PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Damage to Bridges during the 2001 Nisqually Earthquake

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ABSTRACT

The 2001 Nisqually earthquake, which had a moment magnitude of 6.8, damaged at least 78 bridges in western Washington State. Reports of damage sustained by bridges during this earthquake were used to correlate the likelihood of damage with the following parameters: distance to the epicenter, estimated peak ground acceleration, estimated spectral acceleration at periods of 0.3 s, 1.0 s, and 3.0 s; year built; and type of bridge. This goal was accomplished by collecting reports of bridge damage from state and local agencies, and comparing them with the population of bridges listed in the Washington State Bridge Inventory. The level of ground shaking at each bridge site was estimated from ShakeMaps, which were developed from data from the Pacific Northwest Seismic Network.

Of the four ground-motion parameters considered, the likelihood of bridge damage was best correlated with spectral acceleration at a period of 0.3 s. For a given level of spectral acceleration, bridges constructed before 1940 were the most likely to be damaged, while those constructed after 1975 were the least vulnerable. Although the number of movable bridges was small, this type of bridge was particularly vulnerable. Bridges with a steel main span were more likely to be damaged than those constructed of reinforced concrete. However, the number of steel bridges was small, and the most common type of damage to steel-span bridges was actually damage to the reinforced concrete substructure.

ACKNOWLEDGMENTS

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Dr. Stephen Malone, William Steele, and other members of the PNSN staff provided electronic versions of the ShakeMaps, without which the analyses could not have been conducted. John Perry of the Federal Emergency Management Agency provided essential GIS support, which made it possible to link the ShakeMaps and the bridge inventory. FEMA support of the Nisqually Earthquake Clearinghouse facilitated this interdisciplinary cooperation.

The data gathering and analysis was supported by the Pacific Earthquake Engineering Research Center (PEER) through the Earthquake Engineering Research Centers Program of the National Science Foundation under Award number EEC-9701568. Some of this support was provided by PEER matching funds from the State of Washington. Additional support was provided under the National Science Foundation Research Experience for Undergraduates Program. The support of these organizations is gratefully acknowledged.

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1 Introduction

The vulnerability of bridges in the Puget Sound area was investigated by analyzing reports of damage to bridges during the 2001 Nisqually earthquake. By correlating damage with bridge and ground-motion characteristics, it was hoped that the characteristics that most contributed to the damage would be identified. The characteristics that were explored included

- the year that the bridge was constructed;
- the distance from the bridge to the earthquake epicenter;
- the estimated peak ground acceleration (PGA) at the location of the bridge;
- the spectral acceleration at the site of the bridge (SA), and;
- the type of bridge that was damaged.

In the future, the observed trends could be used to prioritize post-earthquake inspections if maps of shaking intensity were available shortly after an earthquake.

1.1 Background

At 10:54:32 AM local time on February 28, 2001, the Nisqually earthquake of magnitude 6.8 occurred at location 47.1525° N, 122.7197° W. The epicenter was approximately 17.6 km northeast of Olympia, 23.7 km SW of Tacoma, and 57.5 km SW of Seattle, Washington (EERI 2001). The Nisqually earthquake occurred deep below the earth's surface, within the subducting Juan de Fuca plate. Because of the depth of the hypocenter, approximately 52.4 km, the damage throughout the area was only moderate. Slight to moderate damage was reported to 78 bridges, with no collapses. Had the earthquake been more shallow, damage in the Olympia and Seattle regions might have been much more severe.

1.2 Research Methodology

Because the state, counties and cities keep separate records, each agency was contacted independently to obtain detailed damage descriptions and photographs of bridges that were damaged during the Nisqually earthquake. To help with this process, a damage report form was composed to consistently extract pertinent information. A copy of the form is provided in Appendix B. Appendix D provides a list of individuals who contributed data or comments to this report.

Concurrently, the Washington State Department of Transportation (WSDOT) provided the Washington State Bridge Inventory (WSBI) in electronic form. This database provides physical and geographical information for nearly all of the bridges in the state. The WSBI was used to normalize the damaged bridge data (WSDOT 2000). The WSBI categories considered in this study were

- latitude and longitude of bridge;
- type of bridge (e.g., movable, truss, etc.);
- material used for the main span (reinforced concrete, prestressed concrete, or steel); and
- year of construction.

