

**SEISMIC PROTECTION DEVICES  
STUDY – MARQUAM BRIDGE**

**Final Report**

**Experimental Features 93-03**



*Oregon Department of Transportation*

**SEISMIC PROTECTION DEVICES STUDY**  
**FOR THE**  
**W. MARQUAM INTERCHANGE – MARQUAM BRIDGE SECTION**  
**Experimental Features Project 93-03**

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| 16. Abstract<br><br>This report summarizes the seismic retrofit of the Marquam Bridge in Portland, Oregon with proprietary bearing/restraint and shock transmission devices. The retrofit was completed in 1995. The devices were supplied by FIP Industries, Inc. and included:  |  |  |  |   |           |
| <ul style="list-style-type: none"> <li>• Bearing Restraint Devices (including shock transmission components); four devices at Piers #2 and #5;</li> <li>• Bearing Restraint Devices: four devices at Piers #3 and #4; and</li> <li>• Shock Transmission Devices: two on each side of Panel Point L13.</li> </ul> <p>The bearing/restraint devices replaced existing bearings and required special modifications to the bridge piers and truss to accommodate jacking operations and bearing installation. After the installation was complete in 1995, Teflon shavings were discovered in the guide bar region in each of the new bearings on Pier #2 and Pier #5. The shavings were the result of the Teflon sliding element being extruded into the guide bar region. Since then, further monitoring has confirmed that the Teflon extrusion process has diminished over time. After almost five years of service, the other devices are performing satisfactorily.</p> |  |  |  |   |           |
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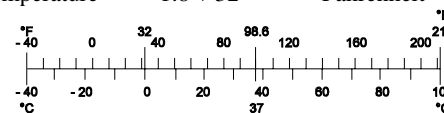
## SI\* (MODERN METRIC) CONVERSION FACTORS

### APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol   | When You Know          | Multiply By | To Find             | Symbol          |
|--|------------------------|-------------|---------------------|-----------------|
| <b><u>LENGTH</u></b>   |                        |             |                     |                 |
| in   | inches                 | 25.4        | millimeters         | mm              |
| ft   | feet                   | 0.305       | meters              | m               |
| yd   | yards                  | 0.914       | meters              | m               |
| mi   | miles                  | 1.61        | kilometers          | km              |
| <b><u>AREA</u></b>   |                        |             |                     |                 |
| in <sup>2</sup>  | square inches          | 645.2       | millimeters squared | mm <sup>2</sup> |
| ft <sup>2</sup>  | square feet            | 0.093       | meters squared      | m <sup>2</sup>  |
| yd <sup>2</sup>  | square yards           | 0.836       | meters squared      | m <sup>2</sup>  |
| ac   | acres                  | 0.405       | hectares            | ha              |
| mi <sup>2</sup>  | square miles           | 2.59        | kilometers squared  | km <sup>2</sup> |
| <b><u>VOLUME</u></b>   |                        |             |                     |                 |
| fl oz  | fluid ounces           | 29.57       | milliliters         | mL              |
| gal  | gallons                | 3.785       | liters              | L               |
| ft <sup>3</sup>  | cubic feet             | 0.028       | meters cubed        | m <sup>3</sup>  |
| yd <sup>3</sup>  | cubic yards            | 0.765       | meters cubed        | m <sup>3</sup>  |
| NOTE: Volumes greater than 1000 L shall be shown in m <sup>3</sup> . |                        |             |                     |                 |
| <b><u>MASS</u></b>   |                        |             |                     |                 |
| oz   | ounces                 | 28.35       | grams               | g               |
| lb   | pounds                 | 0.454       | kilograms           | kg              |
| T  | short tons (2000 lb)   | 0.907       | megagrams           | Mg              |
| <b><u>TEMPERATURE (exact)</u></b>                                    |                        |             |                     |                 |
| °F   | Fahrenheit temperature | 5(F-32)/9   | Celsius temperature | °C              |

### APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol                            | When You Know       | Multiply By | To Find              | Symbol          |
|-----------------------------------|---------------------|-------------|----------------------|-----------------|
| <b><u>LENGTH</u></b>              |                     |             |                      |                 |
| mm                                | millimeters         | 0.039       | inches               | in              |
| m                                 | meters              | 3.28        | feet                 | ft              |
| m                                 | meters              | 1.09        | yards                | yd              |
| km                                | kilometers          | 0.621       | miles                | mi              |
| <b><u>AREA</u></b>                |                     |             |                      |                 |
| mm <sup>2</sup>                   | millimeters squared | 0.0016      | square inches        | in <sup>2</sup> |
| m <sup>2</sup>                    | meters squared      | 10.764      | square feet          | ft <sup>2</sup> |
| ha                                | hectares            | 2.47        | acres                | ac              |
| km <sup>2</sup>                   | kilometers squared  | 0.386       | square miles         | mi <sup>2</sup> |
| <b><u>VOLUME</u></b>              |                     |             |                      |                 |
| mL                                | milliliters         | 0.034       | fluid ounces         | fl oz           |
| L                                 | liters              | 0.264       | gallons              | gal             |
| m <sup>3</sup>                    | meters cubed        | 35.315      | cubic feet           | ft <sup>3</sup> |
| m <sup>3</sup>                    | meters cubed        | 1.308       | cubic yards          | yd <sup>3</sup> |
| <b><u>MASS</u></b>                |                     |             |                      |                 |
| g                                 | grams               | 0.035       | ounces               | oz              |
| kg                                | kilograms           | 2.205       | pounds               | lb              |
| Mg                                | megagrams           | 1.102       | short tons (2000 lb) | T               |
| <b><u>TEMPERATURE (exact)</u></b> |                     |             |                      |                 |
| °C                                | Celsius temperature | 1.8 + 32    | Fahrenheit           | °F              |



\* SI is the symbol for the International System of Measurement

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# SEISMIC PROTECTION DEVICES STUDY

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## 1.0 INTRODUCTION

In the 1990s, greater emphasis has been placed on seismic protection of structures in Oregon. There is geologic evidence of prior catastrophic earthquakes in the region. Most bridges in use today were not designed to withstand devastating earthquakes of similar magnitude. A recent Oregon Department of Transportation (ODOT) study, “*Prioritization of Oregon Bridges for Seismic Retrofit*” found that over half of the State’s bridge inventory (3,257 bridges) lacked structural details to meet current earthquake design standards.

