American Segmental Bridge Institute

Guidelines for Design and Construction of Segmental Bridges for Rail

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DESIGN AND CONSTRUCTION
OF SEGMENTAL BRIDGES FOR RAIL

Published March 2022

by

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CHAPTER 1: PURPOSE 2

Chapter 1:
Purpose

Purpose

The purpose of this document is to provide guidance to the industry (owners, designers, suppliers, contractors, and others) on considerations when using a concrete segmental-type bridge to carry rail, including transit rail, heavy or freight rail, and high-speed rail. To date, most segmental rail projects in North America have been transit jobs and therefore, the guidelines herein are presented with a predominantly transit background. The current document applies to structures supporting all rail types in general. This guideline may be amended in the future to incorporate additional considerations for heavy or high-speed rail if warranted.

Transit rail structures are commonly required in congested urban areas that have limited construction access and need to accommodate difficult geometry. In many cases, the urban setting also calls for aesthetic considerations. Often, the typical length of elevated guideway in a project will justify an investment in specialized equipment for construction. These characteristics make segmental bridges attractive for transit rail structures. Typically built in more rural settings, segmental for heavy freight rail and high-speed rail may be attractive since this technology lends itself so well to long, repetitive stretches. Segmental is also attractive in an environmentally sensitive setting for any type of rail structure.

Terminology common to rail structures can be found in Chapter 2. There are numerous reference documents on the design of rail structures, and several of these are listed in Chapter 3. However, there is not a single technical specification covering all design criteria of rail bridges, similar to the AASHTO LRFD Bridge Design Specifications for highway bridges. Instead, project-specific criteria are typically developed and specified by the Owner. These criteria are frequently based on common codes, such as AASHTO LRFD, but include adaptations that have a number of supplemental loads, load combinations, and other applicable criteria, drawing from various other reference documents. For examples of project-specific design criteria, see Chapter 4. It is rare that segmental structures would be specifically precluded by a given set of project criteria. However, it is often necessary to propose segmental as an alternative technical concept (ATC), especially if it has not been employed previously by the Owner agency.

Segmental rail bridges are similar to segmental roadway bridges, but there are important design and construction considerations that make them unique. These considerations are presented in Chapter 4. Similarly, inspection and maintenance practices for typical segmental structures also apply to segmental rail bridges. Noteworthy considerations are highlighted in Chapter 5.

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Chapter 2:
Terminology

Terminology

Bogie – A bogie is a structure underneath a railway vehicle body to which axles and wheels are attached through bearings. The term “bogie” is synonymous with “wheel truck”, or simply “truck”.

Bonding – Bonding is the interconnection of metallic components, usually concrete reinforcing and post-tensioning systems, in order to monitor and potentially mitigate the effects of stray current. This bonding is independent from Earthing of exposed metallic elements which is done for safety.

Earthing – Also known as Electrical Grounding is a pathway that provides a route for the current to flow back to the ground if there is a fault in the wiring system.

Hunting – This occurs when the wheel set of a truck/bogie shifts toward one rail causing a rolling radius difference. The wheel set then “hunts” for rolling radius equilibrium by oscillating back and forth from side to side.

Stray Current – In DC rail transit systems, the running rails are usually used as the return conductor for traction current. Low resistance between the traction return rails and the ground allows a significant part of the return current to leak into the ground. This is normally referred to as leakage current or *stray current*.

Stray Current Corrosion – Stray currents can create or accelerate the electrolytic corrosion of metallic structures located in the proximity of the DC rail transit system.

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Chapter 3:
Codes, Guidelines and Reports

For a proper and adequate design of a concrete segmental bridge for rail, the following references should be considered along with the AASHTO LRFD Bridge Design Specifications and Owner Structural design criteria.

1. ACI-ASCE Committee 343, "Guide for the Analysis and Design of Reinforced and Prestressed Concrete Guideway Structures" (ACI 343.1R-12), American Concrete Institute, 2012, 38 pp.

2. American Association of State Highway and Transportation Officials (AASHTO), "Guide Specifications for Bridges Carrying Light Rail Transit Loads," 1st Edition, 2018, 40 pp.

3. American Railway Engineering and Maintenance-of-Way Association (AREMA), "Manual for Railway Engineering," 2017, 5,000+ pp.

4. American Railway Engineering and Maintenance-of-Way Association (AREMA), "Practical Guide to Railway Engineering," 2017, 567+ pp.

5. American Segmental Bridge Institute (ASBI), "Construction Practices Handbook for Concrete Segmental and Cable-Supported Bridges," 2019, 440 pp.

6. California High-Speed Rail Authority, "California High-Speed Train Project Design Criteria," 2014, 1,333 pp.

7. European Committee for Standardization (CEN), "Eurocode 1: Actions on Structures" (EN 1991) and "Eurocode 2: Design of Concrete Structures" (EN 1992), British Standards Institution, 2003.

8. International Union of Railways (UIC), "Track/Bridge Interaction: Recommendations for Calculations" (Code 774-3), 2001, 76 pp.

9. Massachusetts Bay Transportation Authority, "Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures," October 2005, 43 pp.

10. Metropolitan Council, "Central Corridor Light Rail Project Design Criteria," Revision 0, July 2008, 387 pp.

11. National Fire Protection Association (NFPA), "Standard for Fixed Guideway Transit and Passenger Rail Systems", NFPA 130, 2020, 74 pp.

12. Regional Transportation District (RTD), "RTD Light Rail Design Criteria," September 2014, 344 pp.

13. Sound Transit, "Design Criteria Manual," Revision 5, Amendment 11, May 2021, 1,032 pp.

14. Transportation Research Board, "Track Design Handbook for Light Rail Transit" Second Edition (TCRP Report 155), National Academy Press, 2012, 695 pp.

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Chapter 4:
Design and Construction of Segmental Rail Bridges

Most design and construction considerations for a segmental roadway bridge apply to a segmental rail bridge. They have similar design features such as span-to-depth ratios, post-tensioning layouts, and cross-sectional shapes. They utilize the same erection methods such as span-by-span (both simple and continuous), precast and CIP balanced cantilever, and launched bridges.

However, there are important design and construction considerations that make a segmental bridge supporting rail unique. These considerations are briefly described in this chapter.

4.1 Structural Configuration

4.1.1 Span Type

Simply-supported structures erected using the span-by-span method are the most common span type for precast segmental rail bridges. Simply-supported spans do not require closure pours between structural units thus making the erection cycle very efficient. Continuity of the top deck can be provided through link slabs at locations where the special trackwork cannot accommodate a structural expansion joint (i.e., crossovers). Alternatively, expansion joints have been used in special trackwork sections as well by using fixed bearings on both sides of the joint and limiting rotations. Span lengths typically are 100 to 130-ft.

Where longer spans are required (i.e., road crossings), structural continuity at the pier locations can be added. Where the increase in span length is moderate, simply-supported structures can be made continuous with a closure pour and additional top post-tensioning. For significantly longer spans, structures erected in balanced-cantilever can be used.

Minimizing variations in span type, span length, and erection methods is critical to a successful project.

Figures 4-1 through 4-4 provide illustrations of various span construction methods that are applicable to rail bridges. More information on these methods can be found in the *Construction Practices Handbook for Concrete Segmental and Cable-Supported Bridges published* by the American Segmental Bridge Institute.

Figure 4-1. Span-by-Span Erection with Overhead Gantry of Sound Transit Box Girder Guideway in Seattle, WA (Photo Courtesy of SYSTRA IBT)

Figure 4-2. Span-by-Span Erection with Overhead Gantry of HART Box Girder Guideway in Honolulu, HI (Photo Courtesy of SYSTRA IBT)

Figure 4-3. Long-Span Variable-Depth Box Girder with Structural Continuity at Piers for Sound Transit in Seattle, WA (Photo Courtesy of SYSTRA IBT)

Figure 4-4. Launching of Full-Span Box Girder with Transporter and Overhead Gantry for Taiwan High-Speed Rail (Photo Courtesy of SYSTRA IBT)

4.1.2 Station Integration

In precast segmental structures the station platform can be either:

- Organized as a separate structure, erected in a second stage, totally independent from precast segmental deck or
- Directly supported by the girders by extending the structure width or
- Indirectly connected to the track structure such as with shared substructure and foundations

If the second option is adopted, the impact on both the precast activities (special forms, heavier segments) and erection activities (wider segments to manipulated, heavier spans) should be considered in the design. Due to high investment and coordination challenges, the second option may only be cost-effective if the project includes several stations with a similar design concept. Operational considerations may affect the configuration of station platforms as well.

Independent station structures are classified as either 'center platform' structures in which inbound and outbound trains diverge around the platform or 'outside platform' structures in which the track structure continues through the station un-interrupted. The latter configuration is particularly efficient for segmental as variations in box type and deck width are not needed. However, operational considerations including passenger flow may dictate the type of platform to be used. Center platform configurations have successfully been implemented by transitioning from double-track girders to diverging single track girders at the stations.

For independent stations, differential displacements between the station and track structure should be carefully considered as discussed in Section 4.2.7, Deflection Control.

Figures 4-5 through 4-8 provide further illustrations of how station integration is achieved with concrete segmental bridges.

Figure 4-5. Station Structure for Sound Transit in Seattle, WA
Independent of Box Girder Guideways at Each End
(Photo Courtesy of SYSTRA IBT)

Figure 4-6. Station Platform Supported Directly
by Box Girder for Metro of Monterrey in Mexico
(Photo Courtesy of SYSTRA IBT)

Figure 4-7. Hammerhead Bent Caps That Will Support Both the Station Platform and the Integral Box Girder Guideway for Réseau Express Métropolitain (REM) in Montreal, Canada (Photo Courtesy of SYSTRA IBT)

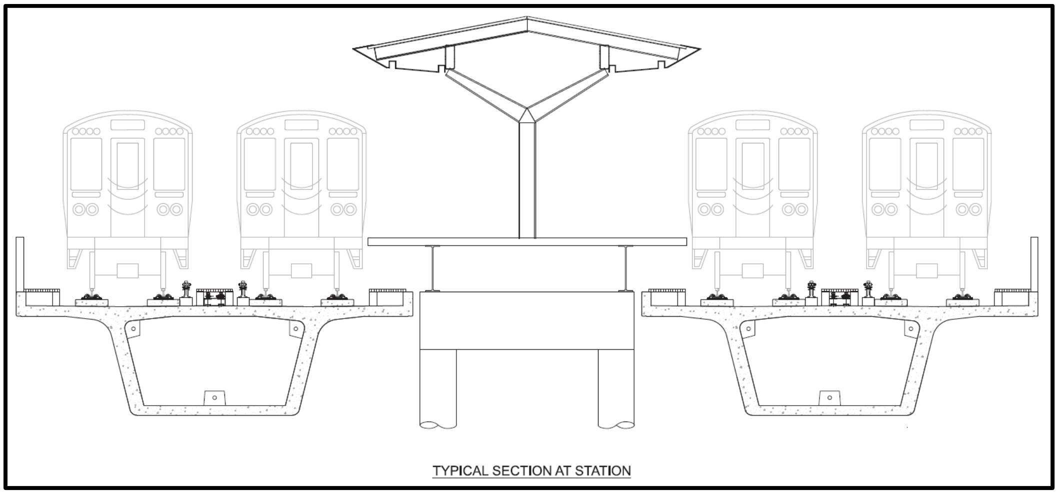


Figure 4-8. Cross-Section Schematic of Independent Station and Guideway Structures for CTA in Chicago, Illinois (Photo Courtesy of SYSTRA IBT)

4.1.3 Superstructure Cross-Section

The most common cross-sections for segmental rail bridges are trapezoidal box girders and U-shaped (channel) sections.