These data are provided in Appendix C for all of the damaged bridges. The average daily traffic data are also included in this appendix. Although this information was not used in this analysis, it could be used to analyze the economic impacts of bridge closures.

To analyze the data, each bridge had to be located, and the corresponding values for the peak ground acceleration and the spectral acceleration had to be estimated. These parameters were extracted from ShakeMaps developed by the Pacific Northwest Seismograph Network (PNSN 2001a), which are shown in Figs. 1-1 and 1-2. The PNSN, centered at the University of Washington, operates a network of seismograph stations throughout the Northwest. It is operated through a joint effort by the University of Washington, the University of Oregon, and Oregon State University, and is funded by the United States Geological Survey (USGS), the United States Department of Energy (USDOE), and the State of Washington. PNSN developed maps of earthquake intensity (ShakeMaps) by interpolating between numerous stations within the network, taking into account geologic conditions.

Access to the ShakeMap data was provided by the Federal Emergency Management Agency (FEMA), which also provided GIS support. The maps provided approximate values for the peak ground acceleration and the spectral acceleration at the location of each damaged and undamaged bridge. The map used to extract the estimated values for each bridge had a range of

48.4125° N - 46.3875° N in latitude, and 124.1125° W – 121.0875° W in longitude. Damaged bridges are identified by triangles in the figures.

