コンクリート工学年次論文報告集，Vol.14，No.2，1992

論　文

[2174] Buckling Load and Ductility of Unbonded Braces Restrained by Reinforced Concrete with F.R.P.

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1 Introduction

The authors have proposed new steel braces in framed structures which effectively resist compressive loads. The new braces called unbonded braces (thereafter, referred to as U.B.), are restrained by reinforced concrete to enhance buckling load up to almost the yield strength of the steel braces without the change of their rigidity by providing insulations between steel braces and reinforced concrete covers. The behavior of U.B. was analyzed and the results were verified through a series of experiments [1], [2]. Furthermore, the U.B. are developed with fiber glass reinforced plastic (thereafter, refered to as U.B.F.) to enhance buckling load and ductility.

The objective of this paper is to investigate the failure mechanism, yield strength and deflection of the U.B. and ductility of U.B.F.

2 Analysis

The U.B. consisted of a flat steel brace and a reinforced concrete cover. The reinforced concrete cover is not transmitted any axial force from the flat steel bar using grease with a thickness of $35 \sim 140\mu m$. It is well known that a buckling mode of a brace on elastic continuous supports depends on the rigidity of the supports (i.e., reinforced concrete cover) [3], that is, the buckling mode transfers to the higher buckling mode with the increase of thier rigidity. The buckling modes of the U.B. which occurred due to their rigidity of the reinforced covers are 1st or 2nd degree in this paper.

2.1 Buckling load of U.B.

The unbonded brace consists of a steel brace and reinforced concrete cover. Although these elements are mechanically insulated with each other by grease, an internal axial force (ΔP) caused by applied load (P) is partially transfers to the reinforced concrete cover. Also bending moment (ΔM), due to the deflection (δ) can be produced in the reinforced concrete cover simultaneously. The buckling load of U.B. is analyzed

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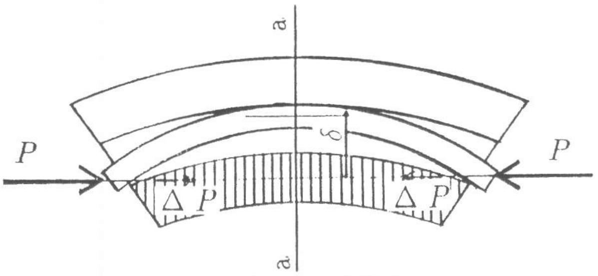
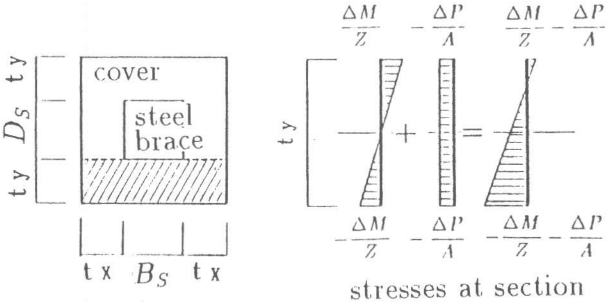
based on these complex stresses (see Fig. 1). Then the buckling load is determined by the failure of compressive part of reinforcement cover. The failure due to tensile or compressive stresses is expressed as follows:

$$\frac{\Delta P}{A} - \frac{\Delta M}{Z} < 0$$

$$\frac{\Delta P}{A} + \frac{\Delta M}{Z} < F_C \tag{1}$$



specimen of U.B.



section a–a

stresses at section a–a

Fig.1 Failure mechanism

Where A and Z are section area and section modulus of compressive part of the reinforced concrete cover, respectively. F_C is the strength of the concrete and ΔM is secondary moment due to the deflection and the internal axial force. Since the reinforcement bars contribution to section area A and section modulus Z is small in comparison with those of reinforced concrete cover in a small range of reinforcement ratio ($0 < P_t < 1\%$), the effects of reinforcedment bars are neglected. Then the deflection (δ) is obtained by following equation as a function of the thickness (t_y) of the reinforced concrete cover and the strength of concrete (F_C).

$$\delta > \frac{t_y}{6} \tag{2}$$

The relation between the deflection of the steel brace and applied load is known as the following equation.

$$\delta_y = a\frac{\mu}{1-\mu} \tag{3}$$

where $\mu = P/P_{CR}$

P : applied axial load

P_{CR}: buckling load of the steel brace

a : inital crookedness of the steel

As the steel brace reinforced by the concrete cover, the buckling load is assumed to be the yield strength of the steel. The deflection being obtained, the buckling load (${}_tP_{cr}$) of U.B. is calculated from equation (3),

$$ {}_tP_{cr} = \frac{P_y(\delta_y - a)}{\delta_y} \qquad (3') $$

From the equations (1), (2) and (3'), it is known that the buckling load P is a function of the thickness of the reinforced cover, the strength of concrete and the initial crookedness of the steel brace.

