行政院國家科學委員會專題研究計畫　成果報告

鋼梁與 SRC 柱之梁柱接頭耐震性能之理論分析研究

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計畫主持人：翁正強

計畫參與人員：王暉舜、陳信賓

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行政院國家科學委員會補助專題研究計畫成果報告

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計畫參與人員： 王暉舜、陳信賓

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處理方式：除產學合作研究計畫、提升產業技術及人才培育研究計畫、列管計畫及下列情形者外，得立即公開查詢
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鋼梁與 SRC 柱之梁柱接頭耐震性能之理論分析研究

Analytical Study on Seismic Performance of Steel Beam-to-SRC Column Connections

C. C. Weng
Professor, Department of Civil Engineering,
National Chiao Tung University

ABSTRACT: Presented herein is an analytical study to predict the seismic resisting capability of steel reinforced concrete (SRC) beam-to-column connection. The main reasons of using SRC structural members are to take their advantages in strength and stiffness as well as in fire protection and corrosion resistance. In this study, the shear strength of the SRC beam-to-column connection is taken as the sum of the shear capacities of the steel section and the reinforced concrete in the connection zone. The steel section in the connection is able to develop shear yielding in ultimate state without premature local buckling due to the protection of the concrete. The strut-and-tie model is utilized to determine the shear capacity of the reinforced concrete in the connection. Furthermore, in recognition of the superior confining effect provided by the steel section in SRC column, the concrete in the connection is sub-divided into two zones, namely "the highly confined area" and "the ordinarily confined area," so that the shear strengths of each part of the concrete can be predicted more rationally.

KEYWORDS: Steel Reinforced Concrete (SRC); Beam-to-Column Connection; Seismic Resisting Capability; Shear Strength; Concrete Confinement; Strut-and-Tie Model; New Design Approach

1. INTRODUCTION

With the fast advance of the construction technology, it has become increasingly popular to design buildings with composite structural system. The steel reinforced concrete (SRC) structural system provides a building with advantages including the ductility of structural steel and the stiffness of reinforced concrete. Additional merits of the SRC structural members are that the concrete also protects the steel shape from corrosion, fire damage and local buckling failure [1, 2].

The SRC structural system has been successfully used in Japan for more than half century [3]. The architectural institute of Japan published its first SRC design code in 1958 and released a latest edition in 2001 [4]. In the United States, guidelines for the design of composite structural system were first introduced in the 1994 NEHRP seismic provisions [5]. Latest design provisions of composite structures can be found from the ACI building code [6], the AISC design specification [7], and the AISC seismic provisions [8]. In Europe, the design guidelines of composite structures can be found from the Eurocode [9]. In Taiwan, buildings constructed with SRC structural system have increased sharply after the Ji-Ji earthquake in 1999. The statistics released by the housing department of Taiwan in 2004 showed that about 19 % of the newly finished buildings were SRC structures. The ministry of the interior of Taiwan published its first official edition of SRC building design code in 2004 [10].

Figure 1 shows a typical layout of a SRC beam-to-column connection. A literature survey conducted by the authors indicated that past studies on the shear strength of SRC beam-to-column connection are very limited. It was found that a majority of past researches were focused on the steel beam-to-concrete filled tubular column (CFT) connections.

2. THE ACI-318 APPROACH

In the current ACI-318 code, the nominal shear strength V_n of a reinforced concrete beam-to-column connection can be determined as follows:

(a) For joints confined on all four faces

$$V_n = 1.67\sqrt{f_c^{'}}A_j \tag{1}$$

(b) For joints confined on three faces or on two opposite faces

$$V_n = 1.25\sqrt{f_c^{'}}A_j \tag{2}$$

(c) For others

$$V_n = 1.0\sqrt{f_c^{'}}A_j \tag{3}$$

where $f_c^{'}$ is the compressive strength of concrete in MPa; and A_j is the effective shear area at the joint.

It has been known that the above equations are relatively conservative and maybe over-simplified. Furthermore, due to the existence of a steel section in the SRC column, it would not be appropriate to directly adopt these equations to predict the shear capacity of the SRC beam-to-column connection.

3. AN ALTERNATIVE APPROACH

This study develops a new analytical approach to estimate the shear strength of SRC beam-to-column connection. In general, the design shear strength $\phi_v V_n$ of the SRC beam-to-column connection is taken as the sum of the shear capacities of the steel section $\phi_{vs}V_{ns}$ and the accompanying reinforced concrete $\phi_{vrc}V_{nrc}$ in the connection zone. That is

$$\phi_v V_n = \phi_{vs}V_{ns} + \phi_{vrc}V_{nrc} \tag{4}$$

where $\phi_{vs}=0.85$ and $\phi_{vrc}=0.75$.