The Marquam Bridge (Bridge #8328), constructed in 1966, is one of Oregon’s most critical transportation links. It is a major interstate (I-5) freeway system bridge (Figure 1.1) that crosses the Willamette River in Portland, Oregon. Because of its location, regional importance, and vulnerability, the Marquam Bridge was retrofitted with seismic control devices in 1995. This report describes the seismic refit and follow-up monitoring of the Marquam Bridge.



Figure 1.1: A View (looking west) of the Marquam Bridge Across the Willamette River

The Marquam Bridge main spans are steel trusses carrying two superimposed roadways for a length of 318 m (1043 ft) (Figure 1.2). The end spans measure 92 m (302 ft) and consist of trusses cantilevered 27 m (90 ft) into the middle length, providing support for the 79 m (260 ft) suspended main span. Bridge supports include Pier #2, near the east bank of the Willamette

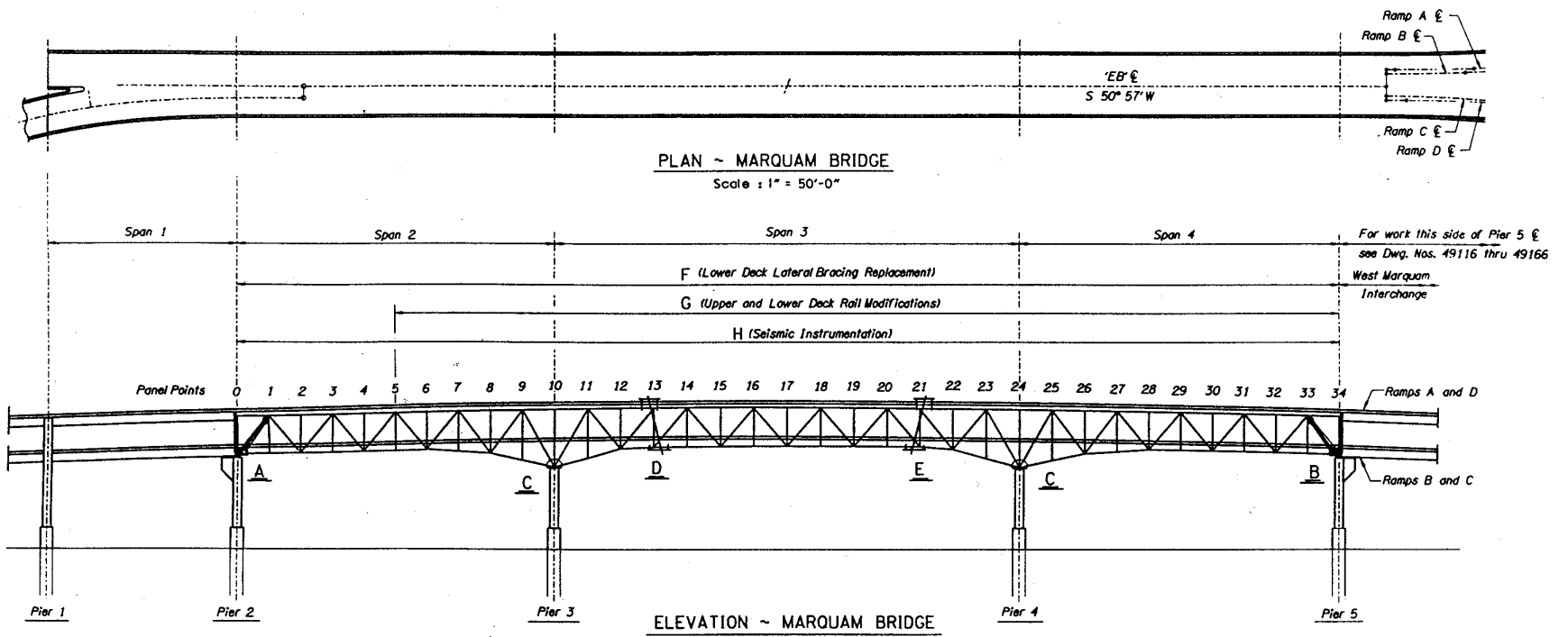


Figure 1.2: Marquam Bridge Drawings

River, Piers #3 and #4 which are in the river, and Pier #5, close to the Willamette River's west bank. In plan view, the structure is characterized by a straight longitudinal axis.

The bridge piers are reinforced concrete configured upon a two-column transverse framework connected by two struts (Figure 1.3). The columns are spaced at 19.8 m (65.0 feet) on center. The upper section is circular with each column having a diameter of 3.7 m (12.0 feet) while the lower section's columns are elliptical. The columns are connected by means of rectangular section struts, placed one each, at the top and where the section of the columns changes from elliptical to circular.