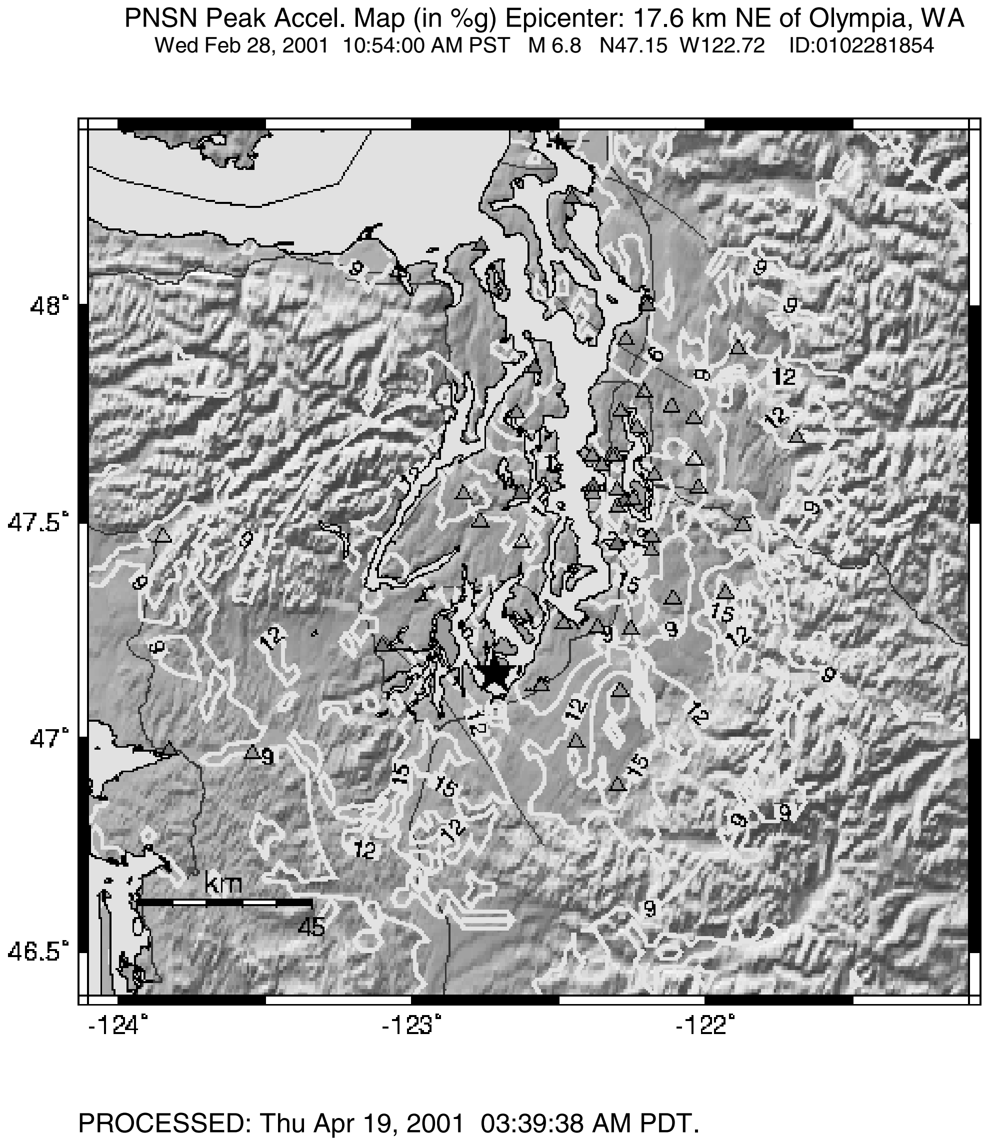
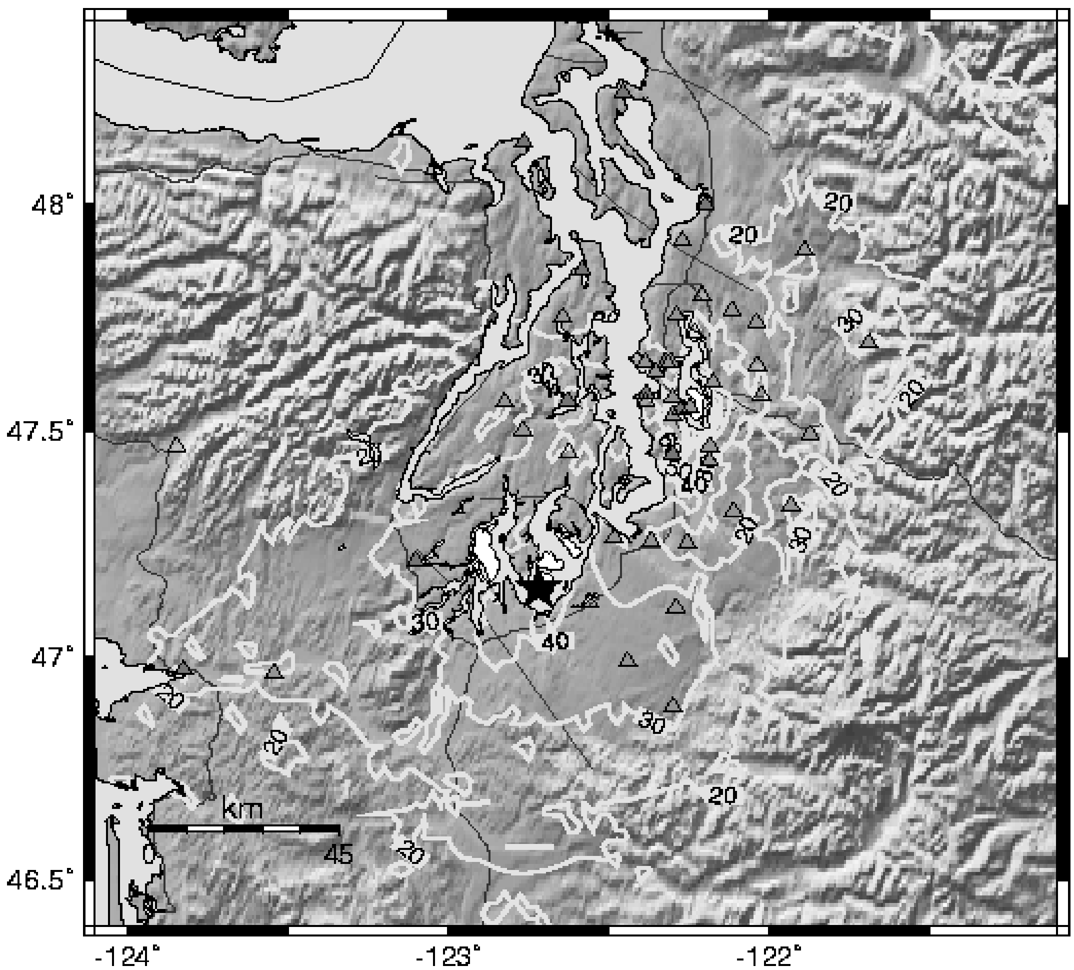


Fig. 1-1: ShakeMap showing estimated peak ground acceleration (PNSN 2001b)

PNSN 0.3 s Pseudo-Acceleration Spectra (%g) Epicenter: 17.6 km NE of Olympia, WA
Wed Feb 28, 2001 10:54:00 AM PST M 6.8 N47.15 W122.72 ID:0102281854



PROCESSED: Thu Apr 19, 2001 03:39:38 AM PDT.

