

# The Evolution of Washington Metro's Track Standards

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## ABSTRACT

In 1969 the opportunity to design the construction of a completely new transit track system using the latest technology occurred with the decision to construct the Washington Metropolitan Area Transit Authority Metro system. The system offered the track designer a wide spectrum of challenges. The 101 route miles of double track system included underground structures of several types, at-grade track, and several extensive aerial structures. In the 15 years since the first phase of Metro track was designed, many of the design features have evolved from their original concept to significantly different concepts as a result of construction problems, maintenance problems, and new developments. Presented here are brief descriptions of these evolutions with respect to direct fixation track including grout pads, anchorage systems and the fasteners themselves, rail, rail welding, ballasted track tight radius curves, and special trackwork designs including inserts and methods of support.

Washington, D.C., is a city of wide boulevards and numerous monuments. In spite of the broad streets and many open spaces, by the late 1950s the traffic to government offices and commercial centers in the area had become intolerable. The rush hours produced long lines of traffic, and midday traffic created unacceptable levels of congestion. Clearly the time had come for a complete analysis of the city's future transportation needs. It would take more than highways and buses to accommodate the traffic anticipated by the year 2000 by which time the metropolitan area population was expected to grow from 2 million to 5 million.

## SYSTEM BACKGROUND

The transportation analysis concluded that a heavy rail transit system with an extensive feeder bus system was needed. The selected alternative comprised nine radial alignments emanating from the central business district into suburbs near the Capital Beltway (Interstate 95 and 495), which circles the city at a radius of about 10 miles. (See Figure 1.). Among its many tasks, De Leuw, Cather and Company was given responsibility for the design of the trackwork system including final design and provision of engineering service during construction.

The heavy rail system will eventually comprise 101 route miles of dual track with 86 passenger stations. To serve the 5 routes and 600 revenue cars operating on them requires 1 major repair yard, 4 service and inspection yards, and 3 storage yards. The breakdown of track mileage between types and stages of construction is given in Table 1.

## INITIAL TRACK STANDARDS

A chronicle of the evolution of trackwork standards from their inception to the standards currently in effect must begin with a brief review of the original standards and how they were developed. In 1967 an in-depth investigation, which included detailed questionnaires, was conducted of the eight heavy rail transit systems operating in North America. The findings were published in 1968 in a report titled "Trackwork Practices of North American Rapid Transit

Systems (1)." The study provided the Metro designers an extensive enumeration of the materials, concepts, and methods of transit track installation then in current use.

Working from background information obtained from the survey of transit systems, De Leuw, Cather engineers developed a second report, "Recommended Trackwork Standards" (2). Every component of the track system was analyzed and alternatives compared. In some cases, where analytical methods were unavailable or inadequate, the recommendations were based on the experience of the operating transit systems. The following paragraphs contain the principal recommendations made in the report, which was published in 1969.

## Direct Fixation Rail Fasteners

The development of direct fixation rail fasteners, particularly for transit application, was (and still

TABLE 1 Metro System Trackwork Statistics

Category	In Service (as of 12/84)	Under Construction	Future	Total
Main line track (miles)				
Underground DF <sup>a</sup>	68.68	0.66	23.66	93.00
Aerial DF	<u>11.91</u>	<u>0.46</u>	<u>1.00</u>	<u>13.37</u>
Total DF	80.59	1.12	24.66	106.37
Ballasted track	<u>41.73</u>	<u>17.12</u>	<u>35.36</u>	<u>94.21</u>
Total all main line	122.32	18.24	60.02	200.58
Yard track (ballasted)	19.01	5.73	10.56	35.30
Passenger stations				
Underground	38	0	12	50
Aerial	3	0	0	3
At grade	<u>19</u>	<u>4</u>	<u>10</u>	<u>33</u>
Total	60	4	22	86
Special trackwork units				
Main line DF	96	4	22	122
Main line ballasted	<u>67</u>	<u>20</u>	<u>36</u>	<u>123</u>
Subtotal	163	24	58	245
Yard, ballasted	<u>148</u>	<u>37</u>	<u>84</u>	<u>269</u>
Total	311	61	142	514

<sup>a</sup>DF = Direct fixation.

