# BEHAVIOR OF CONFINED COLUMN UNDER UNI-AXIAL LOADING BY WELDED WIRE REINFORCEMENT

## INTRODUCTION

Columns are vertical compression members of structural frame intended to support the load-carrying beams. They transmit loads from upper floors to the lower levels then to foundation. Since columns are compression elements, failure of one column in critical location can cause the progressive collapse of the structure.

To design reinforced concrete column, the structural designer must consider strength and ductility of column. In seismic zone, ductility of column is required to resist earthquake force. To design low-rise concrete building under earthquake force the design computation must follow specification of transverse reinforcement for seismic-resistant. Many researches indicate that confinement of the core concrete by transverse reinforcement can increase strength and ductility of reinforced concrete column.

For the past ten years, cold-drawn steel wire has been used instead of typical transverse reinforcement known as Welded Wire Reinforcement (WWR). WWR offers a highly practical and cost-efficiency alternative to traditional reinforcement.

Experimental research was conducted to investigate WWR as transverse reinforcement and indicated that WWR can be used effectively as reinforced confinement, providing more ductility and improvement of the structural performance of column and also advantages such as being prefabricated and incurring less labor cost during construction.

## Objectives

1. To study behavior of rectangular reinforced concrete columns under uni-axial loading confined by welded wire reinforcement (WWR) as transverse tie reinforcement.

2. To study the effect of the spacing of transverse tie reinforcement on strength and ductility of reinforced concrete columns.

3. To compare the behavior of strength and ductility of reinforced concrete columns confined by WWR with those confined by round bar.

## Scope of Research

Test specimens in this study are the rectangular reinforced concrete columns, sizing 15cm. x 15cm. x 100cm. The concrete compressive strength is 320 kg/cm$^2$ (cylinder). The specimen will be tested by uni-axial load until ultimate load capacity is reached.

# LITERATURE REVIEW

Structural column failure is of major significance in terms of economic as well as human loss. Thus extreme care needs to be taken in column design, with higher reserve strength than in the case of beams and other horizontal structural elements, particularly since compression failure provides little visual warning.

Strength design of members for axial loads shall be based on assumptions given below and on satisfaction of applicable conditions of equilibrium and compatibility of strains

1. Maximum usable strain at extreme concrete compression fiber shall be assumed equal to 0.003.

2. The tensile resistance of the concrete is negligible.

3. Linear strain distribution exists across the thickness of column.

4. Strain in steel and concrete are the same.

Building code requirements for structural concrete (ACI 318-02); maximum concentric load capacity of the short column can be obtained by.

$$P_O = 0.85 f_c^{'} \left( A_g - A_{st} \right) + A_{st} f_y \tag{1}$$

Where

$P_O =$ Nominal axial load strength at zero eccentricity

$f_c^{'} =$ Specified compressive strength of concrete

$A_g =$ Gross area of section

$A_{st} =$ Total area of longitudinal reinforcement

$f_y =$ Specified yield strength of nonprestressed reinforcement

It is well – known that confined concrete behaves differently from unconfined concrete. Concrete confined in two orthogonal directions has a higher compressive strength in the third direction than unconfined concrete. The compressive stress-strain behavior is also much more ductile with a sustainable post-peak load carrying capacity. This property of concrete is especially relevant in column where axial compression is pre dominant.

In such cases, confinement to the concrete is provided by lateral steel ties. Studies of the effects of tie on column confinement in circular and rectangular column span over more than 70 year.

ACI Committee 105 (1930) concluded lateral ties are used to hold the vertical bars in position and providing lateral support, do not contribute to the strength, as indicated by column studies that present tie requirement which are conservative for ordinary columns with grade 40 reinforcement, but may not be conservative for column with high – strength reinforcement, with large or bundled bars.

The characteristics of confined concrete have been researched extensively during the last two decades, and the primary parameters of confinement have been identified both experimentally and analytically.

Blume *et al.* (1961) studied relationship between axial force & moment and axial force & curvature. The result showed ductility of column when subjected to axial force, ductility was reduced due to axial force. Transverse reinforcement is used to hold the vertical bars in position and resisted to shear force in column.

