Procurement and Selection of Direct-Fixation Fasteners for Transit Projects

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ABSTRACT

Direct-fixation fasteners are used by U.S. and Canadian transit properties to secure rails to concrete in tunnels and on elevated structures. These fasteners utilize elastomeric pads, steel plates, insulating components, and anchoring devices. Bonded and unbonded type fasteners have been used. Direct-fixation fasteners provide five primary functions. They maintain gage and alignment, control longitudinal rail movements, provide resilience, and assure electrical insulation. In addition, they help attenuate noise and vibrations. Generally, procurement specifications set forth minimum performance requirements as a guide for the design and manufacture of direct-fixation fasteners. Compliance with these specifications is evaluated by laboratory tests. Several applications of direct-fixation fasteners have shown problems ranging from failure of fastener components to electrical leakage. In this paper, the practices used by transit properties for the procurement of direct-fixation fasteners are reviewed, the requirements for direct-fixation fasteners are outlined, and the methods employed for evaluating fastener designs are presented. Also, recommendations for improving fastener performance are presented.

Direct-fixation fasteners are used by U.S. and Canadian transit properties to secure rails to concrete in tunnels and on elevated structures. These fasteners utilize elastomeric pads, steel plates, insulating components, and anchoring devices. Direct-fixation fasteners are unbonded or bonded. An unbonded fastener utilizes a steel plate resting on an elastomeric pad. A bonded fastener utilizes one or two steel plates bonded to an elastomeric pad.

Unbonded fasteners that utilize separate plates and pads have been used on transit projects in Miami (Florida) and Philadelphia (Pennsylvania) as well as in Calgary and Edmonton (Alberta, Canada), and Toronto (Ontario, Canada). Figure 1 shows this type of fastener as used on the Metropolitan Dade County (MDC) transit system in Miami. Bonded fasteners with a single steel plate bonded to the top of an elastomeric pad have been used on transit projects in Atlanta (Georgia) and Baltimore (Maryland). Bonded fasteners with two steel plates and an elastomeric pad bonded between them have been used on transit projects in Buffalo (New York), Chicago (Illinois), Detroit (Michigan), Pittsburgh (Pennsylvania), San Francisco (California), Vancouver (British Columbia, Canada), and Washington, D.C. Figure 2 shows this type of fastener as being used in the Advanced Light Rapid Transit (ALRT) system in Vancouver. To permit accurate gaging of track during construction and regaging to compensate for rail wear, most direct-fixation fasteners have provisions for lateral adjustment.

Direct-fixation fasteners provide similar functions to those provided by cross-tie fasteners. They maintain gage and alignment, restrain longitudinal rail movements, provide resilience, and assure electrical insulation (1). However, because of the elimination of ballast, direct-fixation fasteners exhibit considerably lower spring-rate values to help improve ride quality and attenuate noise and vibrations. Generally, procurement specifications set forth minimum performance requirements as a guide for the design and manufacture of fasteners. Compliance with these specifications is evaluated by laboratory tests (2,pp.29-39). Also, procurements have stipulated compliance with qualification requirements as a requisite for acceptance of a fastener design.

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PROCUREMENT PRACTICES

Procurement documents do not ordinarily include detailed fastener designs. They consist of a series of laboratory performance tests with acceptance criteria and a minimum of dimensional constraints to ensure interchangeability, economy, and ease of maintenance. Also, procurement documents stipulate sampling and limited quality control tests. This approach gives

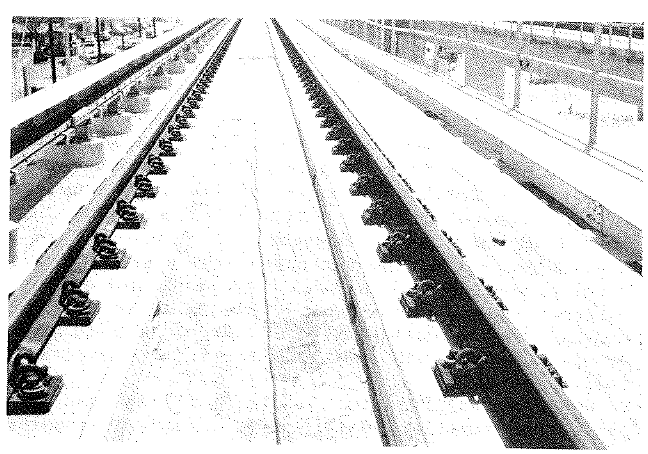

FIGURE 1 Direct-fixation track on MDC in Miami.

