

Original Research Paper

Experimental Study of Composite Beams Made of Steel Tubes Filled with Concrete under the Confinement Effect of U-Links and Stud-Plate

¹Moayyad Al-Nasra, ¹Madiha Ammari, ²Taher Abu-Lebdeh and ³Abdelqader Najmi

¹Department of Civil and Infrastructure Engineering,
American University of Ras Al Khaimah, AURAK, Ras Al Khaimah, UAE

²Department of Civil, Architectural and Environmental Engineering,
North Carolina A&T State University, Greensboro, USA

³Department of Civil Engineering, University of Jordan, Amman, Jordan

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Corresponding Author:

Taher Abu-Lebdeh
Department of Civil,
Architectural and
Environmental Engineering,
North Carolina A&T State
University, Greensboro, USA
Email: taher@ncat.edu

Abstract: Concrete strength improved substantially when lateral confinement stresses are provided. This effect has been exploited in this study in composite beams at the concrete compression zone. New type of confinement is used in this research. The confinement of concrete in the compression zone is accomplished by providing U-links and stud-plate systems. The U-links are steel bars in the shape of the letter U welded internally in a steel tube at the compression concrete zone. These tubes provide confinement effect similar to the stirrups used in reinforced concrete beams. The stud-plate element used in this study is made of steel bar welded to a horizontal plate at one of its end, while the other end is welded to the top of the steel tube at the compression zone from the inside of the tube. The main function of these two elements is to provide the concrete in the compression zone with confinement stresses. The composite beam is tested in bending under single load at the mid-span. The effect of the new confinement system is studied and compared with concrete filled tube without any confinement element. The failure mechanism is also a focus of this research along with the deflection at the mid-span of the beam. The effect of the new confinement system on the structural behavior of the composite beam is presented.

Keywords: Composite Beams, Concrete-Filled Tubes, U-Links, Stud-Plate, Concrete Confinement

Introduction

After hurricane Katrina in August of 2005 that caused severe destruction and financial damage to almost every town and city in its path, especially the city of New Orleans, Louisiana in the United States, researches shifted focus toward concrete filled tubes. The concrete filled tubes provide viable solution to retaining structures off shore. The concrete filled tubes are also advantages when it comes to the speed of construction.

Several researchers showed that the concrete filled steel tubes are of superior performance compared with reinforced concrete beams (Hajjar, 2000). It is believed that this shift in the behavior is due to the confinement effect of the concrete in compression. This justified the

use of the concrete filled steel tubes as columns and beam-column members in building subjected to relatively large applied loads. The concrete filled tubes are also exhibited great advantage when it comes to durability and deformability (Kang *et al.*, 2007).

Al-Nasra (2013; 2015) studied the effect of using new type of shear reinforcement to improve the shear performance of reinforced concrete beams. He showed that there is substantial improvement in the shear performance of reinforced concrete beams due the use of swimmer bars. These swimmer bars are steel reinforcing bars that add rigidity to the reinforced concrete beams at the same time provide confinement to the concrete in the shear zone. Several types of swimmer bars were used to reduce the cost and increase the effectiveness of the new

shear reinforcement system (Al-Nasra *et al.*, 2013a; Al-Nasra and Asha, 2013a; 2013b). Swimmer bars are also used to improve the confinement effect on the punching shear resistance of flat slabs (Al-Nasra *et al.*, 2013b; 2013c). The punching shear load carrying capacity improved by the use of welded swimmer bars.

Ammari *et al.* (2013) studied the use of the U-links in concrete filled steel tubes beams. They concluded that there is substantial improvement on the load carrying capacity of beams due to the confinement effect. Also, they concluded that the mode of failure will be altered due to the confinement effect of concrete filled beams compared to other beams. Abdel-Halim and Abu-Lebdeh (1989) investigated concrete confinement in tied columns and showed significant compressive strength improvement due to the lateral confinement effect.

Several studies showed an interesting interaction between the concrete and steel in the concrete filled steel tubes. The main findings were about the increase in the concrete stiffness and the improvement in the buckling performance of the concrete filled tubes. This is due to the steel encasement of concrete under compression. Slight increase in the confinement pressure can increase substantially the load carrying capacity of the concrete in compression (Kostovos, 1987).