Box girders are well-known in the segmental bridge industry due to their structural efficiency and large torsional rigidity. This rigidity allows them to be used effectively for curved bridges. They are also very stable during construction. Box girders supporting one track (single track) or two tracks (double-track) are used with double-track girders being more structurally efficient.

U-sections benefit from having structural parapets that reduce the overall depth of the structure and minimize superimposed dead loads. The parapets resist potential derailment and support the evacuation footpath at a similar height as the train floor. Since the evacuation footpath is tied to the height of the parapet, the overall section height is limited in the range of 6 to 7 ft. This limitation reduces the maximum span length that is typically used for a U-section. Since it is an open section, the designer must consider torsion carefully (warping or restrained torsion).

U-sections are typically designated as narrow U (carrying one track) or wide U (carrying two tracks). The narrow U has the benefit of being light, in the range of 140-150t for a full span. It can be prefabricated in straight full spans in a casting yard with pre-tensioning strands or post tensioning tendons and erected at site with simple cranes or launching gantries. The main drawback is that sections with sharp radii have to be accommodated with shorter chorded spans or a wider cross section so that the distance to an evacuation footpath remains reasonable. Also, the transverse distance between adjacent tracks has to be larger for a narrow U-section to accommodate the width of each inner parapet wall and top flange. This could have an impact on the right of way and can generate additional costs.

A comparison of box girders and U-sections is made in the table below (+ sign indicates the best option). A summary of primary advantages and disadvantages of each section is as follows:

- Box girders can accommodate longer span lengths than U-sections.
- Box girders have less material demand and thus are more sustainable.
- Box girders are more durable and maintainable due to future PT capability.
- U-sections have shallower depth and provide better underside clearance.
- Narrow U girders cast as a full-span are quicker to install.

As far as construction costs are concerned it is more difficult to select the best option in advance. Box sections are generally cheaper however the cost of additional elements such as walkways, noise barriers, safety barriers, stations may reduce or even eliminate the overall cost difference.

Table 4-1 provides a comparison of three superstructure cross sections, Narrow U, Wide U and Box Girder.

Figures 4-9 and 4-10 provide further illustration of the geometric differences between cross-section types.

Figures 4-11 through 4-13 provide illustrations of various cross-section types.

	Narrow U	**Wide U**	**Box Girder**
Span Length (ft.)	-- 80-100	- 100-115	++ >115
Deck Width Variation	-	-	+ Can accommodate variable widths: useful for turnout structures.
Structure Depth / Clearance	+ Shallower depth	+ Shallower depth	- Deeper by 5’
Track Axis	- Larger by 2’	+ Unchanged	+ Unchanged
Parapet/Walkway Installation	+ Integrated in Structure	+ Integrated in Structure	- Additional Superimposed Dead Load
Noise Reduction	+ U sections can accommodate light noise barriers clamped to the webs.	+	- Sound barriers required.
Curve Radii	-- Chorded Decks-Shorter Spans for Sharp Curve	- Special Care of Restrained Torsion required.	+ Largest torsion capacity.
Erection Cycle	++ 1 Span/Day with Cranes* - 2 to 3 Spans with LG	- 1 Span/5 Days	- 1 Span/5 Days
Quantities	+ Larger concrete quantities than box girder, but positive impact of pretension (no anchorages).	-- Largest concrete/PT/rebar quantities of the three options.	+ Box girder more efficient with lower reinforcement and concrete quantity.
Seismic Impact	-	-	+ Lower mass
PT Replacement/Future Provision	- Not possible for U sections.	-	+
Pierhead	-- Wide pierheads required with large PT/rebar quantities.	- Pierhead width smaller than the narrow U one, but at the cost of a large diaphragm.	+

(*) this is depending on the access. This hypothesis is based on dense urban area assumption with full span transport and erection performed at night only.

Table 4-1 Comparison of Superstructure. Cross-Sections

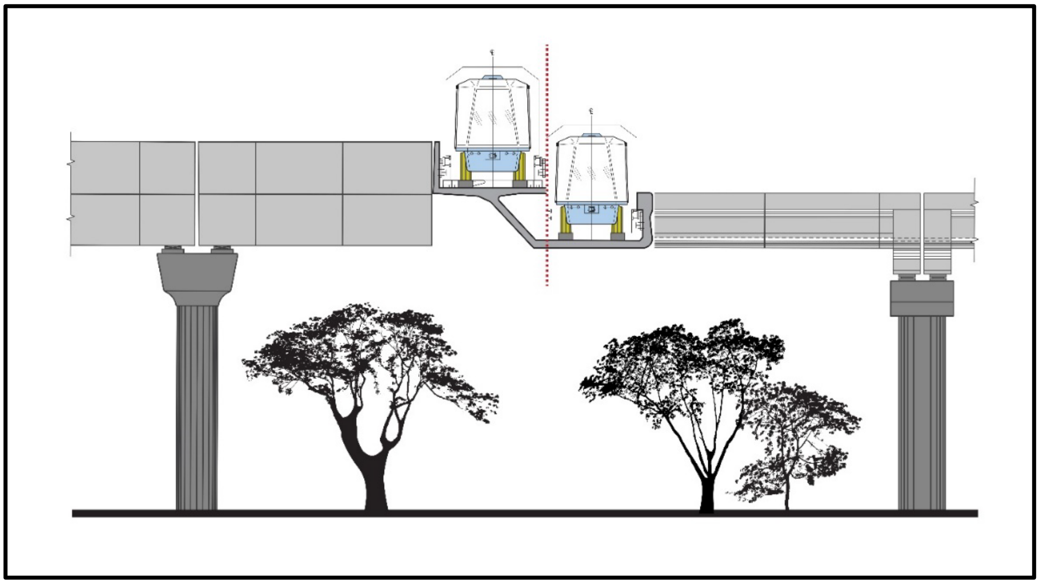


Figure 4-9. Comparison of Rail and Structure Height for Box-Girder and U-Section Guideways (Photo Courtesy of SYSTRA IBT)

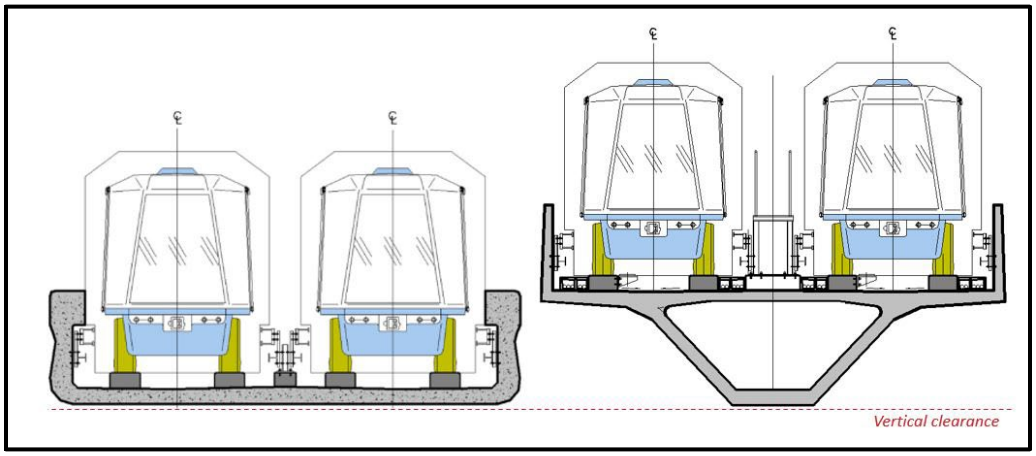


Figure 4-10. Comparison Between Box-Girder and U-Section Girders with Respect to Vertical Clearance (Photo Courtesy of SYSTRA IBT)

Figure 4-11. U-Section Guideway for Dubai Metro in the United Arab Emirates (Photo Courtesy of SYSTRA IBT)

Figure 4-12. Full-Span Erection of Narrow U-Section Guideway with Cranes for Jabodebek Greater Jakarta LRT, Indonesia (Photo Courtesy of SYSTRA IBT)

4-13. Cross-Section of U-Girder Showing Top of Parapet at Required Evacuation Path Height (Photo Courtesy of SYSTRA IBT)

4.2 Structural Analysis

4.2.1 Live Loads

Live load consists of the weight of the train and the weight of the passengers. Standard train loads are defined in the AASHTO guide spec (ref. 2 in Chapter 3) for light rail and in AREMA (ref. 3 in Chapter 3) for heavy rail. Agency-specific train loads are defined by the agency or train supplier. If the train supplier is known at the time of design, train loads are well-defined such that load factors typically used in highway bridge design may be too conservative. This issue should be addressed on a project-specific basis in the project design criteria.

In addition to the typical passenger train operation, live loads may include a number of special cases. These may include infrequently used maintenance vehicles, or removal of a train that has broken down. In all cases, the design criteria should include the applicable loads, and applicability of that special case (i.e., service, strength, extreme or fatigue).

In addition, the trains transmit significant lateral forces to the structure in both the longitudinal and transverse directions. Longitudinal forces are governed by braking and acceleration of the trains. Transverse loads are generated by toe effects; hunting, which is a small transverse shimmy of the train between the rails, and centrifugal forces as the train navigates curves.

In both cases, the magnitude and application of the lateral loads is tied to the operational characteristics of the train, primarily the maximum possible speed and the permissible braking force. Because of this, the design loads for the structure are closely tied to the operational requirements of the system. Care should be taken to coordinate these aspects during the development of the design criteria.

4.2.2 Derailment Loads

Derailment loads consist of concurrent vertical and lateral loads applied to the top deck and barrier wall of the guideway. They are typically provided in the project specifications and often include large impact factors that result in as much as twice the normal weight of the vehicle applied to the edge of the deck. As a result, this load condition typically governs the transverse design of the guideway and should be carefully considered.

