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Development of Composite Action in Existing Non-Composite Bridges

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Summary

An experimental investigation was undertaken to increase the load carrying capacity of existing slab-on-steel girder bridges without composite action. This particular type of bridge was mainly built 30 to 50 years ago. The main goal of this research was to provide a composite action between the concrete slab and the steel girders by means of fasteners. Many commercial anchors were tested and some prototypes as well. The results of this investigation are presented in this paper.

Introduction

Before the seventies, short and medium span steel bridges were frequently erected with a concrete deck directly cast on steel girders without any mechanical connection. Even if the theoretical evaluation of these bridges with actual truck loads shows underdesign conditions, the majority of these structures still behave relatively well. The main objective of the first part of the experimental investigation was to evaluate the carrying capacity of slab-on-steel girder bridges without composite action. Test results show that the flexural capacity of the steel beams is significantly increase because friction at the steel-concrete interface is sufficient to provide lateral restraint of the compression flange against lateral buckling (Dionne et al. 1994).

In this part of the experimental program, some specimens were strengthened with connectors to provide composite action between steel beams and concrete slab. Test results indicated that it is very important to eliminate the gap between the connectors and the surrounding materials. In fact, we found out that a relative displacement as small as 2 mm is sufficient to completely lose the composite action. Therefore, connectors should incorporate a device to fill the gaps in the holes of the beam flange.

In the second part of the experimental program, special connectors were designed and subjected to static and fatigue tests. Results of these tests are reported in this paper. The main objective of this research was to provide an efficient connection between the concrete slab and the steel girders by means of anchors.

Experimental program

The specimens used for the static and fatigue shear tests are shown in figure 1. A steel plate is connected to a reinforced concrete block with two anchors. The specified compressive strength of concrete was 30 MPa. The specimens were placed in a testing machine and the load was applied to the steel plate while the concrete block was held in place by a steel frame connected to the testing machine base.

Static shear tests were first carried out on various types of anchors in order to find out a shear connector which had a stiffness under service loads and an ultimate strength similar to end welded studs used in modern composite construction.

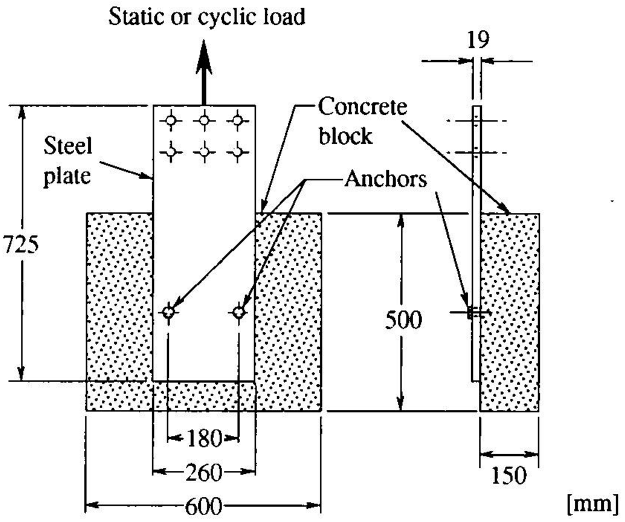


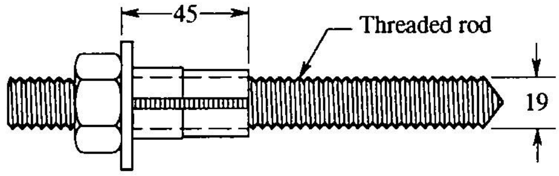
Fig. 1 *Typical specimen used for shear tests*

Many commercially available mechanical and chemical anchors were subjected to static shear tests. Mechanical anchors have an expansion device which presses against the wall of the hole in the concrete block while the anchor is tightened. Twenty one tests were carried out on seven different types of mechanical anchors. Chemical anchors comprise a threaded rod and a rapid setting epoxy which locks the anchor in the concrete hole. Eight tests were carried out on three different types of epoxy.

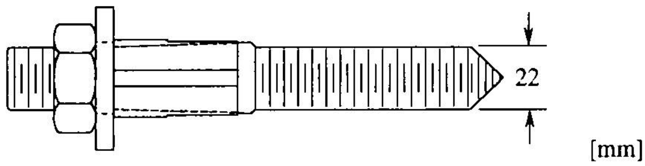
Commercial anchors are not designed with the requirement of eliminating the gap between the anchor rod and the hole in the steel plate (beam flange). The diameter of this hole is at least 2 mm larger than the diameter of the anchor rod to make the fastener installation easier. Although some anchors have an ultimate strength which compares well with end welded studs, slip under service loads is much higher and the composite action is impaired.

