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UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF REGRESSION MODELS FOR PREDICTING PROPERTIES OF HIGH STRENGTH CONCRETE USING NONDESTRUCTIVE TESTS

SHIBLI RUSSEL HAJI MOHIUDDIN KHAN

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By

SHIBLI RUSSEL HAJI MOHIUDDIN KHAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

May 2007

To My Parents Haji Mohiuddin Khan - Haji Begum Rokeya, Eldest Sister Hosne Ara Khan and My Beloved Wife Shegufta Rahman

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: Associate Professor Ir. Mohd Saleh Jaafar, PhD

Faculty : Engineering

High strength concrete (HSC) is a relatively recent development in concrete technology. It is being used increasingly in major civil engineering and building projects. This leads to the need for quality assurance of the in-situ concrete. Testing of concrete traditionally involved compression testing of cylinders or cubes to obtain the properties and these may not adequately represent the in-situ properties of concrete. This necessitates the use of non-destructive test (NDT). There are no standard relationships that had been established for high strength concrete physical and mechanical properties using Sclerometer test, Ultrasonic Pulse Velocity (UPV) methods and Pullout test. Prediction models need to be developed for concrete strength, density and static elastic modulus estimation. They are normally required in building or structural assessment, especially with the present trend of constructing modern structures using high strength concrete.

Eight different mix proportions of HSC containing sandstone aggregate of nominal sizes of 10mm and 19mm and silica fume content were investigated in this study.

The silica fume contents were varied at 0%, 5%, 10% and 15%. These mixes produced concrete at 28-day strength between 40 MPa to 100 MPa. A total of 360 standard cubes (150mm), 144 cylinders (150 x 300mm) and 16 reinforced beams were cast for this study. A total of forty-five standard cube specimens for each mix were tested at the age of 3, 7, 14, 28 and 56 days in both, nondestructive and destructive manner. On the other hand, eighteen cylinder specimens for each mix were tested at the age of 28 and 56 days in both, nondestructive and destructive manner. As for the pullout test some forty-five inserts were prepared for each mix at the age of 3, 7, 14, 28 and 56 days. For each destructive test, an average of 45 values of nondestructive tests was obtained, which depends on the type of NDT techniques used. The results were analyzed using statistical tools (SPSS ver.13). The prediction models for each NDT technique were developed based on the obtained experimental results. Statistical tests of significance on the predicted models were performed to ascertain their reliability in estimating the concrete properties. Predicted models were also further validated using data from other researchers.

The models developed in this study are expected to be used to estimate strength, density and static elastic modulus parameters using Sclerometer test, UPV method and Pullout test. The generalized power models for strength, density and modulus of elasticity prediction using Sclerometer and Pullout test were found to be unaffected by the aggregate sizes. The maximum error of these models were found to be ±12.5% for strength-Sclerometer test, ±25% for strength-Pullout test, ±3% for density-Sclerometer test, ±2% for density-Pullout test and ±5% for static elastic modulus-Sclerometer test.

Strength, density and static modulus of elasticity prediction for direct and indirect UPV methods indicated that aggregate sizes should be known in advance. Generalized quadratic models were proposed for concrete mix with nominal aggregate size 10mm (series A_{10}) for strength, density and modulus of elasticity prediction using UPV direct method. The maximum error of these models was found to be ±20% for strength, ±3% and ±5% for density and static modulus of elasticity respectively. A linear model for strength, a power model for density and a logarithmic model for static elastic modulus was proposed for 19mm maximum aggregate size. The quadratic models are valid for pulse velocity range between 4.7 to 6.1 km/sec and the other models are 4.3 to 5.5 km/sec. All of these models are found to be capable of predicting strength between 30 to 110 MPa, density between 2320 to 2525 kg/m^3 and static elastic modulus between 28 to 40 GPa. Combined NDT methods were found to improve some of strength prediction.

