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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:

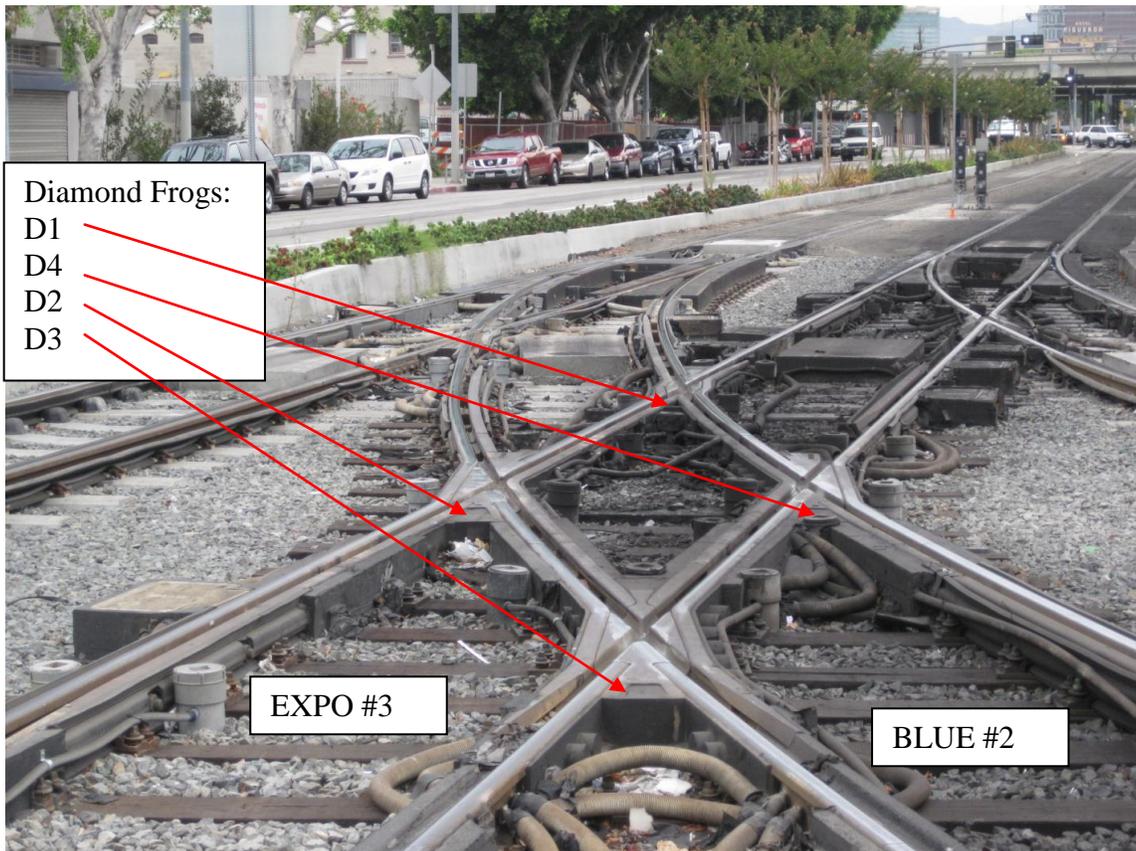
- Avoid the need to for demolition of the existing Grand station.
- Avoid removal of any vehicular traffic lanes on Flower Street or Washington. Note that this constraint may need to be waived in order to provide an acceptable track layout.

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.