Richart (1929) studied confinement of concrete by lateral pressure from liquid. The result from experimental showed lateral pressure has effect on ability of compressive strength of concrete column. Therefore he proposed equation to predict stress in concrete when subjected to lateral pressure.

$$f'_{cc} = f'_c + 4.1 f_1 \tag{2}$$

Where

$f'_{cc}$ = Strength of concrete subjected to lateral pressure (kg/cm$^2$)

$f'_c$ = Compressive strength of concrete cylinder (kg/cm$^2$)

$f_1$ = Lateral pressure (kg/cm$^2$)

Richart (1933) concluded the result in testing concrete column under axial load by studying the effect of size, creep, shrinkage of concrete by varied compressive strength in range 140 – 150 kg/cm$^2$ and longitudinal reinforcement around 1.5 – 6 percent of section. Compressive strength of this column was calculated from strength of concrete, longitudinal reinforcement and confinement from transverse reinforcement. The capacity of column that used spiral transverse reinforcement, has efficiency in resisting lateral force more than ties transverse reinforcement.

Chan (1955) studied behavior of transverse reinforcement and compared between spiral transverse reinforcement and tie transverse reinforcement. The results show that tie transverse reinforcement can be used with confined concrete but has efficiency quite lower than spiral transverse reinforcement around 50% in case of equal volumetric longitudinal reinforcement. Continuity has more effect to transverse reinforcement, because more lateral displacement. The proposed formula for predicted lateral pressure from confinement is as below.

$$f_l = \frac{\sum R A_{sh} f_{yh}}{b_c s} \qquad R = 0.50 \tag{3}$$

Where

$f_1$ = Lateral pressure

$A_{sh}$ = Area of transverse reinforcement

$f_{yh}$ = yield strength of transverse reinforcement

$b_c$ = Width of column

$s$ = Longitudinal spacing of transverse reinforcement

Razvi and Saatcioglu (1989) studied welded wire fabric (WWF) for use in concrete column. They tested 34 small columns with 160x120 mm section reinforced with conventional ties and WWF wrapped around columns, under concentric compression. They are concluded that it's very favorable but practical difficulties existed in placing WWF in columns, especially when 135° hook ties were used. Furthermore, wrapping WWF around a column would require overlap of WWF, which means more material and more construction labor.

Saatcioglu *et al.* (1995) studied behavior of column under eccentric loading, test on rectangular sections by 3 types of transverse reinforcement. The test parameters included the arrangement, spacing and volumetric ratio of confinement reinforcement, shown in Figure 1.

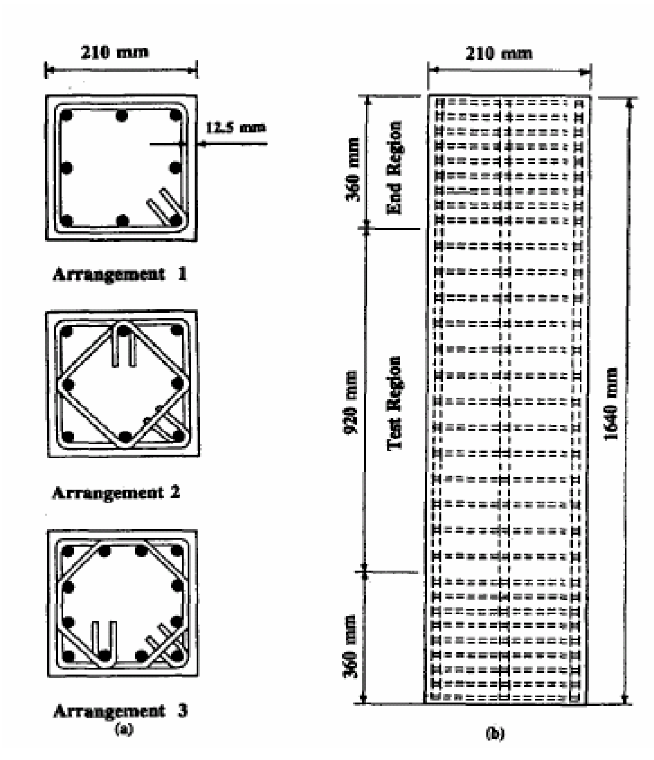



**Figure 1** Reinforcement Arrangements and Geometric Properties of Column: (a) Cross Section; (b) Elevation

Source: Saatcioglu (1995)

