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NOTICE

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ABSTRACT

Stringers to floorbeam joints usually are designed as shear connections. The moment carrying capacity of these joints is beneficial to the load carrying strength of the stringer but also induces local stresses in the connection itself. Some results of recent studies on the behavior of stringer-floorbeam connections with respect to fatigue are presented.

INTRODUCTION

The floor systems of railroad and highway bridges usually contain stringers which are connected to floorbeams by rivets or bolts and connection angles. An example is sketched in Fig. 1. These angle connections are designed to carry shearing forces at the ends of the stringers. The capacity of the connection to carry some bending moment at the stringer ends reduces the bending moment and related stresses at the middle portion of the stringers. However, the bending moments at the ends of the stringers also introduce rotation and deformation of the connections, as shown exaggeratedly in Fig. 2. These deflection and deformation generate local stresses in the stringer web and the floorbeam web as well as in the connection angles and rivets or bolts. When live loads travel on the bridge, the stresses fluctuate in the components of the connections. If these live load stresses are high and the number of load application is large, fatigue damage could occur [1,2]. Examples are given in Figs. 3, 4 and 5, showing failure of rivets, a crack in a leg of a connection angle on the stringer web, and the total failure of a connection angle, respectively [3].

Studies were conducted on the behavior of stringer-floorbeam connections to gain insight of the fatigue problem, and to develop guidance for design and retrofit [3,4]. Some results are summarized below.

ROTATION AND DEFORMATION OF CONNECTION ANGLES

The rotation of stringer ends and the deformation of connection angles are dependent on the floor system geometry and the dimensions of the connection angles. The rotation and deformation are interdependent. Figure 6 shows the typical rotational configuration. The more flexible the connection, the larger the rotation. On the other hand, for a specific stringer-floorbeam connection, the stringer end rotation and bending moment are practically linearly proportional. This condition is depicted in Fig. 7 for a stringer which is subjected to either a concentrated load or a uniformly distributed load.

The moment-rotation relationship of Fig. 7 is obtained through an analysis by the finite element method, which incorporates the deformation of the connection angles. The deformation shape of a connection angle corresponding to the rotational configuration of Fig. 6a is shown in Fig. 8. The corresponding principal stresses on the inside surface of the angle legs are depicted in Fig. 9. For this example, the highest tensile stress due to a HS-20 truck is about 22 ksi at the fillet at the upper end of the connection angle, without considering impact.

MOMENTS AND STRESSES DUE TO MOVING LOADS

For the examination of connection stresses due to moving trucks, a simple span bridge with five lines of stringers and four floorbeams is analyzed. The plan of the bridge is shown in Fig. 10, and the finite element model in Fig. 11. The stiffness of the stringer-floorbeam connection (or the moment-rotation relationship) is incorporated in the model.

As a HS-20 truck travels on the bridge, the bending moment at the connection changes with time. The variation is plotted in Fig. 12 for connections C1, C3 and C5 of Fig. 10. Connections C3 and C5 are subjected to some negative bending moment, compatible with the condition that the stringers are "partially" continuous.

The stresses at all points of the connection are directly proportional to the bending moment. Thus, the curves in Fig. 12 are essentially the stress-time variation at points of the connection angles. For connection C3, the maximum live load stress corresponding to the peak moment is about 22 ksi (as shown in Fig. 9). The maximum range of stress is about 24 ksi, from -2 ksi to +22 ksi.

FATIGUE OF CONNECTION ANGLES

A limited number of tests have been conducted to examine the fatigue strength of connection angles [3,5]. The results are summarized in Fig. 13 for the first observation of fatigue crack in a connection angle [3]. The fatigue strength data are above the category A curve of the AASHTO specification [6].

For connection C5 of Fig. 10 with the moment-time relationship of Fig. 12 and a corresponding maximum stress range of 24 ksi, the fatigue life of the connection is more than two million cycles when category A curve is used as reference.

The evaluation of live load stress ranges in a connection angle, as demonstrated here, requires an elaborate analysis of the bridge structure and the connection details. Therefore the assessment of fatigue cracks such as those of Figs. 3, 4 and 5 is seldom conducted. The practical approach to alleviate fatigue problem of stringer-floorbeam connection is to establish some limits of connection angle dimensions.

INFLUENCE OF CONNECTION ANGLE DIMENSIONS

For a stringer-floorbeam connection in a bridge, the moment and stresses in the connection angle is dependent on the length of the angle (L_a), the thickness of the angle legs (t), and the gage length of the rivets or bolts, (g). The gage length is defined as the distance from the heel of the angle to the centerline of the rivet holes, as shown in Fig. 14. From the parametric study of Ref. (4), the results of Fig. 15 are obtained. The maximum connection moment is about 40% of the fixed-end moment for the case shown.

These results show that the moment in an angle connection increase with the length of the angle, increase with the thickness of the angle leg, and decrease with the gage length. Therefore, to reduce the magnitude of moment and the corresponding stresses in the angle, shorter angles, thinner angle thickness, or larger gage length for the rivets or bolts should be used. In other words, a more flexible connection with respect to bending moment is preferable.

The method of achieving some flexibility has been the using of a formula such as [3,7]

$$g \geq \sqrt{\left(\frac{L_s t}{12}\right)}$$

where g is the gage length for the first line of rivets or bolts from the angle heel, L_s is the span length of the stringer, and t is the thickness of the connection angle. For $L_s = 25$ ft. and $t = 0.5$ in., $g \geq 3.5$ in.

While this empirical relationship provides some flexibility for the angle connection, the more effective approach is to use a shorter connection angle, as it is indicated in Fig. 15.

SUMMARY AND RECOMMENDATIONS

In summary, it can be said that the "shear connections" at ends of stringers do carry bending moment, which causes rotation and deformation of the connection. To alleviate the problem of fatigue failure due to high local stresses, the connection should be sufficiently flexible. A large distance from the heel of the connection angle to the line of rivets or bolts, and a relatively short connection angle, are recommended.

REFERENCES

1. Fisher, J. W.
Fatigue and Fracture of Steel Bridges Case Studies
John Wiley & Sons, 1984

2. Yen, B. T., Huang, T., Lai, L. Y., Fisher, J. W.
Manual for Inspecting Bridges for Fatigue Damage Conditions
Pennsylvania Department of Transportation Report No. FHWA-PA-89-022+85-02; Lehigh University, Department of Civil Engineering Report No. 511.1, Jan. 1990

3. Wang, D.
Fatigue Behavior of Mechanically Fastened Double Angle Shear Connections in Steel Bridges, Ph.D. Dissertation, Department of Civil Engineering, Lehigh University, 1990

4. Zhou, Yi
Moments and Stresses of Double Angle Connections in Bridge Floor Systems
M.S. Thesis, Lehigh University, Department of Civil Engineering, Sept. 1990

5. Munse, W. H., Bell, W. G. and Chesson, Jr. E.
Behavior of Riveted and Bolted Beam-to-Column Connections
Journal of the Structural Division, ASCE 85(ST3), March, 1959