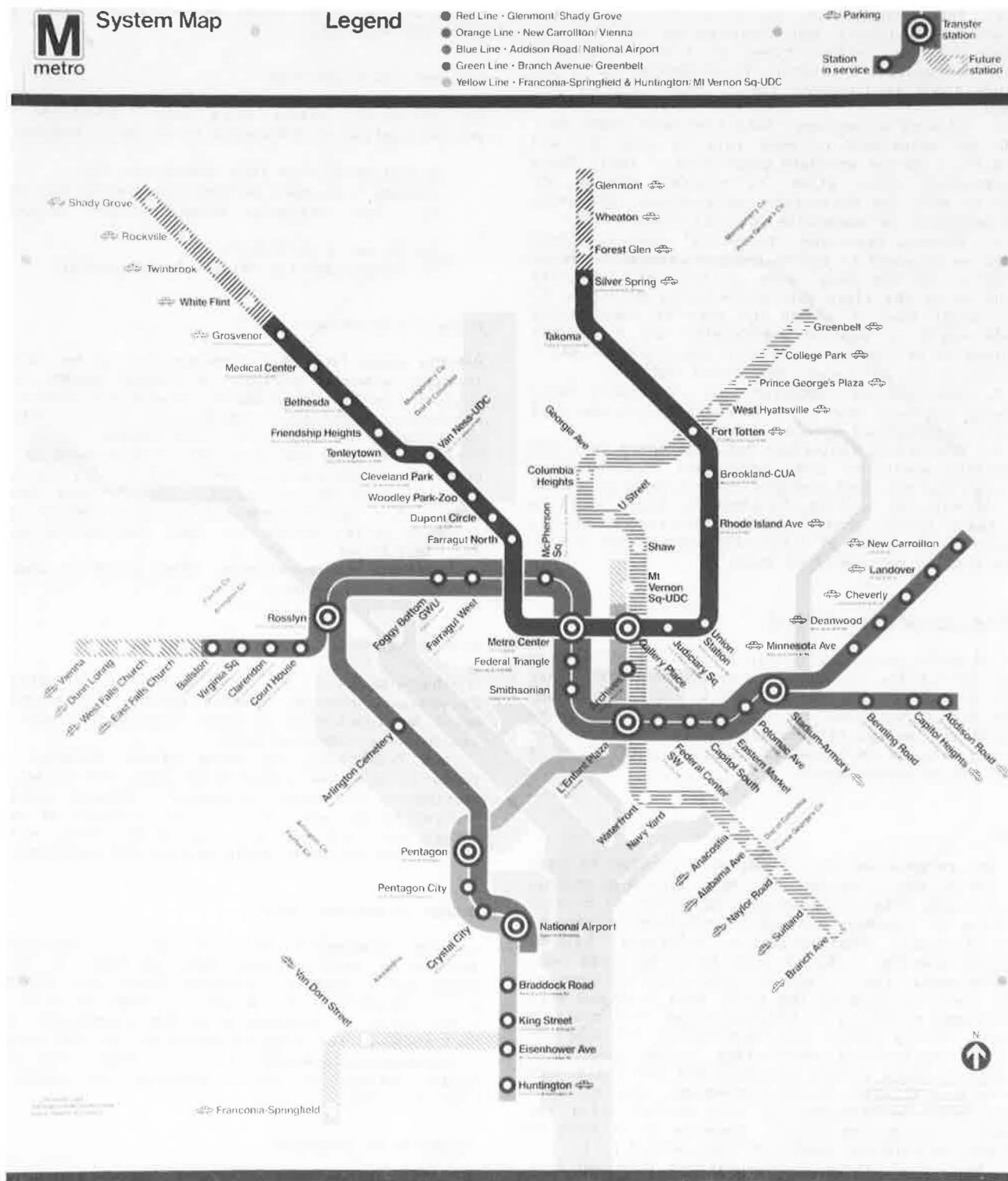


FIGURE 1 Metro system map.

is) in a state of evolution. Several fasteners were available which, with modifications, could meet the criteria developed for Metro and provide a satisfactory solution to Metro installation and maintenance plans.

It was recommended that the criteria for rail fasteners be fully developed during the final design stage and incorporated in a detailed performance specification. The criteria developed included the following:

1. Service life. Rail fasteners were to be designed for a minimum service life of 50 years, which was equivalent to the calculated life of tangent rails with Metro loadings, assuming favorable operating conditions. It was recommended that laboratory testing of rail fasteners to predict service life cover a minimum of 3 million load cycles. Up to 10 million cycles could be required to establish a definite trend or pattern of performance characteristics.

2. Interchangeability and simplicity. Standardization of fasteners and minimization of fastener components for various types of track structures would be considered during final design to limit future stock requirements and to facilitate maintenance.