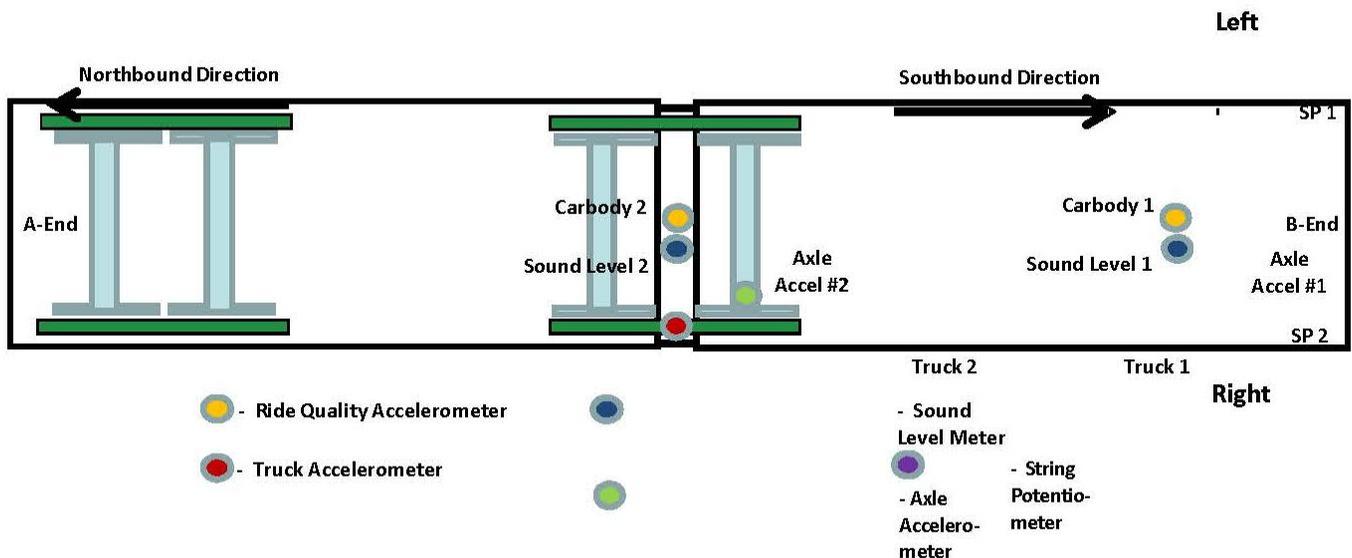


Figure 2. Sensor Layout Used For Test Vehicles

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

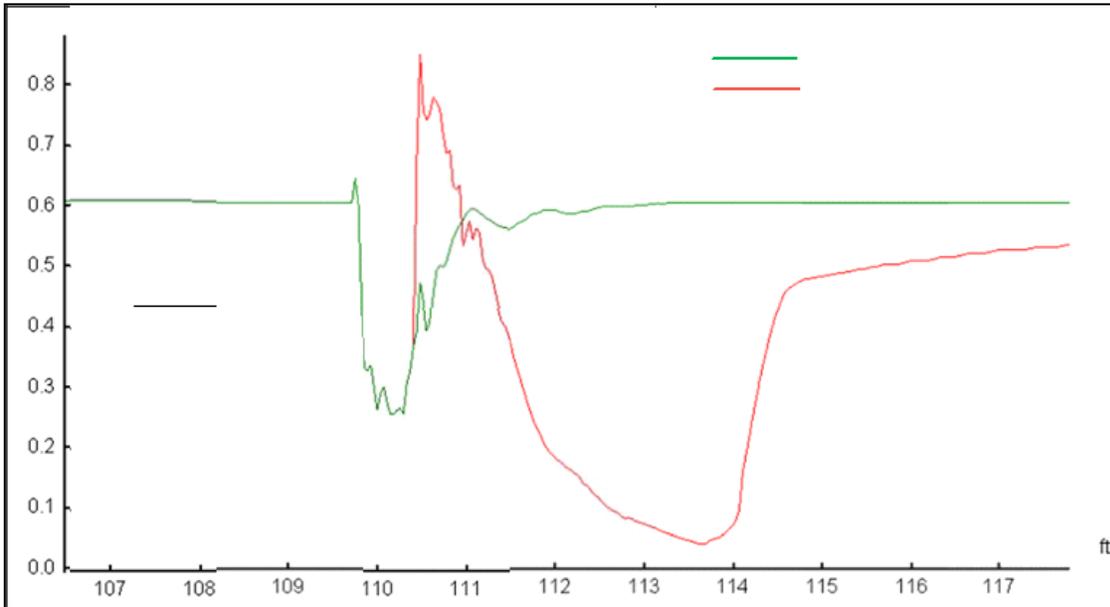


Figure 3. Comparison of L/V Ratio on the Lead Right Wheel through a Standard Frog (Green) and Expo Frog (Red)

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.

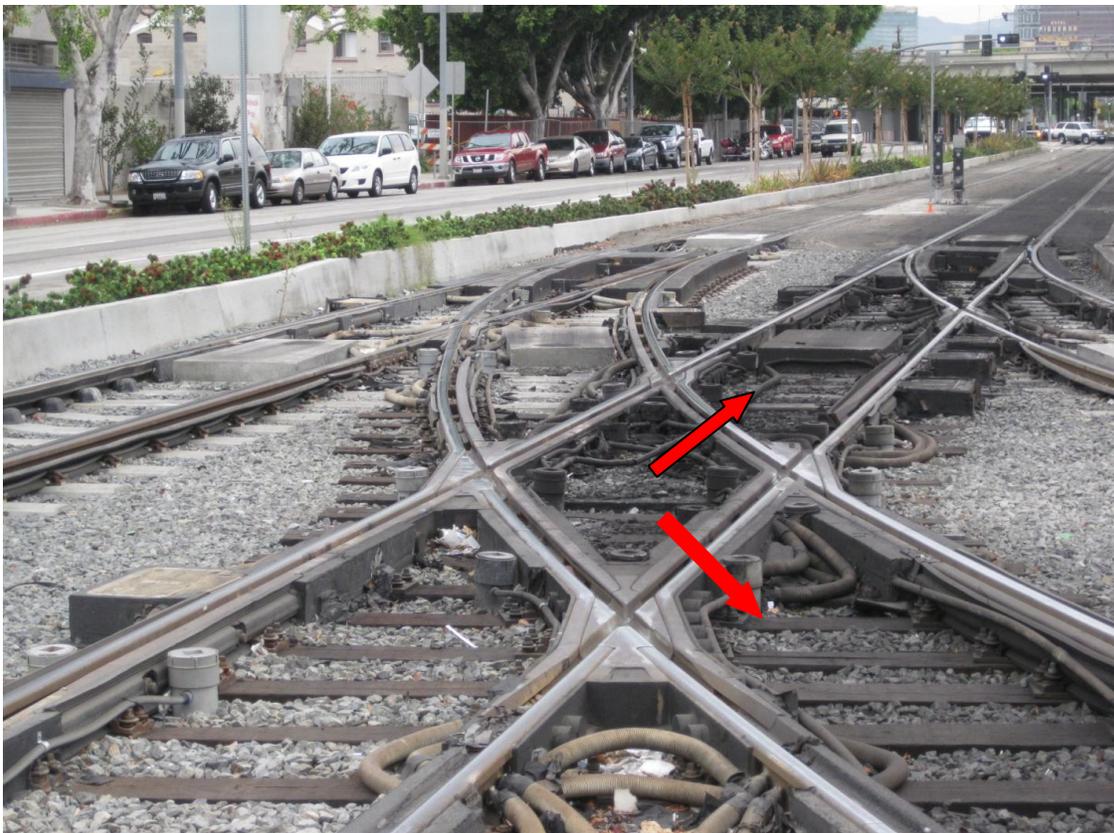


Figure 4: Junction Diamond. RED arrows indicate direction of normal travel.

