Bridge Bearing Replacement

John A. Van Lund, *Washington State Department of Transportation*

The Washington State Department of Transportation (WSDOT) has removed and replaced nonfunctioning bridge bearings to extend the service lives of existing bridges. Inoperable roller nests and seismically vulnerable steel rocker bearings with excessive tipping have been removed and replaced to restore expansion capability. The superstructure must be raised to replace bridge bearings. Case studies that show three recent bridge bearing replacement projects designed by WSDOT are presented. In the first case study, a 113.0-m single-span truss built in 1925 was raised from below by placing two hydraulic jacks and the upper steel distribution plates directly under the bearing pin gusset plates. The unreinforced pier cap was post-tensioned to prevent spalling. A sliding disc bearing was installed in place of the frozen roller nest. In the second case study, the bearings were removed and were replaced as part of an overall structural rehabilitation project. The existing concrete deck was removed and the ends of seven 54.9-m single-span trusses were lifted sequentially from above with a pair of jacking beams consisting of two W36 × 245 steel beams. Hanger rods were attached directly to the jacking beams and the floor beam top flange. Four 50-metric-ton jacks (two per jacking beam) simultaneously raised the ends of the trusses. Sliding fabric pad bearings were used to replace the frozen expansion roller nests. In the final case study, seismically vulnerable tipping rocker bearings were replaced with elastomeric bearings. Jacking diaphragms were located in the exterior bays at the girder centerline of bearings so that the lifting loads would not cause tipping of the pier. Additional shelf width was provided by adding a continuous corbel to the pier cap. Superstructure lifting recommendations are given. Jacks are sized for at least 1.5 times the calculated lifting loads. Bearing design loads, replacement bearing costs, and costs for lifting bridge superstructures are presented.

The Washington State Department of Transportation (WSDOT) has removed and replaced nonfunctioning bridge bearings on older steel truss bridges. After 60 to 70 years of service, the steel roller nests, which were used to provide for expansion and contraction, are inoperable because of excessive tipping and extensive corrosion. In addition, tipping rocker bearings are seismically vulnerable and are replaced with more stable bearings. As shown in the second case study, removal and replacement of nonfunctioning bearings can be included as part of bridge rehabilitation or seismic retrofit projects. Replacement bearings include multirotational disc bearings, fabric pads with polytetrafluoroethylene (TFE) and stainless steel sliding surfaces, elastomeric bearings, and lead-core isolation bearings. It is WSDOT's policy to remove and replace defective or seismically vulnerable bearings to extend the service lives of existing bridges.

To replace bridge bearings, the superstructure must be raised. Hydraulic jacks have been used to raise existing bridge superstructures so that defective pot bearings could be removed and replaced (*1*). In Washington State jacks were used to raise one bridge superstructure by as much as 6.3 m so that avalanches could pass below the bridge without hitting the girders. On another project jacking was used as a means of transferring the dead load of the superstructure from one existing substructure to another. Jacks with a capacity of 1.5 to 2 times the calculated lifting loads are used (2). Generally, jacking under a live load is not recommended. However, traffic is permitted on the bridge after the girders have been safely blocked. Blocking and member connections must be designed for the total dead and live loads. On one recent WSDOT project, jacking was done under a live load. Initially, jacking was done at night, and later the operation was expanded to permit jacking under traffic during daylight hours.

WSDOT shares responsibility with the contractor for the success of the lifting operation by designing the most practical lifting procedure based on past experience. As the owner, WSDOT is concerned that no damage to the bridge should occur during a lifting operation. In most cases the WSDOT-designed lifting procedure is used, but the contractor may propose an alternate procedure. In either case the contractor submits working plans and independent calculations, which are stamped by a registered professional engineer.

The following case studies show three recent bridge bearing replacement projects designed by WSDOT.

Case Study 1: Puyallup River Bridge, Bridge No. 167/20E, Pierce County, Washington

The Puyallup River Bridge, originally the Meridian Street Bridge, was built in 1925. The bridge consists of a 113.0-m single-span steel truss that spans the river and two 5.8-m timber approach spans at each end of the main span (Figure 1). The two trusses are narrowly spaced at 7.3 m and are 19.0 m high at the midspan.

