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EXPERIMENTAL OF RESTRAINED STEEL-CONCRETE COMPOSITE BEAMS UNDER CYCLIC LOADS

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Composite structures are made from steel connected with slab concrete holding together with shear connectors. This facilitates in loading capacity according to AISC and AASHTO standard design. The test on restrained steel-concrete beams under monotonic loading and cyclic loading condition is with the fully composite and the partially composite. The result of this research is that the fully composite is more loading capacity than the partially composite. Moreover, the study also focuses on the deformation capacity ratio between the fully composite and the partially composite under both mentioned conditions. In this aspect, it is found that the deformation capacity of the fully composite is less than the partially composite. From the study, it is suggested that the steel-concrete composite be design for the fully composite because it can hold the highest strength, prevent slipping between steel and slab concrete, and increase the durability.

Keywords: Restrained steel-concrete composite beams, Cyclic loads.

1 INTRODUCTION

Nowadays, bridge engineering technologies for transportation is rapidly advanced. There has been analysis on the long bridge designs. There are also the developments on material structure of beam bridges in which strength and ductility have been made higher in order to be capable of resistance to force and deformation. These facilitate in load capacity, from previously 21 to 25 Ton according to the international standard (AASHTO 2012, ACI 2008, AISC 2010).

Since the volume of transportation becomes higher, then the cyclic loading on the bridge automatically increases. Consequently, the beam bridge load resistance needs to be deeply studied. This is a reason why the study on strength and ductility of restrained steel–concrete composite beams under cyclic loading comes into existence.

For highway bridges with 40-60 m, the most efficient beam bridge is composite beam bridge. It consists of steel beams and slab concrete, which is molded at the site. This slab concrete is connected with shear connectors helping in increasing live load capacity (Ernst *et al.* 2010, Loh *et al.* 2004).

The continuous steel–concrete composite is widely used in buildings and bridge constructions. According to Plastic analysis, it shows that the continuous steel-concrete composite is able to reduce the depth and the load of buildings and beam bridges approximately 20-30 percent. However, the other analysis called Elastic analysis is not enough to moment, which is internal support and middle beam. It is also found that the moment resistance at the internal support is less than the moment at the middle of the beam because there is distribution of moment of the continuous steel-concrete composite beam. (Shiming and Yuanlin 2008).

This research of restrained steel–concrete composite beams under cyclic loading is greatly beneficial for study design of steel-concrete composite continuous beam in Thailand.

2 EXPERIMENTAL

2.1 Steel-Concrete Composite Beams

The cross section of steel – concrete composite beams as shown in the Figure 1 consists of steel beam, shear connector and concrete slab. It also consists of the major beams with the length of 3.80 m. (A-B) and the minor beams with the length of 2.20 m. (B-C). There are hinge and roller supports in both of them with the restrained supports at the minor beams. In monotonic and cyclic loading as shown in the Figure 2 and 3, steel – concrete composite beams demonstrate the load forces at the middle span of the major beams or at the maximum positive moment. However, the design of restrained steel - concrete composite can be divided into 2 categories.

2.1.1 The fully steel-concrete composite beams

It is designed for not to slip between concrete slabs and steel beams. The distance between the shear connectors is 6 cm.

2.1.2 The partially steel-concrete composite beams

It is designed for slipping between concrete slab and steel beams. The distance between the shear connectors of major beams is 19 cm. On the contrary, the distance between the shear connectors of minor beams is 6 cm in order to prevent the slip at the surface of slab concrete and steel beams

2.2 The Material Properties

The test on the material properties for the restrained steel-concrete composite is shown in the Table 1.

Table 1. The material properties of steel beams and reinforced concrete.

Material	Yield Strength (ksc)	Tensile Strength (ksc)
Steel Beam	3506	4732
Reinforcement	4705	6858

The loading on steel-concrete composite of restrained beams with monotonic loading is regularly carried with the speed of 1 ton/minute. Similarly, the loading on steel-concrete composite of restrained beams with cyclic loading is also carried with the speed of 1 ton/minute. But with the cyclic loading, each circle is increased 12% or 0.12 $P_{\max}$ of the maximum loading for monotonic loading test, and after the maximum loading is tested, the loading then is continuously reduced until it reaches zero Ton. The next circles are continued with the same method. In this test, load cells, vertical load displacement transducers and strain gauges are installed to record the loading, the displacement, the rotation at the internal supports, the slip of concrete slab at the surfaces of steel beams, the strain of steel beams, strain of shear connectors, the strain of reinforcement and the strain of concrete slab.

