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Autor: Tan, Kiang-Hwee / Shem, Qingqing

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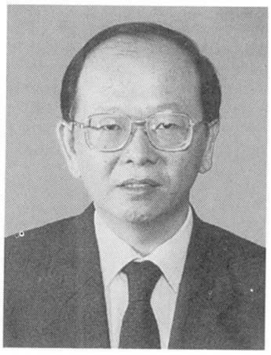
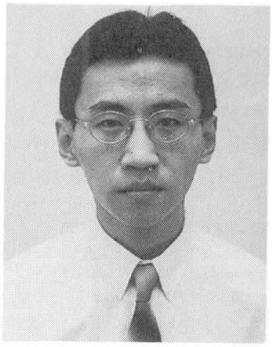
Performance of Plain Concrete Columns Bonded with Glass Fiber Wraps

Kiang-Hwee TAN
Associate Professor
National University of Singapore
Kent Ridge, Singapore



Kiang-Hwee Tan, born 1955, received his doctorate degree in civil engineering from the University of Tokyo in 1985. His research interests include external prestressing and fibre-reinforced polymer (FRP) reinforcement.

Qingqing Shen
Research Engineer
National University of Singapore
Kent Ridge, Singapore



Qingqing Shen, born 1967, received his civil engineering degree from Tongji University, PRC, in 1989.

Summary

A test program was carried out to examine the effect of bonding unidirectional glass fiber wraps on the strength and ductility of circular and square plain concrete columns. Twenty-four specimens, bonded with up to three plies of the material in orientations varying from 0 to 90 degrees to the specimen axis, were tested to failure. The corners of the square columns were not rounded off intentionally. Test results indicated that both the strength and ductility of the columns increased with increasing plies of wraps with the same fiber orientation. For circular columns, bonding the wraps with the fibers orientated at 90 degrees to the specimen axis led to higher strength than when they were orientated otherwise. For square columns, placing the wraps with fibers orientated at between 30 to 45 degrees to the specimen axis resulted in comparable axial strength but considerably higher ductility than when the fibers were at 0 and 90 degrees.

1. Introduction

Fiber-reinforced polymer (FRP) materials utilizing high-performance fibers such as carbon, aramid and glass, are increasingly being used to strengthen and confine concrete columns due to their low unit weight, easy handling and low maintenance costs. They are also preferred over other strengthening methods using steel plates and enlarged sections, as they do not lead to significant change in the size of the member that is being strengthened.

Several studies had been carried out on the use of FRP composites in the repair and strengthening of concrete columns (Ramirez, 1996; Saadatmanesh, et al., 1994; Hosotani, et al., 1997; Tan and

Shen, 1997). They have so far demonstrated the potential of bonded external FRP sheets or wraps in improving both the compressive strength and ductility of the repaired columns by strengthening the potential plastic hinge regions or the entire height of the columns. However, most of the studies dealt with circular columns only and the behavior of square concrete columns bonded with external FRP composites have not been investigated adequately. Furthermore, the effect of varying the fiber orientation in both circular and square columns has not been examined.

The purpose of this study is to examine the effect of bonding unidirectional glass fiber wraps on the strength and ductility of circular and square plain concrete columns. Twenty-four plain concrete columns, bonded externally with up to three plies of glass fiber wraps at orientation varying from 0 to 90 degrees to the specimen axis, were tested to failure under uniaxial compression. The effects of fiber orientation on the compressive stress-strain response and failure characteristics of the strengthened column specimens are discussed.

2. Test Program

Two series of column specimens, consisting of twelve circular and twelve square plain concrete columns respectively, were prepared. The circular specimens measured 150-mm in diameter and 600-mm in height while the square ones measured 100-mm by 100-mm in cross-section and 500-mm in height. The specimens were designated as CO-ab and SO-ab for circular and square columns respectively. Symbol "a" indicates the number of plies of glass fiber wraps and "b" represents the angle at which the fibers of the wraps were orientated to the longitudinal axis of the specimen, with H, D, X and V indicating orientations at 90, 45, 30 and 0 degrees, respectively. For specimens bonded with two wraps, the second layer was wrapped symmetrically with respect to the first layer. For specimens bonded with three wraps, the interior two wraps were the same as those with two wraps, and the exterior third wrap was bonded with fibers orientated horizontally.

