Design Optimization of Steel Box Girder Bridges

YUHE YANG, P.E., S.E

MATT PREEDY, P.E.

Biography

Yuhe Yang is a Senior Supervising Structural Engineer with the Seattle office of Parsons Brinckerhoff Quade & Douglas, Inc. He is a Professional Associate and the Seattle Structural Group Manager.

Yuhe received his Master of Science in civil engineering from the University of Miami in 1986 and Bachelor of Science degree from Tongji University in Shanghai, China in 1981. He has worked on a number of large and complex structural projects, including curved steel box bridges, post-tensioned segmental bridges, tunnels, etc. He has also published several papers for national and international conferences.

Matt Preedy is an Engineering Manager with the Washington State Department of Transportation (WSDOT), currently responsible for the agency's highway construction program in Seattle and surrounding areas. He served as Resident Engineer in charge of construction management during construction of the Sunset Interchange.

Matt received his Bachelor of Science in civil engineering from the University of Washington in 1992. Working as a Resident Engineer, he has managed a wide variety of highway, geotechnical and structural projects. He specializes in construction of foundations, bridges, seismic upgrades, and environmental retrofits. Matt is a current member of the WSDOT/ACEC (American Council of Engineering Companies) committee, which addresses project design and delivery issues of common interest to WSDOT and the consultant design community.

Summary

Two curved steel box girder bridges were completed in late 2003 approximately 18 miles east of downtown Seattle. The steel box girder structures were selected because of their fast erection over Interstate-90, tight horizontal curvature and no construction support in the environmentally sensitive creek below the structure. Major design optimizations included:

1. Two bridges carrying different ramps were laid out with similar maximum span lengths to share sections and details.
2. Concentrically connected pipes and structural tubings were used for lateral bracings and cross frames instead of eccentrically connected steel WT and angle shapes as in conventional designs. With concentric connections, these shapes are more efficient in resisting torsional moment due to tight horizontal curves.
3. Seismic isolation bearings were used to minimize the seismic forces, and resolved a constructability issue.
4. A unique design of breakaway expansion joints was constructed at the abutments. These breakaway joints function properly under normal service conditions, but will breakaway during a major earthquake to protect the structures.

DESIGN OPTIMIZATION OF STEEL BOX GIRDER BRIDGES ON THE I-90 SUNSET INTERCHANGE

By
YUHE YANG, P.E., S.E.
MATT PREEDY, P.E.

PROJECT DESCRIPTION

Approximately 15 miles east of downtown Seattle, nestled between the base of the Cascade foothills and Lake Sammamish, Issaquah is one of the fastest growing cities in Washington State according to the U.S. Census Bureau. Plans to build the new Issaquah Highlands urban village community and a new Microsoft campus atop the Sammamish Plateau caused transportation access improvements to become a major priority in this area. To alleviate increasing traffic congestion, improve safety, and add improved connections to Issaquah and the Sammamish Plateau, the I-90 Sunset Interchange project was undertaken. This proved to be the largest and most complex interchange project in Washington State in the last decade (see Figure 1).

Figure 1: the I-90 Sunset Interchange

The I-90 Sunset Interchange project includes two steel box girder bridges. The Flyover Bridge carries the I-90 eastbound off-ramp traffic, then turns almost 90 degrees over the I-90 freeway and up toward the Sammamish Plateau. This flyover bridge was ranked as one of the "Top 10 Bridges" of 2004 in *Roads & Bridges* magazine. The Issaquah Creek Crossing Bridge, as the name suggests, carries traffic from another leg of the I-90 eastbound off-ramp over Issaquah Creek and connects the ramp to an intersection with Highland Drive.

CONSTRAINTS AND CHALLENGES

From preliminary design to construction support, the engineers faced several site constraints and design challenges:

- During the entire construction period except for a few night closures during girder erections, three lanes in each direction of the I-90 freeway had to be kept open for traffic. However, the Flyover Bridge and a post-tensioned concrete box girder bridge were constructed crossing over the I-90 freeway. This created the need to lay the steel girders in pieces, which was difficult given that so many lanes remained open. In addition, the Flyover Bridge is on top of the new concrete box girder bridge, which created difficulty for the construction falsework.
- The Issaquah Creek Crossing Bridge spans over the Issaquah Creek at approximately a 65-degree skewed angle. This large span generated a greater need for support. However, no in-stream support (not even temporary construction support) was allowed, because Chinook salmon are present in the environmentally sensitive salmon-bearing East Fork Issaquah Creek, and Chinook salmon were declared an endangered species in western Washington while the project was in process.

- The preceding two constraints created the demand for relatively long spans. Typically, the longer the span, the deeper the girders. One of the design challenges for this three-level interchange was to minimize the girder depth as much as possible. This is because increasing structure depth consequently leads to higher ramp profiles and thus longer ramps, which not only increases project cost but may also create difficulties for the alignment design.
- Because of site constraints and the construction equipment's maximum available capacity, the constructible sizes of pier columns and footings were not able to provide the necessary resistance demanded by the calculated lateral force. Because of this, the project engineers had to find innovative ways to reduce lateral force demands on the substructures.
- The I-90 Sunset Interchange is located in a scenic section of the I-90 corridor considered part of the Mountain to Sound Greenway. The aesthetic desire to maintain clean lines and minimize the structure depth to lessen visual impact added challenges for structural appearances.