Concrete Confinement

The concrete strength increases due to the confinement effect, which is basically lateral force that has the tendency to prevent the concrete from deforming in the lateral direction (Abdel-Halim and Abu-Lebdeh, 1989). Poisson's ratio of concrete is about 0.17 for normal strength concrete, which is defined as the ratio of the lateral strain to the longitudinal strain. The concrete will deform in the direction perpendicular to the direction of loading. This increase in strength due to confinement can be expressed as a factor greater the one as shown in the following equation:

$$f_{con} = \zeta f_c' \quad (1)$$

Where:

f_{con} = The confined concrete strength

ζ = Magnification factor reflecting the increase in strength due to confinement

f_c' = Concrete compressive strength under uniaxial loading

The increase in the value of ζ results in the increase in the confinement strength, which can be accomplished by the increase in the confinement stresses. The zero confinement stress results in having the confinement strength to be the same as f_c' and a value of ζ to be one. Therefore, the confinement strength factor can be expressed as a linear equation as shown in Equation 2:

$$\zeta = (1 + \kappa) \quad (2)$$

where, κ = the increase in strength factor due to the confinement effect.

Therefore Equation 1 can be expressed in terms of the new factor, κ , as shown in Equation 3:

$$f_{con} = (1 + \kappa) f_c' = f_c' + \kappa f_c' \quad (3)$$

Confinement System Used, U-Links and Stud-Plate System

Two types of beams were tested; the first is the concrete filled steel tubes and the second type is concrete filled steel tubes with U-links and stud-plate system. The outer dimensions of the tubes used here are 150 mm as the width and 300 mm as the total height. The thickness of the wall is taken as 6 mm. The tubes were built up of two angle sections welded together forming a box section. The clear span of the beam is 2.8 m while the total length of the beam is taken to be 3.0 m. The total steel area of the built up section is estimated to be 6084 mm². The steel yield strength used in this experiment for the box section is 303 MPa and the concrete compressive strength is 17 MPa. The area of the concrete section is calculated to be 38088 mm². The total height to thickness ratio of the built up box section is 300/6 which is 50. The diameter of the U-link bars used in this experiment is taken as 12 mm. The U-links are placed at 50 mm clear span in the longitudinal direction. The yield strength of the U-links used here is 297 MPa. The diameter of the studs used in the stud-plate element is taken to be 16 mm with the yield strength of 428 MPa. The plates welded to these studs are of 130 mm in width by 1300 mm in length and 8 mm in thickness. The cross-sectional dimensions of the concrete filled tubes with U-links stud-plate system is shown in Fig. 1. Figure 2 shows three-dimensional representation of the U-links stud-plate beam.

Experimental Set-Up

The composite beams were subjected to a concentrated load at the mid span. The beams were considered as simply supported beams, where the supports are designed to rotate freely. The confinement system used here is exclusive to the middle section of the beam as shown in Fig. 3. The deflection is measured at the center of the beam as shown in Fig. 4. A dial gauge with accuracy of 0.01 mm was used to measure vertical deflection at the mid-span of the composite beam. The strain is also measured at the mid span of the composite beam, above and below the neutral axis of the beam.