In 1991 the bridge was closed to traffic and was rehabilitated. Part of the rehabilitation effort involved removing and replacing the frozen roller nests at the expansion end of the truss span. The trusses were raised by jacking from the top of the existing pier cap. Before raising the bridge, the unreinforced pier cap was post-tensioned with two 35-mm-diameter high-strength bars to prevent spalling of the pier cap concrete. The post-tensioning bars were located directly under the truss gusset plates and jacks (Figure 2).

The end of each truss was raised individually to prevent possible lateral movements that might have occurred if both trusses were raised simultaneously. Analysis showed that there was no overstress in the end portal and connections when the trusses were lifted independently. The differential vertical deflection between the jacked and the unjacked bearing was not to exceed 25 mm, and no jacking was permitted when the wind speed exceeded 40 km/hr. Two 180-metric-ton locknut jacks were placed as close as possible to the bearing pin. Locknut jacks were used because no suitable blocking points were available. The jacking cylinders were centered directly under the gusset plates. A steel distribution plate and an epoxy leveling course were used to provide a level jacking surface, because the bottoms of the gusset plates were uneven (Figure 3). The purpose of the epoxy leveling course was to distribute the lifting load uniformly to the gusset plates and to prevent overstressing of individual gusset plates during the lifting operation. The epoxy leveling course was a two-component epoxy consisting of a resin and a catalyst similar to that used in the wire rope industry for resin socketing. The resin-catalyst was pourable and hardened within 15 min with a fully cured compressive strength of 131 MPa. The lifting load, based on hydraulic pressure gauge readings, was approximately 150 percent greater than the calculated dead load, which may be attributed to heavy rusting of the roller nests, internal friction forces in the jacks caused by binding,

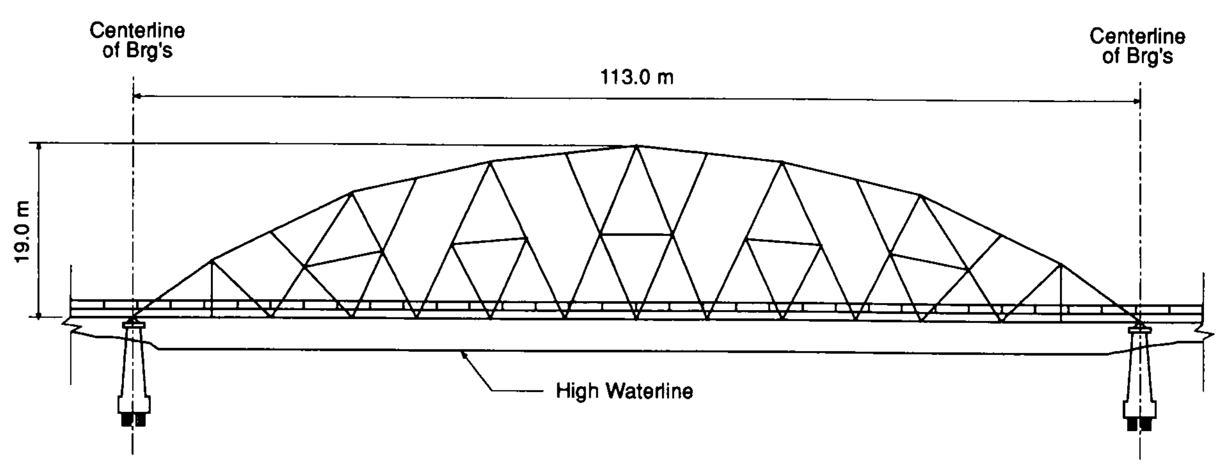

FIGURE 1 Case Study 1: elevation, Puyallup River Bridge.

