Los Angeles County
Metropolitan Transportation Authority
Office of the Inspector General

Review of the Expo/Blue Line Junction

Case No. 2011-0040 **December 18, 2012**

Metro

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Los Angeles County
Metropolitan Transportation Authority

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DATE: December 18, 2012

TO: Los Angeles County Metropolitan Transportation Authority Chief Executive Officer
Los Angeles County Metropolitan Transportation Authority Board of Directors
Exposition Metro Line Construction Authority Chief Executive Officer
Exposition Metro Line Construction Authority Board of Directors

FROM: Karen Gorman, Acting Inspector General

SUBJECT: Review of the Expo/Blue Line Junction,

We are making public disclosure of this report in the interest of transparency and to promote public confidence in the safety of Metro's operations.

Executive Summary

The Office of the Inspector General (OIG) initiated a review of certain construction matters associated with the Exposition Metro Line Construction Authority (Expo) rail line Phase 1 to Culver City, which included the design, installation, and performance of special track work at the Blue Line/Exposition Line Junction at the intersection of Washington Boulevard and Flower Street (see picture of junction at Attachment A). Subsequently, on July 26, 2012, the LACMTA Chief Executive Officer and the LACMTA Board asked the OIG to review the Washington and Flower street junction for safety and maintenance issues that had been raised. On August 6, 2012, the OIG presented an update to the Metro Board on the results of its review.

Soon after the Washington and Flower street junction was installed, LACMTA ("Metro") staff conducted inspections and observed excessive wear and metal "shavings" or "filings" affecting the rail and train car wheels stemming from one area of the special track work of the junction. Staff immediately made management at Metro, Expo, and subsequently California Public Utilities Commission (CPUC) aware of the high maintenance area. They worked together to monitor and attempt to resolve the matter. Expo took action to make modifications to the special track work area in an attempt to reduce any damage to the rail vehicles by directing the construction contractor to place a hard-face weld ("bulb") on one area of the special track work to provide an improved guide for rail vehicle wheels. Subsequently, this bulb was re-welded twice.

Since the discovery of the high maintenance section of track, Metro personnel have frequently inspected the special track work at the junction and the rail cars to ensure safety. Metro considered the modifications to be a temporary mitigation to avoid further damage while a permanent solution is being considered and implemented. Experienced rail personnel that we interviewed had different professional opinions as to the underlying cause or causes of the problem at the junction.

Representatives from Expo and the prime contractor, Flatiron/Fluor/Parsons JV (FFP), have indicated that they believe that the special track work was designed and installed properly to accommodate the geometry and parameters of the junction, which were dictated by the pre-existing design of the area beginning with the location of the Blue Line Grand Station.

The CPUC conducted multiple inspections at the Washington and Flower street junction and found this section of track to be an operational and maintenance concern. After the contractor welded the bulb, Metro instituted procedures to monitor the special track work, and other mitigation efforts were implemented, the CPUC advised Metro that it could proceed with the opening of the Expo line. Several months later, based on public concerns that have been expressed, the maintenance experience thus far, the repeated need to reweld the bulb, and an inspection on July 13, 2012, the CPUC advised Metro and Expo that portions of the junction special track work is unacceptable, the weld has not fixed the situation, and the high maintenance track work should be replaced. Pending this action, the CPUC allowed the line to continue to operate, subject to speed limits and other conditions.

Subsequently, Metro and Expo officials met with CPUC representatives and agreed to hire a rail track expert to recommend a permanent solution to the high maintenance area. Expo hired an independent rail track expert, Harsco Rails' Zeta Tech Business Unit ("Zeta Tech"), to determine the next steps to resolve the matter. On October 9, 2012, Expo received an Initial Safety Assessment from the track expert. The assessment opined that the existing special track work "may continue to be safely used in its present condition, provided that there is no excessive delay in implementation of the modifications." This opinion is subject to certain speed and maintenance requirements.

On December 11, 2012, the track expert issued a final report that stated the problems associated with the special track work are a direct result of an inappropriate design that was not in compliance with American Railway Engineering and Maintenance-of-Way Association (AREMA) specifications. The report made both interim and permanent recommendations, which consisted of three options to fix the problem concerning the high maintenance area in the junction.

The logical next step is for the special track work to be promptly modified by the Expo contractor to operate safely, at speeds that accomplish the headways necessary to carry the anticipated number of passengers as set forth in the contract specifications, and without heavy maintenance conditions such as those evidenced by shavings and track/car damage thus far experienced. This should be based on considering the recommendations of the track expert and others described herein, and in consultation with Metro, Expo, and the CPUC. Further conclusion remarks are set forth beginning on page 22 of this report.

Scope of Review

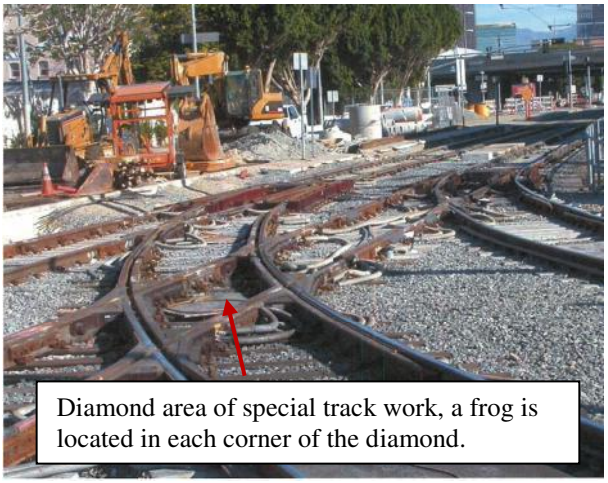
During this review, the OIG has obtained and reviewed numerous documents, interviewed numerous experienced rail personnel at Metro, CPUC, Expo, FFP, and the contractors who built and installed the special track work at the junction; analyzed technical documents; visited the

special track work area; monitored the activities of Metro, Expo, CPUC, contractors, and others; and reviewed train car maintenance records and cost of repairs. This review covered the period of events and actions up to the report issued by the track expert.

Background

1. **Blue Line**. The Blue Line, which opened in 1990, runs north and south between downtown Los Angeles and Long Beach. Certain curve portions of the line were built with a track gauge[1] of 4'9". The AREMA standard track gauge is 4'8½". In approximately 1993, Metro converted all of the Light Rail Vehicles' (LRV) truck/wheel assemblies to the AREMA standard gauge width to facilitate vehicle maintenance and standardize future orders of parts and track. Metro also converted the gauge width of most of the Blue Line's curve portions to the 4'8½" AREMA standard. However, since the curves at the Washington and Flower street junction were embedded in the ground at the time and had no special track work, it was Metro's opinion that there was no need at the time to change these curves to the AREMA standard gauge until capital work was to be done in the future.

2. **Expo Line**. The Expo Line shares the tracks with the Blue Line from the 7th Street Metro Center Station to the Washington and Flower street junction where the two lines diverge. This junction contains special track work consisting of a track crossing called a "diamond." Within the diamond, there are four track areas called frogs,[2] which are numbered D-1, D-2, D-3, and D-4 (see picture of the diamond and frogs at Attachment B). This special track work allows Expo Line and Blue Line LRVs traveling southbound from the 7th Street Metro Center Station to diverge at the Washington and Flower street junction and travel either on tracks turning left onto Washington Boulevard going south to Long Beach (via the Blue Line) or on tracks going straight and then west to Culver City (via the Expo Line).



Diamond area of special track work, a frog is located in each corner of the diamond.

a. Preliminary Drawings. We were provided preliminary pre-construction designs made by a contractor (DMJM/AECOM) in February 2004, prior to the award of the Expo Phase I contract. These preliminary designs showed the general layout of the Washington and Flower street junction. They did not show the detail specifications of the diamond, which was designed and installed by the Expo Line Phase I prime contractor and subcontractors.

[1] The track gauge refers to the distance or width between the track rails.
[2] A frog is built up pieces of track work that allow rail tracks to cross another. The frog is designed to ensure that rail vehicle's wheel crosses the gap in the rail without "dropping" into the gap.

b. Approval of Final Design. The Expo Chief Project Engineer stated that the diamond for the Washington and Flower street junction was designed by the Parson's Transportation Group (part of the FFP joint venture), whom he described as the Engineer of Record. During the design process, AREMA #10 turnouts and AREMA #8 turnouts (#10 turnouts have a larger radius than #8 turnouts) were considered, but the designers determined that neither would work because of their respective radii. Therefore, the designers utilized the 190' radius turnouts, which he described as a Metro standard, to come up with a solution that would work in the junction and not impact the Grand Station on the Blue Line. The Chief Project Engineer stated that the 190' radius turnout is a Metro standard, which calls for a wider gauge (4'9"). Accordingly, the diamond was designed with the same wider gauge. He stated that the special track work was built per AREMA standards and Metro design criteria. However, the final report by the track expert (Zeta Tech) stated: "All problems associated with the D4 Frog being damaged by passing wheels are the direct result of an inappropriate diamond design that was not in compliance with AREMA Specifications."

c. Parameters Impacting the Design on the Junction. Expo officials stated that the configuration of the junction is dictated by the physical layout of the Washington and Flower intersection and the pre-existing design of the Blue Line, which affects the special track work's layout at the junction. Expo considered other options, but determined that the special track work was the only design that would work within the parameters of the junctions, which included:

- Maintaining a steady flow of traffic south on Flower Street,
- Ensuring two traffic lanes on Washington Boulevard,
- Maintaining the fixed location of the Grand Station on the Blue Line, and
- Keeping the tracks as close as possible to the original configuration of the over-head catenary system, which supplies power to the train cars.

The Senior Project Manager for Parsons stated that based on conversations he had with Expo personnel, the use of the 190' turnout resulted in less impact to the area. He speculated that a #10 turnout (which is larger than a 190' turnout) was not used because it would have involved right-of-way issues involving property owned by the Los Angeles Trade Tech College, which would have required use of additional land located northeast of the special trackwork to complete the curve.

In addition, the Senior Project Manager for Parsons stated that the use of the #10 turnout would have affected the track leading to and from the Grand Station on the Blue Line, which would have required demolishing and rebuilding the station. Another scenario involving the #10 turnouts would have required the track being placed further west, which would have affected the traffic flow on Flower Street, and might have reduced the lanes on Flower Street from three lanes down to one.

d. Metro Design Criteria. Section 4.4 (Track Work) of the Metro Design Criteria, dated July 2005, states:

- "The standard track gauge shall be 4'8 ½"…Wider gauges (only applicable to T-rail) shall be used in some curves, depending upon the degree of curvature. Track gauges shall be as follows: …
  - C. Curves with radius larger than 82' but less than 250' – gauge: 4'9"."
- "Gauges for special trackwork shall be as recommended in the AREMA Portfolio of Trackwork Plans except as modified to reflect the physical and operation characteristics of the system."
- "No.10 turnouts shall be used on mainline tracks except if higher speed is required and as approved by Metro."
- "190-Foot Radius Lateral turnouts shall be used for turnouts and crossovers in yards and in areas where there are space limitations."[3]
- "In regard to Track Construction Tolerances, Total deviation in track gauge for Horizontal track Alignment is + or – 1/8 in. for mainline, direct fixation, embedded, mainline and ballasted track."
- "Special trackwork shall be manufactured and installed as recommended in the AREMA specifications and standards, except where modified to meet the special conditions of the LRT. All frogs and flange ways shall be designed to accommodate an AAR wheel profile."
- Table 4-2 shows the maximum speed for a 190-Foot Radius Lateral Turnout as 10 MPH.

The Senior Project Manager for Parsons stated that Parsons did the engineering layout for the special track work, which included its configuration and alignment, general construction details, fabrication details, and drawings based on Metro standard drawings. He said that Expo provided FFP Metro's standard drawings, which were based on a previous contractor's work (identified as DMJM Harris). According to the Senior Project Manager, FFP was told to utilize the designs given to them. FFP subsequently questioned Expo to clarify the gauge (4'9" vs. 4'8½") as well as the width of what is called the flangeway pertaining to the special trackwork. Expo responded that the 190' radius turnout should not be used and that the turnout should have a radius greater than an AREMA #8. Subsequently, FFP reviewed Metro Design Criteria and developed and submitted a plan, which included the use of an AREMA #10 turnout.

The Senior Project Manager for Parsons said that subsequently, in February 2008, Expo changed its mind and issued a Stop Work Notice. He said that in April 2008, Expo

[3] Note: Metro and Expo officials advised us that this statement is correct versus the statement in the Design Criteria that read: "...and in areas where there are no space limitations."

issued a letter or a proposed Change Order directing FFP to go back and use the 190' radius turnout, which the Senior Project Manager said is unusual for a mainline operation.

3. **Contract and Agreements**.

   a. Contract between Expo and FFP. The contract indicates that FFP is ultimately responsible for the design, construction, and installation of the special track work. The Scope of Work provided to FFP states: "Approval by the Authority or its designee of submitted Drawings and associated calculations does not relieve the Contractor from responsibility for errors or omissions in the Drawings and associated calculations, or from deviations from the Contract Documents...The Contractor is responsible for correctness, accuracy and completeness of the drawings, for shop fits and field connections, dimensions and quantities and for results obtained by use of such drawings." (See Attachment C for additional information.)

   A Senior Project Manager for Parsons told us that ultimately, Expo had to approve FFP's drawings; and if Expo had a concern, Expo would point it out and would not approve FFP's work until the matter was addressed.

   b. Scope of Work. Section 3.3-B (Contractor's Responsibilities) of the Scope of Work states: "Approval by the Authority or its designee of submitted Drawings and associated calculations does not relieve the Contractor from responsibility for errors or omissions in the Drawings and associated calculations, or from deviations from the Contract Documents, unless such deviations were specifically called to the attention of the Authority or its designee in the Letter of transmittal submitted with the Drawings. The Contractor is responsible for correctness, accuracy and completeness of the drawings, for shop fits and field connections, dimensions and quantities and for results obtained by the use of such drawings." (See Attachment C for additional information.)

   c. Memorandum of Understanding between Expo and Metro. According to the Memorandum of Understanding (MOU), effective May 5, 2006, between Expo and Metro, Expo has the exclusive power of awarding and overseeing all design and construction contracts pertaining to Expo Phase I, and has all powers necessary for planning, acquiring, leasing, developing, jointly developing, owning, controlling, using, jointly using, disposing of, designing, procuring, and building the project as defined under Public Utilities Code sections 132600(e) and 132610.

Special Track Work

1. **Contract for Building the Diamond Crossing**. The Expo Chief Project Engineer stated that in April-May 2008, an Invitation for Bid (IFB) was issued to build the special diamond track work for the Washington and Flower street junction. The IFB included the design of the diamond. In September 2008, Nortrak was awarded the contract to build the diamond.

Nortrak used copies of the drawings and designs provided to them by FFP to manufacture the diamond. (See Attachment D for chronology of significant events.)

2. **Identification of High Maintenance Area**. Soon after the special track work was installed in April 2010, Metro and CPUC personnel observed excessive wear and metal shavings and filings near one of the frogs at the Washington and Flower street junction, which indicated that the wheels of the LRVs were not traveling smoothly through the diamond area. Further inspections determined that the wheels were making hard contact with one of the frogs leaving metal shavings on the ground.

Possible Reasons for Junction Maintenance Issues

Experienced rail personnel that we interviewed have different opinions on what is causing the high maintenance problem at the Washington and Flower street junction. From these interviews and review of documents and reports, it appears that the problem could be due to one or a combination of several contributing factors including:

- Radius of the track (curvature of the special track work).
- Gauge (width of track) of the special track work is inconsistent with AREMA standards.
- Alignment of the diamond and special track work.
- Installation of the special track work.
- Other issues such as special track work not being embedded.

Expo representatives stated that the special track work was designed and installed to AREMA standards and Metro design criteria, and it was installed properly. Expo representatives also believe that the geometry of the junction is dictated by the pre-existing design of the area beginning with the location of the Blue Line Grand Station, which affects the special track work's layout at the junction. Expo considered other options, but determined that the special track work was the only design that would work within the parameters of the junction.

A memo[4] prepared in November 2010 by a Metro Wayside Systems Supervising Engineer summarizes, in his opinion, a number of potential matters that could have contributed to the maintenance issues at the Washington and Flower street junction. Summarized below are opinions of various experienced rail personnel concerning the junction maintenance issues; sometimes, they cited different or conflicting views:

1. **Radius of the Special Track Work Turnout**. The report prepared by the Supervising Engineer stated: "The original Metro Blue Line (MBL) Curve Data was Existing Curve #103 for MBL Track #2 was 160 foot radius, and the other existing curve #203 for MBL Track #1 was 150 foot radius...The original idea was to install this Expo At-Grade Junction using 190' Radius Turnouts that would have a radius greater than the existing curve and would act and work like a spiral because the 190' radius turnout would be larger than the actual curve and

[4] The memo was sent to the Executive Officer Wayside Systems and the observations for the memo were made during November 2-15, 2010.

work like a spiral to move the LRV's into these tight MBL curves. Metro suggested that the use of 190' Radius Turnouts were not desirable as a mainline Turnout, and indicated how standard AREMA #10 turnouts could be accommodated...Expo subsequently...took the approach that the current tracks would be left untouched and joined by using custom 190' Radius Turnouts."

The Supervising Engineer stated that what this means is that on the southbound track, "Expo should have made the diamond a 190' radius, but instead made it a 160' radius." He believed that there is insufficient distance between the end of the 190' radius turnout, and the 160' radius diamond. The effect of this configuration, in his opinion, is that "the spiral (considered more like a connecting rail due to its short length) between the 190' radius turnout and the 160' radius diamond is too short." The Supervising Engineer also gave suggestions to mitigate the design issues.

Expo Response. In a response to the November 2010 memo, Expo staff in April 2011 stated: "The existing curvature of the MBL tracks from Flower Street to the median of Washington Boulevard, for all intents and purposes, dictated the new design alignment...Although there was a design attempt to utilize #10 turnouts, as specified in the Metro Design Criteria, the geometry requirements of the layout failed to satisfy the existing roadway, Grand Station location, and the OCS [over-head catenary system] arrangement through the intersection. The costs and operational impacts to the MBL service were a significant concern. The only feasible solution that minimized these impacts was to use 190-foot radius turnouts, which Metro had introduced in early 1990s for use in yards and other geometrically restricted locations in the light rail systems."

The Expo Chief Project Engineer also stated that a contractor to FFP surveyed the diamond and concluded that it was designed and installed according to plan. Because of the fixed geometry, the length of the transitional spiral is the only choice that the geometry will allow, due to the constrained area. He said that the engineers of record at FFP came up with the specifications to fill the need at the junction.

