The Performance of Coiled Spring Pin Connectors under Static and Fatigue Loading

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Summary

Coiled spring pin connectors provide a simple low-cost method for upgrading the fatigue life of composite bridges, but their satisfactory performance is dependent on achieving a close tolerance fit between the pins and the steel and concrete elements into which they are installed. The authors describe the behaviour of coiled spring pin connectors observed in fifteen shear (push-out) tests under static and constant amplitude repeated loading. The tests were commissioned to validate the retrofit design and installation of this type of connector for upgrading the fatigue life of a multi-span composite box girder structure carrying a mass rapid transit system in Canada. The retrofit installation was completed in 1995.

1. Introduction

Coiled spring pins are widely used as fasteners in the mechanical engineering industry, but have found relatively little application on civil engineering projects. They were first used to upgrade the fatigue life of composite plate girder bridges on the Docklands Light Railway, London in 1988. The test data available from that application were considered to be insufficient to validate their use on the Canadian project to which the authors refer and a series of static and fatigue tests was commissioned at TWI, Cambridge to obtain further data on the load-slip behaviour under static and constant-amplitude shear loading.

2. Test Specimens

Fifteen specimens with a reinforced concrete block cast between two parallel steel plates were fabricated to the dimensions shown in Figure 1. The density of reinforcement in the block was based upon the requirements of BS5400 Part 5. Steel straps were welded to the side plates to resist the forces of separation. In the structure, these forces are resisted by the heads of the existing welded stud connectors. Plate thicknesses of 25mm and 35mm, which were representative of the majority of flange plates in the structure were used to study the influence of plate thickness on load-slip behaviour. Four 175mm long x 20mm dia heavy duty zinc plated pins were installed in each specimen. The pins were manufactured by Spirol Industries Limited to IS08748.The diameters of the pins and of the holes into which the pins were installed were carefully measured to ensure the test specimens were representative of the tolerances specified for the retrofit scheme. In two specimens, the pins were lightly coated with molybdenium disulphide grease before insertion to reproduce conditions on a small number of pins in the actual structure where grease was used to reduce the jacking load.

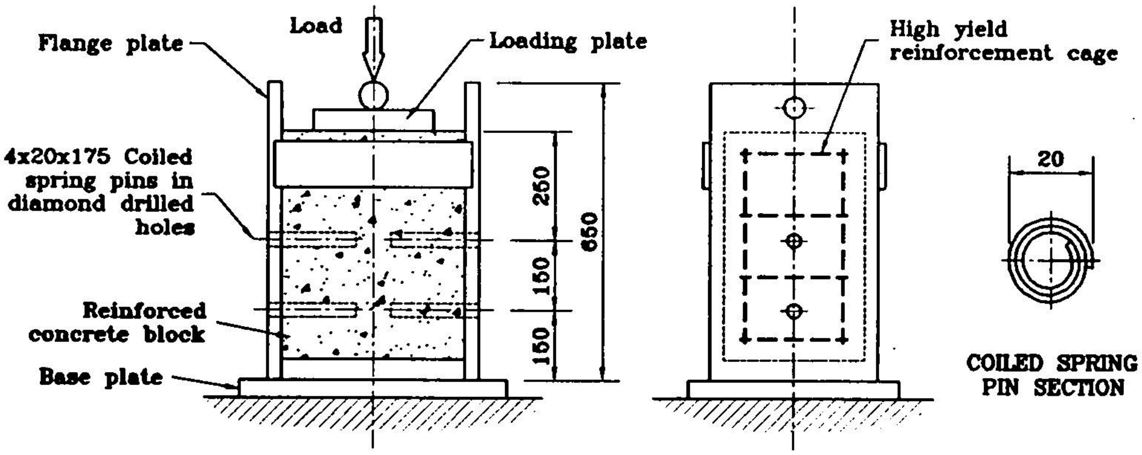

Figure 1 Test Specimens

3. Load Testing

Three specimens were loaded through their central axis to failure at a constant static loading rate of 1mm/min. The remaining 12 specimens were subjected to constant amplitude cyclic loading at a uniform frequency of either 8.3 or 10 Hz. Prior to fatigue testing, each specimen was subjected to three shakedown cycles. The purpose of the shakedown tests was to ensure that any residual bond between the concrete slab and steel plate was broken before the start of the fatigue loading test, but useful information was also obtained on the shear stiffness and the non-recoverable slip of the pins on initial loading and on subsequent unloading/reloading over three static loading cycles.

