

STUDY OF BEHAVIOUR OF STRINGER TO FLOOR BEAM CONNECTION IN RIVETED RAILWAY OPEN WEB GIRDER BRIDGES

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ABSTRACT

Stringer-to-floor-beam connections in riveted railway bridges have in many cases shown to be critical details with respect to fatigue. These connections, while generally designed with respect to shear forces alone, are often subjected to repeat secondary bending as a result of their rotational stiffness. The behaviour of double-angle stringer-to-floor-beam connections in riveted railway bridges has been analyzed based on performance of full scale bridge parts. The response of these shear connections has been studied under the action of bending moment. It is found that these connections are capable of developing appreciable moments due to restraint they exert on the rotation of stringer of stringer ends associated with bending. The resulting bending and axial stresses in the angles and the rivets of the connection might consequently be considerable. High stress concentrations are also present in these components, which further increase their fatigue-damage susceptibility. The paper discusses the important findings of the study.

1.0 INTRODUCTION

The floor-system in old riveted railway truss bridges is typically designed as a grid structure consisting of longitudinal and transverse members (stringers and floor-beams) connected through their web plates by means of riveted double-angles. The main function of these connections is to transfer the end reactions of stringer to the floor-beam through shear action.

One general assumption that is made in the design of these double-angle connections is that they have sufficient rotational flexibility to allow for the stringer-end rotation associated with bending without developing appreciable moment. This assumption is also often adopted today. Analyses of the load-carrying capacity of double-angle stringer-to-floor-beam connections in existing riveted bridges, and the assessment of their fatigue strength, are generally made with reference to the shear forces acting on the connections only.

The assumption of null degree-of-fixity might be justifiable when it comes to the ultimate load-carrying capacity of the connections and the connected members. However, overlooking the effect of the rotational stiffness of these connections might result in an inadequate

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fatigue-damage cases in double-angle stringer-to-floor-beam connections have been reported, the majority of which were attributed to the moment acting on these connections.

2.0 BEHAVIOUR OF RIVETED DOUBLE ANGLE CONNECTION

2.1 As per prevailing IRS practice, the connection between stringer and cross beam is designed as a shear connection to transmit the vertical shear at the joint location considering the stringer as simply supported. Practically the stringer is not simply supported as the riveted double angle connection is not free to rotate in the plane of stringer axis. The rotational stiffness of such a joint is also not sufficient enough to design the stringer as completely fixed at supports. Fig. 1 illustrates the assumed, theoretical and practical conditions at joint for understanding the proper support conditions of stringer