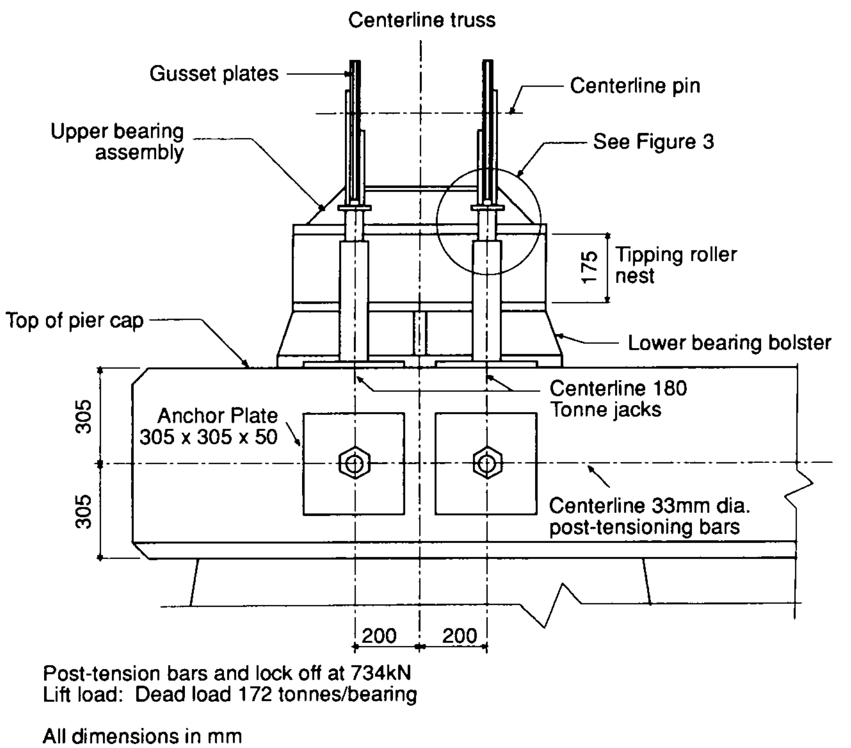

FIGURE 2 Case Study 1: pier cap post-tensioning and jack location, Puyallup River Bridge.

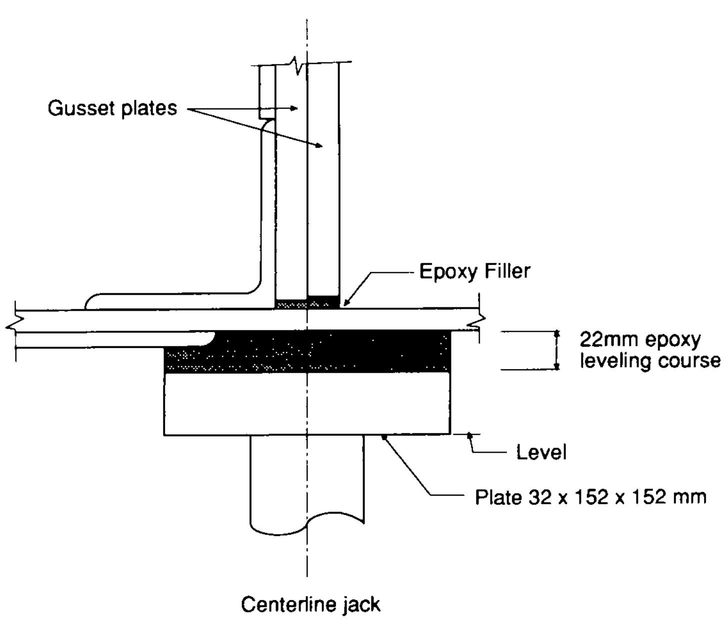

FIGURE 3 Case Study 1: epoxy leveling course.

or faulty gauges. During the lifting operation, the pier was monitored for potential tipping because the jacks were positioned 560 mm from the pier centerline. No tipping from the eccentric lifting loads was observed. However, just as the truss started to rise, the epoxy leveling course cracked but supported the truss without failing. The roller nests were removed, the new sliding disc bearings were installed.

If epoxy is used as a leveling course for uneven gusset plates, it should be confined along each side to prevent failure. Steel confinement bars can be welded to the upper load distribution plate. The depth of confinement should be equal to one-half the height of the leveling course to prevent spalling. It is also important to have temporary blocking available to be installed in the space formerly occupied by the bearing in case the epoxy leveling course fails. Steel shims, which require careful machining, could also be used in lieu of epoxies to obtain a level bearing surface for uneven gusset plates.

Case Study 2: Snohomish River Bridge, Bridge No. 529/10E, Snohomish County, Washington

The Snohomish River Bridge was built in 1926 and consists of a 44.5-m steel lift span, eight single-span steel trusses (seven with spans of 54.9 m and one with a span of 42.9 m), and numerous reinforced concrete approach spans. The overall length of the bridge is 816.8 m. In 1994 the bridge was closed to traffic and rehabilitated at a cost of $6.0 million. The concrete deck, steel stringers and floor beams, and truss panel point gusset plates were removed and replaced.