The mutual beneficial correlation between the steel section and the reinforced concrete in the SRC joint is one of the important factors in developing the new design approach. It is noted that due to the protection of the reinforced concrete, the steel section embedded in the SRC connection is able to develop “shear yielding” in the ultimate state without premature failure caused by local buckling. Thus, the nominal shear strength of the steel section can be taken as

$$V_{ns} = 0.6 f_{ys} A_w \tag{5}$$

where f_{ys} is the yield strength of the steel section; and A_w is the area of the web of the steel section.

In addition, as shown in Fig. 2, in recognition of the superior confining effect provided by the steel section in the SRC column, the concrete within the column is sub-divided into two different zones, namely "the highly confined area" and "the ordinarily confined area," so that the shear strengths of each part of the concrete can be predicted more rationally.

In this study, the strut-and-tie model is utilized to estimate the shear capacity of the reinforced concrete in the connection. Figures 3 (a) and (b) show the possible diagonal compressive struts in the SRC beam-to-column joint. The shear capacity of the reinforced concrete in SRC joint, V_{nrc}, is taken as the sum of the horizontal components of the capacities of the diagonal compressive struts of the "highly confined concrete" and the "ordinarily confined concrete" in the connection zone. That is

$$V_{nrc} = V_{hc} + V_{oc} \tag{6}$$

where V_{hc} and V_{oc} are the shear capacities of the "highly confined concrete" and the "ordinarily confined concrete" in the connection, respectively.

As shown in Fig. 4, in the highly confined area, it is possible for this part of concrete to remain sound without major cracking due to the protection the steel section in the SRC joint. Thus, by using the strut-and-tie model, the shear strength of the "highly confined concrete" can be approximated as the horizontal component of the maximum capacity of the compressive strut. It is further simplified as

$$V_{hc} = 0.85 \left(f'_{cc} \right)_{hc} \times \left(A_{eff} \right)_{hc} \tag{7}$$

where $\left(f'_{cc} \right)_{hc}$ is the compressive strength of the highly confined concrete considering the beneficial confinement effect provide by the steel section and the hoop reinforcements; and $\left(A_{eff} \right)_{hc}$ is the effective area of the highly confined concrete in the connection.

As shown in Fig.5, in the ordinarily confined area, it is more difficult for this part of concrete to remain sound in the ultimate state due to the absence of the confinement provided by steel section. However, it is noted that the shear strength of the "ordinarily confined concrete" is significantly influenced by the constraint provided by the surrounding SRC beams at the joint. Thus, by using the strut-and-tie model, the shear strength of the "ordinarily confined concrete" can be approximated as the horizontal component of the maximum capacity of the compressive strut. It is further simplified as

(a) For joints confined on all four faces

$$V_{oc} = 0.85 \left(f'_{cc} \right)_{oc} \times \left(A_{eff} \right)_{oc} \tag{8}$$

(b) For joints confined on three faces or on two opposite faces

$$V_{oc} = 0.63 \left(f'_{cc} \right)_{oc} \times \left(A_{eff} \right)_{oc} \tag{9}$$

(c) For others

$$V_{oc} = 0.51 \left(f'_{cc} \right)_{oc} \times \left(A_{eff} \right)_{oc} \tag{10}$$

where $\left(f'_{cc}\right)_{oc}$ is the compressive strength of the ordinarily confined concrete considering the beneficial confinement effect provide by the hoop reinforcements; and $\left(A_{eff}\right)_{oc}$ is the effective area of the ordinarily confined concrete in the connection.

It is found that the effective area of the "highly confined concrete" $\left(A_{eff}\right)_{hc}$ can be expressed as

$$\left(A_{eff}\right)_{hc} = b_{cf} \times a_{he} \tag{11}$$

where b_{cf} is the flange width of the steel column perpendicular to the shear direction; and a_{he} is the effective depth of the highly confined concrete parallel to the shear direction.

$$a_{he} = \frac{M_{hc}}{0.85f'_c b_{cf} h_{cs}}\left(1+\frac{P_{hc}}{0.85f'_c b_{cf} h_{cs}}\right) \times \cos\theta_{hc}(\cos\theta_{hc} + \sin\theta_{hc}) \tag{12}$$

where M_{hc} and P_{hc} are the bending moment and the axial force shared by the highly confined concrete, respectively; h_{cs} is the depth of the steel column parallel to shear direction; and θ_{hc} is the angle between the horizontal shear force and the diagonal strut of the highly confined concrete.