4. Load-Slip Behaviour under Static Shear Loading

The load-slip behaviour of one of the three specimens subjected to static loading is shown in Figure 2. The similarity of the results for all these specimens was remarkably consistent. Slip measurements on the specimens were terminated at 20mm, but even at slips up to 38mm, the pins continued to carry more than 70 per cent of their ultimate load, due to progressive cracking at different locations in the pins and shear cracking of the concrete block due to yielding of the transverse reinforcement.

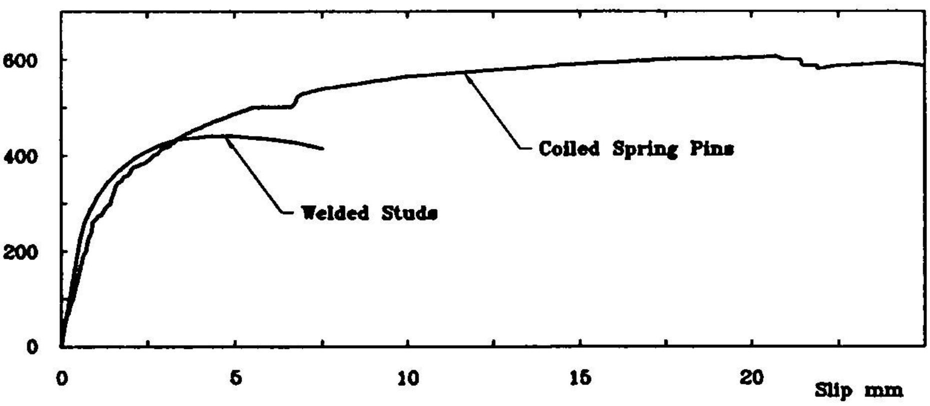

Figure 2 Typical Load-Slip Behaviour of Specimen Under Static Shear Loading

From these three tests, the static nominal ultimate load of a 20mm diameter pin, P_u, was determined as 130kN using the method recommended in Clause 5.3.2.4 of BS5400 Part 5 for tests on non-standard connectors. Figure 2 also shows the typical load-slip behaviour for a 100mm long x 19mm diameter welded stud embedded in concrete of similar strength for which

BS5400 Part 5 gives P_u = 107 kN. The effect of lightly greasing the pins in specimen 3 had a negligible effect on the ultimate load capacity but, as expected, slightly increased the slip for a given load.

5. Load-Slip Behaviour under Constant Amplitude Cyclic Loading

5.1 Shakedown Tests

The load-slip relationship observed in specimen 14 with a plate thickness of 35mm is shown in Figure 3 for the following conditions:

(i) on initial loading

(ii) on subsequent unloading/reloading over 3 cycles

(iii) on completion of 0.55 x 10^6 cycles of loading over the range 0.1 P_u - 0.44 P_u.

On the eight specimens tested with 35mm plates, the elastic stiffness of the pins on initial loading, K_{p1}, varied between 65 kN/mm to 110 kN/mm and after 3 cycles of loading, K_{p3}, between 65 - 120 kN/mm. In the specimens with 25mm plates, the stiffness of the pins on initial loading varied between 70-75 kN/mm and after 3 cycles of loading between 90 and 110 kN/mm.

On completion of the constant amplitude cyclic loading tests, the stiffness of the pins, K_{pf}, generally reduced, due to the formation of fatigue cracks in the specimen. However, on specimen 14, no significant loss of stiffness was observed on completion of the fatigue test at N = 0.55 x 10^6 cycles.

