International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 10, Volume 2 (October 2015) www.ijirae.com

Behaviour of Self Compacting Concrete by Partial Replacement of Fine Aggregate with Coal Bottom Ash

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Abstract*— Self-compacting concrete, defined as a concrete which can be placed and compacted under its self weight with little or no vibration without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. This paper presents the experimental investigation carried out to study the behavior of self-compacting concrete incorporating coal bottom ash at different replacement level of fine aggregate. To find the optimum replacement level the replacement levels of coal bottom ash to fine aggregate is set up from 5 - 30% at 5% increment. Then the optimum mix was subjected to variations (increment and decrement in coal bottom ash in optimum mix). The fresh and hardened properties such as compressive strength, split tensile strength, flexural strength and modulus of elasticity of the concrete at the age of 28 days of curing were conducted for all the variations. Results shows that the strength of the concrete with coal bottom ash increased up to replacement level of 10%.This show that bottom ash can be used as supplementary cementitious materials, having the pozzolanic reactivty.
***Keywords*—Coal Bottom Ash, Compressive Strength, Flexural Strength, Modulus of Elasticity, Splitting Tensile Strength.**

I. INTRODUCTION

Concrete is essentially a mixture of paste and aggregate. The paste, comprised of cement and water, binds the aggregate into a hard mass, the paste hardens because of the chemical reaction of the cement and water called hydration. Self-compacting concrete (SCC) is a innovation in concrete technology and can be categorize as a new kind of high performance concrete with excellent deformability and segregation resistance, which can be placed and compacted under its self weight with little or no vibration without segregation or bleeding. High slump that can easily be achieved by superplasticizer addition to a concrete mix and special attention has to be paid to mix proportioning. The incorporation of mineral admixtures also eliminates the need for viscosity-enhancing chemical admixtures. The lower water content of the concrete leads to higher durability, in addition to better mechanical integrity of the structure. The use of coal bottom ash in normal strength concrete is a new dimension in concrete mix design and if applied on large scale would revolutionize the construction industry, by economizing the construction cost and decreasing the environment depletion.

II. LITERATURE REVIEW

Aggarwal et. al [1] carried out experimental investigations to study the effect of use of bottom ash as a replacement (0-50%) of fine aggregates. Strength development at various percentages of replacement of fine aggregates with coal bottom ash can easily be equated to the strength development of normal concrete at various ages. The workability of concrete decreased with the increase in coal bottom ash content due to the increase in water demand, incorporated by increasing the content of superplasticizer. The density of concrete decreased with the increase in coal bottom ash content due to the low specific gravity of coal bottom ash as compared to fine aggregate. The research work carried out by Kim and Lee [2] indicates that the compressive strength of concrete mixtures made with coal bottom ash as a substitute for sand was not strongly affected. However, flexural strength and modulus of elasticity of concrete decreased with the increase in the content of coal bottom ash. Boukendakdji et. al [3] investigated the effects of granulated blast furnace slag and superplasticizer type on the fresh properties and compressive strength of self-compacting concrete. Results showed that polycarboxylate based superplasticizer concrete mixes give more workability and higher compressive strength, at all ages. Inclusion of blast furnace slag by substitution to cement was found to be very beneficial to fresh self-compacting concrete.Yogesh Aggarwal and Rafat Siddique [4], were studied microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates. They concluded that the mechanical behavior of the concrete with fine aggregate replacements was comparable to that of conventional concrete except for 60% replacement. The inclusion of waste foundry sand and bottom ash as fine aggregate does not affect the strength properties negatively as the strength remains within limits except for 60% replacement. *Guneyisi et. al* [5] conducted experimental study on the hardened characteristics of the self-compacting concrete made with cold bond fly ash lightweight aggregates. Test results have showed that incorporating the mineral admixtures enhanced significantly the permeability characteristics. Moreover, it was observed that the compressive strength of the self-compacting cold bonded fly ash lightweight aggregate concrete with silica fume was much higher than those of the control concrete.

This paper intends to investigate the potential used of coal bottom ash in the production of SCC. To find the optimum dosage of coal bottom ash by fine aggragate. The study focused on the strength development of the concrete mixes with varying coal bottom ash, including compressive strength, splitting tensile strength and flexural strength. The study on the influence of the coal bottom ash particles on the workability of the concrete was also conducted.