DESIGN OPTIMIZATION

During the initial study, several structural types were evaluated for the project's two bridges. The initial study narrowed down and quickly focused on steel girders because of constructability considerations. Three steel structural types were evaluated: 1) plate girders with integral pier caps, as shown in Figures 2 and 3, 2) a single steel box girder, and 3) twin steel box girders, as shown in Figure 4. Each type of superstructure is supportable by single-column piers. The twin steel box girders were eventually selected for the flyover bridge and the Issaquah Creek Crossing Bridge because of the following relative advantages:

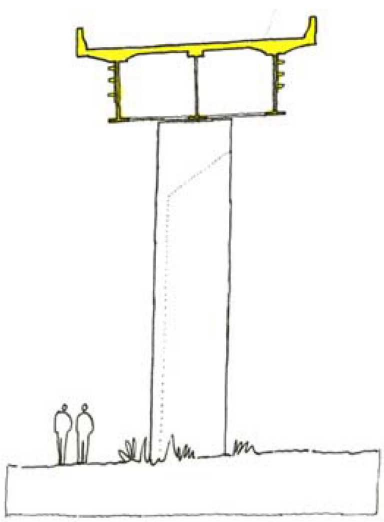

Figure 2: Plate Girder with Integral Pier Cap (section view)

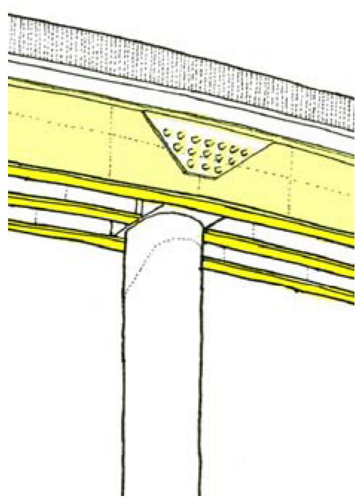

Figure 3: Plate Girder with Integral Pier Cap (side view)

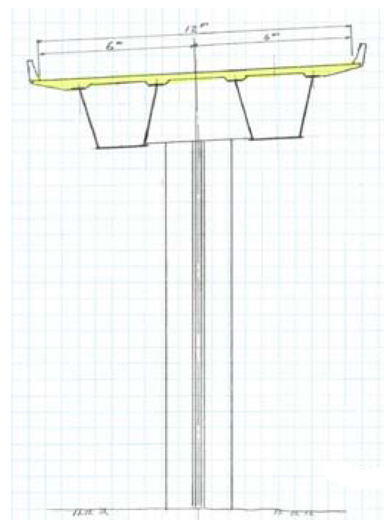

Figure 4: Twin Steel Box Girders

- The twin box girders were able to provide the maximum torsional stiffness for the flyover bridge, which has a horizontally-curved alignment with only a 100-meter radius.
- The twin box girder structures allowed the shallowest structural depth among the girder type bridges, which led to overall cost savings for the interchange due to reduced lengths of ramps and heights of walls.
- With their streamlined shape, the box girders blended well visually with the surrounding environment, including the existing bridges in the vicinity.

During design of the twin steel box girder structures, a few design features were included for overall design optimization. The benefits of the optimized design are discussed in following sections.

Minimal Traffic and Environmental Impact

This project's construction constraints included the fact that three lanes of traffic in each direction of I-90 were required to remain open for traffic during the entire construction period, with the exception of a few night closures for girder erections. Also, no temporary or permanent support was allowed in the salmon-bearing Issaquah Creek. To meet this requirement, the project engineers selected steel box girders and optimized the span layout, including using some of the largest steel girder segments ever to be transported and installed in the State of Washington. This **user-friendly construction method** provided convenience to the public, significant cost savings from prevented traffic delays and jams, and minimal environmental impact to the Issaquah Creek.

Optimized Bridge Layout

Among other innovative features, the design optimizations included a cost-effective integral design process for both bridges. Through careful layout design, the maximum span lengths for both the flyover bridge and the Issaquah Creek Crossing Bridge were arranged so both bridges could share the same steel box section and details (Figure 6). This **simplified the fabrication process and consequently led to cost savings**.

Maximizing Girder Span/Depth Ratio

One of the design challenges for this three-level interchange was minimizing girder depth as much as possible, to **lower ramp profiles and thus create shorter, more cost-effective ramps**. This not only decreased project cost but also enabled a more flexible alignment design. By introducing properly spaced cross-frame and lateral bracings combined with half-inch-thick web plates, the project engineers were able to minimize girder depth **without using costly haunched girders and longitudinal stiffeners**. The tight curvature of the flyover bridge creates greater internal forces than a straight bridge. The forces in each of the 75-meter curved spans could be roughly equivalent to the forces in a straight span roughly 1.2 times longer, so the equivalent span/depth ratio would be approximately 31 – a practical span limit for a constant depth girder.

Savings on Substructure Compensates the Higher Steel Cost

Steel box girders were selected partially for substructure cost savings. Although precast/prestressed concrete girders are generally considered to be cost-effective alternatives to steel girders, if the flyover bridge were designed with pre-stressed girders (because of the tight horizontal radius – 100 meters), the number of interior piers would approximately double (increasing from three to seven) and the traffic impact would increase severely. Typically, piers and footings are expensive elements of the structures located within the seismic category zone C or D, as was the case for Sunset Interchange.

Concentrically Connected Cross-Frames and Lateral Bracings

Large axial forces on the cross frames and lateral bracings were induced by large torsion moments generated from the horizontal curvature. The axial forces would have generated large bending moments, due to the eccentric connections if WT or L shapes were used for the cross frames and lateral bracings. Unique designs using steel pipes and structural tubings enabled concentric connections (Figures 12 to 15) that essentially eliminated bending moments in the members, thus significantly reducing member sizes and weight and consequently contributing to **reducing the girder depth and producing final cost savings.**

Seismic Isolation Application Reduced Footing Size

During drilling for the bridge foundations, the contractor ran into boulders the size of small automobiles left behind from centuries-old glacial activity, making the intended method for shaft excavation practically infeasible. In order to solve the construction problem and maintain the schedule, the originally designed shaft sizes had to be reduced. This in turn required reducing the lateral force demands on substructures. The design, which was revised simultaneously with the construction period, applied seismic isolation (Figure 16) and consequently reduced the footing size. **This saved construction costs and brought construction back on schedule**

Cost-Effective Breakaway Expansion Joints

A unique breakaway joint (Figure 24) was designed and constructed for the bridges in lieu of a more expensive modular joint. This design made it **feasible to use cost-effective strip seal joints** to meet motion range requirements under normal operating conditions. However, in a major earthquake the front portion of the approach slab will break away when hit by the bridge deck, allowing the girders to move and provide additional damping.