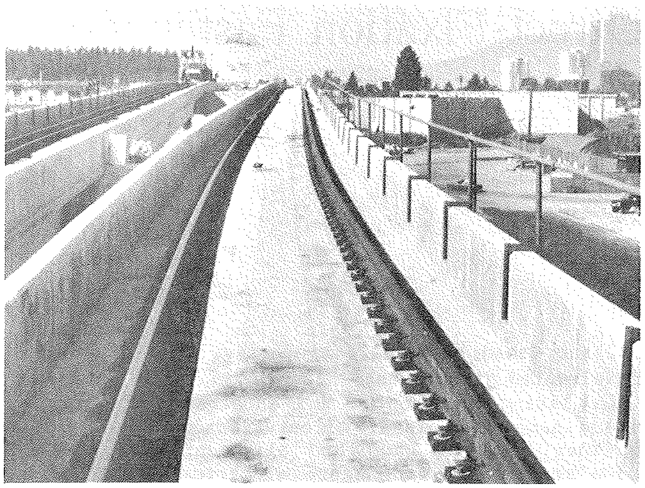

FIGURE 2 Direct-fixation track on ALRT in Vancouver.

the suppliers the freedom to develop solutions within the specified parameters and thus enables procurement from multiple competitive sources. However, other procurement methods have been employed by transit properties. These methods include (a) 1-phase procurement, (b) 2-phase procurement, and (c) sole-source procurement.

In a 1-phase procurement, the bidder is expected to furnish, after contract award, a product meeting the requirements stipulated in the procurement specifications. Availability of an acceptable design before a contract award is not required. However, compliance with qualification test requirements is generally required before acceptance of the proposed design. Also, compliance with production test requirements is generally required before acceptance of the manufactured product. This practice has been used in the procurement of fasteners for several transit projects including those in Atlanta, Baltimore, Miami, and Washington, D.C. This procurement practice could result in extensive delays if the initially proposed fastener design does not meet the specified requirements and subsequent design modifications and reevaluations are required. In several procurements, exceptions and deviations from specifications were permitted by the transit properties because of time restraints.

In a 2-phase procurement, prequalification of fastener design is a requisite for consideration. This prequalification is performed by the supplier or by the transit property as the first phase of procurement. When prequalification is performed by the transit property, potential fastener designs are selected and subjected to a prequalification testing program. Based on test results, the most promising designs are identified and considered in the second phase of procurement. The selected design may be subjected to additional qualification and production tests to ensure that properties of the manufactured product are similar to those of the fasteners used in the prequalification tests. This practice has been used for the procurement of fasteners for a transit project in the Vancouver ALRT system. In this case, prequalification tests were performed on three fastener types, two of which were selected and considered for procurement. The fastener design ultimately selected was then subjected to a series of qualification tests.

When prequalification is performed by the supplier, the supplier is expected to furnish--together with the bid documents--adequate test data to indicate the likelihood of compliance of the proposed design with the stipulated requirements. Generally, the selected design will be subjected to a full qualification testing program before acceptance by the transit property. This practice has been employed for the procurement of fasteners for a transit project for the Southeastern Pennsylvania Transportation Authority (SEPTA) in Philadelphia. The 2-phase procurement has the advantage of identifying the most promising designs before the contract award and thus avoiding possible delays for design modification and reevaluation. Also, this practice permits procurement from multiple competitive sources.