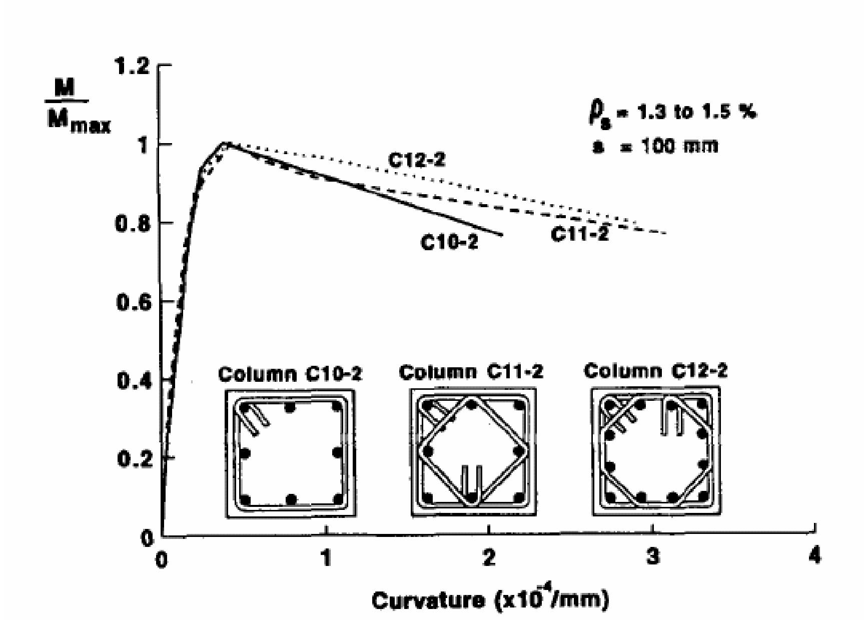



**Figure 2** Effect of tie arrangement on Moment-Curvature relationship
Source: Saatcioglu (1995)

The results show extremely ductility behavior, developing inelastic displacement exceeding 4% of the drift ratio without a significant loss of strength. Those with a low volumetric ratio and wide spacing of transverse steel developed strength decay immediately after the peak load.

The confined-concrete model proposed by Saatcioglu and Razvi (1992) was used to conduct the analysis. The model is based on the computation of confinement pressure developed from the materials and geometric properties of column. The following equations describe the model, shown in Figure 3 and Figure 4.

$$f_c = f_{cc}^{'}\left[2\left(\frac{\varepsilon_c}{\varepsilon_1}\right)-\left(\frac{\varepsilon_c}{\varepsilon_1}\right)^2\right]^{1/(1+2K)} \leq f_{cc}^{'} \qquad (4)$$

$$f_{cc}^{'} = f_{co} + k_1 k_2 f_l ; k_1 = 6.7\left(f_{le}\right)^{-0.17} ; f_{le} = k_2 f_l \qquad (5)$$

$$k_2 = 0.26\sqrt{\left(\frac{b_c}{s}\right)\left(\frac{b_c}{s_l}\right)\left(\frac{1}{f_l}\right)} \leq 1.0 \; ; \; k_1 = 0.67\left(f_{le}\right)^{-.017} \qquad (6)$$

$$f_l = \frac{\sum A_s f_{yt} \sin\alpha}{sb_c} \qquad f_{co}^{'} = 0.85 f_c^{'} \tag{7}$$

$$\varepsilon_1 = \varepsilon_{01}(1 + 5K) \qquad K = \frac{k_1 f_{le}}{f_{co}} \tag{8}$$

$$\varepsilon_{85} = 260\rho\varepsilon_1 + \varepsilon_{0.85} \qquad \rho = \frac{\sum A_s}{s(b_{cx} + b_{cy})} \tag{9}$$

Where

$f_{cc}^{'}$ = Confined concrete strength in members (MPa)

$f_l$ = Average lateral confinement pressure (MPa)

$f_{co}^{'}$ = Unconfined concrete strength in members (MPa)

$k_1$ = Coefficients of lateral pressure

$k_2$ = Coefficients of confined column

$A_{sh}$ = Area of transverse reinforcement ($mm^2$)

$f_{yh}$ = Yield strength of transverse reinforcement

$b_c$ = Width of column (m.)

$s$ = Longitudinal spacing of transverse reinforcement (m.)

$s_1$ = Spacing of Longitudinal reinforcement (m.)