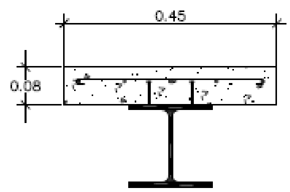

Figure 1. The restrained steel-concrete composite beams.

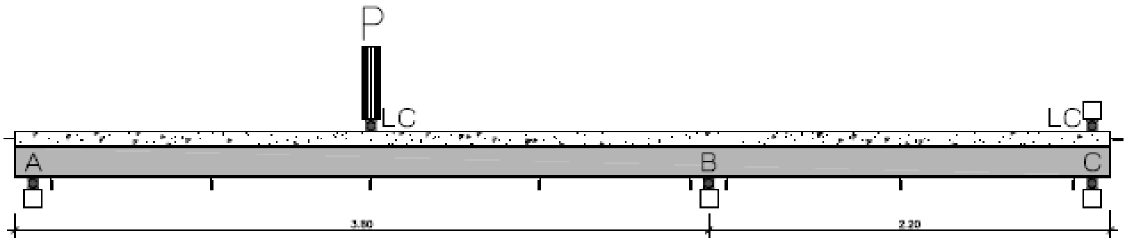

Figure 2. The middle of span loading of restrained steel-concrete composite beams.

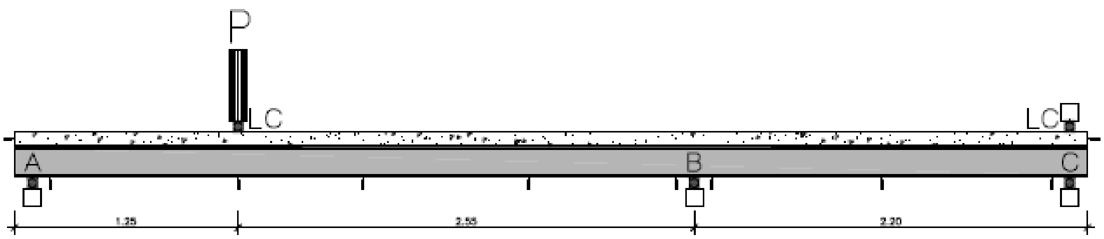

Figure 3. The load at the maximum positive moment of sections for the restrained steel-concrete composite beams.

3 THE RESULT AND DISCUSSION

3.1 Load and Deflection of Restrained Steel-Concrete Composite Beams with Monotonic and Cyclic Loading

From the test, the study demonstrates the facts on the beams with the shear connectors having distance of 6 and 19 cm as shown in the Figure 4(a) and (b).

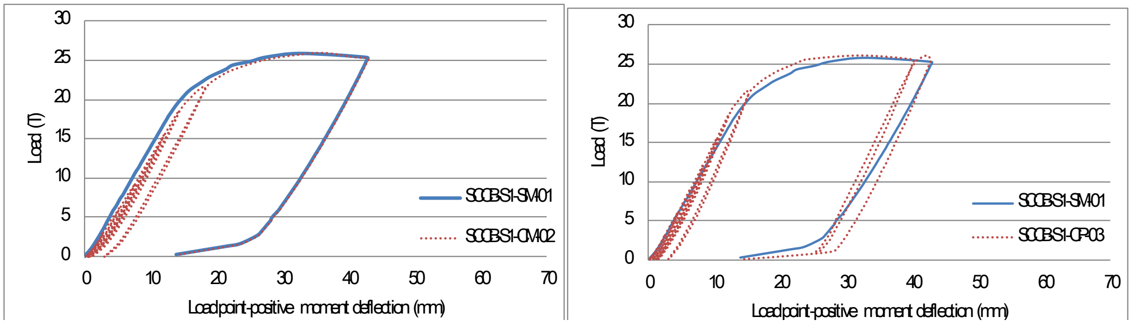

Figure 4. The relationship between loading capacity and deflection capacity (a) SCCB-S-SM-01 and SCCB-S1-CM-02; (b) SCCB-S-SM-01 and SCCB-S1-CP-03.

Figure 5(a) and (b) shows that the maximum load and the deflection of steel-concrete composite beams of SCCB-S1-CM-02 are equal to 26.03 T and 35.89 mm respectively. The other one SCCB-S1-SM-01 is equal to 25.85 T and 32.93 mm respectively.