The expansion ends of the trusses were raised sequentially with a pair of steel jacking beams so that the frozen expansion bearing roller nests could be removed and replaced (Figure 4). The jacking beams consisted of two W36 × 245 steel beams placed side by side and had a mechanical advantage of 2 to 1. Each jacking beam weighed 11.5 metric tons and could be placed anywhere on the bridge by an overhead crane, which was supported by rails attached to the upper chords of the trusses.

Four 25.4-mm-diameter high-strength hanger rods connected the jacking beam and the floor beam (Figure 5). Four 50-metric-ton jacks (two per jacking beam) simultaneously raised the ends of the jacking beams 50 mm. Adequate space was provided between the jacks to install blocking so that the jack's cylinders could be lowered. The roller nests were removed, and new fabric pad bearings with TFE and stainless steel sliding surfaces were installed. The maximum lifting load was 91.0 metric tons, and the maximum jacking beam deflection was approximately 8 to 10 mm.

Raising trusses from above is a practical lifting technique during rehabilitation projects after the existing deck slab has been removed. In this case study, the weight of the deck slab accounted for 70 percent of the truss dead load. Smaller jacking beams and jacks were used because of this reduction in dead load. Raising these trusses from above with the deck slab in place was not feasible because the end floor beams and floor beam-to-truss connections would be overstressed and would require extensive reinforcement.

Case Study 3: Kalama River Bridge, Bridge No. 5/113, Cowlitz County, Washington

The Kalama River Bridge, which was built in 1970, is a two-span steel plate girder bridge that spans over Interstate 5. There are four plate girders with simple spans of 44.5 m, and fixity is provided at the end abutments. Two sets of rocker bearings permit expansion at the intermediate pier. Shortly after construction it was observed that the rocker bearings at the intermediate pier had tipped toward the west. The tipping occurred because of 0.3 to 0.6 m of settlement of the west approach fill, which continued after construction because of underlying organic soil. In early 1972 the bridge was jacked, the base plates were slotted, and the rocker bearings were plumbed. The tipping continued and was monitored for the next two decades until the settlement stabilized.

In 1995 the tipping rocker bearings were replaced with reinforced elastomeric bearings. Plate girder diaphragms, which had been installed to raise the bridge in 1972 and which had been left in place as permanent bracing, were again used to raise the ends of the girders (Figure 6). The jacking diaphragms were located in the exterior bays at the girder centerline of bearings so that the lifting loads would not cause tipping of the pier. Additional shelf width was provided by post-tensioning a new 305-mm-thick continuous corbel to the pier cap. The bridge was raised 25 mm by four 90-metric-ton jacks located adjacent to each girder. The existing rocker bearing was removed, and the upper bearing block, which was welded to the bottom flange of the plate girder, was cut free by arc gouging and was ground smooth to remove any excess weld metal. A concrete pedestal, which was integral with the continuous corbel, was constructed because the height of the new elastomeric bearing is 230 mm less than that of the original rocker bearing. The plan dimensions of the new elastomeric bearing are 305 by 650 mm, and the height is 78 mm. Six 14-gauge steel shims reinforce the 12.7-mm-thick internal elastomer layers. The external elastomer thickness is 6.4 mm.

Jacking Procedure
1. Remove concrete deck
2. Remove and replace floorbeams and stringers
3. Install jacking beams
4. Use two 50 tonne jacks at each jacking point
5. Raise the superstructure not more than 50mm and block
6. Do not jack when wind speed exceeds 40km/hr
7. Coordinate jacking with utility companies