Former Metro Employee. A former Metro rail employee offered a different perspective. The employee stated that the special track work has a diamond crossing with a 160' radius instead of a diamond crossing with a continuous 190' radius to match the existing 190' radius turnout. The employee believed that changing the diamond's radius to a 190' would fix the problem.

The former rail employee also sent several concerns directly to Zeta Tech. One of the employee's concerns is: "Poor alignment design, particularly the direct transition from the 190' radius curve into the diamond without a transition spiral, which generates excessive lateral forces and can result in a derailment." A CPUC representative asked Zeta Tech to evaluate the former employee's concerns. On November 9, 2012, Zeta Tech provided the following response:

> "Given the very tight geometry of the diamond location, the alignment design represents a realistic configuration within all of the engineering and design constraints of the location. While having a transition spiral located between a sharp radius curve and tangent section is highly desirable, the low speed nature of the operations here (10 mph) and the fact that the entire area is flat, with no super elevation, supports the design as being adequate for the intended use. Detailed testing of lateral and vertical force and acceleration levels by Ensco, Inc. in May 2012 revealed no reported excessive lateral force or Lateral force/Vertical force [L/V] levels at the transitions. Field observations by ZETA-TECH personnel further supported this. While the lack of a spiral may require some form of additional maintenance, there is no evidence of unsafe operating conditions."

Metro Executive Officer, Rail Wayside Systems. The Metro Executive Officer believes that the design of the special track work was flawed because the diamond portion of the track should have been of a constant radius and of a standard gauge.

2. **Inconsistent Track Gauge Width**. Another factor cited by various experience rail personnel is the inconsistency in the width of the track gauge within the special track work area. This could create more "play" in the special track area. The memo prepared by the Metro Supervising Engineer stated that: "According to AREMA, the gauge of the running rails associated with frogs used in turnouts or track crossings should be 4'8½" to ensure proper truck - wheel rail - interface through these special areas...Upon examination of the installed 190' Radius Turnouts on the Metro Blue Line, the tangent portion of the turnout is constructed using standard track gauge of 4'8½" while the diverging or curved portion of the turnout is designed with a ½" wider gauge or 4'9" that creates potential problems when interacting with parallel track diamond due to the tight track centers...This Curve widening allows the track wheels assembly to 'yaw' creating wear problems on the running rails. Existing Metro 190' Radius Turnouts as indicted by Metro Standard drawing indicate no such gauge widening. While this may be acceptable for a simple curve, it is not acceptable when it must interface with other 'Special Track Work' such as Diamonds. This freedom for a truck-wheel assembly to 'yaw' makes the angle of attack on the diamond frogs increased resulting in excessive wear on the frog points..." The report also found that the track gauge in parts of the special track work for the Blue Line southbound track ranged from 4'-8⅜" to 4'-9$^{3}/_{16}$" (see Attachment E).

   Expo Response. In a response to the Metro Supervising Engineer's report, Expo in April 2011 stated: "This drawing [Metro Standard Drawing TS-773, dated May 1994] shows the turnout geometry with gauge widening to 4 ft. – 9 inches through the curve side of the turnout. This Standard Drawing was included in the bid documents that the special track work fabricator, Nortrak, used in bidding the work and preparing the shop drawings for the intersection turnouts. The Federal Railway Administration and CPUC allow deviation of gauge depending on the class of track...In this case the class of track is rated at class 1 and class 1 track allows for ½" wide gauge [deviation]."

Additional Information Provided by the Metro Supervising Engineer. The Supervising Engineer said that the actual dimensions of the installed special track work do not reflect the dimensions in Metro Standard Drawing TS-773 (dated May 18, 1994), which shows a 190' radius turnout with a track gauge of 4'8½"on either end (see Attachment F). He said that Nortrak built the 190' radius turnout with the wider gauge of 4'9" at the end of the turnout, which is inconsistent with the Metro Standard Drawing (see Nortrak Design at Attachment G).

The Supervising Engineer also stated that Metro's Design Criteria, which states that curves with a radius larger than 82' but less than 250' should have a gauge of 4'9", is incorrect as it is based on heavy freight rail, and not light rail. In addition, Metro's Design Criteria was written at a time before Metro reverted back to the standard track gauge of 4'8½".

Former Metro Employee. A former Metro rail employee wrote in an email dated August 3, 2012, that "typically, on straight track, the gauge is 4 feet 8 1/2 inches. Widening the gauge through sharp radius curves is standard practice and part of Metro's Track Design Criteria, and that Expo used the same Metro criteria." The former employee also stated that the "gauge of the curved diamond at Washington and Flower is 4 feet 9 inches to meet the gauge of the 190' Radius Turnout, which is also 4 feet 9 inches...Gauge widening through sharp curves is necessary to accommodate the wheel trucks, which are stiff." The employee further stated "that narrowing the gauge will only increase the tendency for the wheels to climb over the rails." During an interview on August 8, 2011, the former employee stated that the "gauge is fine and that it was established by Metro's criteria from 1983."

The former rail employee also communicated the following concern directly to Zeta Tech: "The contractor did not follow standard industry practice in the design of the Washington and Flower special trackwork." On November 9, 2012, Zeta Tech provided the following response:

> "This has been addressed in the ZETA-TECH report regarding the use of wide gauge in the turnouts not being in accordance with AREMA standards. ZETA-TECH specifically recommends the tightening of the gauge back to industry standard levels."

Nortrak Site Visit. During a June 2010 site visit, the Nortrak Project Manager concluded that the basic layout design of the crossing is the source of the problem. On June 24, 2010, he sent a letter to FFP stating:

- "Our standpoint is that the design should have specified standard gauge of 4'8½" and 1⅞" flange ways and the guarding should have been continuous on both sides through the crossing."
- "Based on this assessment, our recommendation is to redesign the crossing to the above specs and resupply a new crossing."

CPUC Assessment. A CPUC Supervisor (Operations and Safety) agreed with Nortrak's assessment. In addition to noting that the 4'9" gauge in this area of track is wider than the standard 4'8½", he indicated that the wide gauge of the track is contributing to the problem, with the inconsistency of the gauge width throughout the special track work a contributing factor. The CPUC Supervisor stated that the wider gauge allows the wheels of the LRV to move more freely, which allows the wheels of the LRV to make hard contact with the point of frog D4. He stated that another concern is the total alignment of the special track work and diamond. He said that the general assumption is that the entire area throughout the special track work is not in total alignment.

Zeta Tech Report. The report states: "The cause of the initial problem (flange strikes on D4 frog), appears to be the result of wide gauge through the diamond. With the maximum guard face gauge being 53.125 inches and the minimum wheel back-to-back being 53.094 inches, the back of the wheels are contacting both flangeway guard rails simultaneously. As a wheel approaches the D4 frog, it is aimed directly at the ½ inch point." And that "All problems associated with the D4 Frog being damaged by passing wheels are the direct result of an inappropriate diamond design that was not in compliance with AREMA Specifications." The report also states:

> "It should be noted that the MTA Design Criteria Section 4.4 – TRACK GAUGE requires track gauge to be widened as the radius of curvature decreases. The criteria states that for a curve of radius larger than 82' but less than 250', for Light Rail Transit Systems, the gauge should be widened to 4'9"; however, the last paragraph of Section 4.4 states: 'Gauges for special track work shall be as recommended in the AREMA Portfolio of Track Work Plans except as modified to reflect the physical and operation characteristics of the system.' The AREMA Portfolio of Track Work Plans does not recommend gauge widening in diamond crossings."
>
> "This situation would not have occurred had the diamond been installed using standard gauge through both legs. The question is, if standard gauge were used in the 160 foot radius curved track, would this result in wheel sets in the bogies of existing vehicles becoming pinched while trying to traverse the diamond."

The report proceeds to describe various measurements used in calculations along with figures showing key measurements and analysis parameters and concludes that "… using standard gauge in the junction diamond would not cause the wheel sets to bind while transversing through the 160 foot radius curve portion."

Balfour Beatty Project Manager. The Project Manager for the contractor that installed the special track work told the OIG that he thinks the wide gauge through the 190' radius turnout is the cause of the problems associated with the frog. He noted that in accordance with Metro Design Criteria, the gauge through the turnout was widened by ½ inch. The Project Manager believed that it would be difficult to narrow the turnout's gauge because the turnout is mounted on concrete ties.

Parsons Senior Project Manager. The Senior Project Manager commented on the issue of the ½" widening of the gauge through the special trackwork. He said that from an engineering point of view, the train is going forward into a tight curve and that logic would indicate adding space through the curve. He said that the question is whether or not ½" is enough. He acknowledged that other rail experts might have different opinions.

3. **Alignment of Special Track Work**. The memo prepared by the Metro Supervising Engineer in November 2010 stated: "The original installation had the alignment with kinks and was not properly aligned making the wear on the diamond frog points excessive and unacceptable...The corrective action has improved the overall alignment and the kinks have been modified to produce a more uniform transition from turnout to curve." The memo referred to several mitigating actions including the welded bulb.

   Metro Supervising Engineer. The Supervising Engineer told us that the contractor installed the special track work with a shorter transitional spiral and rotated the entire diamond a couple of degrees out of tangent to prevent the track from obstructing access to a parking lot at Los Angeles Trade Tech College (LATTC).

   CPUC Representative. A CPUC Supervisor (Operations and Safety) stated that the alignment issues begin approximately 100 to 200 feet north of the junction/diamond on the southbound track, and end about one hundred feet south of the diamond. He said that the design shows a straight tangent to the turnout, which then goes into the diamond. But in reality, a piece of track had been inserted, which makes a diversion to the right between the turnout and the diamond. Therefore, there is a compilation of items contributing to the problem throughout the junction including the variation of gauge, the irregular spiral between the turnout and diamond, and the welded "bulb" on the frog. He further stated that it appears the design of the junction/diamond did not anticipate the track movement to accommodate LATTC's parking lot, thus resulting in the alignment issues in the junction/diamond. In addition, it appears that the contractor tried to accommodate the geography by making changes to the diamond after installation, which accounts for the irregularities.

   Expo Chief Project Engineer. The Chief Project Engineer advised us that the change order to FFP regarding LATTC had no impact on the design of the diamond because the change had already been taken into account at the time the diamond was designed and IFB for the diamond issued.

4. **Installation of the Diamond**. According to the Expo Chief Project Engineer, the diamond was pre-assembled at Nortrak, and then shipped to Expo. The delivery arrived in four sections, D-1, D-2, D-3, and D-4 on March 8, 2010. Prior to installation, the diamond was pre-assembled again, dismantled, and then installed at the junction in April 2010. The Expo subcontractor installed the new track work for the junction in two phases. Phase 1 was completed during the weekend beginning November 20, 2009. Phase 2, which included the installation of the diamond crossing, was completed during the weekend of April 3, 2010. Our interviews with several individuals indicated concerns with the installation of the diamond.

a. Metro Track Inspector. A Metro Track Inspector stated that he was overseeing the activity during the installation of the special track work in April 2010 by the installation contractor, Balfour Beatty. He claimed that after struggling for some time to get the switches in the diamond (see picture of switch at Attachment H) into the proper position so they could joint-bar them together, contractor employees started cutting the gel type material (a red colored gel substance that surrounds the switch box and holds the switch together) with a sawzall (a powered hand held power saw). He said "contractor employees bumped one of the switches around with a speed swing (a crane-like arm, which can move and lift heavy object items like a switch or piece of rail).

According to the Track Inspector, this action could have miss-aligned the switches. In this regard, he said the metal plate with pre-drilled holes that go on top of the switch box did not line up and cover the switch box area. The Track Inspector said that the contractor had to drill new holes into the plate.

However, the Balfour Project Manager stated that it is normal procedure to use a speed swing to maneuver the special track work into its proper position. He asserted that cutting the gel type material would have no impact on the operation of the special track work. He said that the gel type material gel does not hold the switch together, and is only used if the track work is to be embedded, which in this case the track work was not embedded. He also denied drilling new holes in the switch box metal plate.

The Senior Project Manager for Parsons said that the events described in the statement by the Metro Track Inspector are inconsequential, and the installation contractor's actions would not have affected the special trackwork's performance. He stated that since the special trackwork is situated on ballast, the red gel has no function.

b. Metro Senior Engineer, Major Capital Project Engineering. We discussed with a Metro Senior Engineer the "cut & bump" actions by the installation contractor while installing the diamond and switches described by the Metro Track Inspector. He characterized the special track work as very "sophisticated," and said specifications need to be exact; thus, the actions described may have affected the performance of the special track work.

c. Former Contractor Employee. We interviewed a former employee[5] of Balfour who was present at the time the special track work was installed in April 2010. He said that although he did not observe the "cut & bump" actions, he did notice that some of the red gel encapsulating the switches was missing and that the red gel appeared to have been cut away. He does not recall if it was associated with the special track work or elsewhere. In addition, he does not know why the gel was cut or missing.

d. Metro's Rail Track Supervisor. The Rail Track Supervisor stated that he recalls seeing some switch boxes associated with the 190' radius turnouts left uncovered after

[5] This individual is currently working at Metro as a Track Inspector.

installation for approximately 1 month. He said that they were uncovered because the pre-drilled holes in the top of the switch box covers (plates) did not match up with the switch boxes. He also stated that the installation contractor sent the plates out to be "cut down" (shaved off on the side) because the flange way in the special track work was too narrow or thin.

e. Zeta Tech Report. The report states that "the diamond was installed correctly for alignment, surface and crosslevel and does not appear to have been modified during installation."

5. **Embedded Application**. Another issue raised in the memo prepared by the Metro Supervising Engineer is his opinion that the junction fabrication "components were not designed for embedded applications and appear to be pieced together but not fabricated as a properly designed and built embedded junction. Having talked with other track manufacturers and custom track designers...the process is to ensure all flange ways are continuous at the appropriate gauge so that the track wheel interaction is properly guided throughout this complex geometry."

Former Metro Employee. A former Metro rail employee expressed the opinion that it is a problem that the diamond was placed into the intersection without a concrete base slab.

The former rail employee directly communicated a concern to Zeta Tech that "there is no base slab under the special track work." In responding to this concern, Zeta Tech stated: "Industry practice allows for the use of ballasted track construction. Given the maintenance requirements of the diamond, the ballasted track construction allowed for better ease of access for maintenance."

The former rail employee expressed another concern to Zeta Tech that the special track work is: "Substandard construction and components, particular the use of a jointed (bolted) diamond instead of a solid rail-bound manganese diamond." Zeta Tech's response to this concern stated: "While a solid rail bound manganese diamond would have been preferable from a maintenance and longer life point of view, the current design is safe and in accordance with industry practices (e.g. AREMA)."

Metro Executive Officer, Wayside Systems. The Executive Officer, Wayside Systems stated that the diamond was installed on granite/ballast stones with Metro's concurrence because the diamond would be easier to connect to the existing track and easier to fit onsite. In addition, it would be easier to replace at some point in the future. He also said that the diamond's installation on granite/ballast stones versus being installed on top of a concrete slab would have no effect on the performance of the diamond.

Balfour Beatty Project Manager. The Balfour Project Manager said that because the special trackwork is on ballast and the LRVs travel over the diamond in only one direction, the diamond had pivoted in a counter-clockwise direction, resulting in the diamond being out of

alignment by approximately 1" to 1 ¼" predominately at the D-4 frog. The Manager claimed that in June 2011, Balfour rotated the diamond by a slight amount to return it back to its original alignment.

Senior Project Manager Parsons. The Senior Project Manager for Parsons stated that he had no knowledge of the special trackwork pivoting in a counter clockwise position as described by the Balfour Project Manager. However, he believes that the preponderance of a train travelling over the area in one direction will push the track into the most compatible position.

Expo Chief Project Engineer. The Chief Project Engineer stated that he has no knowledge of the diamond having ever been moved or slightly rotated out of tangent with other track. He said that the FFP subcontractor surveyed the diamond and concluded that the diamond was designed and installed according to plan.

Mitigation Measures

1. **Modification of the Diamond/Frog**. On June 1, 2010, a Metro employee first reported heavy impact in one location within the junction diamond. Subsequent Metro inspections found excessive wear and metal filings at one of the frogs within the diamond. On September 25, 2010, Expo directed FFP to make modifications to reduce the excessive wear at the frog and mitigate any damage to the LRVs or special track work. The modification included placing a hard-face weld ("bulb") on the side of the frog D2 point to provide an improved guide for wheels at frog D4. During the period September 2010 through June 2012, the bulb was welded in place in September 2010, a small surface flake was identified in March 2012 and a re-weld was performed in April 2012. In June 2012, a new chip was identified where the old one was, where it was suspected that the previous weld got too hot to adhere properly. This small chip was re-welded in July 2012. There were other welding activities that took place at the diamond that were unrelated to the bulb.

   A CPUC official stated that he and his colleagues at CPUC have spoken with other experts in the industry, and have concluded that Expo's modifications are not recognized as a remedy within the industry and are considered unusual. He also said that this type of modification has never been seen before, and that the modification (welding of the bulb) is not an accepted American Public Transportation Association or American Railway Engineering and Maintenance of Way Association standard. He noted that the diamond's manufacturer, Nortrak, has also expressed their dissatisfaction with the modifications, and have sent letters to Expo voicing their concern. On January 11, 2012, Nortrak sent a letter to Metro stating that it does not approve of the welded bulb on the diamond frog.

2. **Metro Inspections of the Diamond/Frog**. Shortly after the special track work was installed, Metro commenced inspections of the area. A Metro inspection conducted on June 15, 2010, found metal shavings scattered around the frog point where the LRVs passed over the diamond. Metro personnel also observed that the LRV's wheels were bumping the standard guard rail, and the wheel truck becomes twisted as it approaches the diamond. In addition,

the front wheel was observed to move through at the proper angle, but the back wheel flange climbs up on the throat of the diamond frog, causing unusual wear. Thereafter, Metro personnel made frequent inspections of the special track work area.

Metro notified the CPUC of a detailed and comprehensive plan for monitoring potential damage to the LRVs and junction special track work at various time intervals ranging from twice per week to once per month. A letter from Metro to the CPUC dated March 6, 2012, states: "In accordance with our Track Maintenance Plan, Metro Wayside Systems – Track will perform semi-weekly visual inspections of surface and alignment of the special track work at the Blue Line/Exposition Line Junction, as well as evaluate any wear and damage to heel blocks, joints and frogs. The metal build out on the frog will be part of this weekly inspection and will verify that it continues to protect the opposite frog point which it was designed to do. Additionally, on a monthly basis, the Track Department will conduct a detailed inspection of the junction special track work. Gauge, surface-and-alignment, condition of switch points, frog points, stock rails, closure rails, rail joints, ties, clips, and fasteners will be inspected and documented. Special track work will be inspected for guard rail gauge, guard check gauge, switch point fit, stock rail interface, lubrication of slide plates, gauge plates. This monthly effort will also include operation of the switch, removal of dirt and debris, and conditioning of and shimming of elastomer pads."