The concrete mix proportion was 1:2:4 by weight of cement, sand and aggregates of 10-mm nominal size, with a water-to-cement ratio of 0.62. The average cylinder and cube compressive strengths of concrete at the time of testing were 28 MPa and 35 MPa respectively. Circular specimens were cast in paperboard molds while square ones in steel molds. All specimens were de-molded one day after casting and moist-cured for the next three days.

About one month after casting, the specimens were bonded with glass fiber wraps with a two-part epoxy using manual placement procedure. The glass fiber wrap measured 1.27-mm in thickness, with an average tensile strength of 450 MPa and an average modulus of elasticity of 22460 MPa, according to the supplier's data. For square columns, the corners were not rounded off intentionally. The bonded glass fiber wraps were cured at room temperature for several days.

Columns CO-0 and SO-0 were not wrapped and served as reference columns. For each column, four strain gauges, equally spaced along the perimeter at the mid-height section, were placed in the longitudinal direction on the surface of the bonded glass fiber wrap. To avoid bursting of the end sections and ensure that failure occurred at the middle portion, the columns were strengthened with one or two steel straps at each end. All circular specimens were tested on a 2000 kN capacity compression-testing machine while all square ones on a 1000 kN capacity machine.

3. Test Results and Discussion

3.1 Failure characteristics

The specimens failed by crushing of concrete, accompanied by bulging of the section and de-bonding of the fiber wraps. For circular specimens, the glass fiber wraps that were orientated horizontally generally ruptured at failure, while those fiber wraps that were orientated diagonally or vertically were sheared through along the fiber direction.

For square specimens, tearing of the wraps occurred along corners of the columns in which the wraps were placed with fibers orientated vertically, and along the fiber direction on the side face of SO-2X. Rupture of fibers was observed generally in specimens with a horizontal wrap and in specimen SO-2D.

3.2 Compressive stress-strain response

The compressive stress-strain curves of the circular and square columns are compared in Figs.1 and 2, respectively. It is observed that all the curves are characterized by three portions: an initial linear elastic portion up to the proportional limit, followed by a non-linear portion with gradually decreasing slope and a final descending portion. Before the proportional limit, the curves are almost identical, indicating that there was little effect due to the external glass fiber wraps. Both the ultimate axial strength and ductility of the columns, however, increased with an increase in the plies of glass fiber wraps.

For circular columns, Fig. 1 indicates that for the same amount of fiber wraps, specimens bonded with the fibers orientated at 90 degrees to the specimen axis (that is, horizontally) exhibited a significantly higher compressive strength than when they were orientated otherwise. For square columns, however, Fig. 2 shows that the ultimate compressive strength is almost the same, regardless of the angle of orientation of fibers. In addition, specimens bonded with the fibers orientated at between 30 to 45 degrees to the specimen axis had a considerably longer descending branch, indicating a more ductile form of failure.

3.3 Effect of fibre orientation on compressive strength

The ultimate compressive strength of the glass fiber wrapped specimens expressed as a ratio of that of the reference column are summarized in Figs. 3(a) and (b) for circular and square columns, respectively. It can be noted that the ultimate compressive strength of the specimens increased with increasing plies of bonded glass fiber wraps with the same fiber orientation.

For circular columns, the strengthening effect is more noticeable for specimens CO-1H, CO-2H and CO-3H. Their compressive strengths are respectively 1.47, 2.04 and 2.94 times that of the reference column CO-0. Although specimens CO-1D and CO-1V were bonded with one ply of glass fiber wrap as in specimen CO-1H, their strengths were relatively less and were about 0.74 and 1.03 times respectively of the strength of the reference column. Similarly, the compressive strengths of specimens CO-2D, CO-2X and CO-2V were also less than that of specimen CO-2H, and varied from 1.17 to 1.35 times that of the reference specimen CO-0. For specimens CO-3D, CO-3X and CO-3V, the compressive strengths were between 1.89 to 1.94 times that of CO-0.