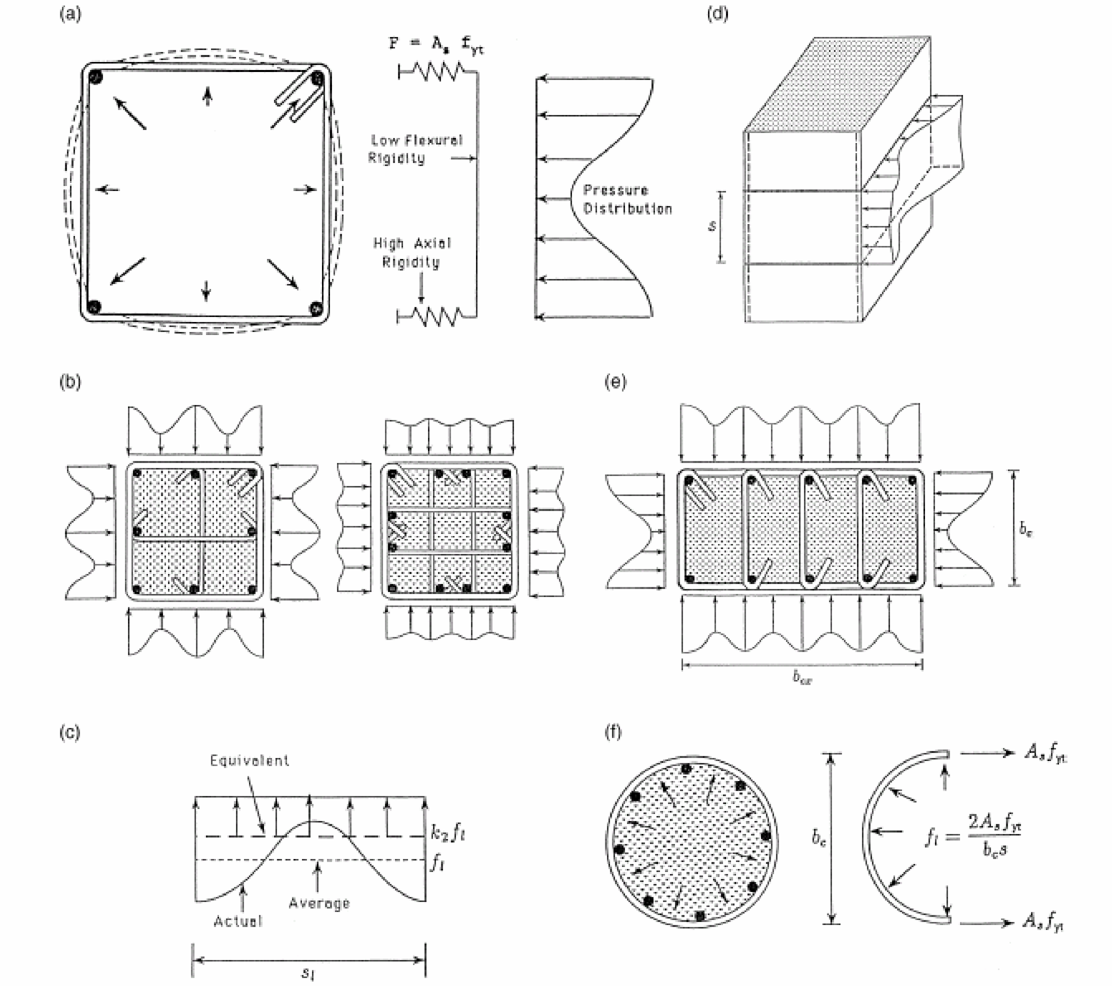



**Figure 3** Confinement pressure resulting from different reinforcement arrangement

Source: Saatcioglu (2000)