3. **CPUC Inspections**. CPUC Rail Transit Safety Section staff performed multiple inspections of the special track work at the Washington and Flower street junction. For example:

   - An inspection on June 2, 2011, found that: "The frog on the outbound/south portion of track has a narrow flange way measuring 1⅜", this does not meet the standard flange way width of 1⅞" documented in the CFR [Code of Federal Regulations] part 213. The narrow flange way is due to an unusual build up on the side of the flange way created by the subcontractor. This process is not found in any known standard and creates measurements that do not comply with CFR regulation. The Guard Check Gauge measures 53⅝"; this does not meet the minimum requirement of 54⅛" noted in the CFR 213.413. Staff believes that this unusual modification to the frog was done to eliminate the frog point damage caused by the wheel of the LRV when entering the frog. It is also the opinion of staff that the wheel is damaging the frog point because the frog is misaligned. Staff has also observed that by modifying the outbound/south frog to avoid point damage, the subcontractor has now created the same point damage on the adjacent frog. Staff has documented extreme point damage on the adjacent frog as well as wheel damage to the Blue Line vehicles. Staff has found a highly unusual amount of wheel shavings in the narrowed flange way that would indicate that the wheel is impacting the side of the flange in such a way to cause the wheel to be shaved every time it enters this flange way."

   - Another CPUC inspection made on July 6, 2012, found that: "The weld modification on the flange way of the frog for southbound (Long Beach bound) trains was defective. The surface weld was damaged and appeared to be separating, this modification was done in layers and it appears that the top layer is compromised."

4. **Tests of the Diamond/Frog Area**. Several tests were made by independent companies of the diamond frog area where the excessive wear was observed.

   a. Dye Penetrant and Ultrasonic Tests. Twining, Inc. (an engineering testing and quality assurance firm) performed two tests at the frog area weld repair at track intersection of track #2 Blue Line and track #3 on Expo Line. These tests showed conflicting results.

      (1) The tests made on June 6, 2012, indicated the following potential problems:

         - "Dye penetrant testing revealed cracking/delamanation of weld repair area…"
         - "Ultrasonic testing of same area...revealed planar type indications at the surface to slightly below surface of the weld repair area."

      (2) The dye penetrant testing and ultrasound tests on July 27, 2012, on the frog at the intersection of tracks #2 and #3 corner of Washington and Flower street junction found no defects.

      In response to the second test results, the Expo CEO stated: "We need something from them [Twining] that tells us to what extent their previous testing would identify defects and what this new procedure does that the previous procedure doesn't do."

   b. Vibration and Sound Tests. Metro contracted with ENSCO, Inc. (an engineering, science and advanced technology solutions firm) to measure and analyze the vibrations, displacement, and noise on both the Siemens and Nippon Sharyo LRVs, which travel over the special track work. On May 24 and 25, 2012, tests were conducted at a speed of approximately 5 mph. over the special track work, which included the modified frog (Expo frog), and another reference frog, which was used for comparison. On July 13, 2012, ENSCO released its final draft report. Subsequently, ENSCO released Rev #2 on July 17, 2012 and Rev #3 on August 8, 2012 to its final draft report. Rev #3 to the ENSCO final draft report stated:

      > "… Expo frog readings were higher than the reference frog readings about 75% of the time…overall, the Expo frog did create a more severe load environment for the vehicles. The testing found that the Expo frog caused significantly higher impact energy, as well as larger truck displacements when compared to a frog of standard design. The sound levels experienced in the Expo frog were also about 5-6 dBA higher than those experienced in the reference frog.
      >
      > Given the above results, it can be inferred that the welded bump in the frog location does not help the vehicles to operate through the Expo frog as compared to a reference frog. The welded bump also deteriorates passenger comfort because of increased noise and reduced ride quality in the Expo frog as compared to the reference frog.

> Dynamic modeling of a vehicle over a standard frog and the Expo frog revealed significant increases in lateral force with the Expo frog design with the bump modeled as a deviation. The simulation also showed that this higher lateral force is accompanied by a higher L/V [lateral/vertical] ratio, which correlates to an increased wheel climb risk."

In response to the ENESCO report, the Interim Director of Rail Operations sent an email, dated July 17, 2012, to Metro rail officials advising them that the operating speed of the Blue Line Track 2 (southbound track) has been reduced from 10 mph. to 5 mph. This reduction of speed is due to excessive vibration and displacement impact measurements as determined by initial analysis data conducted by ENSCO.

c. CH2M Hill Report. Metro contracted with CH2M Hill to (1) assess the ENSCO report findings on the tests of the Expo frog, (2) review track issues pertaining to the Expo frog, and (3) discuss vehicle issues. On August 8, 2012, CH2M Hill issued a draft report that made 10 recommendations including:

- "The results of the ENSCO report should be confirmed. If necessary, the testing should be repeated."
- "Extend the 5 mph speed restriction at the Expo junction for both tracks in both directions."

d. Zeta Tech Report. The report stated:

- "Analysis of the full set of ENSCO data shows that in general the Expo frog readings were higher than the reference frog readings. While ENSCO indicated in its report that this was the case about 75% of the time, review of the actual data did not support this large a percentage, but rather that the measured effects from the Expo frog and the reference frog were similar in many instances."

- "In addition to the actual testing, ENSCO performed a dynamic model analysis of the vehicle going through the junction with the 'blip" using the Vampire vehicle-track dynamic interaction model. A reference analysis was also performed going through a standard frog. The analysis assumed an operating speed of 5 mph through the frog, a new wheel flange angle of 75 degrees and dry rail with a coefficient of friction (μ) of between 0.3 and 0.5. Figure 3 presents a comparison of the two modeling runs, focusing on the L/V ratio (ratio of Lateral/Vertical wheel-rail force). The L/V ratio is a well established indicator of potential wheel/climb risk."

e. Metro Inspections and Repair of Rail Cars. The CPUC has instructed Metro to document all vehicle damage and repairs related to the special track work. Further, they instructed that any discovery or suspicions of a derailment or hazardous condition that is suspected to be related to unusual wear or deterioration shall be immediately reported to the CPUC.

- Inspections. On December 28, 2011, the Metro Executive Officer of the Rail Vehicle Maintenance Department sent a letter to CPUC Utilities Engineer. The letter identifies specific inspection intervals at 7,500 miles, 22,500 miles, 45,000 miles, and 90,000 miles; preventative maintenance tasks; and description of components to be monitored including visual inspections, wheel diameter, hollow wear, flange wear measurements, truck inspection, general underbody inspection, track brake wear and support bracket inspection, undercar/tire and wheel inspection, flange thickness, height, tread and wheel checks, axle inspection, truck-frame inspection, tire check, journal bearing leak test, and journal bearing housing clearance wear measurements for the P865/P2020 and P2000 rail vehicles. It also provides for certain procedures to commence upon notification of unusual damage to the rail cars.

- Repairs. On October 11, 2012, we obtained a report of repairs made to LRV's that traveled over the Blue/Expo Line junction from the Director of Rail Vehicle Acquisition & Maintenance. The report shows that during the period April 1, 2011 to October 10, 2012, 1,253 scheduled maintenance inspections were made of the LRVs. Of this total, 115 vehicles had repairs that pertained to the track wheel hanger, bolt, flange, roller, bar, or spherical. Rail department personnel reviewed these repairs and determined that 81 of the 115 vehicles had repairs that were not related to the issues with the diamond at the Washington and Flower street junction, and the remaining 34 vehicles had repairs that may be "possibly related" to the high maintenance area problem at the junction. The repairs to the 34 LRVs included components such as Center Truck Assemblies, Power Truck Assemblies, Traction Motors, Suspension Systems, and Gear Box Assemblies. The cost to repair the 34 LRVs totaled about $35,000.

Written CPUC Approval Not Required to Open Expo Phase I

In April 2012, portions of Expo Line Phase I opened for public service. Public Utilities Commission General Order 164-B, applicable to Expo Phase I, requires Expo to implement a safety plan, but is silent on whether written approval from the CPUC must be obtained prior to opening Expo Phase I for operation. General Order 164-D, which is applicable to Phase II of the Expo Line, requires written approval before the line can begin operation. Section 12.2 of General Order 164-D states: "Staff [CPUC] shall give its approval of the Safety Certification Verification Report (SCVR) by issuing a formal letter to the Rail Transit Agency. The staff's approval letter...shall constitute provisional Commission approval. The project shall not be placed in service until the SCVR is provisionally approved by staff in this manner."

On April 26, 2012, the CPUC Transitional Director sent an email to the CEOs of Metro and Expo regarding the opening of the Expo Line. The email discusses Expo and Metro efforts to resolve safety issues and does not appear to restrict or prohibit the opening. The email states: "I'm pleased to report that the work performed by Expo and Metro over the last week have resolved the safety show stoppers for opening based on rides by CPUC staff over the last three days. There is obviously still additional work to resolve all open issues that will be continuing,

and to complete permanent fixes for some temporary solutions, but at this point we see no safety impediments to opening the system for revenue service."

CPUC Direction to Replace Diamond/Frog

After the CPUC inspection on July 6, 2012, found shortcomings with the modification to the special track work, on July 13, 2012, the Director of the Consumer Protection and Safety Division of the CPUC sent a letter to the Metro CEO and the Expo CEO advising them that: "The current frog is unacceptable; it is a non-standard frog with a non-standard 'fix' and a repeatedly failing weld." The CPUC directed Metro/Expo to "replace the frog at Washington and Flower junction with a new and properly designed frog."

During the week of July 16, 2012, Metro, Expo, and CPUC representatives met in Sacramento. All parties agreed to hire an outside expert to review the special track work (diamond/frog) in the Washington and Flower street junction.

Actions Initiated for Permanent Solution

On September 3, 2012, Expo hired a track expert (Harsco Rail's Zeta Tech Business Unit) to review the current design, shop drawings and installation of the junction of the Metro Blue Line and Expo Line junction at the intersection of Washington Boulevard and Flower Street.

Initial Safety Assessment Report. On October 9, 2012, Expo received from Zeta Tech an initial safety assessment report. The report stated: "Based on an onsite inspection of the Junction Diamond, it is our opinion that the existing diamond may continue to be safely used in its present condition, provided that there is no excessive delay in implementation of the modifications. This is subject to the following operational restrictions:

1. "The operational speed through the diamond from Expo #4 to Blue #2 track shall never exceed 10 mph. There is no restriction on train operation through the diamond on the Expo #3 to Blue #1 track."
2. "The predominant direction of travel through the 160 foot radius curve of the diamond shall be from Expo #4 to Blue #2 and **at no time shall a train operate in the reverse direction at a speed in excess of 5 mph**."
3. "It is expected that the welded "Blip" on frog D2 will wear over time, allowing the frog point on D4 to be impacted. Weekly inspections shall be made of the weld and D4 frog to ensure the safe operation of trains through the diamond. Any indication of D4 being impacted by passing wheels shall be reason to remove the diamond from service and build the "blip" weld back to ½" stand-off."

Final Report. On December 11, 2012, Zeta Tech issued a final report (see the Exhibit on page 31 for a copy of the entire report). The report stated that:

> "The cause of the initial problem (flange strikes on D4 frog), appears to be the result of wide gauge through the diamond...It was noted from observations and

measurements taken in the field, that the existing diamond was manufactured in accordance with design specifications. In addition, the diamond was installed correctly for alignment, surface and crosslevel and does not appear to have been modified during installation. All problems associated with the D4 Frog being damaged by passing wheels are the direct result of an inappropriate diamond design that was not in compliance with AREMA Specifications."

The report made both interim and permanent recommendations. The interim recommendations were identical to the three recommendations made in Zeta Tech's Initial Safety Inspection Report discussed above. The permanent recommendations state: "Based on the...observations and analysis, there are several possible options that can be considered for a permanent correction to the problem: They include:

1. Complete Removal of the Diamond Junction and replacement with cross-over(s), or
2. Redesign of the Diamond Junction to Cross at an angle greater than 30 degrees, or
3. Correction of gauge back to standard 56½" [4'8½"] gauge.

Other Considerations

- Balfour Beatty Project Manager. During an interview with Balfour's Project manager, we asked him about an undated work plan on written Balfour's letterhead, which describes track modification procedures to the diamond. He responded that the modifications never took place, and that it was just a proposal in response to the problem with the diamond/frog at the Washington and Flower street junction. The work plan "describes the processes and methods to modify the existing crossing diamond at the junction of the Metro Blue Line and the new Expo Line." He said the work plan outlines suggestions on how to narrow the diamond's gauge.

- Metro Supervising Engineer. The Metro Supervising Engineer responded to Zeta Tech's draft report[6] and recommendations in an Interoffice Memo dated November 5, 2012 to the Metro Executive Officer, Waysides Systems.

  The Supervising Engineer noted that the track expert's report did not discuss the existence and any effect of a straight piece of track on the outer curved portion of the rail situated between the 190' radius turnout and the 160' radius diamond crossing.

  According to the memo, the 190' radius turnout is located too far north. Therefore, a straight section of rail was inserted to connect the turnout with the diamond. In his opinion, this configuration prevented a constant compound curve, which impacted the wheel and travel flow as it approached the diamond, which was not evaluated in the track expert's report.

[6] On October 31, 2012, Zeta Tech provided a final draft report to officials at Metro, Expo, and the CPUC.

The Supervising Engineer memo stated: "Had the complete junction been evaluated then the continuation of the 190' Radius Turnout Curve at 4'8½" gauge could have been continued into the redesigned 190' Radius Diamond due to the close track centers and insufficient space to provide a transitional spiral and once having completed the 190' Radius through the Turnout and Diamond at standard gauge 4'8½"then provide a transitional Spiral from the 190' Radius curve to the existing 160' Radius Street Curve as originally suggested by Metro Wayside Systems."

The Supervising Engineer expressed concern whether the recommendations in the Zeta Tech report will correct the problem or accomplish the headways that Metro requires, and that the track expert's recommendation B-1 for the special track work is not in compliance with contract requirements, which specified that a diamond be placed in the junction.

Conclusion

The special track work of the Expo Line/Blue Line junction is experiencing high maintenance at a stress point possibly due to the curvature, track gauge, alignment issues, and/or other factors. It is requiring frequent inspection and repairs and may have an impact over time on the rail vehicle wheels and underbody. All stakeholders (Metro, Expo, contractor, and CPUC) are aware of the high maintenance area and are working towards a solution. To reduce excessive wear and potential damage to the LRVs, Expo directed the contractor to weld a bulb near one of the frogs. The welded bulb has experienced wear and tear that required it to be re-welded twice. It has not proven to be a permanent fix to the junction and LRV wear impact issues. In July 2012, the CPUC directed Metro and Expo to "replace the frog at the Washington and Flower street junction with a new and properly designed frog."

Subsequently, Expo hired Zeta Tech to review the current design, shop drawings and installation of the junction. An initial report by Zeta Tech concluded that the existing diamond may continue to be safely used in its present condition, provided there is no excessive delay in implementing modifications and certain operational restrictions are followed. On December 11, 2012, Zeta Tech issued a final report[7] that stated all problems associated with the D4 Frog being damaged are a direct result of an inappropriate diamond design that was not in compliance with AREMA specifications. The report made both interim and permanent recommendations, which consisted of three options for a permanent fix to the problem.

During the review, we received various opinions from experienced rail personnel as to the underlying cause or causes of the high maintenance area at the Washington and Flower street junction. In some cases, these opinions conflicted with one another. Therefore, we focused our review on analyzing and presenting information about events, documents, requirements, and opinions that would provide transparency, enable full consideration of diverse recommendations, and benefit the stakeholders, future construction efforts, and implementation of a long term solution.

[7] The entire report is included in the Exhibit to this report.

In addition, we documented the existence of two additional plans to mitigate the design issues, which can be added for consideration in addition to the Zeta Tech recommendations.

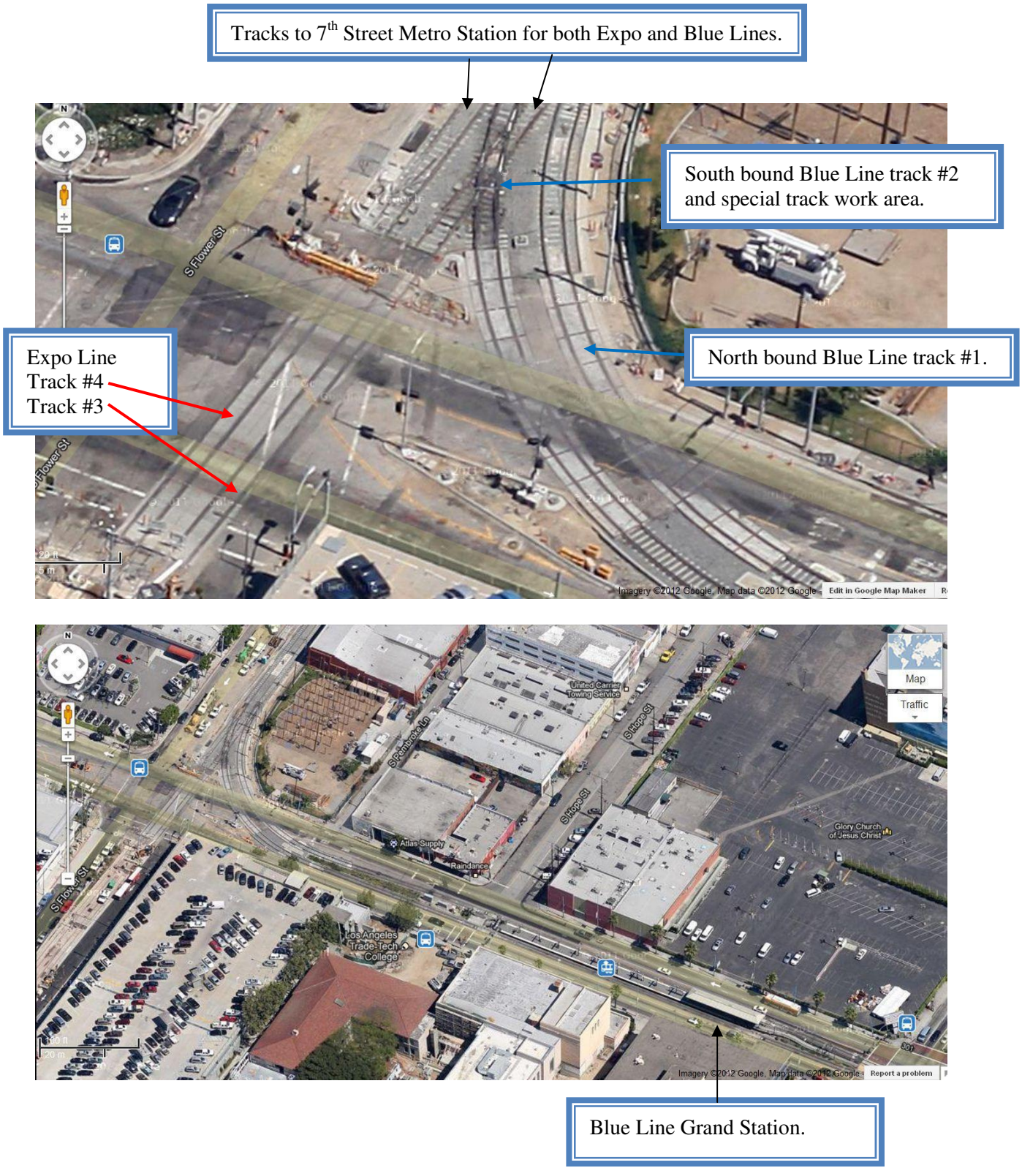
Expo and Metro, in coordination with the CPUC, should work together to expedite the following:

- Assess the permanent fix options presented in the Zeta Tech report,
- Assess the crossing diamond modification methods outlined in the Balfour Beatty work plan,
- Assess the concerns presented in the Metro Rail Operating Maintenance Department's recommendations,
- Select the best option or modified option that will most likely fix the problem, is compatible with existing and future LVRs, and meets operational requirements and maintenance standards, and most importantly meets safety requirements, and
- Implement the option selected.