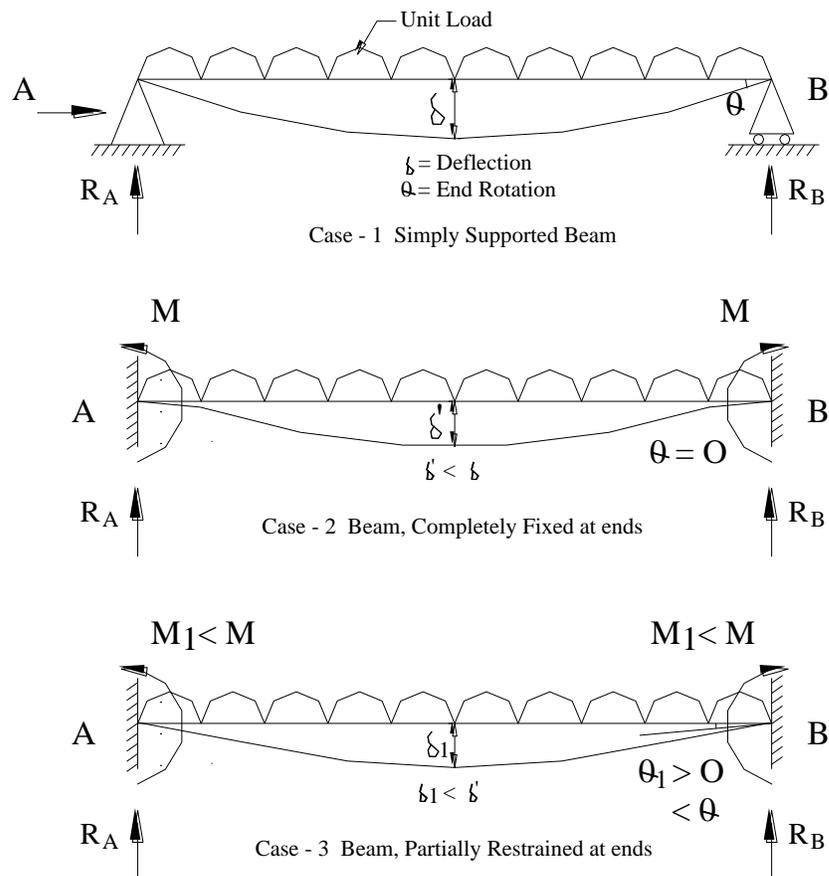


Fig 1 : Deflection, Rotation and Bending Moments Generated under Different Support Conditions

- 2.2 The rotational stiffness of double-angle stringer-to-floor connections is primarily a function of the flexural stiffness of the outstanding legs of the connection angles. The effect of the deformation applied to the connections (by the stringer-end rotation associated with bending) is to subject the outstanding legs in the upper portion of the connection to an out-of-plane flexure, causing bending and axial stresses in the angles and the rivets, respectively. The magnitude of stringer-end moment and the resulting forces in the different components of the connection will depend on the amount of applied deformation that can be accommodated by the flexural flexibility of the outstanding legs.
- 2.3 A large part of the deformation applied to the connection by the rotation of the stringer end is 'locked' by the stiffness of the connection. Consequently, the angle is subjected along most of its depth to tensile forces which are counter balanced by local contact pressure at the bottom of the connection (Fig.2). The upper part of the connection is subjected to relatively high tensile forces and the magnitude of stringer end moment is considerable. The studies have shown that the double-angle 'shear' connections are capable of developing more than 60% of the corresponding moment for a total rigid connection. The moment-load behaviour can be considered linear and the position of the rotational center is only slightly affected by the magnitude of the applied load.

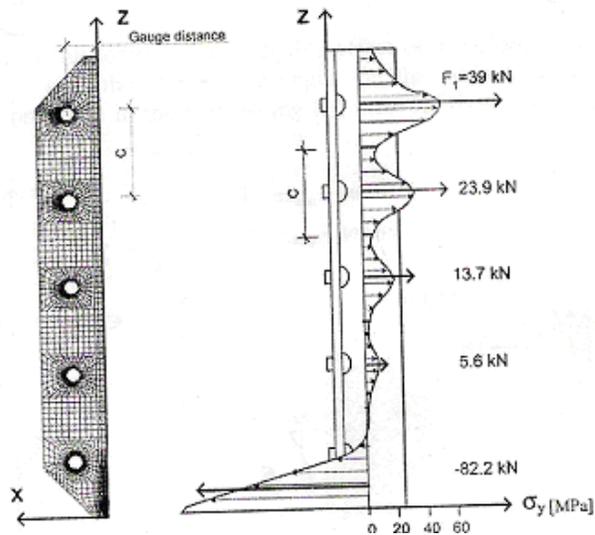


Fig2 The forces acting on the connection due to the action of moment :

- (a) contact pressure on the backside of the outstanding leg**
- (b) axial forces and stresses in the angle leg connected to the stringer web**
(The values shown are typical values observed in studies)

3.0 DEFORMATION CHARACTERISTICS OF CONNECTION ANGLES

- 3.1 As has already been observed, the flexibility of the outstanding legs of double-angle connections subjected to moment has a major impact on the response of these connections. In particular, the gauge distance between the rivets and the fillet of the angle plays a dominant role in the behavior of these connections. On the one hand, the flexibility of the outstanding leg at these locations has a decisive effect on the amount of applied deformation that can be accommodated by the connection and consequently, on the magnitude of the stringer-end moment. Furthermore, due to its locally higher stiffness, the outstanding leg along the gauge distance attracts a larger portion of the tensile forces acting on the connection, resulting in high stress concentration at these locations. The bending stresses in the outstanding leg of the angle are mostly magnified along the gauge length and reach a maximum near the fillet of the angle as shown in Fig. 3.
- 3.2 When the distribution of stresses in the angle shown in Fig. 3 is analyzed, a number of observations can be made. Although the behavior of the outstanding leg of the angle is bending dominated, some 'membrane action' appears to exist. Based on the distribution of stresses through the thickness of the angle near the fillet, the contribution from the membrane action in this location is less than 10% of the bending stresses.