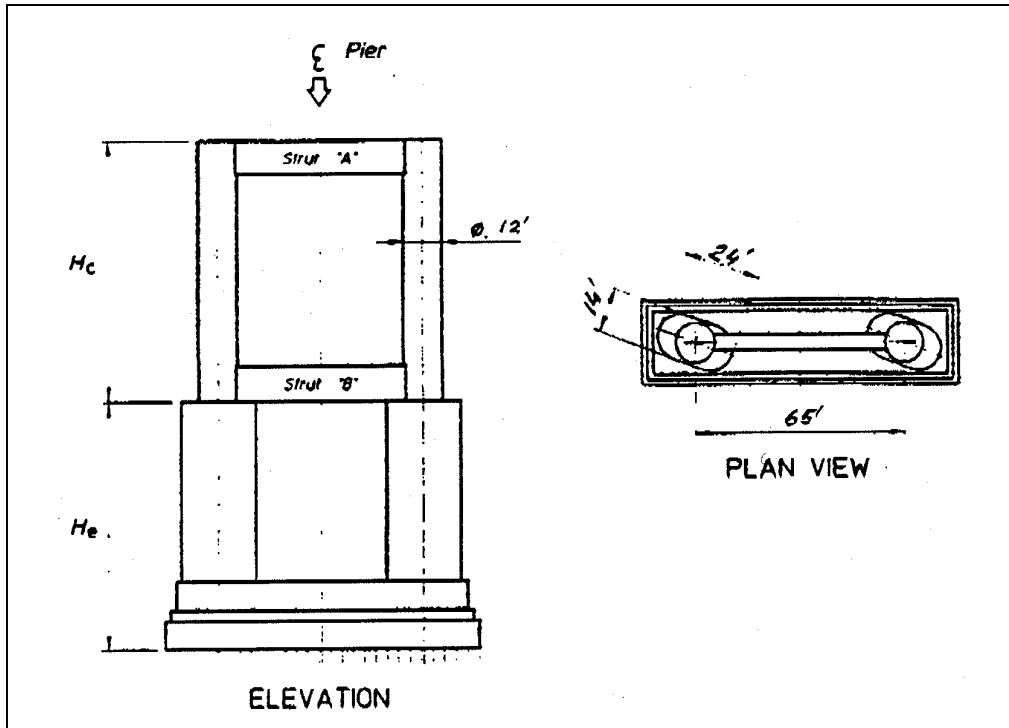


Figure 1.3: Detail of Pier Configuration

The pier height varies. Table 1.1 provides the height of the lower section of the pier,  $H_e$  and the height of the upper columns,  $H_c$ .

Table 1.1: Height of the Marquam Bridge Piers

| Pier Number | $H_e$            | $H_c$            |
|-------------|------------------|------------------|
| 2           | 16.5 m (54.0 ft) | 24.7 m (81.0 ft) |
| 3           | 17.4 m (57.0 ft) | 20.4 m (67.0 ft) |
| 4           | 18.3 m (60.0 ft) | 20.1 m (66.0 ft) |
| 5           | 14.0 m (46.0 ft) | 24.7 m (81.0 ft) |



## 2.0 RETROFIT PLAN

The seismic retrofit of the Marquam Bridge attempts to achieve the following objectives:

- To attain seismic protection for superstructure pull-off in the event of seismic movements from the design event.
- To minimize future strengthening of existing structural elements.
- To maintain the existing system of service load transfer.
- To limit seismic deflection to values compatible with the existing configuration.

The retrofit involved installation of proprietary bearing/restraint devices and shock transmission devices from FIP Structural Systems, Inc. This was the first application of these devices in the United States. Since they had not been used before, the seismic protection devices were selected by ODOT as an experimental feature for research, so they could be fully evaluated during and after construction.

The bearing/restraint devices and shock transmission devices required by the contract specifications included:

- Bearing Restraint Devices (including shock transmission components): four devices at Piers #2 and #5 (two at each pier). FIP device number: **VEP 1400/280-ST** (Figure: 2.1)
- Bearing Restraint Devices: four devices at Piers #3 and #4 (two at each pier). **FIP device number: VEP 5200** (Figure 2.2).
- Shock Transmission Devices: two on each side of Panel Point L13. **FIP device number: OT 440/5.5"** (Figure 2.3).

The specifications also required the manufacturer of the devices to test them prior to installation. The devices were tested in December 1994 in Italy, in accordance with the project specifications. Dr. Andrew Whittaker of the University of California's Earthquake Engineering Research Center observed and certified the testing for compliance. Testing included the following:

- Bearing/Restraint Devices
  - Friction Test
  - Vertical Static Load Test
  - Lateral Static Load Test
  - Simulated Dynamic Load Test
- Shock Transmission Devices
  - Impressed Deflection Test
  - Simulated Dynamic Force Transfer Test

The test results demonstrated that the devices met the project specifications.

In addition to the bearing/restraint devices and shock transmission devices, strong-motion instrumentation was also designed for the bridge to evaluate the devices under seismic loading. The instrumentation allows a comparison between site ground response, substructure response, and superstructure response. The effectiveness of the protection devices can be determined by comparing actual response to predicted response of different portions of the structure. The seismic instrumentation was installed on the bridge by the United States Geological Survey.

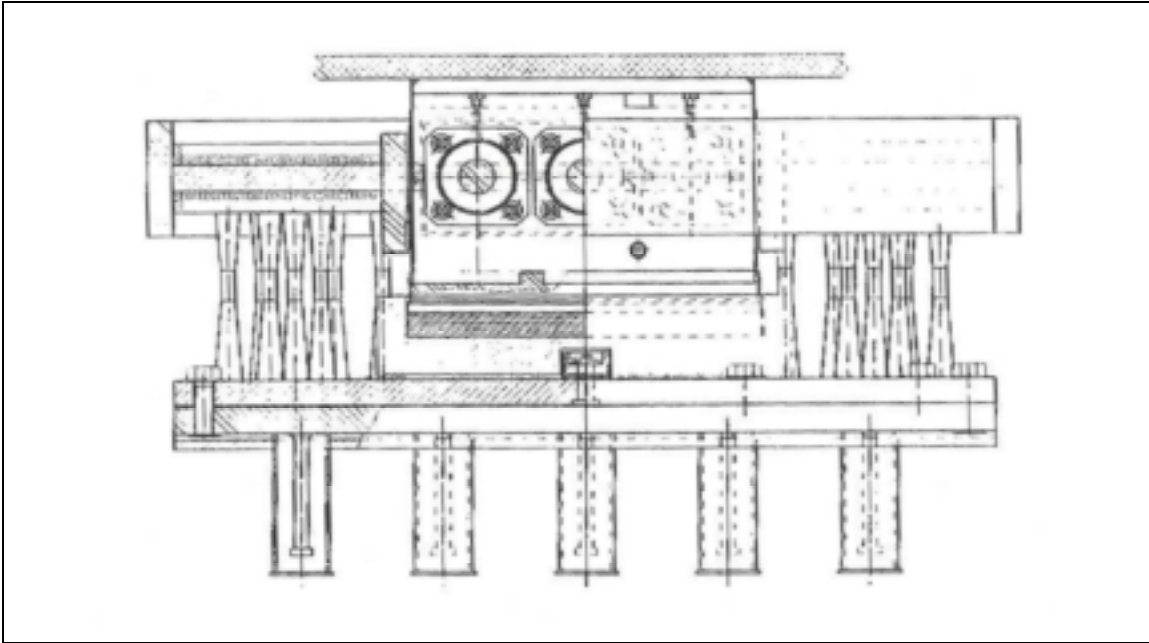


Figure 2.1: Bearing Restraint Devices; Piers #2 and #5 (FIP Device Number: VEP 1400/280-ST)