3. Lateral adjustment. Rail fasteners would provide for adjustment of each rail of  $+3/8$  in. and  $-5/8$  in. from the standard gauge line of rail. These requirements would allow for accurate gauging of rail to meet the prescribed construction tolerances and regauging to compensate for rail wear.

4. Lateral stability. Individual rail fasteners would be designed to resist service lateral loads of 3,900 lb on the gauge side of the rail head and 2,700 lb on the field side while being subjected to a vertical load of 13,500 lb. Each of the lateral loads would be applied separately, and a maximum deflection of the rail head at a point  $5/8$  in. below the top of the rail would not exceed  $1/8$  in.

5. Longitudinal restraint. Rail fasteners would provide not less than 3,600-lb restraint to the rail in the longitudinal direction.

6. Electrical isolation. Rail fasteners in a dry condition would not pass more than 1 microampere between the rail and fastener bolts with a potential of 100 volts DC applied. In addition, there would be at least 10,000 ohms impedance to frequencies between 20 cycles and 10 kilocycles tested with a maximum applied voltage of 50 volts AC.

#### Roadbed Sections and Ballast

For at-grade sections, 12 in. of crushed stone ballast over 8 in. of subballast was recommended. Ballast shoulders were to be 10-in. wide for timber ties and 12-in. wide for concrete ties. In underground and aerial structures, direct fixation fasteners were to be installed on grout pads and held in place by anchor bolts.

#### Rail

It was recommended that 115RE rail section be used on the Metro system for both main line and storage yard track. This recommendation was based on consideration of numerous variables including structural and electrical characteristics, stiffness, height, support spacing, life of rail based on head wear predictions, future availability, and subsequent cost over the life of the rail. Main line and yard track were generally to be constructed with controlled carbon steel rail conforming to American Railway Engineering Association (AREA) specifications. On sharp curves both high and low rails were to be heat treated. It was recommended that all running rails be continuously shop welded using the electric flash-butt method. Thermite welds were to be used to join the lengths of shop-welded rail.

Adoption of these recommendations provided continuously welded rail throughout the system except in the following situations where bolted joints were recommended to join

1. Switch rails with closure rails,
2. Rails at insulated joints,
3. Rail ends with crossing and turnout frogs, and
4. Rails with stock rails of turnouts.

#### Special Trackwork

It was recommended that all special trackwork be heat treated and conform to the latest specifications

of the AREA folio of Trackwork Plans and Specifications (3).

#### Turnouts and Crossovers

The following turnout sizes were recommended for standardization of components in the Metro system:

- Junctions of main line routes: No. 15.
- Permanent turnback service crossovers: No. 10.
- Main line emergency crossovers and turnouts: No. 8.
- Yards: No. 6 (minimum).
- Center storage tracks: No. 4 equilateral.

#### Frogs and Crossings

Movable point frogs and crossings were to be avoided in Metro whenever possible. A special design using short curves between frogs for system crossovers was prepared that minimized the distance between points-of-switches. By making all the curves within the crossing the same radius as the closure curve in the turnouts, speed was not restricted any further than that required by the turnout itself. This design permitted a more economical crossing design with crossing angles within the AREA permissible range for rigid frogs.

Railbound manganese steel frogs would be used in all special trackwork.

#### Special Trackwork Fastening

In the underground and nonballasted aerial portions of Metro, switches, turnout frogs, and crossings would be fabricated on steel base plates and installed on elastomeric pads.

The feasibility of using plated switches and frogs in at-grade construction also was to be investigated. The plates in special trackwork would be secured to the wood switch ties by means of screw spikes or lock spikes. All other rods, clips, braces, and so forth, would be standard components.

#### Method of Joining Rails

It was recommended that joint bars of appropriate section be used to join the rail ends of switch rails and turnout and crossing frogs with abutting rails. Joint bars would also be used to join the stock rails of turnouts with the continuous rails just ahead of the point of switch and at heel blocks.

Closure rails would be cut to length from shop-welded strings of CWR to minimize the number of bolted joints.

#### EVOLUTION OF STANDARDS

From the standards described in the previous sections, many changes have taken place over the years. Each final design phase of trackwork has resulted in a reevaluation of the previous designs. This reevaluation occurs automatically and is directed primarily at specific maintenance and construction issues that surfaced during previous phases. Each new design is also influenced by advances in technology. There have been 10 trackwork final design phases. These designs are referred to as TW-1 through TW-10. The track designed under each contract is currently in the following status: TW-1 through TW-6, TW-8 and TW-9 are in service. TW-7 is under construction. TW-10 is under design.

