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온도 증가에 따른 Unlipped C-형강의 세장비 연구

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Local Buckling and Slenderness Limits for Unlipped Channel Sections Subject to Temperature Gradient

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1.Introduction

The progress of structural engineering in the twentieth century and early in the twenty-first unquestionably tends toward the use of increasingly lighter elements, among which cold-formed thin-walled channels play an important role. However, the big disadvantages of cold-formed thin-walled channels are almost encountered local buckling. In particular, cold-formed thin-walled channels in fire lose a considerable amount of strength and stiffness as its temperature rises and can fail in the local buckling of the flange and web at high temperatures. Due to highly non-linear stress-strain relationships of steel member at high temperatures in fire, the local buckling behaviour becomes more complicated. However, there are very few theoretical studies with validation by experimental result of cold-formed channels under compression at elevated temperatures.

This paper was developed the computer software using the design equations in EC3 Part 1.2 (2000b) and Part 1.3 (1996) to analyze the local buckling stress for cold-formed unlipped channel sections under uniformly compression at elevated temperatures. The local buckling and yield stress, the critical, fail loads and critical temperature for design examples are analyzed by using the computer program of this study and these results are compared with the experimental results by Feng et al. (2003). Limit slenderness ratios of the flange and web of cold-formed unlipped channel sections under uniformly compression at elevated temperatures are the optimum slenderness ratios so that the local buckling does not occur prior to yield or deflection failure, it can be easily analyzed by using the non-linear optimum GINO(Generalized Interactive Optimizer) program developed by Liebman et al. (1986).

2. Material Properties

The rate of thermal expansion of the steel changes at high temperatures. EC3 Part 1.2 (2000b) defines three ranges to model, although more simplified linear models are available. The details of the EC3 model are as follows:

$$\frac{\Delta l}{l} = 1.2\times10^{-5}\theta + 0.4\times10^{-8}\theta^2 - 2.416\times10^{-4} \qquad \text{for } 20°C \le \Theta \le 750°C$$

$$\frac{\Delta l}{l} = 1.1\times10^{-2} \qquad \text{for } 750°C \le \Theta \le 860°C$$

$$\frac{\Delta l}{l} = 2\times10^{-5}\theta - 6.2\times10^{-3} \qquad \text{for } 860°C \le \Theta \le 1200°C$$

where,

l is the length at 20°C of the steel member ;

Δl is the temperature-induced expansion of the steel member ;

θ is the steel temperature (°C).

The BS5950 Part8 (1990b) presents coefficient of linear thermal expansion $=12\times10^{-6}$ to finished structural steels complying with BS4360 at elevated temperatures and are for use in fire calculations. Properties at ambient temperature are given in BS5950 Part 1 (1990a).

3. Local Buckling of Cold-Formed Channel Sections in Fire

The Winter(1947) expression has been accepted in EC3 Part 1.3 (CEN1996) for the analysis of local buckling for cold-formed lipped and unlipped channels under compression at ambient temperature. The effective width for those is evaluate as:

$$\frac{b_{eff}}{b_\rho} = \sqrt{\frac{\sigma_{cr}}{\sigma_{max}}}\left(1 - 0.22\sqrt{\frac{\sigma_{cr}}{\sigma_{max}}}\right) \tag{1}$$

where b_ρ is the notational flat width of plane elements with sharp corners, σ_{cr} is the local buckling stress, σ_{max} is the maximum edge stress of the plate, which may be taken as the yield stress of steel σ_y:

$$b_{eff} = \rho b_\rho \tag{2}$$

$$\rho = 1.0 \quad : \text{if } \lambda_p \le 0.673 \tag{3}$$

$$\rho = \frac{1.0 - 0.22\sqrt{\lambda_p}}{\lambda_p} \quad : \text{if } \lambda_p > 0.673 \tag{4}$$

$$\lambda_p = \frac{b_\rho}{t}\sqrt{\frac{12(1-\upsilon^2)\sigma_{yb}}{\pi^2 Ek}} \tag{5}$$

where b_{eff} is the effective width, k, ρ and λ_p are the local buckling coefficient, reduction and slenderness factor, σ_{yb} is the basic yield strength, υ is the Poisson's ratio for steel, and t is the thickness of cold-formed unlipped channel sections.

The local buckling stress $\sigma_{cr\theta,eff}$ for the effective width of cold-formed unlipped channel sections under compression at elevated temperatures based on EC3 Part 1.3 (CEN1996), Galambus(1998), Yu(2000) and Ghersietal(2001) is given by the equation:

$$\sigma_{cr\theta,eff} = \frac{k\pi^2 E_\theta}{12(1-\upsilon^2)(\frac{b_{eff}}{t})^2} \tag{6}$$