6. AASHTO
Standard Specifications for Highway Bridges, 14th edition
American Association of State Highway and Transportation Officials, Washington, D.C., 1989

7. Fisher, J. W., Yen, B. T. and Wang, D. Y.
Fatigue of Bridge Structures -- A Commentary and Guide for Design, Evaluation and Investigation of Cracking, ATLSS Report 89-02, Center for Advanced Technology for Large Structural Systems (ATLSS), July, 1989

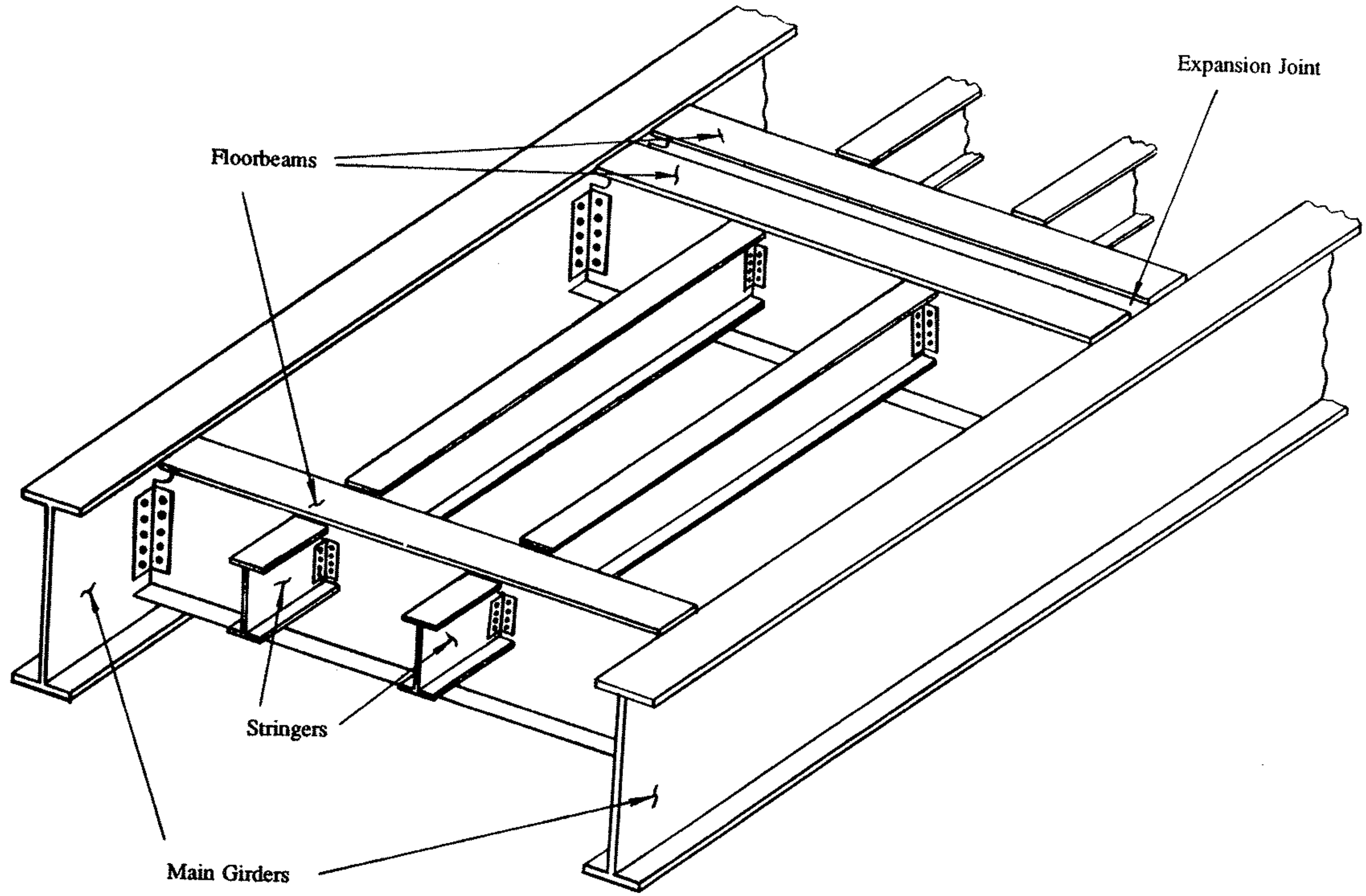

Figure 1. Double Angle Connected Bridge Floor System

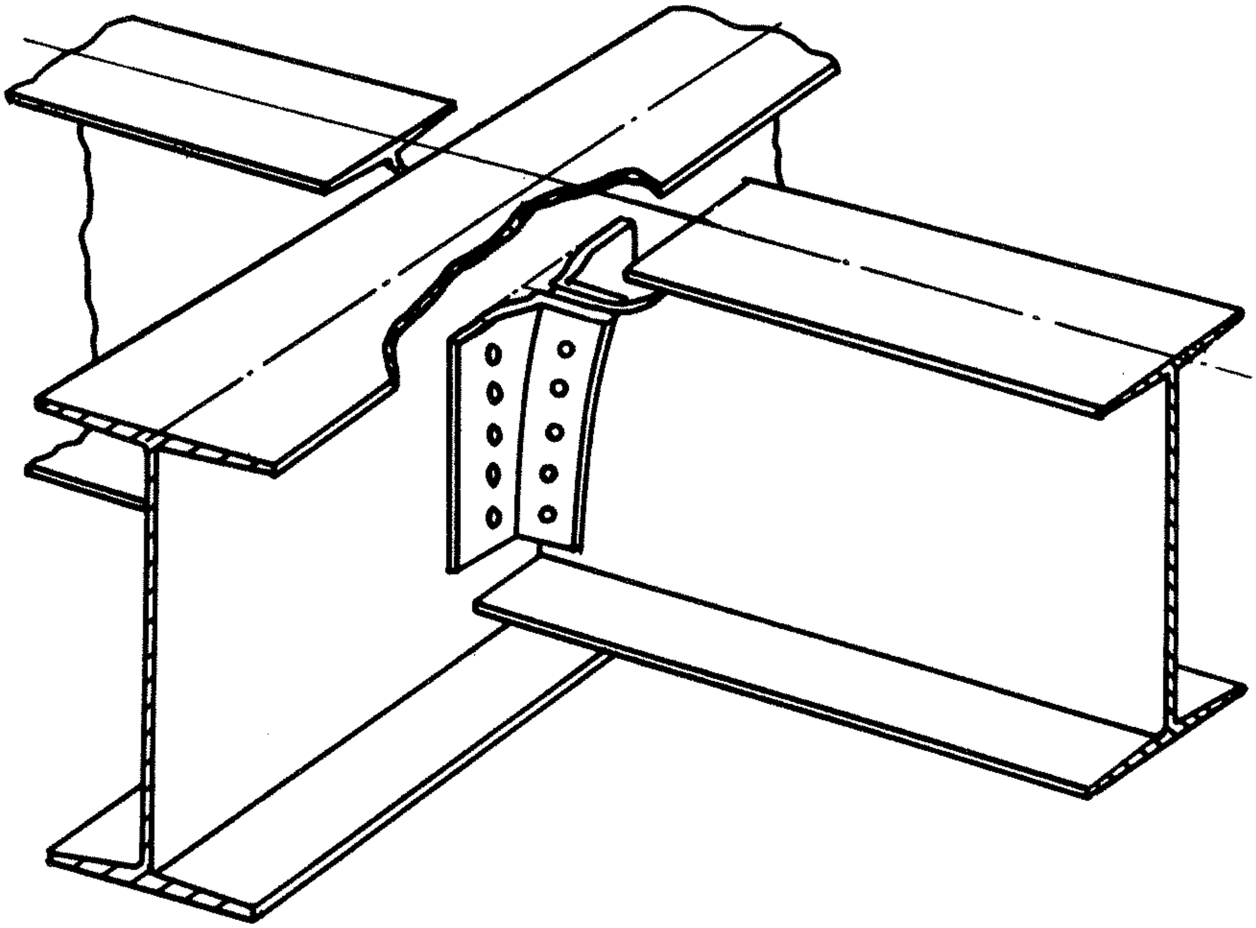

Figure 2. Mechanically Fastened Double Angle Connection