Some of the revisions to the standards have been relatively simple matters of changing dimensions, or materials; some have been more of a procedural nature wherein the method of procurement, quality control testing, or construction method specified has been changed, and finally, a few have been major reworkings of original concepts. In this latter category are two items that will be discussed in detail: direct fixation fasteners and fastener support system.

A number of less extensive changes, but no less important in terms of construction or future maintenance costs to the system, include:

- Rail procurement specifications;
- Joining continuous welded rail (CWR) strings in the field;
- Ties;
- Special trackwork sizes; and
- Bonded inserts, joints and gauge plates in special trackwork.

Each of these will be briefly discussed in this review of Metro track standards.

#### Direct Fixation Fasteners

A direct fixation fastener features an elastomer pad, steel plate, or plates, and various anchoring and insulating components used to attach the rail directly to the tunnel invert or aerial structure deck. The projected Metro system requires approximately 490,000 direct fixation fasteners. To date, 340,000 direct fixation fasteners have been placed under contract; 333,000 are in service, and the remaining 7,000 are in various stages of installation. About 150,000 fasteners remain to be purchased.

#### Procurement History

To ensure the highest possible ride quality, noise and vibration control, electrical insulation, rail-creep prevention, gauge-holding capability, ease of maintenance, and longevity, a comprehensive series of stringent acceptance and quality control tests was developed. They governed the procurement of direct fixation fasteners from TW-1 through TW-8. Laboratory repetitive loading tests were required to provide an indication of future service life. The most severe test was the 3 million cycle combined lateral and vertical repeated load test. The decision to limit the test to 3 million cycles was based on the reasonable assumption and extensive American Association of Railroads (AAR) research laboratory experience that a fatigue failure had a high probability of occurring during that exposure.

The nonproprietary performance specifications prepared for Metro did not include detailed designs but consisted of laboratory performance tests with acceptance criteria and a minimum of dimensional constraints to ensure interchangeability as well as economy and ease of maintenance. They also stipulated the sampling and minimum quality control tests required. This approach has the merit of allowing suppliers maximum freedom to develop solutions within the specified parameters and thus fulfill Urban Mass Transit Administration's objective of procurement from multiple, competitive sources.

Results have been mixed. Three bids were received for two of the seven procurements; two contracts generated two bids each; two were supplied directly by the track installation contractor and one contract was supplied through a sole bidder. Four different designs of fastener went through the series

of acceptance tests at significant cost and with delays incurred in the process. Several variances from the specifications were granted to the manufacturers to keep the construction on schedule.

#### Experience

Metro has approximately 8 years of operating experience with its 27,000 TW-1 direct fixation fasteners. Figure 2 shows their configuration. No significant problems requiring replacements have been encountered with the TW-1 fastener although some have been replaced due to excessive corrosion in portions of the subway having water intrusion problems.

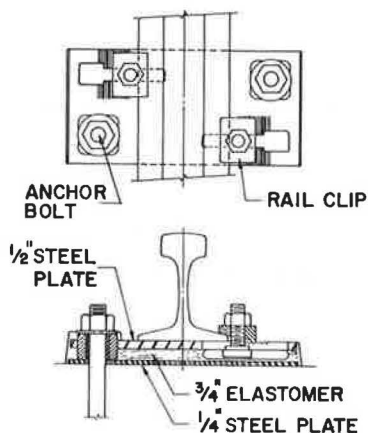


FIGURE 2 TW-1 fastener.

A total of 178,000 fasteners, shown in Figure 3, have been installed in TW-2, 3, and 4. After approximately 6 years of operation, many of the welds on the studs that join the top and bottom plate and provide the resistance to lateral deflection have failed as a result of fatigue.

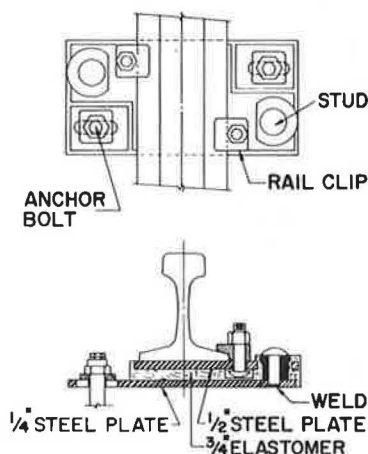


FIGURE 3 TW-2,3,4 fastener.