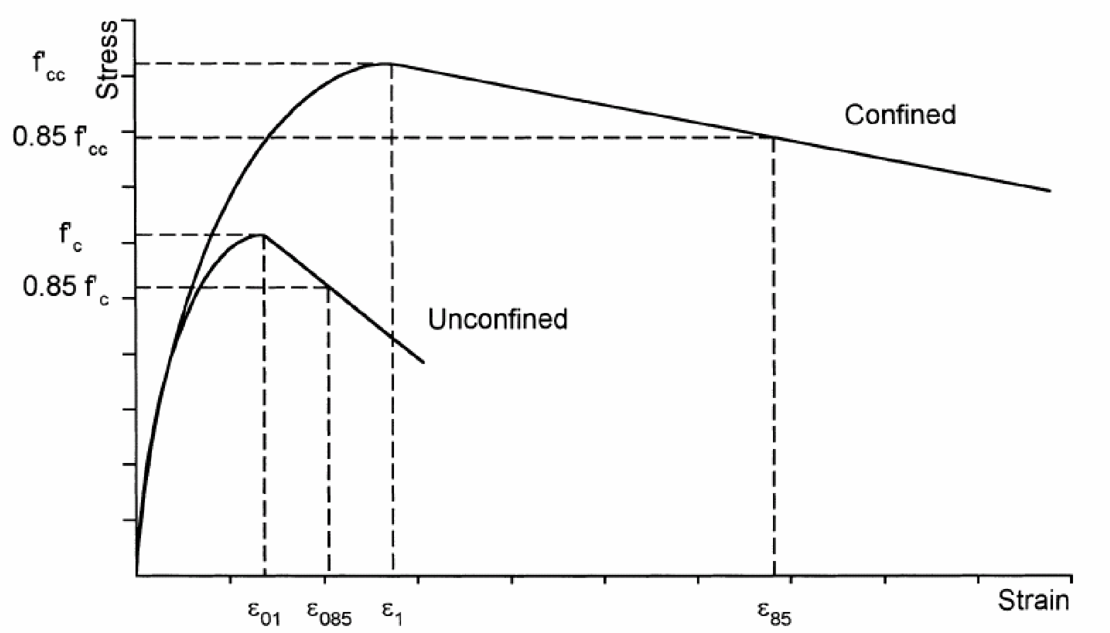



**Figure 4** Confined-concrete model proposed by Saatcioglu and Razvi (1992)
Source: Saatcioglu (2000)

Grira and Saatcioglu (1996) studied behavior of column under seismic conditions. Thus, the axial compression was fixed at 20% and 40% of the expected peak compressive strength and columns were loaded laterally in cycles that simulated the lateral drift experienced by columns during an earthquake. The result concluded most favorable to the use of WWF as a replacement for transverse ties, for increased ductility and strength of concrete columns.

Mau *et al.* (1998) studied behavior of small-column confined by WWF. They investigated the complete uni-axial load – deformation history beyond the ultimate compressive strength, albeit with smaller specimens and smaller wire size. The results concluded that compressive strength of the welded wire reinforced concrete composite in the range of parameter tested, showed the increase in strength could be as high as 40 % and the most dominant factor in strength enhancement was the longitudinal spacing of the WWF when small spacing – to width ratio (S/D) when small enough would increase in volumetric ration of WWF leading to the increase of strength. The different type did not seem to have much effect.