Also, the effective area of the "ordinarily confined concrete" $\left(A_{eff}\right)_{oc}$ can be expressed as

$$\left(A_{eff}\right)_{oc} = b_{oe} \times a_{oe} \tag{13}$$

where b_{oe} is the effective width perpendicular to the shear direction; and a_{oe} is the effective depth of the ordinarily confined concrete parallel to the shear direction. b_{oe} and a_{oe} can be found as follows:

$$b_{oe} = \min\left[\left(b_{bf} + 2b_y\right), \left(b_{bf} + h_{ocx}\right)\right] - b_{cf} \tag{14}$$

where b_{bf} is the flange width of steel beam; and b_y is the distance from the edge of steel beam flange to the center of hoop reinforcement parallel to the shear direction.

$$a_{oe} = \frac{M_{oc}}{0.85f'_c b_{oc} h_{ocx}}\left(1+\frac{P_{oc}}{0.85f'_c b_{oc} h_{ocx}}\right) \times \cos\theta_{oc}(\cos\theta_{oc} + \sin\theta_{oc}) \tag{15}$$

where M_{oc} and P_{oc} are the bending moment and the axial force shared by the ordinarily confined concrete, respectively; b_{oc} is the width of the ordinarily confined concrete perpendicular to shear direction; h_{ocx} is the depth of the ordinarily confined concrete parallel to shear direction; and θ_{oc} is the angle between the horizontal shear force and the diagonal strut of the ordinarily confined concrete.

4. CONCLUDING REMARKS

The proposed new approach is intended to provide an alternative method to predict the shear strength of the SRC beam-to-column connection. This study takes into account the composite nature of the SRC joint so that the interaction between the steel section and the reinforced concrete in the connection zone can be treated more rationally. The mutual beneficial correlation between the steel section and the reinforced concrete in the SRC joint is one of the important factors in developing the new design approach. It is also hoped that this investigation will provide further insight on the understanding on the true mechanical behavior of the SRC beam-to-column connection.

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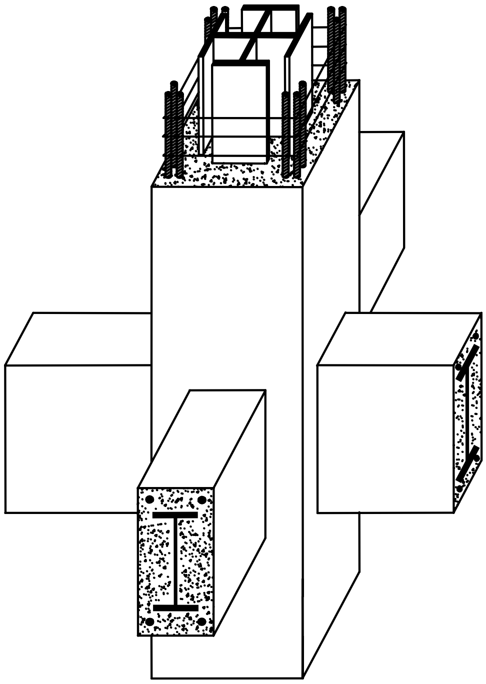


Figure 1 A typical layout of SRC beam-to-column connection

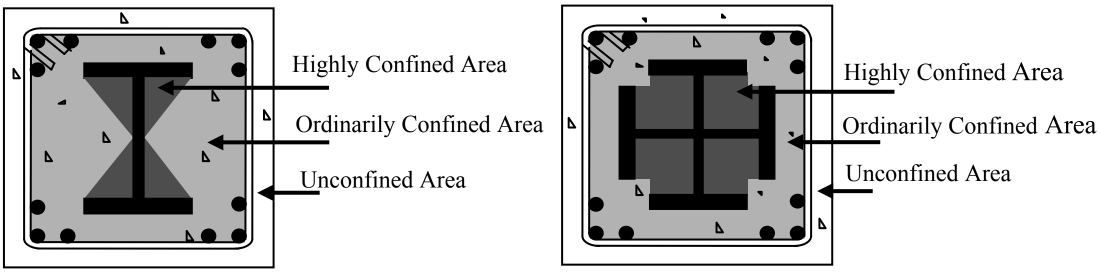
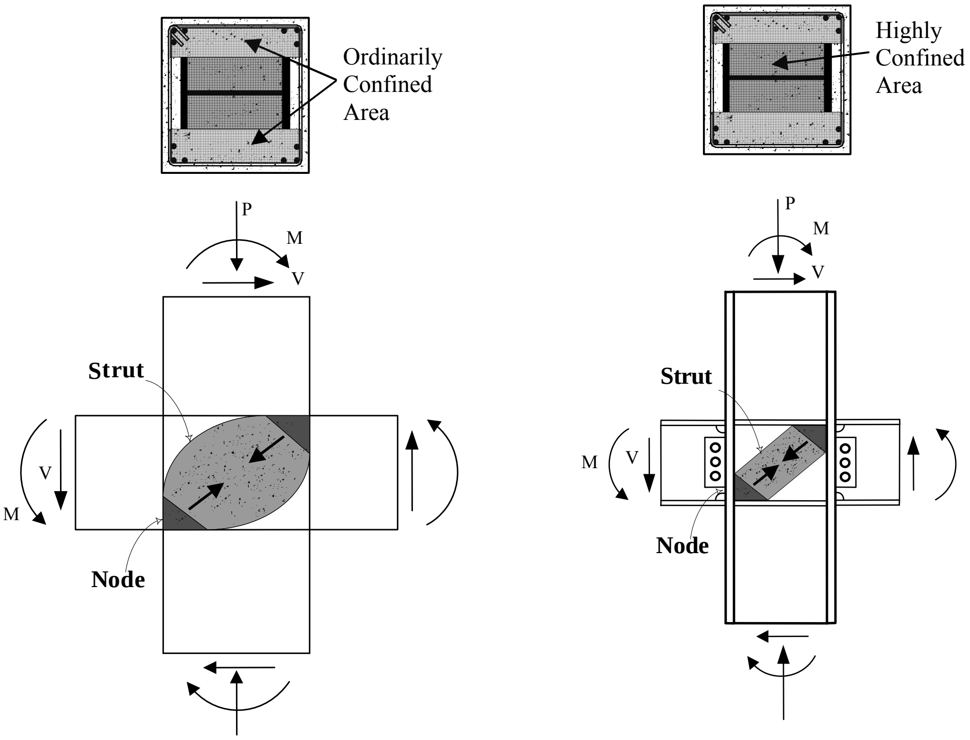


