# Ductility of steel segments made of high strength steel SM570 subjected to combined compression and bending

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## 1. Introduction

The ductility capacity of thin-walled steel box columns made of SS400 with and without longitudinal stiffeners was studied under combined compression and bending through elasto-plastic large deformation FEM analysis, and the corresponding ductility equations were obtained [1, 2]. Recently, however, thin-walled steel segments made of high strength steel SM570 find wide application in urban highway bridges, and suspension and cable-stayed bridge towers in Japan as well as some other countries, and those previous equations are just suitable for the bridge segments made of SS400 and SM490. Consequently, the aseismic capacity, especially the ductility, of such structures made of SM570 needs further and extensive investigation.

## 2. Analytical model

The analytical model of the stiffened stub-columns is shown in Fig. 1, which represents part of a long column between the diaphragms. Due to symmetry of geometry and loading, only quarter of the stub-column is analyzed. The general purpose FEM program ABAQUS and a type of four-node doubly curved shell element (S4R) included in its package are employed. Initial deflections and residual stresses are considered as described in a previous study [1]. A kind of stress-strain relation including a strain hardening part, proposed by Usami et al. [3], is utilized for steel in this study. Its parameters are listed in Table 1 and relationship curves of SS400 and SM570 are illustrated in Fig. 2. *n* (number of subpanels divided by stiffeners) and *m* (number of half-waves of the local initial deflections in the longitudinal direction) are 5 and 1, respectively. The aspect ratio $\alpha$ (=$a/B$) is 0.5 based on the practical engineering. The cross section is shown in Fig. 3, and total 7 cross sections are employed in analysis as listed in Table 2. Seven kinds of axial load ratios $P/P_y$ of 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, and 1.0 are employed.

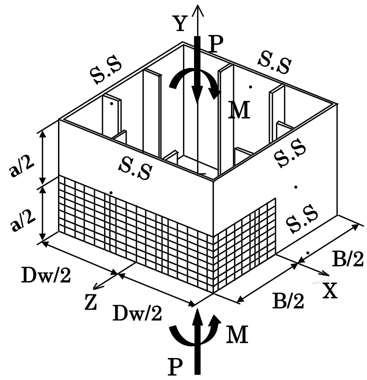



Fig. 1 Analytical model (S.S: simply supported boundary)

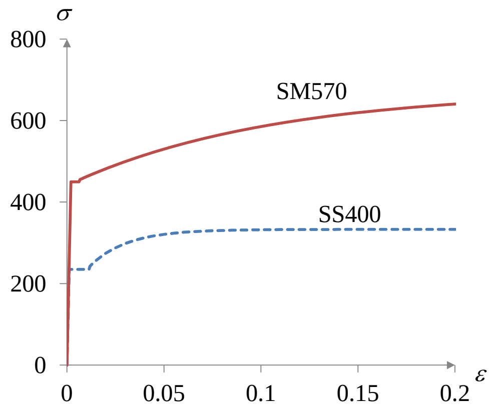



Fig. 2 Stress-strain relationships (SS400 and SM570)

Table 1 Material parameters (SS400 and SM570) [3]

| Material | $\sigma_y$ (MPa) | $E$ (GPa) | $\varepsilon_{st}$ | $E_{st}$ | $\upsilon$ | $\xi$ |
|---|---|---|---|---|---|---|
| SS400 | 235 | 206 | $10\varepsilon_y$ | $E/40$ | 0.3 | 0.06 |
| SM570 | 450 | 216 | $3\varepsilon_y$ | $E/100$ | 0.3 | 0.02 |

Table 2 Analytical cases

| Case | $t$ (mm) | $t_s$ (mm) | $R_f$ | $\bar{\lambda}_s$ | $\gamma/\gamma^*$ | $A$ (mm$^2$) | $I$ (mm$^4$) |
|---|---|---|---|---|---|---|---|
| 1 | 18 | 6 | 0.667 | 0.408 | 3.37 | 2.01E+5 | 2.28E+11 |
| 2 | 21 | 9 | 0.572 | 0.355 | 3.06 | 2.41E+5 | 2.66E+11 |
| 3 | 24 | 14 | 0.500 | 0.309 | 3.00 | 2.89E+5 | 3.05E+11 |
| 4 | 27 | 22 | 0.445 | 0.274 | 3.04 | 3.48E+5 | 3.46E+11 |
| 5 | 29 | 29 | 0.414 | 0.256 | 3.04 | 3.93E+5 | 3.74E+11 |
| 6 | 32 | 43 | 0.375 | 0.237 | 3.01 | 4.74E+5 | 4.17E+11 |
| 7 | 35 | 64 | 0.343 | 0.223 | 3.00 | 5.81E+5 | 4.64E+11 |

## 3. Analytical results

In this study, the ductility of the stub-column is evaluated by using the failure strain $\varepsilon_u/\varepsilon_y$, which is defined here as a point corresponding to 95% of the maximum strength after the peak in the bending moment versus average compressive strain curve [1]. Here, the average strain over the compressive flange is used and calculated by:

$$\varepsilon_a = \frac{2u}{a} \tag{1}$$

Where $u$ is longitudinal displacement of the upper or lower end of the compressive flange. The strain corresponding to the maximum strength $\varepsilon_m/\varepsilon_y$ is considered as an auxiliary ductility index. The computed failure strains are shown in Fig. 4 with respect to $R_f\bar{\lambda}_s^{0.18}$ at different levels of axial force, compared with the curves obtained from Eq. (2) [1] and Eq. (3) [2]. It is obvious that the computed results are larger than the results obtained from Eqs. (2) and (3). The same results are observed in Fig. 5, in which the computed strains corresponding to ultimate strengths are larger than that obtained from Eq. (4) [1].