In a sole-source procurement, the transit property selects, based on previous performance, available test data, or other considerations, one or more fastener designs for procurement. However, the supplier is generally required to perform additional testing to verify compliance of design with specification requirements. This practice has been employed for procurement of fasteners for a transit project in the Massachusetts Bay Transportation Authority (MBTA) in Boston. An advantage of this practice is shortening procurement time. However, it has the potential of reducing competition unless several designs are selected for consideration.

QUALIFICATION TESTING REQUIREMENTS

Direct-fixation fastener evaluations include static, dynamic, and repeated-load tests, electrical tests, and corrosion tests. Static tests evaluate fastener response to statically applied loads. Dynamic tests evaluate fastener response to dynamically applied or short-term cyclic loads. Repeated-load tests evaluate the serviceability of fastener components. Electrical tests evaluate the electrical insulation properties of the fastening assembly. Corrosion tests evaluate the effect of severe environmental conditions on the corrosion resistance of fastener components.

Examples of the static tests include the following:

1. A vertical load test to evaluate the effect of vertical loads on rail vertical deflection;
2. A lateral load test to evaluate the effect of lateral load on rail head lateral deflection when a vertical load is applied;
3. A lateral restraint test to evaluate the effect of lateral shear applied to the rail base on rail lateral displacement; and
4. A longitudinal restraint test to evaluate the effect of longitudinal forces on rail longitudinal movement.

Some examples of dynamic tests include (a) a vertical uplift test to evaluate the effect of alternating downward-upward vertical loads on rail vertical deflection, and (b) a dynamic-to-static stiffness ratio test to evaluate the effect of statically and dynamically applied vertical loads on rail vertical deflection, thus comparing the fastener's dynamic and static stiffness values.

Some examples of repeated-load tests include (a) a vertical and lateral repeated-load test to evaluate the effect of the repeated loads on the serviceability of fastener components, (b) an uplift repeated-load test to evaluate the effect of repeated uplift forces on the serviceability of fastener components, and (c) a push-pull test to evaluate the effect of cyclic push-pull loads or displacements on the serviceability of fastener components.

Some examples of electrical tests include (a) a voltage withstand test to evaluate the effect of high-voltage direct current on fastener components,