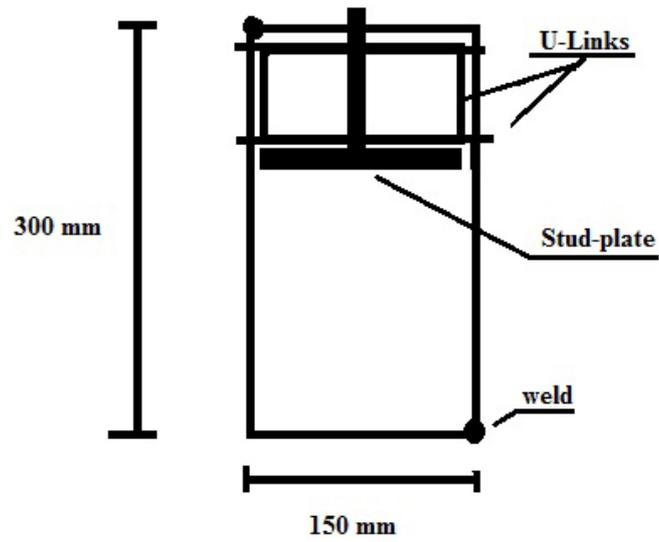


Fig. 1. Cross-sectional dimensions of the U-links stud-plate beam

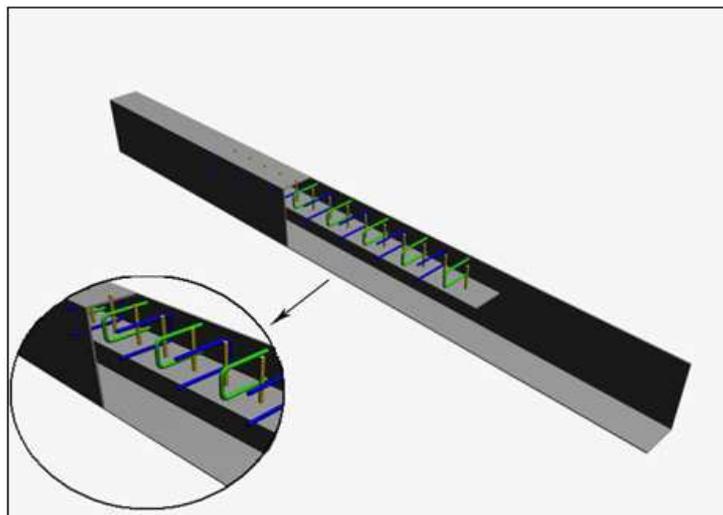


Fig. 2. Three-dimensional view of the U-links stud-plate beam

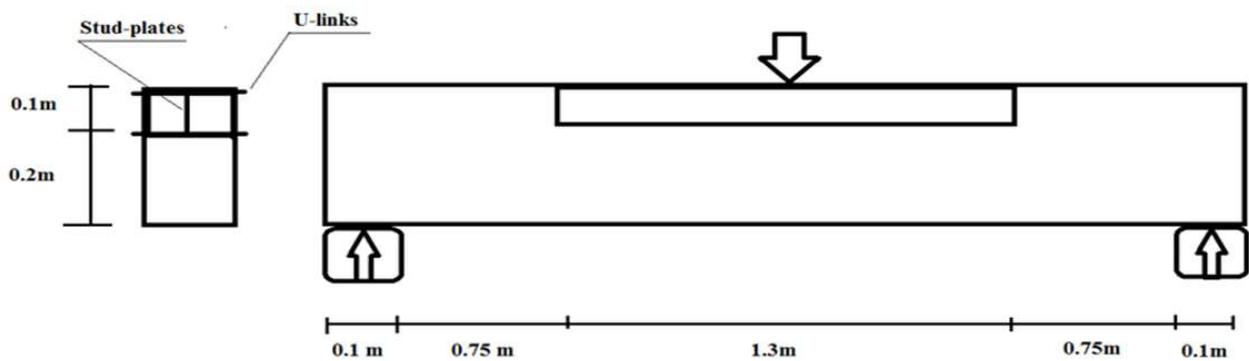


Fig. 3. The experiment set-up, showing the dimensions



Fig. 4. The experimental set-up and deflection measurement

Results

The AISC steel design manual is used here to calculate the ultimate plastic moment capacity of the composite section as well as the location of the plastic neutral axis. These two values were used to draw conclusions about the effectiveness of the new composite beam built with U-link stud-plate system. The plastic moment is calculated according to the AISC steel design manual. The plastic moment M_p is calculated to be 176.9 kN.m for the concrete filled tube composite beam without any special system. This value is compared with the plastic moment value of the concrete filled tube composite beam prepared with the new U-links stud-plate system which is also calculated to be 223.3 kN.m. The improvement due to the new system is about 26%.

The location of the neutral is also monitored. The theoretical value calculated according to the AISC steel design manual is 118.7 mm measured from the top of the beam. This value is compared with the experimental measured value of 111.3 mm measured from the top of the beam. This results in 94% as a ratio of the experimental value to the theoretical value. Figure 5 shows the measured values experimentally for the concrete filled tube made with the new confinement system. These values were recorded with the increase of the applied load. The straight lines connecting the measured values can be used to locate the neutral axis experimentally.

Discussing of Results

The concrete filled composite beams generally fail by bending after showing bulges at the top section of the beam near the mid span of the beam. The size of the bulge is a factor that can be considered here to show the effect of the new confinement system on the

overall performance of the beam. The appearance of the bulge is also a sign of initiating failure, where the load carrying capacity reduces substantially signaling beam failure. Figure 6 shows the failure of the concrete filled tube without any additional confinement system. As shown in that figure, the size of the bulge is relatively large. Figure 7 shows the amount of crushed concrete inside the steel tube made without any special confinement system. This mode of failure can be compared with the concrete filled tube made with the new system of U-links stud-plate system. Figure 8 shows the mode of failure of the concrete filled tube beam made with the new confinement system. The size of the bulge is relatively smaller and the concrete stayed intact inside the tube with no sign of crushing failure. Figure 9 shows the concrete condition at failure in the concrete filled tube beam made with U-links stud-plate system. The concrete condition appears to be in much better shape in the beams made with the new confinement system compared with the concrete filled tube composite beam without any special confinement system.

Figure 10 shows the load deflection relationships between the concrete filled tube beam without any special confinement system and the beam with special confinement system. The load carrying capacity just before failure for the concrete filled tube beam made with U-links stud-plate system registered 319 kN while the load carrying capacity of the concrete filled tube without any special confinement system registered 280 kN. The increase in the load carrying capacity is about 14% in favor of the concrete filled tube composite beam made with U-links stud-plate confinement system. The modulus of toughness is also substantially larger for the beam with special confinement system compared with the beam without any special system.