4.2.3 Rail Structure Interaction

Rail-Structure Interaction (RSI) analysis is intended to capture the structural interaction between the guideway and the continuous welded rail, typically in the final service condition. Loads in the guideway are generated due to restraint provided by the rail. Reasons for RSI analysis include:

- To generate loads for use in the design of the rail-fastener system and rail anchorages if applicable.
- To determine change in axial stress of the rail due to repeated longitudinal loading including temperature effects and wheel loading and the resulting gap opening of the rail if a break were to occur.
- To confirm that the guideway structure is designed for the forces introduced by the rail system including rail break.
- To determine the requirement of implementing rail expansion joints.
- To assess whether the neutral or ‘stress-free’ rail temperature is adequate

A structural analysis model is created that includes the guideway structure, the rail, and rail-fastener connector elements. The rail and guideway are modelled according to the actual alignment and with appropriate section and material properties. Longitudinally, the rail fasteners are typically modeled as bilinear springs that capture a linear force-displacement relationship up to a ‘slip’ load. Beyond the ‘slip’ load, the spring deforms without transferring additional force between the rail and the structure. The longitudinal restraint provided by the rail clips can be varied along the guideway to control the force transfer between the rail and the deck. The fastener restrains the rail in the vertical and transverse directions.

Refer to Figure 4-14 for an illustration of Rail-Structure Interaction Behavior at Structural Expansion Joint.

The rail-structure analysis should include the following loads:

- Temperature loading that captures differential displacements between the structure and the rail.
- Longitudinal train loads due to braking or acceleration (traction).
- Time-dependent effects such as creep and shrinkage.
- Seismic loads as applicable.
- Redistribution of loads in the event of breakage of one rail, which usually occurs at an expansion joint.

The rail-structure analysis may also include analysis of additional loads such as vertical and transverse live load when a more refined estimate of their distribution is desirable.

From an analysis of these loads, the design requirements of the rail fasteners can be checked. It is important to note that the lateral demand on the fasteners is significantly increased on curved alignments.

Thermal and longitudinal train loads (braking and traction) introduce axial forces in the rail. Thermal loading consists of differential temperature applied to the rails and the guideway. A net temperature increase of the rail will cause it to expand and go into compression. A net temperature decrease of the rail will cause it to contract and go into tension. If tension in the rail exceeds its capacity, the rail will break creating a rail gap; and the force in the rail will be distributed to the adjacent rail fasteners. If a rail break were to occur, it would likely happen at a guideway expansion joint where fatigue stress is the greatest due to differential displacement between the guideway and the rail. It is necessary to limit the length of the gap if a rail break occurs to avoid derailment. An important outcome of the rail-structure interaction analysis is to determine the balance between providing enough longitudinal restraint to limit a broken rail gap and prevent rail buckling while also allowing enough slip to limit stresses in the rail and to limit the forces introduced into the guideway. In instances where a broken rail gap cannot be limited to the required gap, a rail anchorage can be provided as long as the corresponding anchorage forces introduced into the guideway are considered. In some instances, a rail expansion joint may be needed, but cost and maintenance concerns from their use need to be considered.

For segmental bridges, a rail-structure interaction analysis is typically performed, especially for complex structures with curved alignment, variable and long span lengths, or differing adjacent structures. One benefit of segmental bridges is that older precast segments will have less creep and shrinkage which will improve the rail-structure interaction.

For some segmental projects, it may be necessary to perform a rail-structure interaction for intermediate stages during installation of the rail. One consideration is to mitigate conditions where continuously welded rail (CWR) is fully clipped to the aerial structure and is abruptly terminated like at the leading edge of construction. Termination of CWR can introduce large restraint forces that will need to be resisted by the structure.

Refer to Figure 4-15 for an illustration of Clipped Rail Fastener Supported by Plinths.

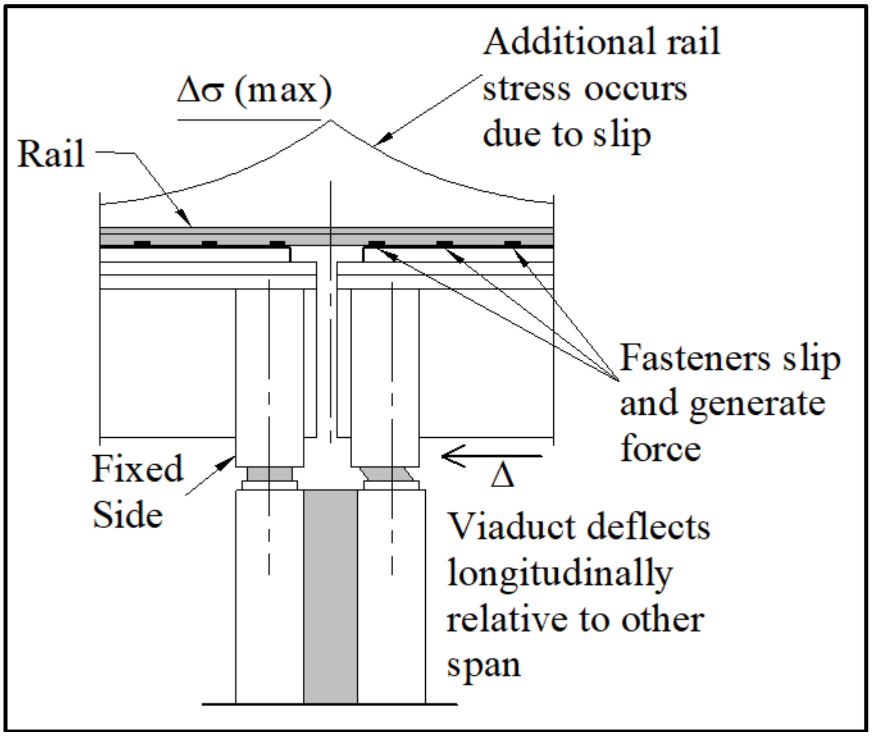


Figure 4-14. Illustration of Rail-Structure Interaction Behavior at Structural Expansion Joint (Photo Courtesy of SYSTRA IBT)

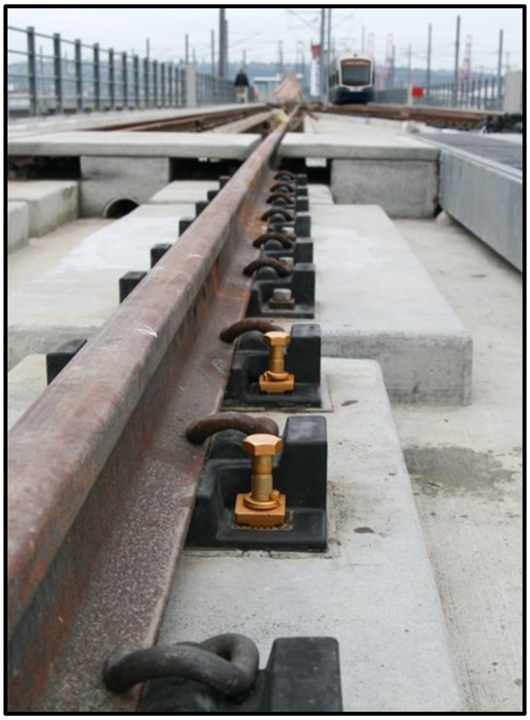


Figure 4-15. Clipped Rail Fastener Supported by Plinths for Sound Transit Guideway in Seattle, WA (Photo Courtesy of SYSTRA IBT)

4.2.4 Vehicle Structure Interaction

Many rail projects include vibration-specific requirements that are not frequently seen on roadway projects. For light rail, some project specific design criteria may, for instance, limit the minimum frequency for the first mode of vertical vibration of the structure to 2.5 Hz, with other values applied for heavy or high-speed rail projects. This requirement is a simple way to limit the dynamic amplification of the structure and to ensure rider comfort but may only be applicable for simple structures with slow-moving trains. A vehicle-structure interaction can be performed to capture the specifics of the project.

A vehicle-structure interaction analysis is intended to capture the dynamic response of a moving vehicle as it crosses the guideway in the final service condition. Purposes of the analysis include:

- To assess vertical accelerations of passengers in the vehicle to evaluate passenger comfort.
- To determine the dynamic amplification of forces and displacements of the guideway for comparison with the specified impact factor in the project design specifications.

The vehicle-structure interaction analysis, also called a rolling-stock analysis, consists of a structural analysis model of the guideway subjected to time-history loads that represent the vehicle crossing the guideway at a specific speed. Important parameters of the analysis include the weight and stiffness of the guideway, Rayleigh damping coefficients of the guideway, and the weight, length, and speed of the vehicle. If available, the dynamic characteristics of the vehicle that capture its suspension should also be included in the analysis.

The loading frequency is a function of the length and speed of the vehicle. The natural frequency of the guideway is a function of its mass and stiffness. If the loading frequency is similar to the natural frequency of the guideway, resonant-type amplification of the guideway response will occur. Vertical accelerations obtained from the vehicle-structure interaction analysis can be compared to limits in the project specifications or from the train supplier. In addition, the structural response of the guideway from the dynamic analysis (i.e., displacements and moments in the deck) can be compared to the corresponding static response to explicitly evaluate the specified dynamic impact factor.

Figure 4-16 provides an example of Guideway Vertical Displacement Versus Time from a Vehicle-Structure Interaction Analysis.

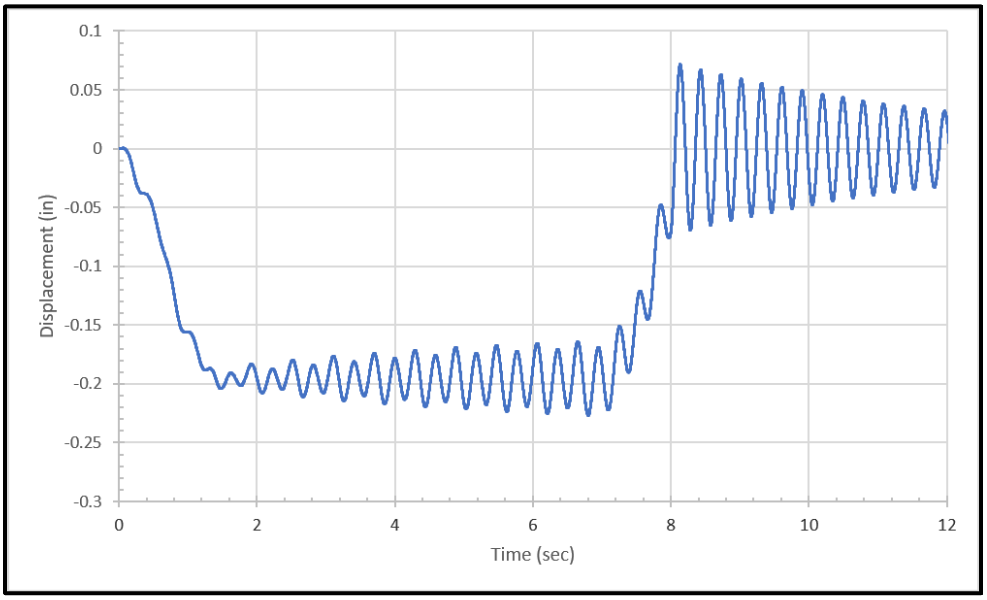


Figure 4-16. Guideway Vertical Displacement Versus Time from Vehicle-Structure Interaction Analysis (Photo Courtesy of SYSTRA IBT)

4.2.5 Seismic Criteria

Seismic design criteria for segmental bridges follow the same requirements as those for relevant highway (AASHTO) or rail (specific light rail, commuter rail or high-speed rail) criteria. For the superstructure, the performance criteria are typically not fundamentally different as compared with other forms of construction for concrete structures.