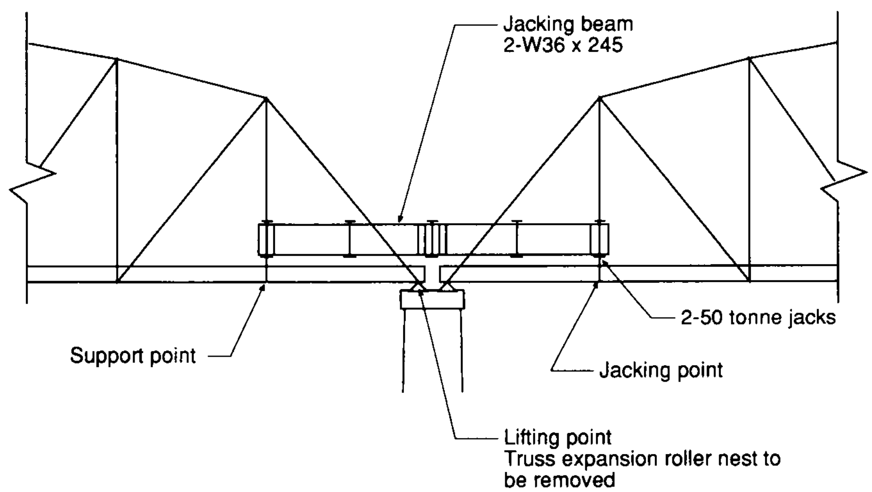

FIGURE 4 **Case Study 2: elevation of jacking scheme, Snohomish River Bridge.**

Superstructure Lifting Recommendations

Lifting recommendations based on WSDOT's experience (*2,3*) and on guidelines from Orr (*4*) are as follows:

1. Show details in the plans for the most practical lifting procedure, and permit the contractor to propose an alternate procedure. Show the lifting points and indicate the lifting loads in the contract plans. The effects of wind loading, construction loading, and live loading, if any, should be included in the calculated lifting loads.
2. Size jacks for at least 1.5 times the calculated lifting load and require backup jacks. If a jack fails, it can readily be replaced if backup jacks are available. The manufacturer's nameplate and the rated capacity of the jack should be attached to each jack. The schematic hydraulic layout, including gauges, valves, manifolds, and other equipment, should be shown in the contractor's working drawings.
3. Control relative vertical displacements so as not to overstress the existing structural members and connections during lifting. Indicate the maximum vertical displacement and the relative vertical displacements permitted between adjacent lifting points and between adjacent girders.
4. Determine maximum permissible deflections. Prevent excessive longitudinal and lateral movement by providing positive restraining systems and by adding temporary cross bracing to prevent member distortion. This may be particularly important for bridges on steep grades, in wind-prone areas, or with high superelevations. Targets and tilt meters can be placed on the structure to monitor any movement.
5. Block and shim during the lifting operation. WSDOT uses locknut jacks whenever space is not available to block the structure. Generally, the structure is shimmed tight or the locknuts are secured after incremental lifts of 3 mm. In the event of a jack failure, there will be no significant differential settlement and a backup jack can be quickly installed.
6. For safety reasons do not permit traffic on the bridge or the presence of any unnecessary construction personnel near the bridge during lifting. Occasionally, WSDOT has permitted jacking under traffic. Extreme care, advance planning, careful coordination, cribbing, and locknut jacks are required when lifting under traffic. A temporary ramp, usually constructed of asphalt, may be required at the approaches if the total height of the lift exceeds 20 mm.
7. Disconnect any utilities, railing, traffic barrier cover plates, and sliding expansion joint plates that will prevent the lifting of the structure.
8. The working drawings, jacking procedures, and calculations should be prepared, stamped, and signed