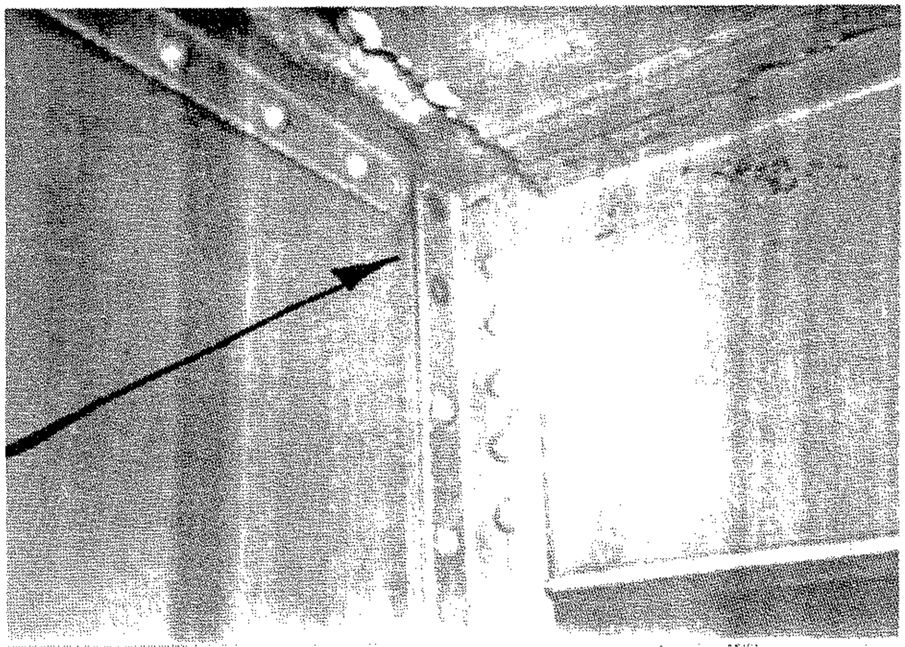

Figure 3. Failed Rivets of Connection Angle

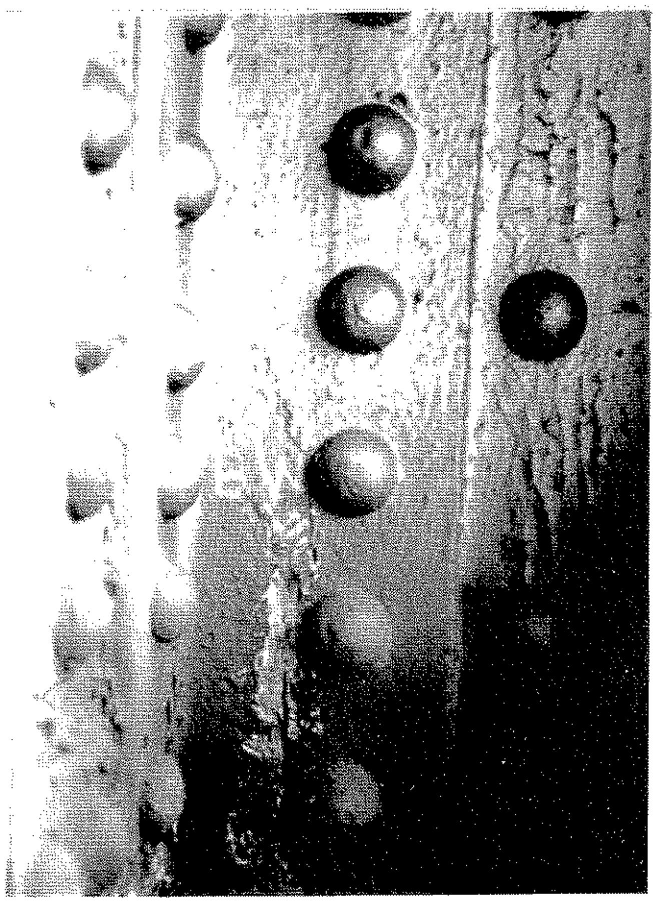

Figure 4. Fatigue Cracked Connection Angle

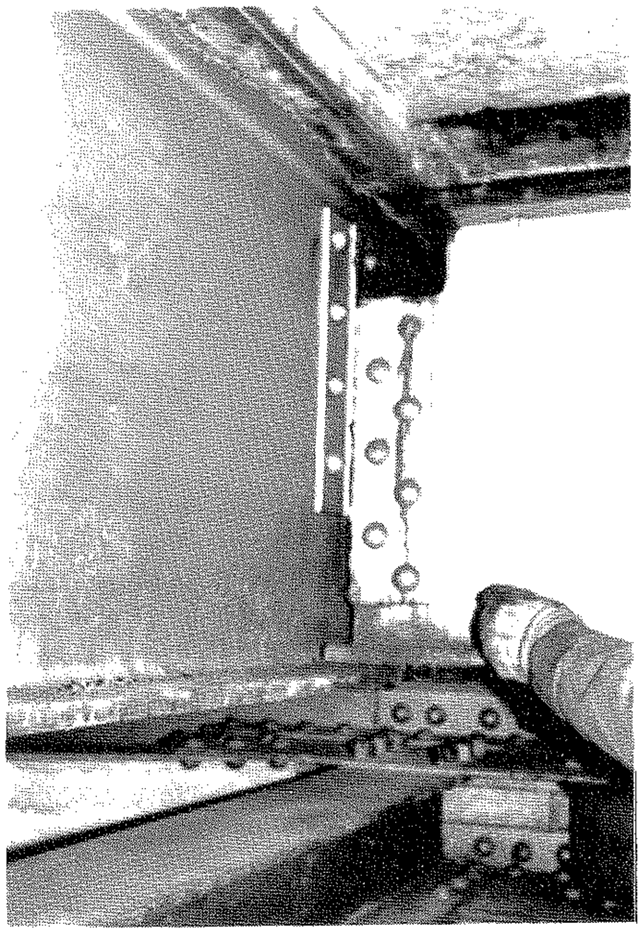

Figure 5. Failed Connection Angles

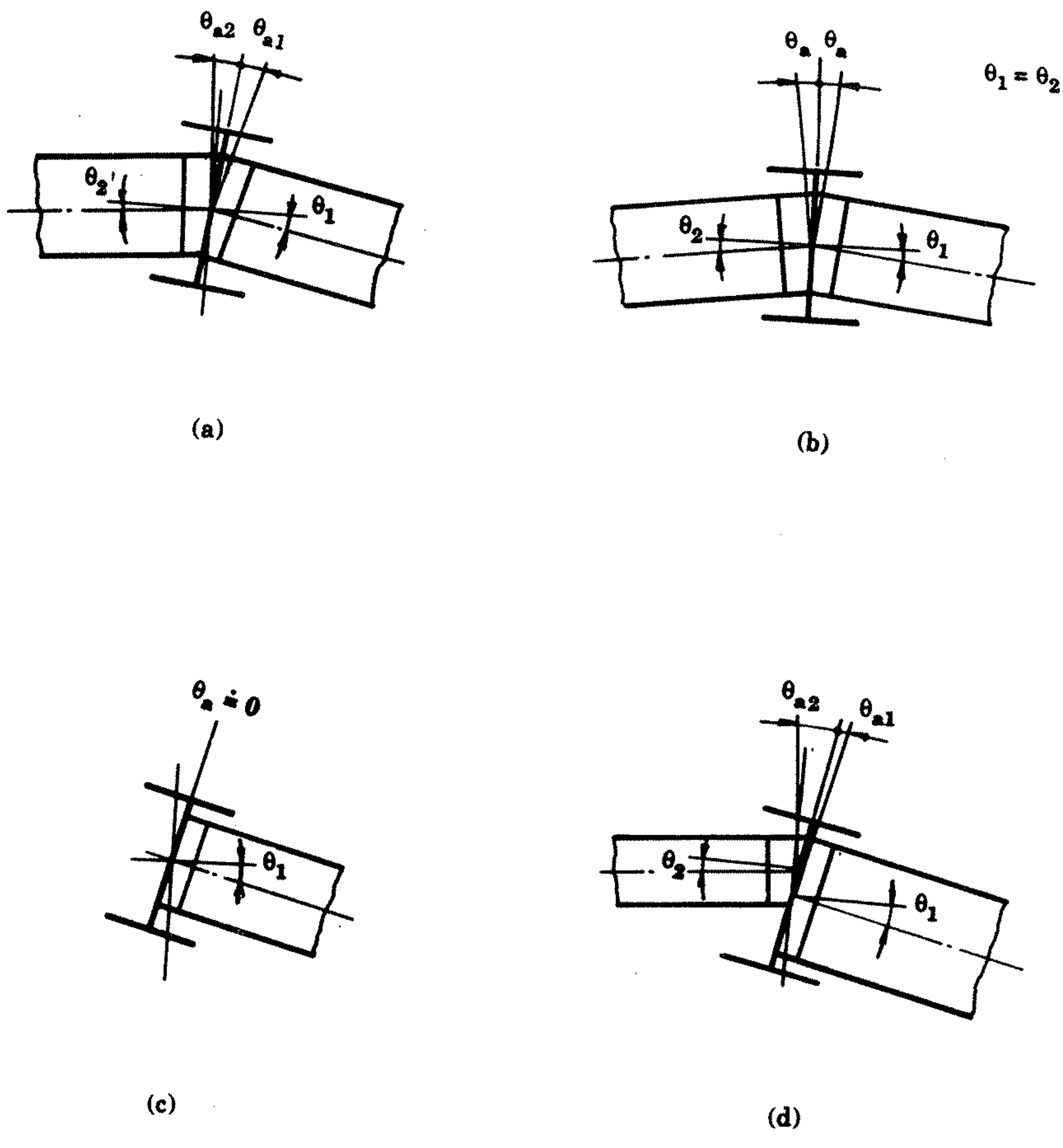