The following measurements were taken at the diamond:

- Flangeway width, outside rail, BLUE#2 – 2 1/8” to 2 1/4” 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 1/2”
- Gauge on BLUE#2 Track – 57”
- Gauge at “Blip” – 56 1/2”

- 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 track and turnouts are built on concrete ties or embedded track (Figures 5 and 6).

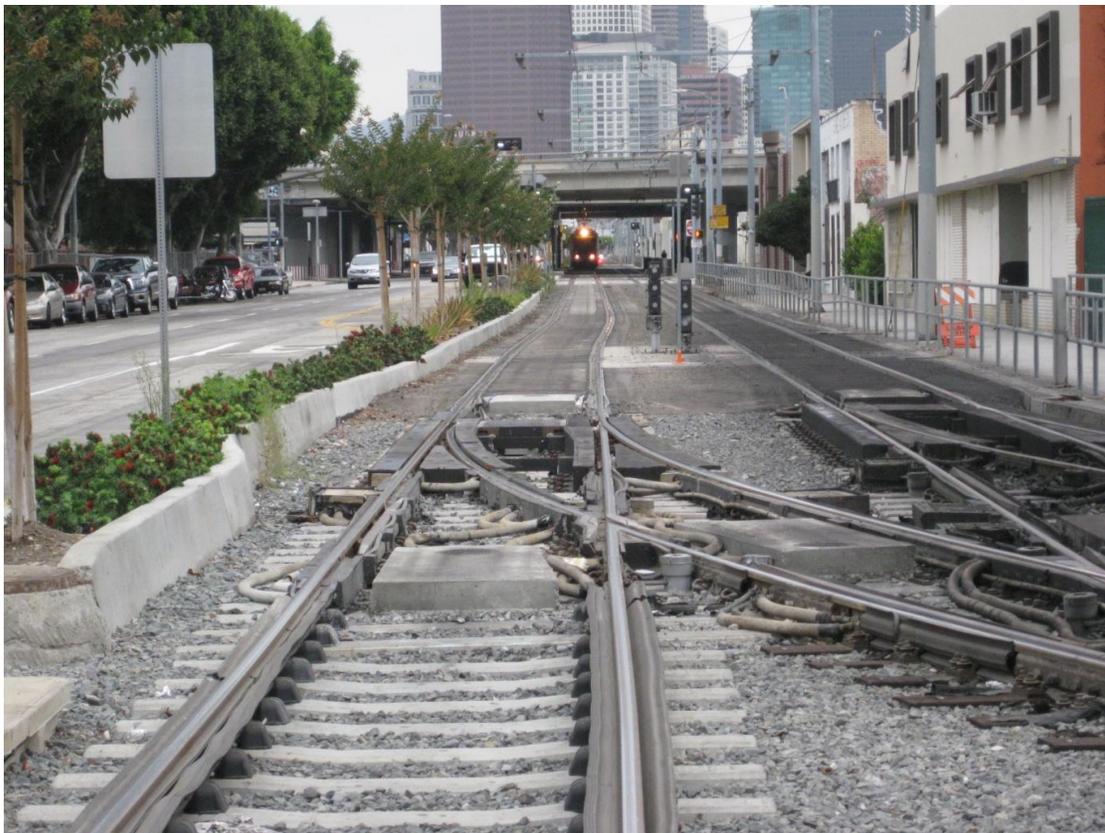


Figure 5: Straight move view of the Junction Diamond Looking North



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°
TRUCK WHEEL BASE	11'-6" & UNDER	11'-6" & UNDER	4'-8 1/2"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"
TRUCK WHEEL BASE	11'-6" & UNDER	OVER 11'-6" TO 12'-1"	4'-9"	4'-8 7/8"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"
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'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"
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 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"
TRUCK WHEEL BASE	OVER 12'-8" TO 13'-3"	OVER 13'-3" TO 13'-10"		4'-9 1/2"	4'-9 1/8"	4'-9"	4'-8 7/8"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"
TRUCK WHEEL BASE	OVER 13'-3" TO 13'-10"	OVER 13'-10" TO 14'-5"			4'-9 1/2"	4'-9 1/8"	4'-9"	4'-8 7/8"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"
TRUCK WHEEL BASE	OVER 13'-10" TO 14'-5"	OVER 14'-5" TO 15'-0"				4'-9 1/4"	4'-9"	4'-8 7/8"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"	4'-8 1/2"
TRUCK WHEEL BASE	OVER 14'-5" TO 15'-0"	OVER 15'-0" TO 15'-7"					4'-9 1/4"	4'-9"	4'-8 7/8"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"	4'-8 1/2"
TRUCK WHEEL BASE	OVER 15'-0" TO 15'-7"							4'-9 1/4"	4'-9"	4'-8 7/8"	4'-8 3/4"	4'-8 3/4"	4'-8 3/4"	4'-8 1/2"

(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 1/2" B TO B		WHEELS 4'-5 1/8" B TO B			
GAGE	FLANGWAYS		GAGE	FLANGWAYS	GAGE	FLANGWAYS		
	IN. RL.	OUT. RL.				BOTH	IN. RL.	OUT. RL.
4'-8 3/8"	1 7/8"	2"	4'-8 1/2"	1 7/8"	4'-8 1/2"	1 7/8"	2"	
4'-8 3/4"	2"	2"	4'-8 3/8"	2"	4'-8 3/8"	2"	2 1/8"	
4'-8 7/8"	2 1/8"	2 1/8"	4'-8 3/4"	2 1/8"	4'-8 3/4"	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"						

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.