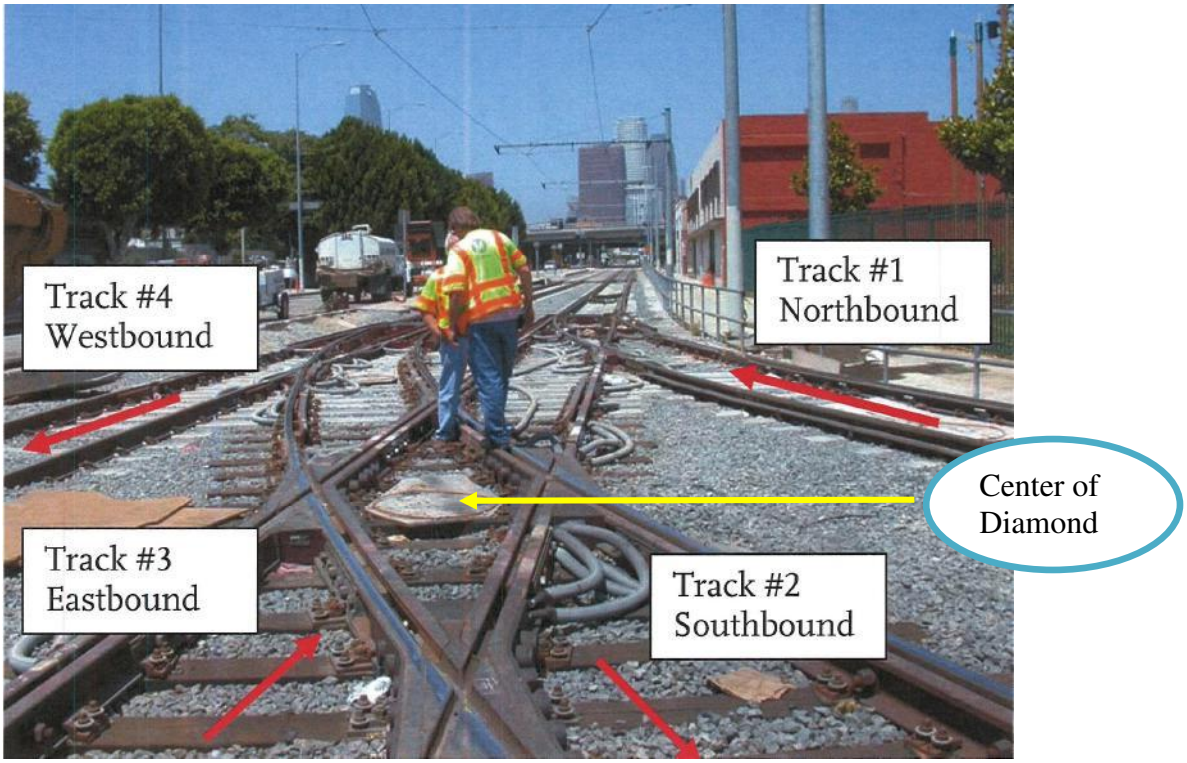
Metro should also adhere to any operational restrictions outlined in the Zeta Tech interim recommendations until the matter is resolved. We will continue to monitor this matter until it is resolved, and provide the Board with subsequent reporting if necessary. In addition, going forward, Metro construction should use AREMA standards unless it is determined that it is not appropriate under the circumstances.

Aerial Pictures of Expo/Blue Line Junction

Pictures of the Washington Boulevard and Flower street junction where the Expo and Blue Lines merge.



Pictures of Diamond/Frogs



1. Contract between Expo and FFP.

According to the contract between Expo and FFP (signed on April 19, 2006) FFP is ultimately responsible for the design, construction, and installation of the special track work because the Baseline Drawings and Reference Documents set forth in the Scope of Work, even if incorrect, are subject to FFP's review and modification.

- The contract specifies that FFP shall hold harmless the Indemnified Parties (including Metro, Expo, and others) from and against any and all claims, damages, losses, liabilities and costs, including reasonable attorney's fees, arising out of, relating to or resulting from errors, omissions, inconsistencies, or other defects in the Design Documents, furnished by contractor, regardless of whether such errors, omissions, inconsistencies or defects were also included in the Baseline Requirements or Reference Documents unless the loss, damage, or cost was caused by negligence or willful misconduct by the Indemnified Party or their agents, servants or independent contractors who are directly responsible to such Indemnified Party.

- In the contract, FFP agreed that, because the Baseline Documents and Reference Documents are subject to review and modification by FFP, such documents shall not be deemed "design furnished" by Authority or any other Indemnified Parties.

2. Scope of Work

On March 17, 2006, Expo provided a Scope of Work to FFP. Pertinent sections include:

a. Scope of Work, Section 3.3-B., Contractor's Responsibilities

- "Approval by the Authority or its designee of submitted Drawings and associated calculations does not relieve the Contractor from responsibility for errors or omissions in the Drawings and associated calculations, or from deviations from the Contract Documents, unless such deviations were specifically called to the attention of the Authority or its designee in the Letter of transmittal submitted with the Drawings. The Contractor is responsible for correctness, accuracy and completeness of the drawings, for shop fits and field connections, dimensions and quantities and for results obtained by the use of such drawings."

b. Project Quality Program Requirements, Section 01460, 3.3, Failure to Perform

- "Nonconforming work is work that the Authority determines does not conform to the requirements of the contract documents. Nonconforming work shall be removed and replaced so as to be acceptable to the Authority, at Contractor's cost; and Contractor shall promptly take all action necessary to prevent similar deficiencies from occurring in the future. The fact that the Authority may not have

discovered the nonconforming work shall not constitute an acceptance of such nonconforming work. In the event the Contractor fails to correct any nonconforming work after receipt of notice from the Authority requesting such correction and within the time specified in the notice, then the Authority may cause the nonconforming work to be remedied or removed and replaced and may deduct the cost of doing so from any moneys due or to become due Contractor and/or obtain reimbursement from Contractor for such cost. Remedy for Contractor's failure to perform will be in addition to any other rights or remedies available to the Authority under this contract."

Chronology of Significant Events

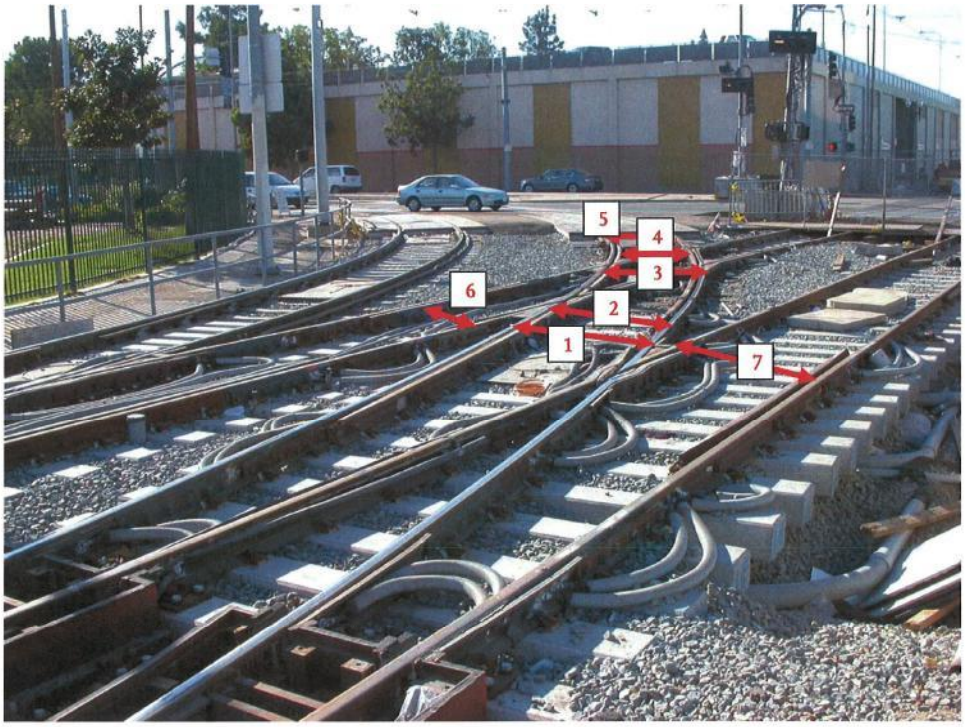
Date	Event
March 17, 2006	Expo provides scope of work to FFP.
April 19, 2006	The contract between Expo and FFP signed.
May 5, 2006	Effective date of MOU between Metro and Expo.
May 14, 2008	FFP issued Notice to Proceed to Nortrak (manufacturer of special track work).
March 25, 2009	The Flower and Washington Track Alignment Drawing # T-E- 142 was prepared by FFP for construction.
May 08, 2009	On May 8, 2009 Expo directed Nortrak to make "major alignment changes". Expo changed the limits of curves 203A and 103A, which caused "significant revisions."
April 3 - 4, 2010	Special track work installed by subcontractor.
June 1, 2010	First documentation of high impact area at frog point.
June 24, 2010	Nortrak letter to FFP recommends replacing the crossing with standard gauge of 4'-8 ½" and $1^{7}/_{8}$" flange ways.
September 2010	Expo contractor places weld bulb on special track work.
May 2011	Expo contractor re-welds bulb on special track work.
June 2, 2011	CPUC inspection report found the special track work to be a "serious safety and maintenance concern."
September 2011	Expo contractor re-welds bulb on special track work.
December 28, 2011	Metro issues letter to CPUC describing its LRV inspection plan for the monitoring of wheels and axles as it relates to the rail vehicle truck interface to the Washington and Flower street junction, and the potential for unusual wheel wear and truck damage.
January 11, 2012	Nortrak letter to Metro states that it does not approve of the welded bulbs (modification) on the diamond frog.
March 14, 2012	CPUC issues letter to Metro and Expo requiring certain maintenance procedures, documentation and reporting requirements.
April 2012	Expo contractor re-welds bulb on special track work.
April 26, 2012	Email from CPUC to Metro and Expo. It discusses Expo and Metro's efforts to resolve safety issues and does not restrict or prohibit the opening: "… we see no safety impediments to opening the system for revenue service.
June 2012	Expo contractor re-welds bulb on special track work.
June 29, 2012	Dye penetrant and ultrasonic testing performed by Twining indicated defects.
July 6, 2012	CPUC inspection – finding of non-compliance.
July 13, 2012	CPUC sent letter to Metro and Expo directing that the frog at Washington and Flower street junction be replaced with a new and properly designed frog.
July 13, 2012	ENSCO released their Final Draft report, which contains findings showing the effects that the special track work is having on the LRVs.
Week of July 16, 2012	In response to the CPUC dated July 13, 2012, CPUC, Metro, and Expo personnel met in Sacramento. All parties agreed to hire an expert to review the special track work (diamond/frog) in the junction.

Chronology of Significant Events

Date	Event
July 17. 2012	Metro's Interim Director of Rail Operations sent an email directing that the operating speed of the Blue Line Track 2 (southbound track) be reduced from 10 mph to 5 mph.
July 27, 2012	Dye penetrant and ultrasonic test performed by Twining found no defects.
August 6, 2012	OIG presents interim report to the Metro Board.
August 8, 2012	CH2M Hill final draft report recommends that the results of the ENSCO report should be confirmed. It also recommends extending the 5 mph speed restriction.
August 20, 2012	The CEOs for Expo and Metro sent a letter to the CPUC advising of a plan and schedule addressing the issues at Washington and Flower street junction. It estimates that the new special track work will be installed sometime in August 2013.
September 3, 2012	Expo hired a track work expert to review the current design, shop drawings and installation of the rail junction of Washington Boulevard and Flower Street.
October 9, 2012	Zeta Tech provides Expo an initial safety assessment report.
October 31, 2012	Zeta Tech provides final draft report to officials at Metro, Expo, and the CPUC.
December 11, 2012	Zeta Tech completes final report.

Different Track Gauge Measurements

The following track gauges on the MBL Southbound Track were measured:

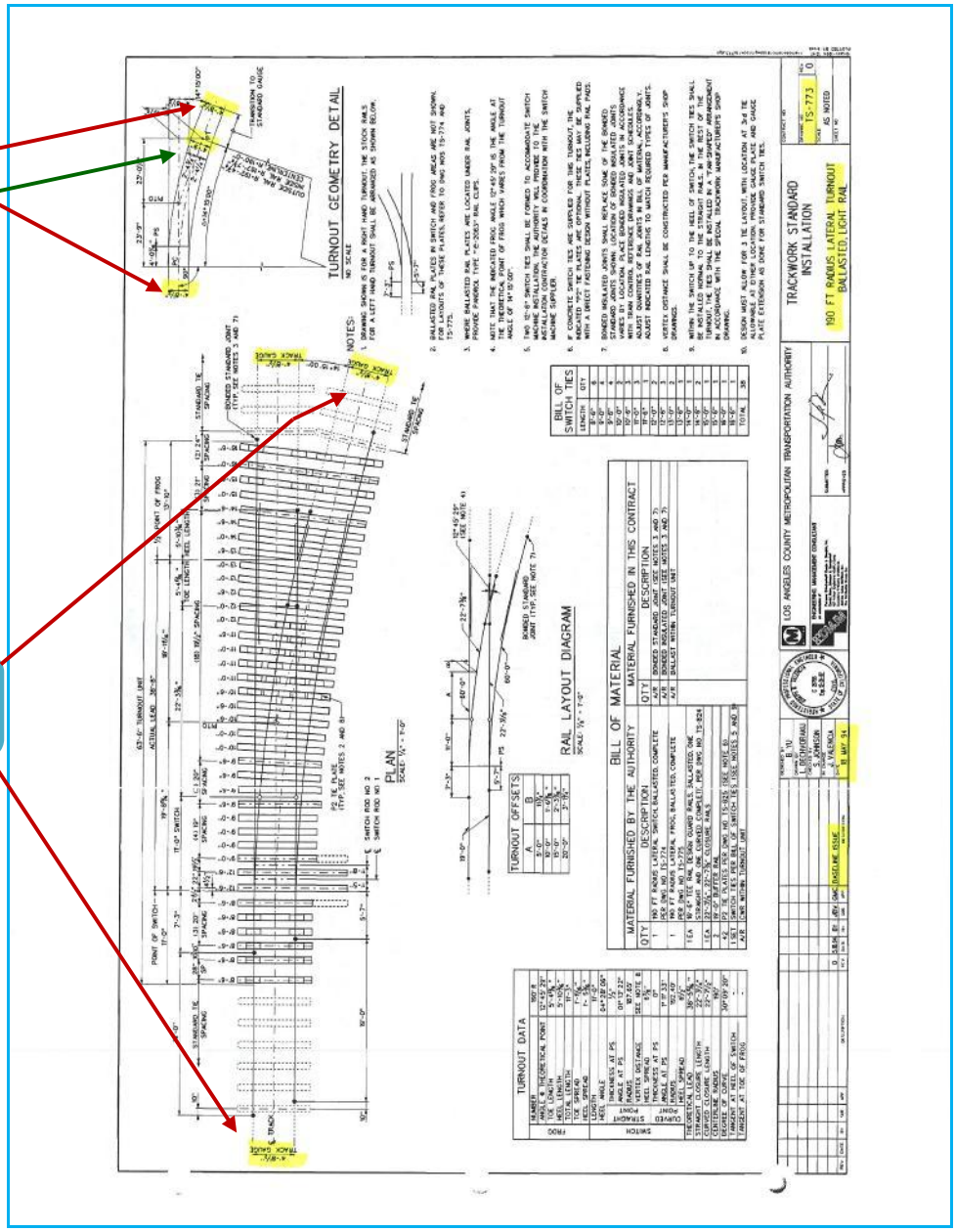


Measuring Point	Location Description	Track Gauge Measurement
1	Heel of 190' Radius Turnout Frog Track 2	56 7/8" = 4'- 8 7/8"
2	½ Point of Diamond Left Frog – North	56 3/4" = 4'- 8 3/4"
3	½ Point of Diamond Right Frog – North	57" = 4'- 9"
4	½ Point of Diamond Right Frog – South	56 13/16" = 4'- 8 13/16"
5	Heel of Diamond – South	57" = 4'- 9"
	Start of Crossing Panels – North End	57 3/16" = 4'- 9 3/16"
6	Toe of Diamond – North	56 3/8" = 4'- 8 3/8"
7	Heel of 190' Radius Turnout Frog Track 2	56 3/8" = 4'- 8 3/8"

