Pressure drop at Horizontal Bend	74
5.2.6	Pumping pressure drop in Vertical pipe Length	76
5.2.7	Radial and Line pressure in concrete pumping pipe-line.....	78
5.2.8	Pumping pressure drop in Vertical Bend	78
5.2.9	Summary of the finding of the concrete pumping field test.....	80
5.3	Influence of Mix-Design Parameters on rheological properties of cement paste and mortar phases of concrete.....	80
5.3.1	Effect of PCE Dosage	80
5.3.2	W/C Ratio	85
5.3.3	Cement Type	88
5.3.4	Fine Aggregate Concentration	90

5.3.5	Fine Aggregate Type.....	92
5.3.6	Summary of the important finding of lab investigation.....	95
CHAPTER 6:	Conclusions.....	96
	References.....	99
	Appendix-I: Theoretical Derivations for Concrete Pipe Flow.....	103
	Appendix-II: Theoretical Derivations for Sheared plus Plug Flow of Concrete	107
	Appendix-III: Specifications and Calibration Report of ICAR plus Concrete Rheometer	110
	Appendix-iv: Specifications of PWF-20MPB Pressure Transducer.....	111
	Appendix-V: Specifications of FLA-5 Strain Gauge.....	112
	Appendix-VI: Bridge Circuit details for Strain Gauges.....	113
	Appendix-VII: Mix Design used for Slab Concrete at CCC	114
	Appendix-VIII: Mix Design used for Slab Concrete at Luna Tower.....	115
	Appendix-IX: Concrete Pumping Data from Several High Rise Constructions.....	116
	Appendix-X: Observation sheets	123

LIST OF FIGURES

Figure 1-1: Estimation of Concrete Pumping Pressure Source: (Bognacki, et al., 1996)	4
Figure 1-2: Pressure loss per meter run Source: (Tamon & Hiroshi, 2010)	5
Figure 1-3: Research Plan	9
Figure 1-4: Guide to Thesis.....	10
Figure 2-1: Shear thinning effect	12
Figure 2-2: ConTec Viscometer 5 Source: (Feys, Khayat, Perez-Schell, & Khatib, Development of a tribometer to characterize lubrication layer properties of self- consolidating concrete, 2014)	17
Figure 2-3: ICAR plus Rheometer	17
Figure 2-4: Some Concrete Rheometers from literature Source: (Ferraris, et al., 2000)	17
Figure 2-5: Tribometer by Feys Source: (Feys, Khayat, Perez-Schell, & Khatib, Development of a tribometer to characterize lubrication layer properties of self- consolidating concrete, 2014)	18
Figure 2-6: Chapdelain's Tribometer Source: (Jolin, Burns, Bissonnette, Gagnon, & Bolduc, 2009).....	18
Figure 2-7: Tribometer by Ngo Source: (Ngo, Kadri, Bennacer, & Cussigh, 2010). 18	
Figure 2-8: Sliding Pipe Rheometer Source: (Mechtcherine, Nerella, & Kasten, 2014)	19
Figure 3-1: Schematic pattern of concrete flow in pipe source: (Choi, Roussel, Kim, & Kim, 2013b)	22
Figure 3-2: Shearing between layers of a fluid	23
Figure 3-3: Bingham Fluid Model	25
Figure 3-4: Flow curve of Bulk Concrete	26
Figure 3-5: Flow curve of Bulk Concrete	27
Figure 3-6: Lubrication Layer.....	28
Figure 3-7: Shear stress applied at r distance to the centre line	29
Figure 3-8: Shear stress, shear strain and shear rate of plug flow.....	30

Figure 3-9: Shear stress, shear strain and shear rate in case of sheared plus plug flow condition.....	30
Figure 3-10: Resulting shear stress to induce fresh concrete pipe flow.....	32
Figure 3-11: Velocity Profile for Sheared flow model by Kaplan.....	33
Figure 3-12: Velocity profile for sheared plus plug flow	33
Figure 4-1: Assembly of the servo motor with vanes (a); Collecting a concrete sample to the container (b) & Arrangement of the ICAR plus Rheometer (c).....	36
Figure 4-2: Conducting a test with ICAR plus Rheometer at the construction site ...	36
Figure 4-3: Mechanism of torque and angular velocity	38
Figure 4-4: Flow condition in ICAR plus Rheometer.....	39
Figure 4-5: Strain gauge transducer to input to Edx-100A	40
Figure 4-6: Pressure transducer attached to the pipe line	41
Figure 4-7: Pressure transducer connection to the pipe line	41
Figure 4-8: NDIS plug of the Pressure Transducer.....	42
Figure 4-9: Quarter Whenston Bridge circuit for Strain Gauge.....	43
Figure 4-10: Compensation of lead wire length in 3 wire strain gauge	43
Figure 4-11: Bridge Circuits used to connect strain gauges to the data logger.....	44
Figure 4-12: Colombo City Centre Tower	45
Figure 4-13: Construction site of 447 Luna	45
Figure 4-14: Field Experiment procedures	48
Figure 4-15: Procedure for lab tests	51
Figure 4-16: Stress Growth Test in ICAR plus rheometer.....	52
Figure 4-17: Flow Curve Test in ICAR plus rheometer	53
Figure 4-18: Schematic Diagram of the V funnel test apparatus	54
Figure 4-19: V funnel test	54
Figure 4-20: Schematic diagram of cone and hammer - flow table test for mortar ...	55
Figure 4-21: Flow Table Test for mortar	56
Figure 5-1: Pipe circuit details of Luna Tower construction site.....	63
Figure 5-2: Photos of the strain gauges.....	64
Figure 5-3: Fixing the altered pipe section to apply pressure transducer	65
Figure 5-4: Data Logger and Bridge circuits	66
Figure 5-5: Pressure and strain variation with pumping of LJ-0482 concrete truck..	67

