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Strengthen of Cold-Formed Steel Column with Ferrocement Jacket: Push out Tests

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Abstract**—**The population growth in the world requires an increase in demand of residential and housing construction. Using lightweight construction materials such as cold formed steel sections and ferrocement could be an alternate solution to foster the construction industry. In this study, a new composite column is introduced. It consists of cold formed steel section and ferrocement jacket. The ferrocement jacket was constructed using self-compacting mortar with two wire steel mesh of 550 MPa yield strength. Experimental push out tests was conducted to investigate the strength capacities and behavior of proposed shear connectors namely, bolt, bar-angle and self-drilling screw shear connectors. It was found that bolt connector showed the best behavior followed by bar-angle. Also, it was concluded that the ferrocement could be used to strength and improve the behavior of cold formed steel column.

Keywords**—**Cold formed steel, composite column, push out test, shear connector, ferrocement, strengthen method.

I. Introduction

THE traditional construction materials such as steel and concrete have exhibited signs of deterioration over the years in their long-term performance, which can be attributed to either the inherent nature of the materials or the weak resistance offered by these materials to adverse environmental conditions and natural disasters such as fires and earth quakes. In addition, retrofitting or rejuvenation of structures composed of such materials requires the use of skilled labors, heavy equipments, excessive energy and time which results in the escalation of the overall cost. Recent evaluation of the civil engineering infrastructure has demonstrated that most of it will need major repairs in the near future.

The maintenance of under-strength or deteriorated steel structures has been a subject of concern for structural engineers for decades. Major causes of distress or premature deterioration pertaining to steel structures include improper design or construction of the structure, changes in the structural function, and modifications in the load specification, corrosion of the steel, and exposure to impact or fire. When the structural member is a steel column, concrete jacketing, by encasing the existing steel section in a reinforced concrete jacket, is a commonly used technique.

Despite wide application of concrete jacketing in strengthening the steel columns of existing structures, research on the jacketing of such cold-formed steel columns is still in the early stages. From the last century, concrete jackets have been provided primarily to serve as protection against corrosion and fire [1], and thus were assumed not to resist structural loading. With present-day modern steel–concrete composite construction techniques, the stiffness and strength gain effects have been taken into account for steel columns strengthened with concrete jackets.

The use of ferrocement as an external jacket to cold-formed column is investigated in this study. Ferrocement is a special form of reinforced concrete, which exhibits a behavior differing much from conventional reinforced concrete in strength performance and potential application. Therefore, the uniform dispersion of reinforcement in the matrix offers in achieving improvement in many of the engineering properties of the material, such as tensile and flexural strength, toughness, fracture, crack control, fatigue resistance and an impact resistance and in addition it also provides advantages in fabrication [2]. In developing countries, the raw materials for ferrocement construction are easily available, and also it could be constructed in any complicated shape. The skill required is of low level and it has superior strength properties as compared to conventional reinforced concrete [3]–[7]. It was proven that, jacketing with rounded corner give certain degrees of confinement by reducing stress concentration at corners [8], [9]. This justifies the development of innovative rehabilitation and strengthening method by ferrocement jacket for cold-formed steel structures. The development of innovative rehabilitation and strengthening technique is required to extend the life expectancy of many steel structures and limited studies were reported for the similar work in case of ferrocement strengthened cold-formed column.

Stud (or bolt) connectors are subjected to flexural and axial forces in resisting the interface forces by means of dowel action. Force transfers in composite structures depend on the strength and stiffness of various components of the composite beam as well as shear connectors. Therefore, it is necessary to determine the design parameters namely, shear strength and stiffness for stud connector prior to their use in construction. This task is mostly accomplished by conducting experiments on push-out specimens. Several types of push-out specimens have been studied in past decades and reported in the literature. Behaviour of stud shear connectors in light weight and normal weight concrete is studied by Al-Salloum [10]. Investigation on the strength of push-out specimens have been carried out by Ollgard [11]. Later, Hawkins [12] has recommended various empirical equations to include the effect of variation in material strength, on the strength of shear connectors. Effect of transverse reinforcement on the shear

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strength of stud shear connectors have been investigated by Oehlers and Johnson [13] using push-out tests.

It is reported in British Standards Institute DD ENV 1994-1-1 [14] that the transverse reinforcement provides confinement to the concrete in the vicinity of studs rather than contribution to the strength. Shear stiffness, ultimate slip capacity and shear strength of stud connectors have been determined. The behavior of stud connectors in high strength and normal strength concrete has been studied byOehlers and Park [15]. Studs in normal strength concrete reported to exhibit ductile behavior as the descending branch was gradual and longer as compared with studs in high strength concrete. In the present study a new composite column with high strength self-compacting ferrocement mortar and cold-formed steel section is proposed, tested and reported.

II. Push-Out Test

Experimental investigation includes testing of three push-out specimens with three different types of shear connectors and ferrocement jacket was carried out. As shown in Fig. 1, a push-out specimen consists of full jacket ferrocement box a rounded to the flanges of I-beam by means of shear connectors. The I-beam was constructed using two lipped C-section cold-formed steel of 300×75×25×4mm oriented back to back. The lipped C-section of cold-formed steel columns was jacketed with two wire mesh layers of ferrocement jacketing. Steel wire mesh of 1.5mm diameter and (20x20 mm) square opening of 550 MPa yield strength was used to strengthen the ferrocment. Self-compacting mortar was designed and used in this study. The 28–day compressive strength of 100mm cube was determined at 71 MPa.