Enhanced Sustainability through Maintenance-Friendly Design

A sustainable steel structure needs regular inspections and preventive maintenance. Light fixtures were installed inside the girders of both bridges to provide illumination for the convenience of inspection and service work. **The depth of the girders is deep enough to allow standing and walking inside the boxes.**

The structural steel used for the two bridges are grade 50 (50 ksi) steel. High Performance Steel (HPS) was not used, partly because the designs were governed by the fatigue stresses.

FINAL BRIDGE DESCRIPTIONS

This section describes the final optimized structural type and layouts of the two bridges. The primary structural design codes or specifications for the project were:

- The American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges,* 16th Edition [1]
- The Washington State Department of Transportation (WSDOT) *Bridge Design Manual* [2]
- The Washington State Department of Transportation (WSDOT) *Standard Specifications for Road, Bridge and Municipal Construction* [3]

Flyover Bridge Crossing the I-90 Freeway

- This is a four-span, continuous, horizontally-curved structure with a minimum radius of 100 meters (see Figure 5).
- The overall bridge length is 282 meters along the curved baseline, which is approximately the centerline of the inside box girder (near the center of the radius).
- The lengths of each span along the baseline are: 70 meters for span one, 71 meters for spans two and three, and 70 meters for span four. The maximum span length along the centerline of the outside box girder is approximately 75 meters.
- The structure section consists of two steel box girders of 2.840 meters deep covered with a 12-meter-wide composite concrete deck. The overall superstructure depth is 3.190 meters (see Figure 6).
- The three interior piers are single-column piers with hammer head-type pier caps (see Figure 7).

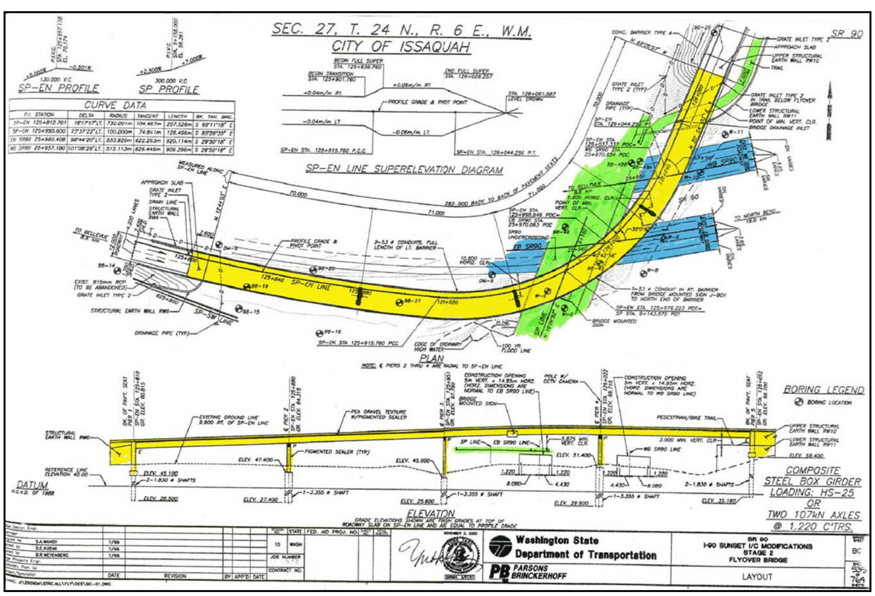

Figure 5: Flyover Bridge Plan and Elevation

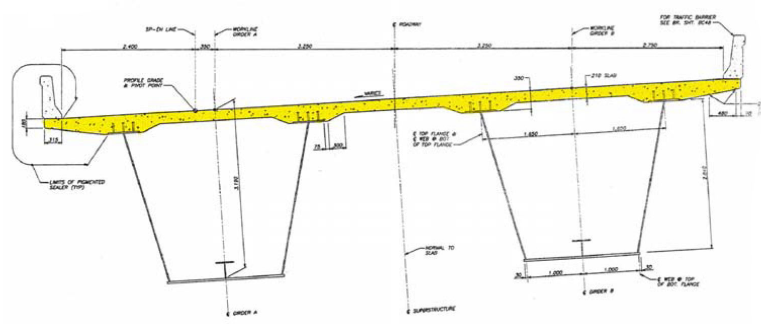

Figure 6: Structure Section—Twin Steel Box Girders

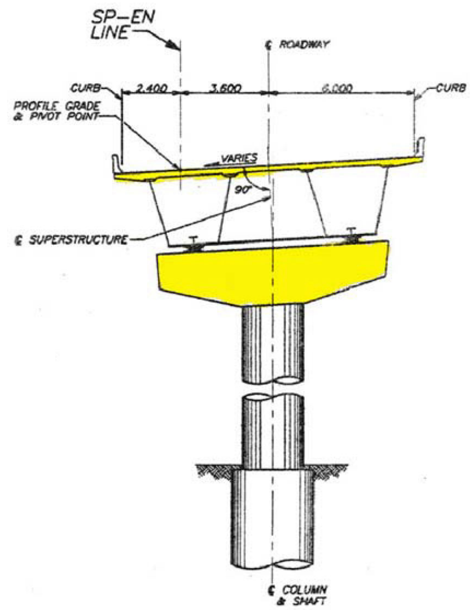

Figure 7: Typical Pier Section

- The footings of the piers are a single 3-meter-diameter drilled shaft under each pier column. The footings for the abutments are two 1.83-meter-diameter drilled shafts under each abutment.