Figure 6. Typical Rotational Configurations of Stringer to Floorbeam Connection

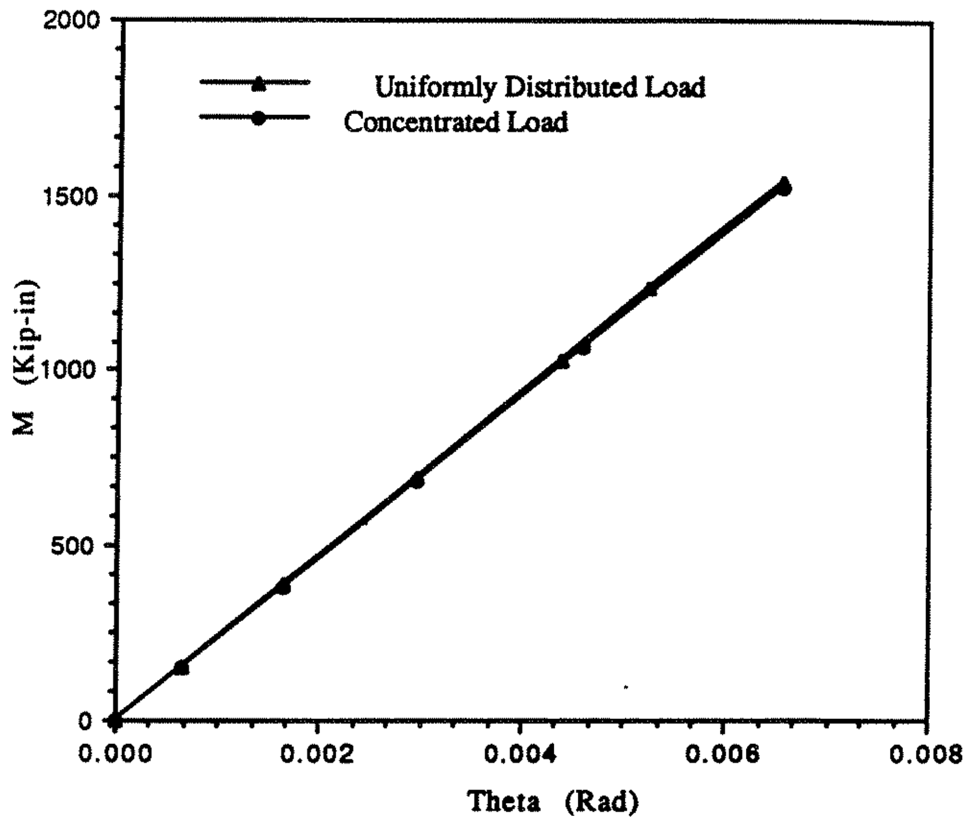

Figure 7. Moment-Rotation Relationship of A Double Angle Connection

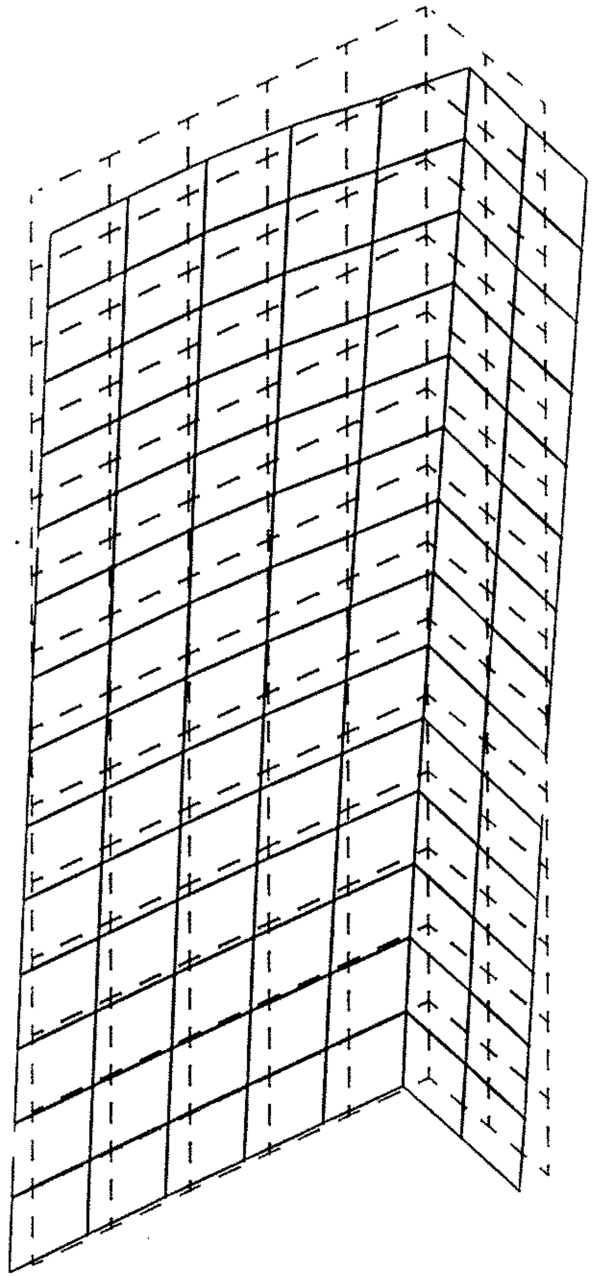

Figure 8. The Deformed Shape of A Connection Angle

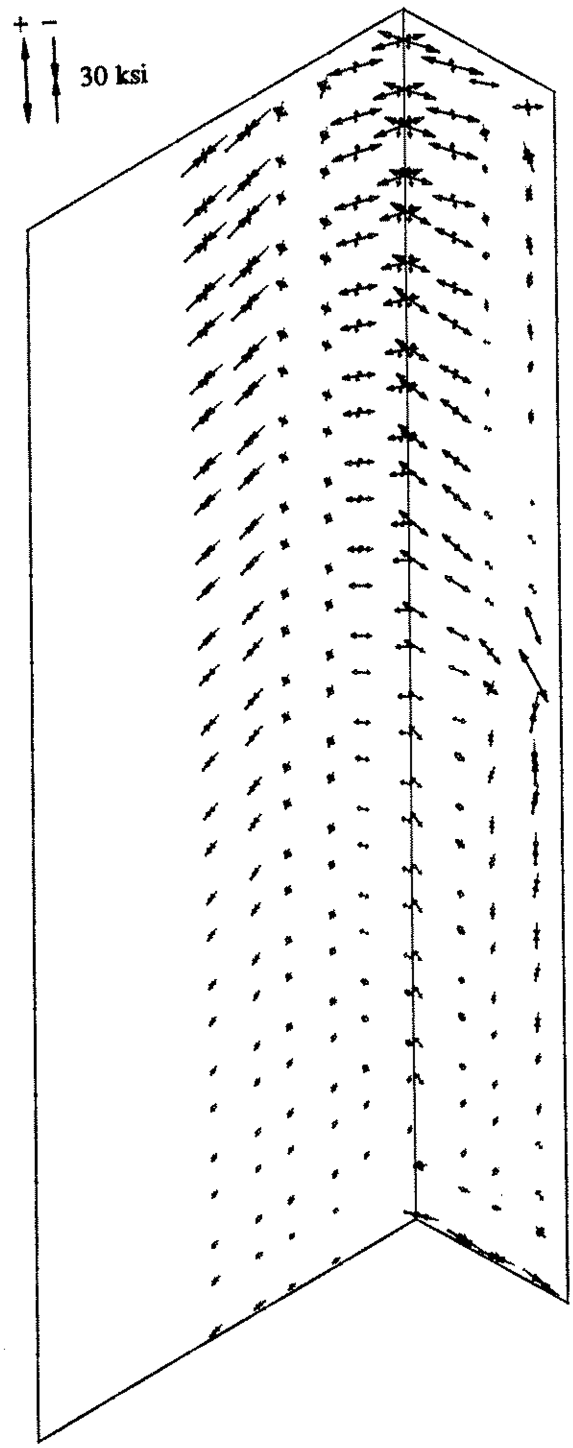