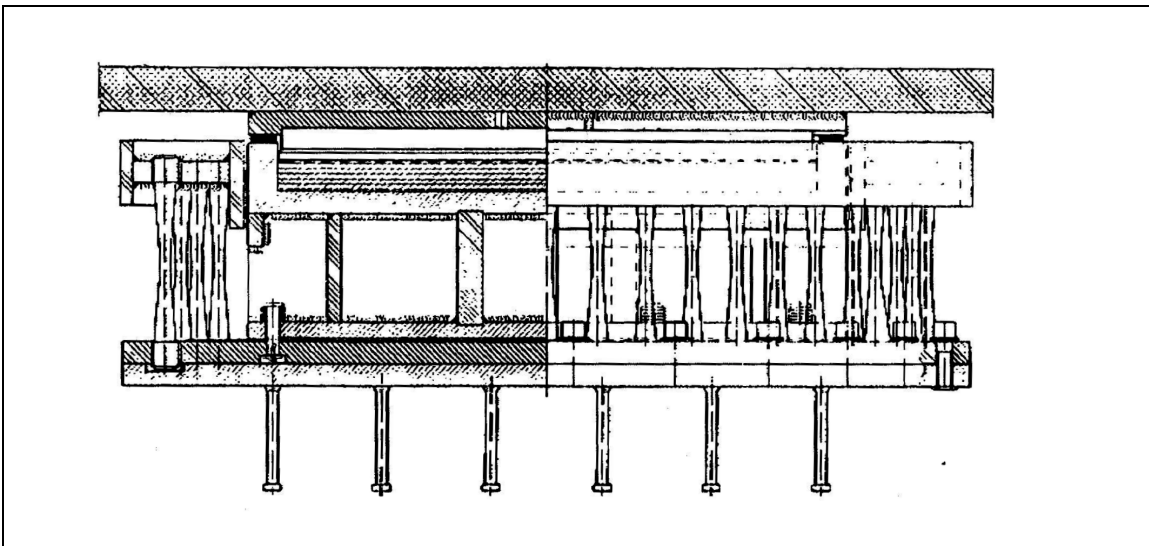


Figure 2.2: Bearing Restraint Devices; Piers #3 and #4 (FIP Device Number: VEP 5200)

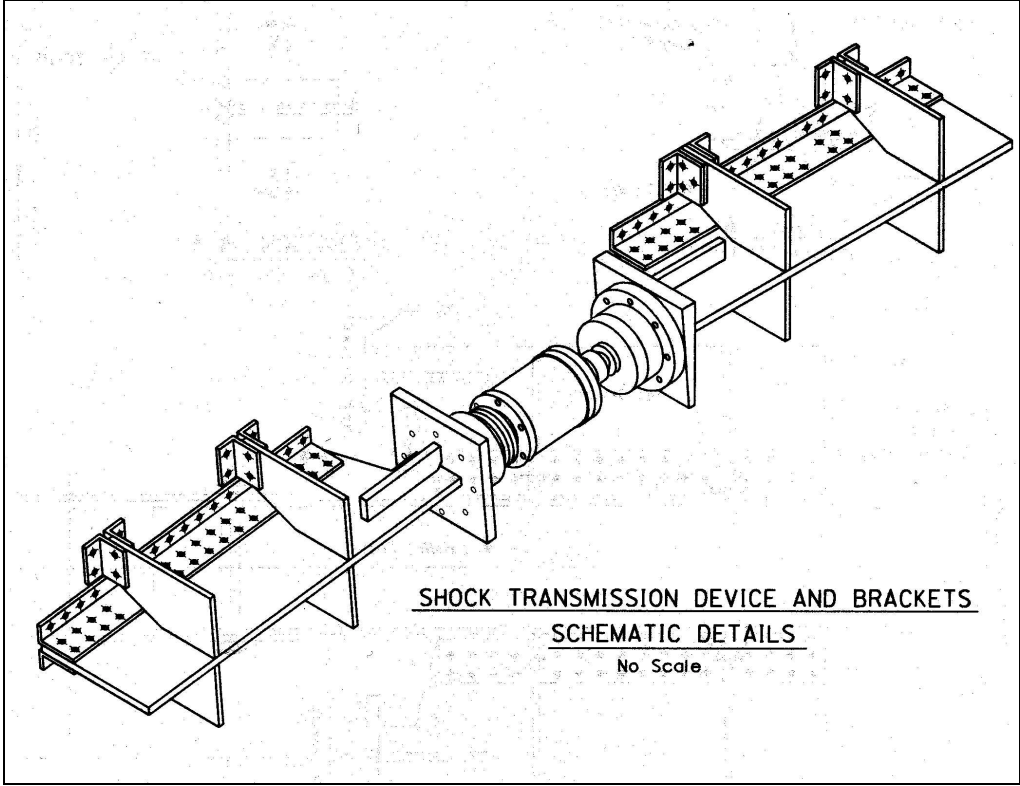


Figure 2.3: Shock Transmission Devices: Panel Point L13 (FIP Device Number: OT 440/5.5")





## 3.0 CONSTRUCTION

### 3.1 CONTRACT INFORMATION

The seismic retrofit work was part of an ODOT construction contract, “Marquam Bridge – West Marquam Interchange (Portland) Section.” Other major work items contained in the contract included the installation of:

- Replacement diagonal bracing under the lower bridge deck;
- Safety hangars, railing and protective fencing construction, and
- Illumination and navigation lights.

The contract was let in January 1994, and awarded to Mowat Construction Company of Kirkland, Washington. In February 1994, the contractor received a Notice-to-Proceed with construction. Prior to installing the bearing restraint devices, the bridge structural system required modification to allow for lifting and support of the structure during the seismic retrofit. The first jacking operation to install bearings on Pier #5 (left) occurred on March 28, 1995. The last bearing to be installed was on Pier #3 (right), and occurred on September 26, 1995. Table 3.1 provides a summary of the bearing/restraint device installation on each of the four piers.