Metro Standard Design for 190’ Radius Turnout

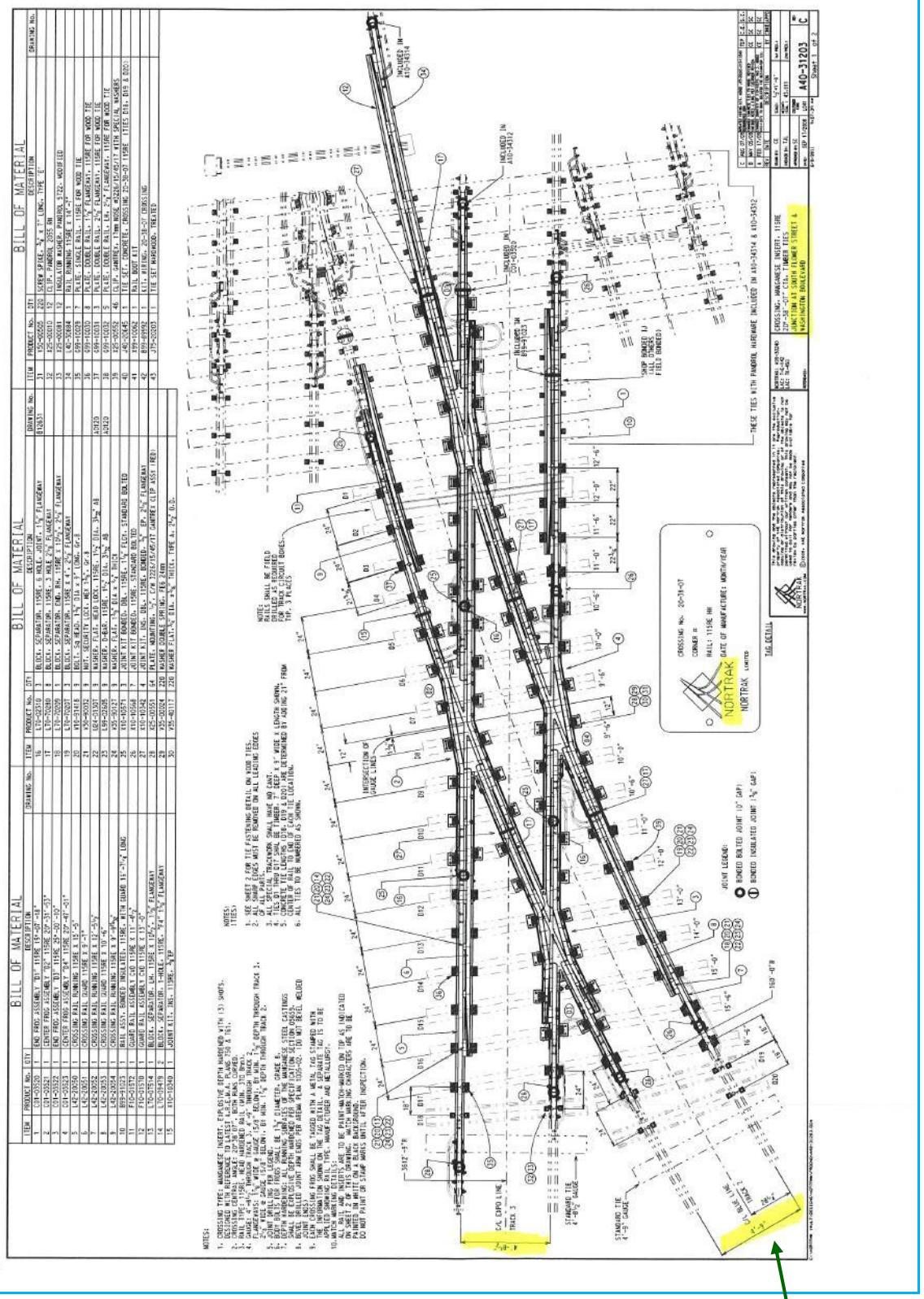
Gauge width 4’8½”
Gauge width 4’9”

Gauge width 4’8½” at either end of turnout



Note: The standard design shows right turnout.

Nortrak Drawing of Special Track Work



Gauge width 4’9” at end of special track work.

Picture of Diamond Switch Box Area

EXHIBIT

Zeta Tech Final Report

Track Expert Review of

LA METRO EXPOSITION LINE TWO TRACK AT-GRADE JUNCTION

December 11, 2012

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Track Expert Review of

LA Metro
Exposition Line Two Track At-Grade Junction

Final Report

FOR:
The
Exposition Construction Authority

December 11, 2012

Submitted by:

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1. Introduction

As part of Phase 1 of the Exposition Line light rail system, a two track at-grade junction was built to connect the double track (Expo Northbound Track #3 & Expo Southbound Track #4) Expo line to Metro's existing double track (MBL Northbound Track #1 and MBL Southbound Track #2) Metro Blue Line.

The point of connection, as indicated in the reference drawings provided, was made at the spiral-to-tangent points of the existing 150 foot radius curve for the MBL Northbound Track #1 with the Expo Northbound Track #3 and at the existing 160 foot radius curve for the MBL Southbound Track #2 with the Expo Southbound Track #4. The existing MBL trackwork within the curves had gauge widening to 4'-9" with no restraining rail. The junction is also located at the intersection of two major city streets; Washington Blvd and Flower Street.

In order to minimize property acquisition, relocation of the Grand Station, disruption to on-going Metro Blue Line operations and to city traffic, the junction was formed using 190' radius turnouts and a nominal 160 ft radius curved diamond off the back of the new 190' radius Turnout on the MBL Southbound Track #2 just north of Washington Blvd. Gauge widening was retained throughout the 150' - 160' - 190' radius tracks.

The trackwork was designed by Parsons Transportation Group under the Fluor/Flatiron/Parsons (FFP) Joint Venture responsible for designing and building the entire project. Special trackwork was manufactured by Nortrak. Trackwork was installed by Balfour Beatty Rail.

Soon after the trackwork was constructed in April 2010, it was noted that the D4 frog was showing signs of severe wear. In order to address this issue, the Contractor welded a "blip" near the D2 frog. This "blip" had the effect of forcing over the train wheels in order to protect the D4 frog in an effort to minimize wear at the frog. (See attached photos)

Other modifications were also made to remove some discontinuities in the restraining rail and to provide "ramps" on approach to the "blip".

While the "blip" was largely successful in protecting the D4 frog and appeared to reduce the amount of wear at the frog point, it has been a cause of concern as to the integrity, longevity, and maintenance of the track modifications as well as the impact to Metro rolling stock. These concerns culminated in direction from the California Public Utilities Commission (CPUC) to modify the junction such as to remove the "blip" and provide more "standard" rail geometry and components.

Harsco Rail's ZETA-TECH Business Unit (ZT) was asked to review the current design, shop drawings and installation as well as all the test data, analyses and other information developed as part of the different performance studies of the diamond. As a part of this review, ZT was asked to determine the acceptability of the existing design as it relates to the current configuration and constraints at the existing junction and to determine if the existing design meets standard railroad and Metro requirements and criteria. If the design was deemed to be suboptimum, ZT was to determine which areas need to be adjusted by redesign or alignment changes so that appropriate operations, force levels, and degradation behavior of the diamond occurs. This is to include recommendations

for modifying or improving the design so that the junction operates properly and without requiring special modifications.

To the greatest extent possible, the design modifications are intended to:

- Provide safe and reliable bi-directional operation for Metro trains
- Provide smooth transitional spirals between turnouts and curves
- Eliminate all special weldments and special build-out or abnormal frog assemblies
- Minimize impact forces to Metro trains, to the extent practicable
- Be compatible with Metro's existing rolling stock
- Provide a minimum speed in the curved track of 10 mph
- Be compatible with operation at peak service levels of 5 minute headway on the Expo and Blue Lines
- Be compatible with the deployment of train control in the junction
- Comply with CPUC, FRA and AREMA track standards
- Use standardized special trackwork components, to the extent practicable
- Adhere to Metro Design Criteria where possible. If it is not possible explain why it is not possible or why something else is better for the existing conditions
- Be designed for a long term cost effective, reliable, and maintainable section of special trackwork, sufficient to enable all special inspection instructions imposed by the CPUC to be eliminated
- Recommend, as appropriate, any alternative short-term modifications pending any long-term solution.

To the greatest extent possible, the recommendations should:

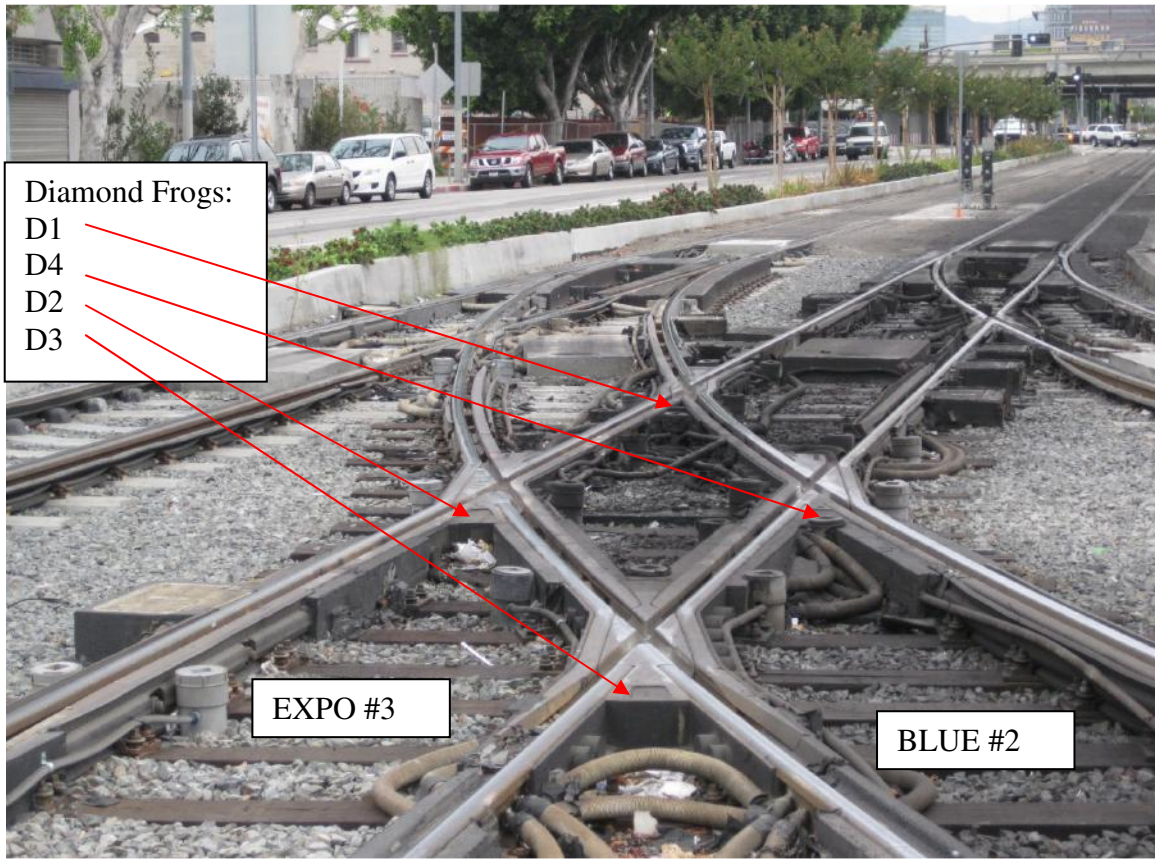
- Avoid the need to for demolition of the existing Grand station.
- Avoid removal of any vehicular traffic lanes on Flower Street or Washington. Note that this constraint may need to be waived in order to provide an acceptable track layout.

This report presents ZETA-TECH's review of the design, operation and history of the junction together with recommendations for addressing the current problems.

2. Identification of the Problem and Follow-up Testing

As noted in the introduction, the severe wear that was experienced at the D4 frog was addressed through the introduction of a welded "blip" near the D2 frog and associated approach "ramp" north of the "blip" in the southbound direction. This "blip" had the effect of forcing over the train wheels to protect the D4 frog in an effort to minimize wear at the frog. (see Figure 1). Note, however that no approach ramp was added in the northbound direction since this was not the primary direction of travel.

While the "blip" did provide protection for the D4 frog and did appear to reduce the batter at the frog point, significant concern was raised about the magnitude of the lateral forces generated by the blip and associated safety and integrity issues. To address these issues, ENSCO Incorporated was brought in to instrument a service vehicle and measure the level of impact loading and acceleration at the frog in question.



Note: RED arrows indicate direction of normal travel.

Figure 1: Junction with all four Diamond Frogs (D1-D4)

Testing was performed in May 2012 with test operations conducted from 7th St/Metro Center and ended at the intersection of Washington and Long Beach, thus checking the movement through the "blip" and D2 and D4 frogs. A reference run at 5 mph was made on the Blue Line starting before Pico Station and ending after Grand Station to provide reference dynamic performance data on a comparable frog without the 'blip", ramp, etc.

The primary instrumentation consisted of truck (axle) and car body mounted accelerometers, as shown in Figure 2, plus some supplemental instrumentation.

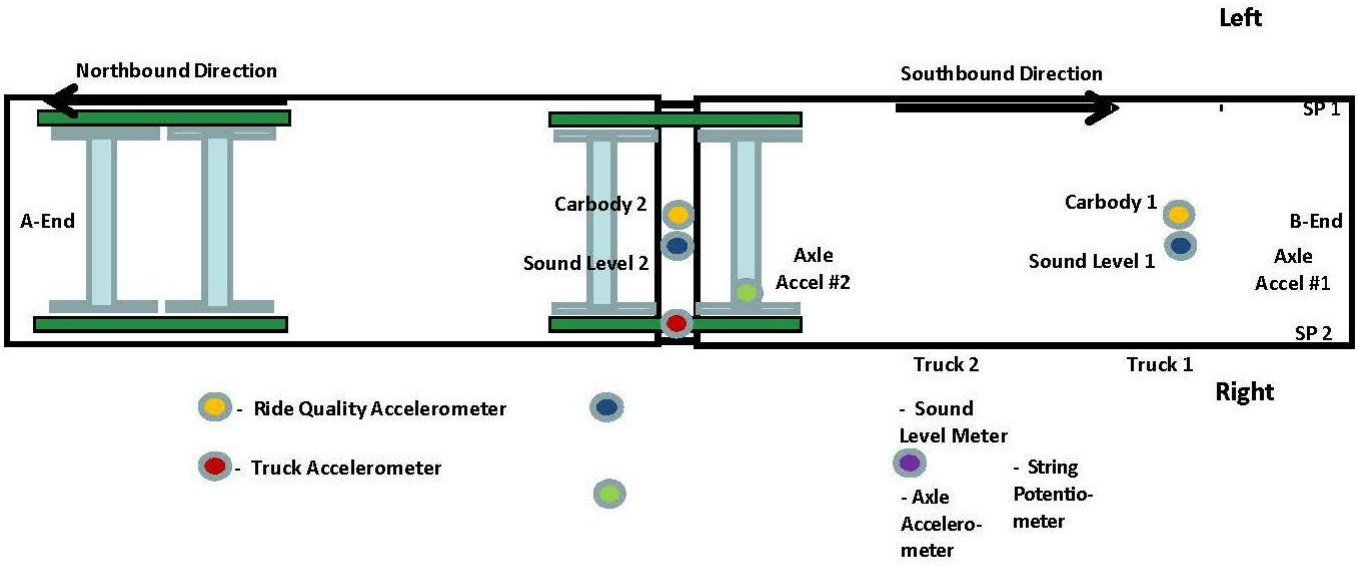


Figure 2. Sensor Layout Used For Test Vehicles

Tables 1 and 2 summarize the results for the testing performed by ENSCO over both the test and reference frogs. In both Tables 1 and 2, the Expo frog data from the run having the closest speed to that of the reference frog test was chosen so as to compare runs with the test parameters being as similar as possible. Of primary interest is the impact data presented in table 2.

Table 1. Summary of Peak-to-Peak Vibrations (g)

Accelerometer Information		Siemens				Nippon Sharyo			
		Southbound		Northbound		Southbound		Northbound	
		Expo	Ref	Expo	Ref	Expo	Ref	Expo	Ref
Sensor	Orientation	8.3 mph	7.5 mph	9.5 mph	7.9 mph	3.4 mph	3.7 mph	6.1 mph	6.6 mph
Axle 1	Lateral	-	-	-	-	2.74	5.44	7.08	8.20
	Vertical	10.14	12.77	14.25	10.10	5.89	13.63	16.02	14.67
Truck 1	Lateral	2.83	1.54	2.18	1.91	0.99	1.19	1.49	1.57
	Vertical	3.01	2.37	4.40	1.85	2.55	4.00	4.85	5.03
CB 1	Lateral	0.30	0.22	0.35	0.14	0.18	0.09	0.24	0.12
	Vertical	0.36	0.17	0.33	0.19	0.10	0.14	0.16	0.15
Sensor	Orientation	8.1 mph	7.7 mph	5.6 mph	7.4 mph	3.6 mph	3.4 mph	5.3 mph	5.0 mph
	Lateral	6.11	3.16	2.93	3.58	5.62	6.12	5.66	6.90
	Vertical	11.95	11.61	6.69	8.77	9.65	9.50	10.33	8.60
	Lateral	3.65	1.31	2.35	2.56	1.97	1.53	1.88	2.47
	Vertical	5.06	4.17	4.26	3.03	4.14	2.51	4.92	3.00
	Lateral	2.22	0.40	0.63	0.42	0.38	0.23	0.46	0.16
	Vertical	1.26	0.82	0.47	1.48	0.54	0.33	0.44	0.25

Table 2. Summary of Impacts (grms)

Accelerometer Information		S				Nippon			
		Southbou		Northbound		Southbound		Northbound	
		Ex	R	Exp	R	Exp	R	Exp	R
Sensor	Orientation	8.3	7.5	9.5	7.9	3.4	3.7	6.1	6.6
Axle 1	Lateral	-	-	-	-	10.6	15.8	33.2	18.7
	Vertical	23	14.9	40.8	15.8	5.56	6.11	10.8	6.00
Truck 1	Lateral	1.	0.69	0.84	0.74	0.50	0.50	0.79	0.54
	Vertical	1.	0.93	2.00	0.92	1.13	1.52	2.18	1.74
CB 1	Lateral	0.	0.09	0.20	0.06	0.10	0.06	0.14	0.07
	Vertical	0.	0.06	0.11	0.06	0.05	0.04	0.06	0.05
Sensor	Orientation	8.1	7.7	5.6	7.4	3.6	3.4	5.3	5.0
Axle 2	Lateral	14	4.86	7.37	11.5	14.4	7.94	11.6	10.9
	Vertical	22	9.15	10.8	10.6	42.4	18.7	23.2	14.0
Truck 2	Lateral	1.	0.58	0.63	1.21	0.89	0.59	0.79	1.04
	Vertical	2.	0.97	1.99	1.25	1.62	1.10	1.89	1.42
CB 2	Lateral	0.	0.18	0.15	0.16	0.15	0.08	0.19	0.06
	Vertical	0.	0.31	0.14	0.57	0.19	0.07	0.19	0.07

Of greatest concern is the report of high levels of lateral loading and associated lateral to vertical loadings of the Nippon Sharyo car in both the Northbound (worst case) and Southbound directions. Note, these loadings are significantly higher than those for the reference frog movement.

