CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 SUMMARY

- To find the basic Properties of Geopolymer Concrete like Compressive Strength, Split Tensile Strength, Flexural Strength and Static Modulus of Elasticity for both sand and M-sand, Rigorous trial-and-error method was adopted.

- It is proposed to identify the mix ratios for different grades of Geopolymer Concrete by trial and error method. A new Design procedure was formulated for Geopolymer Concrete which is relevant to Indian standard.

- The applicability of existing Mix Design was examined with the Geopolymer Concrete. Two kinds of systems were considered in this study using 100% replacement of cement by ASTM class F flyash and 100% replacement of sand by M-sand. It was observed from the test result that the Indian standard mix design itself can be used for the Geopolymer Concrete with some modification.

- The developed theory is validated with experimental investigations of flexural behavior of Reinforced GPC concrete using sand and M-sand for different types of curing.
Twenty four reinforced GPC with cross section size 100mm × 200mm × 2000mm for both sand and M-sand in Ambient curing, and twenty four beams for heat curing with different reinforcement ratios were studied.

The experimental outcomes such as Ultimate load, Maximum Deflection, First crack load, Moment curvature and the Ductility parameters namely Displacement Ductility, Curvature Ductility etc., are discussed in detail.

The Ultimate loads of beams tested are calculated and compared with the theoretical load calculated as per the flexural strength theory developed for reinforced Geopolymer concrete beams.

Design charts were developed, for both GPC using sand and M-sand reinforced beams for both the curing, so that these charts can be readily used for the design application.

Numerical Analysis using ANSYS 13.0 software was performed for the specimen tested and the critical load, Deflection, Mode of failure were studied and compared with experimental results.

Design examples are presented to calculate the strength of RGPC using sand and M-sand beams based on the present approach.
7.2 CONCLUSIONS

- In this thesis BIS method (IS 10262:1982) was followed and based on this method a new design procedure was formulated for Geopolymer Concrete which was relevant to Indian standard (IS 10262-1982). The applicability of existing Mix Design was examined with the Geopolymer Concrete. It was analyzed from the test result that the Indian standard mix design itself can be used for the Geopolymer Concrete with some modification.

- The relationship between the Compressive strength and Tensile strength of sand and M-sand of Geopolymer concrete is found to be \( f_t = 0.892(f_{ck})^{0.422} \) and \( f_t = 0.720(f_{ck})^{0.483} \).

- The relationship between the Compressive strength and Modulus of Elasticity of sand and M-sand of Geopolymer concrete is found to be \( E_c = 3175(f_{ck})^{0.656} \) and \( E_c = 4389(f_{ck})^{0.535} \).

- The basic material of the geopolymer based on fly ash is of prevailingly amorphous character, only seldom containing needle-shaped minority crystals. An XRD pattern shows that the geopolymer materials are prevailingly of X-ray amorphous character where the unique diffraction is that at solely occurring in systems with a high content of slag. The line obviously corresponds to the C–S–H phase formed.

- The depth of the section is 5% less for Geopolymer concrete using sand and 10% less for Geopolymer concrete using M-
sand when compared to conventional concrete reported in the literature.

- Moment-curvature curves have the same trend as that of the load-deformation curves [i.e., showing ductile behavior]. It is observed that when the load is increased, the specimen loses its flexural rigidity due to deflection and reduction in effective moment of inertia due to development of crack.

- Tables 5.9 to 5.14 show that the ductility index decreased as the tensile reinforcement is increased. The deflection ductility significantly increased for beams with tensile reinforcement ratio less than 1%, whereas the deflection ductility is moderately unaffected for beams with tensile reinforcement ratio greater than 1%. These test trends are similar to those observed in the case of reinforced Portland cement concrete beams (Warner et. al., 1998).

- Ductility index is found to be in the range between 2.1 to 3.1 for ambient cured beams, and 2 to 3.5 for heat cured beams. However, tested beam results show that the heat cured M-Sand used beams have adequate ductility index.

- The first flexural cracking of experimental beam occurred 65mm from the beam centerline, which was 115mm in the ANSYS 13.0. But theoretically this first crack should occur in the bottom face of the beam centerline. From experimental point of view, it was impossible to find out the causes of this variation in location of crack formation. Rather in the model generated by ANSYS 13.0 it was well observed that principal tensile stress was developed earlier.
From the analytical investigation it was observed that under reinforced ratio is the best type of reinforcement ratio among the others since it shows greatest warning zone (Figure 7.43 and 7.44) before failure, where warning zone for balanced condition and over reinforcement ratios were 83.58% and 27.89% of under reinforcement condition respectively.

The experimental load deflection results obtained from the test conducted on beam specimens are compared with ANSYS 13.0 results and the graphs are plotted for various mix proportions. Experimental results are found to have good agreement with finite element analysis.

The cracking moments of reinforced geopolymer concrete beams were calculated using the design provisions contained in the IS 10262-1982. The mean value of test/calculated cracking moments is between 1.05 to 1.225 with a standard deviation of 0.07 to 0.30.

The flexural capacity of the beams was influenced by the longitudinal tensile reinforcement ratio and the concrete compressive strength. As the longitudinal tensile reinforcement ratio increased, the flexural capacity of the beams increased significantly. Because the test beams were under reinforced, the flexural capacity increased only marginally when the compressive strength of concrete increased.

The ductility of reinforced geopolymer concrete beams, as indicated by the ratio of mid-span deflection at ultimate moment-to-mid-span deflection at yield moment, increased as
the tensile reinforcement ratio decreased. Test results showed that the ductility increased significantly for beams with tensile reinforcement ratio less than 1%. For beams with tensile reinforcement ratio greater than 1%, the ductility was moderately unaffected. These test trends are comparable to the behaviour of reinforced Portland cement concrete beams.

- Good correlation is found between the test and calculated ultimate bending moments. In the case of beams with low tensile steel ratio, the test values are conservative due to the neglect of the strain-hardening effect of tensile steel bars on the ultimate bending moment.

- The measured service load deflections of test beams were compared with the Analytical values calculated using ANSYS 13. Good correlation between test and Analytical values is found. The mean value of ratio of test/calculated deflections is between 0.79 to 1.06 with a standard deviation of 0.0012 to 0.034 shown in table 6.6.

- The study demonstrated that the design provisions contained in the draft Indian Standard for Concrete Structures are applicable to reinforced geopolymer concrete beams with a slight modification.
SCOPE FOR FUTURE WORK

The present study can be extended for future work with consideration to the following points:

- To Study the Reinforced Geopolymer Concrete columns for Different grades using sand and Manufactured Sand.

- To Study the buckling of Geopolymer Concrete columns.

- The buckling of geopolymer concrete columns is to be compared with that of the conventional concrete column by experimental and analytical method.

- The work can be extended by varying the admixtures like GGBS and comparative analytical study can be made.

- The experimental work can be done for steam curing condition.