In TW-5 and 6, 104,000 fasteners similar to those shown in Figure 2 were installed with about 58,000 of these in service for about 3 years. An additional 7,000 fasteners were bought in the TW-5 and 6 procurement for installation in TW-7. Another 50,000 of these fasteners have been installed by maintenance forces as replacements for the fatigue-failed TW-2,

3, and 4 fasteners. With up to 4 years of service on some of these fasteners no major service problems have been identified.

The last fastener procurement was for TW-8 and included 21,000 units. The configuration of this fastener is shown in Figure 4. The fasteners have been in service for nearly 2 years and have shown no defects to date. Because of the cutaway top plate around the anchor bolts, lateral loads are not evenly distributed to both anchor bolts. Because of this, TW-8 fasteners were installed only on tangents and curves of greater than a 2,000-ft radius.

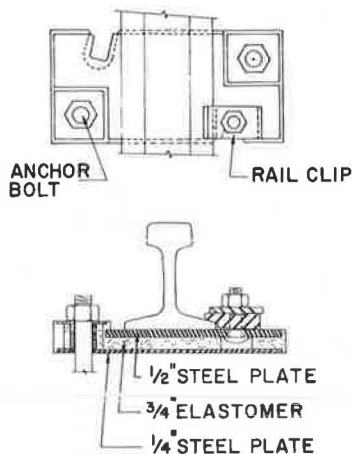


FIGURE 4 TW-8 fastener.

#### New Specification Development

The experience with fasteners through TW-8, especially the fatigue-failed TW-2, 3, and 4 fasteners, led to a research program to develop a better understanding of the loading environment and a major revision to the procurement specification to improve the performance and maintainability of future fasteners.

One of the research programs was conducted by the Transportation Systems Center (TSC), Cambridge, Massachusetts. The objective of this program was, in part, to obtain realistic estimates of the fastener service loads. A load cell was designed that could be inserted between the direct fixation track and the concrete invert. Once installed, the fastener forces (vertical, lateral, and roll moment) could be measured in track under service loads. Loads were measured on a 755-ft radius curve with standard WMATA fasteners and with fasteners modified to make a major reduction in lateral stiffness and only a minor reduction in roll moment stiffness. The standard fastener had a lateral rail head displacement of 0.09 in., whereas the soft fastener displaced slightly less than 0.25 in.

Vertical loads on both fasteners were measured to be about one-half the load specified for repeated load testing. As expected, the laterally softer fastener allowed better distribution of the wheel load to adjacent fasteners; the softer fastener carried less than one-half the load that the stiff fastener carried. Unexpectedly, the laterally soft fastener also experienced a 15 percent reduction in the wheel-to-rail load to be distributed to the fasteners.

Field tests of a specially designed vibration attenuating fastener concluded that lowering the vertical spring rate of the fastener to about 70,000 lb/in. produced significant attenuation of ground-

borne vibration that would permit elimination of expensive floating slabs in many locations.

The new TW-10 specification reflects the findings of the preceding studies. The new fastener will be more in tune with its environment and more compatible with the WMATA vehicle. The changes to the specification are in three areas: physical characteristics, mechanical properties, and test load environment. There are several changes to the physical characteristics of the new fastener. The configuration limitations have been relaxed from previous specifications, but are still sufficient to permit interchangeability. Allowing the overall size and thickness to vary within the limits shown in Figure 5 gives suppliers more freedom to develop their designs.

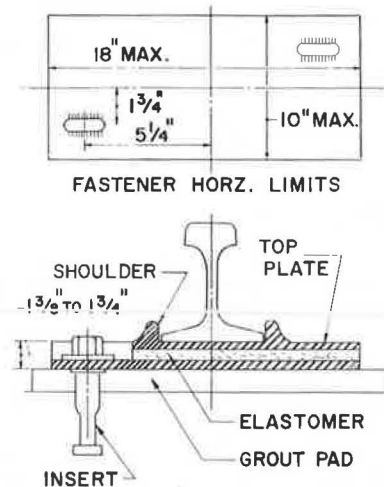


FIGURE 5 TW-10 fastener envelope.