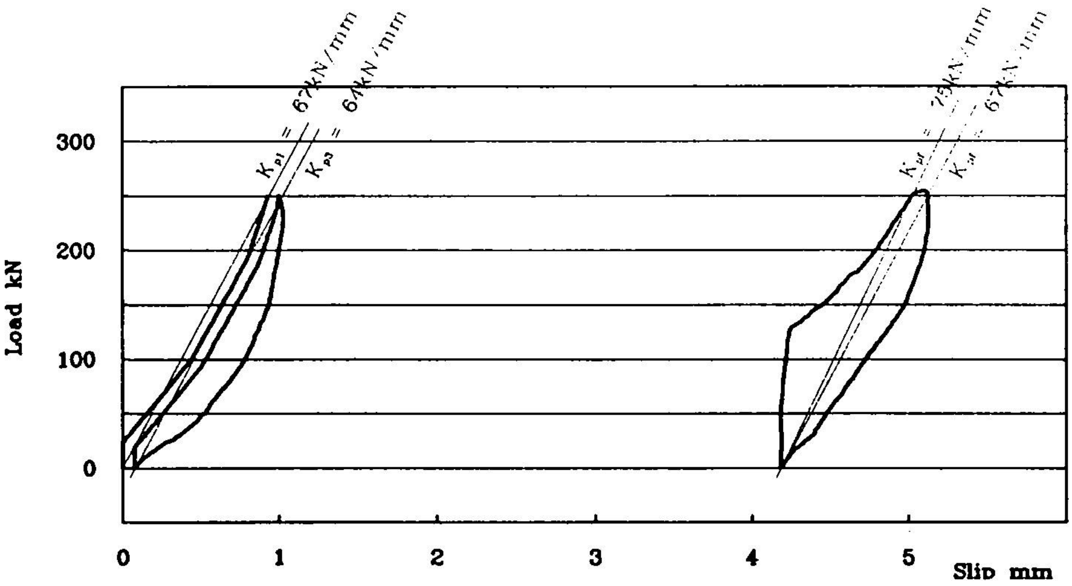

Figure 3 Typical Load-Slip Response in Specinien with 35mm Flanges

5.2 Load-Slip Behaviour under Constant Amplitude Cyclic Shear Loading

The shear displacement of the steel plate in relation to the concrete block under constant amplitude shear loading was logged against time on opposite faces of the test specimens. From these results, the mean slip for a given number of loading cycles was determined, as shown in Figure 4 for specimen 15.

The cyclic loading tests were generally terminated when the slip reached 5mm, but in five tests loaded in the range 0.1 P_u to 0.4 P_u, the specimens sustained more than 11 million cycles without exceeding 2.4mm slip displacement.

The cyclic shear loading tests demonstrated that fatigue failure of a coiled spring pin connector is quite different to that of a welded stud connector and cannot be defined in the same way as for a stud where failure is characterised by sudden failure of the entire shank of the stud with rapid loss of load at a clearly defined number of cycles of loading. Thus, for coiled spring pins, it was concluded that fatigue failure should be defined as the number of cycles of loading sustained for a given slip displacement.