**Table 3.1: Summary of Bearing Installation on Bridge Piers**

| Location        | Device Type     | Date Installed     |
|-----------------|-----------------|--------------------|
| Pier #5 (Left)  | VEP 1400/280-ST | April 5, 1995      |
| Pier #5 (Right) | VEP 1400/280-ST | April 26, 1995     |
| Pier #2 (Left)  | VEP 1400/280-ST | May 15, 1995       |
| Pier #2 (Right) | VEP 1400/280-ST | June 5, 1995       |
| Pier #3 (Left)  | VEP 5200        | July 5, 1995       |
| Pier #4 (Right) | VEP 5200        | August 2, 1995     |
| Pier #4 (Left)  | VEP 5200        | August 29, 1995    |
| Pier #3 (Right) | VEP 5200        | September 26, 1995 |

As mentioned earlier, the seismic protection devices were proprietary, thus the contractor was required to obtain the devices directly from the supplier, FIP Structural Systems, Inc. The prices for the devices totaled almost \$500,000 and included the following cost for each device:

- Bearing Restraint Devices (including shock transmission components); FIP device number: VEP 1400/280-ST; four devices at Piers #2 and #5 (two at each pier) at **\$46,967 each**.

- Bearing Restraint Devices; FIP device number: VEP 5200; four devices at Piers #3 and #4 (two at each pier) at **\$60,967 each**.
- Shock Transmission Devices; FIP device number: OT 440/5.5"; two on each side of Panel Point L13 at **\$24,467 each**.

The contract specifications required shop drawings for the seismic protection devices and instructions for their installation. The bearing/restraint devices and shock transmission devices were installed in accordance with the manufacturer's instructions and contract specifications. In the next three sections, the installation of the bearing/restraint devices and shock transmission devices is reviewed.

### **3.2 VEP 1400/280-ST INSTALLATION AT PIERS #2 AND #5**

Installation of the VEP 1400/280-ST bearing/restraint devices at Piers #2 (left and right) and #5 (left and right) required that the existing base of the pier columns be modified to accommodate placement of the jacking columns. At the pier base, concrete support collars were constructed to carry the jacking pipe supports (Figure 3.1).



Figure 3.1: Collars Being Constructed Around Pier Columns

A lifting shoe for jacking the structure was constructed and bolted to the bottom of the bridge truss chord. An additional strut was attached to strengthen the structure to accommodate the jacking at the bearing connection (Figure 3.2).

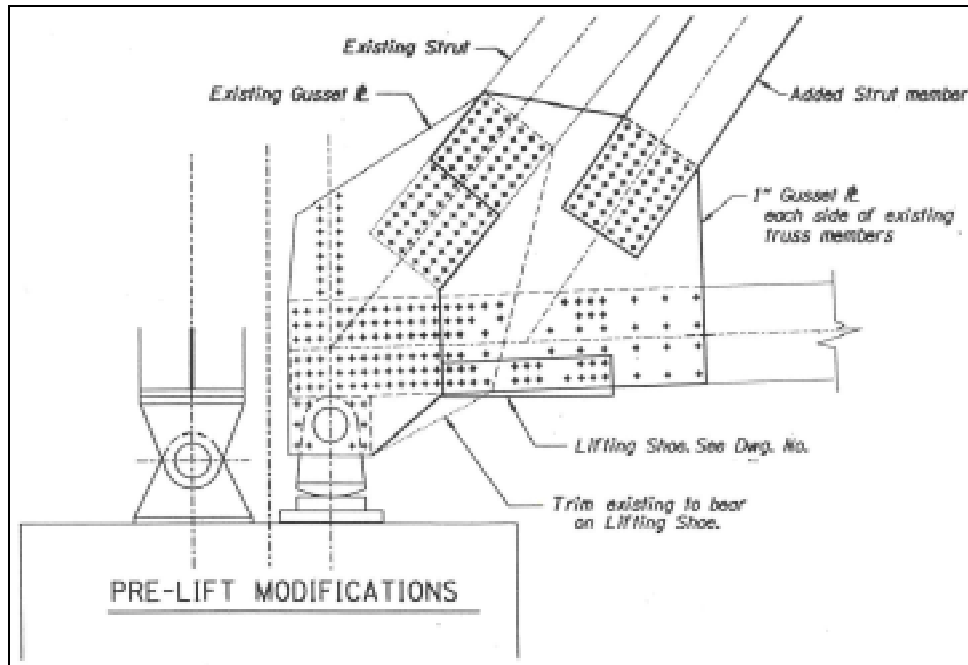


Figure 3.2: Additional Strut and Lifting Shoe Assembly at Piers #2 and #5

Once the concrete support collars were built, the lifting assembly for each bearing/restraint device was constructed alongside the pier column. The lifting assembly consisted of two pipe columns (outside diameter - 863.6 mm (34.0 in)), one lifting beam, temporary bearings and four jacking devices (Figure 3.3 and Figure 3.4).



Figure 3.3: The Lifting Assembly for Piers #2 and #5

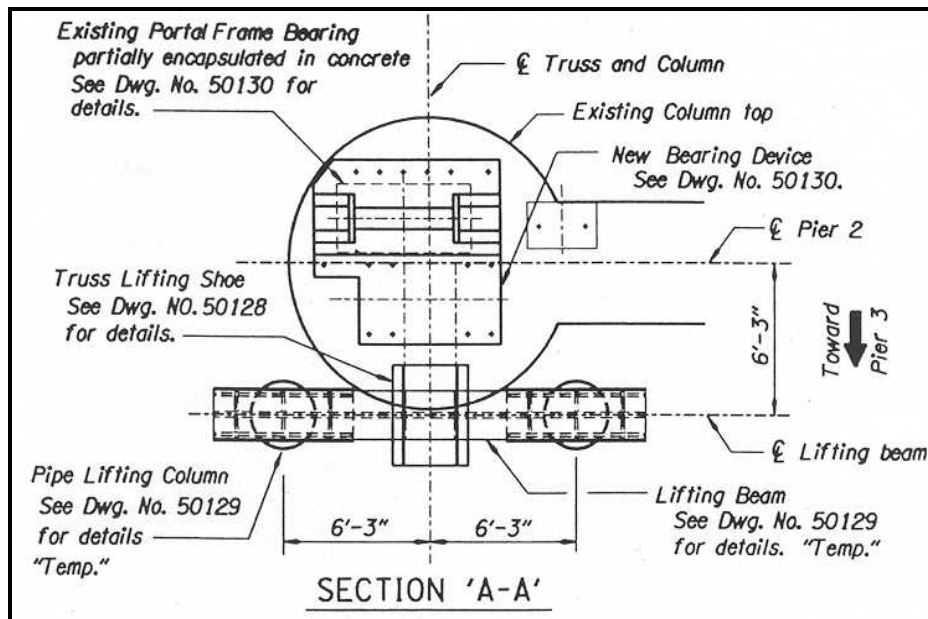


Figure 3.4: Section View Showing the Two Lifting Columns and Beam for Piers #2 and #5