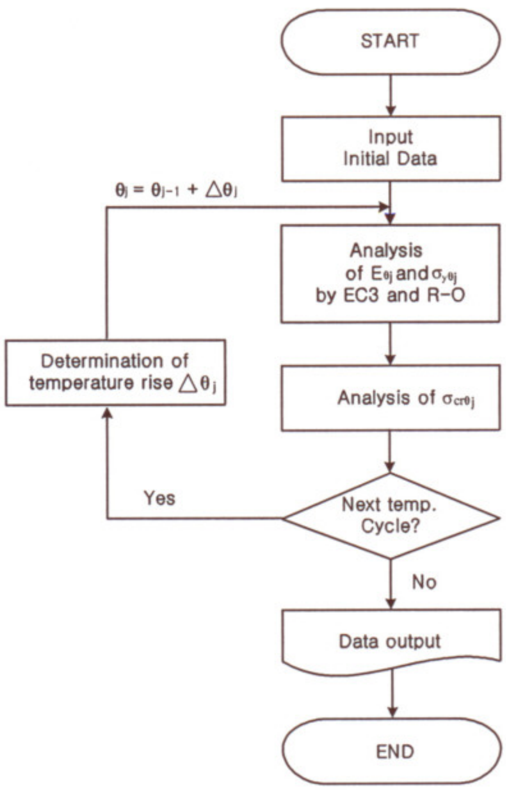
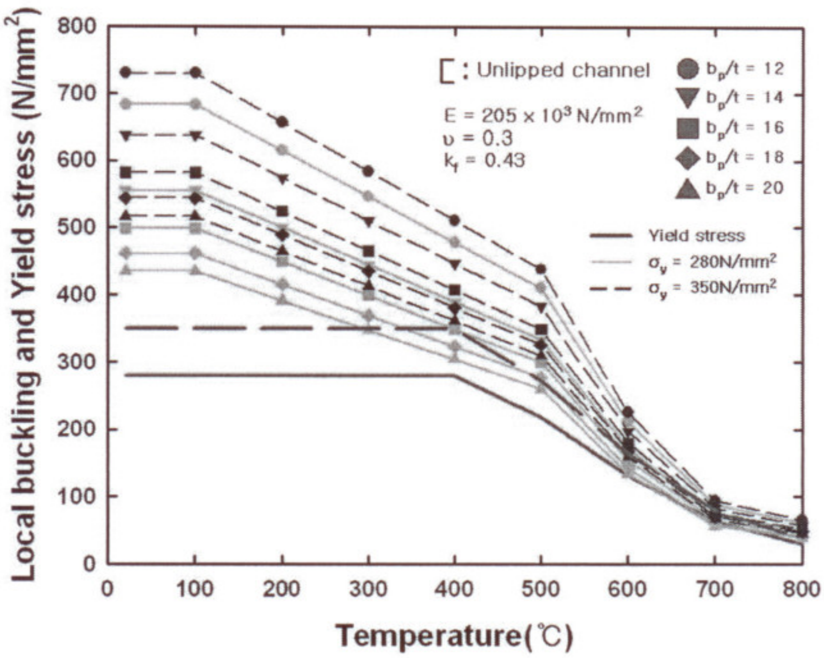


Fig.1 Flow chart of the local buckling stress analysis of cold-formed channels

4. Limit Slenderness Ratios of Unlipped Channel Sections in Fire

It is very important to predict the limit slenderness ratios, $(b_p/t)_{lim}$ for the flange and web of cold-formed unlipped channel sections under uniformly compression at elevated temperatures.

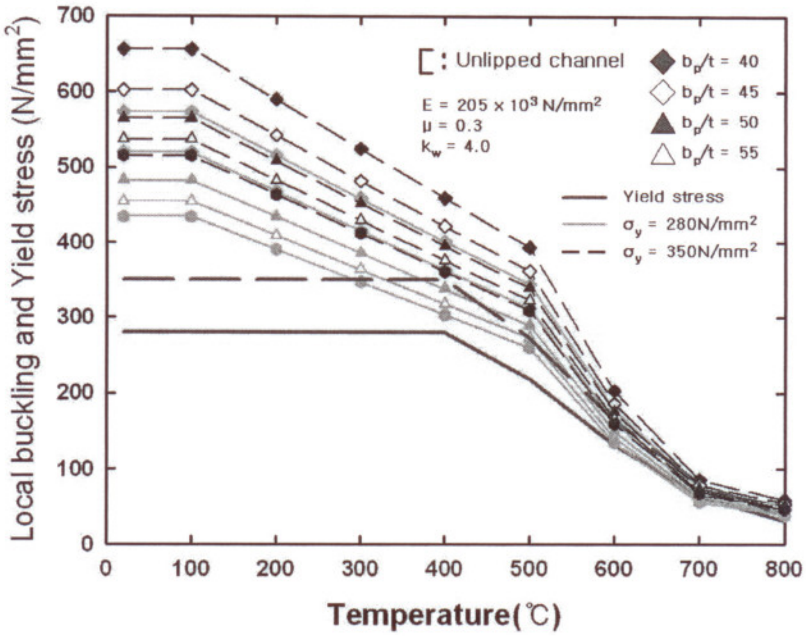


(a) flange

Fig.2 Local buckling and yield stress for the slenderness ratios of the flange for cold-formed unlipped channels under uniformly compression at elevated temperatures

In this study, the optimum limit slenderness ratios of cold-formed unlipped channel sections under uniformly compression at elevated temperatures can be easily calculated by using the non-linear optimum GINO program developed by Liebman et al. (1986). The objective function is the unit volume of cold-formed unlipped channels. The constraints are the design limits defined by the local buckling strength, the maximum slenderness ratios and minimum thickness. The design variables are the slenderness ratios of the flange and web of cold-formed unlipped channels. The yield strengths at ambient temperatures are taken as $280N/mm^2$ and $350N/mm^2$.