III. MATERIALS AND METHODS

Ordinary Portland Cement (53 MPa) conforming to relevant Indian standard specifications [8-9] with consistency as 35% and specific gravity as 3.14 was used. M sand with 4.75 mm maximum size was used as fine aggregate, fulfilling the requirements of IS:383-1970 [9] along with blended 12 and 6 mm sized arrregates was used as coarse aggregate. The particle size distribution fine aggregate was shown in Figure 1. The physical properties of fine aggregate and coarse aggregate was tabulated in Tables 1 and 2 respectively. Coal bottom ash obtained from Hindustan Newsprint Limited, Kottayyam, Kerala, India was used as partial replacement of fine aggregates. The coal bottom ash was screened to remove the oversized particles and the material passing through 4.75 mm sieve was used in manufacturing of concrete. The physical properties of coal bottom ash used in this research are given in Table 3. The particle size distribution of bottom ash used in this investigation was shown in Figure 2. Fly ash used for the present investigation was also taken from Hindustan Newsprint Limited, Kottayyam, Kerala. The physical properties of coal bottom ash used in this research are given in Tables 4 .The superplasticizer used in this present investigation was Master Glenium SKY 8233 manufactured by BASF Chemicals Pvt. Ltd. Properties are depicted in Table 5. Portable clean drinking water available in the water supply system was used for casting as well as curing of the test specimens.

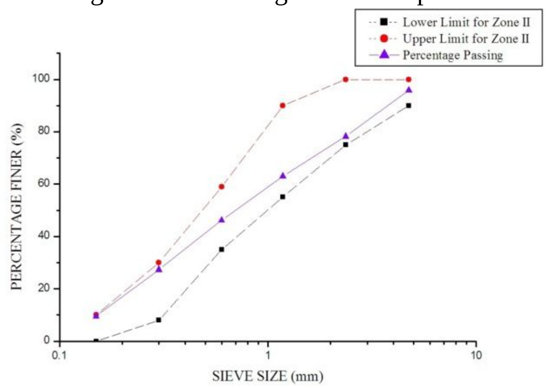

Fig 1 Grading Curve of Fine Aggregate

TABLE 1
PHYSICAL PROPERTIES OF FINE AGGREGATE

Sl.No.	Properties	Values
1	Specific gravity	2.59
2	Water absorption	12%
3	Fineness modulus	3.787
4	Zone	II

TABLE II
PHYSICAL PROPERTIES OF COARSE AGGREGATE

Sl.No.	Properties	Values
1	Specific gravity	2.97
2	Water absorption for 12 mm + 6 mm aggregates	0.892%
3	Aggregate crushing value	29.57%

TABLE III
PHYSICAL PROPERTIES OF COAL BOTTOM ASH

Sl.No.	Properties	Values
1	Specific gravity	2.967
2	Water absorption	18%
3	Fineness modulus	2.967
4	Zone	II

TABLE IV
PHYSICAL PROPERTIES OF FLY ASH

Sl.No	Properties	Value
1	Colour	Blackish
2	Specific Gravity	2.12

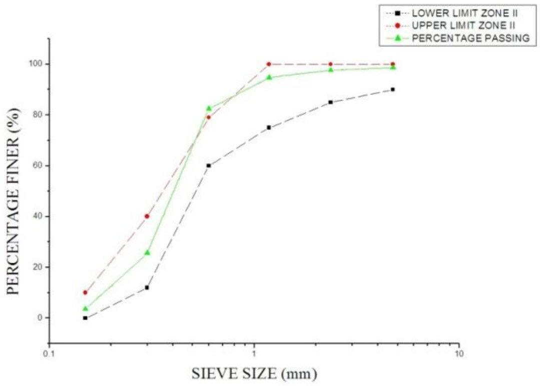

Fig 2 Grading Curve of Coal Bottom Ash

TABLE V
PROPERTIES OF SUPERPLASTICIZER (AS PER DATA FROM MANUFACTURER)

Sl.No	Properties	Value
1	Aspect	Light brown liquid
2	pH	≥ 6
3	Relative density	1.08 ±0.01 at 25°C
4	Chloride ion content	< 0.2%