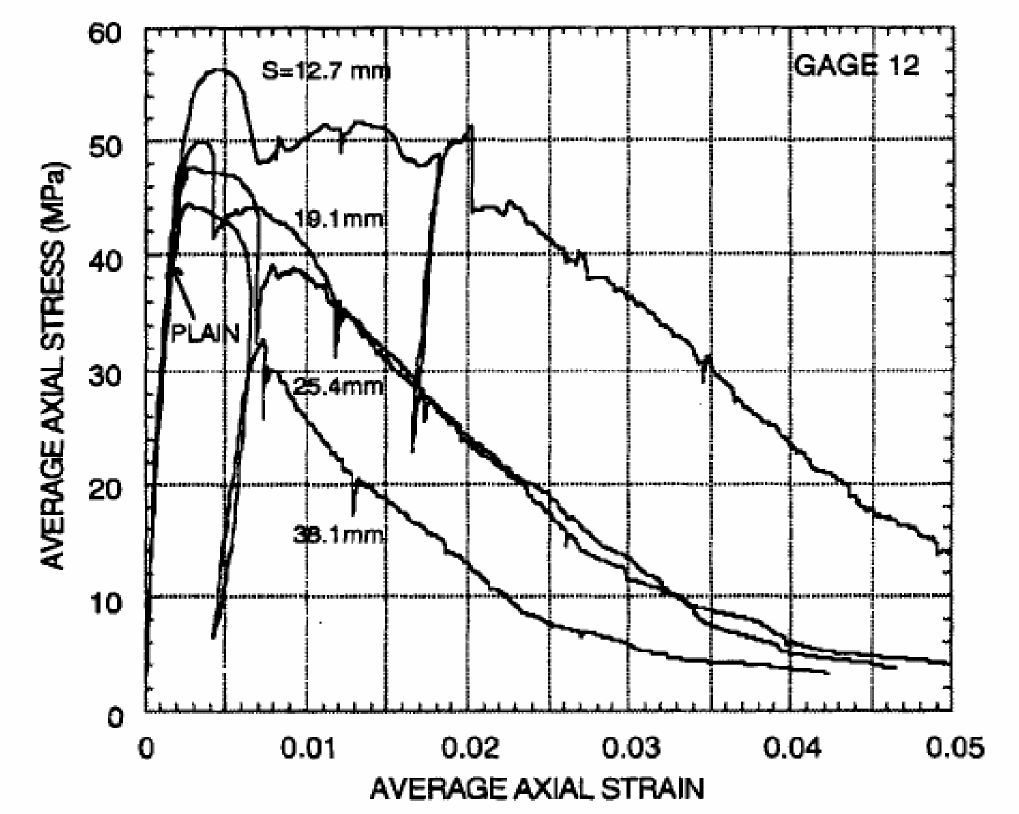



**Figure 5** Uniaxial Compressive Stress-Strain Curve
Source: Mau *et al.* (1998)

They provided the formula to predict confined stress provided by WWF to the concrete as below.

$$\frac{f_{cp}}{f_{co}} = 1 + 2\frac{\rho E_{sl}}{f_{co}}\left(1 - \frac{S}{D}\right) \qquad (10)$$

Where

$f_{cp}$ = The peak compressive stress of reinforced column

$f_{co}$ = Average compressive strength of plain concrete column

$S$ = Longitudinal spacing of WWF

$D$ = Width of specimen

$\rho$ = Volumetric ratio of WWF

$E_{sl}$ = Young's modulus of the wires

The expression $\left(1-\frac{S}{D}\right)$ is to represent the effect of spacing in reducing the effective confining stress in concrete column.

Ductility index $\left(\frac{\varepsilon_1}{\varepsilon_0}\right)$, expressed as a strain ratio, is suggested. It gives the maximum axial strain at which load equal to the plain concrete strength can still be sustained. The demarcation value of this index is 8; larger than values signify ductility behavior. The volumetric ratio and S/D ratio is suggested as the boundary that separates the ductility region from the brittle region. They were proposed formula for separated ductile and brittle as below.

$$\rho = 15 \sim 20\frac{S}{D} \tag{11}$$

Where

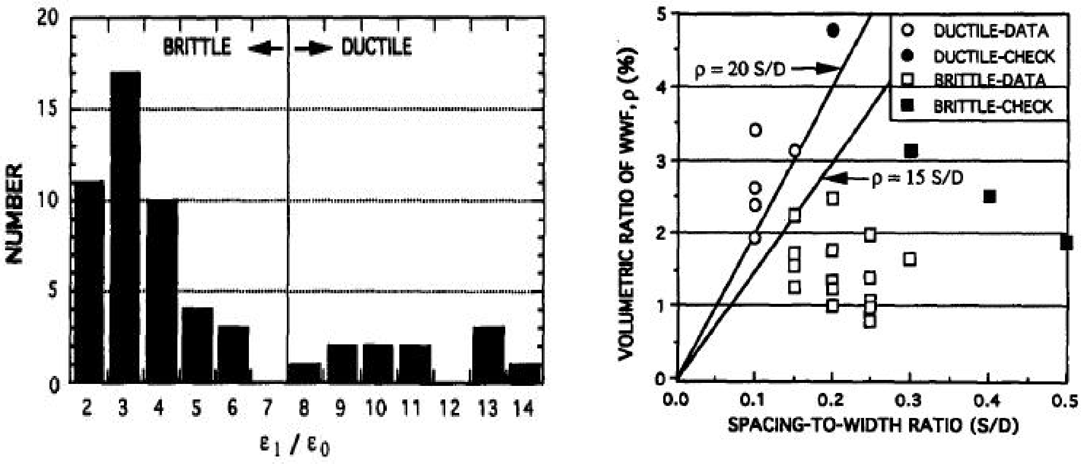
$\rho$ = Volumetric ratio of WWF

$S$ = Longitudinal spacing of WWF

$D$ = Width of specimen

$\varepsilon_0$ = Axial strain of plain concrete column

$\varepsilon_1$ = Axial strain of reinforced concrete column




(A) (B)

**<u>Figure 6</u>** (A) Definition of $\varepsilon_1$ / $\varepsilon_0$

(B) Ductile-Brittle Behavior as function of volumetric Ratio of WWR and Spacing-to-Width

Source: Mau *et al.* (1998)

Binici (2005) concluded stress-strain behavior of confined concrete, strength and ductility of concrete are highly dependent on the level of confinement provided by the lateral reinforcement. Models for describing axial stress-strain behavior of steel confined concrete have been developed on basis of an extensive database of experimental research. In these models the ultimate strength and stress-strain have been adjusted as a function of confinement provided by the lateral reinforcement ratio and uniaxial compressive strength.