Figure 2 “Highly confined concrete” and “ordinarily confined concrete” in SRC columns



(a) Strut of ordinarily confined concrete

(b) Strut of highly confined concrete

Figure 3 Compressive strut of concrete in SRC beam-to-column joint

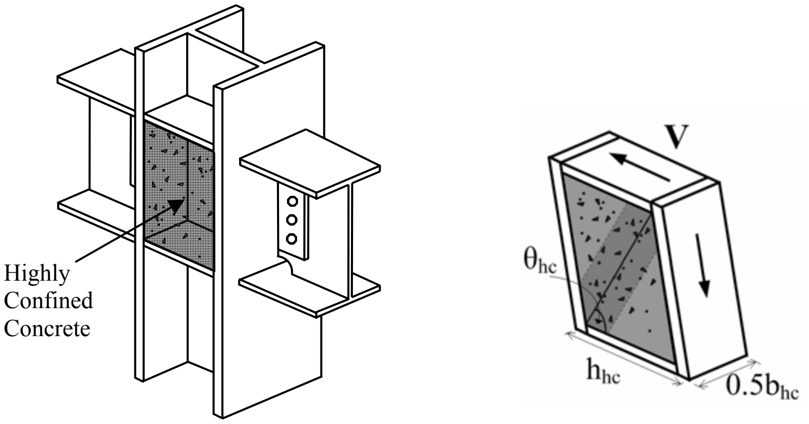


Figure 4 Highly confined area of concrete in the SRC joint

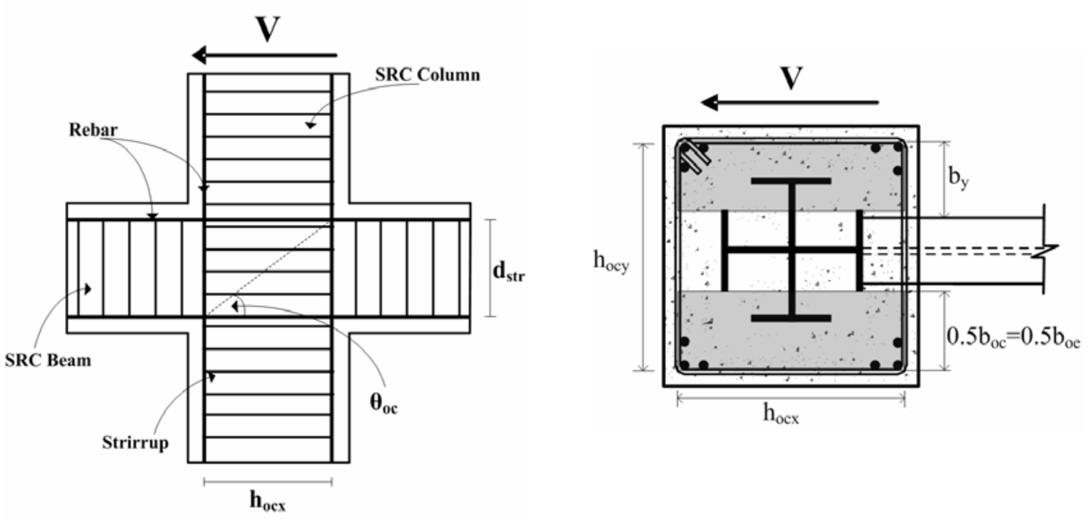


Figure 5 Ordinarily confined area of concrete in the SRC joint