Figure 9. Stresses on the Inside Surface of Connection Angle, "HS-20" Truck

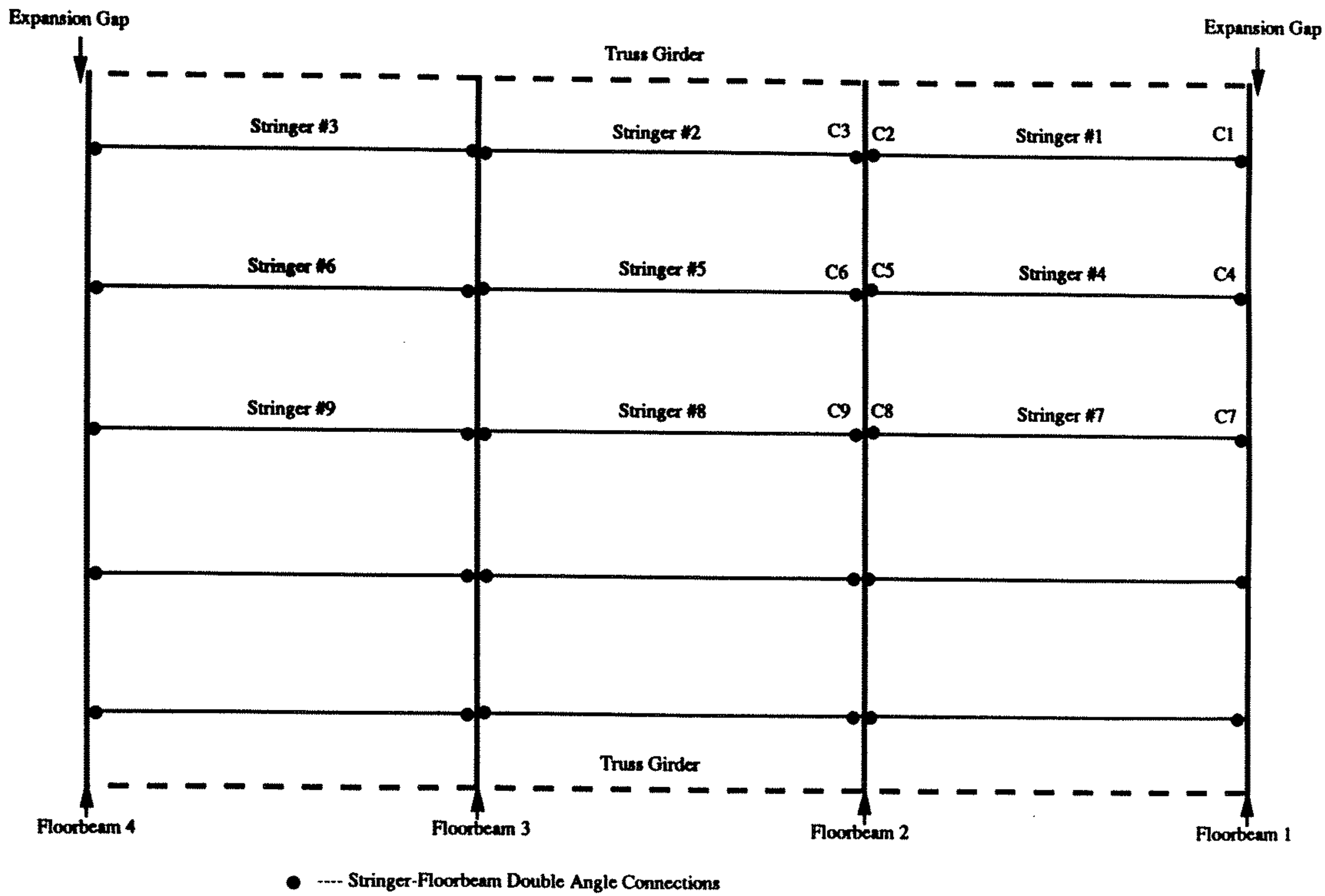

Figure 10. Plan of Bridge Floor System Between Expansion Joints

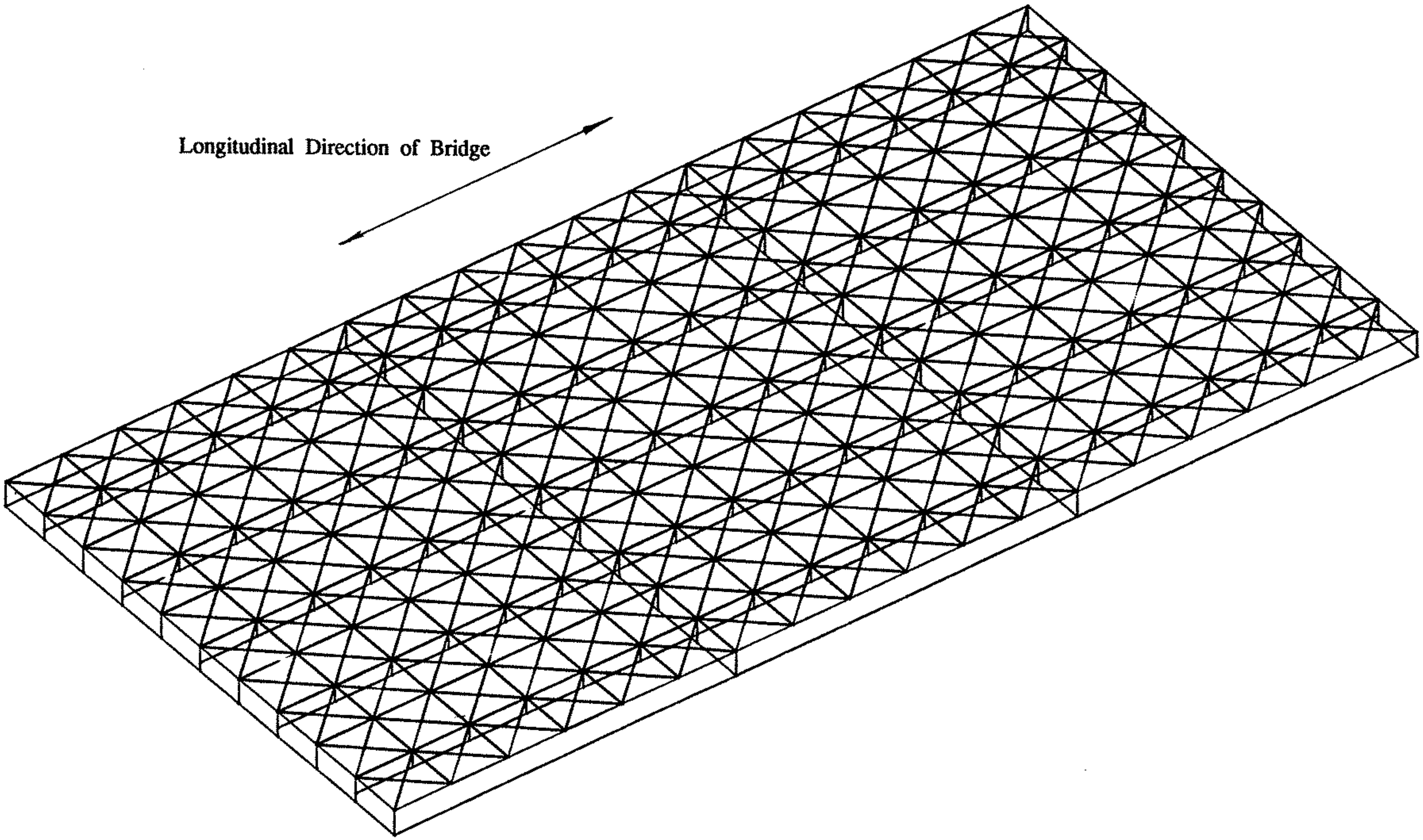

Figure 11. Finite Element Model for Bridge Floor System with Concrete Roadway Deck