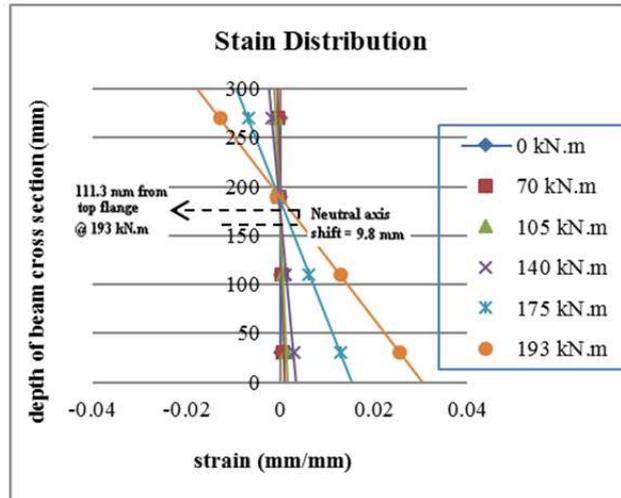


Fig. 5. Stain distribution measurement for the concrete filled tube beam with U-link stud-plate system



Fig. 6. Concrete filled tube beam without any special confinement system at failure



Fig. 7. Crushed concrete in the concrete filled tube beam without any special confinement system at failure



Fig. 8. Typical mode of failure of concrete filled tube beams made with U-links stud-plate system

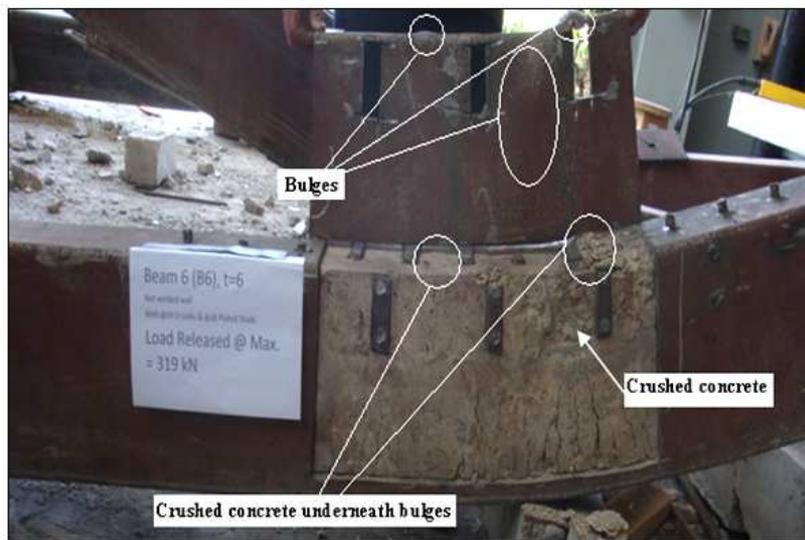


Fig. 9. The concrete condition of a concrete filled tube beam made with U-links stud-plate system

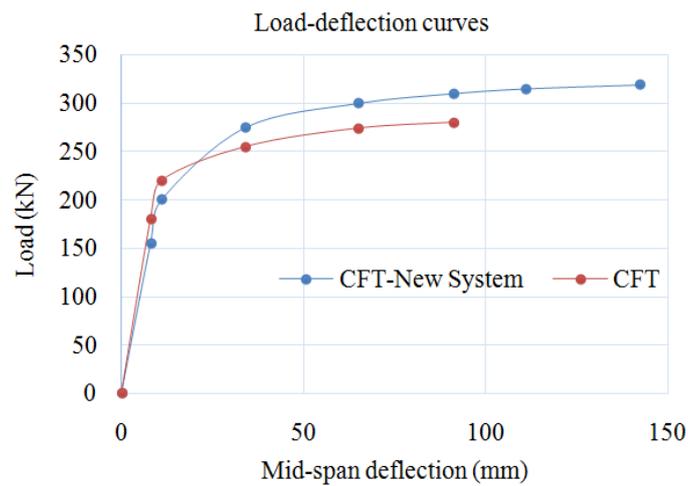


Fig. 10. Load deformation relationship

Conclusion

New confinement system has been introduced. The system is mainly U-links stud-plate confinement system added at the middle section of concrete filled beams. The performance of the beams with the new system is substantially improved in terms of the failure mode and the load carrying capacity. The load deformation relationship is also improved. The beams build with the new confinement system kept the majority of the concrete intact at failure at the same time reduced the bulging size under the applied load. The new system showed an improvement on the overall behavior of the beam. The new confinement system has the potential to be used under both static and dynamic loads.

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Author's Contributions

Madiha Ammari and Abdelqader Najmi: Performed laboratory work and conducted data analysis of the research.

Moayyad Al-Nasra and Taher Abu-Lebdeh: Provided the research topic and guided the research development, experimental plan and data analysis. All authors contributed to the writing of the manuscript.

Ethics

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