# I - A12 Initial Strength Curves In Force Space for Concrete-filled Steel Frame Members

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**Introduction** This paper is to explore the possibility of developing a two-surface type constitutive model in force space for concrete-filled steel frame members. For this purpose, cyclic inelastic deformation characteristics of concrete-filled steel sections were investigated through numerical analysis. Based on the analytical results, the initial strength curves of the concrete-filled steel sections were defined in the axial force—uniaxial bending moment space.

**Method** The following simplifications were made as premises of the numerical analysis: 1) All plane cross-sections before deformation remain plane in their deformed state; 2) Deformations within the plane of cross-section were neglected. 3) Only normal stress to the cross-section was considered.

Used for calculating the normal stress of steel elements was the modified two-surface model for steels with yield plateau ( Shen et al. 1995 ), which can accurately account for the cyclic inelastic behavior of structural steels. As for the concrete constitutive model , only the compressive stress resistance was taken into account, and on the compressive side, the plasticity model used was of perfect plastic type.

The relationship between stress resultants (axial force $N$, bending moment $M$) and sectional deformations ( axial strain $\varepsilon$ , curvature $\Phi$ ) was examined numerically. First the cross-section was divided into small uniform stress elements. Two types of concrete-filled sections were examined in this study, namely, the box section and the pipe section. Next a given loading path in $\varepsilon - \Phi$ space was divided into small loading steps. For each loading step, the normal stress at each element was calculated, then the internal force was computed by integration over the entire cross-section. Thus the internal force path corresponding to the loading path can be obtained, and the relationship between bending moment $M$ and curvature $\Phi$ as well as the relationship between axial force $N$ and axial strain $\varepsilon$ can be extracted for any loading path.

**Results** The initial strength curves were defined in a normalized force space $(m,n)$. $m$ denotes the bending moment normalized by $M_y^*$, which is the yield moment of the section when only curvature is exerted on the section. $n$ denotes the axial force normalized by $N_y^*$. $N_y^*$ is given by: $N_y^* = A_s\sigma_{sy} + \frac{1}{2}A_c\sigma_{cy}$ ; where $\sigma_{sy}$, $\sigma_{cy}$ are yield stresses of steel and concrete respectively, and $A_s$, $A_c$ are areas of steel and concrete respectively.

Proportional loading paths were adopted for calibrating the initial strength curves in the $(m,n)$ space, that is, the ratio between the axial strain $\varepsilon$ and the curvature $\Phi$ was kept constant during one loading path ( Fig.1 ). As an $m - \Phi$ curve and an $n - \varepsilon$ curve can be obtained for each loading path, three sample points i.e. points on the initial yielding curve, on the yield plateau curve and on the bounding curve were extracted from each loading path. The concept of extracting sample points for the three initial strength curves is illustrated in Fig 2.

The initial yielding curve was approximated by straight lines in $(m,n)$ space. The equation was given by:

$$|hm| + |n - \alpha_n| - r_y = 0 \qquad (1);$$

where $h$ is the slope of the straight lines and was taken to be of positive sense. $r_y$ is the curve radius on $n$-axis; $\alpha_n$ is offset on $n$-axis. The yield plateau curve was approximated by:

$$\left[\frac{m}{f_y}\right]^{C_1} + (n - \gamma_n)^{C_2} - 1.0 = 0 \qquad (2);$$

where $C_1$, $C_2$ are constants, and $f_y$ is the shape factor; $\gamma_n$ is offset on $n$-axis. As indicated by equation (2), the radius of the yield plateau on $n$-axis is 1.0, because $N_y^*$ is used to normalize the axial force. And the bounding curve was approximated by:

$$\left[\frac{m}{r_B \cdot f_B}\right]^{C_3} + \left[\frac{n - \beta_n}{r_B}\right]^{C_4} - 1.0 = 0 \qquad (3);$$

where $C_3, C_4$ are constants; $r_B$ is the radius of the bounding curve on $n$-axis; $f_B$ is the shape factor; $\beta_n$ is offset on $n$-axis.

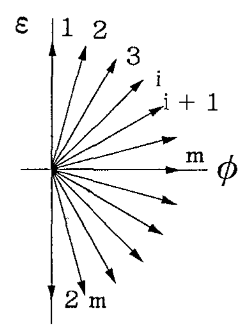

Fig.1 Proportional loading paths

The parameters of each curve were got based on the obtained sample points by the least square method. To guarantee the convexity property of the yield plateau curve and the bounding curve, constant $C_1$ and $C_3$ for both box section and pipe section were taken as 1.0. Table 1 gives the curve parameters for the pipe section obtained in this study.

Key word : Constitutive relationship, Concrete-filled steel structure, Cyclic loading, Inelastic analysis
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The steel involved is SS400, and compressive yield stress of concrete is 15.69*Mpa*. Fig.3 and Fig.4 illustrate the obtained initial model curves for the pipe section with $D/t$ =100 and $D/t$=40 respectively.