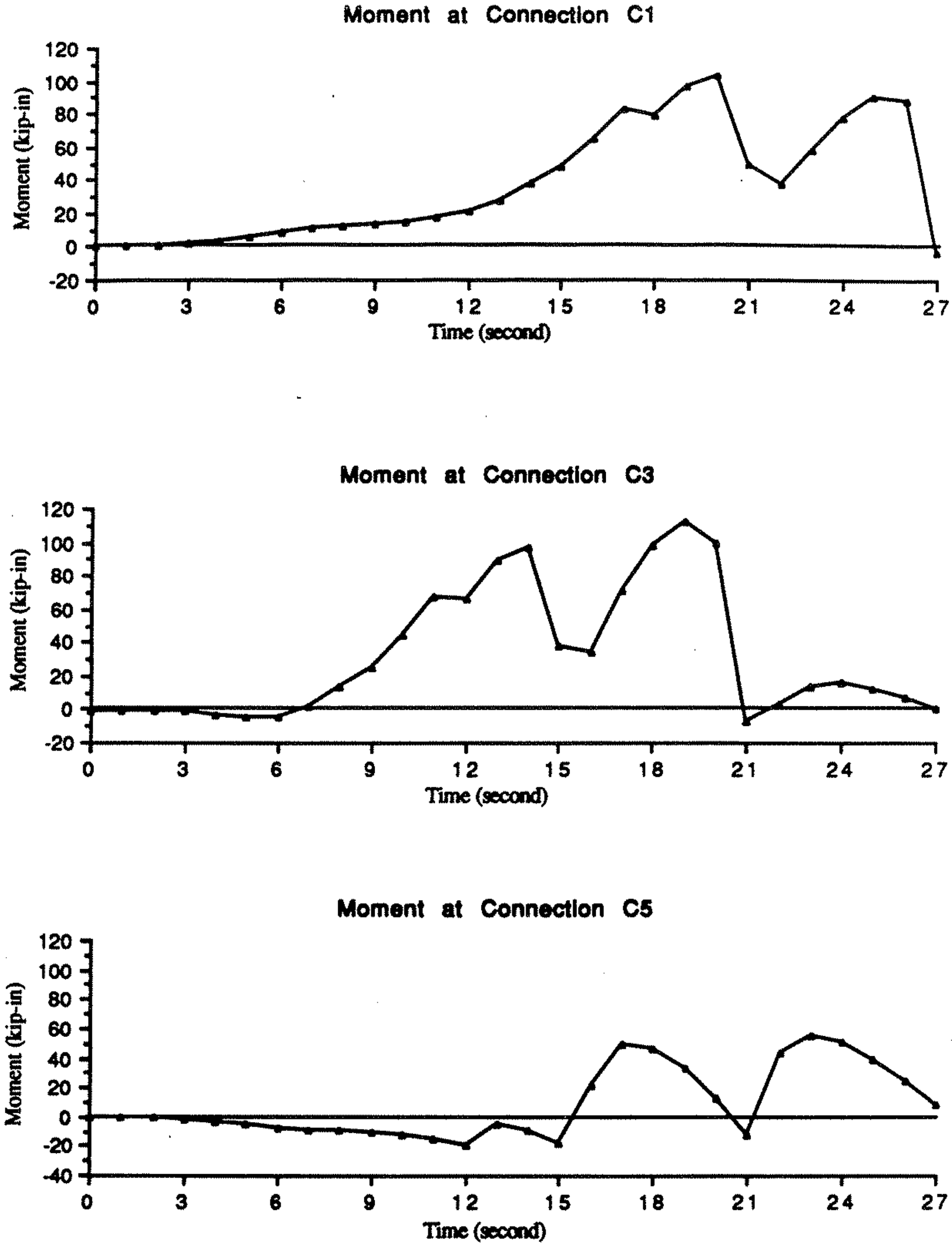

Figure 12. Moment vs. Time Relationship for Connections, HS-20 Truck

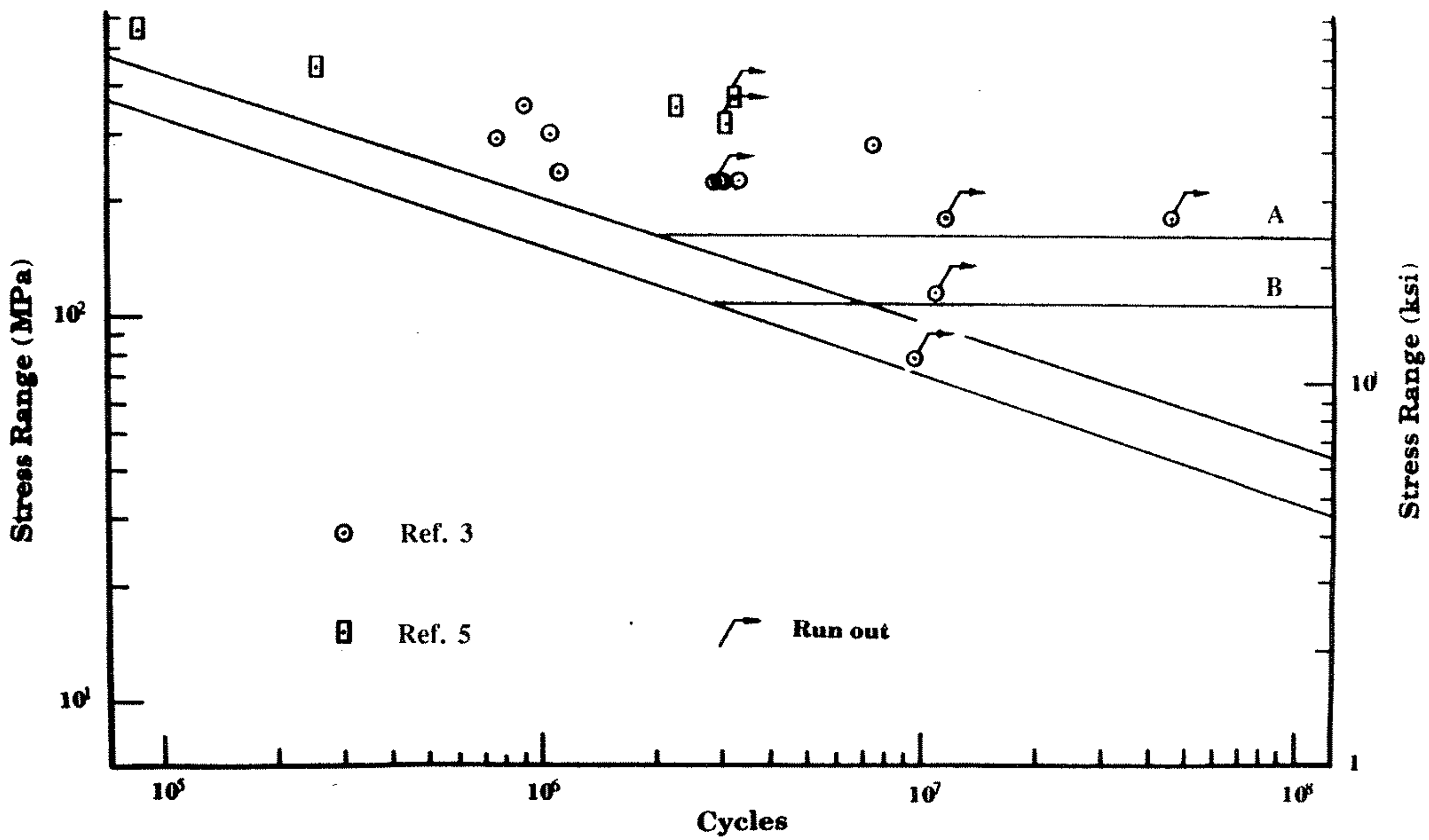

Figure 13. Experimental Results of Fatigue Crack Initiation, Taking "g" as the "Beam Length" (plotted by tests).