Analysis of the full set of ENSCO data shows that in general the Expo frog readings were higher than the reference frog readings. While ENSCO indicated in its report that this was the case about 75% of the time, review of the actual data did not support this large a percentage, but rather that the measured effects from the Expo frog and the reference frog were similar in many instances. The Expo frog did create a more severe load environment for the vehicles. The testing found that the Expo frog caused measurably higher impact energy, as well as larger truck displacements when compared to a frog of standard design. The sound levels experienced in the Expo frog were also reported to be about 5-6 dBA higher than those experienced in the reference frog.

In addition to the actual testing, ENSCO performed a dynamic model analysis of the vehicle going through the junction with the 'blip" using the Vampire vehicle-track dynamic interaction model. A reference analysis was also performed going through a standard frog. The analysis assumed an operating speed of 5 mph through the frog, a new wheel flange angle of 75 degrees and dry rail with a coefficient of friction (μ) of between 0.3 and 0.5. Figure 3 presents a comparison of the two modeling runs, focusing on the L/V ratio (ratio of Lateral/Vertical wheel-rail force). The L/V ratio is a well established indicator of potential wheel/climb risk.

L/V Ratio

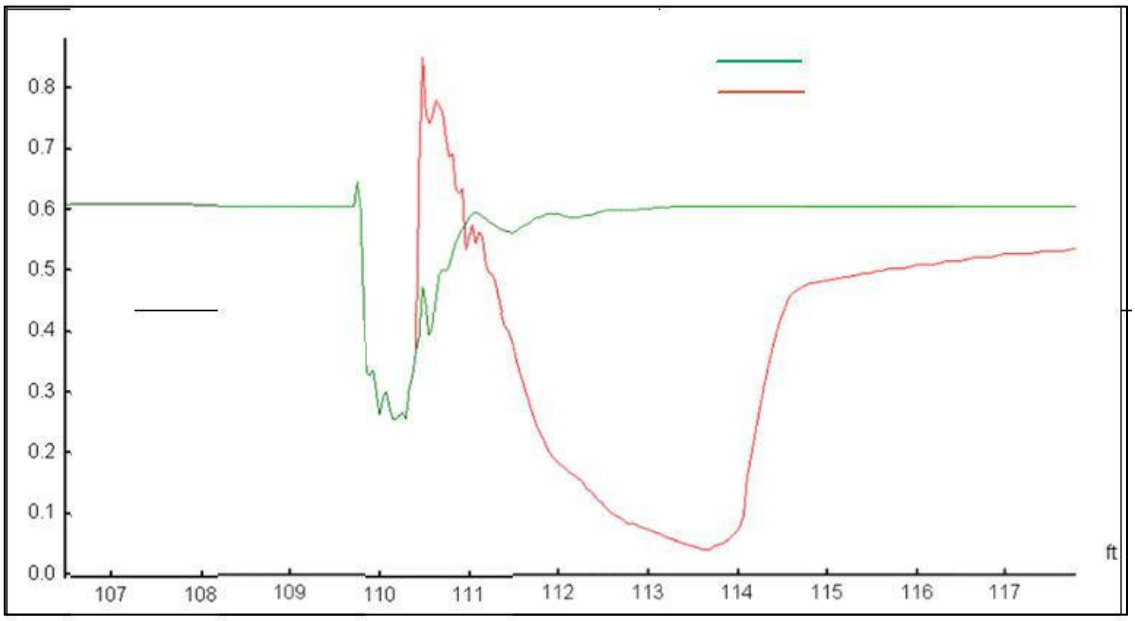


Figure 3. Comparison of L/V Ratio on the Lead Right Wheel through a Standard Frog (Green) and Expo Frog (Red)

As can be seen from this Figure 3, the Expo frog movement showed an L/V ratio of 0.8, as opposed to the standard movement of 0.6. While 0.8 is sometimes regarded as the "minimum" L/V threshold, ZETA-TECH performed a more detailed analysis of the L/V ratio threshold as a function of the actual wheel flange angle and coefficients of friction using the Nadal wheel climb analysis methodology. The results of the analysis showed that for the new wheel flange angle of 75 degrees (the same as was used by ENSCO in the modeling run) and for a range of coefficient of friction of 0.3 to 0.5, the actual L/V derailment threshold is 1.13, well above the model calculated L/V ratio through the Expo frog (of 0.8). This indicates that there is no risk of wheel climb, since the L/V ratio was less than the Nadal calculated derailment threshold.

The actual thresholds, as a function of coefficient of friction (μ) is as follows:
For $\mu = 0.3$ L/V threshold for derailment = 1.62
For $\mu = 0.35$ L/V threshold for derailment = 1.47
For $\mu = 0.4$ L/V threshold for derailment = 1.34
For $\mu = 0.5$ L/V threshold for derailment = 1.13

As was noted above, this was based on a wheel flange angle of 75 degrees (same as was used in the ENSCO Vampire analysis). For these wheels, as the wheels wear, the wheel flange angle increases- and the corresponding L/V threshold increases, - the worst case scenario is the new wheel with the wheel flange angle of 75 degrees, as noted above.

Thus, based on the L/V values calculated by ENSCO, there does not appear to be a risk of wheel climb at an operating speed of 10 mph.

3a. Field Evaluation of Junction

Harsco Rail's ZETA-TECH Business unit began its evaluation with a field inspection of the LA Metro Junction Diamond on Wednesday, September 5, 2012. The inspection was performed by Mr. D. R. Holfeld, Director – Field Engineering for ZETA TECH accompanied by David Walker, Sr. Manager Construction, EXPO Authority, two Flag persons from LA Metro and two Representatives from the California Public Utilities Commission (CPUC).

Upon arrival at the Junction Diamond, several trains were observed travelling through the diamond on Track Blue #2 (small radius direction) as well as EXPO #3 (large radius direction). See Figure 4.

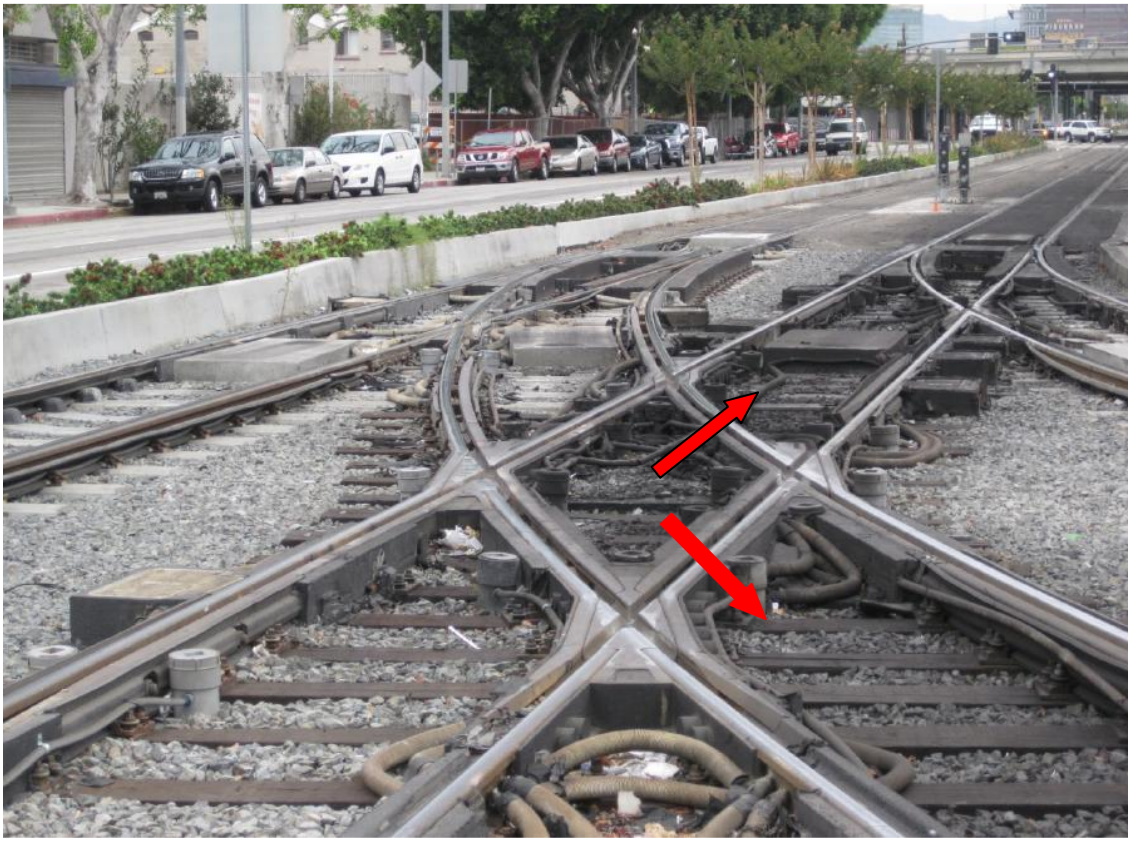


Figure 4: Junction Diamond. RED arrows indicate direction of normal travel.

The following measurements were taken at the diamond:

- Flangeway width, outside rail, BLUE#2 – 2 1/8" to 2 ¼" at the "Blip" on D2 = 2 3/8"
- Flangeway Width, inside rail, BLUE#2 – 1 3/4" to 1 7/8"
- Gauge on EXPO#3 track – 56 ½"
- Gauge on BLUE#2 Track – 57"
- Gauge at "Blip" – 56 ½"

- Guard Face Gauge – 52 7/8” – 53 1/8”
- Track center to center distances Blue#1-Blue#2 = 14.45’
- Track center to center distances EXPO#3-EXPO#4 = 12.77’
- Diamond Angle – 20°38’ 7”
- Radius of Blue#2 through Diamond = 160’
- Frog number of turnout coming off EXPO#4 to Blue#2 = #4 ¼ with 190’ radius curve
- Gauge at the ½” point of frog for the above noted turnout = 57 ½”

The junction diamond is located between the Grand Station on one side (Figure 5) and Washington Blvd. and Flower Street on the opposite side (Figure 6).

The diamond junction is built on wood tie and ballast track where-as all other tack and turnouts are built on concrete ties or embedded track (Figures 5 and 6).

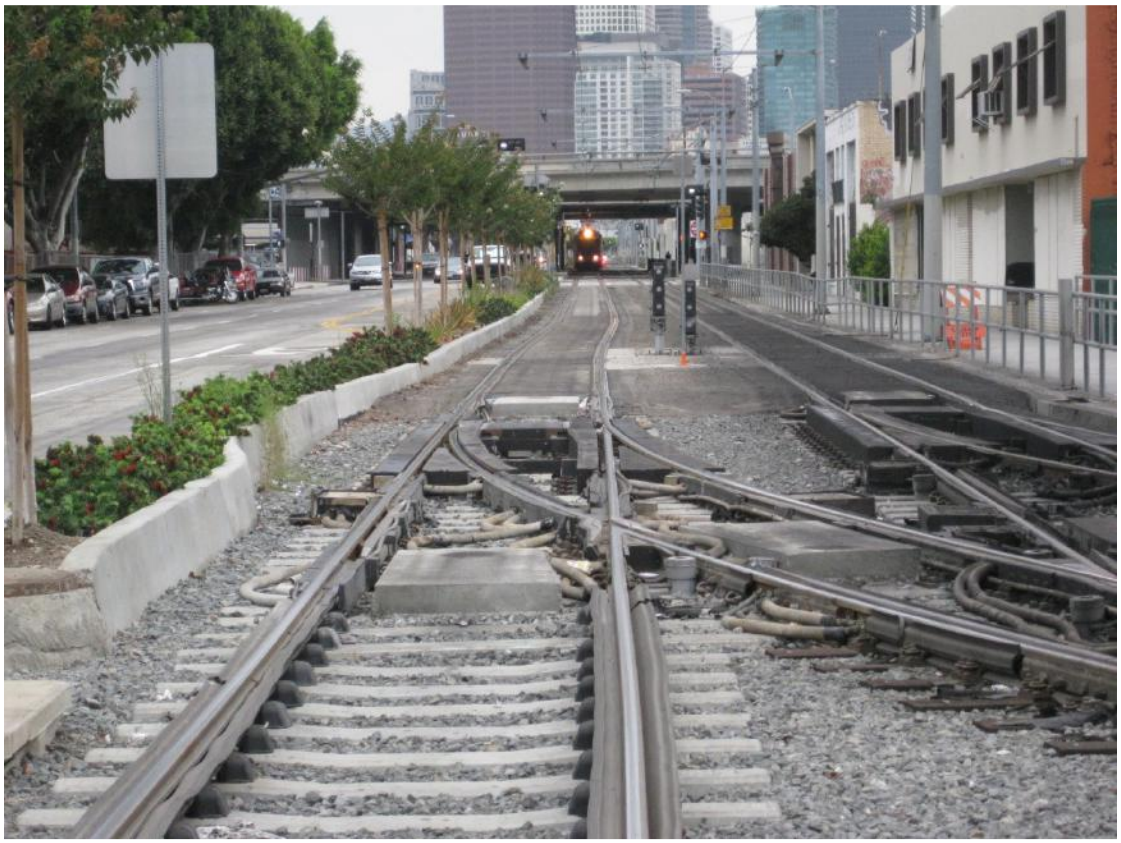


Figure 5: Straight move view of the Junction Diamond Looking North

Figure 6: Flower Street View of Diamond Looking South

Observation of the frogs elements of the diamond indicates that the flangeways in the diamond on track Blue#2 (both outer and inner rails) are being abraded by the back of flange of passing wheels. In addition, the wing rail of the frog in the turnout on EXPO #3 is being worn by the back of flange of passing wheels. (see Figure 7)

Figure 7: Observed Wing Rail Wear

As noted previously, there is a transition ramp welded onto the center frog of the diamond just ahead of the "Blip" that aids in moving the wheel flange onto the Blip without causing a large impact (see Figures 8 and 9). However, this is for Southbound movement of trains, there is no ramp for trains operating in the reverse (northbound) direction.

Also, as can be seen in Figure 8, there is a small section of the flangeway opposite the "Blip" that has been either ground off or worn away that allows the wheel flange to move over when making contact with the "Blip". Observation of train movements through the junction showed very little impact noise generated at the blip when trains are operating at speeds less than 10 mph.

Figure 8: "Blip" and Ramp on D2

Figure 9:

In order to allow for proper analysis of the movement through the frogs in question, the following supplemental data was obtained during the field visit.

- Vehicles that operate through the junction diamond are of two types: Nippon Sharyo P865 (54 cars) and P2020 (15 cars) as well as Siemens P2000 (23 cars).
- All vehicles are equipped with the RTD-1 wheel profile having a 1.1563 inch flange thickness, compound flange/tread radius and modified tread conicity.
- Axle to axle spacing for the Nippon Sharyo vehicles is 1900mm = 74.8 inches and for the Siemens vehicles is 2100mm = 82.7 inches.
- Wheel diameters at the tape line for the Nippon Sharyo and for the Siemens vehicles is 28 inches.
- Both vehicles operate as married pairs with a single center truck.
- Back to back measurements for both vehicle types is 53 3/32 to 53 3/8 inches (53.094" to 53.375") with an average of 53.235 inches
- AREMA Standard Plan 791-12 states that for back to back spacing of 53 1/4" where track gauge is 56 1/2", flangeways shall be 1 7/8"on both inner and outer rails. For back to back spacing of 53 1/8', the inner flangeway shall be 1 7/8" and the outer flangeway shall be 2". This is AREMA design criteria.

Table 3: AREMA: Table of Practical Gages and Flangeways for Curved Track

791–12

TABLE D–GAGES — CURVED TRACK — LOCOMOTIVES

6 WHEEL TRUCK			4 WHEEL TRUCK 10′–0″ MAX	GAGES DEGREE OF CURVATURE											
	"G" GUARDED CURVES	"P" UNGUARDED CURVES		33°	30°	28°	26°	24°	22°	20°	18°	16°	14°	12°	10°
				4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	—	11′–6″ & UNDER		4′–8 7/8″	4′–8¾″	4′–8¾″	4′–8⅝″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	11′–6″ & UNDER	OVER 11′–6″ TO 12′–1″		4′–9 ″	4′–8 7/8″	4′–8¾″	4′–8¾″	4′–8⅝″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 11′–6″ TO 12′–1″	OVER 12′–1″ TO 12′–8″		4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8¾″	4′–8¾″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 12′–1″ TO 12′–8″	OVER 12′–8″ TO 13′–3″		4′–9 1/4″	4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8 7/8″	4′–8¾″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 12′–8″ TO 13′–3″	OVER 13′–3″ TO 13′–10″			4′–9 1/4″	4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8 7/8″	4′–8¾″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 13′–3″ TO 13′–10″	OVER 13′–10″ TO 14′–5″				4′–9 1/4″	4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8¾″	4′–8¾″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 13′–10″ TO 14′–5″	OVER 14′–5″ TO 15′–0″					4′–9 1/4″	4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8¾″	4′–8⅝″	4′–8½″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 14′–5″ TO 15′–0″	OVER 15′–0″ TO 15′–7″						4′–9 1/4″	4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8¾″	4′–8⅝″	4′–8½″	4′–8½″
TRUCK WHEEL BASE	OVER 15′–0″ TO 15′–7″	—							4′–9 1/4″	4′–9 1/8″	4′–9″	4′–8 7/8″	4′–8¾″	4′–8⅝″	4′–8½″

(A) Data for Table "D" were derived from Plan No.792.

(B) Gages are given to the nearest 1/8" and are based on maximum wheel diameter of 42", spaced back to back of flanges 4′–5 3/8" and average total lateral play in middle and end axles of 6-wheel truck amounting to 3/8".

(C) For gages for trucks having an average total lateral play in middle and end axles other than 3/8", see Note 4(b) Plan No.792.

(D) For gages for trucks having wheels spaced back to back of flanges 4′–5 1/4" or 4′–5 1/8", see Note 4(c) Plan No.792 for "UNGUARDED CURVES" and Note 4(d) Plan No.792 for "GUARDED CURVES".