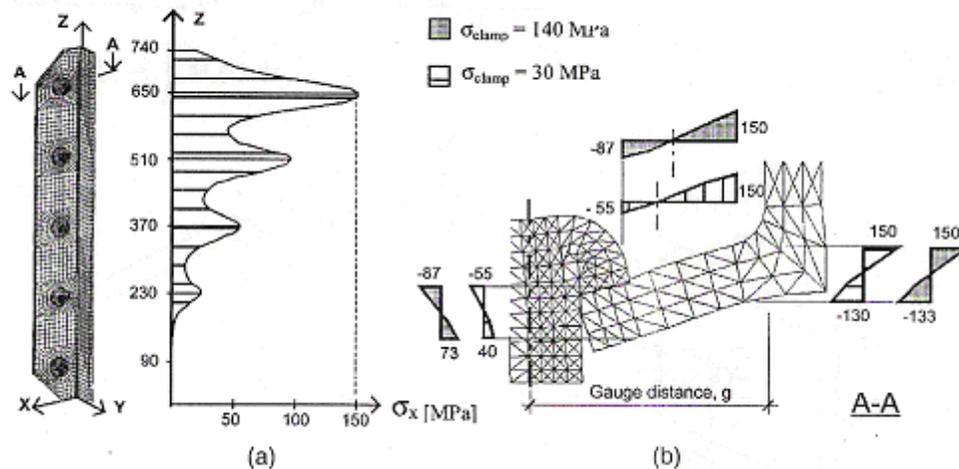


Fig. 3 The distribution of bending stresses in the connection angle
(a) near the fillet along the depth of the connection of the connection
(b) along the gauge distance and through the thickness of the angle
(The values shown are typical values observed in studies elsewhere)

- 3.3 The rivet-clamping force had a negligible effect on the magnitude of maximum bending stresses near the fillet of the angle. On the other hand, higher bending stresses were produced in the outstanding leg near the rivet when the latter had a higher clamping force. The outstanding leg of the connection angle behaves as though it was partially fixed under the rivet head. The same behavior explains the slightly stiffer response obtained for the connections with a higher rivet-clamping force. The deformation of the outstanding leg near the rivet is restricted by the axial and bending stiffness of the latter and is consequently affected by its clamping force. The axial stiffness of the rivets is typically several times greater than the flexural stiffness of the outstanding leg of the angle and the contribution from rivet elongation to the flexibility of the connection is relatively small.

4.0 AXIAL AND BEARING STRESSES IN THE CONNECTING RIVETS

- 4.1 It is known that the clamping force in the fasteners of connections subjected to fluctuating moment and/or tensile forces has a significant influence on the fatigue strength of these fasteners. For a given applied load, a higher clamping force will simply result in a smaller increase in the axial force developed in these fasteners. Several previous investigations relating to riveted connections have concluded that hot-driven rivets could develop considerable clamping force. The average clamping ratio (i.e. the ratio between the clamping stress in the rivet and the rivet yield stress) was found to be about 70%. The clamping force in the rivets of flange-to-web connections was investigated for stringer and the average value of the clamping ratio found in these rivets was 42%.
- 4.2 Generally, the clamping force in hot-driven rivets is highly undetermined variable. In addition to its dependence on the grip length (i.e. shank) of the rivet and the stiffness of the connected plates, it is also affected by the driving temperature and the driving method (e.g. hand-hammering or using hydraulic-pressure riveters). The magnitude of the clamping force is also expected to reduce with time through relaxation or due to the fretting of the connected components.
- 4.3 In particular, the rivets in stringer-to-floor-beam connections are expected to have substantially lower clamping stress. These connections are generally assembled on site, which often involves uncontrolled riveting conditions and installation problems that could result in faulty, misshapen rivets.
- 4.4 The effect of the clamping force in the rivets on their fatigue strength is even more pronounced when taking account of the variation in local

stresses in the rivet shank, where the effect of rivet bending is also. In fact, the bending of the rivets caused by the flexure of the outstanding legs of the connection angle, together with the stress concentration present at the junction between the rivet shank and its head, are the major mechanisms behind crack initiation and fracture in these rivets (rather than the variation in the nominal axial tensile stress in these rivets). The out of plane distortion of the connection angles has been measured and verified by FE modeling and relationship has been developed with gauge distance (g) an angle thickness (t) etc. The displacement of the connection angle with depth of connection Fig.4