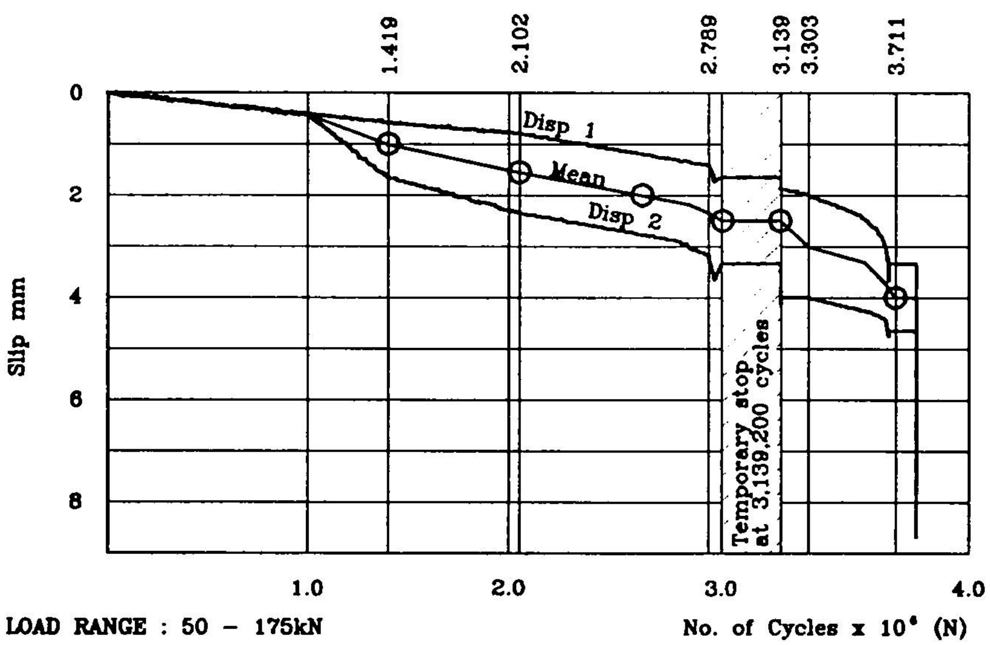

Figure 4 Typical Slip History for Specimen 15 with 35mm Flanges

In a retrofit scheme, if the new connectors are to share subsequently applied loadings more or less uniformly with the existing connectors, it is necessary that the connectors which are added are of a similar stiffness to the existing connectors.

For 19mm stud connectors, permanent slip under service loadings is generally in the range 1 to 2 mm so an upper limit of 2mm was adopted for Spirol pins.

The number of cycles of loading sustained by each specimen for different ranges of shear loading was then determined at slips of 1, 1.5mm and 2mm and was plotted as log $_{10}P$ against log $_{10}N$. The mean log $_{10}P$/log $_{10}N$ relationship of the test results was then obtained from a linear regression analysis of the test results and was compared with the mean value for 19mm stud connectors given in BS5400 Part 10.

In BS5400 Part 10, a probability of failure of 2.3% is adopted for the design of all welded details, including stud shear connectors. A low probability is appropriate for welded studs because fatigue failure of a stud is characterised by sudden loss of loading caused by fatigue failure of the weld at the root of the connector or in the shank itself. Cracking in the concrete embedded stud cannot be readily detected by non-destructive tests.

In contrast, the tests on coiled spring pins, showed that fatigue failure is characterised by gradual loss of load capacity with cracking at different locations in the pin. Also, the bore of the pins can be inspected for fatigue cracks and additional pins added nearby if necessary. It was therefore concluded that a 10% probability of failure could be accepted for fatigue failure of a coiled spring pin, provided a limit of 2mm was imposed on permanent slip under repeated service loading.

The test results obtained for 20mm diameter pins and the mean and 10% design lines are compared in Figure 5 with the mean and 2.3% design P-N relationship for 19mm welded studs recommended in BS5400 Part 10. From this, it can be seen that the fatigue endurance of 20mm diameter pins is better than that of 19mm welded studs at $N < 10^6$ cycles and, at 10^7 cycles, the maximum range of design shear load is 18.8 kN compared with 20.7 kN for a 19mm stud (ie about 10% lower).