WIDENED GAGE PER NOTE 2(a) OR 2(c)			ADJUSTED GAGE FOR GUARDED CURVES PER NOTE 2(b)					
WHEELS 4′–5 3/8" B TO B			WHEELS 4′–5 1/4" B TO B		WHEELS 4′–5 1/8" B TO B			
GAGE	FLANGEWAYS		GAGE	FLANGEWAYS	GAGE	FLANGEWAYS		
	IN.RL.	OUT.RL.		BOTH		IN.RL.	OUT.RL.	
4′–8 5/8"	1 1/8"	2 "	4′–8 1/2"	1 1/8"	4′–8 1/2"	1 1/8"	2"	
4′–8¾″	2"	2"	4′–8 5/8"	2"	4′–8 5/8"	2"	2 1/8"	
4′–8 7/8"	2 1/8"	2 1/8"	4′–8¾″	2 1/8"	4′–8¾″	2 1/8"	2 1/4"	
4′–9"	2 1/4"	2 1/4"	4′–8 7/8"	2 1/4"	4′–8 7/8"	2 1/4"	2 3/8"	
4′–9 1/8"	2 3/8"	2 3/8"	4′–9"	2 3/8"	4′–9"	2 3/8"	2 1/2"	
4′–9 1/4"	2 1/2"	2 1/2"	4′–9 1/8"	2 1/2"	4′–9 1/8"	2 1/2"	2 5/8"	
4′–9 3/8"	2 5/8"	2 5/8"						
4′–9 1/2"	2 3/4"	2 3/4"						

NOTES

1. GENERAL
   PURCHASER SHALL IN ALL CASES SPECIFY: The gage and the width of flangeways to be used in crossings and other trackwork units to suit the curve and equipment as described in Notes 2 and 3.

2. GAGE
   (a) For operation with wheel mounting per Note "B", specify from Table "D" the gage required by the longest truck wheel base.
   (b) For operation with trucks having wheels spaced back to back of flanges 4′–5 1/4" or 4′–5 1/8", see Note "D" for gage determination. For convenience in specifying adjusted gages for guarded curves, comparable gages to those shown in Table "D" are listed in Note 3, below.
   (c) For economy in maintenance of curved crossings, 4′–9" gage should not be exceeded.

3. FLANGEWAYS
   Width of Flangeways for various gages and equipment shall be specified as listed below:

4. CAR TRUCKS
   Two axle car trucks can be operated on all curves where gages and widths of flangeways suitable for locomotives are specified.

5. REFERENCES
   (a) See Plan No.790 for flangeways and other data when gage is not widened for curvature.
   (b) See Plan No.100, Section 7, for permissible variations in manufacture.

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE OF WAY ASSOCIATION

TABLES OF PRACTICAL GAGES AND FLANGEWAYS FOR CURVED TRACK

PLAN NO. 791–12

Adopted 1934. Converted to C.A.D. June 2002.

3b. Observations and Discussions:

a) It has been postulated that poor alignment design, particularly the direct transition from the 190' radius curve of the Turnout into the diamond without a transition spiral, will generate excessive lateral forces and can result in a derailment.

Given the physical constraints of the area such as the proximity to the Grand Station and travel lanes on Washington Street, the use of tight radius curves and limited spiral transition curves represents a realistic configuration. While having a transition spiral located between a sharp radius curve and tangent section is highly desirable, the low speed nature of the operations here (10 mph) and the fact that the entire area is 'flat, with no superelevation, supports the design as being adequate for the intended use. Detailed testing of lateral and vertical force and acceleration levels by Ensco, Inc. in May 2012 revealed no reported excessive lateral force or Lateral force/Vertical force [L/V] levels at the transitions. Field observations by ZETA-TECH personnel further supported this. While the lack of a spiral may require some form of additional maintenance, there is no evidence of unsafe operating conditions.

b) It has also been postulated that the current design uses substandard construction and components, particular the use of a jointed (bolted) diamond instead of a solid rail-bound manganese diamond.

While a solid rail bound manganese diamond would have been preferable from a maintenance and longer life point of view, the current design is safe and in accordance with industry practices (e.g. AREMA).

c) There has been a concern expressed about the ability to transition from the R190 frog at 57 inch gauge[1] to the newly gauged diamond at 56 ½ inch. Should the frog be regauged as well to 56 ½ inches and if not, is there a problem having this transition over such a short distance?

It would be better if the frog diverging route was reset to standard gauge so that there would be no transition and the frog wing rail would not be subjected to the observed high wear (as noted in Figure 7). However, if, due to time and cost restraints, this procedure is not a realistic option, this lack of transition does not represent a serious problem so long as the "line" rail remains uniform throughout this transition zone. The change in gauge must be facilitated by moving the "grade" rail (inside rail) closer to the line rail by ½ inch and NOT moving the "line" rail from its current position. This transition should take place over a distance not less than the longest axle to axle spacing of any vehicle using this route. In this case, 82.7 inches.

[1] NOTE: The actual gauge, at the ½ inch point of frog for the diverging route was measured at 57 ½".

4. Analysis of Problem and Cause(s)

The cause of the initial problem (flange strikes on D4 frog), appears to be the result of wide gauge through the diamond. With the maximum guard face gauge being 53.125 inches and the minimum wheel back-to-back being 53.094 inches, the back of the wheels are contacting both flangeway guard rails simultaneously. As a wheel approaches the D4 frog, it is aimed directly at the ½ inch point (see Figure 10).

It was noted that from observations and measurements taken in the field, that the existing diamond was manufactured in accordance with design specifications. In addition, the diamond was installed correctly for alignment, surface and crosslevel and does not appear to have been modified during installation. All problems associated with the D4 Frog being damaged by passing wheels are the direct result of an inappropriate diamond design that was not in compliance with AREMA Specifications.

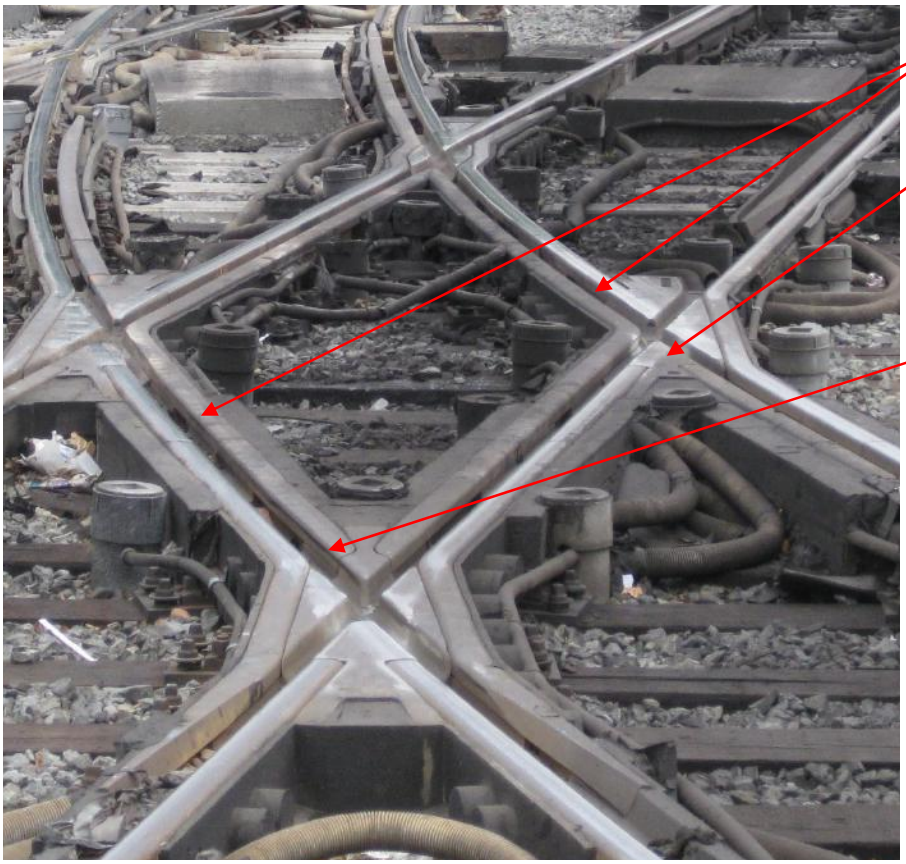


Figure 10: Movement through D4 Frog

It should be noted that the MTA Design Criteria Section 4.4 – TRACK GAUGE requires track gauge to be widened as the radius of curvature decreases. The criteria states that for a curve of radius larger than 82' but less than 250', for Light Rail Transit Systems, the gauge should be widened to 4'9", however; the last paragraph of Section 4.4 states: "Gauges for special trackwork shall be as recommended in the AREMA Portfolio of

Trackwork Plans except as modified to reflect the physical and operation characteristics of the system." Plan 791-12 of the AREMA Portfolio of Trackwork Plans does not recommend gauge widening at the diamond crossing based on the degree of curvature and vehicle types being used.

This situation would not have occurred had the diamond been installed using standard gauge through both legs. The question is, if standard gauge were used in the 160 foot radius curved track, would this result in wheel sets in the bogies of existing vehicles becoming pinched while trying to traverse the diamond.

In order to addresses this clearance issue, and to determine the ability to use standard gauge through the diamond, an analysis of the wheel sets negotiating the 160 foot radius curve of the junction diamond was performed.

The following measurements were used in the calculations:

- Back-to-back spacing is 53.375 inches (worst case)
- Wheel diameter is 28 inches
- Flange width at the rail gauge face contact point is 1.1563 inches
- Axle-to-axle spacing on each truck is 74.8 and 82.7 inches
- Centerline radius of the curved diamond is 160 feet
- Gauge may vary from 4 foot 8 ½ inches up to 4 foot 9 ¼ inches

Figures 11A though D show the key measurement and analysis parameters.

Figure 11A: Wheel Dimensions. Note actual contact is at the ¾" point.

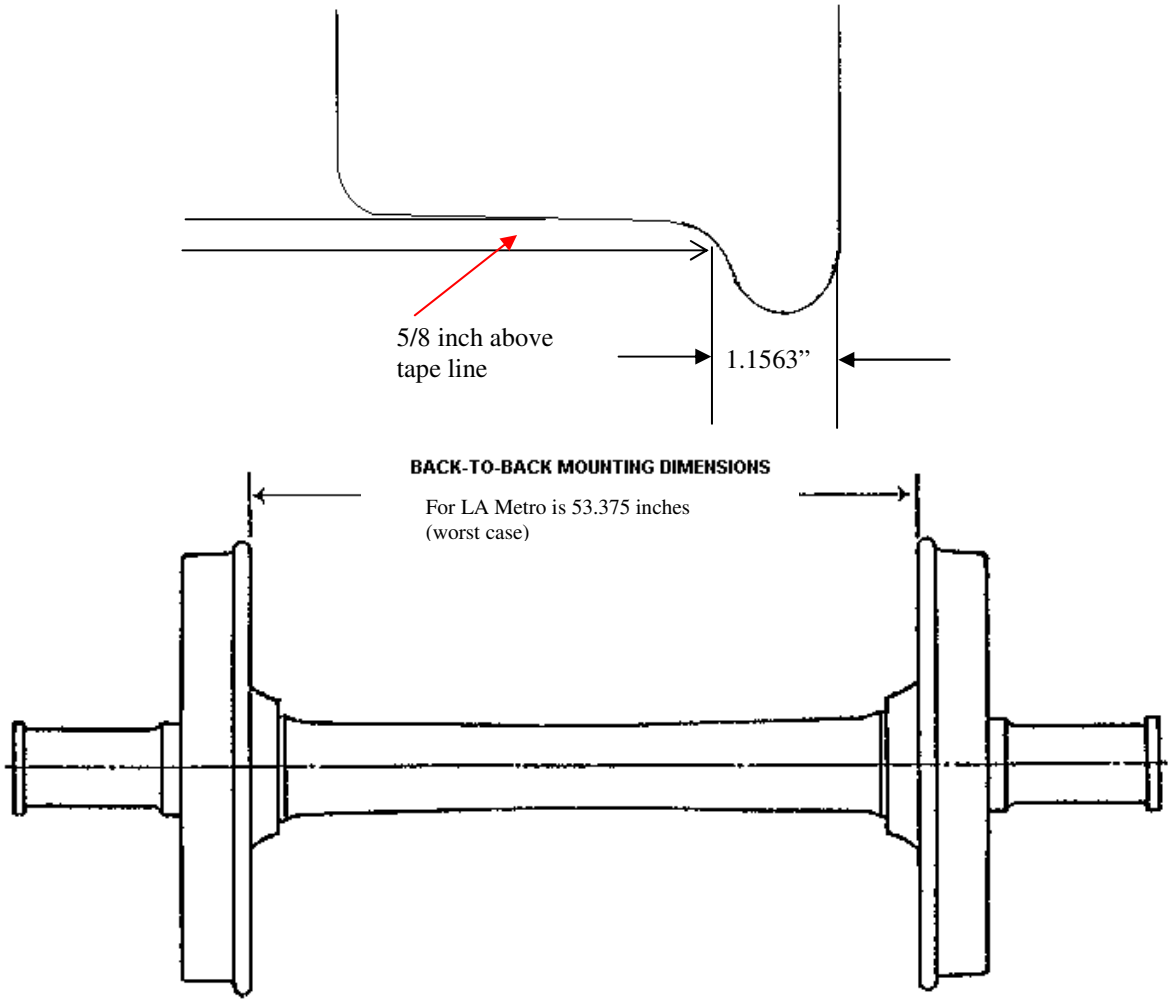
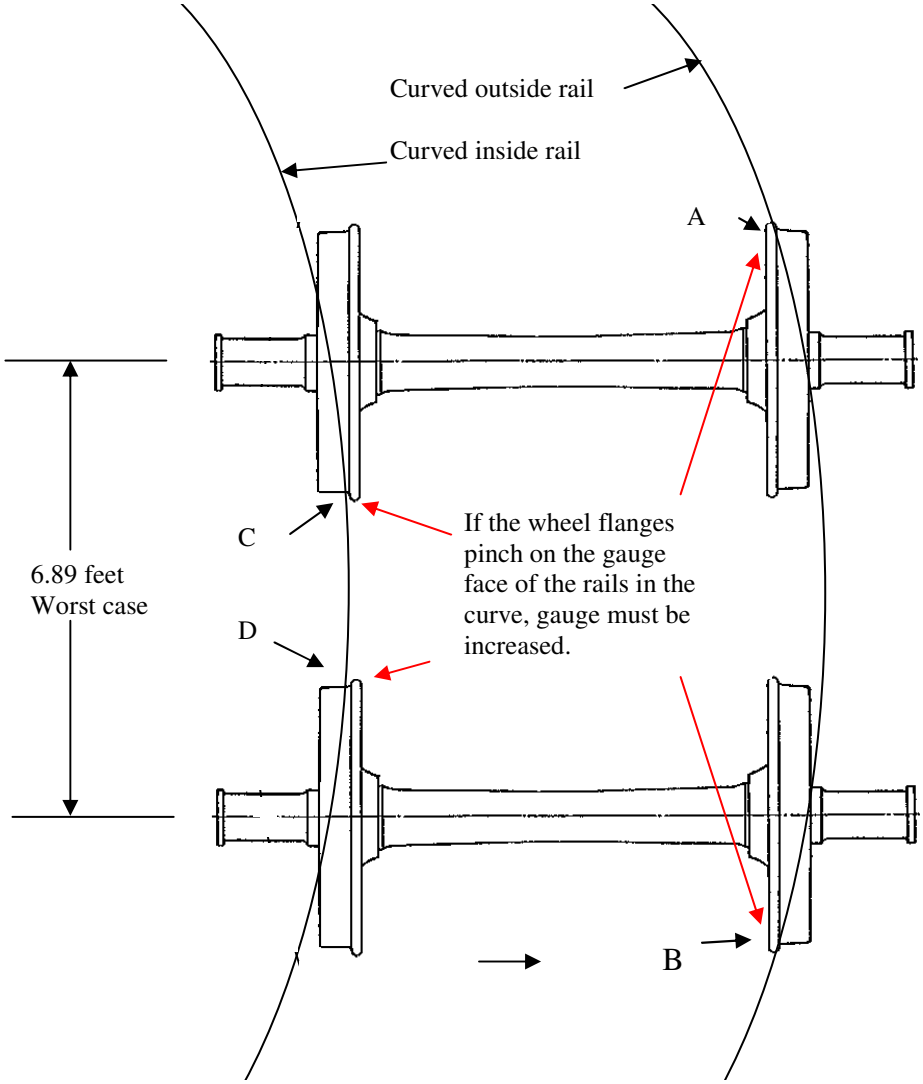


Figure 11B: Wheel Back to Back Dimensions

Figure 11C: Truck Negotiation of Curve



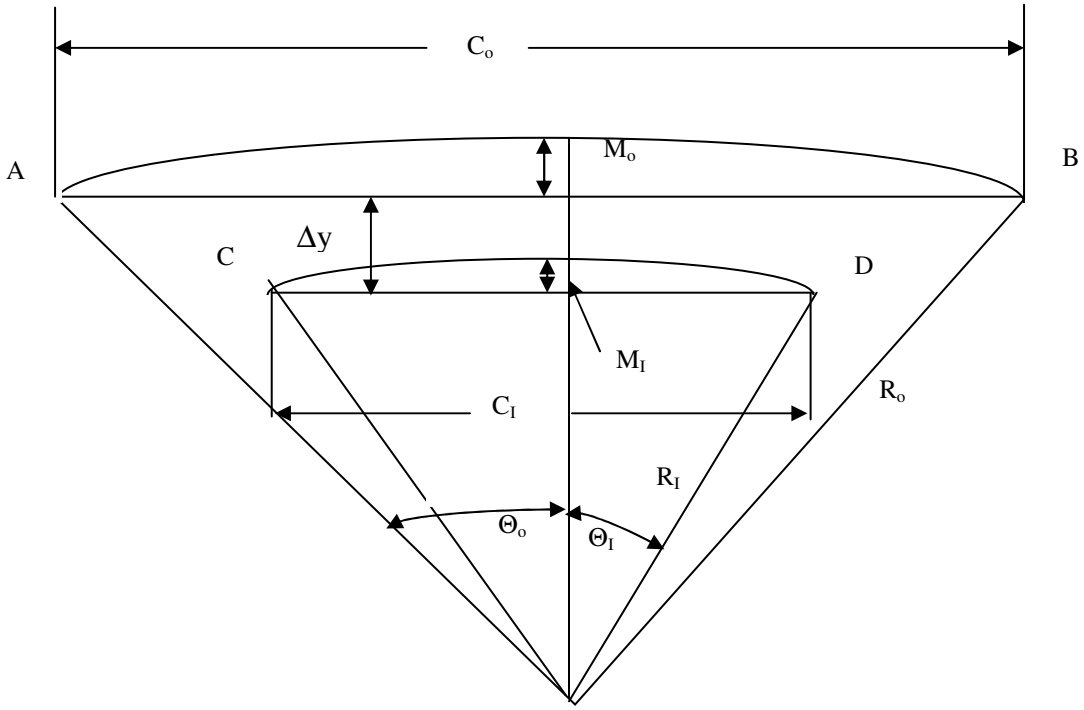


Figure 11D: Clearance Calculations

Using the following formulae:

$C_o = 2R_oSin(\Theta_o)$
$M_o = R_o(1-Cos(\Theta_o))$
$C_I = 2R_ISin(\Theta_I)$
$M_I = R_I(1-Cos(\Theta_I))$
$\Delta y = (R_o - M_o) – (R_I – M_I)$
$= (R_o- R_I) + (M_I - M_o)$
$= G + (M_I - M_o)$

Where:

G = Track Gauge (minimum allowable)
R_o = Radius of outer rail
R_I = Radius of inner rail
A = Axle spacing = 82.7" = 6.89'
X = Distance to contact point from axle = 14.75" (with a 28" diameter wheel)
B = Back-to-back distance of wheel/axle set = 53.375"
Y = Distance from back of flange to contact point – 1.1563"
Δy = Distance between chords (binding lines) = B + 2y
C_o = Length of outer chord = A + 2X
C_I = Length of inner chord = A – 2X
R_{CL} = Radius of centerline of track in diamond, = 160'
$R_o = R_{CL} + ½G$
$R_I = R_{CL} - ½G$

Therefore:

$$\mathbf{G = 2[B + 2y + R_{cl}(Cos\Theta_I - Cos\Theta_o)]/(Cos\Theta_I + Cos\Theta_o)}$$
$$\mathbf{= 56.308 \underline{inches}}$$

Which means that the gauge through the junction diamond could be reduced to 56.308 inches before a Siemens truck would flange on all four wheels. This also assumes that:

1. All the wheels are brand new

2. The axles are perfectly rigid

3. The back-to-back measurements are maximum 53.375 inches.

Therefore, using standard gauge in the junction diamond would not cause the wheel sets to bind while traversing through the 160 foot radius curve portion.