NOTES

- 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.
- 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.
- FLANGWAYS**
Width of Flangeways for various gages and equipment shall be specified as listed below:

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE OF WAY ASSOCIATION

TABLES OF PRACTICAL GAGES AND FLANGWAYS FOR CURVED TRACK

PLAN NO. 791-12

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 gauge¹ 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?

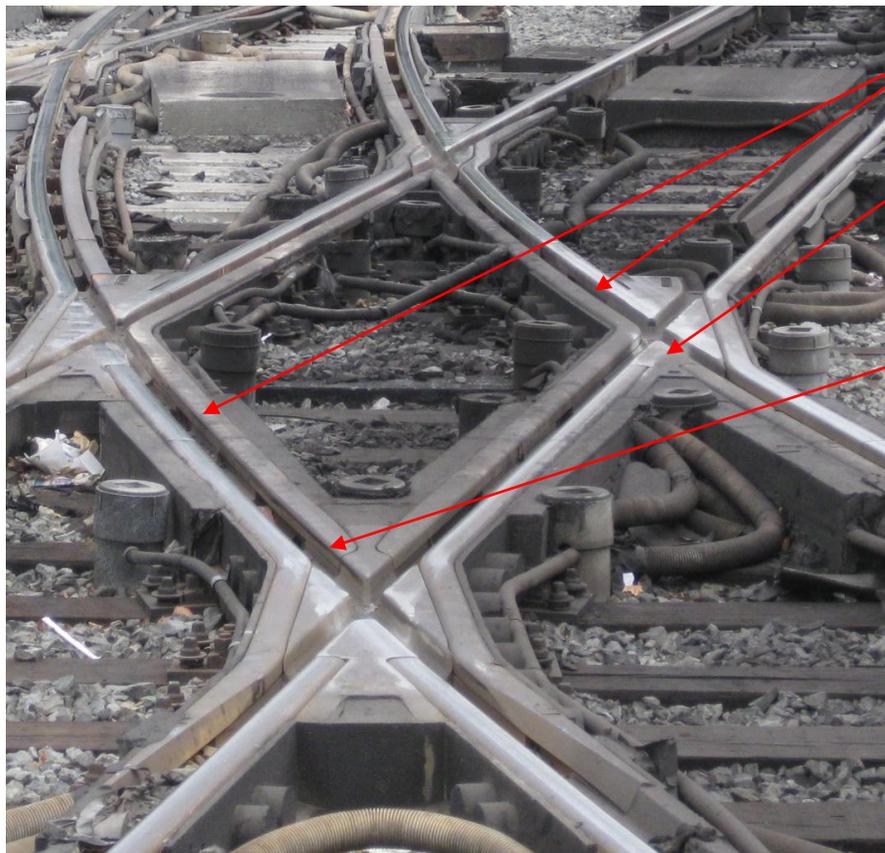
It would be better if the frog diverging route was reset to standard gauge so that there would be no transition and the frog wing rail would not be subjected to the observed high wear (as noted in Figure 7). However, if, due to time and cost restraints, this procedure is not a realistic option, this 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.



NOTE: With wheels pinching both flangeway guard rails, frog D4 must be struck by passing wheel sets. By observation, both flangeway guard rails are being worn by passing back of flanges.

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 address 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 through D show the key measurement and analysis parameters.

Figure 11A: Wheel Dimensions. Note actual contact is at the $\frac{3}{4}$ " point.