For many rail systems, there are two design earthquakes defined; the Maximum Considered Earthquake (MCE) and the Operational Basis Earthquake (OBE). The MCE is a very low-probability event in which collapse prevention is typically the goal. The OBE is a more common event in which little damage or disruption to service is expected. These criteria are often combined with desired levels of performance and structural classifications to define the overall level of performance for individual structures but are not unique to segmental bridges.

There are details common to segmental bridge construction that have an impact on the seismic behavior of the superstructure. For long elevated viaducts, the superstructure is often simply supported and constructed with the span-by-span method, resulting with an expansion joint at each pier and typically with spans supported on elastomeric bearings. It is important to have a designated load path for lateral forces, that is often in the form of a seismic shear buffer located at the top of the pier. The buffer requires detailing to permit service movements to occur but will be engaged in a seismic event. Shock transmission units (STUs) may be used to transmit forces between the superstructure and the substructure during a seismic event while allowing relative displacements during longer-term loadings.

A benefit of span-by-span construction with multiple joints is that the differential movement of spans is distributed along the viaduct and results in lower rail stresses for the OBE event due to the smaller relative movements at the expansion joint.

An illustration of Shock Transmission Units (STUs) connecting the end of a guideway to the substructure is provided in Figure 4-17.

Figure 4-17. Shock Transmission Units (STUs) Connecting End of Guideway to Substructure on Sound Transit in Seattle, WA (Photo Courtesy of SYSTRA IBT)

4.2.6 Seismic Isolation

The same care for non-segmental, seismically-isolated structures applies to segmental superstructures. Seismic isolation is generally challenging for structures carrying rail due to large relative displacements for non-seismic lateral loads (braking, traction, hunting, rail-structure interaction, etc.). A fusing system may be implemented to maintain rigidity during the service condition. Beyond the service condition, the isolation bearing is engaged at a level below the design capacity of the substructure and foundation elements.

If a feasible seismically isolated system was implemented, certain aspects of segmental structures could be beneficial, such as the span-by-span construction method mentioned previously. The use of typical elastomeric bearings could be replaced with seismic isolation bearings, therefore requiring minimal changes to the existing structural system.

4.2.7 Deflection Control

Limits on the deflection and the rotation of the guideway due to live load are typically given in the project specifications. The purpose of the limits is to ensure that the guideway is stiff enough to meet the requirements of the train supplier along the entire alignment. Common limits include (see reference 6 and 13 in Chapter 3 for examples):

- Vertical deflection limits of guideway due to live load plus impact as function of span length.
- Relative rotation of the guideway about transverse bridge axis at expansion joint.
- Relative rotation of the guideway about vertical axis at expansion joint due to lateral deflection.

An analysis of the guideway that appropriately accounts for the foundation stiffness should be performed to evaluate the above limits. A Rail Structure Interaction (RSI) analysis as described in Section 4.2.3, Rail Structure Interaction, can be used for this purpose, however, the stiffness of the rail typically does not contribute much to the overall structure stiffness.

Deflection control limits are applicable for all rail bridges. Segmental bridges often utilize simply supported spans with expansion joints at the piers. As a result, it is necessary to confirm that the relative rotation of the guideway at the expansion joints, or the angle break, is within the project requirement.

Illustrative examples for consideration can be found in Figures 4-18 and 4-19.

An important consideration is differential deflections between the structures supporting the rail and the station, especially if the structures are independent. The project design criteria should establish this value so that it can be accommodated in the design.

Another consideration is camber creep over time. Simply-supported segmental rail bridges will typically creep upward over time due to post-tensioning effects in excess of dead load effects. Occasionally, there are stringent criteria in the project documentation for camber creep to ensure that the track profile is maintained over the long term.

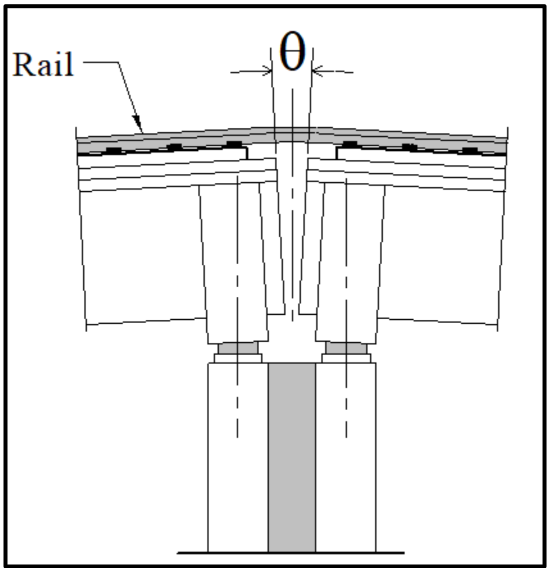


Figure 4-18. Sketch Showing Exaggerated Rotation About Transverse Bridge Axis at Structural Expansion Joint (Photo Courtesy of SYSTRA IBT)

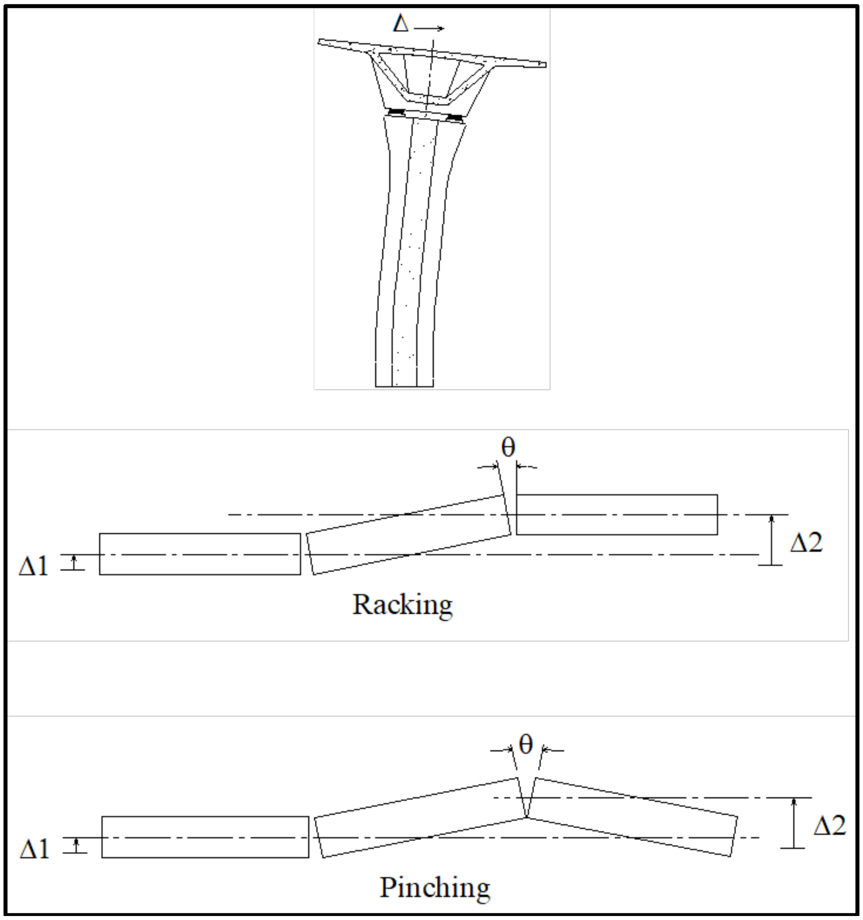
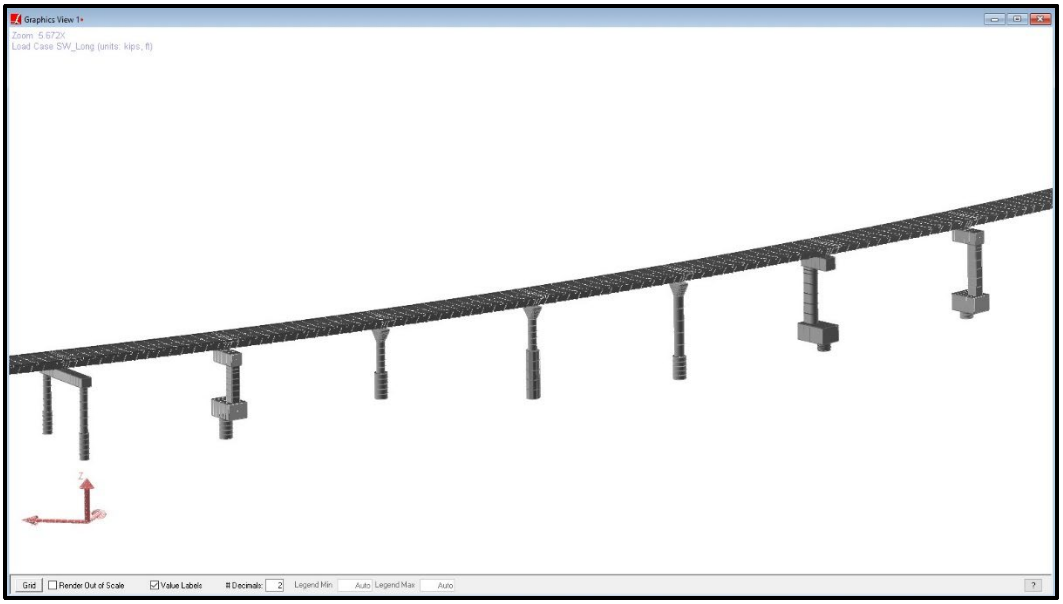


Figure 4-19. Sketch Showing Exaggerated Rotation About Vertical Bridge Axis at Structural Expansion Joint (Photo Courtesy of SYSTRA IBT)

4.2.8 Additional Analysis Requirements

Rail structures are typically very long and often have variable span arrangements, substructure arrangements, and soil conditions along their length. Even subtle variations from span-to-span can impact load distribution. Consider an example of a curved box girder span supported by a typical column at one end and a C-bent at the other. The difference in transverse stiffness of the substructure at the ends of the span combined with the large torsional stiffness of the box girder may generate large compatibility torsion demand in the deck and affect the bearing design. Situations like this should be carefully analyzed with detailed analysis models. Figure 4-20 provides a screen shot of one such structural analysis model.

To analyze the entire alignment, several models are often needed to limit their size and runtime. Appropriate overlap and boundary conditions should be used to obtain accurate results.



