suspect because of trouble in the batching operation. The shotcrete in the cores appeared sound to the eye. The apparent cause of the low strength was inadequate cement content resulting from faulty operation of the Concrete Mobile. The layer was sounded and no drummy areas were found. The matter was discussed with structural engineers who thought that this slight strength deficiency could be tolerated in this area where loading conditions are insignificant. The batching machine was adjusted, and cores taken from the next drop were very good. It was therefore decided to accept this drop and allow the contractor to proceed with the second shotcrete layer. The appearance of the shotcrete in the cores from the structures was very good; there were a minimum of lenses and sand pockets. Because of the favorable results obtained, the number of cores was reduced for the later piers.

HNTB is of the opinion that the aesthetics achieved by the contractor were much better than anticipated. The specifications called for a flashcoat finish, but at the suggestion of the contractor a sample with a finish struck off with a trowel was administered to a section of a pier and compared to a sample of the flashcoat. The finish with the trowel was selected. Wire guides were used on every corner and at about 3 or 4 foot centers on flat surfaces. The combination of trowel finish and wire controls produced very sharp lines much like those of a formed surface, except that there were no form marks.

In order to protect the repaired piers from new salt penetration they were treated with Chem-Trete BSM40 weatherproofing after the proper cure time had elapsed.

HNTB believes that the well-researched, clear, and strictly adhered to specifications will achieve the desired 50-year life expectancy of this major shotcrete repair project. A second rehabilitation contract for the bridges has been let. This contract will include a new deck, about 10 ft wider than the existing deck, with sealed expansion joints and a closed drainage system. The westbound bridge was rehabilitated in 1983, and the eastbound bridge is scheduled for completion in 1984.

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Rivet Replacement Criteria

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ABSTRACT

The New Jersey Transit Corporation (NJ Transit) is currently implementing a major capital improvements program to upgrade its physical plant. The rehabilitation of existing bridges is a major element of this work. The adoption of rivet replacement criteria for the various bridges programmed for rehabilitation is discussed in this paper. The rivet replacement criteria have been developed for use as a guideline by the engineer during inspection, design, and construction of the various bridges programmed for rehabilitation. The criteria developed are simple, reliable, and reproducible and provide a uniform evaluation scheme for the 600 railroad bridges found within NJ Transit's physical plant. In this paper the importance of loading conditions, type of connection, grip length, and cost as parameters to be considered in assessing if a rivet should be replaced is discussed.

The New Jersey Transit Corporation (NJ Transit) was created by the state legislature in 1979 and has been chartered to run all commuter passenger trains in the state of New Jersey. NJ Transit is the third largest commuter rail system in the nation and includes 490 route miles of track, 600 undergrade bridges, 75 locomotives, 968 passenger cars, and 142 stations. As a result of years of deferred maintenance, NJ Transit is in the process of implementing a major capital improvements program to upgrade its physical plant. The rehabilitation and replacement of various bridges within the rail system is a major element of this program. NJ Transit bridges vary in length from 5 ft to 2,926 ft and were found to have deficiencies that ranged from minor paint loss to major structural deterioration.

In this paper the adoption of uniform rivet replacement criteria for the various bridges that are programmed for rehabilitation is discussed. The criteria are developed to meet the following goals: (a) provide standard rivet replacement criteria that are simple, reliable, and reproducible for the 600 railroad bridges within NJ Transit's physical plant; (b) provide the various consulting firms, construction contractors, and in-house staff standard criteria to be used for the many bridges programmed for rehabilitation; (c) give guidance to the engineer during the inspection, design, construction, and quality control phases in selecting which rivets should be replaced; and (d) allow the development of more accurate rivet replacement costs for the bridges programmed for rehabilitation.

PROBLEM FORMULATION

Any structure consists of individual members that must be fastened together to create a structural system that is compatible with its intended service. If the connections are inadequate the structural system will behave in such a manner that the design stresses of the individual connecting members will not be in agreement with the actual stresses experienced in the system. Therefore, no matter how efficiently the individual members are designed, proper attention must be given to the connections of the structure. The concept of a properly functioning structural system is especially important in the rehabilitation of railroad bridges.

After the bridges that were programmed for rehabilitation had been inspected it was observed that rivet head deterioration varied from zero to 100 percent. Field observations led to discussions centered around the following questions.