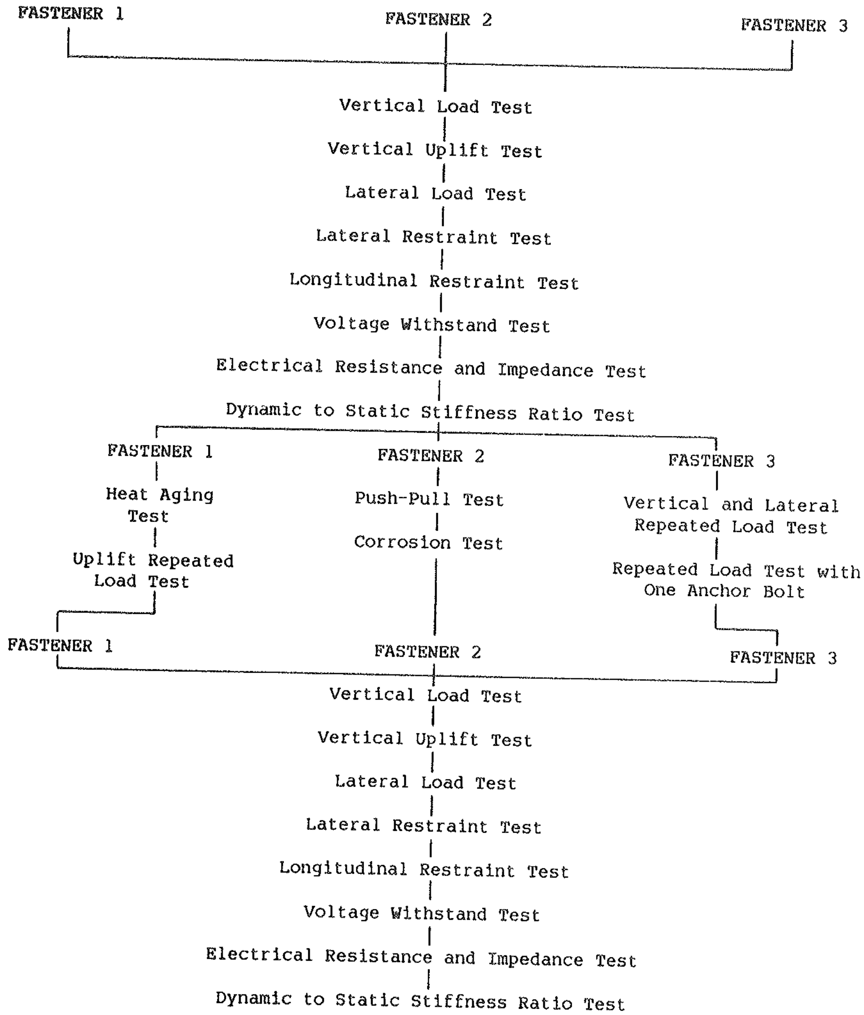

FIGURE 3 Sequence of qualification tests.

(b) a resistance test to evaluate the electrical resistance of wet and dry fasteners, and (c) an impedance test to evaluate the electrical impedance of wet fasteners.

The salt spray test is an example of a test generally specified to evaluate fastener resistance to corrosion.

Qualification and prequalification tests are generally performed on a number of fasteners. Figure 3 shows the test sequence employed for the prequalification testing of direct-fixation fasteners for a transit project in SEPTA in Philadelphia (3). Slightly different testing programs have been specified for the procurement of fasteners for other transit projects.

Recent specifications for direct-fixation fasteners have stipulated test conditions for the laboratory evaluation of fasteners. Test loads and environment are based on expected vehicle weight and dynamic effects and track and vehicle conditions. For test conditions, fasteners are expected to meet the following requirements (3-12):

1. A spring rate between 80,000 and 300,000 lb/in.;
2. A maximum rail head lateral deflection of 0.3 in.;
3. A longitudinal restraint of not less than 2,000 lb for subway fasteners and not more than 1,000 lb for aerial fasteners;
4. A dynamic-to-static stiffness ratio of not more than 1.5;
5. A ratio of upward-to-downward deflection of not more than 2.05;
6. No failure during 3 million cycles of simultaneously applied vertical and lateral repeated loads;
7. No failure during 1.5 million cycles of upward and downward vertical loads;
8. No failure during 25,000 cycles of longitudinal push-pull-type load or displacement;
9. A resistance to 15 kV of direct current;
10. A minimum resistance of 10.0 and 1.0 megohms for dry and wet fasteners, respectively;
11. A minimum impedance of 10,000 ohms for wet fastener components; and
12. A resistance to corrosion and salt spray.

Recent investigations have shown that the use of fasteners with low spring-rate values has a favorable effect on noise and vibration levels. Fasteners with spring rates as low as 50,000 lb/in. have been used in test installations to evaluate their effect on noise vibration levels. Figure 4 shows a test installation at the Washington Metropolitan Area Transit Authority (WMATA) in Washington, D.C., that uses fasteners of this type.

Also, procurement specifications have included qualification testing programs for the evaluation of fastener anchor inserts. These tests are generally

FIGURE 4 Low spring-rate, direct-fixation track on WMATA in Washington, D.C.

RAIL FASTENERS A & B

Vertical Load Test

Lateral Load Test

Longitudinal Restraint Test

Voltage Withstand Test

Electrical Resistance and Impedance Test

Dynamic to Static Stiffness Ratio Test

Vertical & Lateral Repeated Load Test

Vertical Load Test

Lateral Load Test

Longitudinal Restraint Test

Voltage Withstand Test

Electrical Resistance and Impedance Test

Dynamic to Static Stiffness Ratio Test

FIGURE 5 Sequence of production tests.

performed on a number of anchor inserts embedded in a concrete test block. These tests evaluate the effect of torsion and uplift forces on the bond between the insert and concrete. Examples of anchor insert tests include torsion and restrained and unrestrained pull-out tests. Recent procurement specifications have stipulated that the anchor inserts must have a resistance to (a) a 400-ft-lb torque, (b) a 20,000-lb uplift force in a restrained pull-out test, and (c) a 12,000-lb uplift force in an unrestrained pull-out test (3).