The rail will be held to the fastener by a resilient one-piece threadless spring clip. Although previous specifications did not prohibit spring clips, the lateral load test forced the supplier to use a rail clip that could resist a large toe load, making the spring clip infeasible as a result. The field measurement data demonstrated that the qualification test configuration generated too large a roll moment compared to the in-service measured roll moment. With the test loads and configuration properly coordinated to the in-service fastener load environment, the roll moment is reduced to a level that requires only minimal toe load. The rail spring clip, which will provide the minimum toe load, is more tolerant of the variables at the rail-fastener interface. The use of spring clips in place of threaded parts facilitates installation and maintenance. It also eliminates the corrosion problems associated with threaded parts.

The lower longitudinal restraint provided by the spring clip compared to the rigid bolted clip makes it possible to use one type of spring clip fastener throughout an aerial structure. With the rigid clip, which has high longitudinal restraint, it was necessary to use a second type of fastener with very low longitudinal restraint to keep the CWR-aerial structure interaction forces within practical limits. The spring clip fastener will reduce procurement and inventory requirements from two types of fasteners interspersed throughout the length of the structure to one design used throughout.

The fastener's rail seat will have nonadjustable shoulders that will provide positive positioning of the rail. This will facilitate rail installation and



renewal. Lateral adjustment of the fastener will be accomplished with the fastener anchor bolts. Future anchor bolts will screw into female inserts installed in the concrete track bed. The inserts will have adequate bearing area on the bottom of the fastener so that the fastener will be securely clamped by the anchor bolts.

Although no major change to the electrical insulating characteristics has been made over the years, the new fastener will have a surface leakage distance of 3/4-in. instead of the previous 1/2-in. in response to the problem of stray current leakage in wet areas of tunnels.

The mechanical properties of the new fastener have been substantially changed. The new fastener is more resilient vertically and laterally and, as previously discussed, has less longitudinal restraint than previous Metro fasteners.

The new fastener will have an average dynamic vertical spring rate of 70,000 lb/in. compared to 150,000 lb/in. or more for previous designs. This change results in better distribution of wheel loads to adjacent fasteners and greater attenuation of vibrations.

The new specification requires the fastener to be much softer laterally than the old specification permitted. Figure 6 compares the lateral deflection acceptance ranges. The required deflection assures distribution of the lateral wheel-to-rail forces to adjacent fasteners and a reduction in the wheel-to-rail loads.

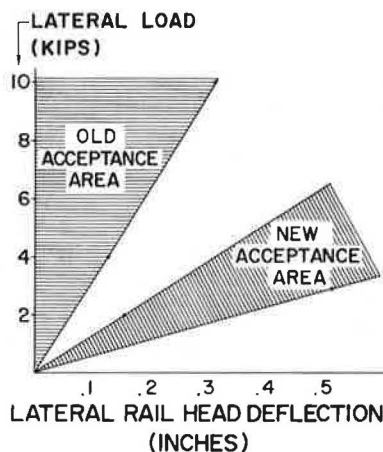


FIGURE 6 Static load acceptance criteria.

The qualification tests have been changed to make them compatible with the field conditions. The magnitude of loads, the manner in which the loads are applied, and the number of cycles of loading have been revised from previous specifications. The most significant change is in the repeated load tests. Formerly, four separate sequences of tests were performed on separate fasteners. The new specification requires one set of four fasteners to undergo a single sequence of tests. A successful fastener will have to survive more than 10 million cycles of load application.

Because the load environment is probabilistic, three load cases in a ratio of 98:1:1 will be applied for the 9 million cycles of repeated lateral and vertical loads. Figure 7 shows the load cases. The 98 percent load case applies relatively low forces whereas the 1 percent cases each apply a combination of high vertical and lateral loads. To du-

		CASES			LOAD POINT ON CURVE EXH. VII
		A	B	C	
VERTICAL LOADS		-261	-324	-213	LBS A
		+6	+7.5	+5	KIPS B
		+3.9	+4.9	+3.4	KIPS C
LATERAL LOADS		-104	-212	-212	LBS D
		+2.4	+5	+5	KIPS E
		+9	+1.9	+1.9	KIPS F
		98*	1*	1*	

\*NO. OF CYCLES OF EACH CASE  
PER 100 CYCLES OF REPEATED  
LOAD TEST.

FIGURE 7 Load cases.

plicate the field conditions requires specifying the loading rate as well as the load amplitudes. Figure 8 shows the load rates in seconds for the repeated load test. To account for torsional resistance of rail and reduced roll moment, the lateral loads are applied at a point 3 in. above the base of the rail instead of at the gauge point on the head of the rail.