Statistical significant tests on the prediction models have been carried out to ascertain their reliability in estimating strength, density and static elastic modulus properties of concrete. Moreover, validation of the predicted models with other researchers further enhances reliability of each model. Thus, the proposed models for different NDT techniques can be used as a practical guide in the assessment of in-situ concrete properties.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL-MODEL REGRESI DENGAN MENGUNAKAN UJIAN-UJIAN TANPA MUSNAH UNTUK RAMALAN SIFAT-SIFAT KONKRIT KEKUATAN TINGGI

Oleh

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Konkrit kekuatan tinggi merupakan salah satu pembangunan terkini dalam teknologi konkrit. Ia sedang digunakan dengan meluas dalam bidang kejuruteraan awam dan projek-projek bangunan. Ini memerlukan kepada keperluan kepada jaminan kualiti konkrit di situ. Ujian konkrit secara tradisional melibatkan ujian mampatan silinder atau kiub. Ujian sedemikian mungkin tidak memadai untuk menggambarkan sifat konkrit di situ malah membawa kepada keperluan menggunakan ujian tanpa musnah. Tidak ada hubungan piawai yang pernah ditubuhkan di antara parameter fizikal dan mekanikal bagi konkrit kekuatan tinggi dengan menggunakan ujian "*Sclerometer*", kaedah ultrabunyi halaju denyut dan ujian tarik keluar. Model-model ramalan perlu dibangunkan untuk menganggarkan kekuatan konkrit, ketumpatan dan modulus kekenyalan static. Ciri-ciri ini biasanya diperlukan dalam penilaian bangunan atau struktur, terutama dengan keperluan semasa yang menggunakan konkrit kekuatan tinggi dalam pembinaan struktur.

Dalam penyelidikan ini, lapan bancuhan konkrit kekuatan tinggi dengan nisbah campuran berbeza yang terdiri daripada agregat batu pasir bersaiz nominal 10mm dan 19mm dan mengandungi serbuk silika telah dikaji. Kandungan serbuk silika dipelbagai pada 0%, 5%, 10% dan 15%. Campuran ini menghasilkan konkrit dengan kekuatan di antara 40MPa hingga 100MPa pada hari ke 28. Sejumlah 360 kiub piawai (150mm), 144 silinder (150 x 300mm) dan 16 rasuk bertetulang telah dihasilkan dalam kajian ini. Empat puluh lima spesimen kiub piawai dan spesimen untuk ujian tarik keluar telah disediakan dan diuji bagi setiap campuran pada umur 3, 7, 14, 28 dan 56 hari dalam kedua-dua ujian tanpa musnah dan musnah. Lapan belas spesimen silinder telah diuji bagi setiap campuran untuk mendapatkan modulus kekenyalan statik pada umur 28 dan 56 hari. Hasil kajian dianalisa menggunakan perisian statistik (SPSS ver.13). Model-model ramalan bagi setiap teknik ujian tanpa musnah telah dibangunkan berdasarkan keputusan ujikaji. Ujian statistik yang nyata ke atas model ramalan telah dilaksanakan untuk memastikan kebolehannya dalam menjangka ciri konkrit. Pengesahan model ramalan juga dilakukan dengan membandingkan data dengan keputusan penyelidik lain.

Dalam kajian ini, model-model yang telah dibangunkan dengan menggunakan ujian "*Sclerometer*", kaedah ultrabunyi halaju denyut dan ujian tarik keluar adalah untuk menganggarkan parameter seperti kekuatan, ketumpatan dan modulus kekenyalan statik. Secara menyeluruh didapati saiz agregat tidak mempunyai kesan terhadap ramalan kekuatan, ketumpatan dan modulus kekenyalan hasil daripada model-model yang dihasilkan menggunakan ujian "*Sclerometer*" dan ujian tarik keluar. Ralat maksimum daripada model-model ini didapati antara ±12.5% bagi ujian kekuatan "*Sclerometer*", ±25% bagi ujian kekuatan tarik keluar, ±3% bagi ujian ketumpatan "*Sclerometer*", ±2% bagi ujian ketumpatan tarik keluar dan ±5% bagi ujian modulus kekenyalan statik "*Sclerometer*".

Kaedah ultrabunyi halaju denyut secara langsung dan tidak langsung menunjukkan saiz agregat dalam konkrit perlu diketahui terlebih dahulu bagi menganggarkan kekuatan, ketumpatan dan modulus kekenyalan statik. Secara umum, model-model kuadratik telah dicadangkan bagi campuran konkrit dengan agregat bersaiz nominal 10mm (siri A_{10}) untuk meramal kekuatan, ketumpatan dan modulus kekenyalan menggunakan kaedah ultrabunyi halaju denyut secara langsung. Ralat maksimum daripada model-model ini didapati antara ±20% bagi kekuatan, ±3% bagi ketumpatan dan ±5% bagi modulus kekenyalan statik.Model berasaskan persamaan lelulus, kuasa dan logaritma untuk kekuatan, ketumpatan dan modulus keanjalan telah di cadangkan untuk konkrit yang mempunyai saiz agregat 19mm. Model kuadratik adalah sahih bagi halaju denyut di antara 4.7 hingga 6.1 km/saat dan lain-lain model adalah di antara 4.3 hingga 5.5 km/saat. Kesemua model-model ini didapati berkemampuan untuk menjangka kekuatan di antara 30 hingga 110 MPa, ketumpatan di antara 2350 hingga 2500 kg/m^3 dan modulus kekenyalan statik di antara 28 hingga 40 GPa.