1. How will the riveted connections behave under the existing railroad loadings if the rivet is not able to hold the connection tight?
2. What minimum acceptable percentage of rivet head should be specified in order for the connection to remain tight?
3. Do the type of loading (i.e., direct shear, prying action) and the type of connection influence the minimum acceptable percentage of rivet head that is required for the connection to remain tight?
4. Can uniform rivet replacement criteria, which would be utilized by inspectors, design engineers, and field engineers, be established for the bridges programmed for rehabilitation?

RIVETS

The rivets found on NJ Transit's bridges were predominantly button head of a rounded shape with diameter of 1.5 D + 1/8 in., where D is the nominal diameter of the rivet shank. The height of the rivet head is 0.425 times its diameter. Rivet heads were also found to be flattened to 1/4 in., countersunk, and chipped flush as dictated by clearance requirements.

The hot riveting technique, which was used extensively, consists of heating a rivet to 1,800°F and then inserting the rivet into matching holes (sized 1/16 in. larger than the nominal diameter of the rivet) of the connecting materials. A head was formed on the protruding end of the plain shank by the rapid forging action of a pneumatic hammer. The force of the riveting causes the heated shank to expand laterally and nearly fill the hole. As the rivet contracts and squeezes together the parts being connected, a clamping action develops.

The squeezing effect actually causes some transfer by friction of stress between the materials being connected. The frictional forces developed between the materials being connected are not considered a dependable factor to be included in the calculation of the strength of the connection and were conservatively neglected in the design specifications. Yet the frictional force that is developed in the connection results from the rivet head providing the necessary restraining action to keep the joint tight. As can be seen from Figure 1(A), the equilibrium equations of statics show that the initial compressive force in the plates must equal the initial tensile force of the rivet. The initial tension in the rivet of the connection produces the compressive forces between the back of the connection and the adjacent surface. Figure 1(B) shows the approximate stress distribution developed by Rotsher that is most commonly accepted by the profession (1). This stress distribution depicts the transfer of forces that are generated on a small ring of contact between the fixed head of the rivet and the connecting steel members.

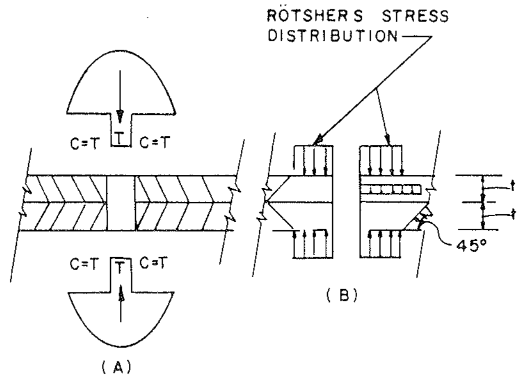

FIGURE 1 Rivet stress distribution.

LOADING CONDITIONS

Riveted connections are usually considered bearing-type joints and are designed in connection members to resist shear forces that must be transferred between the connection members. The clamping force in a rivet is difficult to control and cannot be relied on as can that of high-strength bolts. Therefore, in the analysis of a riveted connection subjected to an in-plane loading through the centroid of the rivet group, the following loading stages exist: (a) static friction prevents slip; (b) external load exceeds the frictional resistance and the joint slips until rivets are partly or all in bearing; (c) the rivet and plates deform elastically; and (d) yielding of the plates or rivets occurs until either the plate fractures or the rivet shears completely.

Three significant loading conditions exist for which the foregoing analysis is somewhat different and more complicated. These loading conditions are pure tension, combined tension and shear, and prying action.

Pure Tensile Load

When a tensile load is applied to a connection, the fastener will elongate and the precompressed members will tend to expand to their original thickness. If the plate expansion does not exceed the initial contraction of the plates, some contact pressure between the connecting members will remain, and the following relationship will hold true.

Rivet Force = Contact Forces + Tensile Load

A further increase in external tensile load will result in a decrease in member contact forces until the plates separate. When the connecting members separate, the rivet force is equal to the applied external load, and the following relationship will hold.