Zoom: 5.672X
Load Case SW_Long (units: kips, ft)

☐ Render Out of Scale
☑ Value Labels
Decimals: 2
Legend Min Auto
Legend Max Auto

Figure 4-20. Structural Analysis Model of Guideway with Different Substructure Types Along Its Length (Photo Courtesy of SYSTRA IBT)

4.3 Systems Integration Considerations

Other components of the system related to track, power supply, rolling stock and signaling have an impact on the geometry and loading of the superstructure and require careful coordination. For a precast segmental bridge, inserts/sleeves/anchors for these systems need to be embedded in the segments in the casting yard well in advance of the erection and commissioning of the bridge. Design and construction schedules that allow for embeds to be defined and located prior to segment casting are necessary to avoid on-site coring, repairs, and in some cases structural retrofits. Different aspects of these systems are discussed hereafter.

4.3.1 Electromechanical

Inserts for cable tray channels should be placed within the rebar cage of the precast concrete parapets or within the webs (for U shaped sections for instance). Channels reduce the on-site work compared to other methods (welding on embedded steel plates, drilling and chemical anchors, or sleeves with post bolting). They should be detailed on the plans.

Viaduct lighting can be integrated in the handrail or in the concrete parapets. In that latter case, specific inserts/holes/sleeves will be required and should be detailed on the plans.

At specific locations, cables can be rerouted out of the viaduct through large openings in slabs or webs. The designer should be informed sufficiently ahead of the construction in order to provide specific reinforcement arrangement before segment casting. If the cables are rerouted below the deck, special attention should be paid to the suspension system and its anchors. The designer should be informed in order to avoid conflicts of these anchors with bottom slab prestressing tendons. The distance between these containments (and their anchors) should be cross checked with a mechanical-electrical-plumbing (MEP) specialist as minimum distances have to be respected between different electronic and electrical systems for electromagnetic compatibility purposes. Cable rerouting and the openings associated with it typically occur in the vicinity of substations, cross-over structures, and stations.

Figure 4-21 provides an example of a transition of system cabling from a U-Section parapet through the opening in and adjacent structure.

Figure 4-21. Transition of System Cabling from U-Section Parapet Through Opening in Adjacent Structure (Photo Courtesy of SYSTRA IBT)

4.3.2 Rolling Stock

4.3.2.1 Segment Width

The width of the precast segments at their “opening” (distance between the inner flanges of the parapets) is determined by the rolling stock static gauge, amplified by its dynamic envelope, then by its kinematic envelope and the swept envelope (considering track curvature, superelevation and speed).

For full precast straight spans "chording” a curved alignment, special attention shall be paid to the swept envelope: bogies are pivotable and follow the track independently from the car body. Main checks are on mid-throw (inside the curve) and end-throw (outside the curve).

The overall segment width also should allow for a gap of about 4 inches to the evacuation walkway (to be defined by the Owner). This value is related to the civil and track construction tolerances and to the deviation of equipment fixed over a structure for many years.

Figures 4-22 through 4-25 provide further illustration.

Figure 4-22. Test Run of Train with Clearance Envelope on Evergreen Line in Vancouver, Canada (Photo Courtesy of SYSTRA IBT)

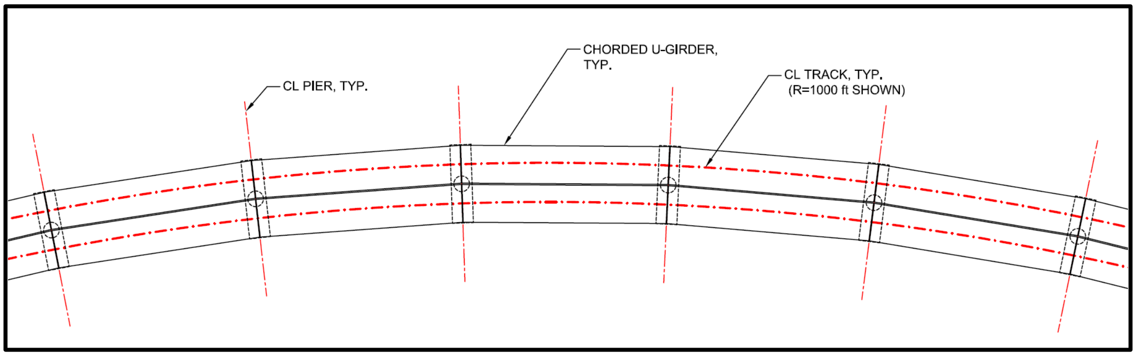


Figure 4-23. Plan-View Schematic of Chorded, Full-Span U-Girders in a Curve (Photo Courtesy of SYSTRA IBT)

Figure 4-24. Chorded, Full-Span U-Girders in a Curve in Faridabad, India
(Photo Courtesy of SYSTRA IBT)

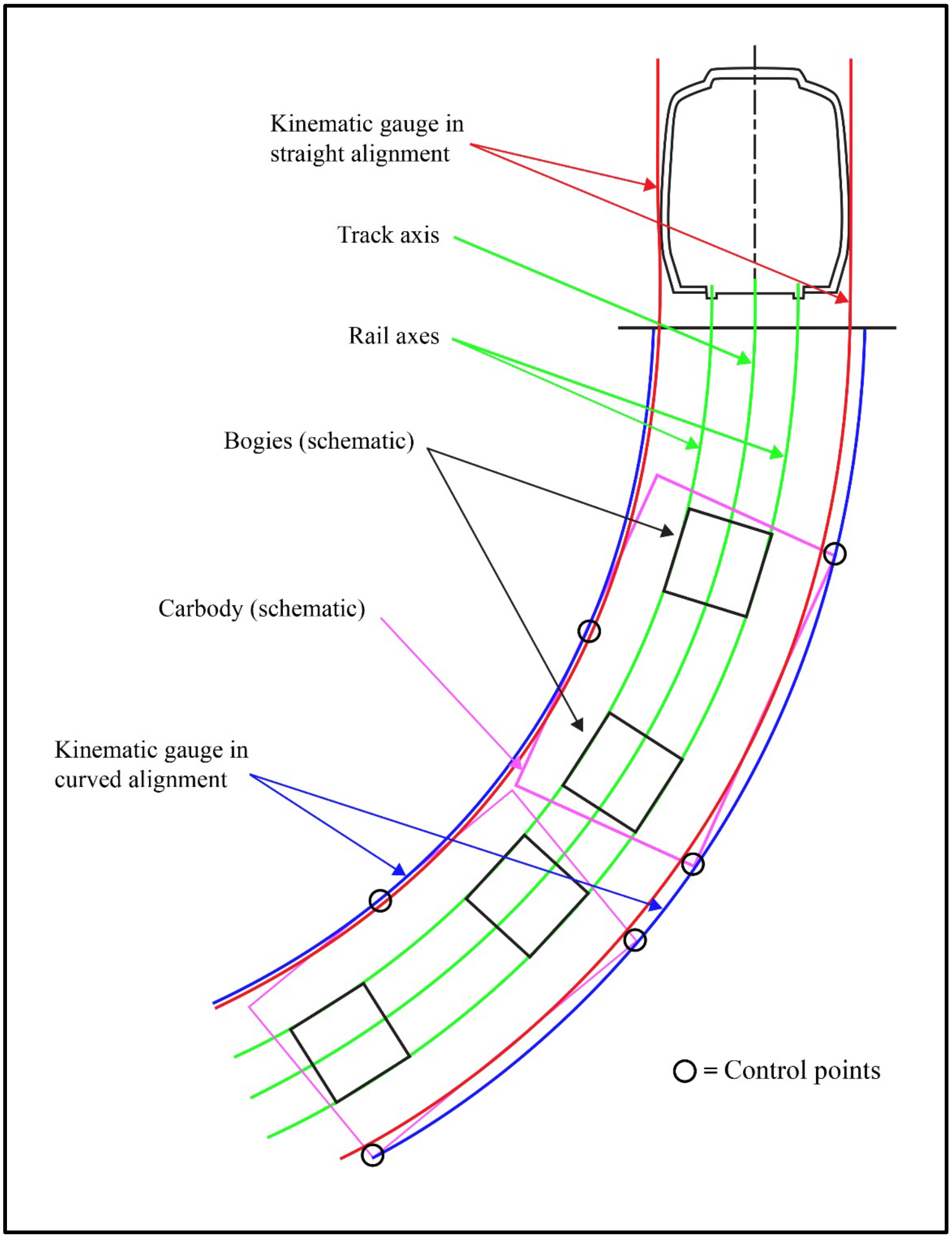


Figure 4-25. Plan and Section Schematic Showing Impact of Kinematic Envelope on Width Between Parapets (Photo Courtesy of SYSTRA IBT)

4.3.2.2 Derailment Containment Systems

An anti-derailing guard rail system often consists of a transverse extension of the concrete track plinth. In that case, the designer should detail the corresponding starter bar reinforcement and consider the extra dead load.

Figure 4-26 provides an illustration of a Plinth Cross-Section with Anti-Derailment Curb

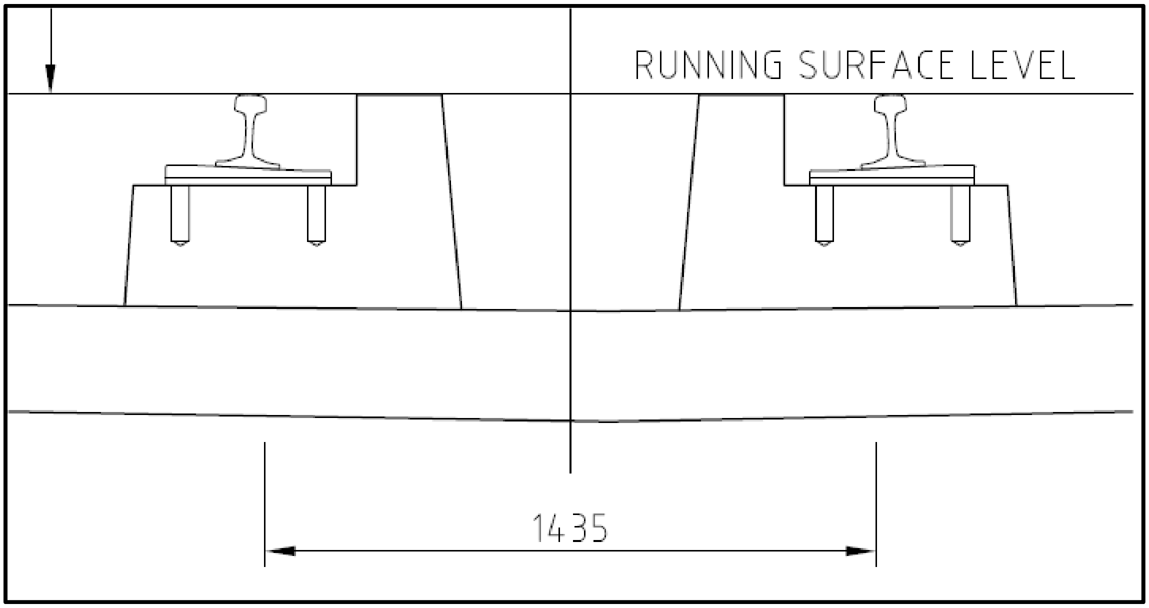


Figure 4-26. Plinth Cross-Section with Anti-Derailment Curb
(Photo Courtesy of SYSTRA IBT)

4.3.3 Signaling

When there is a "singular" point in the line (station, turnout…), there should be a signal, and typically there is little flexibility on its position. Consideration should be taken on the geometry of the segments/parapets at these locations as signals should not infringe with the evacuation gauge.