Ujian statistik yang nyata ke atas model-model ramalan telah dilaksanakan untuk memastikan kebolehannya dalam penganggaran ciri konkrit seperti kekuatan, ketumpatan dan modulus kekenyalan. Selain itu, pengesahan model ramalan dengan membandingkan keputusan dari penyelidik lain menambahkan lagi kepercayaan setiap model. Oleh itu, model-model cadangan ini boleh digunakan sebagai panduan praktikal dalam penilaian sifat konkrit di situ dengan menggunakan teknik ujian tanpa musnah yang berbeza.

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-*Shibli Russel*

I certify that an Examination Committee has met on 14 May 2007 to conduct the final examination of Shibli Russel Hj. Mohiuddin Khan on his Doctor of Philosophy thesis entitled "Development of Regression Models for Predicting Properties of High Strength Concrete Using Non-Destructive Tests" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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SHIBLI RUSSEL HJ. MOHIUDDIN KHAN

Date: 27 JUNE 2007

TABLE OF CONTENTS

				Page
DEDICATION				ii
ABSTRACT				iii
ABSTRAK				vi
ACKNOWLEDGEMENTS				ix
APPROVAL				xi
DECLARATION				xiii
LIST OF TABLES				xvii
LIST OF FIGURES				xxviii
LIST OF ABBREVIATIONS				xli
CHAPTER				
1	**INTRODUCTION**			
	1.1	Background		1.1
	1.2	High Strength Concrete (HSC)		1.2
	1.3	Non-Destructive Test (NDT)		1.4
	1.4	Problem statement		1.5
	1.5	Objective and Scope of the Research		1.7
	1.6	Thesis Layout		1.9
2	**LITERATURE REVIEW**			
	2.1	High Strength Concrete		2.1
		2.1.1	Features of HSC	2.2
		2.1.2	Aspects of HSC in Civil Engineering	2.4
		2.1.3	Constituents of HSC	2.5
		2.1.4	Materials technology of HSC	2.32
		2.1.5	Properties of fresh HSC	2.37
		2.1.6	Properties of Hardened HSC	2.38
	2.2	NDT in Normal strength Concrete		2.49
		2.2.1	Surface hardness test	2.49
		2.2.2	UPV test	2.60
		2.2.3	Pullout test	2.76
		2.2.4	Concluding Remarks	2.82
	2.3	NDT in HSC		2.82
		2.3.1	Surface hardness test	2.83
		2.3.2	UPV test	2.89
		2.3.3	Pullout test	2.97
		2.3.4	Concluding Remarks	2.105
	2.4	Strength Prediction using Combined NDT		2.105
	2.5	Modulus of Elasticity Prediction using NDT		2.111
	2.6	Reliability of NDT in Concrete technology		2.114
		2.6.1	Code provisions for the reliable sample	2.115
	2.7	Conclusion		2.116