IV. EXPERIMENTAL PROGRAMME

A control mix (without coal bottom ash) was made for obtaining 28th day compressive strength of 30N/mm^2 using modified Nan Su method [10]. Then fine aggregate (M sand) was replaced with coal bottom ash by weight from 5% to 30% at 5% increment. The mixes were designated as CBA5, CBA10, CBA15, CBA20, CBA25 and CBA30.The quantities of materials required for all the mixes are tabulated in Table 6. The compressive strength (28th day) obtained for each mix are given in Table 7. Based on the fresh and harden properties of coal bottom ash concrete optimum mix was found out. In the next stage optimum mix was taken as control mix again coal bottom ash was increased and decreased by 5 and 10 percentage of quantity of coal bottom ash used in optimum mix. Afterwards the fresh and hardened properties of each mixes were investigated.

TABLE VI. - MIX PROPORTIONS STAGE 1

Mix Designation	Cement (kg/m^3)	Sand (kg/m^3)	Coal Bottom ash (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)
Control mix	375	881.4	0.00	726	258	5.16
CBA 5	375	836.95	44.05	726	258	5.16
CBA 10	375	793.26	88.14	726	258	5.16
CBA 15	375	748.85	132.15	726	258	5.16
CBA 20	375	704.80	176.20	726	258	5.16
CBA 25	375	660.75	220.25	726	258	5.16
CBA 30	375	616.58	264.42	726	258	5.16

TABLE VII.- COMPRESSIVE STRENGTH OF CUBES (28TH DAY)

Mix Designation	Bottom ash (%)	28th day compressive strength (N/mm^2)
		Average
Control mix	0	39.58
CBA 5	5	39.66
CBA 10	10	39.76
CBA 15	15	37.29
CBA 20	20	36.36
CBA 25	25	35.50
CBA 30	30	35.03

Table 7 presents the effect of coal bottom ash on the compressive strength of SCC. It shows that the compressive strength of the specimens increased with the increase in coal bottom ash up to 10% of replacement level. At the age of 28 days, CBA10 gained its strength almost about control specimens. This may due to the pore refinery effect by pozzolanic reaction of bottom ash. Despite of the increase in porosity due to the replacement of coal bottom ash, the silica content in coal bottom ash particles enhance the formation of C-S-H, a gel responsible for strength development. The compressive strength of the coal bottom ash concrete starts to decrease when the replacement level increased to 15%. Specimens with CBA15, CBA20, CBA25 and CBA30 reduced its strength with that of the control specimens. The pore refinery effect by pozzolanic reaction is not dominant at this level replacement level. The excessive amount of bottom ash has produced porous concrete and reduces its compressive strength. So the optimum replacement level obtained for coal bottom ash was 10% and CBA10 was taken as control mix for second stage. In second stage coal bottom ash was increased and decreased with 5 and 10 percentage of total quantity of coal bottom ash used in the CBA10. They are designated as CM, CMP5, CMP10, CMN5, and CMN10. The mix designations and quantities of materials for each are given in Table 10.

TABLE VIII -MIX PROPORTIONS STAGE 2

Mix Designation	Cement (kg/m^3)	Sand (kg/m^3)	Coal Bottom ash (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)
CM (CBA 10)	375	793.26	88.14	726	258	5.16
CM P5	375	788.85	92.55	726	258	5.16
CM P10	375	784.45	96.95	726	258	5.16
CM N5	375	797.67	83.73	726	258	5.16
CM N10	375	802.07	79.33	726	258	5.16

V. RESULTS AND DISCUSSIONS

A. *Fresh Properties of Self-Compacting Concrete*

The filling ability and stability of self-compacting concrete in the fresh state can be defined by certain key characteristics. They are flow ability (Slump-flow test), Viscosity (T_{500} Slump-flow test or V-funnel test) and passing ability (L-box test). The test results obtained are tabulated in Table 9.