Signals are installed on a mast. The size, weight, allowable movement, and plate requirements should be detailed by the signaling designers so that proper inserts/bolts are installed in the casting yard. Radio antennas for data transfer between trains and the signaling system are typically implemented every 600 to 1,000 ft. Similar mounting details as for the signal masts are required for data system antennas.

Figure 4-27 provides a section detail of a signal post mounted to a segment. Figure 4-28 provides a photograph of the system.

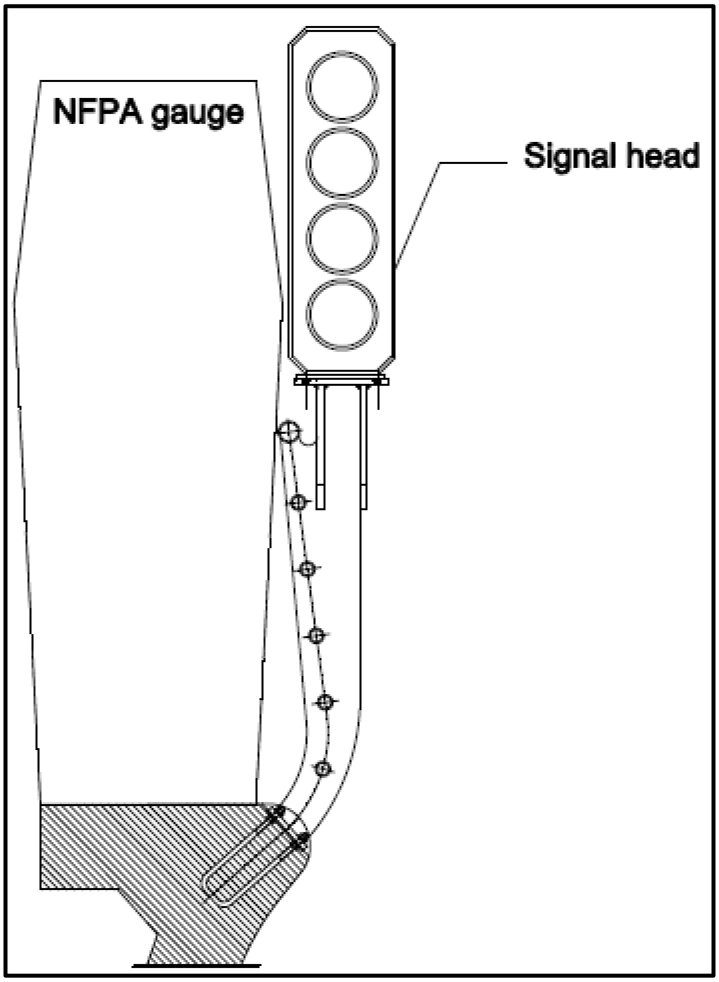


Figure 4-27. Section Detail of Signal Post Mounted to Segment (Photo Courtesy of SYSTRA IBT)

Figure 4-28. Signal Post Mounted to Segment for MMMP in Makkah, Kingdom of Saudi Arabia (Photo Courtesy of SYSTRA IBT)

4.3.4 Power Supply and Stray Current

There are three different aspects affecting stray current: the power supply itself, requirements for grounding (also called earthing and bonding), and requirements to mitigate stray current.

If the power is supplied by overhead electrification (OHE or OCS for overhead catenary system), anchors in each span should be provided even if in a straight alignment OHE mast spacings are typically in the range of 150 ft. It is also common to provide two sets of anchors in the segments/parapets for these OHE masts. This allows some flexibility in the OHE design and in the installation as these bolts are sometimes damaged during construction/transportation. The mast should not infringe upon the National Fire Protection Association (NFPA) evacuation gauge. Mast loads may vary depending on the radius of the guideway.

If the power is supplied by a third rail, the designer should consider the extra weight to the track plinth due to adjacent concrete blocks required for the side conductor.

Typically, cables are laid on a cable trough but can be rerouted at specific locations (near cross-over, stations or substations) generating similar issues to that described in Section 4.3.1, Electromechanical.

The potential for stray current exists in DC systems, where electrical current follows its intended circuit through the running rails to/from the power supply. If there are other possible paths for the current to flow (even if they are embedded in concrete or buried in soil), then there is potential for stray current. Severe corrosion can develop from stray current, occurring at points where the current leaves the conductor and transitions to another medium.

A stray current corrosion specialist should develop the stray current control system to meet the needs of any transit project. An effective means commonly employed in modern projects involves collecting potential stray current via known paths by making rebar in those areas electrically-continuous and bonding the rebar to a continuous, stray-current collector cable running the full length of the train line. All bars in the reinforcement cage are wire bonded to one another. Often, the top mat and plinth reinforcement are spot-welded to each other to achieve electrical continuity. Welded-wire reinforcing mats have also been used. At each segment joint for precast segmental structures and at both sides of a structural expansion joint, the reinforcement mat is bonded to the longitudinal collector cable to provide electrical continuity. Grounding plates bonded to the reinforcement cage and encased in the segments are often used to facilitate these connections. Designers should work with owners to locate the collector cables in areas which minimize the opportunity for theft. Maintenance of these cables should also be addressed in the Operations and Maintenance Manual. For guidelines concerning maintenance, see Chapter 5.

Similar measures are also employed to protect internal and/or external post-tensioning hardware and other metallic embeds as directed by the stray-current corrosion specialist. Post-tensioning anchorage systems that electrically-isolate the prestressing strands from the concrete are also becoming more popular.

Figures 4-29 through 4-31 provide examples of Earthing and Bonding details.

Figures 4-32 through 4-33 provide further illustration of stray current countermeasures.

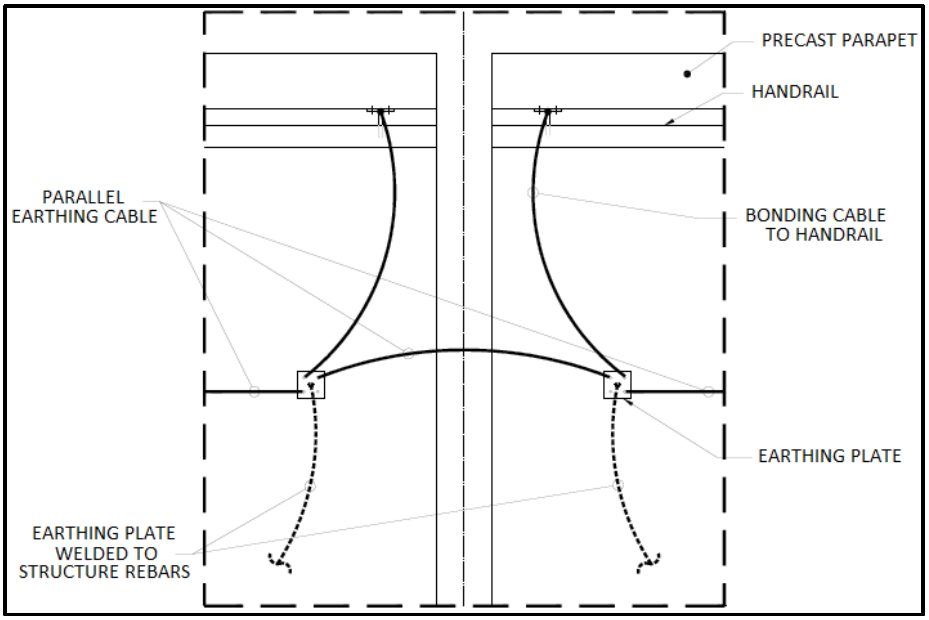


Figure 4-29. Elevation View of Earthing and Bonding Details at Structural Expansion Joint (Photo Courtesy of SYSTRA IBT)

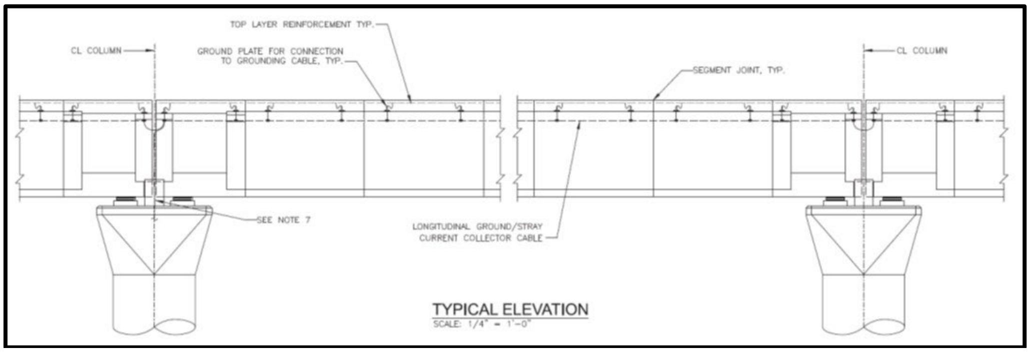


Figure 4-30. Elevation View of Earthing and Bonding Details Along Length of Precast Segmental Guideway (Photo Courtesy of SYSTRA IBT)

Figure 4-31. Bonding Detail for Transverse Post-Tensioning Anchor Head in Top Slab of Guideway
(Photo Courtesy of SYSTRA IBT)

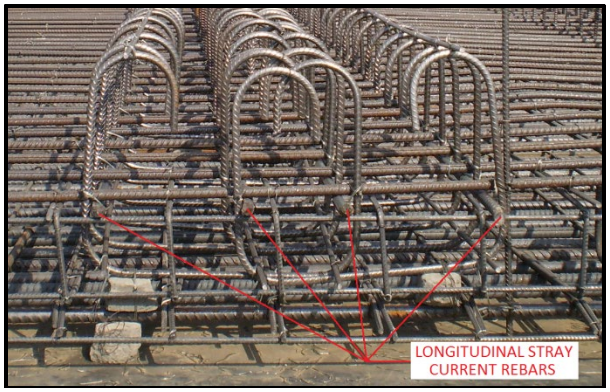


Figure 4-32. Section View of Longitudinal Rebar for Stray Current Mitigation
(Photo Courtesy of SYSTRA IBT)

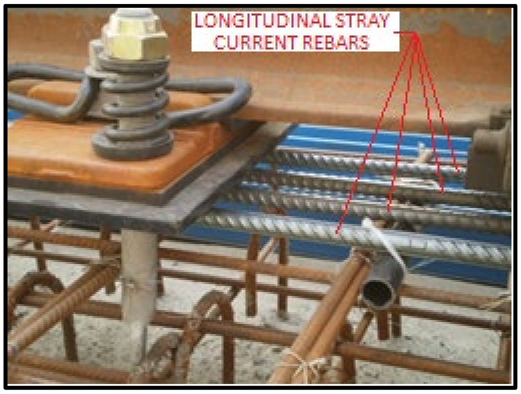


Figure 4-33. View of Longitudinal Rebar for Stray Current Mitigation
(Photo Courtesy of SYSTRA IBT)

4.3.5 Track Work

For direct-fixation tracks and especially for track plinth configurations, starter bars should be implemented carefully. It can become challenging for full precast straight spans used to support curved rail alignments where the transverse position of the starter bars will not be constant over the length of the span.