Issaquah Creek Crossing

- This is a two-span continuous, horizontally curved structure with a minimum radius of 1,031 meters (see Figure 8).
- The bridge has two equal spans of 75 meters each, and the overall bridge length is 150 meters.
- The steel box girders have sections that are identical to the flyover bridge's box girders.
- The composite concrete bridge deck has a constant width of 11.1 meters, except the deck flare near the east-end abutment.
- The center pier is a single-column pier with a hammer-head type pier cap and a single 3-meter-diameter drilled shaft footing.
- Each of the two abutments is supported by two 1.83-meter-diameter drilled shafts.

The preliminary structure layout design was purposely arranged to make the maximum span length approximately the same for both the flyover bridge and the Issaquah Creek Crossing Bridge. In this way, the design could be optimized to use the same steel box section for both structures. The design approach of using one standard steel box section for two bridges simplified the fabrication process and consequently led to cost savings.

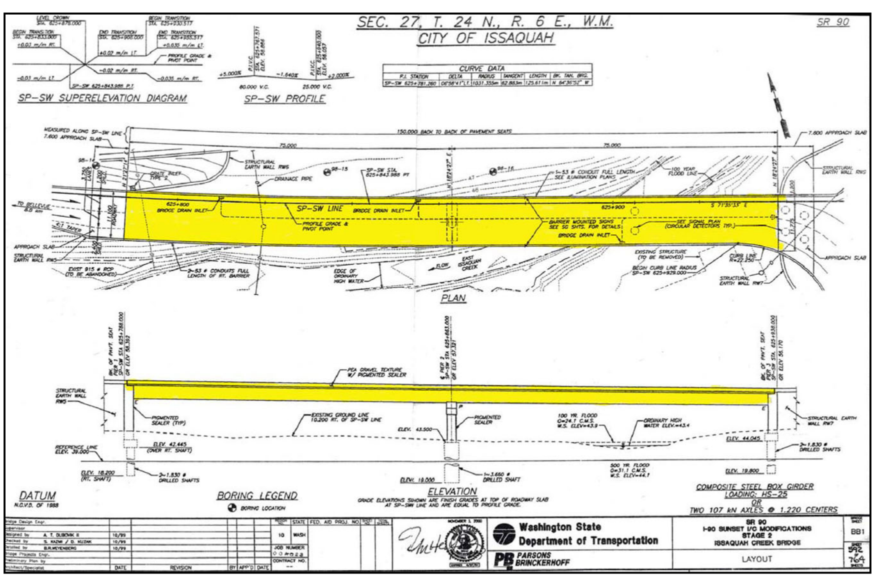

Figure 8: Issaquah Creek Crossing Bridge Plan and Elevation

CONSTRUCTABILITY AND STAGING

Of the varying girder lengths of these two bridges, the maximum were 75-meter-long spans. The maximum length of each girder segment was limited to 40 meter by restrictions placed on the transportation route and the erection equipment's capacity. The project design optimized the locations of girder field splices by balancing the need to satisfy

Figure 9: Steel Box Girder Erection

Figure 11: The Girders Erected

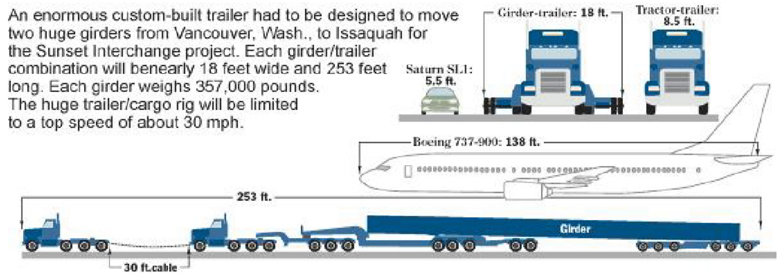

Figure 10: Excerpt from Seattle Times Article

several design parameters. These parameters included the girder length limit, constructability restrictions, the disallowance of supports on the I-90 freeway and Issaquah Creek, girder splicing location limits, and other restrictions.

Even though the maximum girder segment length is limited to 40 meters for ease of transportation and erection, these steel box girder segments are relatively deep and heavy at approximately 80 tons each (see Figure 9). The manufacturing and shipping of the girders from the fabrication plant to the job site made headline news in several newspapers, with headlines such as: "The Heaviest Girders Ever To Ride Washington Highways," "Gird Yourself for an Unbelievable Road Hog," "Caution: Wide, Heavy Load," and "Rolling Thunder." The Seattle Times even compared the size of the girders with a Boeing 737 airplane (see Figure 10).

There are two field splices in each span. The girder segments over the interior piers were erected first. The in-span segments were then erected and field-connected to the pier segments (see Figure 11). The entire erection operation was completed with minimum interruption and only a few night closures on the I-90 freeway. Following this, the reinforced concrete decks were poured on the positive moment span portions and poured over the piers.

UNIQUE CROSS FRAMES AND LATERAL BRACINGS

Because of restrictions put on the project and the girders needed, several challenges arose during design. One challenge was the design of girder cross frames and bracings.

Conventional designs of cross frames and lateral bracings typically consist of WT- or L-shaped steel members. Because of their asymmetrical section properties, when axial forces are applied to either WT- or L-shaped members, the centerlines of the axial forces applied to the members through the end connections are generally offset from the neutral axis of these members. Consequently, bending moments are created along with the axial forces to those members. In other words, members of conventionally designed steel girder cross frames and lateral bracings resist both axial forces and moments.