Therefore, some prototypes were designed to satisfy service load requirements,. The two most promising anchors are shown in Figure 2. The first one was obtained by adding a steel sleeve to a commercially available chemical anchors. Not only this sleeve eliminates the gap between the anchor rod and the plate hole but it also increases the shear strength at the steel-concrete interface, the most stressed cross section of the anchor rod. The second anchor (Fig. 2 b) has an inverted conical sleeve which expands and presses against the wall of the plate hole when the nut is tightened. The epoxy is injected into the concrete through a hole which is drilled along the longitudinal axis of the rod.

The anchors shown in Fig. 2 were specially designed to develop composite action in existing non composite bridges. Anchor installation on the bridge site is an important problem. There is no commercial machine which can perform the three main operations of the installation of an anchor, that is to drill a hole in the steel flange, in the concrete slab and to insert the anchor. Such an apparatus was devised and efficiently used to connect a concrete slab to steel girders (Croteau et al. 1996; patent pending). The apparatus includes a piston which firmly fix the machine between the beam flanges. It is indeed very important to immobilize completely the machine during the three main operations of the installation of each anchor. The machine was designed to install mechano-chemical anchor with abutment sleeve (Fig. 2a) because it is the less expensive anchor.



a) Mechano-chemical anchor with abutment sleeve



b) Mechano-chemical anchor with inverted conical sleeve

Fig. 2 Mechano-chemical anchors

The anchors shown in Fig. 2, as well as shear studs, were subjected to cyclic shear loading at a stress range of 90 MPa (frequency : 10 Hz). According to the Canadian standard for bridge design (CSA 1988), shear studs should withstand 2 million cycles at this stress range. The maximum load of the loading cycles, which corresponds to the maximum service load, was determined from the following equation :

$$P_{max} = \frac{\bar{P}_u - 2s}{\gamma}$$

Where $\overline{P_u}$ is the average static ultimate shear load of the anchors (kN), s is the standard deviation (kN) and γ the safety factor ($\gamma = 3$). The minimum load of the loading cycles was computed to obtain a stress range of 90 MPa. For threaded rods, the shear stress is computed on the net area of the cross-section.

Test results

Tensile tests were carried out to determine the ultimate tensile stress (F_u) of steel used for studs and anchors. The average values of the measured ultimate tensile stress are as follows : 19 mm studs, $F_u = 488$ MPa; 22 mm studs, $F_u = 499$ MPa; anchors with abutment sleeve (Fig. 2a), $F_u = 998$ MPa; anchors with inverted conical sleeve (Fig. 2b), $F_u = 579$ MPa. Three tests were carried out in each case except for the 19 mm studs fir which six tests were carried out. The values of the coefficient of variation (standard deviation divided by the mean) are quite low (from 0.2% to 0.7%). High strength steel is used for threaded rods of anchors with abutment sleeve.

Static shear tests were first carried out to compare the behavior of commercial anchors to shear stud behavior. The stiffness under service loads is particularly important to maintain composite action. Typical load-slip curves are shown in Figure 3. The initial portion of the curves which is enlarged, clearly shows that significant slip occurs at low load for both commercial anchors. As mentioned previously, tests on composite beams, where the slab was connected with commercially available anchors, have shown that the composite action is no longer effective when slip is larger than 2 mm. As shown in Figure 3, for commercial anchors, this critical slip is reached at low loads for commercial anchors compared to shear studs. It should be noted that the results shown in Figure 3 were obtained with the most efficient commercially available anchors.

Following these results, we tried to modify commercially available anchors and even designed some prototypes. The objective of this exercise was to come up with a connector as stiff as studs and offering similar ductility and ultimate resistance.