The push out specimen was subjected to a vertical load which produced shear load along the interface between the ferrocement jacket and the cold-formed steel column on both sides. The shear load was transferred to the ferrocement jacket through shear connectors. As shown in Fig. 1, a recess of 50 mm was provided between the bottom of the jacket and the lower end of the steel column to allow for the slip at the steel-ferrocement interface during testing. The objective of this study is to investigate the strength capacity and behavior of varied shear connectors between cold-formed steel jacketed with ferrocement. Three types of shear connectors were used namely, bolt (10mm diameter), L-bar angle (10mm diameter) and self-drilling screw of 6.3mm diameter as shown in Fig. 2. The ferrocement jacket, which used to strengthen the cold-formed steel section, resulted in a uniform cross section of 400×250mm^2 along the full length of the cold-formed column. The overall thickness of the ferrocement jacket of the specimen was 50mm. For all push-out specimens in this test program, the total number of connectors were 8 (4 bolt in each side) with spacing of 85mm between connectors. All shear connector were embedded 40mm inside the ferrocement jacket. Bolt and bar-angle shear connectors were tied by two nuts directly to the flange of cold-formed steel column.

All columns were tested using hydraulic compression testing machine until failure. The slip between ferrocement jacket and cold formed steel section was measured using two LVDTs. The test setup of the push out specimen and LVDTs positions are shown in Fig. 3.

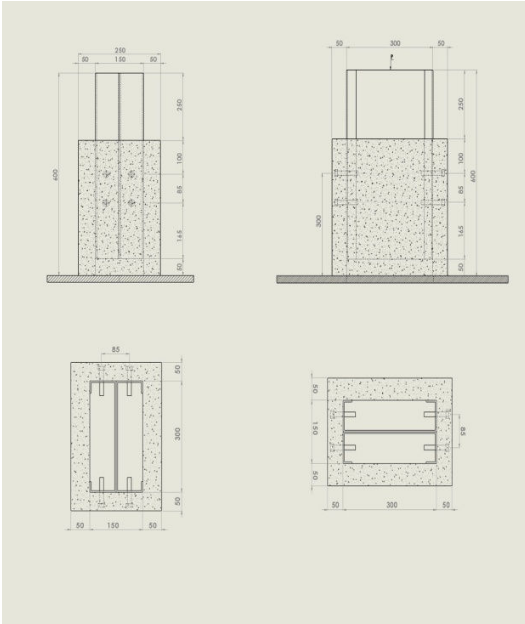

Fig. 1 Details of Push-out Specimen

Fig. 2 Shear connector types

Fig. 3 Push-out specimen under testing

III. Test Results

All tests results are summarized in Table I. The load-slip curves are shown in Fig. 4. The failure mode of all test specimens could be attributed to the failure of the shear connectors. The specimen resisted the applied load in elastic manner up to about 80% from the ultimate load. However, the specimen showed plastic behavior in a very limited range before the failure where the shear connector was sheared-off. Longitudinal cracks were observed on the ferrocement jacket at early stage of loading and become wider as load increase. Fig. 5 shows the failure mode of the specimens.

According to the test results, the load slip responses of all specimens seem to exhibit a similar pattern. It can be observed from Fig. 4, that specimen with shear connector of 10 mm bolt showed better resistance to the applied load and more ductile behavior as compared to bar-angle and self-drilling screw shear connectors with an improvement up to 45%. However, self-drilling screw shear connector showed the lowest resistance to the applied load. This is expected due to the smaller diameter (6.3mm) of the screw as compared to the bolt and bar-angle.

TABLE I
Test Results

specimen	Shear connector	Ultimate load per connector (kN)	Ultimate slip (mm)	Failure mode
S(1)	10mm bolt	36.062	1.16	shear-off the bolt
S(2)	bar-angle	29.075	1.12	shear-off the bar-angle
S(3)	drilling screw	24.832	0.58	shear-off the screw

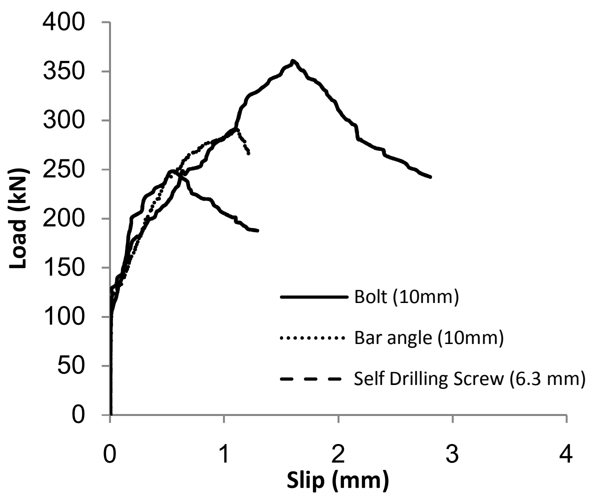

Fig. 4 Load-slip curves of the specimens

(a) Bolt

(b) Bar-angle

(c) Self drilling screw

Fig. 5 Failure modes of specimens

IV. Conclusion

New composite column consists of two C-lipped channel of cold formed steel oriented back-to-back and jacketed with ferrocement is proposed, tested and reported. Three types of shear connectors were used to form the composite action between steel column and ferrocement namely bolt, bar-angle and self-drilling screw shear connectors. The ferrocement slab was constructed using self-compacting mortar with two wire steel mesh of 550 MPa yield strength. From the push out test it was found that 10mm bolt shear connector showed the best behavior as compared to others. Also, it was concluded that ferrocement could be used to strength and improve the behavior of the cold formed steel column.

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