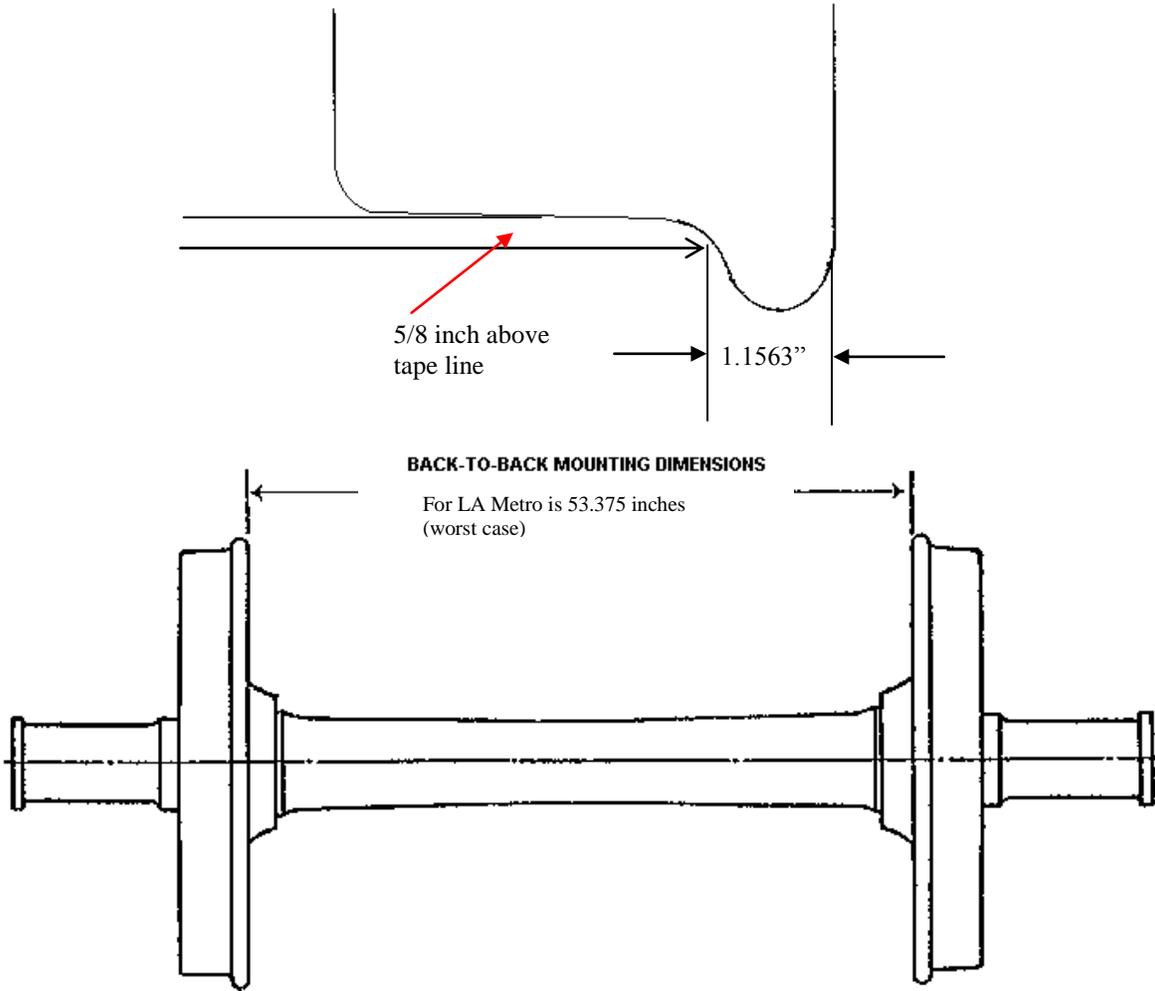
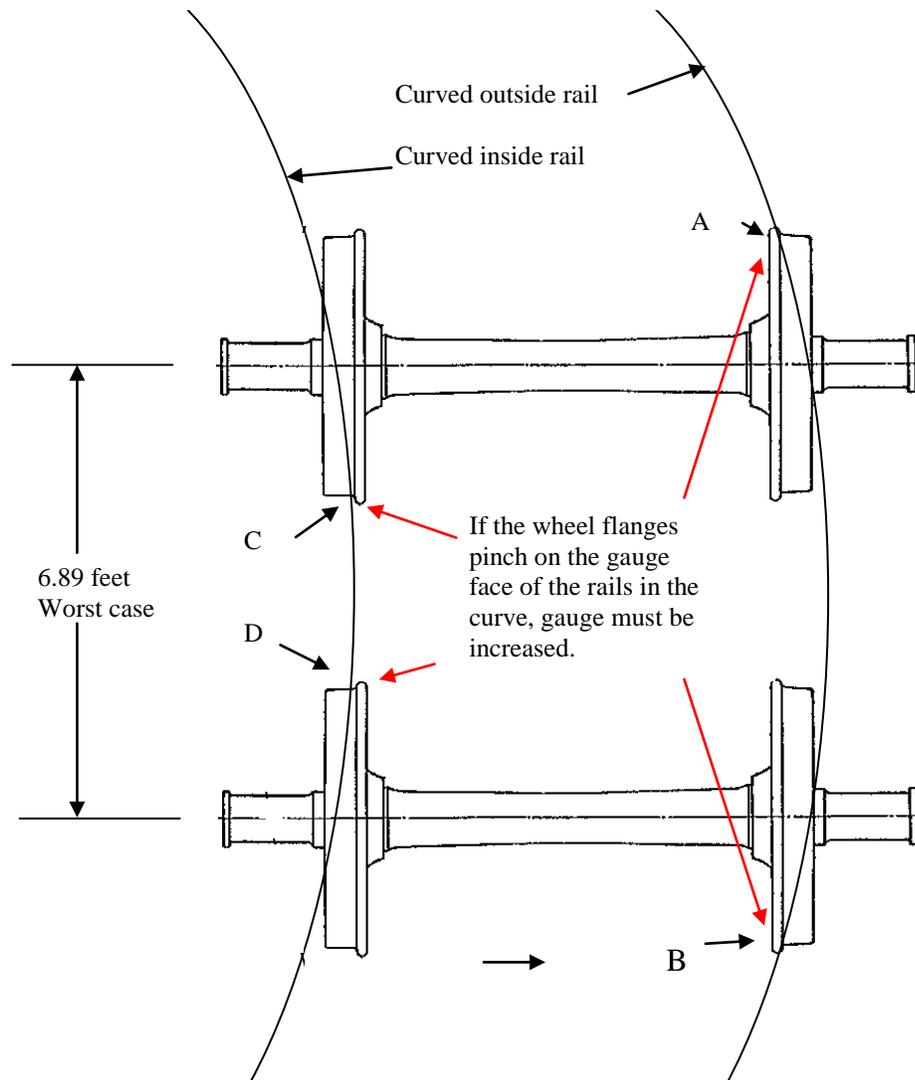