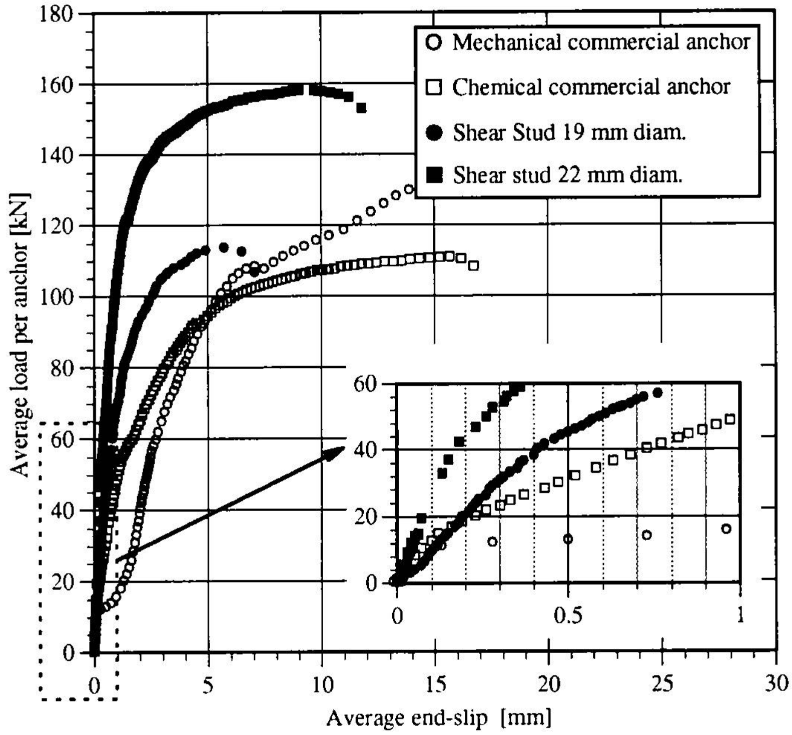


Fig. 3 Commercial anchors versus welded shear studs

The specially designed anchors shown in Figure 2 were first subjected to static shear loads in order to verify that stiffness under service loads and ultimate shear strength were similar to these of welded shear studs. As shown in Figure 4, the measured ultimate shear strength of mechano-chemical anchors with abutment sleeve is larger than the strength of 19 mm diameter studs but lower than the strength of 22 mm studs. The mechano-chemical anchors with inverted conical sleeve are as resistant as 22 mm diameter shear studs. Furthermore, we can see in the enlarged portion of the curves that both anchors have a stiffness under service loads clearly higher than the stiffness of 19 mm diameter studs. Therefore, both anchors justified further investigation.

In order to verify the behavior under cyclic loads, these anchors as well as studs were subjected to cyclic shear loading at a stress range of 90 MPa as explained previously. Two fatigue tests were carried out in each case except three tests for 19 mm studs. All anchors and studs sustained two million cycles of loading without fatigue fracture. The specimens were then statically tested up to ultimate load. Typical results are shown in Figure 5.

As we can see on this figure, the mechano-chemical anchors with abutment sleeve show less degradation under cyclic loads than the 19 mm diameter studs and even seem to have gained some ultimate resistance. This increase is due to the orientation of the sleeve. We found out that when the slot is perpendicular to the direction of the shear force, the ultimate resistance increases by about 10%.