The moments in the members of cross frames or lateral bracings are generally acceptable until the horizontal curvature becomes quite large. For the flyover bridge, which has a horizontal curve with a minimum radius of 100 meters, analysis indicated that the tight horizontal curve would induce larger-than-normal torsional moments in the girders during the pour of concrete decks. If WT- or L-shaped members were used for the cross frames and lateral bracings, larger-sized steel members would have been required to resist the increased forces and moments due to the larger torsional moments in the girders. The increased weight of the cross frames and bracings would have added to the total dead load of the box girders, which would have further increased the torsional moments in the girders. Eventually, deeper girders might have been required to resist the additional dead loads, which would have created the need to increase the ramp profiles and lengths.

To optimize the design, steel pipes and structural tubings that enabled concentric connections were used for the cross frames and lateral bracings. Because the centerline of axial forces in the pipes and tubings coincided with the neutral axes of the members, bending moments in the members were essentially eliminated (see Figures 12 and 13). The pipes and tubings are truss members and were more efficient compared to WT or steel angles. The ends of the pipes and tubings were sealed for corrosion protection (see Figures 14 and 15). By using steel structural pipes and tubings for cross frames and lateral bracings, the weight of bridge superstructures was reduced, and consequently this avoided the use of deeper girders, which would have not only raised the roadway profiles but also required expensive longitudinal web stiffeners.

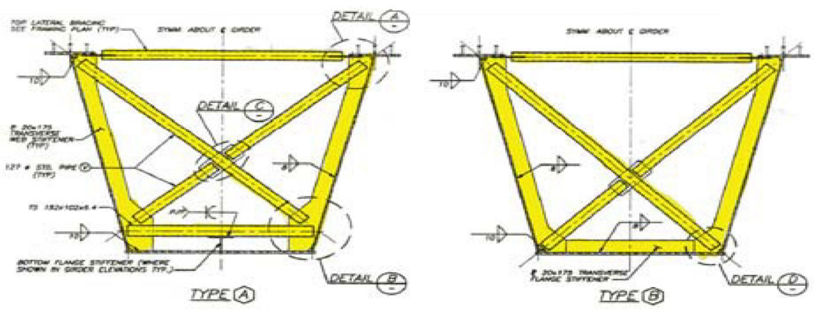

Figure 12: Sections of Concentric Connected Cross Frames and Lateral Bracings

Figure 13: Cross Frames and Lateral Bracings inside the steel box girder

Figure 14: Pipes Sealed for Corrosion Protection

Figure 15: Tubing Sealed for Corrosion Protection

SEISMIC ISOLATION

During drilling for the bridge foundations, the contractor ran into previously undetected massive underground boulders left behind from centuries-old glacial activity, making the intended method for shaft excavation practically infeasible. The footing construction became the critical path that could impact the entire project schedule. The use of special construction equipment (an oscillator) was proposed to cut through the boulders.

Figure 16: Isolation Bearings under Girders

However, the oscillator's maximum cutting capability was 3 meters (approximate 10 feet) in diameter, which was 0.6 meters (approximate 2 feet) smaller than the shafts' designed maximum diameter. The designer, after discussions with the project owner and the contractor, decided that the optimal solution for this unique constructability problem was to reduce the lateral force demands from the structures to the foundations, thus enabling the designer to reduce the shaft size. For that purpose, the bridge designs were revised and re-analyzed within a limited timeframe while construction was occurring. This resembled a design/build process. Seismic isolation bearings (see Figure 16) and uniquely-designed breakaway joints at the ends of the bridge decks were added onto the two horizontally-curved bridges during construction [4].

The design of a seismic isolation system was analyzed by using multimode spectra analysis, and verified by time history analysis.

Multimode Spectra Analysis

Because of the amount of iterations involved and constraints on the design budget and schedule, time history analysis was used for the design verification only. Instead, multimode spectral method analyses were performed according to design procedures described in the *Guide Specifications for Seismic Isolation Design* (*Guide Specifications* hereafter) published by the American Association of State Highway and Transportation Officials (AASHTO) [5].

Two three-dimensional space-frame models that were originally analyzed during the bridge design phase were modified for the multimode spectral seismic analyses. The effects of seismic isolation were simulated by inputting the effective stiffness (Keff) of the isolator units into the model. The effective stiffness (Keff) was calculated from the assumed post-elastic stiffness (Kd) of the bilinear isolation system. When a new value of Kd was assumed for the analysis, Keff was recalculated for the computer model.

The Iteration Process

The design process included iteration runs of the multimode spectra analysis. The goal of the iteration analysis was to find a set of values for the design parameters that would satisfy the performance criteria.

Because the effective stiffness of the bearing (Keff) depends on its displacement (d bearing), the iteration involved assuming an initial effective stiffness, running the analysis, recalculating the effective stiffness based on the resulting displacements, and continuing until it converged.

The displacement (Δ) relative to the ground at the bearing level includes the displacement of the isolation unit (d bearing) and of the pier column (dcol) (see Figure 17). The maximum allowable displacement at the top of the pier was limited by geometric constraints, column strength, and the P-Delta effect [6] (see Figure 18).

The lateral force at the bearing level is also governed by the column strength and the P-Delta effect. The maximum allowable lateral force (Fh allowable) decreases as the displacement increases, because of the P-Delta effect (see Figure 18).

The characteristic strength of the isolator unit (Qd) and the second-slope stiffness of the bilinear hysteresis curve (or post-elastic stiffness (Kd)) were the two most frequently revised parameters during the iteration analyses. Information from manufacturers and other resources (i.e., from the HITEC reports) were considered in selecting proper values for the Qd and Kd before each iteration.