Figure 11B: Wheel back to Back Dimensions

Figure 11C: Truck Negotiation of Curve



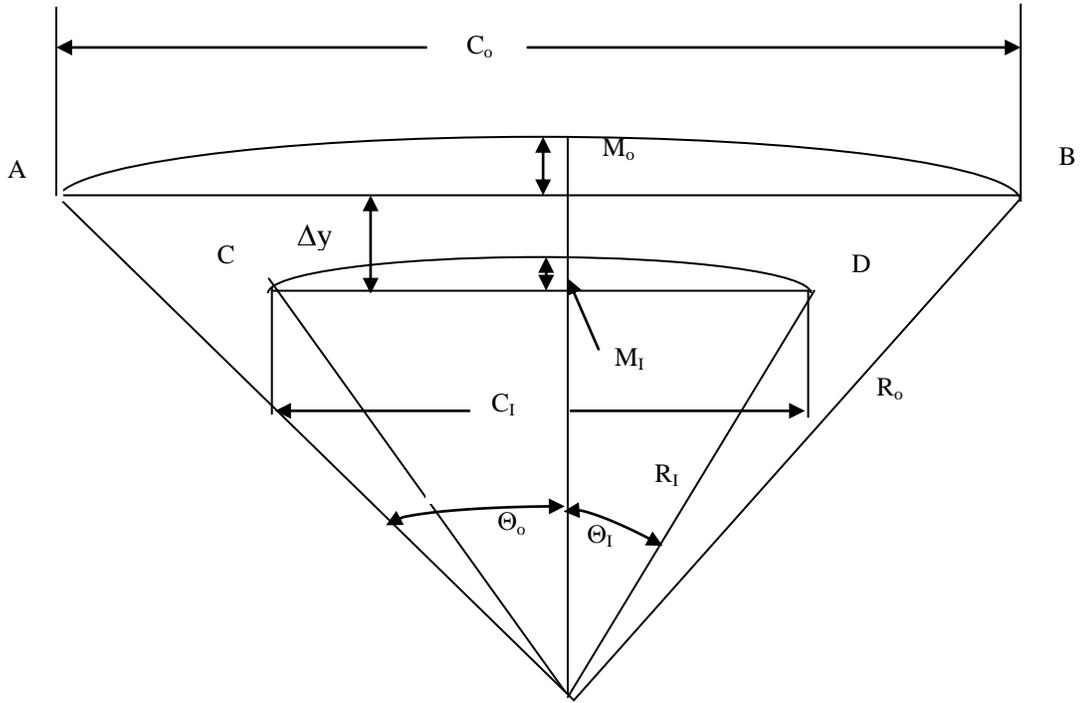


Figure 11D: Clearance Calculations

Using the following formulae:

$$\begin{aligned}
 C_o &= 2R_o \sin(\Theta_o) \\
 M_o &= R_o(1 - \cos(\Theta_o)) \\
 C_I &= 2R_I \sin(\Theta_I) \\
 M_I &= R_I(1 - \cos(\Theta_I)) \\
 \Delta y &= (R_o - M_o) - (R_I - M_I) \\
 &= (R_o - R_I) + (M_I - M_o) \\
 &= G + (M_I - M_o)
 \end{aligned}$$

Where:

$$\begin{aligned}
 G &= \text{Track Gauge (minimum allowable)} \\
 R_o &= \text{Radius of outer rail} \\
 R_I &= \text{Radius of inner rail} \\
 A &= \text{Axle spacing} = 82.7'' = 6.89' \\
 X &= \text{Distance to contact point from axle} = 14.75'' \text{ (with a 28'' diameter wheel)} \\
 B &= \text{Back-to-back distance of wheel/axle set} = 53.375'' \\
 Y &= \text{Distance from back of flange to contact point} = 1.1563'' \\
 \Delta y &= \text{Distance between chords (binding lines)} = B + 2y \\
 C_o &= \text{Length of outer chord} = A + 2X \\
 C_I &= \text{Length of inner chord} = A - 2X \\
 R_{CL} &= \text{Radius of centerline of track in diamond,} = 160' \\
 R_o &= R_{CL} + \frac{1}{2}G \\
 R_I &= R_{CL} - \frac{1}{2}G
 \end{aligned}$$

Therefore:

$$\begin{aligned}
 G &= 2[B + 2y + R_{cl}(\cos\Theta_I - \cos\Theta_o)] / (\cos\Theta_I + \cos\Theta_o) \\
 &= \mathbf{56.308 \text{ inches}}
 \end{aligned}$$

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 excessive² 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