Four 363 Mg (400 ton) jacks raised the lifting assembly. After the lifting assembly was in place, the structure was jacked and temporary bearings and shims were slid into place to support the structure while other modifications were accomplished. The structure was raised about 25.4 mm (1.0 in) as the loads were transferred from the old bearing onto the jack and jacking columns. The existing truss bearing was then removed.

A hydraulic crane lowered a new bearing shoe assembly from the top deck of the bridge. It was placed and bolted to the bottom of the truss chord. Fifteen 31.6 mm (1.25 in) threaded anchor rods, with two hex nuts and a 25.4 mm (1.0 in) x 150 mm (6 in) square plate at the top end of each rod, were drilled and bonded into the existing concrete. The bearing anchor plate was placed so that it was level and supported by the square plates on the anchor rods. The anchor plate was positioned with the transverse axis in line with the centerline of the bearing and the longitudinal axis aligned with the centerline of the bottom truss chord. The adjacent approach bearing device was not removed, but encapsulated in concrete as the concrete pedestal for the new bearing was constructed (Figure 3.5).

The masonry plate was set and connected to the anchor plate. After the masonry plate was set, the structure was jacked to allow for the installation of the new bearing assembly. The structure was raised about 25.4 mm (1.0 in) as the loads were transferred from the temporary bearings back onto the jacks.

The crane positioned on the top deck of the bridge lifted the new bearings from the bridge deck down the side of the bridge. The bearings were maneuvered onto the pier (Figure 3.6) and connected to the masonry plate and the sole plate of the bearing shoe assembly. Once the jacks were lowered, the bearing was operational, and carrying the live and dead loads of the structure.

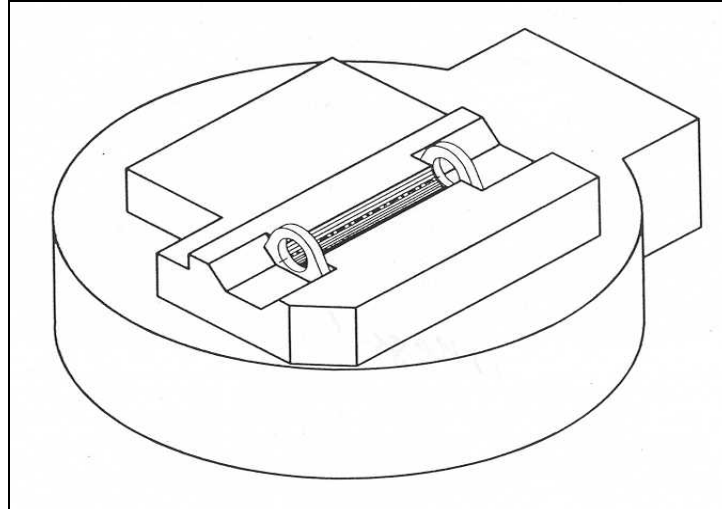


Figure 3.5: New Concrete Bearing Pedestal and Encapsulated Approach Bearing Device

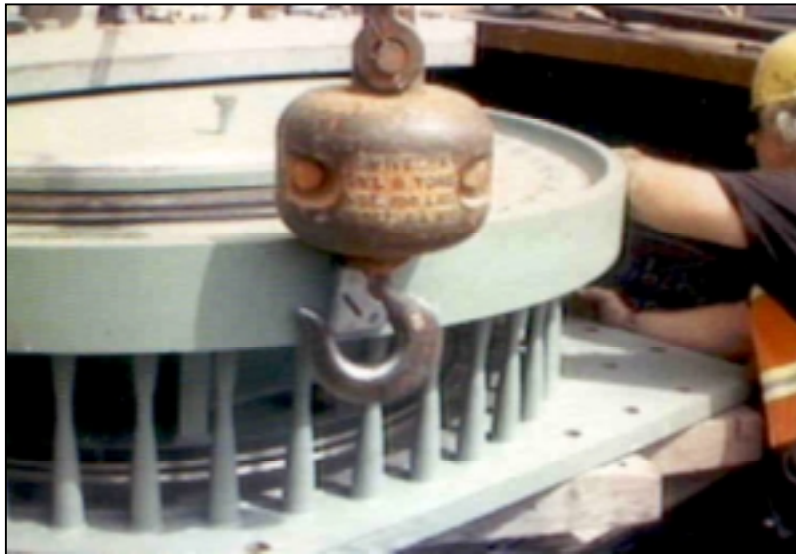


Figure 3.6: Bearing is Positioned between Masonry Plate and Top Sole Plate

### 3.3 VEP 5200 INSTALLATION AT PIERS #3 AND #4

The installation work sequence at Piers #3 (left and right) and #4 (left and right) for the VEP 5200 bearing and restraint devices was similar to the VEP 1400/280-ST bearing/restraint device installation on Piers #2 and #5. Concrete support collars were constructed at the base of the pier columns to support the jacking pipe supports. For each bearing replacement, the lifting assembly consisted of four pipe columns (863.4 mm (34.0 in) outside diameter), two lifting beams and cross braces, four temporary bearings, and eight, 726 Mg (800 ton) jacking devices (Figure 3.7 and Figure 3.8). For this installation, no additional struts were needed on the truss to support the lifting operations. Two lifting shoes were connected to the bottom of the bridge truss chord by replacing existing rivets with high-strength bolts. The lifting beams were turn bolted to the lifting shoes.