5. Recommendations:

Based on the analysis of test data, field inspection, and analysis of vehicle and track condition and performance the following interim and long-term recommendations are presented:

A. Interim Recommendations

Based on an onsite inspection of the above noted Junction Diamond, it is determined that the existing diamond may continue to be safely used in its present condition, provided that there is no excessive[2] delay in implementation of one of the permanent recommendations noted below.

This is subject to the following operational and maintenance restrictions:

1. The operational speed through the diamond from EXPO #4 to Blue #2 track shall never exceed 10mph. There is no restriction on train operation through the diamond on the EXPO#3 to Blue #1 track.
2. The predominant direction of travel through the 160 foot radius curve of the diamond shall be from EXPO #4 to Blue #2 and **at no time shall a train operate in the reverse direction at a speed in excess of 5mph.**
3. It is expected that the welded "Blip" on frog D2 will wear over time, allowing the frog point on D4 to be impacted. Weekly inspections shall be made of the weld and D4 frog to ensure the safe operation of trains through the diamond. Any indication of D4 being impacted by passing wheels shall be reason to remove the diamond from service and build up the "blip" weld back to ½" stand-off.
4. If a permanent repair has not been implemented at the end of 6 months of operation, the diamond shall be thoroughly inspected and evaluated by an outside expert to determine what, if any, action must be taken in order to continue operating in a safe mode. NOTE: It is highly recommended that a permanent repair be implemented as quickly as possible.

B: Permanent Recommendations

Based on the above observation and analysis, there are several possible options that can be considered for a permanent correction to the problem. They include:

1. Complete Removal of the Diamond Junction and replacement with cross-over(s),or
2. Redesign of the Diamond Junction to Cross at an angle greater than 30 degrees, or
3. Correction of gauge back to standard 56 ½" gauge.

These options will be discussed as follows:

B.1 Complete Removal of the Diamond Junction and replacement with cross-over(s)

[2] Refer to item 4

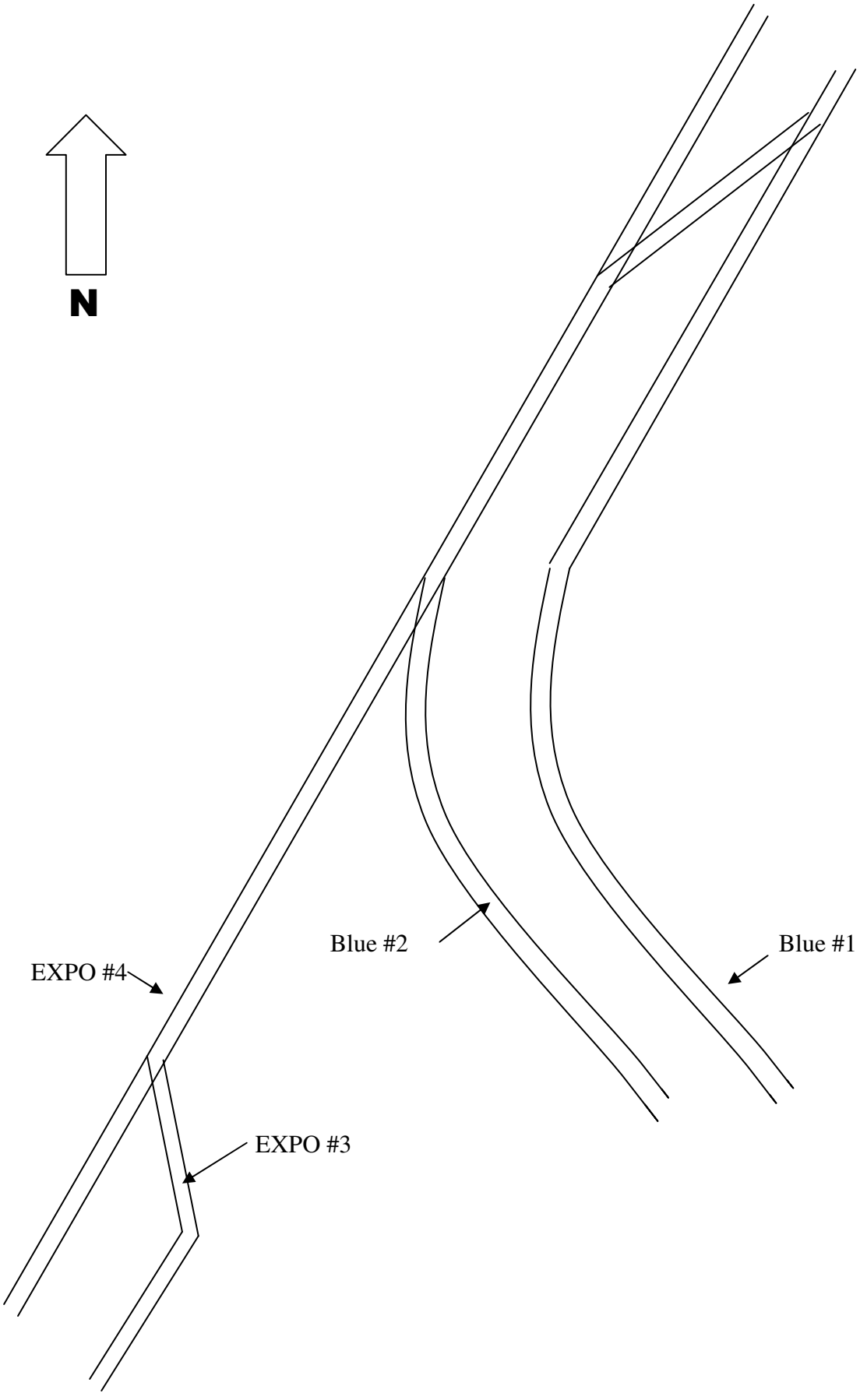
The diamond junction was originally installed to provide the greatest level of operating flexibility. However, due to space limitations, the diamond had to be designed with a 150 foot radius curve which limits train speed and may present maintenance issues. The full diamond junction can be replaced with a crossover. This would remove the existing diamond configuration and its associated maintenance problems, and increase speed of operation through this junction area.

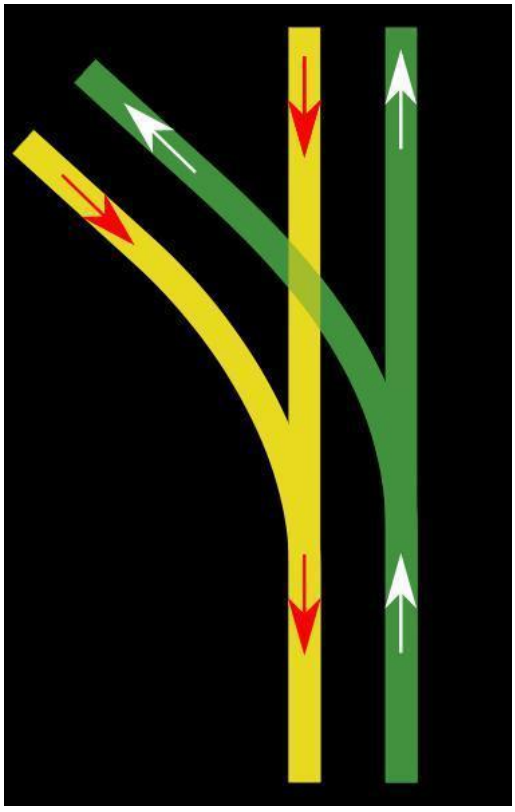
This is accomplished through the new –proposed- junction configuration shown in Figure 12A. In this configuration, EXPO#3 is joined to EXPO#4 south of Flower Street, then single tracked across the roadway and through the 4.5 turnout, with a cross-over installed to bring EXPO#3 back over to Blue#1. The diamond could then be removed and Blue#2 would be connected directly to the number 4.5 turnout (see Figure 12A.).

Figures 12B and 12C show the proposed traffic flows.

If this level of operation is acceptable, then it is strongly recommended that the diamond be eliminated and replaced with this new, higher speed, operating configuration. In addition to the higher operating speeds, this configuration would greatly reduce the level of maintenance at this junction. However; it is possible that this layout may impact and limit future operating flexibility and headways and therefore must be reviewed and approved by Operations prior to any modifications being made.

Figure 12A: Replacement Junction Configuration





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Figures 12B: Before Traffic Flow

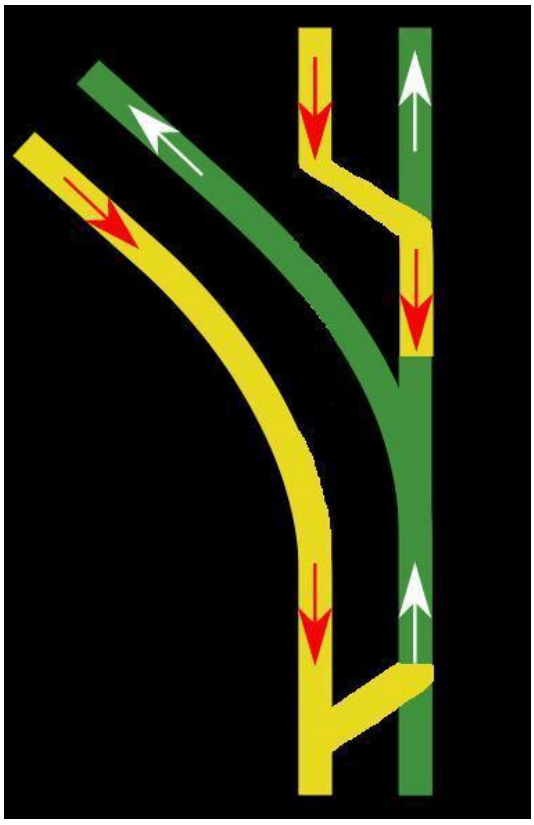

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Figure 12C: After Traffic Flow

B1 Pros and Cons:

Pro: Greatly reduces the complexity of the installation and the corresponding level of maintenance, which is very high.

Con: Reduces the operational capability of the cross-over with a corresponding decrease in operational flexibility.

B.2 Redesign of the Diamond Junction to Cross at an angle greater than 30 degrees

If a diamond must be installed, it is always preferable to cross at an angle greater than 30 degrees. However, with the space restriction imposed by the two road crossings and the station location, this realignment is not a possibility.

B2 Pros and Cons:

Pro: Higher crossing angle results in significantly reduced dynamic loading and corresponding maintenance.

Con: Current configuration makes this very difficult without a major redesign and realignment effort. Due to the space restriction imposed by the two road crossings and the station location, this realignment would require taking several traffic lanes from Washington Blvd and most likely the demolition/reconfiguration of Grand Station.

B.3 Correction of gauge back to standard 56 ½" gauge.

If, due to operating requirements, a diamond junction appears to be required at this location in order to maintain existing line capacity and headways and the diamond cannot be eliminated then the gauge must be corrected back to standard gauge.

As noted previously, the problem with the existing diamond is the fact that the gauge through the diamond on track Blu#2 has been widened to 57" resulting in the back of flanges of passing wheel sets being pinched between the flangeway guardrails. To mitigate this problem, the gauge must be returned to 56 ½ inches. This can be done by either:

a. Removing and replacing the existing diamond with a new diamond having proper gauge throughout or
b. Modifying the existing diamond back to standard gauge on both legs. As previously discussed, standard gauge through the 160 foot radius curve will not pinch vehicle wheel sets, but will push wheels away from the frog at D4.

B3 Pros and Cons:

Pro: Practical and cost effective approach that can be implemented in a relatively short period of time.

Con: While this corrects the current improper design and associated high impact issues that currently exist, it is not a fundamental redesign of the entire complex system that exists at the junction between the two LRT lines.

Of these two gauge restoration options, B3b is recommended.

The gauge replacement can then be accomplished by the following procedures:

1. Cut the running rail and guard rail in the center of the diamond between frogs D1 and D2, removing a section of rail equal to 1.419 inches.
2. Perform the same rail removal between frogs D4 and D3.
3. North of the diamond, cut both running rails on track EXPO#3.
4. North of the diamond cut the north rail of Blue#2.
5. Also, south of the diamond, cut the north rail of Blue#2 and remove 1.38 inches of rail.
6. Loosen all fasteners between all rail cuts and pull the north rail of track Blue#2 together at the cuts noted in steps 1 and 2.
7. Weld or bolt up all remaining rail cuts and reset all plates and fasteners as needed.
8. Replace insert at D2, removing both ramp and “blip”.

Figures 13and 14 illustrates this procedure.

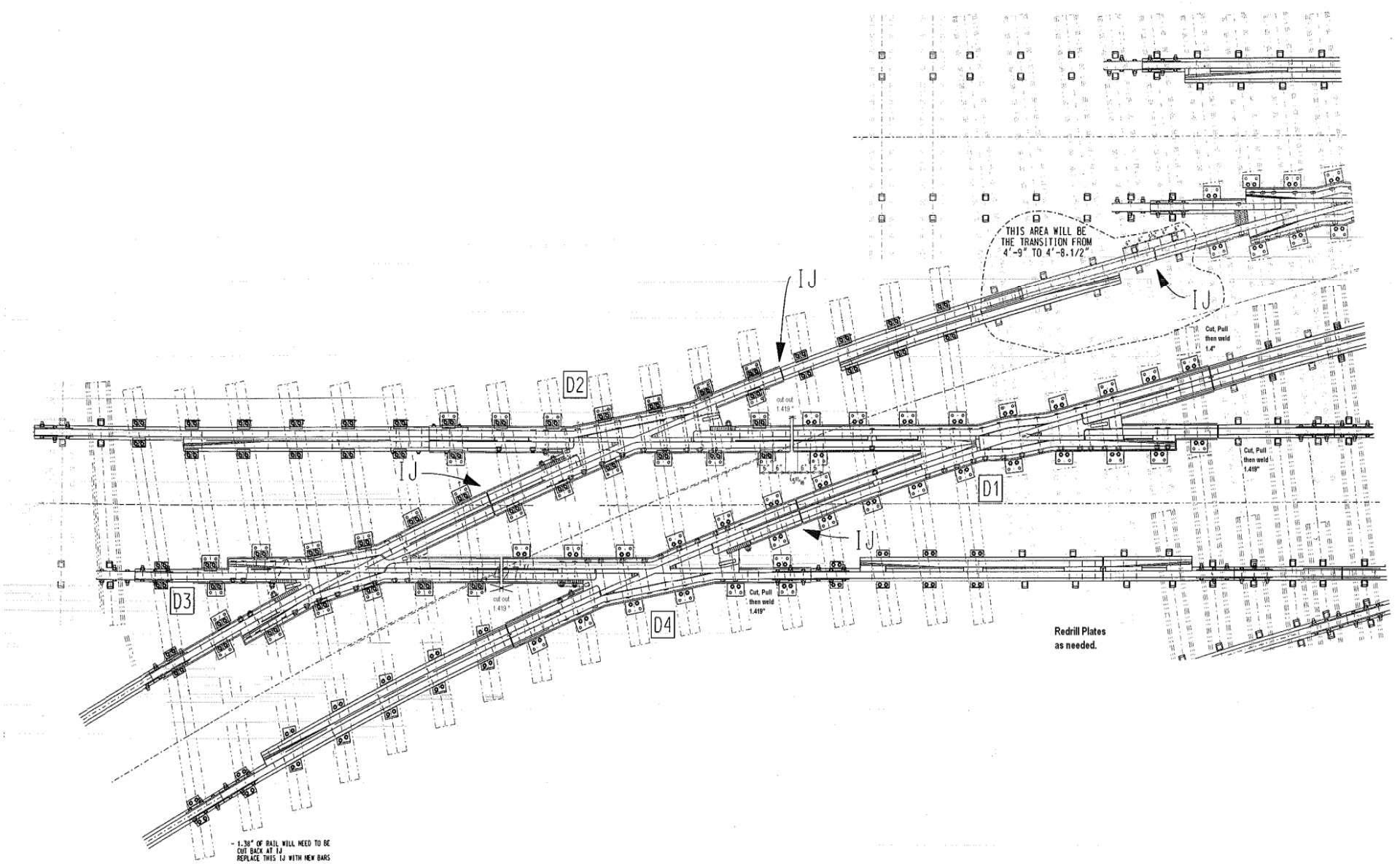

Figure 13: Correction of Gauge

Figure 14: Locations for Cutting Rail to Restore Gauge