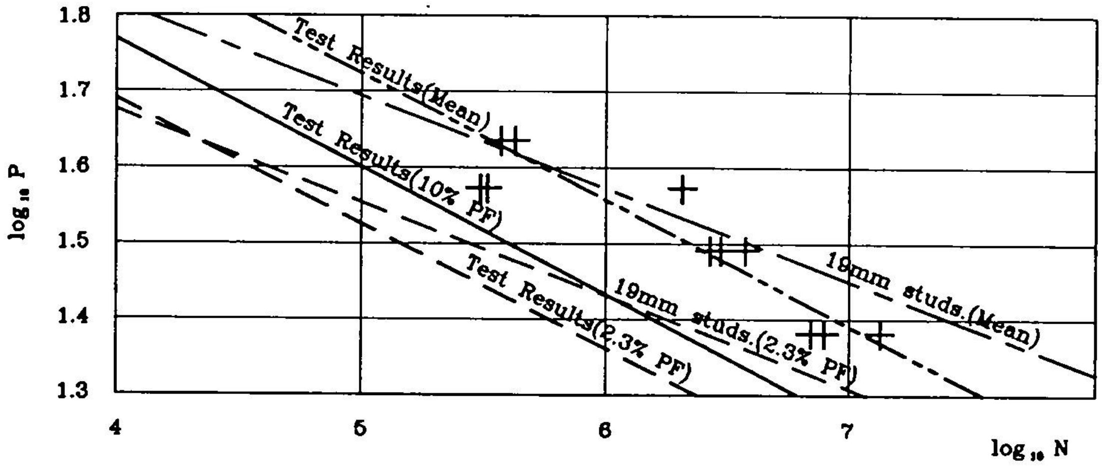

Figure 5 Load-Endurance Relationships for Coiled Spring Pin Connectors

6. Recommended Design Criteria

From the test results which have been obtained, the authors recommended that the following criteria for heavy duty 20mm coiled spring pin connectors could be adopted for the design for pin connectors installed in the Grade 37.5 concrete and 25-35mm thick steel flange plates in the Canadian box girder structure:

i) The nominal static strength of a pin, P_u, can be taken as 130kN
ii) The design fatigue endurance can be determined from the relationship

$$\mathrm{Log}_{10}N = 14.767 - 6.1\ \mathrm{Log}_{10}P$$

The above endurance relationship may be dependent on the fit of pins in the holes. In the tests, the mean interference fit was tighter than recommended by the pin manufacturer (see Table 1) but the hole sizes in the specimens were representative of those achieved on site (see Section 7 below).

	Hole Diameter			Pin Diameter			Mean
	Min	Max	Mean	Min	Max	Mean	Interference
Manufacturer's Data	19.85	20.25	20.05	20.40	21.00	20.70	0.65
Test Specimens (Steel)	19.92	20.14	20.00	20.75	21.01	20.88	0.88
Test Specimens (Concrete)	19.96	20.25	20.04	20.75	21.01	20.88	0.84

Table I Comparison of Manufacturer's Specification with Test Specimens

7. Use of Coiled Spring Pin Connectors for Upgrading the Fatigue Endurance of an Existing Structure

The design values obtained from the tests described in the paper were adopted for upgrading the fatigue life of a multi-span composite box girder rapid - transit guideway structure in British Columbia, Canada. The retrofit contract consisted of drilling close-tolerance holes through the steel top flange and concrete deck of an open-top steel box girder and installing approximately 2500 coiled spring pins over a six month period with no interruption to transit service. The jacking force required for installation of the pins varied from 62 to 205kN.

The specification called for hole diameters to be from 19.85 to 20.25mm with a maximum diameter difference at the steel/concrete interface of 0. 1 mm. This required careful design and operation of the drilling equipment by the contractor. The profiles of all holes were measured and recorded. Table 2 summarises the results of the holes drilled in the structure. Only 14 holes with measured diameters in the range 20.26 to 20.30mm failed to meet the specification. The pins in these holes were abandoned and new holes were drilled for replacement pins. The majority of pins were installed from inside of the box girders but, where the minimum spacing of 100mm could not otherwise be maintained, some pins were positioned from the outside. After installation, the heads of the pins were sealed to prevent moisture ingress.

Girder	Element	Diameter of Hole (mm)			Standard
		Min	Max	Mean	Deviation (mm)
Outbound	Steel flange	19.90	20.28	20.07	0.07
	Concrete	19.90	20.75	20.07	0.08
Inbound	Steel flange	19.90	20.30	20.09	0.07
	Concrete	19.88	20.30	20.07	0.08

Table 2 Hole diameters achieved in retrofit contract

The transit authority is currently considering using the same method to upgrade another section of steel-composite guideway. The principal advantage of using coiled spring pins for fatigue strength enhancement is that they provide an unobtrusive, non-disruptive system for which design rules based on test data are now available. In addition, the pins can be periodically inspected for fatigue cracks and can easily be augmented if required.

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