NOTE: These are automated maps based on instrumental response spectra, and may not be appropriate for comparison with design spectral values.

Fig. 1-2: ShakeMap showing estimated spectral acceleration at T = 0.3s (PNSN 2001b)

2 Observed Damage

The reports of bridge damage were collected from the city, county, and state governments (Appendix D). From these data, it was determined that 78 bridges had been damaged as a result of the Nisqually earthquake (Appendix C). The majority (46) of these bridges were owned and maintained by the WSDOT, and were either overpasses or underpasses along the interstate and state highway systems. The City of Seattle reported damage to 18 bridges.

2.1 Classification of Damage

The damage repair cost for each bridge was classified as slight, mild, or moderate, based on damage estimate ranges of $30,000 or less, $30,001 to $100,000, and above $100,000, respectively. The estimates provided by the individual bridge agencies are listed in Appendix C. In cases where an estimate was not provided, but where the level was obvious, the researchers categorized the damage levels themselves. According to these definitions, the number of bridges in each category is

- Slight (52 bridges)
- Mild (16 bridges)
- Moderate (10 bridges)

No damage was reported to timber or masonry bridges. The four types of bridges (categorized according to material used for main span) that were damaged were

- Reinforced concrete bridges (36)
- Prestressed concrete bridges (20)
- Steel bridges (16)
- Movable bridges (6)

The movable bridges were classified separately because of their particular vulnerabilities, e.g., lack of alignment. For the remaining 72 fixed bridges, the types of damage were classified as

- Damage to concrete (48)
- Damage to steel (6)
- Damage to beams, restrainers or joints (11)
- Settlement damage (7)

The distribution of damage type, sorted primarily by the type of bridge, is shown in Fig. 2-1. For each type of bridge, Fig. 2-1 displays the type of damage as a percentage of the total amount of damage for that type of bridge. For example, of the 36 reinforced concrete bridges that were damaged, 26 sustained damage to the reinforced concrete elements, resulting in a damage percentage of 72%.