3	**MATERIALS AND METHODOLOGY**		
	3.1	Introduction	3.1
	3.2	The Study framework	3.2
	3.3	Materials	3.3
		3.3.1 Cement	3.3
		3.3.2 Aggregate	3.4
		3.3.3 Water	3.6
		3.3.4 Mineral Admixture	3.7
		3.3.5 Chemical Admixture	3.8
	3.4	Mix design of HSC	3.8
		3.4.1 Trial Mix	3.9
		3.4.2 Selection of Suitable Mix	3.11
	3.5	Mixing, Casting and Curing	3.12
		3.5.1 Mixing technique	3.13
		3.5.2 Casting	3.14
		3.5.3 Curing	3.14
	3.6	Testing Methods	3.15
		3.6.1 Non-Destructive test	3.15
		3.6.2 Destructive test	3.22
4	**RESEARCH DESIGN AND ANALYSIS TECHNIQUES**		
	4.1	Introduction	4.1
	4.2	Specimen Design	4.1
		4.2.1 Schedule of Specimens	4.2
		4.2.2 Choice of sample size	4.4
		4.2.3 Statistical test on sample size	4.5
		4.2.4 Reliability Analysis (Cronbach's theory)	4.8
	4.3	Method of Analysis	4.11
		4.3.1 Analysis Data using statistical tools	4.12
5	**RESULTS AND DISCUSSION OF NORMAL STRENGTH CONCRETE**		
	5.1	Introduction	5.1
	5.2	Strength Prediction for normal strength concrete	5.2
		5.2.1 Strength Prediction using Sclerometer test	5.2
		5.2.2 Strength Prediction using UPV method	5.8
		5.2.3 Strength Prediction using Pullout test	5.14
		5.2.4 Model testing for strength	5.21
		5.2.5 Model Calibration for strength	5.27
		5.2.6 Combined NDT strength prediction Model	5.35
	5.3	Density Prediction for normal strength concrete	5.39
		5.3.1 Density Prediction using Sclerometer test	5.40
		5.3.2 Density Prediction using UPV method	5.45
		5.3.3 Density Prediction using Pullout test	5.48
		5.3.4 Model testing for Density	5.51
		5.3.5 Model Calibration for Density	5.54
	5.4	Concrete Elastic Modulus Prediction	5.57
		5.4.1 E_c Prediction using Sclerometer test	5.58
		5.4.2 E_c Prediction using UPV direct method	5.62

5.4.3 E_c Prediction using Pullout test 5.66
5.4.4 Model testing for E_c 5.70
5.4.5 Model Calibration E_c 5.72
5.5 Concluding Remarks 5.77

6 RESULTS AND DISCUSSION FOR HIGH STRENGTH CONCRETE
6.1 Introduction 6.1
6.2 Strength Prediction for HSC 6.2
6.2.1 Strength Prediction using Sclerometer test 6.2
6.2.2 Strength Prediction using UPV method 6.11
6.2.3 Strength Prediction using Pullout test 6.17
6.2.4 Model testing for strength 6.21
6.2.5 Model Calibration for strength 6.29
6.2.6 Combined NDT strength prediction Model For HSC 6.37
6.3 Density Prediction for HSC 6.42
6.3.1 Density Prediction using Sclerometer test 6.42
6.3.2 Density Prediction using UPV method 6.45
6.3.3 Density Prediction using Pullout test 6.47
6.3.4 Model testing for Density 6.50
6.3.5 Model Calibration for Density 6.52
6.4 HSC Static Elastic Modulus Prediction 6.57
6.4.1 E_c Prediction using Sclerometer test 6.57
6.4.2 E_c Prediction using UPV direct method 6.60
6.4.3 E_c Prediction using Pullout test 6.63
6.4.4 Model testing for E_c 6.67
6.4.5 Model Calibration E_c 6.70
6.5 Concluding Remarks 6.76

7 VALIDATION AND SIGNIFICANCE OF PROPOSED MODEL
7.1 Introduction 7.1
7.2 Validation of Proposed Model for NSC 7.1
7.3 Validation of Proposed Model for HSC 7.5
7.4 Significance of Proposed model 7.9
7.4.1 Proposed model using Sclerometer test 7.9
7.4.2 Proposed model using UPV method 7.10
7.4.3 Proposed model using Pullout test 7.10
7.5 Concluding Remarks 7.11