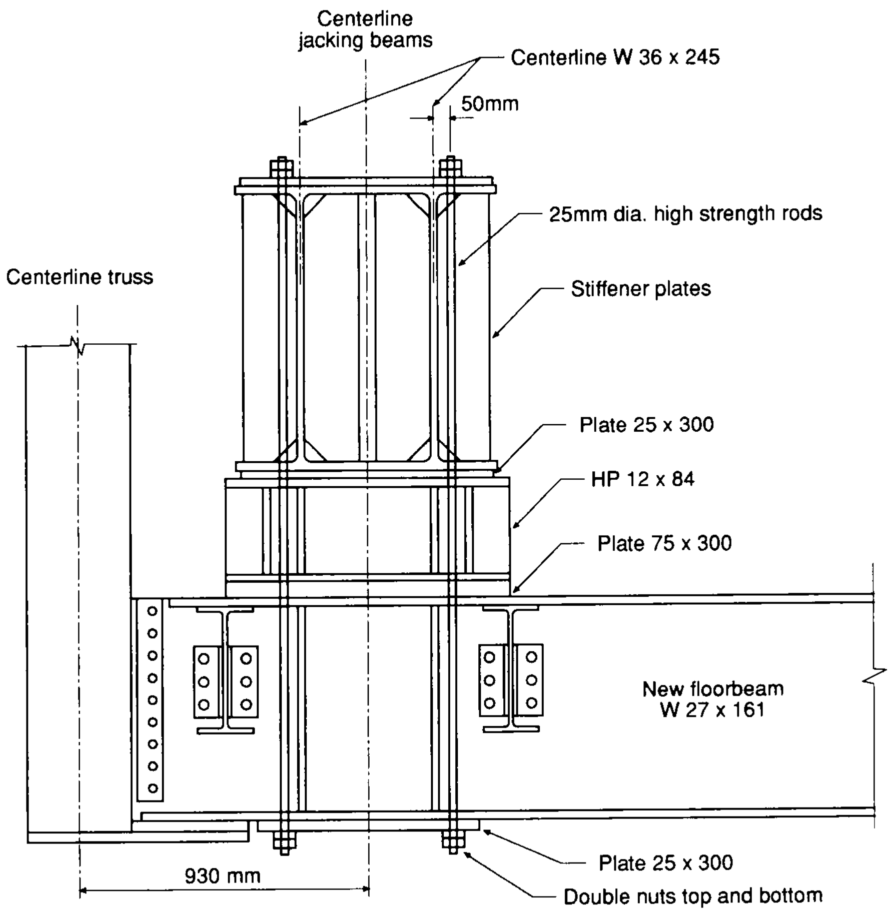

FIGURE 5 Case Study 2: details at lifting point, Snohomish River Bridge.

by a professional engineer licensed in the state where the lifting is to take place. The engineer should inspect all aspects of the lifting operation and be present during the lifting.

Replacement Bearing and Lifting Costs

The design service load limits and costs for various bearing types used by WSDOT are given in Table 1. These costs are per metric ton of the design service load. The lowest cost of $3 to $5/metric ton is for elastomeric bearings, and the highest cost of $13 to $20/metric ton is for multirotational and seismic isolation bearings. Since 1987 WSDOT has not permitted the use of pot bearings because of poor performance, which may be related to overrotation during construction. WSDOT has used fabric pad bearings with a TFE and stainless steel sliding surface and multirotational disc bearings as replacement bearings for frozen truss expansion roller nests. Elastomeric bearings have been used as replacement bearings for steel girder bridges with tipping rocker bearings when the expansion and contraction are less than ±50 mm.

High-load elastomeric bearings can also be used for expansion bearings for trusses, provided that the load and expansion limits are not exceeded. For new bridges WSDOT has designed high-load elastomeric bearings with a maximum elastomer height of 150 mm and for service loads of up to 360 metric tons in accordance with AASHTO's Method B (*5*). Elastomeric bearings can also be designed as isolation bearings that will reduce the seismic forces acting between the superstructure and substructure. Elastomeric bearings show excellent promise as replacement bearings because they are corrosion resistant, durable, easy to install, maintenance-free, and more economical than any other bearing type.

Table 2 provides the lifting costs per bearing per metric ton for the three case studies. The costs range from a low of $22 to a high of $78/metric ton. The figure of $22/metric ton is low because the contractor had unbalanced the bid by overpricing the disc bearings. When the bearing unit price is decreased to reflect a reasonable price for disc bearings, the lifting cost would be ap-