Rivet Force = Tensile Load

Combined Tensile and Shear Loads

Figure 2 depicts a typical girder-floor beam connection in which the rivets are subjected to combined shear and tensile forces. The vertical load being transferred tends to cause the connection to slide downward and is resisted by the shearing strength of the rivets. The downward externally applied load and upward resisting shear force of the rivets produce a couple. The moment produced is Pe. An equal and opposite couple must be produced by the tension

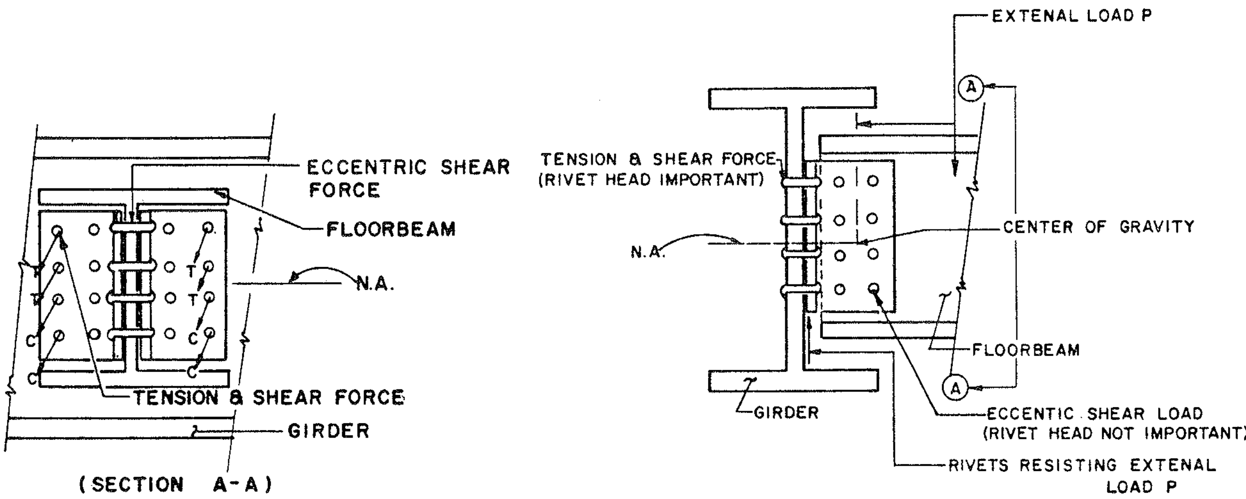

FIGURE 2 Typical girder-floor beam connection.

in the upper rivets and by the compression in the lower part of the connection. As shown in Figure 3 the stresses in the connection are assumed to vary linearly from the neutral axis. Figure 4 shows that the rivet head acts as a restraint in keeping the connecting material tight when tensile loading is experienced within the connection.

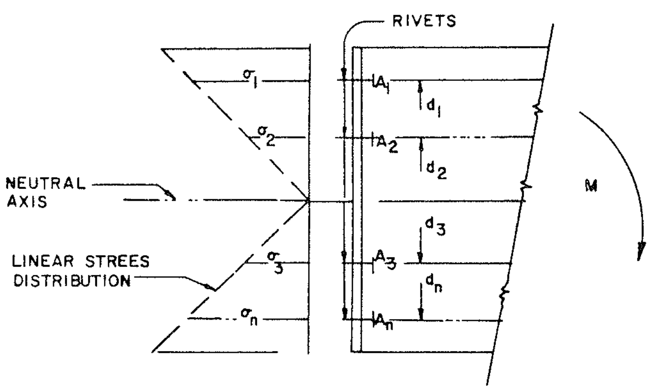

FIGURE 3 Fastener group stress distribution.

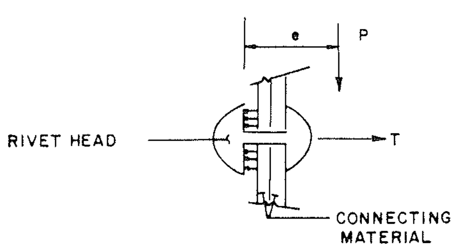

FIGURE 4 Detail of rivet connection.

Prying Action

Prying action forces develop depending on the flexural rigidity of the connection. If the connecting members are not fairly stiff, prying action forces will increase the tensile force in the rivets. Therefore, for equilibrium to exist, the total force in the rivet must equal the applied force plus the prying forces, and the useful capacity of the rivet is decreased by the prying forces developed in the connection. Therefore, depending on the relative stiffness of the rivet fasteners and the connecting material, the prying forces may be negligible or they may be a substantial portion of the total tension in the rivet.