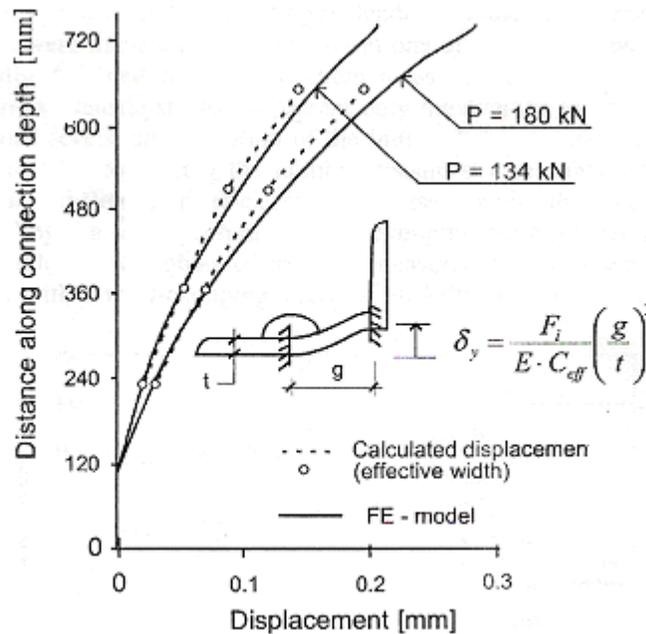


Fig. 4 Out-of-plane distortion of the connection angles (FE model), and the corresponding displacement of the equivalent L-segments with an effective width, C_{eff} .

- 4.5 The rivets in the second row of the connection (looking from the top) also experiences relatively high axial and bending stresses. The 'segmental' tensile forces carried by this rivet were also observed high and were further magnified by the effect of prying. Fatigue failure in the upper two rivets took place in many of the connections during the fatigue tests of the bridge parts.

5.0 CONCLUSIONS

- 5.1 Double-angle stringer-to-floor-beam connections have been a common source of fatigue damage in riveted railway bridges. In many cases, this damage is generated by the secondary stringer-end moment that develops at the connections as a result of their rotational stiffness. The behavior of double-angle stringer-to-floor-beam

connections has been studied. Static and fatigue tests have also been performed on three full-scale bridge parts taken from an old riveted railway bridge. The results of the analysis show that double-angle stringer-to-floor beam connections, although generally assumed to act as 'simple shear joints, exert appreciable restraint on the stringer-end rotation associated with bending and, as a result, high secondary bending moment can be developed at these connections.

- 5.2 The flexibility of the outstanding legs of the connection angles has a major influence on the response of the double-angle connections. In particular the gauge distance between the rivets and the fillet of the angle is found to play a dominant role in the behaviour of these connections. The outstanding legs of the connection angles are subjected by the action of moment to out-of-plane distortion, which in turn generate high flexural stresses in the angles. The distribution of these flexural stresses along the depth of the connection is, however, not uniform. High concentrations of flexural stresses are present near the fillet of the angle at the rivet gauge distances.
- 5.3 The magnitude of the clamping force in the rivets has been found to have only a marginal effect on the rotational stiffness of the connections and the rivet-clamping force virtually does not affect the flexural stresses in the angles. On the other hand, the resulting stress ranges in the rivets of the connection are greatly influenced by the magnitude of clamping force in these rivets. The variation in both axial and bending stresses in the rivets is substantially reduced when a higher clamping force was present.
- 5.4 Rivet bending due to prying action, together with the stress concentration present at the junction between the rivet shank and its head, is the major mechanism behind fatigue cracking in the rivets rather than the variation in the nominal axial tensile stress in these rivets.

6.0 REFERENCES

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