CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary

The purpose of this study was to develop a theory for behaviour of reinforced concrete beam columns for biaxial loading. Functional form of stress strain curve was used for concrete. Equations for Load and Ultimate Load factors, Moment and Ultimate Moment factors and Ultimate Neutral axis factors were developed for three modes of failure and two cases of location of neutral axis. These equations were summarised in chapter 4 as equations 1 through 30. Equations for critical values of mp for demarcation between tension failure and compression failure case were summarised in chapter 4 as equations 31 and 32. Critical values of mp for the demarcation between the balanced design and tension failure case were also formulated and given in equations 33 and 34.

Curves for ultimate load moment interaction and inclination factor of neutral axis were evolved for specific parameters. Critical values of reinforcement to demarcate types of failure were clearly shown on interaction curves.

Tests on twenty four prototype specimens were performed. Variables on specimens were the amount of tension steel, the ratio of compression to tension steel, the ratio of compression to tension steel and the eccentricity ratios. All the test specimens were loaded to failure. Failure modes were (a) tension failure with yielding of tension reinforcement followed by crushing of concrete and (b) compression failure initiated by crushing of concrete. Test results and observation details were recorded in chapter 7.

Computer programme was prepared and used on specific parameters. Interaction curves were plotted from the computer output.

Table 8.1 is prepared to present comparison of test and theory results. Special computer run was commissioned to obtain results on experimental specimen data.

Nine column test results of biaxial moment loading reported by Meek (25), were compared by the theory developed in this study and are tabulated in Table 8.2.

Comparison of results with design charts of Row and Paulay (34), Fleming and Werner (47) and Tung Au (16, 60), are reported in Table 8.3.

Design calculations to compare Pannel's approach detailed by Sarkar (54), and the present theory are shown in Appendix D.

The equations developed are used to check the test data of this study, those of Meek (25), and the theories of other investigators. Good agreement is observed in the results.

8.2 Conclusions

The theory developed in this study appears to provide satisfactory and reliable approach to estimate ultimate load and moment factors for beam columns loaded biaxially. Tables 8.1, 8.2 and 8.3 indicate that computed results agree fairly well with the observed values and test data as well as theoretical results of other research workers. The computer programme has made selection of neutral axis very simple as trials can be done of the output.

The proposed method to estimate ultimate load and moment factors provide more reliable results as it is based on realistic stress-strain curve of concrete

rather than empirical compression block used by previous investigators. The treatment on dimensionless parameters has rendered this method a unique flexibility. Wide range of parameters are covered in this theory facilitating unlimited scope.

Study on interaction curves shows that the effect of direct load is to reduce the ultimate moment of over-reinforced concrete sections and to increase the same for under-reinforced sections. Also, the critical proportions of reinforcement at the demarcation are reduced by the thrust. The curvature is also reduced by thrust.

Eccentricity reduces the ultimate capacities leading sections towards the tensile failure.

Eccentricity ratio also affetcs the inclination of neutral axis. Increase in one eccentricity ratio follows with decrease in the other at same inclination factor of neutral axis and at same ultimate load factor.

Experimental programme achieved encouraging results but accurate measurement of concrete strains could not be obtained. The hinge device developed specially for the present experimental work was useful.

Experimental results compared with the theory are within $\pm$ 13 % for ultimate load and moment factors.

8.3 Recommendations for Biaxial Beam Column Design.

The present theory can be used for medium to large eccentricities conveniently. For small eccentricities further test evidence is necessary as small eccentricity loading was not tried in the present experimental programme. The results obtained are reliable for eccentricity ratios upto 1.6 on both the axes. Very large eccentricity ratios exceeding 1.6 both ways need to be supported by further testing.

Beam column designs falling in these limits can be executed by the present theory to achieve economy and safety.

The charts and design procedure developed here may be fruitfully included in Codes of Practice for reinforced concrete.

Comprehensive research programme, to substantiate the deficiency of test data, is recommended to be evolved.

8.4 Recommendations for Future Research

Though some work is done for beam columns loaded biaxially, a comprehensive approach is lacking.

Test data are insufficient. Codes of Practice are lacking in workable coverage of design approach. Hence the subject has wide scope for further research.

A curvature meter to measure moment-curvature relationships in biaxial bending needs to be developed, as no such device exists at present. Such measurements shall enrich the test data. It is also recommended that a comprehensive research be carried out for flexural rigidity in biaxial bending.

The present literature does not report any work done on comparison of load and moment capacities of biaxial beam columns for different shapes of Reinforced concrete sections. Sections like L, T hollow rectangular and circular may be investigated to widen the scope of the subject.