TABLE IX
FRESH PROPERTIES OF SELF-COMPACTING CONCRETE

Mix Designation	Slump (mm)	T_{500} (s)	Passing Ratio	V Funnel (s)
CMN10	702	1.9	0.99	8
CMN5	696	2	0.97	8
CM (CBA 10)	676	2.4	0.96	10
CMP5	670	3	0.9	11
CMP10	660	3.5	0.89	12

1) *Slump flow + T_{500}*

Slump-flow value describes the flow ability of a fresh mix and check that the fresh concrete consistence meets the specification. Fig 3 and 4 shows the percentage variation in slump flow and spreading time for T_{500} for all mixes with respect to control mix CBA10.

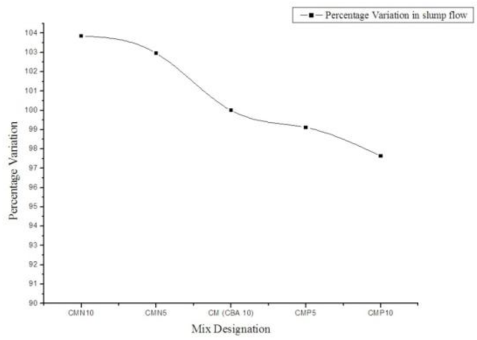

Fig 3 Percentage Variation in Slump Flow with respect to CBA10.

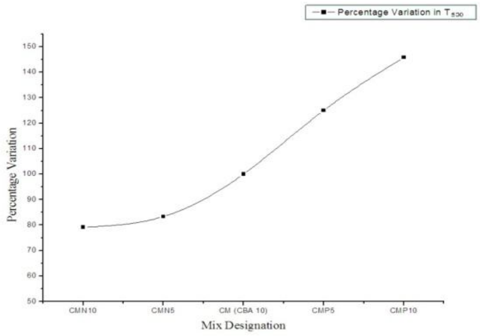

Fig 4 Percentage Variation in T_{500} with respect to CBA10.

From Fig 4 the percentage variation in flow ability of mixtures slightly decreased in parallel with an increment of coal bottom ash. The decrement of slump flow is because of the porosity of coal bottom ash, which absorbed more water with higher content of coal bottom ash. The result obtained implies of the coal bottom ash textures, which have the irregular shape that reducing interparticle friction between aggregates and indicates the addition of coal bottom ash reduces the viscosity of SCC mixtures.

2) L-Box test

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation. Figure 5 shows percentage variation in passing ability of all mixes with respect to control mix CBA10.

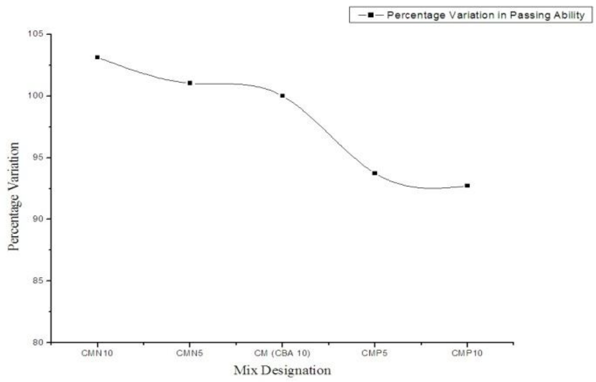

Fig 5 Percentage Variation in Passing Ability with respect to CBA10

The passing ability ratios obtained ranges from 0.89 to 0.98, so this belongs to class-2 (PA2).The h2/h1 ratio decreased from 0.98 to 0.89, shown in Table 9. From the results, all mixtures presented satisfactory passing ability values of the EFNARC [10] recommendation. From Figure 5 the percentage variation in passing ability decreases with increase in coal bottom ash content. This may be due to decreased cohesiveness and lack in paste volume.

3) V-Funnel test

V-funnel test is used to evaluate the viscosity of SCC, Figure 6 shows percentage variation in V-Funnel test of all mixes with respect to control mix CBA10.

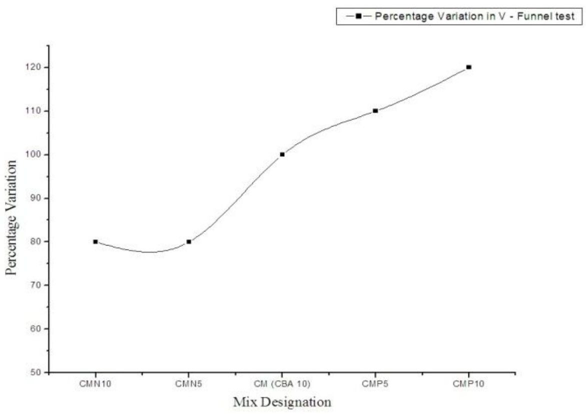

Figure 6: Percentage Variation in V-Funnel test with respect to CBA10.