8 CONCLUSION AND RECOMMENDATIONS
8.1 Conclusions 8.1
8.2 Limitations 8.4
8.3 Recommendations for future Work 8.5

REFERENCES R.1
APPENDICES A.1
BIODATA OF THE AUTHOR B.1

LIST OF TABLES

Table		Page
2.1	Definition of HSC according to Federal Highway Administration (Goodspeed, et al. 1996)	2.3
2.2	Oxide composition of ordinary Portland cement (Gambhir, 2004)	2.7
2.3	Mix proportions of some high strength concretes (Neville, 1995)	2.36
2.4	High strength mix design by Price and Hynes (1996) and Iravani (1996)	2.37
2.5	Recommended values for aggregate coefficients for Different type of coarse aggregate (Iravani, 1996)	2.45
2.6	Durability Requirements Adopted by the Road and Transport Authority, New South Wales, Australia (Ho and Chirgwin 1996)	2.48
2.7	Strength prediction models by Rebound Hammer or Sclerometer test by different researchers	2.59
2.8	Lists of Standards to determine the longitudinal Ultrasonic Pulse velocity of concrete (Komlos et al., 1996)	2.62
2.9	Obtained strength prediction models by UPV by different Researcher	2.73
2.10	Strength prediction models for Lok test for normal Strength concrete obtained from various researchers	2.81
2.11	Strength prediction models by Sclerometer test for HSC obtained by different researchers	2.87
2.12	Strength prediction models by UPV for HSC Obtained by different researchers	2.96
2.13	Strength prediction models by Pullout test for HSC obtained by different researchers	2.104
2.14	Several combined NDT models suggested by different investigators for prediction of compressive strength of concrete (Arioglu, et al., 2001)	2.109

3.1	Chemical composition of Ordinary Portland Cement (OPC)	3.4
3.2	Chemical compositions of densified Silica fume	3.8
3.3	Mix proportions of some High strength Concrete mix (Mehta/ Aitcin, 1990; Toralles Carbonari, 1996; Aitcin, 1998; Ali Mirza & Johnson, 1996)	3.10
3.4	Mix proportions of some High strength concrete mix (Iravani, 1996; Taylor et al., 1996)	3.11
3.5	Actual mix proportions of High strength concrete Used for the study	3.12
4.1	Schedule of specimens of the High Strength Concrete for the study	4.3
4.2	A group of data from the present study for Mix -1 or A_{10} (40 MPa) concrete	4.7
4.3	Cube compressive strength (f_{cu}) and surface hardness value (f_{cst}) of 30 numbers of specimens and tested in five different ages	4.10
4.4	Cronbach's reliability coefficient Alfa (α) for Pullout, Surface Hardness and UPV test with respect to their destructive Test results	4.11
5.1	Cube strength and Sclerometer reading for concrete series A_{10} and A_{19} of Mix 1 and Mix 2	5.4
5.2	Summary of Statistical analysis of test results for cube Strength and Sclerometer test	5.12
5.3	Strength- UPV-indirect correlation models of concrete mix 1 and mix 2 with nominal aggregate size 10 mm and 19 mm	5.14
5.4	Summary of Statistical analysis of test results	5.19
5.5	Strength prediction model for normal concrete using Sclerometer test, UPV and pullout test	5.21
5.6	Summary of Statistical analysis of test results for cube strength and Sclerometer test	5.22
5.7	Typical Statistical test results for slopes of the predictive regression line	5.24
5.8	Typical Statistical test results for intercepts of the predictive regression line	5.24

5.9 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using Sclerometer test 5.25

5.10 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using UPV direct test 5.25

5.11 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using UPV indirect test 5.26

5.12 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using Pullout test 5.26

5.13 Summary of Statistical analysis of test results for density prediction using Sclerometer test 5.45

5.14 Test results Summary of Statistical analysis from concrete density and UPV of concrete mix with nominal aggregate size 10 mm and 19 mm 5.48

5.15 Summary of Statistical analysis results for cube density and Pullout test 5.50

5.16 Density prediction model for normal concrete using Sclerometer test, UPV and pullout test 5.51

5.17 t-statistic tests using Analysis of variance (ANOVA) for density prediction model using Sclerometer test 5.53

5.18 t-statistic tests using Analysis of variance (ANOVA) for density prediction model using UPV direct test 5.53

5.19 t-statistic tests using Analysis of variance (ANOVA) for density prediction model using Pullout test 5.54

5.20 Cylindrical strength and corresponding static elastic modulus and Sclerometer test results for mix 1 and mix 2 in series A_{10} 5.59

5.21 Cylindrical strength and corresponding Static elastic modulus and Sclerometer test results for mix 1 and mix 2 in series A_{19} 5.59