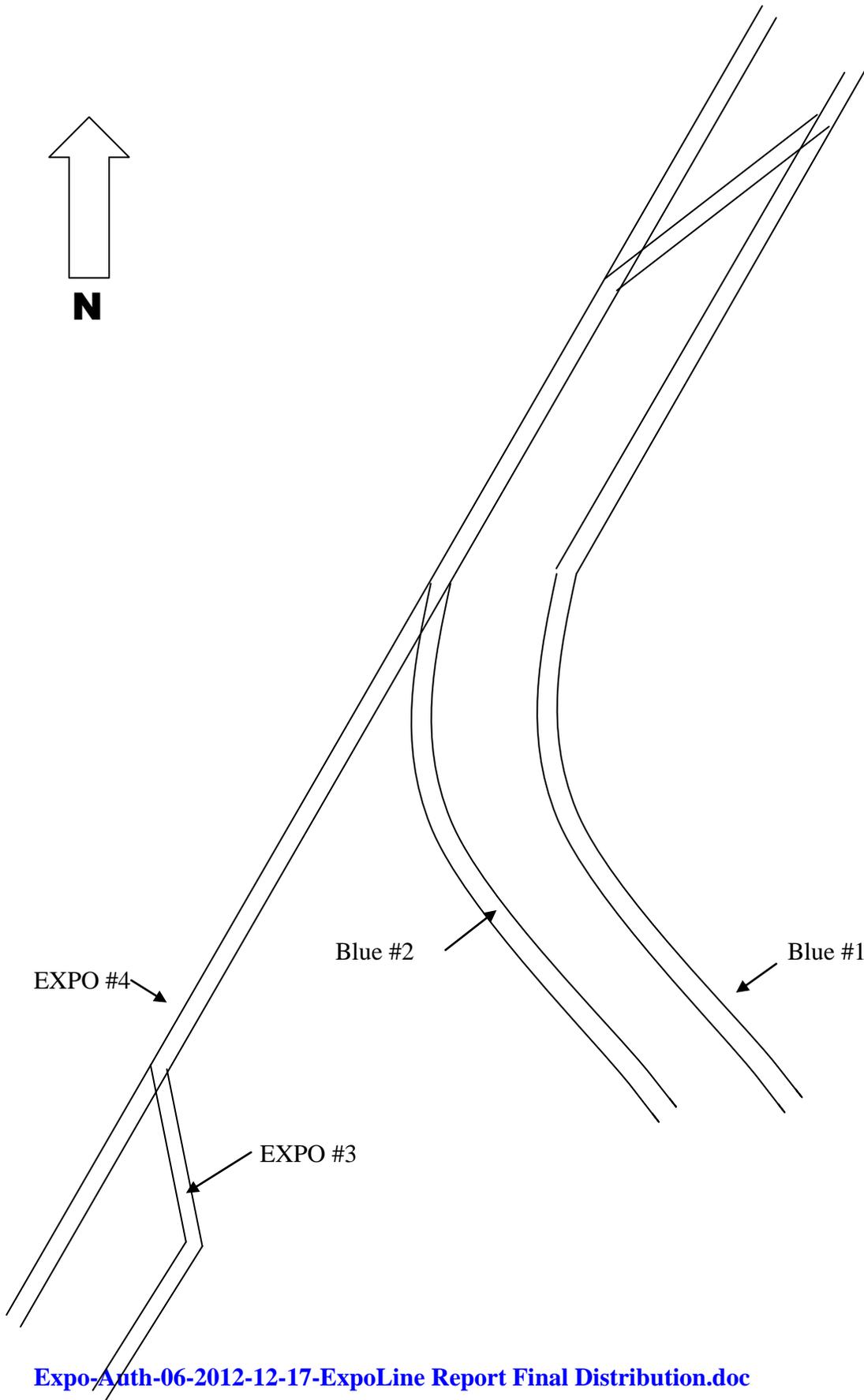
The diamond junction was originally installed to provide the greatest level of operating flexibility. However, due to space limitations, the diamond had to be designed with a 150 foot radius curve which limits train speed and may present maintenance issues. The full diamond junction can be replaced with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

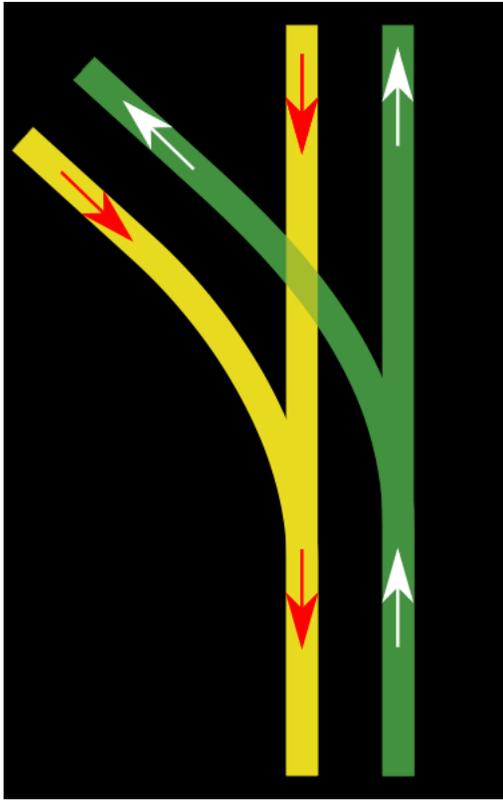
This is accomplished through the new –proposed- junction configuration shown in Figure 12A. In this configuration, EXPO#3 is joined to EXPO#4 south of Flower Street, then single tracked across the roadway and through the 4.5 turnout, with a cross-over installed to bring EXPO#3 back over to Blue#1. The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