$$\frac{\varepsilon_u}{\varepsilon_y} = \frac{0.8(1-P/P_y)^{0.94}}{(R_f\bar{\lambda}_s^{0.18}-0.168)^{1.25}} + 2.78(1-P/P_y)^{0.68} \le 20.0$$

$$0.3 \le R_f \le 0.7, 0.18 \le \bar{\lambda}_s \le 0.75, 0.0 \le P/P_y \le 0.5, \gamma/\gamma^* \ge 1.0 \tag{2}$$

$$\frac{\varepsilon_u}{\varepsilon_y} = \frac{0.7}{(R_f\bar{\lambda}_s^{0.18}-0.168)^{1.3}(1+P/P_y)^{2.2}} + \frac{3.2}{(1+P/P_y)} \le 20.0$$

$$0.3 \le R_f \le 0.7, 0.18 \le \bar{\lambda}_s \le 0.75, 0.0 \le P/P_y \le 1.0, \gamma/\gamma^* \ge 1.0 \tag{3}$$

$$\frac{\varepsilon_m}{\varepsilon_y} = \frac{1.41}{(R_f\bar{\lambda}_s^{0.18}-0.21)^{0.462}} + 0.38 \le 20.0$$

$$0.3 \le R_f \le 0.7, 0.18 \le \bar{\lambda}_s \le 0.75, 0.0 \le P/P_y \le 0.5, \gamma/\gamma^* \ge 1.0 \tag{4}$$

## 4. Conclusion

The ductility equations obtained from steel bridge columns made of SS400 are conservative for the members made of high strength steel SM570, and new equations suitable for the members made of SM570 need to be further investigated and developed.

References: 1) Zheng Y, Usami T, Ge HB. Ductility of thin-walled steel box stub-columns. *Journal of Structural Engineering ASCE* 2000; **126**(11):1304-1311. 2) Ge HB, Kono T, Usami T. Failure strain of steel segments subjected to combined compression and bending and application to dynamic verification of steel arch bridges. *Journal of Structural Engineering JSCE* 2004; **50A**:1479-1488. 3) Usami T, Suzuki M, Mamaghani IHP, Ge HB. A proposal for check of ultimate earthquake resistance of partially concrerete-filled steel bridge piers. *Journal of Structural Mechanism and Earthquake Engineering JSCE* 1995; **508**(I-31):69-82.

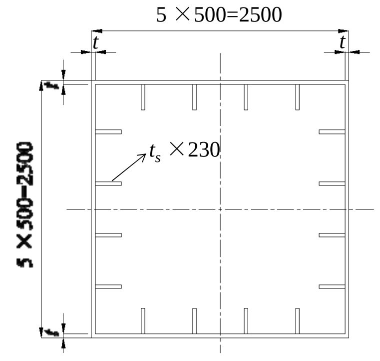
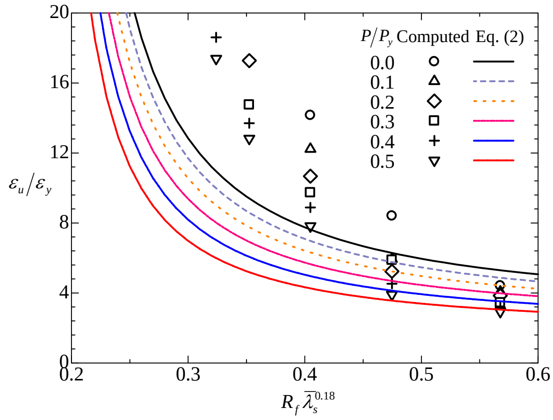
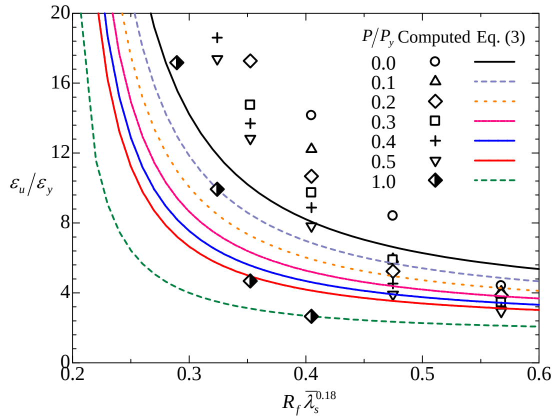



Fig. 3 Cross section (Unit: mm)




(a) Compared with Eq. (2)




(b) Compared with Eq. (3)

Fig. 4 Failure strains of stiffened stub-columns

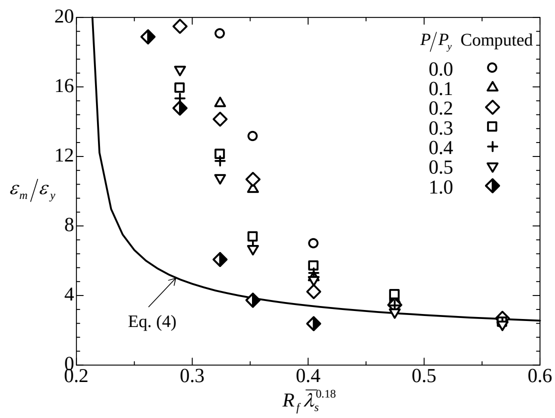



Fig. 5 Strains of stiffened stub-columns corresponding to ultimate strengths