**Table 1 Initial Strength Curve Parameters for pipe section ( SS400, $\sigma_{cy} = -15.69MPa$ )**

| | | |
|---|---|---|
| Yield Plateau curve | $C_1$ | 1.0 |
| | $C_2$ | $1.65 + 2.83 \times 10^{-3}\left[\frac{D}{t}\right]$ |
| | $f_y$ | $1.44 + 1.49 \times 10^{-3}\left[\frac{D}{t}\right]$ |
| | $\gamma_n$ | $\frac{-Ac/As}{34.98 + Ac/As}$ |
| Bounding curve | $C_3$ | 1.0 |
| | $C_4$ | $1.77 + 1.71 \times 10^{-3}\left[\frac{D}{t}\right]$ |
| | $f_B$ | $1.45 + 1.72 \times 10^{-3}\left[\frac{D}{t}\right]$ |
| | $r_B$ | $\frac{40.22 + Ac/As}{34.98 + Ac/As}$ |
| | $\beta_n$ | $\frac{-Ac/As}{34.98 + Ac/As}$ |
| Yielding curve | $h$ | $0.75 - 1.18 \times 10^{-3}\left[\frac{D}{t}\right]$ |
| | $r_y$ | $\frac{34.98 + 0.82Ac/As}{34.98 + Ac/As}$ |
| | $\alpha_n$ | $\frac{-0.82Ac/As}{34.98 + Ac/As}$ |

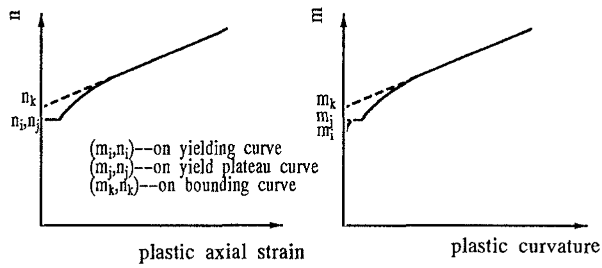


**Fig.2 Sample points on intial strength curves**

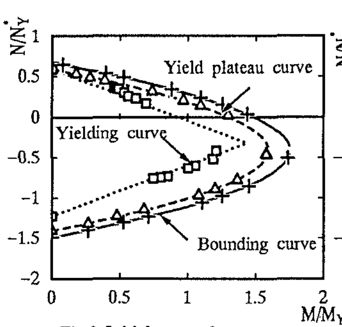


**Fig.3 Initial strength curves for pipe section (D/t=100)**

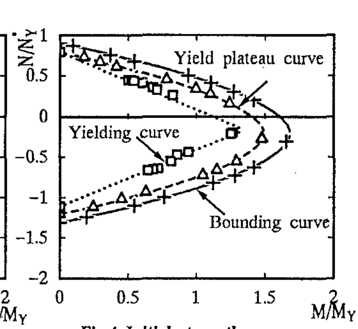


**Fig.4 Initial strength curves for pipe section (D/t=40)**

**Conclusion and Discussion** The initial yielding curve, yield plateau curve and bounding curve are no longer symmetric with respect to the $m$-axis like the case of pure steel sections ( Mizuno et al 1996 ) due to different tension and compression mechanical properties of concrete material. There are offsets on n-axis for all three initial strength curves as reflected by $\alpha_n, \gamma_n, \beta_n \neq 0$. In this study, the cross-section under question is hollowed steel sections filled with plain concrete without reinforcement, and the tensile resistance of concrete was neglected. The modified two-surface model for steel part states that the yield plateau starts sharply from initial yielding, as a result, the initial yielding curve contacts the yield plateau curve on the positive side of $n$-axis. On the other hand, steel and concrete material have different initial yielding strains, which is reflected by the fact that the initial yielding curve sets apart from the yield plateau curve on the negative side of $n$-axis. In other words, the radius of the initial yielding curve on $n$-axis is less than 1.0 . Actually, the radii and offsets of all three initial strength curves on $n$-axis can be determined from the area ratio of steel to concrete part for a certain cross-section knowing the stress-strain relationship for both steel and concrete under uniaxial monotonic loading, since they are related only to the uniaxial tension-compression behavior of the cross section.

The expectation for the aimed two-surface model in the force space for the concrete-filled steel frame members is to achieve great efficiency and economy of computation without sacrificing too much accuracy. The success of the aimed model depends more on establishing the hardening rule than defining the initial strength curves. And the refinement of the model lies in improving the concrete modeling to include the confinement effect and reasonably considering the interaction between the two different materials. In other words, refinement of concrete-filled steel modeling under cyclic loading into elastoplastic stage may require more relevant experimental data.

**References**


1) Itoh, A. "On Cyclic Deformation Characteristics of Concrete-filled Steel Sections in Bending Moment-Axial Force Space", Graduation Thesis, Dept. of CE, Nagoya Univ,.1997;

2) Mizuno, E. , Mamaghni, Iraj H.P. , Usami, T. , "Cyclic Large Displacement Analysis of Steel Structures With Two-surface Model in Force Space", ICASS'96-InE. Conf on Advances in Steel Structures, 1996;

3) Mamaghani, Iraj H.P. , Usami, T. , Mizuno, E. , "Cyclic Elastoplastic Behavior of Steel Structures: Theory and Experiment", Doctor's Dissertation, Dept. of CE, Nagoya Univ. , 1996;

4) Shen, C. , Mizuno, E. , Usami, T., "Development of A Cyclic Two-surface Model for Structural Steel with Yield Plateau", Doctor's Dissertation , Dept. of CE, Nagoya Univ. , 1993.