5.22 Static elastic modulus and UPV-direct test results for mix 1 and mix 2 in series A_{10} 5.63

5.23 Static elastic modulus and UPV-direct test results for mix 1 and mix 2 in series A_{19} 5.63

5.24 Best-fit regression equation and their coefficient of regression,

	mean square error and standard error of estimation	5.65
5.25	Static elastic modulus and Pullout test results for mix 1 and mix 2 in series A_{10}	5.66
5.26	Static elastic modulus and Pullout force test results for mix 1 and mix 2 in series A_{19}	5.66
5.27	Regression models and their parameters for E_c	5.67
5.28	Static elastic Modulus prediction model for normal concrete using Sclerometer test, UPV and pullout test	5.70
5.29	t-statistic tests using Analysis of variance (ANOVA) for static elastic modulus prediction model using Sclerometer test	5.71
5.30	t-statistic tests using Analysis of variance (ANOVA) for static elastic modulus prediction model using UPV-direct method	5.72
5.31	t-statistic tests using Analysis of variance (ANOVA) for static elastic modulus prediction model using Pullout test	5.72
5.32	Proposed strength prediction models for normal strength concrete	5.77
5.33	Proposed density prediction models for normal strength concrete	5.78
5.34	Proposed static elastic modulus prediction models for normal strength concrete	5.79
6.1	Mean Cube strength and Sclerometer test results for Mix 2, Mix 3 and Mix 4 in series A_{10} concrete	6.3
6.2	Mean Cube strength and Sclerometer test results for Mix 2, Mix 3 and Mix 4 in series A_{19} concrete	6.4
6.3	Cube strength and Sclerometer reading for concrete series A_{10} of Mix 2, Mix 3 and Mix 4	6.6
6.4	Cube strength and Sclerometer test value for concrete series A_{19} of Mix 2, Mix 3 and Mix 4	6.7
6.5	Cube strength and UPV (direct method) test results for Concrete series A_{10} of Mix 2, Mix 3 and Mix 4	6.12
6.6	Cube strength and UPV (direct method) test results for Concrete series A_{19} of Mix 2, Mix 3 and Mix 4	6.13
6.7	Strength prediction model for HSC using Sclerometer test, UPV and pullout test	6.21

6.8 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using Sclerometer test of HSC 6.22

6.9 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using UPV-direct test of HSC 6.23

6.10 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using UPV-indirect test of HSC 6.23

6.11 t-statistic tests using Analysis of variance (ANOVA) for strength prediction model using pullout test of HSC 6.24

6.12 Density prediction model for normal concrete using Sclerometer test, UPV and pullout test 6.50

6.13 t-statistic tests using Analysis of variance (ANOVA) for density prediction model using Sclerometer test of HSC 6.51

6.14 t-statistic tests using Analysis of variance (ANOVA) for density prediction model using UPV-direct test of HSC 6.51

6.15 t-statistic tests using Analysis of variance (ANOVA) for density prediction model using pullout test of HSC 6.52

6.16 Static elastic Modulus prediction model for normal concrete using Sclerometer test, UPV and pullout test 6.67

6.17 t-statistic tests using Analysis of variance (ANOVA) for static elastic modulus prediction model using Sclerometer test of HSC 6.68

6.18 t-statistic tests using Analysis of variance (ANOVA) for static elastic modulus prediction model using UPV-direct test of HSC 6.69

6.19 t-statistic tests using Analysis of variance (ANOVA) for static elastic modulus prediction model using Pullout test of HSC 6.69

A1.1 Mean Cube strength and Sclerometer test results for Mix 1 and Mix 2 in series A_{10} concrete A.1

A1.2 Mean Cube strength and Sclerometer test results for Mix 1 and Mix 2 in series A_{19} concrete A.1

A2.1 Sclerometer test results on the cube surface of concrete Mix 1 of series A_{10} at the age of 3days A.2

A2.2 Sclerometer test results on the cube surface of concrete

	Mix 1 of series A_{10} at the age of 7days	A.5
A2.3	Sclerometer test results on the cube surface of concrete mix 1 of series A_{10} at the age of 14days	A.8
A2.4	Sclerometer test results on the cube surface of concrete mix 1 of series A_{10} at the age of 28days	A.11
A2.5	Sclerometer test results on the cube surface of concrete mix 1 of series A_{10} at the age of 56days	A.14
A2.6	Sclerometer test results on the cube surface of concrete mix 2 of series A_{10} at the age of 3days	A.17
A2.7	Sclerometer test results on the cube surface of concrete mix 2 of series A_{10} at the age of 7days	A.20
A2.8	Sclerometer test results on the cube surface of concrete mix 2 of series A_{10} at the age of 14days	A.23
A2.9	Sclerometer test results on the cube surface of concrete mix 2 of series A_{10} at the age of 28days	A.26
A2.10	Sclerometer test results on the cube surface of concrete mix 2 of series A_{10} at the age of 56days	A.29
A2.11	Sclerometer test results on the cube surface of concrete mix 1 of series A_{19} at the age of 3days	A.32
A2.12	Sclerometer test results on the cube surface of concrete mix 1 of series A_{19} at the age of 7days	A.35
A2.13	Sclerometer test results on the cube surface of concrete mix 1 of series A_{19} at the age of 14days	A.38
A2.14	Sclerometer test results on the cube surface of concrete mix 1 of series A_{19} at the age of 28days	A.41
A2.15	Sclerometer test results on the cube surface of concrete mix 1 of series A_{19} at the age of 56days	A.44
A2.16	Sclerometer test results on the cube surface of concrete mix 2 of series A_{19} at the age of 3days	A.47
A2.17	Sclerometer test results on the cube surface of concrete mix 2 of series A_{19} at the age of 7days	A.50
A2.18	Sclerometer test results on the cube surface of concrete mix 2 of series A_{19} at the age of 14days	A.53