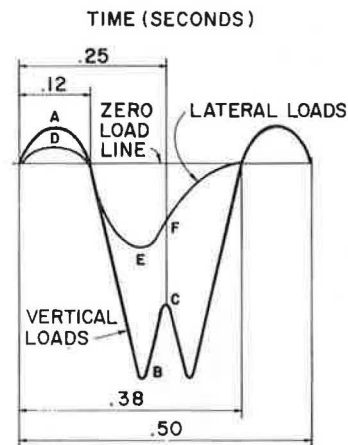


FIGURE 8 Load curves.

#### Fastener Support System

The second major change or evolution from the originally recommended standards involved the method of supporting direct fixation fasteners.

#### History

Over the several phases of the trackwork installation, a variety of methods of supporting the direct fixation fasteners has been specified. All of them fall under the single pour methodology, using a thin grout pad on the concrete invert to achieve the final elevation required for support of the fasteners and using anchor bolts that pass through the grout pad into the concrete invert slab.

In TW-1, the grout pads were placed on cleaned roughened invert and were made of 3,500 psi concrete

grout. Fully threaded steel rods 10 in. long by 7/8-in. diameter were drilled and set in the invert. Subsequent phases added progressively more sophisticated materials and procedures to meet construction and design requirements. On aerial structures, in TW-2 and TW-4, epoxy resin with quartz sand aggregate was used for the grout material. Delamination during curing due to high shrinkage led to a cooler epoxy-modified concrete grout being specified for TW-5, 6, and 8. In underground sections the strength of the portland cement grout was increased to more than 7,000 psi to obtain higher early strengths. This, in turn, led to the use of bonding agents to overcome shrinkage stresses during curing. High strength steel was specified for the anchor bolts beginning with TW-3. In TW-8, galvanized, corrosion-resistant steel bolts were specified.

As part of the final design of TW-7, an in-depth value engineering study of the fastener support system was undertaken to develop a system that, in addition to meeting design requirements, offered improved constructibility and maintainability. All previous systems were analyzed along with those of other transit systems. Several alternatives were considered and the more promising ones were completely developed and costed for comparison.

The selected configuration specified for TW-7 (see Figure 9) was 4,000 psi portland cement grout placed on cleaned invert without a bonding agent. The size of the pads was increased in both width and minimum length. Pads greater than 2 in. thick were reinforced with wire mesh. The fully threaded anchor bolt was replaced with a female threaded insert. The inserts were made of corrosion resistant steel and were epoxy coated. Quality control tests were specified to ensure minimum bonding and to insert pullout strengths throughout the installation.

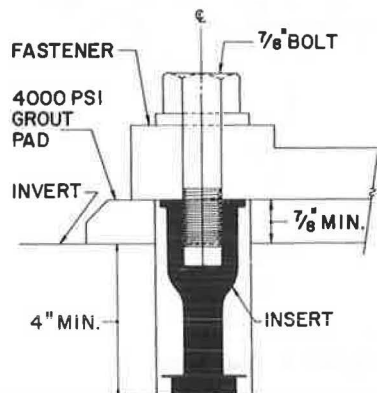


FIGURE 9 Fastener installation.

Several advantages to this new system were foreseen. The lower strength grout reduced the shrinkage problems and lessened the delamination due to differential movement during both curing and thermal expansion on aerial structure pads. Because the lower strength grout would have lower bonding requirements, the bonding agent was eliminated. The use of the threaded insert allowed a lower pullout requirement because the high strength connection required for the fastener would now be entirely between the metal components and would not involve the pullout strength of the threaded rod in the invert. The insert allows removal of a single fastener with minimal disturbance to adjacent fasteners. Shimming of fasteners can be done without raising the fastener more than is needed to insert the shim, which simplifies final profiling of the track. The epoxy

coating of the insert provides added electrical isolation of the rail from ground.

The remaining paragraphs are a brief summary of several significant evolutions of WMATA standards.

#### Spectral Trackwork

Although most special trackwork details are in accordance with AREA recommendations and have remained unchanged, the following improvements have evolved.

#### Size of Turnouts

The only change from the originally recommended turnout sizes and crossing geometry to be used on Metro has been the elimination of the No. 4 equilateral turnouts in center storage tracks. The high rate of wear experienced by these turnouts during the interim period, when the center storage track also serves as the temporary turnback for the route until it is extended, has resulted in the installation of No. 6 equilaterals that have flatter curves and are less subject to wear. At the National Airport station, the No. 4 equilateral that was used for turnback service wore so rapidly that it was replaced with a No. 6 equilateral guarded turnout even though this required a special design and an expensive change-out performed under service.