FAILURE MODES OF RIVETED JOINTS

Failure of riveted joints occurs if the applied load exceeds the tensile capacity of the net section, the shear capacity of the rivet, or the bearing strength of the connecting material. It is assumed that the rivets are tight and that the heads are full and provide the area needed to develop a restraining force. Many of the rivets observed during bridge inspections had heads substantially reduced by corrosion. If the head of the rivet is corroded and is not able to provide the restraining action required to keep the joint tight, the rivet head should be considered in assessing whether the joint is adequate to resist the applied load.

Head Reduction

The type of connection (rigid, semirigid, or flexible joint) and the loading conditions experienced by the connection should be parameters to consider when assessing whether a rivet should be replaced because of rivet head deterioration.

In particular, it appears that reduction of the rivet head should be investigated when rivets are experiencing loading conditions of pure tension, combined shear and tension, and prying action. Thus, if the rivet is subjected to any type of tensile force, the reduction of the rivet head should be considered as an additional parameter in deciding if the rivet should be replaced.

Depending on the rotational characteristics under load, connections can be classified as simple, semirigid, and rigid. A rigid connection is one that does not rotate and has complete moment resistance; a connection that is flexible, free to rotate, and has zero moment resistance is a simple connection. A semirigid connection falls somewhere in between the rigid and flexible connection. The three classifications of joints can be characterized as follows.

- Rigid connection--resists greater than 90 percent of moment (2),

- Semirigid connection--resists 20 to 90 percent of moment (2), and
- Flexible connection--resists 0 to 20 percent of moment (2).

The type of structural connection in which the rivet head is significant is the flexible connection in which the three loading conditions discussed previously develop. A flexible connection is designed to rotate and, if the connecting angles are light connectors, the angles will deform. If the connecting angles deform, the rivets must also deform; thus it becomes apparent that the rivet head contributes to keeping the connection tight.

As illustrated in Figure 5 for the floor beam-to-stringer connection, the connecting angle deformation could exist. The applied loading tends to cause the connection to slide downward, and this tendency is resisted by the shear strength of the rivets. The heavy live loads experienced on the railroad bridges tend to rotate the connection by pulling the upper rivets away from the web by inducing a tensile force in these rivets. Thus the rivet head becomes an important parameter to investigate in assessing whether the connection is adequate when subjected to tensile force [see Figures 6(A) and 6(B)].

As shown in Figure 6(A), the rivet head acts as a restraining support that holds the joint in place as the rivet shank bends. It can be inferred that if the rivet head is 100 percent deteriorated [Figure 6(B)], the rivet connection will resist the shear force but not the tensile force (produced by the rotation of the joint) that develops from the heavy live loads experienced on railroad bridges. This logic seems to indicate that the rivet connection will fail in tension and that these stresses will be further redistributed to other rivets, causing an unbuttoning and failure of the connection. Thus, when any rivet experiences a tensile loading and the connection is not designed as a rigid connection, the rivet head should be considered as a structurally significant parameter when determining if the rivet should be replaced. A minimum acceptable percentage of rivet head should be defined to ensure that the rivet is able to resist the secondary tensile stresses produced by joint rotation.

Grip Length

Unless the connecting plates are rigid with respect to the rivets, the connection remains elastic, the load is transmitted from one plate to another, and the distribution of forces is not uniform. It must be emphasized that the longer the joint is, the greater will be the number of rows of rivets and the greater will be the proportion of the load transmitted by the outer rivets. The grip length of a rivet in the joint must be investigated to determine if the clamping force is adequate to keep the joint tight. In joints fastened with long rivets the individual plates have adjusted to the loads experienced and have assumed a curved shape within the connection. Tests on high-strength bolts have confirmed this behavior; shear tests of single bolts yield shear planes at almost 90 degrees to the bolt

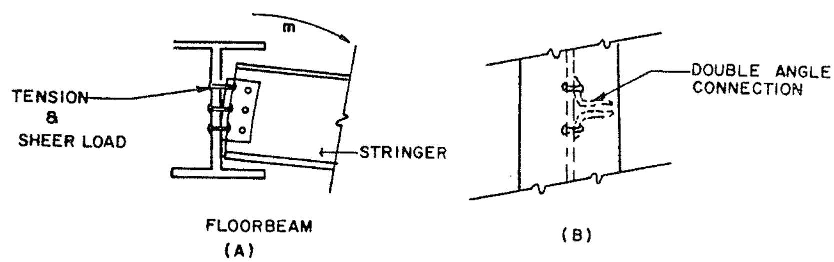

FIGURE 5 Typical deformation in floor beam-stringer connection.