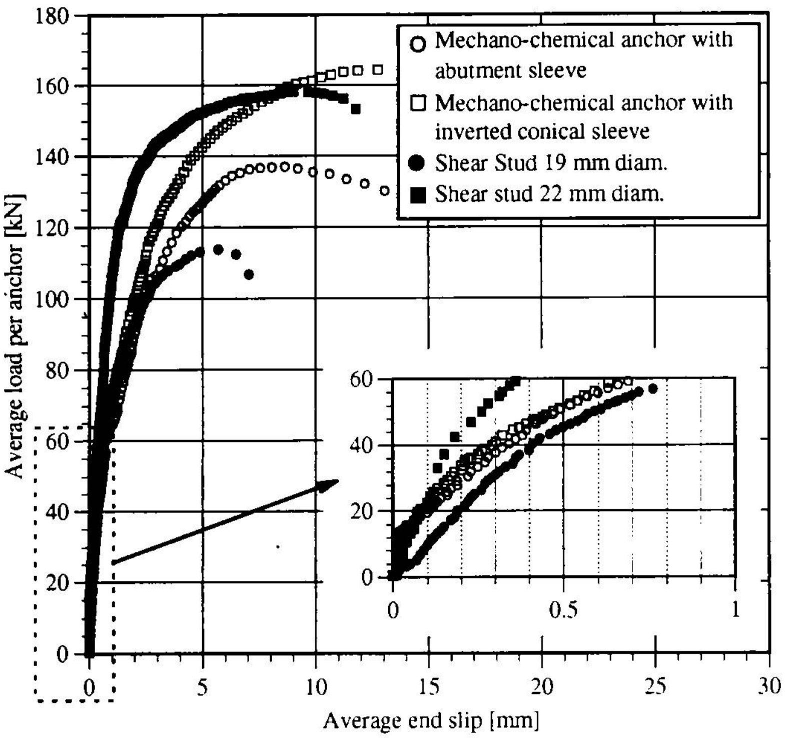


Fig. 4 Mechano-chemical anchors vs welded shear studs

By comparing the enlarged portions of Figures 4 and 5, it can be seen that there is no significant loss of stiffness in the service load range for both anchors after two million cycles, which is a suitable behaviour for bridge strengthening. It can also be seen that there is some degradation in the behaviour of welded studs since slip under service loads is larger for the specimens which were subjected to cyclic loading.

As shown in Figure 5, the behaviour of specially designed anchors is similar to the behaviour of 22 mm diameter studs. Even if the behaviour of both anchors is adequate, the anchor with an abutment sleeve is easier to fabricate and therefore cheaper. It was therefore recommended for further investigation (Croteau et al. 1996).

Conclusion

Commercially available anchors are not designed to efficiently strengthen slab-on-steel girder bridges. To be fully effective, the connector must be able to fill the space needed for its insertion. With this in mind, we designed prototypes in order to improve the stiffness of shear connectors at service load.

The two most effective prototypes developped to connect the concrete slab to steel beams were presented in this paper. They were devised to reduce as much as possible the relative displacement between the two materials. These anchors can develop full composite action and they well sustain cyclic loading. The strengthening technique can be used to connect the concrete slab to steel girders or transverse beams in existing non-composite bridges. The anchors can also be used to improve composite action which has deteriorated due to slip increase at the steel concrete interface. This technique can also be used to upgrade the fatigue life of bridges who have reach a critical amount of sollicitation by adding additionnal connectors. Finally it is likely to consider the use of such anchors when the existing concrete slab or wood deck is replaced by a precast slab (Mohsen et al. 1995).

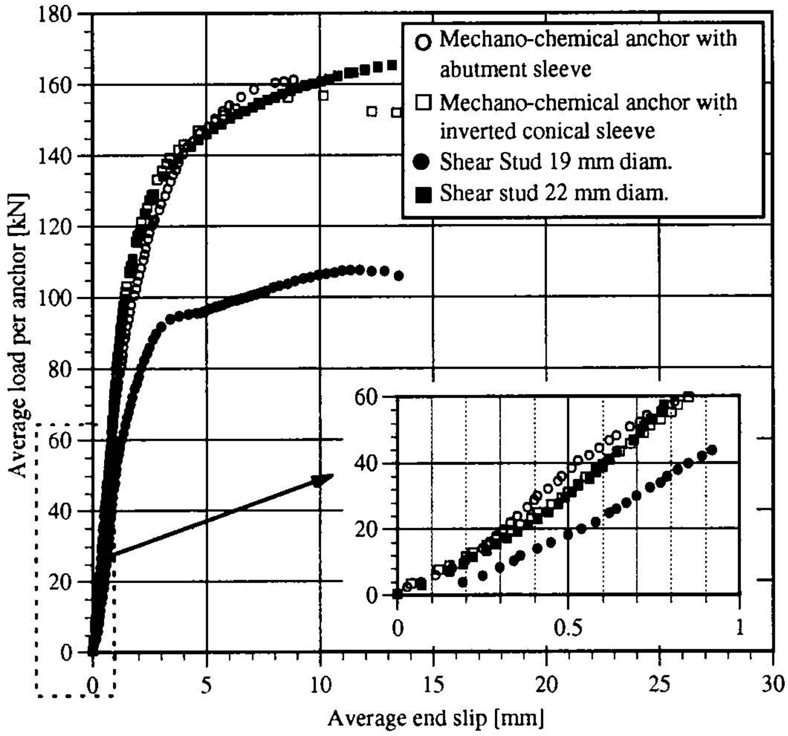


Fig. 5 Mechano-chemical anchors vs welded shear studs after 2 000 000 cycles

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