The elastic modulus at ambient temperatures is $205 \times 10^3 N/mm^2$. Cold-formed unlipped channel sections are assumed to be subject to a uniformly temperature profile through its section.



(b) web

Fig.3 Local buckling and yield stress for the slenderness ratios of the web for cold-formed unlipped channels under uniformly compression at elevated temperatures

The local buckling stress of the flange and web of cold-formed unlipped channels with simply supported ends under uniformly compression at elevated temperatures is under taken for temperatures of the following values, i.e. Θ=20, 100, 200, 300, 400, 500, 600, 700 and 800°C.

The slenderness ratios for flange and web of cold-formed unlipped channel sections are b_p/t=12, 14, 16, 18 and 20 for the flange, and b_p/t=40, 45, 50, 55 and 60 for the web.

Table 1. Critical temperatures for the slenderness ratios of cold-formed unlipped channels under uniformly compression at elevated temperature

Yield stress (N/mm^2)		b_p/t	b_{eff}/t	b_{eff} (mm)		$\sigma_{y\Theta}$ (N/mm^2)		$\sigma_{cr\Theta,eff}/\sigma_{y\Theta}$	Critical Temperature (°C)
				$\sigma_{y\Theta}$	$\sigma_{cr\Theta,eff}$	$P_{u\Theta}$	$P_{cr\Theta}$		
Flange	280	12	10.80	170.66	300.88	16.59	29.25	1.76	-
		14	11.98	170.66	244.62	1.84	26.37	1.43	-
		16	12.64	170.66	219.71	19.41	24.99	1.29	-
		18	13.14	83.22	83.21	9.84	9.84	0.99	672
		20	13.54	112.11	112.06	13.66	13.65	0.99	629

Flange	350	12	10.45	213.32	321.34	20.06	30.22	1.51	-
		14	11.18	213.32	281.03	21.46	28.264	1.32	-
		16	11.70	99.82	99.69	10.51	10.50	0.99	677
		18	121.1	140.14	140.13	15.27	15.27	0.99	629
		20	12.42	173.18	171.99	19.36	19.23	0.99	592
Web	280	40	35.96	170.66	252.45	55.23	81.71	1.48	-
		45	37.78	170.66	228.74	58.03	77.77	1.34	-
		50	39.21	69.78	69.59	24.63	24.56	0.99	692
		55	40.38	88.59	88.55	32.19	32.18	0.99	664
		60	41.34	113.46	113.37	42.21	42.18	0.99	627
	350	40	33.63	213.32	288.72	65.56	87.38	1.35	-
		45	35.08	88.06	88.04	27.80	27.80	0.99	691
		50	36.23	114.10	114.06	37.20	37.19	0.99	660
		55	37.16	151.90	151.89	50.80	50.80	0.99	615
		60	37.93	176.43	176.14	60.23	60.13	0.99	589

Figs.2 to 3 show the analytical results of critical temperature, ultimate load, local buckling and yield stress for the slenderness ratios of cold-formed unlipped channels with simply supported ends under uniformly compression at elevated temperatures. It can be seen that local buckling stresses of cold-formed unlipped channels with simply supported ends are almost invariable in $\Theta \leq 100°C$ and that are decreased slowly in about $100°C < \Theta \leq 500°C$ and very rapidly in about $500°C < \Theta < 800°C$ and that yield stresses of those are almost invariable in about $\Theta \leq 400°C$ and are decreased rapidly in about $400°C < \Theta < 800°C$.

5. Conclusions

1) It can be seen that the present study is good agreement with the experimental results of Feng et al. (2003) and that the flange and web of cold-formed channels under compression at elevated temperatures should consider the local buckling because the local buckling occurs in most cases prior to yield failure.

2) It can be seen that the case using the yield stress σ_y=280N/mm^{2}occurs the local buckling in the flange slenderness ratio, $b_p/t \geq 18$ and the web slenderness ratio, $b_p/t \geq 50$ and the case using the yield stress σ_y=350N/mm^2 occurs the local buckling in the flange slenderness ratio, $b_p/t \geq 16$ and the web slenderness ratio, $b_p/t \geq 45$ prior to yield failure.

3) The critical temperatures of the flange and web of cold-formed unlipped channels under uniformly compression at elevated temperatures with the low yield stress are higher than those with the high yield stresses.

4) Yield stress and modulus of elasticity of steel, slenderness ratio and local buckling coefficient are main affect of the local buckling stress of the flange and web of cold-formed channels under uniformly compression at elevated temperatures.

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