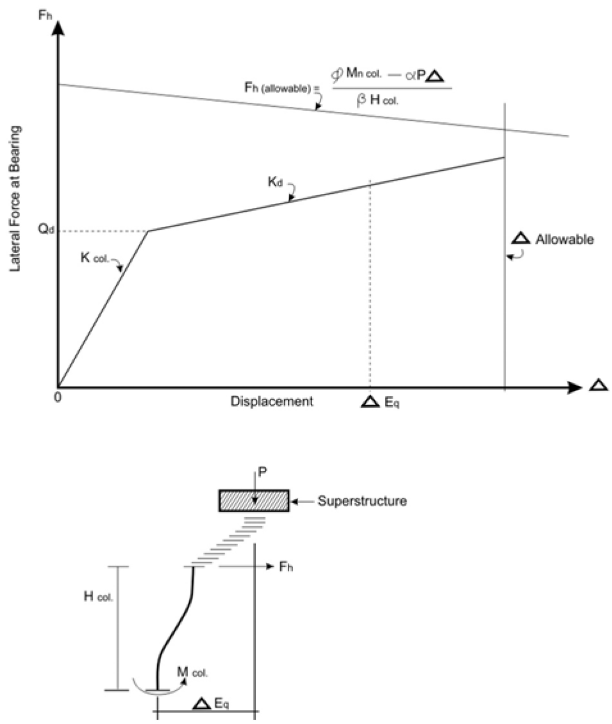

Figure 17: Displacement

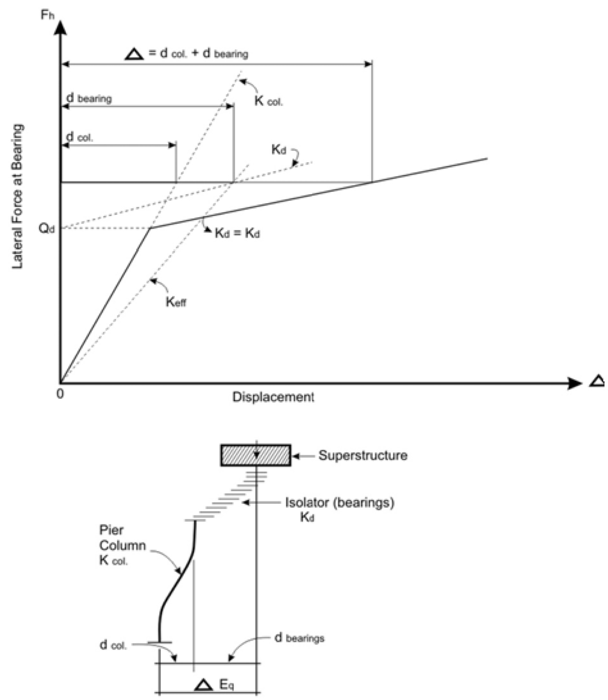

Figure 18: Maximum Allowable Displacement

Wind Force Complication

Ideally, the characteristic strength of the isolator unit (Qd) should be higher than the maximum wind force that could be exerted on the isolation unit. This ensures that the isolation units will not be activated during strong winds.

The tall, relatively slender pier columns and long bridge spans in the I-90 Sunset Interchange project posed a design challenge. Because the slender pier columns were flexible, for them to be effective it would have been preferable that the isolation units require only a small initial force to be activated or have a small characteristic strength (Qd). However, the lower value of the Qd was constrained by the strong wind force exerted on the long bridge spans. If the values of Qd became too low, the isolation units would have been prematurely activated under a strong wind, which would not have been desirable (see Figure 19). On the other hand, a characteristic strength (Qd) value higher than the maximum wind force would have required a small post-elastic stiffness (Kd) in order to limit the lateral forces below the maximum allowable force level (Fh). An isolation unit with small post-elastic stiffness (Kd) may not have provided enough seismic restoring force for the structure, and the seismic-induced displacement may have been too large for the practical design purpose.

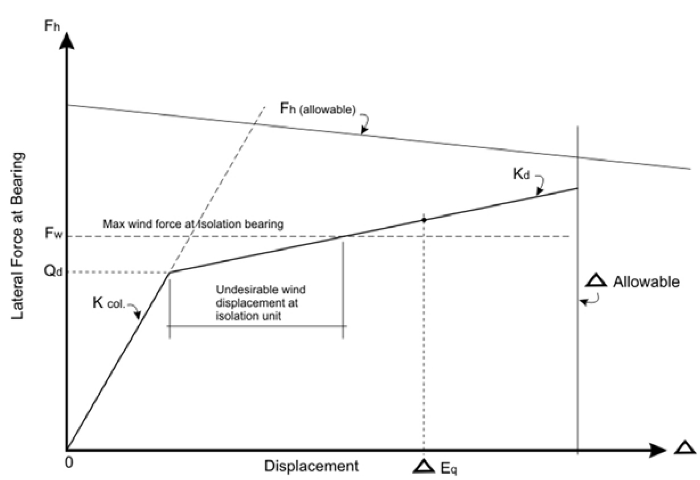

Figure 19: Characteristic Strength and Wind Effect

To solve this dilemma, wind lock devices were attached to the seismic isolation bearing units. The wind locks were designed to break

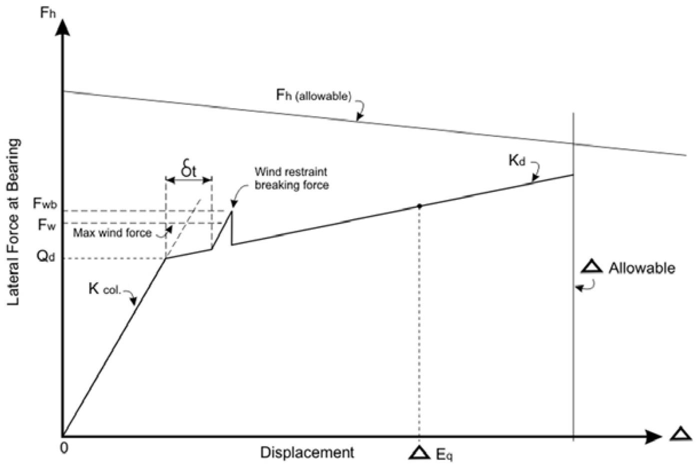

Figure 20: Effect of Wind Lock Devices

when seismically-induced initial force exceeds the maximum wind force, therefore activating the isolation units. As soon as the wind lock devices break and the isolation bearings are activated, the seismic lateral force on the structures will immediately drop because the effective stiffness of the isolation bearings is much less than that of the pier columns (see Figure 20).