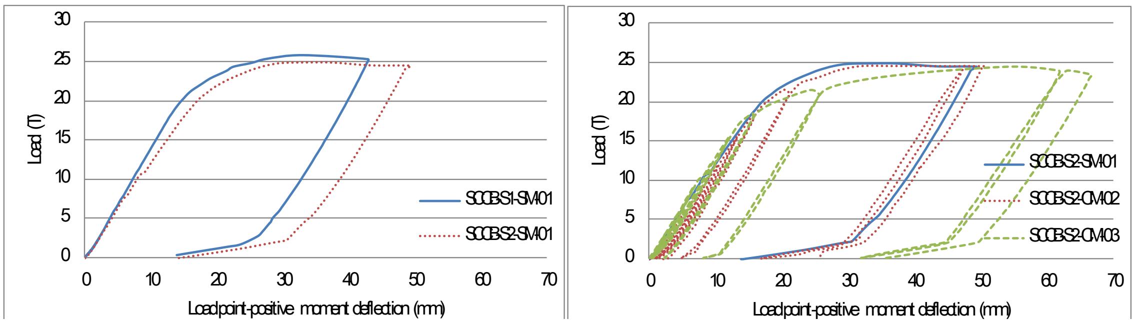

Figure 5. The relationship between loading capacity and deflection capacity (a) SCCB-S1-SM-01 and SCCB-S2-SM-01; (b) SCCB-S1-SM-01, SCCB-S2-CM-02 and SCCB-S2-CM-03.

When the comparison is made between the distance of 6 cm and 19 cm of shear connectors using for steel-concrete composite with monotonic loading, it is revealed that the maximum load and the deflection of SCCB-S1-SM-01 is equal to 25.85 T and 32.92 mm respectively. As a result, it has more loading and deflection capacity than SCCB-S2-SM-01, which has loading and deflection capacity only 24.87 and 29.91 mm respectively.

When considering loading and deflection capacity of the shear connectors with the distance of 19 cm, it is shown that the maximum load and deflection of SCCB-S2-CP-04 is equal to 25.55 T and 31.83 mm respectively. The tests were also conducted on SCCB-S2-SM-01, SCCB-S2-CM-02 and, SCCB-S2-CM-03 the results concerning on the maximum load and deflection of the mentioned beams are shown as the following. The maximum load and deflection of SCCB-S2-SM-01 is equal to 24.87 T and 29.91 mm respectively. The maximum load and deflection of SCCB-S2-CM-02 is equal to 24.52 T and 32.06 mm respectively. The maximum load and deflection of SCCB-S2-CM-03 is equal to 24.52 T and 33.69 mm respectively.

Comparing on loading and deflection capacity between the distance of 6 cm and 19 cm of shear connectors using for steel-concrete composite with cyclic load, the facts show that the maximum load and deflection of SCCB-CP-03 is equal to 26.03 T and 32.10 mm respectively. It has more loading and deflection capacity than SCCB-S2-CP-04 which its maximum load and deflection are 25.55 T and 31.83 mm respectively as shown in Figure 6(a) and (b).

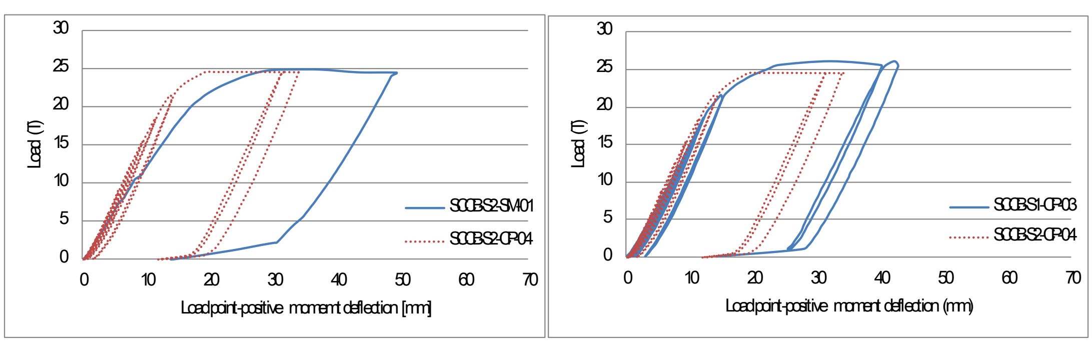

Figure 6. The relationship between loading capacity and deflection capacity (a) SCCB-S1-SM-01 and SCCB-S2-CP-04 (b) SCCB-S1-CP-03 and SCCB-S2-CP-04.