Also limited work is done for disposition of reinforcement of all varied types in beam column sections. Such work needs to be supported by further test data.

The subject of biaxial bending should be investigated by the versatile Finite Element Method. A model, to respond to such sophisticated approach can be developed to widen the horizons of knowledge.

TABLE 8.1

ULTIMATE LOAD AND MOMENT FACTORS

Specimen No.	Calculated Values		Test Values			$\dfrac{P_u, \text{ test}}{P_u, \text{ cal.}}$
	$P_u,$	$M_u,$	P_u (T.)	$P_u,$	$M_u,$	
1	0.2812	0.1283	13.2	0.2112	0.0963	*
2	0.1668	0.1066	10.1	0.1616	0.1032	0.96
3	0.1288	0.1057	6.3	0.1000	0.1143	0.77
4	0.1403	0.1134	8.7	0.1393	0.1125	0.99
5	0.3591	0.1697	14.2	0.2797	0.1321	*
6	0.2905	0.1887	9.5	0.1871	0.1215	*
7	0.2200	0.2007	8.8	0.1733	0.1580	0.78
8	0.2700	0.2348	14.2	0.2797	0.2432	1.03
9	0.4500	0.2800	20.0	0.4020	0.2501	0.89
10	0.5100	0.3117	17.7	0.3557	0.2172	*
11	0.3000	0.3030	8.8	0.1768	0.1785	*
12	0.2708	0.3661	11.4	0.2281	0.3083	0.84
13	0.0994	0.0835	7.0	0.1169	0.0982	1.17
14	0.1010	0.0837	7.1	0.1185	0.0982	1.17
15	0.1448	0.0917	9.3	0.1544	0.0977	1.06
16	0.2229	0.1130	13.5	0.2254	0.1144	1.01
17	0.0738	0.0799	5.5	0.0874	0.0946	1.18
18	0.1000	0.0827	7.2	0.1144	0.0946	1.14
19	0.1070	0.0844	8.0	0.1272	0.1003	1.18
20	0.1473	0.0903	11.0	0.1749	0.1072	1.18
21	0.1702	0.2020	8.3	0.1435	0.1703	0.84
22	0.1003	0.0819	6.8	0.1176	0.0960	1.17
23	0.1279	0.0829	8.1	0.1401	0.0908	1.09
24	0.1489	0.0890	10.2	0.1764	0.1054	1.18

$\pm$ 13 %

* Bracket Failure

TABLE 8.2

COMPARISON WITH EXPERIMENTAL DATA OF JOHN MEEK (25)

Column No.	Concrete Strength psi.	$\equiv \dfrac{Myo}{Mxo}$	M_u (25) in. kips	M_u, (25)	M_u, Present study
1	5600	0.95	93.9	0.2614	0.2600
2	4860	0.57	87.3	0.2806	0.3000
3	5430	0.47	99.6	0.2866	0.2850
4	5350	0.61	97.6	0.2850	0.2800
5	5430	0	95.6	0.2750	0.2800
6	4800	0.34	87.9	0.2860	0.2886
7	4800	0.48	94.7	0.3082	0.3100
8	5400	0.36	87.6	0.2530	0.2800
9	4630	0.96	101.2	0.3415	0.3300

TABLE 8.3

ULTIMATE LOAD AND MOMENT FACTORS

Investigator	Parameters	Calculated values from investigator's study		Values obtained from present study	
		P_u,	M_u,	P_u,	M_u,
1. Thattey (14)	$mp = 0.02$, $Z = 0.5$ $N = 1.0$, $D_y' = 0.2$	0.3979	0.3356	0.3979	0.3356
2. Tung Au (60)	$D_y' = 0.19$, $Z = 1.0$ $N = 0.90$	0.1714	0.1206	0.1700	0.1000
3. Row and Paulay (34)	Beam 13 Column 14 Specimen 15 Nos. 16	0.1050 0.0941 0.1482 0.2312	0.0837 0.0834 0.0891 0.1238	0.1010 0.0994 0.1448 0.2227	0.0849 0.0835 0.0919 0.1130
4. Fleming and Werner (47)	$mp = 0.06$, $e_x/e_y = 0.60$ $e_y/b = 0.50$ $e_x/b = 0.30$ $f_y = 60000$ psi $p \cdot f_y/f_o' = 0.10$	0.1440	0.1500	0.1413	0.1563
5. Tung Au (16)	$g/d_y = 0.30$ $g_o/d_y = 0.15$ C_1 and C_2	0.2500	0.0400	0.2579	0.0418
	$g/d_y = 0.2336$ $g_o/d_y = 0.0463$ C_1 and C_2	0.0953	0.0620	0.1000	0.0827