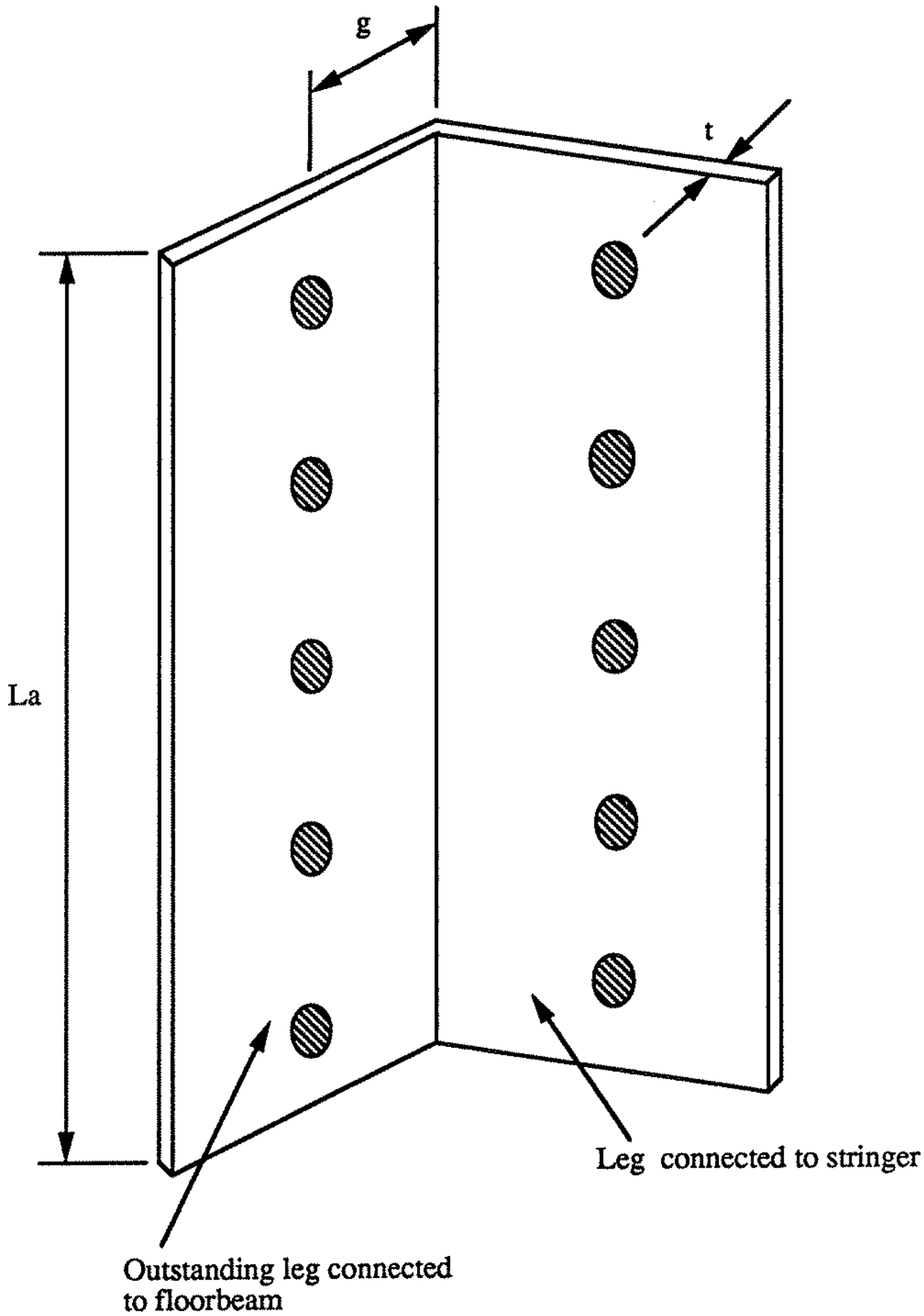

Figure 14. Schematic of a Connection Angle

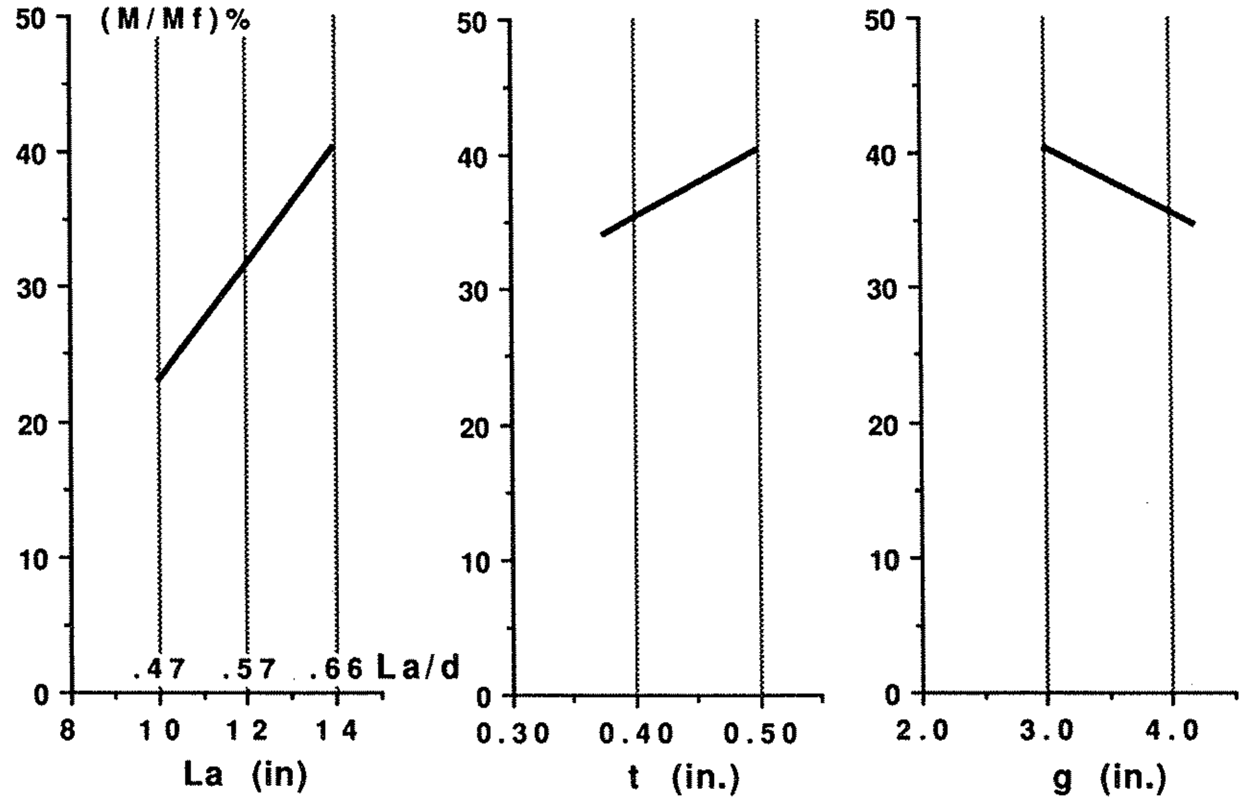

Figure 15. Effects of Connection Angle Dimensions