3.2 The Moment Resistance and Rotation at the Internal Support of Restrained Steel Concrete Composite Beams with Monotonic and Cyclic Loading

The fully composite beams as shown in the Figure 7(a) demonstrate the envelop curves of the maximum positive moment, negative moment, deflection at the loading points and rotation at internal supports in SCCB-S1-SM-01, SCCB-S1-CM-02 and SCCB-S1-CP-04. The maximum positive moments M^{+}_{u} are equal to 18.555, 18.439 and 18.948 T-m respectively. The maximum negative moments M^{-}_{u} are equal to 9.903, 9.065 and 3.226 T-m respectively. The deflection at the loading points is equal to 32.93, 35.89 and 32.10 mm. respectively. The rotation of internal supports is equal to 0.0143, 0.0103 and 0.0131 radian respectively.

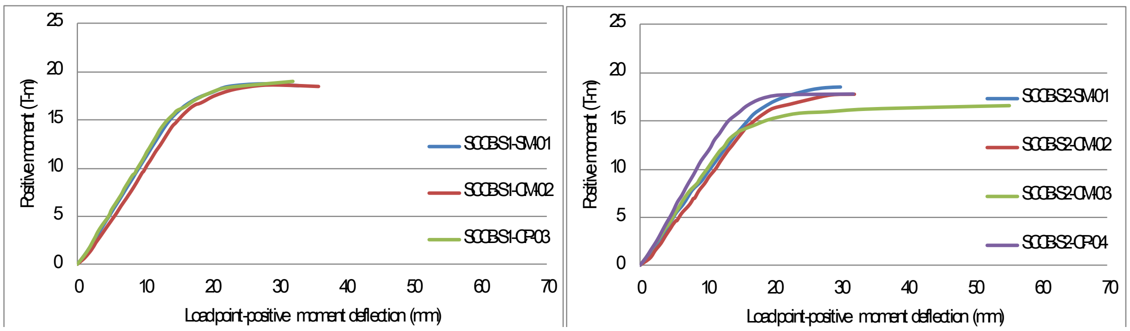

Figure 7. The envelop curves of restrained steel-concrete composite beams (a) Fully composite beam (b) Partially composite beam.

The partially composite beams as shown in the Figure 7(b) illustrate the envelop curves of the maximum positive moment, negative moment, deflection at the loading points and rotation of internal supports in SCCB-S2-SM-01, SCCB-S2-CM-02, SCCB-S2-CM-03 and SCCB-S2-CP-04. The maximum positive moments M^{+}_{u} are equal to 18.503, 17.778, 16.603 and 17.744 T-m respectively. The maximum negative moments M^{-}_{u} are equal to 7.075, 7.674, 10.064 and 4.723 T-m. respectively. The deflection at the loading points is equal to 29.91, 32.06, 33.69 and 31.83 mm. respectively. The rotation of internal supports is equal to 0.0020, 0.0132, 0.0173 and 0.0093 radian respectively.

It can be concluded that the positive moment resistance, the negative moment resistance, the deflection and the rotation at the internal supports of the fully restrained steel-concrete composite beams are higher than the partially restrained steel-concrete composite beams; that is 5.623%, 0.153%, 5.553% and 22.115% respectively.

4 CONCLUSION

From the results of the study on strength and ductility of restrained steel – concrete composite beams under cyclic loading; it can be concluded as the following.

The fully restrained steel-concrete composite with monotonic and cyclic loading has more loading capacity than the partially restrained steel-concrete composite monotonic and cyclic loading that is 5.528%.

The moment resistance, deflection and rotation at the internal supports of the fully restrained steel-concrete composite with monotonic and cyclic loading are higher than the partially restrained steel-concrete composite with monotonic and cyclic loading. The highest positive moment resistance is 5.623%, the highest negative moment resistance is 0.153%, the highest deflection is 5.553% and the highest rotation at internal support is 22.115%

To be precise, the fully restrained steel-concrete composite is suitable for the highway bridge design because the load standard of the highway bridges in Thailand is increased from 21 T to 25 T With the load of 25 T, it does not only provide the strength but it also prevents the slip between the concrete surfaces and the steel beams. Furthermore, its durability is considered to be sufficient for the highway bridge standard in Thailand.

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