A2.19 Sclerometer test results on the cube surface of concrete mix 2 of series A_{19} at the age of 28days A.56

A2.20 Sclerometer test results on the cube surface of concrete mix 2 of series A_{19} at the age of 56days A.59

A.3.1 Summary of data from concrete Density and Sclerometer test results for series A_{10} concrete A.62

A.3.2 Summary of data from concrete Density and Sclerometer test results for series A_{19} concrete A.63

A4.1 Cube strength and UPV (direct) test results of mix 1 concrete in series A_{10} A.64

A4.2 Cube strength and UPV (direct) test results of mix 2 concrete in series A_{10} A.64

A4.3 Cube strength and UPV (direct) test results of mix 1 concrete in series A_{19} A.65

A4.4 Cube strength and UPV (direct) test results of mix 2 concrete in series A_{19} A.65

A5.1 Concrete Density and UPV (direct) test results of mix 1 concrete in series A_{10} A.66

A5.2 Concrete Density and UPV (direct) test results of mix 2 concrete in series A_{10} A.66

A5.3 Concrete Density and UPV (direct) test results of mix 1 concrete in series A_{19} A.67

A5.4 Concrete Density and UPV (direct) test results of mix 2 concrete in series A_{19} A.67

A6.1 Cube strength and UPV-indirect test results of mix 1 concrete in series A_{10} A.68

A6.2 Cube strength and UPV-indirect test results of mix 2 concrete in series A_{10} A.68

A6.3 Cube strength and UPV-indirect test results of mix 1 concrete in series A_{19} A.69

A6.4 Cube strength and UPV-indirect test results of mix 2 concrete in series A_{19} A.69

A7.1 Cube strength and Pullout (Lok test) test results of mix 1 concrete in series A_{10} A.70

A7.2 Cube strength and Pullout (Lok test) test results of mix 2 concrete in series A_{10} A.70

A7.3 Cube strength and UPV (direct) test results of mix 1 concrete in series A_{19} A.71

A7.4 Cube strength and UPV (direct) test results of mix 2 concrete in series A_{19} A.71

A7.5 Mean Cube strength and Pullout test results for Mix 1 and Mix 2 in series A_{10} concrete A.71

A7.6 Mean Cube strength and Pullout test results for Mix 1 and Mix 2 in series A_{19} concrete A.72

A8.1 Concrete Density and pullout test results of mix 1 concrete in series A_{10} A.72

A8.2 Concrete Density and pullout test results of mix 2 concrete in series A_{10} A.72

A8.3 Concrete Density and pullout test results of mix 1 concrete in series A_{19} A.73

A8.4 Concrete Density and pullout test results of mix 2 concrete in series A_{19} A.73

B1.1 Sclerometer test Results on the cube surface of concrete mix 2 of series A_{10} at the age of 3days A.74

B1.2 Sclerometer test Results on the cube surface of concrete mix 2 of series A_{10} at the age of 7days A.77

B1.3 Sclerometer test Results on the cube surface of concrete mix 2 of series A_{10} at the age of 14days A.80

B1.4 Sclerometer test Results on the cube surface of concrete mix 2 of series A_{10} at the age of 28days A.83

B1.5 Sclerometer test Results on the cube surface of concrete mix 2 of series A_{10} at the age of 56days A.86

B2.1 Sclerometer test Results on the cube surface of concrete mix 3 of series A_{10} at the age of 3days A.89

B2.2 Sclerometer test Results on the cube surface of concrete mix 3 of series A_{10} at the age of 7days A.92

B2.3 Sclerometer test Results on the cube surface of concrete