Buffer stops are provided at the ends of tracks typically located within train stations. There are several types of buffer stops. In the case of friction buffer stops, special configuration may require local strengthening of the track due to the short braking distance and possible high speeds. The starter bars configuration may need to be different at these locations. To increase the uplift capacity of the rails at these locations, rails can be clamped to a steel I section buried in the concrete guideway. All such special configurations impact the design and drawings of a segmental guideway.

Figure 4-34 provides a photograph of a typical Friction Buffer Stop.

Figure 4-34. Elevation View of Friction Buffer Stop
(Photo Courtesy of SYSTRA IBT)

4.3.6 Drainage and Snow/Ice Removal

As with all segmental structures, drainage must be a consideration. Drainage requirements for railway structures are often different than those for roadway structures. For example, in most rail applications, it is not necessary to crown the deck surface. However, it is necessary to prevent water accumulation between rail plinths. Whether the rail profile is sloped or not, a minimum slope for drainage purposes should be incorporated, transversely, longitudinally, or both. The extra weight of concrete plinths, if used to provide minimum slope for drainage, should be considered in the superimposed dead load. For some projects, it may also be necessary to provide embedded or attached scuppers, pipes, or other collection systems. In colder climates, subject to snow and ice accumulations, removal systems or other measures may be needed that would impact the guideway structure design. Typically, requirements for such systems are determined and specified by the Owner.

4.3.7 Access Considerations

See Section 5.7, Access Considerations, that need to be addressed in the design.

4.4 Construction

4.4.1 Geometry Control

As with any segmental bridge, geometry control is essential. For rail bridges, the geometry is governed by the rail alignment. Tolerances are tight and the use of spirals is more common than for roadway bridges.

Although currently available geometry control procedures for segmental structures allows construction with limited tolerances, compatible with track installation requirements, it is advisable that the track alignment be designed considering precast segmental technology constraints. The constraints are:

- Constant track transverse spacing.
- If plinthless, the same cross slope of the two adjacent tracks at the same section of the alignment (see Section 4.4.2, Plinth vs. Plinthless).
- Use one of the track alignments as master alignment to define the deck geometry.

The above requirements are not mandatory; however, they are strongly suggested to achieve more standardization in precast production.

4.4.2 Plinth vs. Plinthless

For most at-grade applications, rails are supported on railroad ties (or sleepers) that maintain gauge and are embedded in ballast. This type of track support can also be used for elevated guideway, but for most aerial structures, the rails may be attached directly to the guideway. This is known as direct fixation. The two main categories of direct fixation commonly applied in segmental bridges are ‘plinth’ and ‘plinthless.’ Plinths are concrete blocks cast on top of the guideway deck that support several rail fasteners under a single rail. The use of plinths has several advantages:

- Allows for greater precasting and erection geometric tolerances necessary to accommodate the trackwork hardware, since the plinths are cast-in-place after the bridge has been erected.
- The height of plinths can be varied to accommodate the superelevation.
- Separation of the rail from the top of deck can provide space for system and drainage requirements.

With plinthless construction, the rail fastener is directly attached to embedded anchors in the deck of the guideway. As a result, weight and construction cost and duration associated with the plinths may be removed but at the ‘cost’ of much tighter geometric tolerances (<¼ inch or tighter). Significant coordination, planning, and design between the train supplier, guideway designer, trackwork designer, contractor and others are necessary for successful implementation. The only means of adjusting the rail profile in plinthless construction is the use of shims between the bridge deck and the rail fastener. Other than coring to relocate rail fastener embeds, which defeats the benefit of plinthless, there are no easy on-site measures to correct horizontal out-of-tolerance errors. Careful coordination between the track alignment and the geometry control of the guideway is required, especially when superelevating the deck in curves. For plinthless construction, special care is necessary to compute precise theoretical locations of the embedded anchors, which must be placed precisely during precasting using a special-purpose jig. Common simplifying measures, such as chording, typically employed for computing the "theoretical" segmental geometry of roadway bridges should be avoided or at least carefully studied before using them with plinthless. The proposed alignment constraints listed in Section 4.4.1, Geometry Control, must be considered, along with several other measures intended to address the tighter tolerances. Also, this option is generally best suited to the box girder section (as opposed to a U-shaped section) as it is more adaptable to variations in rail profile, horizontal curvature, and superelevation.

Figure 4-35 provides an illustrative example of Direct-Fixation Rails Supported by Plinths while Figure 4-36 illustrates the Plinthless Rail Attachment.

Figure 4-35. Direct-Fixation Rails Supported by Plinths on Sound Transit in Seattle, WA (Photo Courtesy of SYSTRA IBT)

Figure 4-36. Plinthless Rail Attachment on Vancouver Rapid Transit in Vancouver, Canada (Photo Courtesy of SYSTRA IBT)

4.4.3 Deck Furniture and Other Embeds

On a rail bridge, the girder has to accommodate the rails, plinths, walkways, power systems, railings, drainage, and other utilities. A high level of coordination and accurate design scheduling are required to successfully account for these items, especially for precast segments. Standardization is key. Identifying placement tolerances for embeds is recommended to improve efficiency and to focus attention on items with tight tolerances such as bearing pintles at the interface between the superstructure and the substructure for example.

For plinth construction, starter bars are embedded in the structure. They need to be located accurately to accommodate future installation of typical fasteners and special trackwork fasteners. They also can impact on-site operations such as the ability to drive equipment on the completed deck.

4.4.4 Bearing Installation

Many rail structures are designed as simply supported structures or continuous structures supported on bearings. Bearing design itself has significant implications in both design and construction of the guideway structure and trackwork. As the bearing installation impacts the construction cycle, the bearings and pier heads should be designed with the assumption that the spans will be erected on temporary bearings, and permanent bearings will be installed after the span erection cycle. Special care is required in defining sufficient space for:

- Temporary Bearings
- Span Adjustment Jacks
- Erection Gantry Fixing Bars
- Span Tie Downs (If Needed)

Typically, the permanent bearings are installed prior to the installation of the rail. As discussed in the next section, installation of the rail can impose longitudinal forces on the bearings. The plans to install the bearings and the rail should be reviewed by the guideway design team to confirm the adequacy of the structure during all stages of construction.

4.4.5 Rail Type and Installation

4.4.5.1 Rail Type

Rails are either jointed with bolted connections or continuously welded. For modern aerial structures including segmental bridges, continuously welded rail (CWR) is the most common type. It has several advantages over jointed rails including:

- Better ride quality.
- Reduction in noise and vibration.
- Reduction in track maintenance.
- Reduction in dynamic impact forces introduced into the guideway.
- Reduction in wear of the rolling stock.

The use of CWR requires consideration of the interaction between the rail and the structure as described in Section 4.2.3, Rail Structure Interaction. Jointed rail typically has enough play in the connections such that RSI analyses are not applicable.

For direct fixation track, the rails are attached to the plinth or deck with specialized mechanical fasteners. Typically, the fastener is bolted to the plinth or deck at a spacing of 2 to 2½ ft. Rails can also be attached to crossties (also called sleepers) in ballast in lieu of direct fixation. The layer of ballast limits the transfer of forces between the rail and the guideway structure. However, tie and ballast systems are less common for aerial structures due to higher dead load, poorer ride quality retention, and additional maintenance.

4.4.5.2 Rail Installation

Installation of CWR includes laying out several hundred feet of rail and partially clipping it into place. In a second stage, the rail is heated to its neutral or ‘stress-free’ temperature and the rail is fully clipped to the fasteners. Ideally, the guideway is similar to its neutral temperature during this stage so that the temperature differential between the rail and the structure is as designed. Once fully clipped, the rail will impose loads onto the structure due to temperature changes.

At the leading edge of rail installation, several hundred feet is partially clipped in anticipation of the next section of rail. It is often necessary to stagger the starting point of the fully-clipped rail in adjacent tracks to limit the forces from the rail on the structure. The design engineer should evaluate the need for a rail installation plan during design development. For design build projects, the contractor and designer should work together to determine a rail installation plan that meets the requirements of the project. Although not unique to segmental construction, common adverse effects of improper rail installation sequence include excessive initial bearing deformation, bearing deterioration/walking, and pedestal damage.

4.4.6 Erection Methods

Segmental rail bridges are generally erected in linear fashion in which identification of the critical path and staging to avoid bottlenecks is necessary. The erection equipment should be able to accommodate all scenarios encountered on the project such as variable substructure types, sharp radii, or congested urban areas.

Figure 4-37 illustrates the use of an overhead gantry for erection.

More information on erection methods can be found in the *Construction Practices Handbook for Concrete Segmental and Cable-Supported Bridges*.

Figure 4-37. Overhead Gantry Erection of Sound Transit Box Girder Guideway in Seattle, WA (Photo Courtesy of SYSTRA IBT)

GUIDELINES FOR DESIGN AND CONSTRUCTION
OF SEGMENTAL BRIDGES FOR RAIL

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CHAPTER 5: MAINTENANCE CONSIDERATIONS FOR SEGMENTAL BRIDGES CARRYING RAIL

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Chapter 5:
Maintenance Considerations for Segmental Bridges Carrying Rail

This chapter discusses considerations that designers and owners will want to evaluate when developing designs and maintenance and inspection plans for segmentally constructed rail structures. In many aspects, the in-service inspection and maintenance of rail structures are very similar to that of conventional roadway structures. Also, such considerations for segmental rail structures are often very similar to that of other types of guideway structures. As such, several of the considerations presented in this chapter are not necessarily unique to segmental construction of rail structures.

5.1 General In-Service Inspection Considerations

There are general inspection considerations for all types of segmentally constructed structures. Due to the unique nature of segmental construction, owners are highly encouraged to require the development of an Operations and Maintenance Manual as part of the construction project requirements for each structure which outlines additional inspection requirements. Owners and operators should always consider the segmental experience and subject matter knowledge of the staff proposing to perform the routine, special, and in-depth inspections, but particularly so in the absence of such a document.