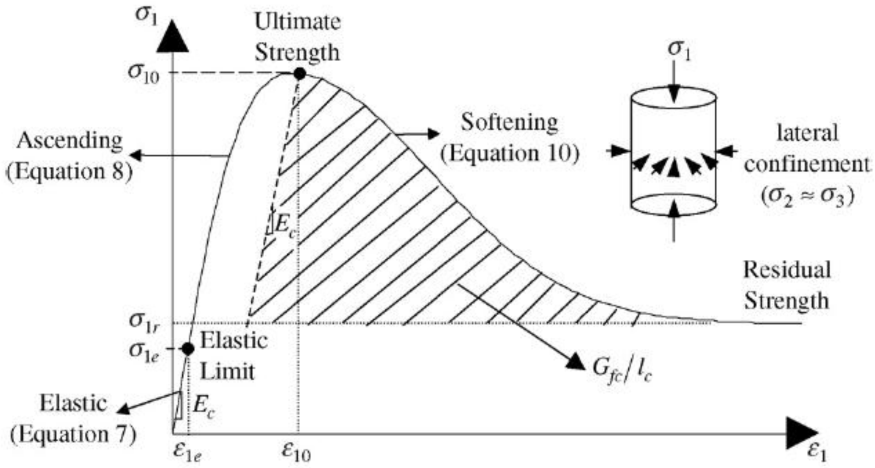



**Figure 7** Confined concrete stress-strain curve.
Source: Binici (2005)

The model used to compare behavior of FRP and steel confined having a uniaxial compressive strength, initial stiffness and ultimate strengths of steel and FRP confined concrete are similar, but the overall behaviors are different. In axial direction, the stress-strain response for FRP confined concrete was bilinear but for steel confined concrete, it was non linear at first then an almost perfectly plastic response. The concrete strength and lateral reinforcement ratio are the two most important factors affecting the descending region of stress-strain curves for steel confined concrete. The yield strength of steel is found to affect only the ultimate strength.

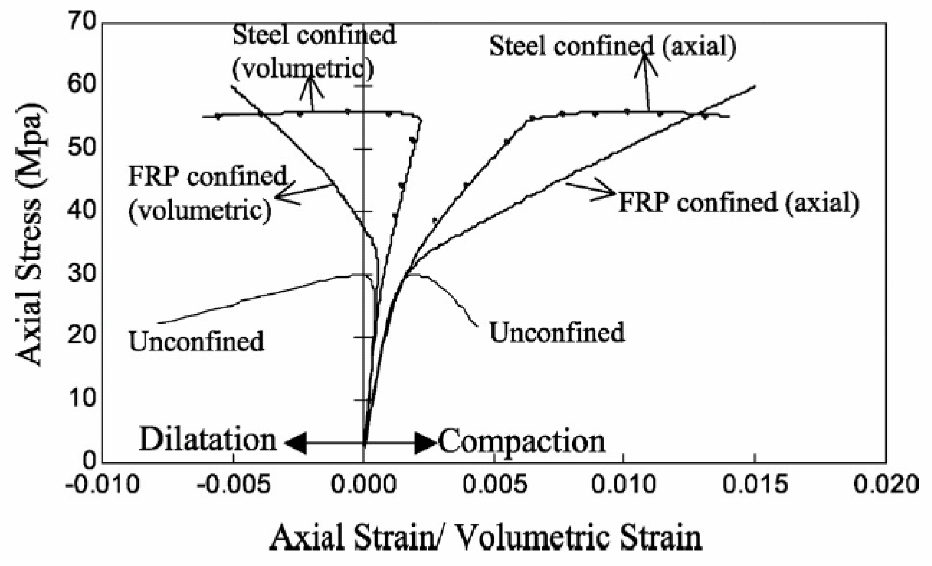



**Figure 8** Comparisons of axial and volumetric of FRP and steel confined concrete.
Source: Binici (2005)