In the case of square columns, the increase in compressive strength of specimens bonded with the same plies of glass fiber wraps did not differ much, even though the fiber orientation varied from 0 to 90 degrees. The compressive strengths ranged from 1.37 to 1.40, 1.37 to 1.67 and 1.71 to 1.81 times that of the reference specimen SO-0 for specimens bonded with one, two and three piles of glass fiber wraps respectively.

3.4 Effect of fibre orientation on strain at peak compressive strength

The compressive strains at which the peak compressive stresses were attained, expressed as ratios of that of the reference column, are shown in Figs. 4(a) and (b) respectively, for circular and square columns. These strains were found to increase with the plies of fiber wraps. For circular columns, it is noted from Fig. 4(a) that the strain at peak compressive strength increased with increasing angle of fiber orientation, for the same ply of wraps. However, for square columns, the peak compressive stress occurred at almost the same longitudinal strain for the same ply of wraps.

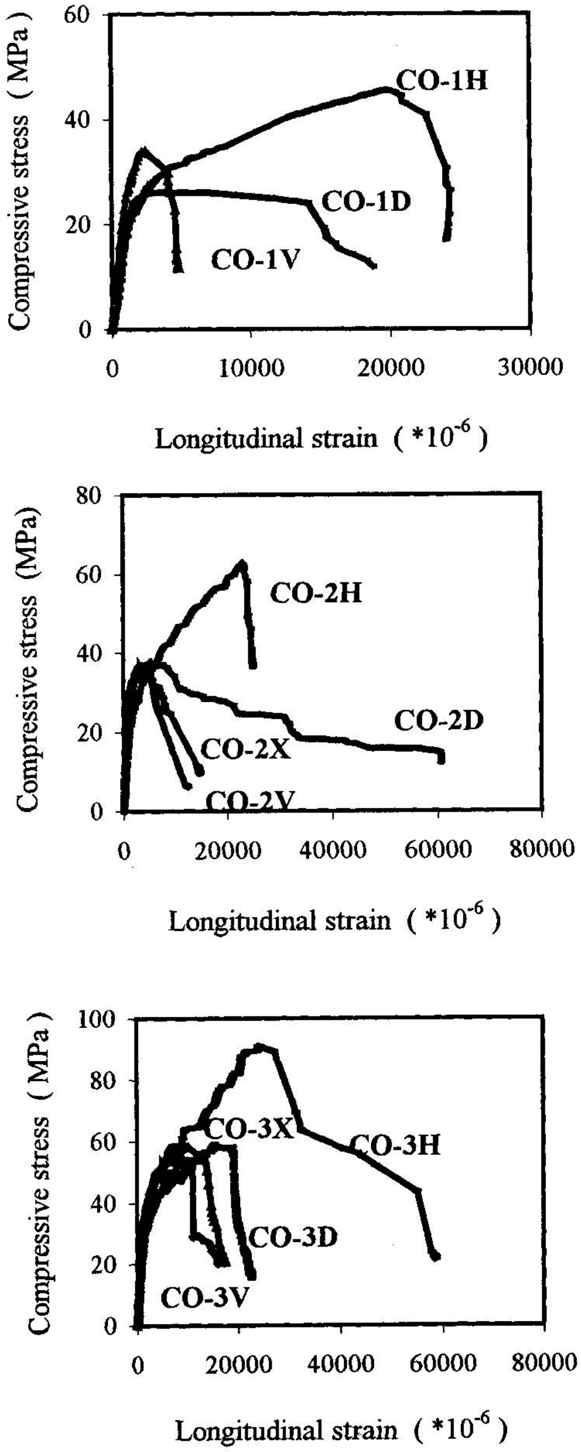


Fig. 1 Compressive stress-strain curves for circular columns

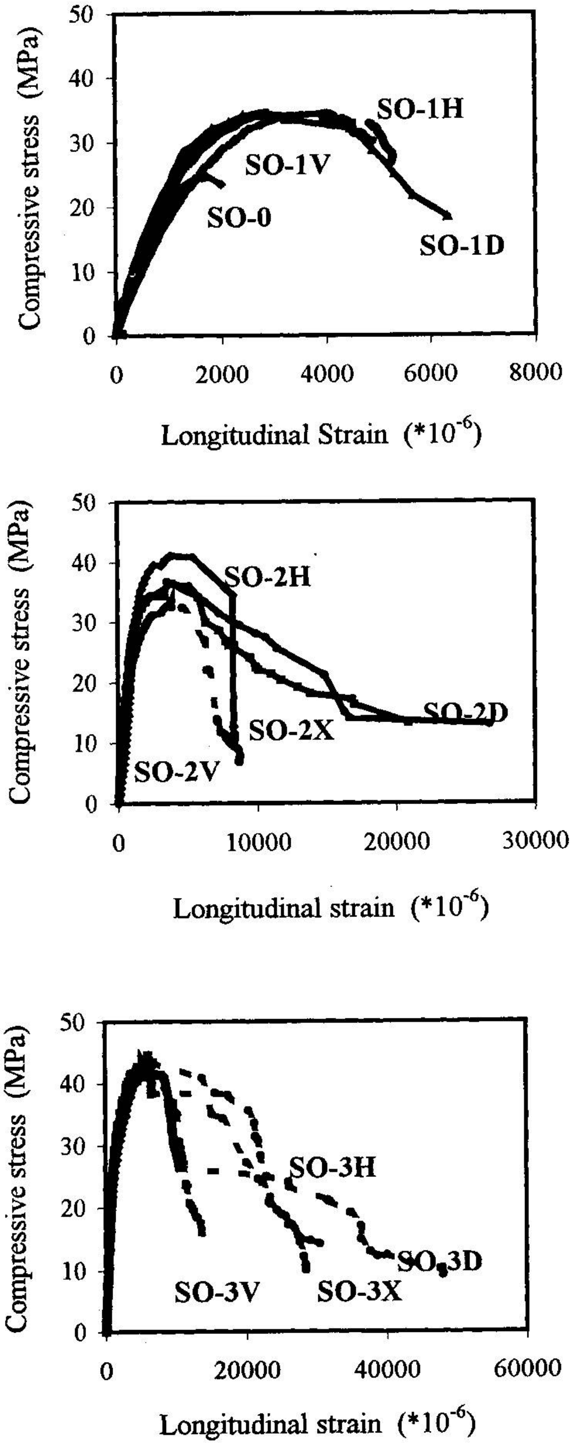
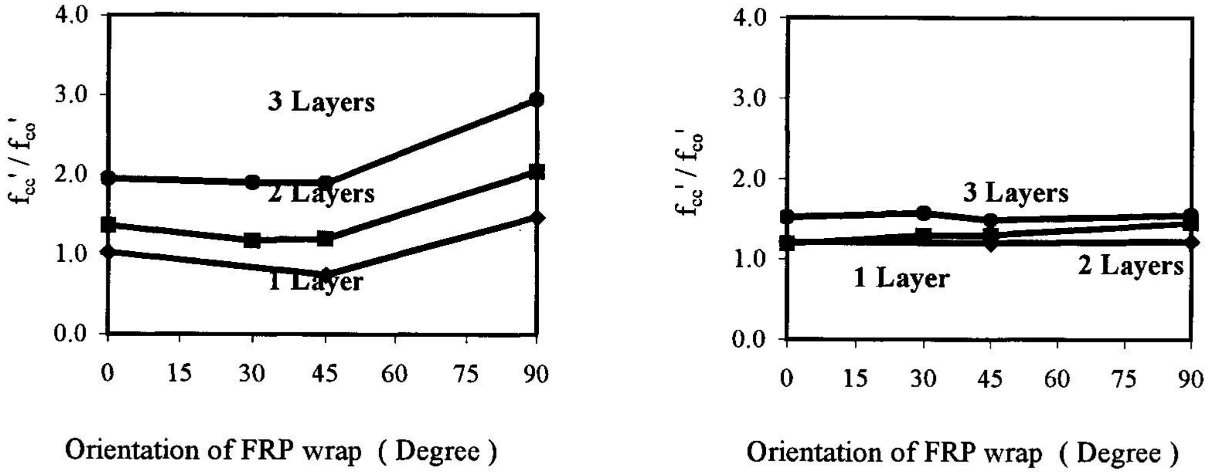
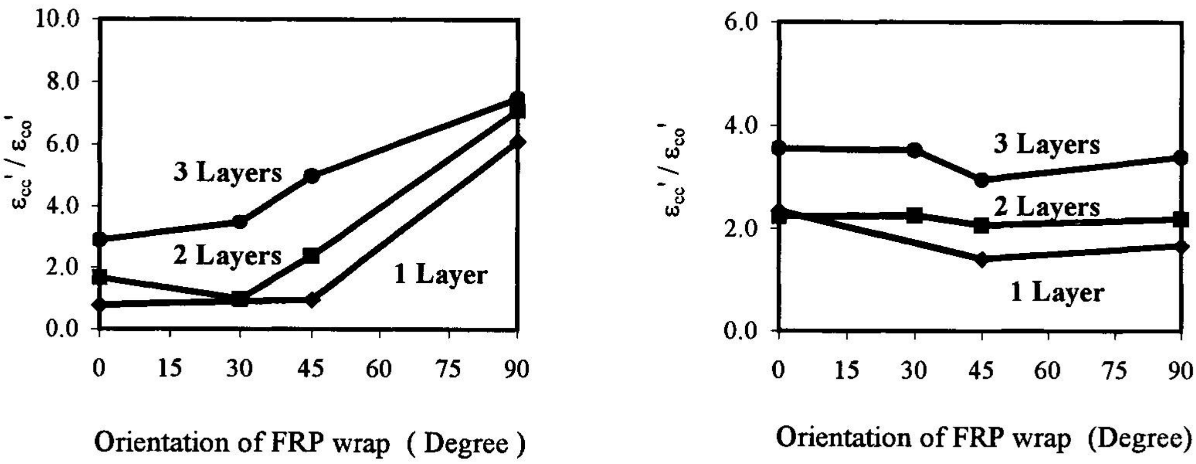