PRODUCTION TESTING REQUIREMENTS

In addition to the qualification testing program required for the evaluation of fastener designs, procurement documents have generally specified production testing programs for the evaluation of the manufactured product (3-11). This testing program is intended to monitor fastener quality during production and assure its similarity to the design fasteners used in the qualification testing program. Sampling frequency and the extent of testing is specified in the procurement document. Production tests include selected static, dynamic, and repeated-load tests, and electrical tests. Figure 5 shows the test sequence intended for the production testing of direct-fixation fasteners for a transit project on SEPTA in Philadelphia (3).

FASTENER PROBLEMS AND POTENTIAL SOLUTIONS

Experience to date has shown acceptable performance of direct-fixation fasteners on several transit systems. However, some applications of direct-fixation fasteners have shown problems ranging from failure of fastener components to electrical leakage (13, pp.3-28).

Two problems have occurred on some transit properties. These are (a) the failure of the anchorage system and (b) the rapid corrosion of fastener components. Failures of anchoring devices are generally attributed to inherent design deficiencies of the anchoring system, poor construction practices, or lack of adequate quality control during the installation of anchor bolts or inserts. Rapid corrosion of fastener components is caused by inadequate drainage and the resulting wet condition of the fasteners or lack of corrosion protection. Another serious fastener problem is damage of the serrations used in some fastener designs for adjusting track gage. Loss of the serrations makes it practically impossible to ensure proper track gage.

To help reduce track problems and to assure passenger comfort and safety, the following measures should be adopted by the transit industry:

1. Stringent qualification testing programs should be performed before acceptance of design to assure good performance in track. The testing program should be stringent enough to meet service needs, but not so stringent as to require over-designed systems with unneeded and costly characteristics.
2. Adequate quality control programs should be implemented during production to assure that production units are of equal or better quality than those used in design qualification testing.
3. Suitable construction and installation procedures should be followed to eliminate damage to track components during construction.
4. Adequate maintenance programs should be im-

plemented to slow track deterioration, increase service life, and assure safety.

Recent experience with direct-fixation fasteners at the Washington Metropolitan Area Transit Authority has led to a research program to develop better understanding of fastener loading environment and to improve procurement specifications (14,pp.185-212). The program was conducted by the Transportation Systems Center of UMTA. The objective of the program was, in part, to obtain realistic estimates of fastener service loads. This was accomplished by specially designed load cells installed between the direct-fixation fastener and the concrete insert. Once installed and calibrated, vertical, lateral, and torsional forces exerted on the fastener could be measured in track under service conditions. Test data have indicated that fasteners are subjected to vertical loads significantly lower than those specified in qualification testing programs. Measured lateral loads, however, generally exceeded those used in laboratory fastener tests. Therefore, the fasteners are subjected to loading conditions that produce a higher lateral-to-vertical load ratio than specified for qualification testing programs. Also, test data have indicated, as expected, that the distribution of vertical and lateral wheel loads is influenced by the vertical and lateral stiffness of the fastener, respectively.

Based on results of the field measurements, new specifications have been developed for the procurement of direct-fixation fasteners for future WMATA projects (15). The significant deviations in these specifications from those commonly used by other transit systems include the following:

1. The fastener should exhibit a lower vertical spring-rate value, about 70,000 lb/in., to allow for a better distribution of vertical wheel loads to adjacent fasteners and to provide greater attenuation of vibrations.
2. The fastener should be significantly softer laterally to permit better distribution of lateral wheel loads to adjacent fasteners.
3. The pattern and magnitude of vertical and lateral load used for fastener qualification tests are modified to simulate data obtained from field measurements. Also, the number of load applications required for the evaluation of fastener serviceability has been increased from 3 million to 9 million to represent a reasonable service duration.