Inspection of both the interior and exterior surfaces of the guideway segments should be required on a routine cycle.

Cracks larger than 1/16-inch wide should be measured, noted directly on the concrete surfaces with the end of the cracks marked, dated and recorded on segment sketches with orientation including, transverse, longitudinal, diagonal or map.

External tendons should be observed visually and sounded regularly for signs of damage. Areas identified as having a discontinuity inside the duct should be marked in the field and recorded. The inspector should sight down the external tendons to identify sags or kinks in the duct that may be an indication of loss of capacity. The inspector should record and pay special attention to any tendons with indications of moisture. The ducts should be inspected for deterioration at or near embedded connections, as well as for cracks along the free length of the duct. These areas should be marked in the field and recorded.

If tendons are suspect or voids are known, non-destructive or destructive/exploratory methods can be utilized to determine the extent of voids or detect the presence of strand corrosion. Due to the inaccessibility of internal tendons, the concrete around internal tendons should be monitored for cracking or efflorescence which could provide a path for water or indicate that water is present around the tendon.

In-depth inspections, such as crack mapping less than 1/16 inch or non-destructive testing of tendons, are generally not included on routine inspection cycles, although they can be performed on less frequent intervals or on an as-needed basis.

Match cast joints and closure joints should be inspected for cracks, spalls water leakage and efflorescence should be documented.

The pier diaphragms are a very important part of the structure, they contain the anchorages for the longitudinal posttensioning and the location where the vertical loads are transferred to the piers. Cracking should be measured and called out on the diaphragms with the end of the cracks marked, dated, and recorded on segment sketches with orientation including, transverse, longitudinal, diagonal or map. Any cracks radiating from anchorage locations should be clearly identified.

Similar to the anchorages or pier diaphragms, the deviation blocks should be closely inspected for cracks, spalls, and delamination. Cracking should be measured and called out on the diaphragms with the end of the cracks marked, dated, and recorded on segment sketches with orientation including, transverse, longitudinal, diagonal or map. Any cracks radiating from the deviation block locations should be clearly identified. See Figure 5-1 for an example of a deviation block.

Figure 5-1. External Tendons and Deviation Block Inside a Box Section (Photo Courtesy of ASBI)

Additional general safety considerations must also be evaluated when planning an inspection of a segmentally constructed bridge. The inside of a box girder is often considered a confined space and additional measures must be taken to properly classify the space and ensure that the inspection staff is properly trained and equipped.

5.2 Rail Bridge General Considerations

Track time for deck inspections and rail-mounted access equipment is always a constraint for rail structures. This often necessitates work during non-revenue hours in non-emergency conditions. Agencies often also require additional permitting and safety precautions to be followed in order to request and get time on the structure, adjacent to rails. Providing access to the structure at regular intervals along its length, which can be easily accessed by maintenance and inspection personnel without disruption to rail operations, allows inspection and maintenance tasks to be completed inside the box independent of rail service hours.

Figure 5-2. Active Trains Can Present Challenges for In-Service Inspection
Sound Transit Line in Action
(Photo Courtesy of ASBI)

5.3 Rail Maintenance

Rail structures include components which are not included on roadway bridges, including rails, plinths, ties, switches, and signals. Deck and slabs may also be concealed by a ballasted system to support the rails and ties. While live loads can be distributed through the ballast, inspection of the top deck is restricted and tension cracks in top decks cannot be seen without removing the ballast and liner.

For light rail structures, power systems such as third-rail or overhead contact systems (OCS) are also present, as are grounding systems. These systems typically require alternative inspection and maintenance procedures, which can be the responsibility of the owner's or facility operator's track and power maintenance personnel.

Although not unique to segmental bridges, the inspection of the rail and fastening system is an important part of the structural maintenance for railway structures. As rails become worn, fasteners can become loose creating slight rail misalignments. These misalignments, combined with the necessary vertical adjustments for changes in camber, can negatively affect ride quality. Also, the effects of vehicle hunting become more pronounced. These effects increase as the speed of the trains increases. Track assemblies for both heavy and light rail should be inspected and maintained at regular intervals by agency staff during routine track walks. These inspections should include checks of plinths, ties, rail fasteners and rail alignment, gage and general condition. Remediation measures should be checked by a bridge designer.

5.4 Power Considerations

For light rail structures, electric vehicles are traditionally powered with OCS or a third rail adjacent to the running rails. It is important to provide additional worker safety for access around these power systems. Both OCS and third rail systems have their own support systems. It is important for inspectors to note the condition of the plinths or pole support bases associated with these power systems. Depending on the rail agency, inspection around OCS and third rail may require de-energization or a power down with lockout/tag out procedures which should be a consideration when planning inspection time. Typically, this includes work within 10 feet of an OCS wire. Inspectors and maintenance personnel should ALWAYS assume that third rail or OCS power systems are active and energized and should abide by the appropriate safety considerations, unless the systems are known to have been powered down and locked out.

The presence of an OCS-system creates an additional set of assets for the bridge owner that must be maintained and preserved. OCS poles should be maintained and inspected at specific pre-determined intervals. Although loads are not typically the same magnitude as what a roadway luminaire or sign structure would experience, OCS pole foundations are prone to the same types of deterioration as ancillary highway structures. Foundations must be checked for cracking and deteriorations and anchor bolts and hardware must be checked for tightness as well as signs of fatigue or damage.

It is also important for inspectors to understand equipment restrictions around power systems. Some owners dictate the use of fiberglass ladders. Inspectors should also consider non-conductive tape measures when working around powered elements.

It is important for inspectors to develop a site and agency specific safety plan which may include escort requirements, track access allocation, agency specific training, access and emergency egress of confined spaces and work around OCS or third rail.

5.5 Stray Current

Unlike roadway structures, most rail structures must consider the effects of stray current. It is common in new rail bridge construction to weld top deck reinforcing mats to make them electrically continuous and to provide a grounding source for stray current. For cast-in-place concrete segmental structures, top mats can be connected across segment joints where longitudinal reinforcement is continuous across segments. For precast structures, segments need to be connected to each other with a steel or copper bonding cable. See Section 4.3.4, Power Supply and Stray Current, for additional guidelines related to design for Power Supply and Stray Current and mitigating stray current corrosion. As stray current can accelerate the degradation of steel reinforcing and tendons, it is important for inspectors to make sure that any cables or other hardware installed for the mitigation of stray current remain intact and for designers and owners to locate these cables in areas which minimize the opportunity for theft.

5.6 Expansion Joints, Bearings and Dampers

Many rail agencies still prefer simple span construction at piers. While this does help limit the total expansion/contraction at individual joints, additional expansion joints and bearings are required when compared to continuous segmental roadway bridges with multi-span units.

Design of expansion joints and bearings also should consider maintainability. While joints are typically sized during design, the size of expansion seals should be re-evaluated during construction or inspection based upon the as-built length and placement of segments and spans. This helps to ensure that joints will have their full range of motion based upon differences from plan length in addition to operating movement and long-term effects as predicted by design.

Consideration needs to be given in design to make sure that expansion joints and/or rail covers do not have exposed conductive components which would allow electrical arcing around third rails.

The design of expansion joints and bearings should also consider, and appropriately restrict, movement of the structure as differential movements of structures across a joint adds stress to the rails and adjacent fasteners, which can lead to additional maintenance needs, the possibility of rail break or rail alignment issues.

In areas of high seismic activity, seismic dampers may be installed to dissipate energy during a seismic event. Special inspection recommendations should be provided in an Operations and Maintenance Manual. These recommendations should include statements of how frequently to check fluids and/or the condition of moving parts.

5.7 Access Considerations

Access to rail structures is often more restricted for inspectors than highway bridges because temporary traffic control is more limited. Train traffic can only be conveyed on the existing track locations. Limiting train traffic, especially during revenue hours, is not ideal. For this reason, special consideration should be given to how maintenance and inspection personnel will access the bridge following construction. Special consideration should be given to placing access locations where maintenance and inspection staff can get to them without specialty equipment. Coordination of bottom slab access hatches with the topography and ground conditions can allow underside access with only a ladder. Inspection and maintenance costs increase as the degree of difficulty for access of the structure increases. When planning a segmental rail superstructure, designers should consider the needs of future maintenance and required inspection and balance that with the operational capabilities of the rail agency operations department. See Figure 5-3 for an example of an access with a ladder.

Top deck access openings are typically well placed for construction, but often such locations can lead to difficult access during revenue hours. In the event that access is provided from the top deck, hatches should be placed in such a way that they can be accessed without, or with minimal, disruption to rail service. This is possible on dual track structures where a hatch could be located so that access could be granted while rerouting train traffic onto the second set of tracks.

Access to a box girder interior from bottom slab access hatches, when not accessible by ground, is typically provided by the use of an under-bridge inspection vehicle, bucket truck, or man lift, so proper training regarding the use of these types of equipment (especially if rented) and the use of fall protection is required. Use of this equipment may restrict rail traffic unless it is ground based or can be done during non-revenue hours. If specialty inspection access is needed, this should be detailed in the Operations and Maintenance Manual for purposes of inspection planning.

Reasonable access should be provided to all spans. While hatches provide access to the box interiors at regular intervals, access should be provided through end diaphragms and deviators which allow maintenance and inspection staff to pass through with equipment between hatch locations. In the event that access cannot be provided through an end diaphragm or crossbeam, hatches should be provided to allow each span on either side of the barrier.

Inspection safety plans, developed prior to accessing the right-of-way, should detail anticipated use of access hatches as well as have adequate safety equipment and staff available in the event of emergency and alternative hatches must be used.

Figure 5-3. Bottom Slab Access Hatch Entered with External Ladder
(Photo Courtesy of ASBI)

5.8 Considerations for Limited Pedestrian Traffic

Unlike roadway bridges with sidewalks or pedestrian paths, rail structures typically are not built with human traffic in mind. Consideration should be given to the limited foot traffic which needs to access the bridge. This includes maintenance, operations, and inspection staff in addition to emergency egress. Pathways should be outfitted with safety rails compliant with current standards.

5.9 Bridge Cleanliness

Due to concerns for stray current, it is important to keep rail structures clean and free of dirt and debris. Build-up can cause ponding to occur, increasing the likelihood for electrical arcing from passing trains or third rail systems.

Track slabs also tend to accumulate debris and sand at rates exceeding roadway bridges. This is partially due to the traction systems on rail vehicles as well as the tendency of rail to transport and deposit debris regularly. This debris will trap water and accelerate the rate of deterioration of decks, expansion joints, drains and rail plinths. Routine maintenance is critical to keeping track slabs clean.

Bridge drains on structures with third rails are also an area of concern, especially on systems that use third rails. Bridge drains need to be regularly inspected for signs of clogs and blown out as necessary to prevent ponding which can increase the likelihood of electrical arcing.