Ultimate Strength of Steel-Concrete Composite Sections under Biaxial Bending

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Summary

Effects of loading path on the ultimate strength and the moment-curvature relation of cross sections subjected to axial load and biaxial bending were investigated by analyzing four kinds of cross section: wide flange, square tube, CFT and SRC sections. Three types of loading path were considered. It was found that an identical point on the ultimate strength interaction was reached regardless of the loading paths, and the maximum values of bending moments may be different from those at the ultimate strength point on the interaction.

1. Introduction

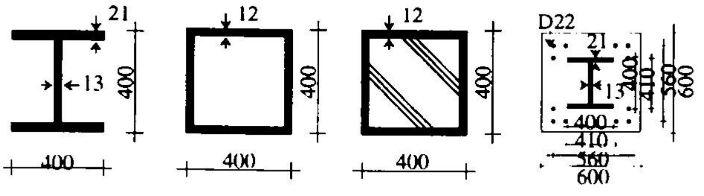
The ultimate strength interaction curves of reinforced concrete and steel reinforced concrete (SRC) cross sections were extensively investigated, and several mathematical formulas were proposed [1,2]. However, no research was found which mentioned the effect of loading procedure. The purpose of this investigation is to clarify the effect of the loading procedure on the ultimate strength by the numerical analysis of the moment-curvature relation considering the strain reversal and the local buckling of steel elements.

2. Moment-Curvature Relations

The moment-curvature relations of four cross sections were analyzed: wide flange, square tube, concrete-filled square tube (CFT) and SRC containing wide flange as shown in Fig. 1. The stress-strain relations of steel, reinforcements and concrete were assumed as shown in Fig. 2. The relation of the steel contains the stress reduction part caused by the local buckling [3]. Materials assumed here were SM490 class ($\sigma_y = 323.4\ N/mm^2$) for steel, SD40 class ($\sigma_y = 211.6\ N/mm^2$) for reinforcement, and the 300 kgf/cm^2 ($F_c = 29.4\ N/mm^2$) for concrete. Parameters for the stress-strain relations are shown in Table 1.

Figure 3 shows the strain distribution in the cross section subjected to the axial load N and the biaxial bending moments M_x and M_y, which were calculated for given values of the curvature by the numerical integration, dividing the cross section into small elements and assuming the uniform stress distribution in each element. The following three loading procedures were considered:

A: M_y was kept constant, and M_x was gradually increased.
B: M_x and M_y were gradually increased so that the deformation angle ($\theta_f = tan^{-1}(\phi_y / \phi_x)$) was kept equal to the value which was already obtained at the ultimate stage in the procedure **A** .
C: Proportional loading with the bending angle ($\theta_m = tan^{-1}(M_y / M_x)$) kept equal to the value which was obtained at the ultimate stage in the procedure .



(a) Wide flange (b) Square tube (c) CFT (d) SRC

Fig. 1 Cross-sections

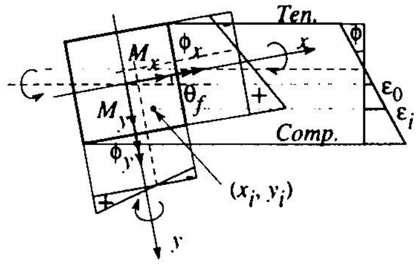


Fig. 3 Strain distribution

Table 1 Parameters

$_{st}E(kN/mm^2)$	205.8
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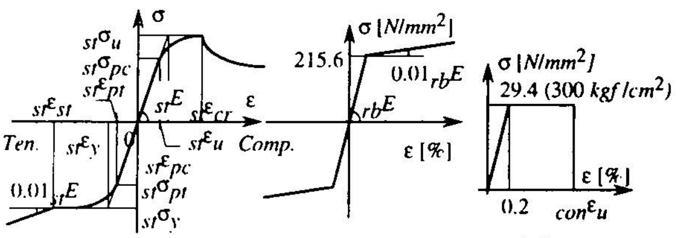
$_{st}\sigma_{pc}(N/mm^2)$	196
$_{st}\sigma_{pt}(N/mm^2)$	-196
$_{st}\sigma_y(N/mm^2)$	-323.4
$_{st}\sigma_u(N/mm^2)$	288.6
$_{st}\varepsilon_u$ (%)	0.14
$_{st}\varepsilon_{cr}$ (%)	0.67
$_{con}\varepsilon_u$ (%)	0.6(CFT) 0.4(SRC)

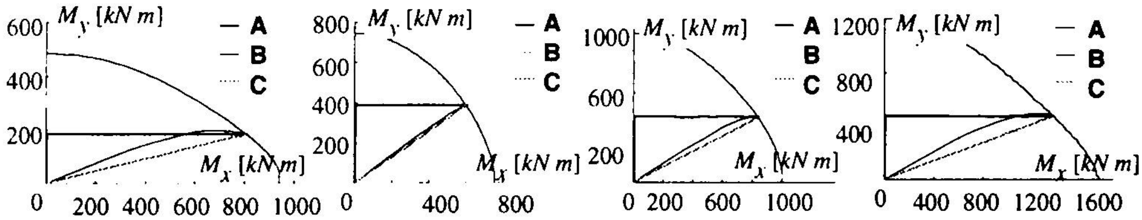


(a) Steel (b) Reinforcement (c) Concrete

Fig. 2 Stress-strain relations of material

3. Ultimate strength

Figure 4 shows the M_x-M_y paths of four cross sections together with the ultimate strength interaction curve which was calculated at the stage that the compressive strain of any element reached to the strain of the local buckling or the strain of the concrete crash. The procedure **A** in which M_y was kept constant, and the procedure **C** in which the bending direction was kept constant show the linear relation from the beginning to the ultimate stage on the interaction curve. On the other hand, procedure **B** shows the curved relation. However, M_x-M_y paths obtained from three analyses met at the exactly same point on the interaction curve for the ultimate strength of the cross section. The maximum values of M_x and M_y of the wide flange and the SRC sections are different from the strengths given by the ultimate point on the interaction curves. This is because these cross sections have unequal strengths about two major axes.



(a) Wide flange (b) Square tube (c) CFT (d) SRC

Fig. 4 Biaxial Ultimate Strength

4. Conclusion

1) An identical point on the interaction curve for the ultimate strength of the cross section subjected to the axial load and the biaxial bending moment was reached regardless of the loading procedure.
2) The ultimate strength point on the interaction curve was not the same as the maximum point of M_x and M_y in the case of the procedure **B** with the constant deformation angle for the section having unequal strength about two major axis.

References

[1] B. Bresler (1960), *Design Criteria for Reinforced Concrete Under Axial Load and Biaxial Bending*, ACI Journal, Vol. 57, No. 5, pp. 481-490. [2] C. Matsui, S. Morino and Y. Ueda (1984), *Maximum Strength of Steel Reinforced Concrete Section Subjected to Axial Thrust and Biaxial Bending*, Research Papers, Faculty of Engineering, Kyushu University, pp. 95-101. [3] J. Kawaguchi, S. Morino, H. Atsumi and S. Yamamoto (1991), *Strength deterioration Behavior of Concrete Steel Tubular Beam-Columns under Repeated Horizontal Loading*, Proc. of 3rd International Conference on Steel-Concrete Composite Structures, pp. 119-124, Fukuoka, Japan.