Figure 3.7: The Lifting Assembly for Piers #3 and #4

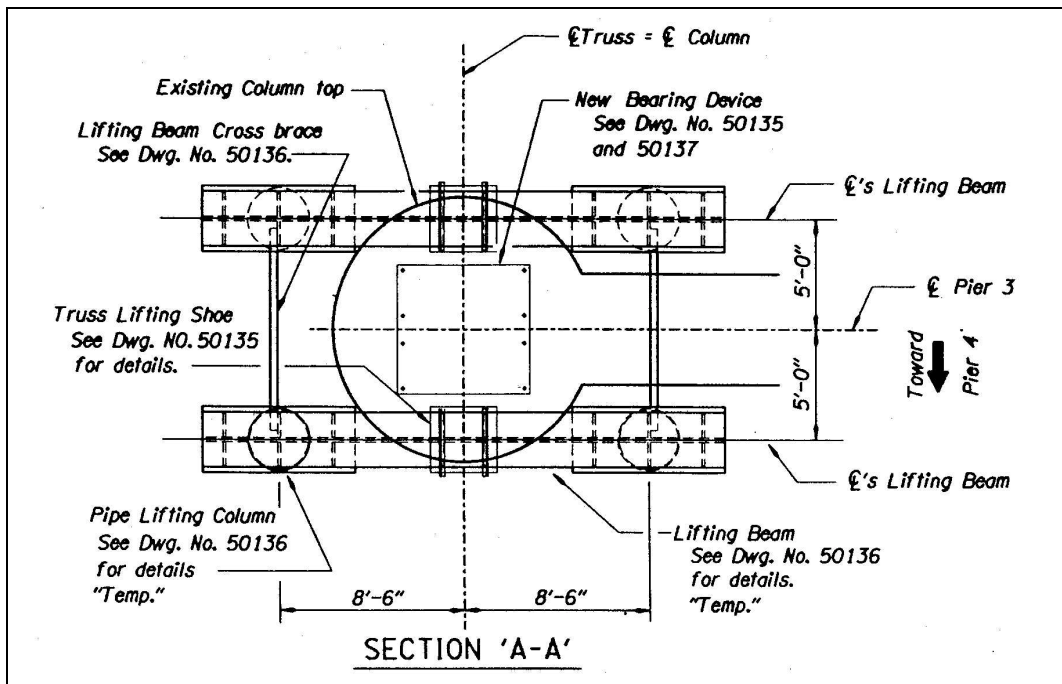


Figure 3.8: Section View Showing the Four Lifting Columns and Beam for Piers #3 and #4

After the lifting assembly was in place, the structure was jacked and temporary bearings and shims slid into place to support the edifice while the other modifications were made. To transfer loads from the old bearing onto the jacks and jacking columns, the structure was raised about 25.4 mm (1.0 in). The existing truss bearing was removed, and the new bearing shoe assembly lowered by a crane from the top deck, placed, and bolted to the bottom of the truss chord.

Next, reinforcing steel and leveling rods for the concrete pedestal were placed. Twelve 31.6 mm (1.25 inch) threaded anchor rods, with two hex nuts and one 25 mm (1 in) x 150 mm (6 in) square plate at each rod, were drilled and bonded into the existing concrete.

Subsequently, the bearing masonry plate was set and a concrete pedestal was constructed. The masonry plate was supported by the 25 mm (1 in) x 150 mm (6 in) square plates at the top end of the anchor rods. As before, the masonry plate was positioned on the leveling nuts so the transverse axis would be in line with the centerline of the new bearing and the longitudinal axis would align with the centerline of the bottom truss chord. Figure 3.9 shows the pedestal detail with anchor rods.

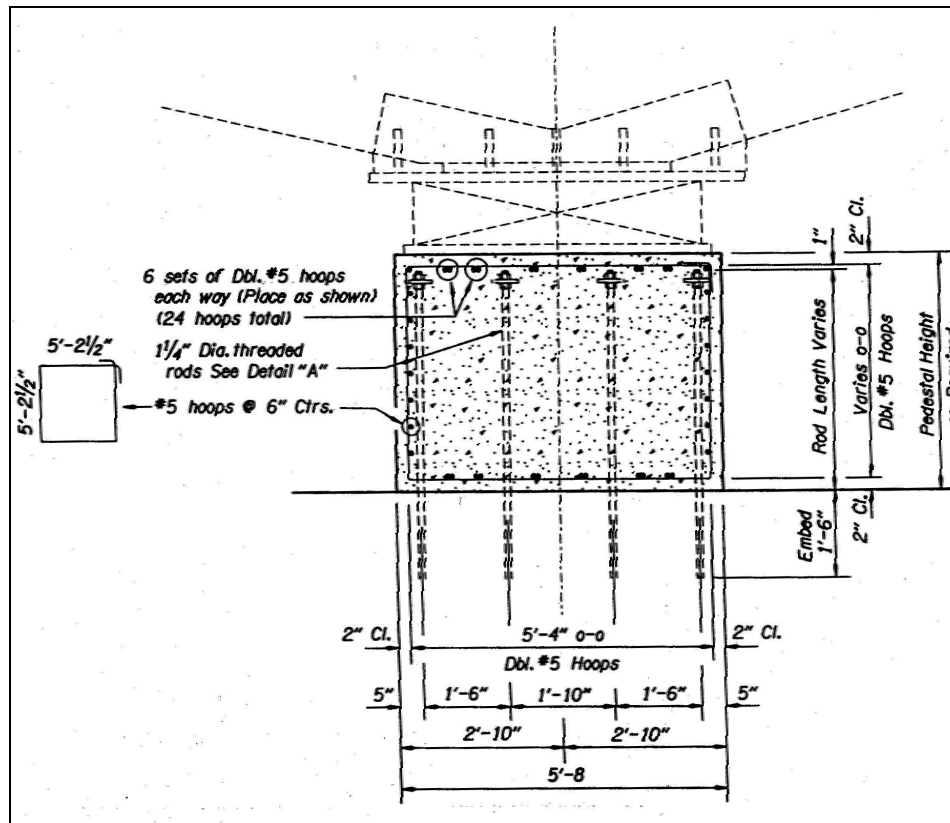


Figure 3.9: Bearing Pedestal Detail at Piers #3 and #4

After the concrete pedestal was constructed, the structure was jacked to allow for the installation of the new bearing assembly. The structure was raised about 25.0 mm (1.0 in) as the loads were transferred from the temporary bearings back onto the jacks. Once in position, the bearing assembly was bolted to the masonry plate, and to the bearing shoe's sole plate and the structure was lowered onto the new bearing. The new bearing/restraint device was then fully operational.