2.2 Buckling load of U.B.F.

It is stated before that the buckling load depends on the thickness of the reinforced concrete cover, the initial crookedness of the steel brace and the strength of concrete. This new method could be applied for U.B.F. Then the buckling load is also obtained by eq. (3')

2.3 Comparison with analysis and the experiments

Table 1 and Fig. 2 show the testing program and the specimen of U.B.F., respectively. Table 2 shows both the analytical and experimantal results of the specimen RA with respect to various initial crookedness (i.e., $a = L/1000$, $L/1500$ and $L/2000$). Hence the results obtained by eq. (3') corresponds to the experimental results by taking initial crookedness as $L/1500$ or $L/2000$. Fig. 3 shows the hysteresis loops of each U.B.F. specimen. The loops become stable with the increase of reinforcement ratio. For the purpose of investigataing the relation between buckling load and slenderness ratio, the specimen RA is used as an example. The results is shown in Fig. 4. It is obvious that the buckling load decrease linearly with the increase of the slenderness ratio.

3 Ductility

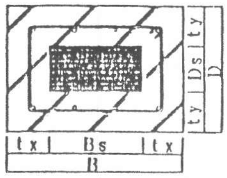
As stated before, a buckling mode depends on the rigidity of reinforced concrete covers. The modes of specimens RA and RB are first. Thus failure point of each specimen is at the center of its length and the buckling load is calculated using eq. (3)'. Since the reinforced concrete cover is reinforced with F.R.P., the deflection could still develop until the deflection at the boundary between reinforced concrete cover and F.R.P. reaches to the value of $t_y/6$ keeping the same buckling load (Fig. 5). This development of the deflection is one of the factors to increase ductility. Also, if the resisting moment (rM) of U.B.F. is lager than that of applied moment (aM), the U.B.F. would sustain further deflection. This is the second factor. For satisfying the second ductility factor, the relation between rM and aM becomes:

$$ aM < rM $$

$$ \mu = \frac{rM}{aM} > 1 \qquad (4) $$

Table 1 Testing program of U.B.F.

Specimen	L (cm)	λ	FRP-Cover Length	B × D (cm²)	Reinforce.	P t (%)
RA − 1	86.0	157 (286)	L/2	6.5×5.9	4-2.0φ	0.33
− 2					4-2.0φ, 2-2.6φ	0.60
− 3					6-3.2φ	1.26
RB − 1	91.9	200 (339)		6.5×5.6	4-2.0φ	0.35
− 2					4-2.6φ	0.68
− 3					8-2.6φ	1.17
RC − 1		266 (453)		7.0×4.8	4-2.0φ	0.37
− 2					4-2.6φ	0.63
− 3					8-2.6φ	1.26



*)Vinyl paraffin is used for insulation

Specimen	Bs (cm)	Ds (cm)	Tx (cm)	Ty (cm)
RA	1.9	1.9	2.3	2.0
RB	1.6	1.6	2.0	2.0
RC	1.2	1.2	1.6	1.8

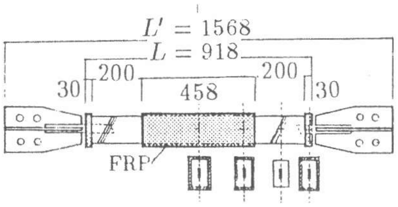


Fig.2 Specimen of U.B.F.

Table 2 Results of U.B.F.

	Experiment		Analysis					
	Pt (%)	ePcr(t)	L / 1000		L / 1500		L / 2000	
			tPcr (t)	(3)/(4)	tPcr (t)	(3)/(6)	tPcr (t)	(3)/(8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RA − 1 − 2 − 3	0.33 0.60 1.26	8.30 8.70 9.00	7.39	1.12 1.17 1.23	8.13	1.02 1.07 1.11	8.59	0.97 1.02 1.05
RB − 1 − 2 − 3	0.35 0.68 1.17	10.90 11.90 11.60	8.57	1.27 1.39 1.35	9.66	1.13 1.23 1.20	10.21	1.07 1.17 1.14
RC − 1 − 2 − 3	0.37 0.63 1.26	11.90 11.00 12.10	9.42	1.26 1.17 1.28	11.09	1.07 0.99 1.09	11.71	1.02 0.94 1.03