Time History Analysis

Time history analysis was applied to verify the multimode analysis design results. Per the *AASHTO Guide Specifications* requirements, a geotechnical subconsultant firm provided three pairs of ground motion time history response spectrums as input information for the analyses.

The type of isolation bearings selected for this project were friction pendulum bearings (see Figures 21 and 22).

Figure 21: Typical Friction Pendulum Bearing

Figure 22: Friction Pendulum Bearings in Place

Unique Breakaway Expansion Joints

The seismic isolation bearings at piers and abutments comprised only part of the isolation system for these bridges. Without properly designed or modified deck expansion joints at the abutments, the bridge seismic isolation system would not have performed as desired. Figure 23 (left side) shows a bridge structure's seismic behavior without seismic isolation. The right side of Figure 23 presents an extreme scenario, showing the behavior of a bridge that has seismic isolation bearings without properly designed expansion joints. For a bridge on a sharply curved alignment such as the I-90 eastbound-northbound flyover bridge, proper expansion joints were extremely important for achieving seismic isolation for the superstructure.

Commercially available large modular joints that satisfy seismic displacement requirements are relatively expensive, particularly due to the low probability of needing extremely large seismic displacement capacity. To reduce the project cost and possibly lower long-term maintenance costs, project engineers designed a unique breakaway joint specifically for this project (see Figure 24). This design made it feasible to use the inexpensive strip seal joints under normal operational conditions. However, in a major earthquake the front portion of the approach slab will break away, allowing the girders to move and providing additional damping.

Construction Challenges

Although it was understandable that no girders could be fabricated and erected exactly according to the plan dimensions due to variations in temperature, material weight, etc., the application of seismic isolation bearings onto horizontally-curved girder bridges did pose some unique construction challenges. For example, with a curved girder the temperature variation and deflection (due to self-weight) not only affected the longitudinal and vertical positions at the bearings but also slightly changed the horizontal positions. These horizontal movements during erection, although very small compared to the magnitude of the girders, were significant enough to cause trouble during installation of the wind locks for the isolation bearings. Working together with the client and the isolation bearing fabricator, the project engineers solved the problem by revising the design of the double wind lock to a single wind lock per bearing, which allowed more tolerance for the imperfect horizontal geometry.

AESTHETIC CONSIDERATIONS

The I-90 Sunset Interchange is located in a scenic section of the I-90 corridor. Aesthetic considerations at the project site were highly important for the local community, the Mountain to Sound Greenway Trust (a community group focused on developing and retaining trail systems in western Washington), and the owner (the Washington State Department of Transportation).

Because the bridges are major components of the interchange, the structural aesthetics were never considered to be an afterthought or "add-on". Instead, aesthetic considerations were incorporated from the outset of the design process. A unique artistic approach was developed to enhance the aesthetics of this gateway to the Cascade Mountains (see Figures 25 and 26). The steel twin box girders, supported by slender-looking single columns provided a simple and streamlined appearance, which blended seamlessly with other box girder bridges in the interchange and with the surrounding natural environment (see Figures 27, 28 and 29).

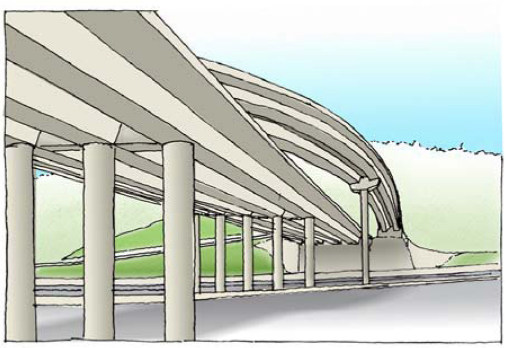

Figure 25: Sketch of Flyover Bridge (top) Looking North

Figure 26: Sketch of Flyover Bridge and Issaquah Crossing Bridge Looking East

Figure 27: Flyover Bridge (Top) Looking

Figure 28: Flyover Bridge Looking East

The abutments of these two steel bridges also became continuations of much larger, artistically-designed retaining walls that incorporated various floral leaf and seedling patterns. These decorative imprints were selected to symbolize and represent the natural and human environment around the interchange (see Figure 30). This contrast with the rough surfaces of the walls further enhanced the beauty and simplicity of the streamlined steel box girders.

Figure 29: Flyover Bridge and Issaquah Crossing Bridge Looking West

Figure 30: Retaining Wall with Floral Leaf Imprints under the Flyover Bridge

CONSTRUCTION COST

This interchange opened to traffic in August 2003. According to WSDOT, the final cost of the entire I-90 Sunset Interchange project was about $116 million. For the two steel bridges, the design engineer's construction cost estimates were as follows:

- Flyover Bridge: $5,346,000 ($1,496 per square meter/$139 per square foot)
- Issaquah Creek Crossing Bridge: $2,952,000 ($1,677 per square meter/$156 per square foot)
- The estimated total and averaged unit cost of these two steel bridges was: $8,388,000 ($1,555 per square meter/$144 per square foot)

Four contractors bid on the project and bids were opened on February 7, 2001. The costs for the two steel bridges, as extracted from the contractors' bids, were as follows.