It should be recognized that data generated from this research program were obtained for specific track designs, operating conditions, and rolling stock characteristics. Data obtained may not be valid for other conditions. Consequently, a great deal of research and development is still needed to properly identify track loading environment and to improve specifications. With suitable information on loading environment, however, optimum and economical track designs can be developed for other specific locations.

CONCLUDING REMARKS

Direct-fixation fasteners are used by U.S. and Canadian transit properties to secure rails to concrete in tunnels and on elevated structures. These fasteners provide five primary functions. They maintain gage and alignment, control longitudinal rail movements, provide resilience, assure electrical insulation, and help attenuate noise and vibrations.

To assure the ability of direct-fixation rail fasteners to provide their intended functions, specifications give minimum performance requirements. These requirements are utilized as a guide for the design and manufacture of rail fasteners. Compliance with these specifications is evaluated by laboratory tests. In these tests, fastener performance is evaluated under specific loads or in a specified environment. This is accomplished by comparing fastener response to acceptance criteria set forth in specifications.

No nationally acceptable standard or recommended practice has yet been developed for fastener evaluation. Therefore, specifications have been developed for individual projects in the United States and Canada. Although test procedures and acceptance criteria vary, specifications generally include tests on complete fastening assemblies to evaluate the fastener's ability to perform the following functions:

1. Provide adequate resilience,
2. Resist uplift forces without damage to fastening components,
3. Control longitudinal rail movements,
4. Restrain lateral rail movement and hold proper gage,
5. Resist repeated vertical and lateral loads without damage to fastening components,
6. Provide adequate electrical insulation, and
7. Exhibit adequate corrosion resistance.

To help develop a nationally acceptable practice for fastener evaluation, it is recommended that a major research and development effort be undertaken to identify the effects of fastener properties, rolling stock characteristics, track configuration, operating conditions, and environment on fastener loads. With these results, an accurate evaluation of fastener designs can be obtained expeditiously to select optimum and economical track designs for each specific application.

Because of time constraints, transit properties have frequently tolerated many exceptions and deviations from specification requirements. Therefore, to help enforce specifications, it is recommended that technical prebid or prequalification submissions be required to eliminate faulty and nonconforming designs from consideration. As an alternative, adequate time should be allowed during the procurement process to enable the transit property to reject nonqualifying designs and seek alternatives.

Finally, it should be recognized that tolerances in material properties, component dimensions, or manufacturing processes could significantly influence fastener characteristics and performance. Therefore, adequate qualification and production test programs should be enforced to ensure compliance of the manufactured fasteners with the intended requirements.

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The Reduction of Wheel/Rail Curving Forces on U.S. Transit Properties

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ABSTRACT

Summarized in this paper are recent government-sponsored studies to determine the effectiveness of various methods for reducing wheel/rail curving forces and resulting wear and component failure on U.S. transit properties. It describes the factors affecting the trade-off between curving performance and truck stability as it affects ride quality and the potential for derailment. A simplified description of truck-curving mechanics is presented, outlining three sources of lateral wheel/rail forces and three key methods for reducing those forces. References to more detailed papers and reports are included. Finally, the results of wheel/rail force measurements made for various truck and track configurations are presented and compared with theory. It is concluded that reductions in curving forces of up to 75 percent can be obtained by using tapered wheels and softening the longitudinal primary suspension or incorporating steerable trucks, or both.

Wheel/rail wear and related component failures have plagued transit systems since their inception at the turn of the century. In recent years, however, reports of such problems have occurred with increasing frequency. The Transportation Systems Center (TSC) sponsored by UMTA, U.S. Department of Transportation, has conducted studies and experiments to determine the causes and methods of reducing the incidence of high wear and component failure rates. Measuring wheel/rail wear and determining the factors that cause it are difficult and time-consuming. An interim step is to measure the wheel/rail forces that are a significant cause of the wear. Methods of reducing these forces can more rapidly be determined. Subsequently, the actual reduction in wear and component failures resulting from selected force reduction methods can be established over a longer period of

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