Figure 5-6: Readings corresponding to several strokes	67
Figure 5-7: Prediction of dynamic pressure from strain gauge measurements	68
Figure 5-8: Averaging pressure and strain values in dynamic range	69
Figure 5-9: Pressure drop in horizontal length versus theoretical values	71
Figure 5-10: Pressure drop in horizontal section w.r.t. Plastic Viscosity	72
Figure 5-11: Asymmetric flow profile due to gravity	73
Figure 5-12: Possible flow curve patterns for fresh concrete	74
Figure 5-13: Pressure drop in 90 ⁰ Horizontal bend w.r.t. guidelines predictions	75
Figure 5-14: Pressure drop in Vertical length	77
Figure 5-15: Pressure drop in Vertical 90 ⁰ bend w.r.t. guideline predictions	79
Figure 5-16: DYS over PCE dosage - Paste phase	82
Figure 5-17: PV over PCE dosage - Paste phase	82
Figure 5-18: DYS over PCE dosage - Mortar phase	83
Figure 5-19: PV over PCE dosage - Mortar phase	83
Figure 5-20: Flow-rate prediction over PCE dosage - Mortar phase	84
Figure 5-21: DYS over w/c ratio - Paste phase	86
Figure 5-22: PV over w/c ratio - Paste phase	86
Figure 5-23: DYS over w/c ratio - Mortar phase	87
Figure 5-24: PV over w/c ratio - Mortar phase	87
Figure 5-25: Flow-rate prediction over w/c ratio - Mortar phase	88
Figure 5-26: DYS over Cement type - Paste phase	89
Figure 5-27: PV over Cement type - Paste phase	89
Figure 5-28: DYS over Fine Aggregate Concentration - Mortar Phase	91
Figure 5-29: PV over Fine Aggregate Concentration - Mortar phase	91
Figure 5-30: Flow-rate prediction over Fine Aggregate Concentration - Mortar phase	92
Figure 5-31: DYS over Fine Aggregate type - Mortar phase	93
Figure 5-32: PV over Fine Aggregate type - Mortar phase	93
Figure 5-33: Flow-rate prediction over Fine Aggregate type - Mortar phase	94

LIST OF TABLES

Table 1-1: Equivalent Horizontal Pipe Length Source: (Tamon & Hiroshi, 2010).....	5
Table 4-1: Mix proportions of concrete phase control specimen.....	49
Table 4-2: Paste phase control sample	49
Table 4-3: Control sample in mortar phase.....	50
Table 4-4: Mix design parameters studied in lab experiments	50
Table 5-1: Change of fresh concrete properties	59
Table 5-2: Average Dynamic pressure at each section	69
Table 5-3: Pressure Drop in 15.3 m Horizontal Straight Pipe section	71
Table 5-4: Pressure Drop in Horizontal 90 ⁰ Bend of 370 mm radius	75
Table 5-5: Pressure Drop in 39 m long Vertical Straight Pipe	76
Table 5-6: Pressure Drop in 90 ⁰ Vertical Bend of 400 mm radius	78
Table 5-7: Tested Cement Types	88

LIST OF ABBREVIATIONS

<i>ACI</i>	-	<i>American Concrete Institute</i>
<i>JSCE</i>	-	<i>Japan Society of Civil Engineers</i>
<i>rpm</i>	-	<i>revolutions per minute</i>
<i>SYS</i>	-	<i>Static Yield Stress</i>
<i>DYS</i>	-	<i>Dynamic Yield Stress</i>
<i>PV</i>	-	<i>Plastic Viscosity</i>
<i>CA</i>	-	<i>Coarse Aggregate</i>
<i>FA</i>	-	<i>Fine Aggregate</i>
<i>w/c</i>	-	<i>Water to Cement ratio by weight</i>
<i>CCC</i>	-	<i>Colombo City Centre</i>
<i>OPC</i>	-	<i>Ordinary Portland Cement</i>
<i>PCE</i>	-	<i>Poly Carboxylic Ether</i>
<i>PLC</i>	-	<i>Portland Limestone Cement</i>
<i>MS</i>	-	<i>Manufactures Sand</i>