Fig. 2 Compressive stress-strain curves for square columns



(a) Circular columns *(b) Square columns*

Fig. 3 Effect of fibre orientation on compressive strength



(a) Circular columns *(b) Square columns*

Fig. 4 Effect of fibre orientation on strain at peak compressive stress

3.5 Implications for effective application of glass fiber wraps

The above results indicated that to maximize the effectiveness of glass fiber wraps in confining and strengthening columns, the wraps should be bonded with fibers orientated at 90 degrees to the member axis (that is, horizontally) for circular columns. In the case of square columns, the fiber wraps may be placed with fibers at between 30 to 45 degrees to the member axis to achieve the confinement and strengthening effects without having to round off the corners of the columns. Where the fiber wraps are placed horizontally, the corners of the square columns should be rounded off so as to avert stress concentration and hence rupture of the fibers at failure.

4. Conclusions

The experimental study on circular and square plain concrete columns bonded with external glass fiber composite wraps indicates that as a result of the confinement provided by the external wraps, the concrete columns will have a higher load-carrying capacity and fail at a larger strain than if they were unconfined. Depending on the degree of confinement, significant increase in strength and ductility can be achieved.

It was further concluded that in general, increasing the plies of bonded glass fiber wraps with the same fiber orientation led to an increase in ultimate axial compressive strength and ductility for both circular and square sections. With the same piles of external glass fiber wraps, test results showed that for circular columns, bonding the fiber wraps with the fibers orientated at 90 degrees to the member axis leads to higher strength than when they were orientated otherwise. For square columns, placing the wraps with fibers orientated at between 30 to 45 degrees to the specimen axis resulted in comparable axial strength but considerably higher ductility than when the fibers were orientated at 0 or 90 degrees. Therefore, to maximize the effectiveness of the material, it is suggested that the fibers should be orientated horizontally for circular columns and at between 30 to 45 degrees to the member axis for square columns.

Acknowledgment

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