4. Discussion of IABSE SURVEYS «Limit States of Composite Bridges» R.P. Johnson, published in February 1987 in IABSE PERIODICA 1/1987

A Discussion by D.J. Oehlers, Cork, Ireland

I found Professor Johnson's paper of great interest as it is one of the few papers which deals directly with the problems of the durability of composite structures; an area in which I am involved through research into the behaviour of stud shear connectors subjected to monotonic and fatigue loads. One of the main problems or hindrances in this area of fagitue of shear connectors is that existing analysis techniques are often based on, or use as a guide-line, the design of steel components; probably because composite construction was developed from steel construction. However recent research [1] has shown that the fatigue behaviour of dowels embedded in concrete is not fully represented by the fatigue behaviour of steel components; therefore analogies between the steel and composite systems of design should be used with care.

In dealing with shear connectors, Professor Johnson's question in Sect. 1 on 'which limit states are most likely to be reached' may not always be directly determined or apparent. For example, the loss of shear connection (that is the reduction in the monotonic strength of the connectors) may lead directly to fracture of the shear connectors when the beam is overloaded, or alternatively the associated loss of interaction may lead to other limit states being reached such as buckling or fatigue failure of the tension flange in continuous structures. Furthermore, it has been found in tests [2] that fatigue loads on stud shear connectors not only cause a loss of interaction and a loss of shear connection, but also a loss of ductility in the connectors. This may affect the design philosophy used in a code. For example, the loss of ductility may reduce the ability to redistribute the shear load near failure so that the flexural capacity may be more closely estimated from an elastic analysis than a plastic analysis. Furthermore, as the connectors become less ductile the strength of the connection may be governed more by the strength and scatter of the individual connectors than by the strength and scatter of the mean.

Regarding Professor Johnson's remark on detectability in Sect. 6, the present of construction do not allow the loss of interaction nor of shear connection to be measured directly in composite beams. However, research into the fatigue behaviour of composite beams [3] shows that these losses and hence the fatigue damage cause an increase in the sag of a composite beam (that is deflection due to dead load acting on the composite section), but do not cause a significant loss of stiffness nor an increase in deflection over a cycle of load as a vehicle traverses a bridge. A possible solution to this problem of monitoring the behaviour of connectors during their design life would be measurement of the initial camber of the composite beam immediately after construction and subsequently the sag during routine inspections of the bridge; this simple procedure would be only a qualitative gauge of the fatigue damage as the results would include the effects of creep, of cracking of the concrete, and of fatigue on the tension striffness of the reinforced concrete slab. A quantitative measure of the fatigue damage can only be achieved by instrumenting a bridge after construction to allow direct measurement of the interface slip and slip strain. It is felt that too little attention is paid to this aspect of composite construction at the design and construction stages.

There may at present be no direct evidence of deterioration in bridges which were replaced for other reasons after twenty-five years or so (Sect. 6), but it remains to be determined how many existing bridges show indirect signs of fatigue damage through sag, as mentioned in the previous paragraph. However, there is substantial experimental evidence to show that the monotonic strength of a connector reduces during the fatigue life although possibly not enough evidence to quantify the rate of deterioration. Direct evidence has been found in tests on push specimens and on beams which initially were subjected to fatigue loads and then failed monotonically. Those tests were not part of a controlled parametric study, because their primary purpose was the determination of endurance under fatigue loads and then, through impatience or lack of time, the fatigue tests were stopped and the specimens loaded monotonically to failure. Five push specimens subjected to fatigue loads and then loaded monotonically at Cork [1, 2] failed at between 52% and 73% of their expected static strenghts, and Mainstone and Menzies [4] also noted that the strengths of two push tests had reduced to less than half the expected values after fatigue loading. It would appear also that one of the beams tested by Roderick and Ansourian [5] failed prematurely when the applied load was being increased for the next block of cyclic loads. Substantial indirect evidencf fatigue damage has been accumulated by many research workers from the analysis of the pemanent set which occurs in stud shear connectors under cyclic loads [2, 6, 7]; this release of energy, which occurs throughout the fatigue life, is available to crush the concrete or crack the connector; both effects would cause the monotonic strength of the connector to reduce. Theoretical evidence [1] also point to a mechanism in the dowel action which allows a uniform rate of crack propagation in the stud throughout the fatigue life, in contrast to the behaviour of steel sections subjected directly to fatigue; this indicates that the present techniques used in composite design, which are based on the steel codes, are not truly applicable to steel dowels embedded in concrete.

As part of a 'situation' to cause failure in Sect. 3, it may be worth including the possibility of limit states being reached by modes of failure not considered in the codes and therefore not designed against. One such mode of failure, which is not considered directly in codes of practice, is the splitting of the concreted slab due to the dispersal of the concentrated dowel force into the slab [8, 9]; although this mode of failure ist designed against indirectly by stipulations on cover and lateral reinforcement. It is suggested that a 'situation' comprising of deliberate passage of an overload, coupled with a prior check which neglects splitting and possible deterioration of the concrete may lead to a loss of interaction and of shear connection due to splitting; as the resistance of a laterally reinforced slab after splitting only reduces gradually [2], these losses would probably lead to some other ultimate limit state being reached.

References

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Reply of the Author to Dr. Oehlers' Discussion

I am grateful to Dr. Oehlers for providing detailed support for the concern expressed in Section 6 of the paper, for the long-term vulnerability of composite bridges to deterioration of the shear connection.

In welded steelwork, experience has shown that a structure can be assumed to maintain its initial static resistance throughout its design fatigue life. Dr. Oehlers reminds us that there is insufficient lenght of experience to validate this assumption for shear connection; and that the evidence from research points the other way and is too limited to enable the rate of deterioration to be quantified.

This problem was considered during the drafting of Eurocode 4. Let us suppose that the static strength of a shear connection were a known function of its cumulative fatigue damage, and diminished with time. Should one allow for this by more conservative design for static loads only, for fatigue only, or for combination of the two? The calculations would have to be based on predictions of traffic loads a century or more into the future. In the current absence of any major failures, designers would not easily be persuaded to abandon existing methods in favour of more complex and conservative new ones. In some circumstances there may be a margin of safety in the current rather crude design methods. Perhaps that should be determined, and used up first!

We concluded that it was too early to attempt to write design rules on this subject. Dr. Oehlers and other research workers should be granted the resources to quantify this loss of static strength, and to develop and validate better design methods. Meanwhile, the shear connection should be monitored in a few important bridges, by regular measurement of the change of slip and the change of deflection due to passage of a known load. Measurement of changes in total deflection can be unreliable, for in welded steelwork these can be increased by yielding of steel in highly stressed regions, as well as by the creep, shrinkage, and cracking of concrete.

At present, the evidence is so limited that it is difficult even to assess how important the problem may be. The fact that in other respects composite bridges are usually much stronger than expected (reference 5 of the paper) may encourage complacency. Bridge engineers are therefore encouraged to use any available opportunity for checking the static stiffness and strength of the shear connection in a bridge after a few decades of service.