Figure 3.10 (A & B) shows a "before" picture on Pier #3 with the original bearing and a picture on pier #4 after the VEP 5200 bearing/restraint device installation.





Figure 3.10A: Original Bearings on Pier #3



Figure 3.10B: New Bearings on Pier #4

### 3.4 SHOCK TRANSMISSION UNITS

Shock transmission units were installed on each side of the lower deck bridge truss at panel points 13 and 21 (Figures 3.11 and 3.12). The shock transmission devices are designed to diffuse the rapidly applied loads of a seismic event. With their action, both longitudinal and

transverse seismic forces are shared by all base isolation devices in approximate proportion to substructure strengths. This minimized structure displacements and provided maximum damage protection.

Safety hangers, installed on both sides of the main span of the bridge at panel points 13 and 21, are visible in Figure 3.11. These two panel points are the locations of the expansion joints for the suspended portion of the bridge.



Figure 3.11: Shock Transmission Unit at Panel L13

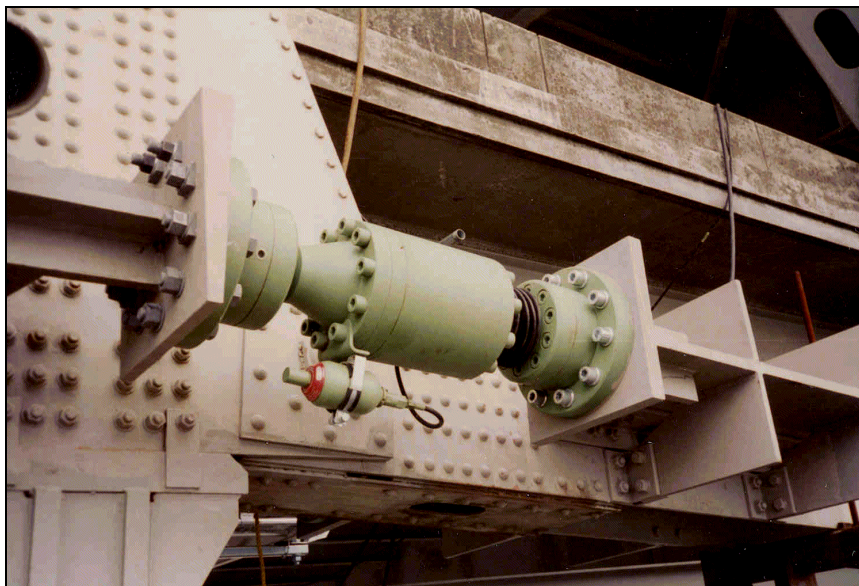


Figure 3.12: Close-up of Shock Transmission Unit



## 4.0 POST-CONSTRUCTION INSPECTION

Shortly after the installation of the 1400/280-ST devices at Piers #2 and #5, Teflon shavings were found in the guide bar area in each of the bearings. On October 18, 1995, Dr. Rene Medeot of FIP Industries, Inc. met with ODOT representatives to jointly inspect the bearings and review the problem. Dr. Medeot attributed the shavings to Teflon sliding element extrusions into the guide bar region (*Starkey 1997*).

Dr. Medeot theorized that the Teflon was able to extrude because the rivets holding the brass restraining bars had broken. This was caused by the plastic flow of Teflon under the brass retaining strips, which produced unanticipated tension on the rivets. According to Dr. Medeot, the driving force for this action was the sustained dead loading on the bearing. He believed the rivets failed because the restrainer bars were designed for a sustained dead load of 4,005 kN (900 kips) which was about 20% less than the apparent dead load present (4,893 kN (1,100 kips)). The higher load produced Teflon plastic flow between the restrainer bar and its attachment, which in turn caused the rivet tensile force and the rivet shear force from containment.

According to Dr Medeot, the extrusion process proceeds in a logarithmically decreasing fashion, and would stabilize over time. On this advice, the contractor (Mowatt Construction Company), FIP Industries Inc., and ODOT agreed to extend the contract time for a one-year period to allow for additional monitoring. The one-year observation period ended in December 1996. The measurements showed that the overall Teflon thickness was not varying appreciably, so it was believed the extrusion process had abated. FIP Industries, Inc. also provided a five-year warranty for the bearings. The warranty ends September 26, 2000.

Recently, on January 31 2000, ODOT's contract inspector and Region 1 bridge inspector visually inspected the bearings on Pier #2. They found some Teflon shavings around each of the bearings, but it appears that the Teflon extrusion process has subsided. The amount of Teflon found indicates the problem has diminished considerably and no further action is required at this time. However, further monitoring is necessary to ensure there are no long-term affects.

There have been no problems reported with any of the bearing/restraint devices on Piers # 3 and #4. Additionally, in the most recent bridge inspection performed by ODOT's Region 1 bridge inspector in July 1998, no problems were noted associated with any of the seismic protection devices.



## **5.0 CONCLUSIONS AND RECOMMENDATIONS**

The bearings and shock transmission units appear to be in generally good condition and suitable for the purpose intended.

All seismic protection devices should be monitored for serviceability on a continuing basis. Special attention should be given to the bearing/restraint devices on Piers # 2 and # 5 to verify that the Teflon extrusion has been curtailed. Monitoring frequency for these bearing/restraint devices (on Piers # 2 and # 5) should be yearly. The other devices should be closely inspected at the time of the regularly scheduled biennial bridge inspection.

If a seismic event occurs, the devices should be inspected for any damage, and to assess suitability for continued service load performance. The bridge's actual response should be compared to the predicted response to evaluate the effectiveness of each device.



## 6.0 REFERENCES

Oregon Department of Transportation. *Prioritization of Oregon Bridges for Seismic Retrofit. Final Report.* January 1997.

Oregon Department of Transportation. *Bridge Inspection Report – Willamette River Marquam Bridge.* July 17, 1998.

Starkey, Steve. *ODOT Construction Completion Inspection Report.* Oregon Department of Transportation. June 28, 1997.