Bids from the low bidder:

- Flyover Bridge: $4,826,000 ($1,328 per square meter/$123 per square foot)
- Issaquah Creek Crossing Bridge: $2,547,000 ($1,447 per square meter/$134 per square foot)
- The total and averaged unit bid costs of these two steel bridges were: $7,373,000 ($1,367 per square meter/$127 per square foot), which was approximately 12 percent lower than the engineers' estimate.

Average bids from the lowest three bidders:

- Flyover Bridge: $5,743,000 ($1,580 per square meter/$147 per square foot)
- Issaquah Creek Crossing Bridge: $3,035,000 ($1,724 per square meter/$160 per square foot)
- The total and averaged unit bid costs of these two steel bridges were: $8,778,000 ($1,627 per square meter/$151 per square foot), which was approximately 5 percent higher than the engineers' estimate.

This cost comparison (see Figure 31) is for construction costs only, and does not include additional costs (e.g., construction administration and engineering support, etc.).

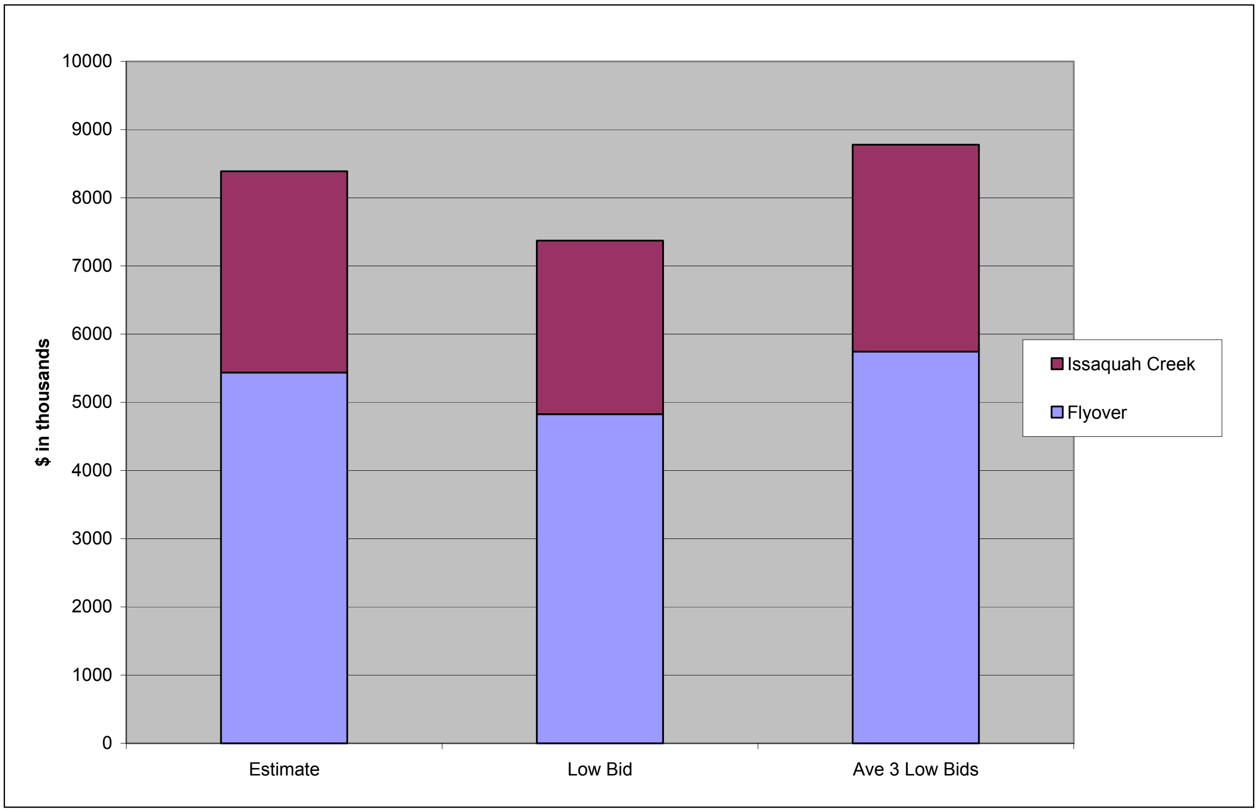

Figure 31: Estimates vs. Bids

The final constructed cost was higher than the bids. One of the reasons for this was the previously-mentioned underground boulders discovered during the construction.

PROCUMENT METHOD AND THE PROJECT TEAM

The I-90 Sunset Interchange project was procured via two design-bid-build contracts (Stage I and Stage II contracts). All new bridges, including the two steel bridges for this project, were constructed in the Stage II contract. The Stage II contract was advertised for bid in spring of 2001, bids were opened on February 7, 2001, and contract was awarded to the Kiewit Construction Company. Key project team members included:

- Clients: Washington State Department of Transportation, City of Issaquah, King County, Port Blakely Communities.
- Construction Management: Washington State Department of Transportation
- Design Engineer and Construction Support: Parsons Brinckerhoff, Inc.
- General Contractor: Kiewit Construction Company
- Steel Fabricator: Universal Structural, Inc.

SUMMARY

In summary, the benefits and cost-effective aspects of the optimized design and application of steel box girder bridges in this project are:

- By using steel box girders for fast erection, traffic and environmental impacts were minimized, which created potential cost savings from avoiding traffic jams and delays.
- Standardized girder sections and shared details saved design, fabrication and erection costs.
- The maximized girder span/depth ratio reduced overall project costs.

- Substructure cost savings compensated for the higher steel costs
- Unique concentrically-connected cross frames and lateral bracings reduced member weight and contributed to cost savings of the project.
- The innovative application of seismic isolations reduced footing size and construction costs.
- Uniquely-designed seismic breakaway expansion joints are less expensive than modular joints.
- Maintenance-friendly design features reduce maintenance costs and help achieve sustainable structures.

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