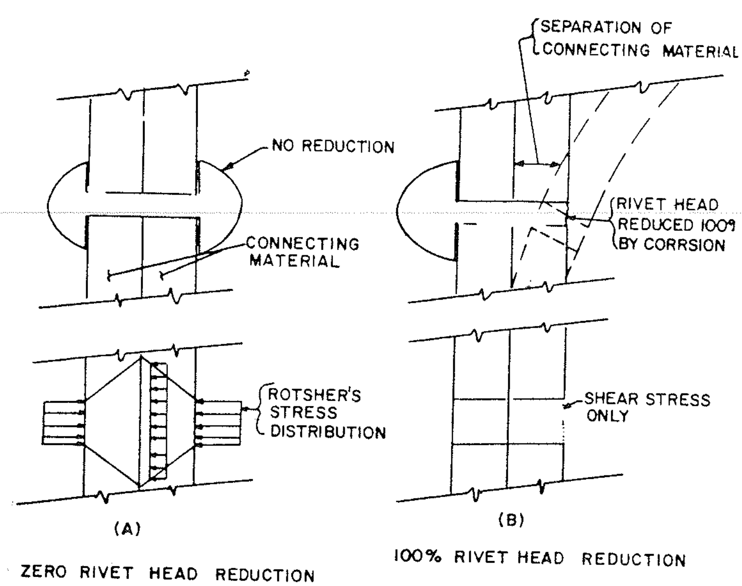

FIGURE 6 Example of reduction in rivet head.

TABLE 1 Field Report

Existing Rivet Condition	Rivet Replacement Criterion A	Rivet Replacement Criterion B	Rivet Replacement Criterion C	Rivet Replacement Criterion D
Percent of rivet head remaining	25	50	75	85
Rivets to be replaced (%)	5	10	15	20

TABLE 2 Relative Cost Values

Rivet Replacement Criterion	Unit Price ($/rivet)	Rivets to be Replaced (%)	Relative Cost Value ($)
Criterion A	60	5	300
Criterion B	60	10	600
Criterion C	60	15	900
Criterion D	60	20	1,200

by the total number of rivets to be replaced according to criteria A, B, C, and D (Table 1).

According to Table 2, rivet replacement based on criterion D will cost four times more than rivet replacement based on criterion A. Clearly, the rivet replacement criterion adopted for a particular bridge will influence rivet replacement cost.

In addition, a great variance in cost can develop if (a) the rivet replacement criteria used by the engineer in developing cost estimates are not identical to the rivet replacement criteria used by the contractor in developing the bid price or (b) each contractor in developing bid costs for rivet replacement uses different rivet replacement criteria. If standard rivet replacement criteria are incorporated in the contract documents, there should not be major variances between the engineer's estimated cost, the contractors' bids, and the actual cost of a particular bridge rehabilitation. Furthermore, as the magnitude of the job increases, so does the number of rivets to be replaced. This increases the cost of rivet replacement. For these reasons uniform rivet replacement criteria have been developed and adopted by NJ Transit for bridge rehabilitation work.

CONCLUSION

The need for and development of the uniform rivet replacement criteria adopted by NJ Transit for use in its programmed bridge rehabilitations have been discussed. In summary, it has been shown that the type of loading, type of connection, and grip length are important parameters to be considered when determining if a rivet must be replaced. The criteria developed and adopted by NJ Transit will (a) provide the various architectural and engineering firms, construction contractors, and in-house staff uniform rivet replacement criteria for the various bridge rehabilitations, (b) provide consistent and reasonable cost estimates for the various bridge rehabilitations, and (c) provide NJ Transit, for its 600 railroad bridges, standard rivet replacement criteria.

Further studies should attempt to determine the amount of rivet head reduction that would be acceptable to maintain service loads (highway, railroad). The following research should be undertaken to determine what structural impact the rivet head has in the connection.

- Empirical testing,
- Theoretical research, and
- Correlation studies of theoretical results and empirical testing results.

The results of such research should be incorporated in standard specifications such as those of the American Railway Engineering Association, the American Institute of Steel Construction, and AASHTO. This information would be beneficial to the practicing engineer tackling bridge rehabilitation problems.

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