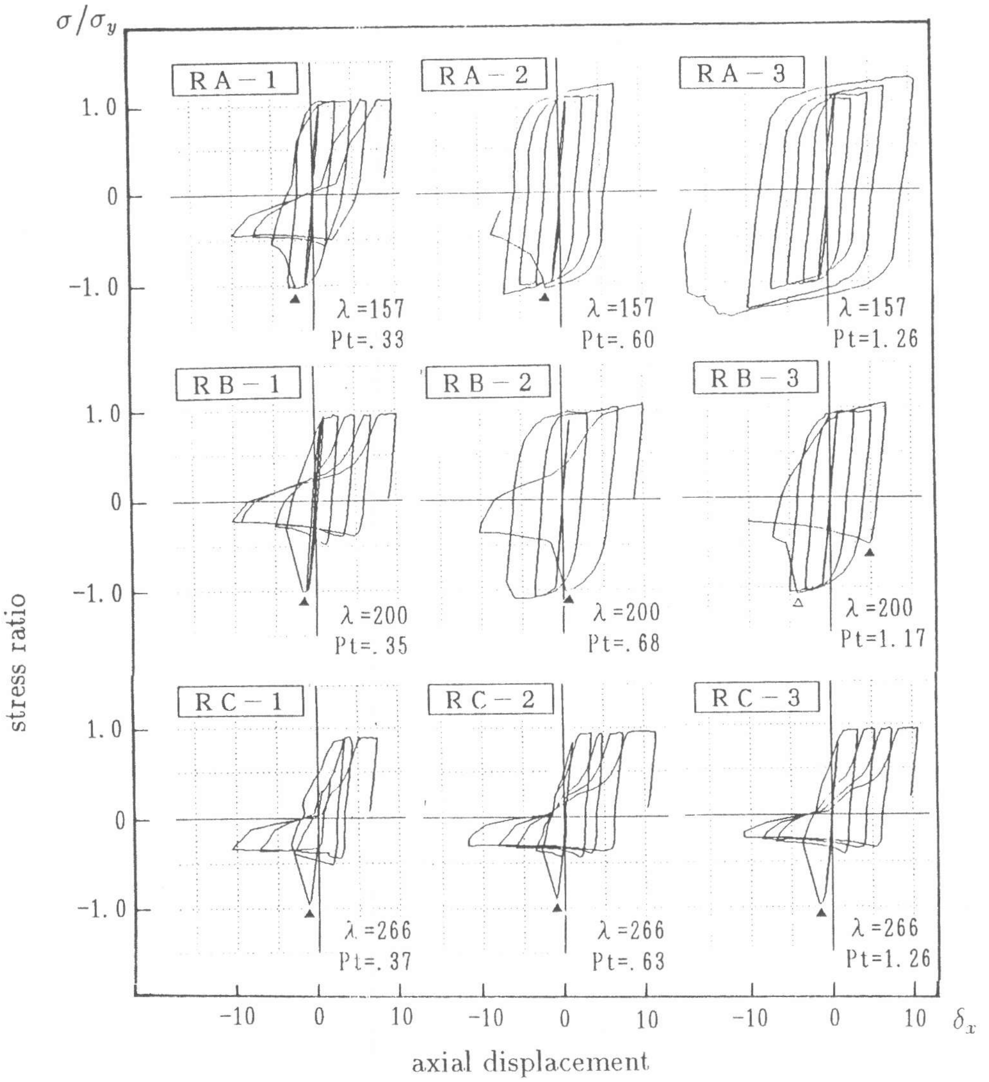


Fig.3 Hysteresis loop of U.B.F.

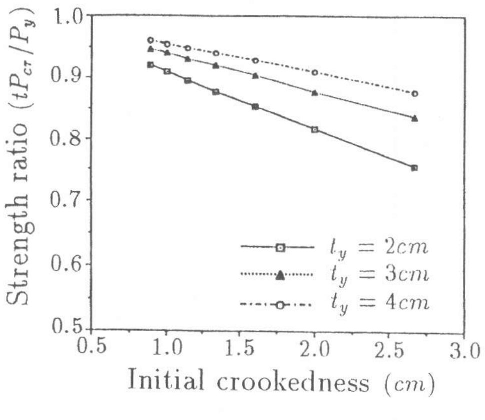


Fig.4 The relation between strength ratio and slenderness ratio

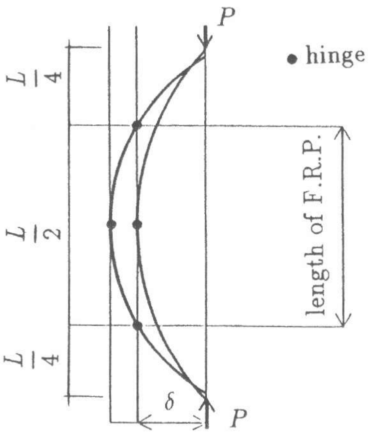


Fig.5 Deflection of U.B.F.

On the other hand, the buckling mode of the specimen RC is second. Therefore the failure point occurres at $L/4$ of U.B.F. around the boundary and the effect of F.R.P. for ductility does not appear. Then the ductility of this model is not enough.

4 Conclusions

The results obtained in this paper have led to the following conclusions:

1) The new equation for obtaining buckling load of unbonded braces is proposed. The equation is conducted by taking the secondary stresses effects into account.

2) It is possible to consider the effect of reinforcement bars in the reinforced concrete cover to the buckling load but it is not the main factor to enhance the buckling load in the reinforcement ratio range from 0 to 1%. The main factors are thickness of reinforced cover, the initial crookedness of the steel brace and the strength of concrete.

3) The buckling load also depends on initial crookedness. Larger value of initial crookedness causes lower buckling load. The effect is remarkable for the thinner reinforced concrete cover U.B.

4) The one-half length of F.R.P. does not enhance effectively the buckling load but is one of the factors to contribute to ductility.

5) The reinforcement ratio influences the ductility of U.B.

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