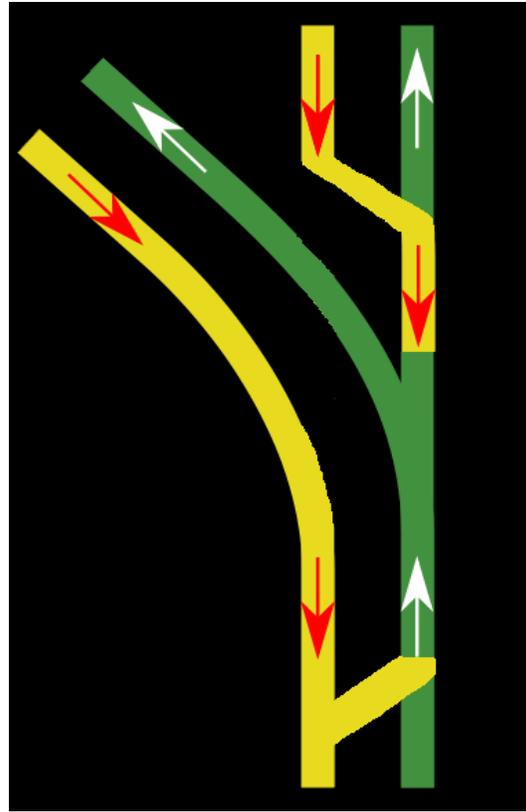
Figure 12A: Replacement Junction Configuration





From this

Figure 12B: Before Traffic Flow



To this

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 13 and 14 illustrates this procedure.

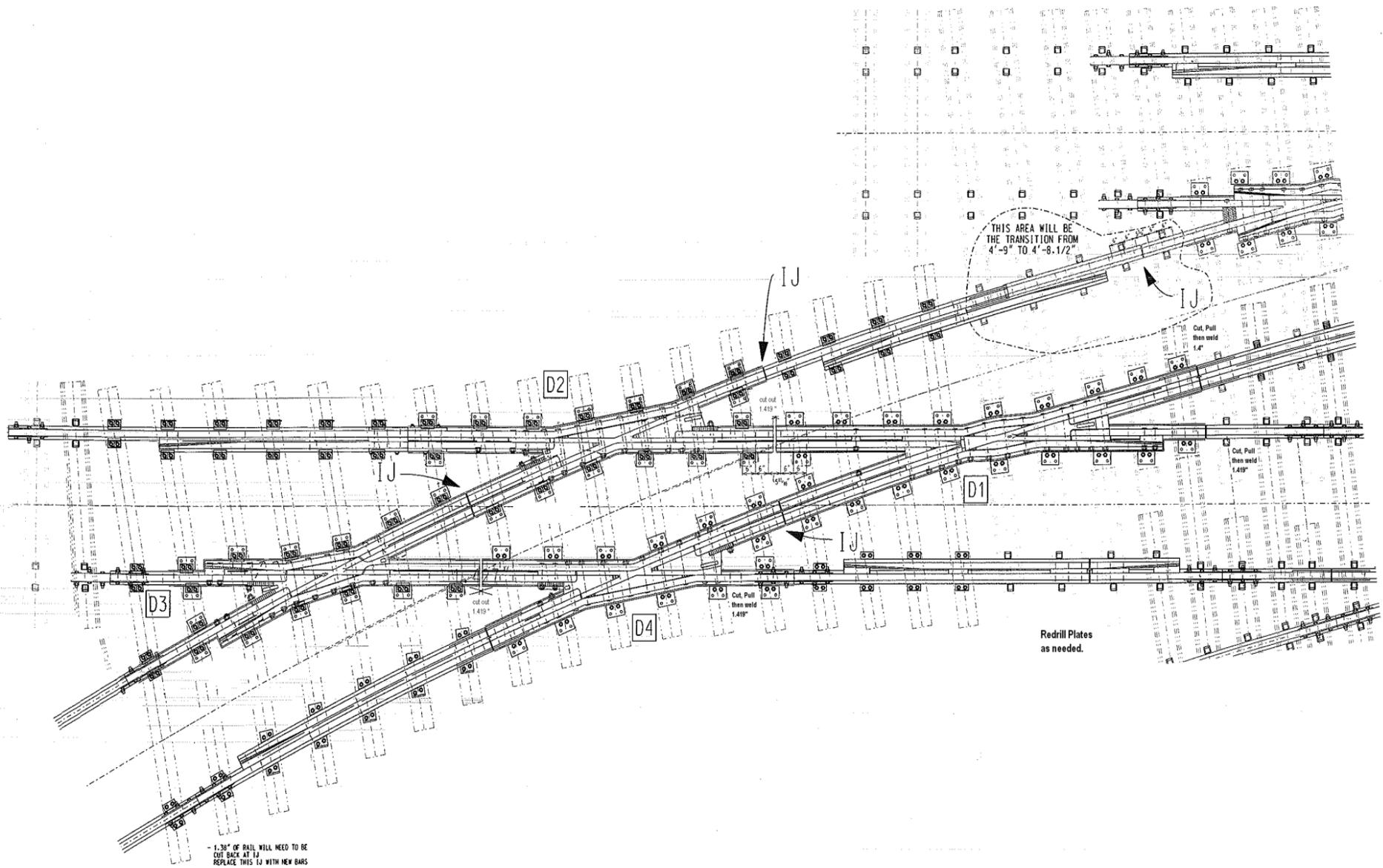


Figure 13: Correction of Gauge



Figure 14: Locations for Cutting Rail to Restore Gauge