Mixes CMN10 and CMN5 can be considered as a viscosity class 1 (VF1), while CM, CMP5 and CMP10 as viscosity class 2 (VF2) according to EFNARC [10]. The percentage variation in time in V-funnel increased with the increase in the percentage of coal bottom ash.

B. Hardened properties of concrete

1) *Compressive strength*

The compressive tests were carried out for finding the optimum mix and then for finding the variations in compressive strength by adding and subtracting coal bottom ash with fine aggregate. Figure 7 shows the percentage variation in compressive strength of cube and cylinder for all the mixes with respect to the control mix.

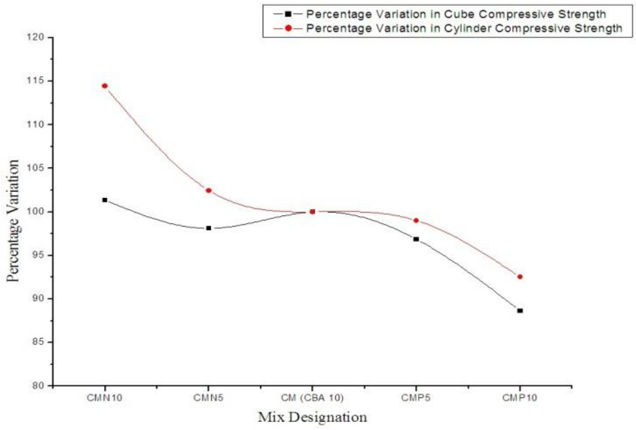

Fig 7 Cube and Cylinder Compressive Strength Percentage Variation with respect to CBA10

From Figure 7 it is clear that while comparing to Control Mix (CM), the percentage variation in compression is lower for mixes containing higher percentage of coal bottom ash, while mixes with lower percentage of coal bottom ash have increment in percentage variation. This shows that compressive strength of mixes decreases with increase in quantity of coal bottom ash, due to the replacement of the stronger material with the weaker material and increased porosity. The decrease in the free water content of the coal bottom ash concrete mixtures due to absorption of part of water by the porous particles of the coal bottom ash internally also contributed to some extent in negating the effect of the factors responsible for reduced compressive strength..

2) *Splitting Tensile Strength*

The percentage variation in splitting tensile strength of cylinders for all the mixes with respect to the Control Mix (CM) is shown in Figure 8.

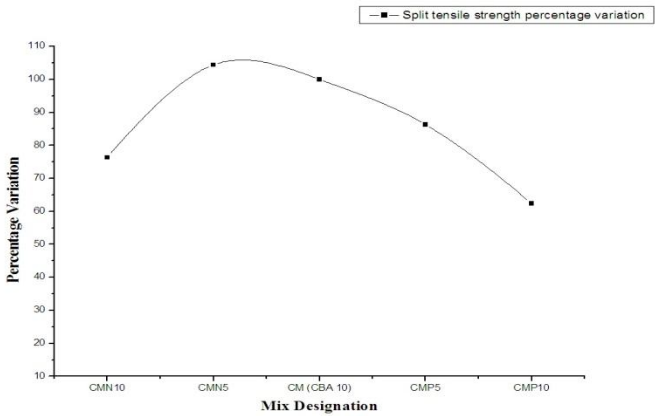

Fig 8 Splitting Tensile Strength Percentage Variation with respect to CBA10

From Figure 8, the splitting tensile strength of concrete have a pattern of obtaining its maximum value with coal bottom ash at CMN5. The results suggested that the bonding between aggregate and cement paste are the most important factor in affecting the strength of concrete especially the tensile strength. The splitting tensile strength of the concrete mixes decreased at 10.5% (CMP5), and 11% (CMP10) of replacement with coal bottom ash. The increment in the replacement level of coal bottom ash had produced more porous concrete with more pores distributed around the coal bottom ash aggregate surface, hence reducing its strength.