#### Bonded Inserts

The use of bonded joints through main line special trackwork required installation of epoxy-bonded inserts at the heel of the switch rail and at the heel of the frog to transfer thermal stresses from the running rails to the closure rails and then back to the running rails thereby maintaining the continuity of the stress. Use of the bonded joints serves to stiffen the turnout and produces an improvement in ride quality. The inserts at the heel of the switch were designed to allow removal of the switch rail without disturbing the bonded insert. Three yards were built with bonded joints and inserts. Because of the concentration of turnouts in ladder tracks, the continuity of the rail caused the lateral stresses from thermal expansion to make lining the ladders difficult. Therefore, in yards, bolted joints are now used in turnouts. This eliminates the need for bonded inserts and results in less expensive procurement, construction, and maintenance.

#### Support Plates

In accordance with the recommended standard, all direct fixation special trackwork units are supported on steel plates that rest on 3/4-in.-thick elastomer pads. The plates are fastened to the invert with 7/8-in.-diameter bolts. The rail components are held to the plates by a crane rail type clamp device that is removable, thereby allowing replacement of the rail without disturbing the plates. This permits rapid change-out of frogs and stock rails, important on transit systems because of the limited maintenance time available. The concept was extended to main line ballasted trackwork in TW-1 and in TW-3 to yard turnouts.

Over the years minor problems with alignment of main line turnouts on direct fixation have led to design modifications to the plates. More clamps were added in the area around the bonded inserts, and gauge plates were added at the switch points and frogs were added to prevent lateral movement.

## CONCLUSION

The Metro system carries more than one-third of a million passengers each day. It does this with a high degree of reliability, speed, and comfort. The completion of the 101-mile system remains the principal goal of WMATA in spite of funding cutbacks that have delayed expansion of the system.

Only the more significant changes to the trackwork standards that have evolved through 10 design phases have been discussed. Lesser changes and the many standards that have not been changed have been passed over due to lack of time and space.

At De Leuw, Cather and Company, the changes that have been made are viewed as the result of advancing technology and as responses to construction and maintenance as proof of the dynamic nature of the state-of-the-art in transit track. We look forward to the future as an opportunity to further advance the state-of-the-art and to improve on what is al-

ready one of the finest transit systems in the country.

## REFERENCES

1. Trackwork Practices of North American Rapid Transit Systems. WMATA Rapid Transit Development Program. De Leuw, Cather and Company, Washington, D.C., 1968.
2. Recommended Trackwork Standards. WMATA Rapid Transit Development Program. De Leuw, Cather and Company, Washington, D.C., 1969.
3. Trackwork Plans and Specifications. American Railway Engineering Association, Washington, D.C., 1984.

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## Track Rehabilitation and New Construction in An Operating Environment at BART

VINCENT P. MAHON

## ABSTRACT

The Bay Area Rapid Transit District is completing the last phase of a three part construction and track rehabilitation project designed to relieve a bottleneck in the city of Oakland downtown "wyé". This paper contains a before, during, and after description of the Oakland downtown junction area in sufficient detail to illustrate the impact of the construction project on system operations. Also outlined are the planning, coordination, management, and cooperation required between all divisions of the power and way maintenance, train operations, and engineering departments to complete the project on time and minimize the impact of construction on revenue schedules. Several innovative railroad construction methods are detailed without which this project could not have been completed within the minimal impact mandate.

Decreasing train headways on the Bay Area Rapid Transit District (BART) system involves several problems, one of which is a bottleneck in the city of Oakland downtown "wyé" junction. The BART KE Line Expansion is a three part project designed to eliminate this bottleneck and provide additional operational facilities in support of the Close Headways program.

Project construction began in April 1980, and included the following tasks: building approximately 2.4 miles of track; changing the alignment by approximately 12 ft of more than 700 ft of revenue track; building and installing 15 main line turnouts; precisely locating existing facilities in the work site area; relocating or reconstructing existing facilities in conflict within new work; constructing two aerial structures; installing subsur-

face raceways and conduits; upgrading traction power facilities; and installing additional train control and communication equipment.

The probability was high that this construction project would interfere with revenue operations because of its magnitude and location. BART management mandated that the project be completed without impact on peak revenue service schedules and with only minimum effect on service during the lightest patronage periods.

## BART TRACK SYSTEM DESIGN DETAILS

The BART revenue track system is divided into four double track lines covering a three-county area. The lines are designated as follows: the Alameda (A)