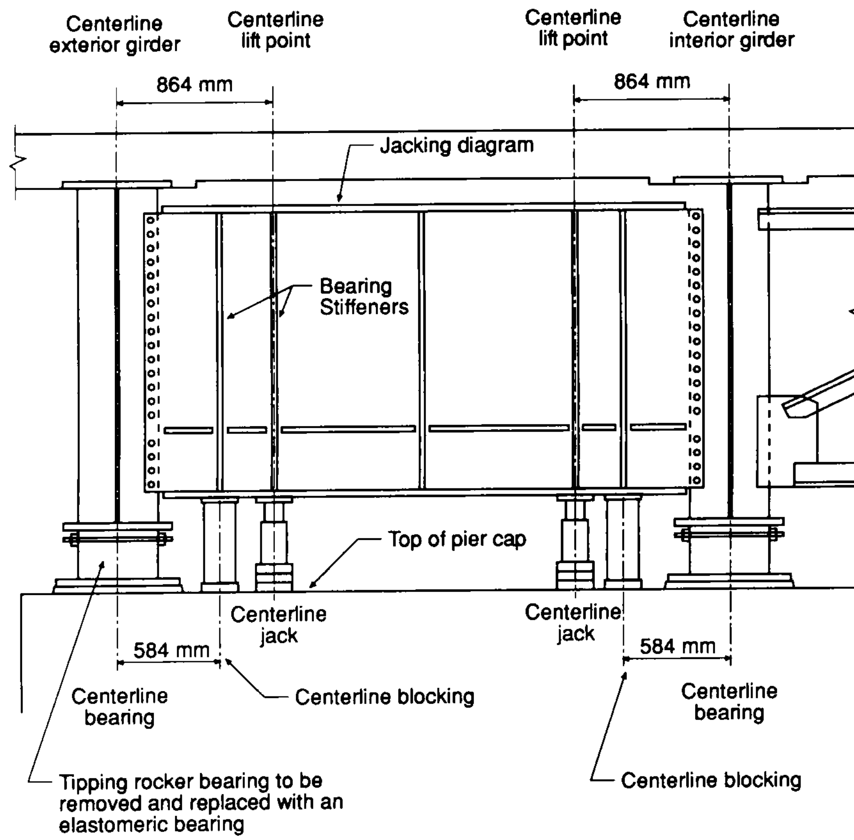

FIGURE 6 Case Study 3: jacking details, Kalama River Road Overcrossing.

proximately \$50/metric ton. The high cost of \$78/metric ton included the fabrication of the jacking beams used for raising the Snohomish River Bridge.

SUMMARY

1. It is WSDOT's policy to remove and replace non-functioning or seismically vulnerable tipping rocker bearings to extend the service lives of existing bridges.
2. Details of three recent bearing replacement projects in Washington State are presented. Case studies describe three different lifting approaches: direct bearing on truss gusset plates, the use of a jacking beam as a pry bar with a mechanical advantage of 2 to 1, and the use of jacking diaphragms placed between the ends of plate girders.
3. WSDOT shares responsibility for the success of the lifting operation by including details in the plans for the most practical lifting procedure on the basis of past experience. As the owner WSDOT is concerned that no damage to the bridge should occur during a lifting operation. The contractor may propose an alternate lifting procedure. Generally, jacking under live load traffic is not recommended.
4. Hydraulic jacks are used as a means of lifting bridges so that defective or frozen bearings can be removed. Jacks should be sized for a minimum of 1.5 times the calculated lifting loads to account for discrepancies between hydraulic gauge readings and calculated

TABLE 1 Bearing Design Loads and Costs, 1991 to 1995

Bearing Type	Design Service Load (tonnes)[a]	Cost/tonne (\$ U.S.)
Elastomeric[b]	<360	3-5
Fabric Pad[b]	<270	5-10
Steel Pin	>270	6-20
Disc or Spherical[b]	>360	10-20
Seismic Isolation[b]	<360	13-20

[a]All loads are in tonnes (metric tons).
[b]Replacement bearing types used by WSDOT.

TABLE 2 Superstructure Lifting Costs, 1991 to 1995

Case Study	Bridge	Description	Cost/tonne ($ U.S.)
1	Puyallup River Bridge Br. No. 167/20E	Jacking against truss gusset plates	22[a]
2	Snohomish River Bridge Br. No. 529/10E	Jacking beams 2-W36X245	78[b]
3	Kalama River Bridge Br. No. 5/113	Jacking diaphragms between girders	58

[a]Contractor unbalanced bid by overpricing the disc bearings. When a reasonable disc bearing price is used, the lifting cost is increased to $50/tonne.

[b]Includes fabrication of jacking beams.

lifting loads. The gauge readings indicate that heavier lifting loads occur and may be attributed to the increased force required to break the bond caused by heavy rusting of the roller nests, internal friction in the jacks caused by binding, or faulty gauges.

5. In the first case study, epoxy was used as a leveling course for uneven gusset plates. This was the first time that WSDOT specified an epoxy as a means of uniformly distributing lifting loads. To prevent spalling, the epoxy leveling course should be confined by steel bars along each side for a depth equal to one-half height of the leveling course.

6. Bridge bearing replacement is simplified if it is coordinated with rehabilitation projects. As shown in the second case study, it was easier to lift the bridge from above with jacking beams after the concrete deck was removed because the deck accounted for 70 percent of the dead load. Smaller jacking beams and jacks were used because of the reduced dead load.

7. Replacement bearings include multirotational disc bearings, fabric pads with TFE and stainless steel sliding surfaces, elastomeric bearings, and lead-core isolation bearings. Elastomeric bearings show promise as replacement bearings because they are corrosion resistant, durable, easy to install, maintenance-free, and more economical than other bearing types.

8. Maximum design loads for replacement bearings, costs for replacement bearings, and costs for lifting bridges are given.

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