3) Flexural Strength Test

The percentage variations of each mix with respect to control mix were shown in Figure 9. The flexural strength of all specimens was observed to exhibit the same behavior as splitting tensile strength.

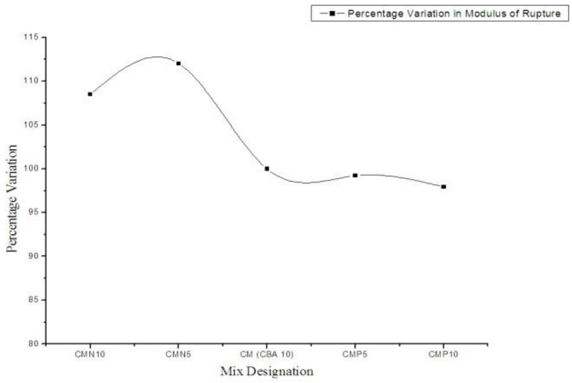

Fig 9 Flexural Strength Percentage Variation with respect to CBA10

From Figure 9, it is evident that flexural strength of coal bottom ash concrete with 9% (CMN10) and 10% (CMN5) replacement of bottom ash are higher compared to other bottom ash concrete. However, the flexural strength of the specimen decreased with 10%, 10.5% and 11% replacement of coal bottom ash to sand. It is evident that the coal bottom ash replacing 9% (CMN10) gave maximum strength.The decreased flexural strength of the specimen as the replacement level of coal bottom ash increased is believed due to the poor interlocking between the aggregate, as bottom ash particles are spherical in nature.

4) Modulus of Elasticity

Modulus of elasticity of concrete mixtures was measured at the curing age of 28 days. Figure 10 shows the percentage variation in modulus of elasticity of all mixes with respect to control mix. It was found that the modulus of elasticity decreased with a corresponding increase in the replacement of fine aggregate by the coal bottom ash. This decrease in strength was observed from a replacement of 10% of fine aggregate with coal bottom ash. This may be due to the porous behavior of coal bottom ash resulting in the reduced density of the specimen. The modulus of elasticity of coal bottom ash concrete decreased with the decrease in its unit density.

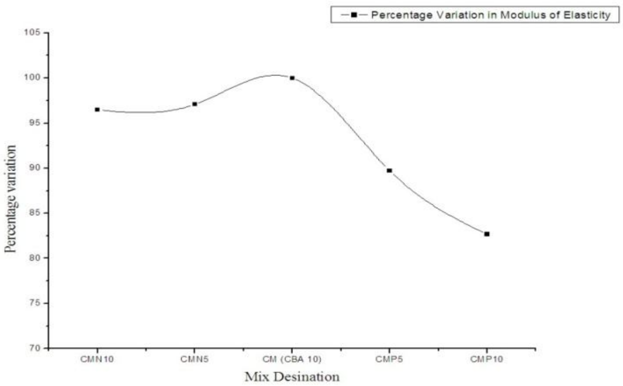

Fig 10 Percentage Variation in Modulus of Elasticity with respect to CBA10

VI. CONCLUSIONS

- The slump flow and the L-box passing ability ratio decreased with the increased of coal bottom ash content, thus reduces the viscosity of the fresh concrete mixture.
- It is possible to produce concrete strength up to 30 Mpa by replacing sand with bottom ash up to 10%. CBA5 and CBA10 exhibit higher strength compared to control specimens for compressive strength. This might be due to the pore refinery effect by pozzolanic activity of bottom ash particles.
- By varying the quantity of coal bottom ash compressive strength, splitting tensile strength, flexural strength, shear strength and modulus of elasticity of fine aggregates replaced coal bottom ash self-compacting concrete decreased with the increased coal bottom ash content.
- Bottom ash used as fine aggregates replacement enables the large utilization of waste product.

ACKNOWLEDGMENT

I thank God, the almighty for his blessings without which nothing would have been possible. I also wish to extend my heartfelt thanks to Dr. Mathews M Paul, Professor, Department of Civil Engineering, M A College of Engineering Kothamangalam for his cooperation, guidance and most generous help for completing the work. I extend my thanks to all the faulty members of Civil Engineering Department, M A College of Engineering Kothamangalam and to all my friends and family for their valuable support.

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