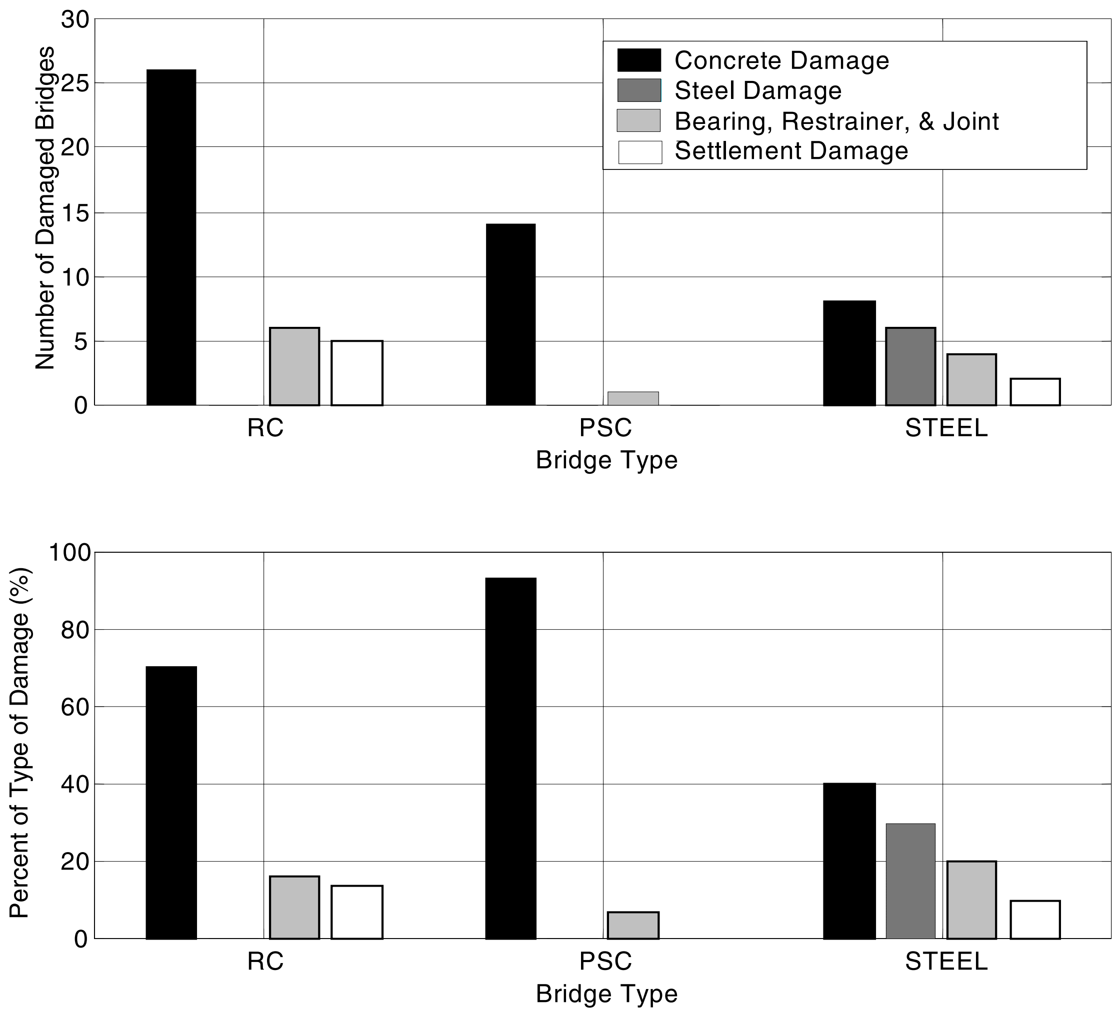


Fig. 2-1: Distribution of types of damage for each type of bridge

According to the figure, concrete damage was the most prevalent type of damage for each of the three types of bridges. It had been expected that concrete damage would predominate in reinforced concrete and pre-stressed concrete bridges. More surprising is that damage to steel components represented only 30% of the damage to steel bridges. In comparison, 40% of damaged steel bridges were reported to have damage primarily to the reinforced concrete substructure. Most of the concrete damage to the steel bridges consisted of minor spalling of the concrete columns.

A complete list of damaged bridges, along with their physical and geographical characteristics is presented in Appendix C. Numerous photographs of bridge damage are available at http://www.ce.washington.edu/~nisqually.

Fig. 2-2: Damage to a movable bridge (099/530w)

Fig. 2-3: Damage due to settlement of approach (Chambers Creek Bridge)

Fig. 2-4: Damage due to liquefaction on bridge 002/6s-w (WSDOT)

2.2 Damage to Movable Bridges

Of the 78 bridges that were damaged by the earthquake, six were classified by the WSBI as movable bridges. Typical types of damage that were reported for these bridges include: damage to the leafs, dislodging of the counterweights, damage to the centerlock, and lateral shifting to the bascule towers. An example of damage to a movable bridge is shown in Fig. 2-2.

2.3 Damage due to Settlement

Significant settlement was reported for seven bridges. Six of these bridges reported settlement at the approach or within the bridge embankment. This type of damage ranged from minor differential settlement to a reported movement of 100 yards of the approach. An example of approach settlement can be seen in Fig. 2-3.

The seventh reported sighting of settlement was attributed to liquefaction around one of the piers, as shown in Fig. 2-4.

Fig. 2-5: Damage to concrete on Spokane St. Viaduct (WSDOT)

2.4 Damage to Reinforced or Prestressed Concrete

Of the 72 fixed (not movable) bridges that were damaged, 48 had damage to a concrete element. The types of damage included spalling and cracking of columns, diaphragms, and abutments. An example of concrete damage is shown in Fig. 2-5.

Fig. 2-6: Damage to steel on bridge 005/322 (WSDOT)

2.5 Damage to Steel

Only six fixed bridges sustained damage to the steel superstructure. Such damage usually consisted of bent and broken cross frames and bearing stiffeners. An example of steel damage is shown in Fig. 2-6.

2.6 Damage to Restrainers, Joints, or Bearings

Damage to the restrainers, joints, or bearings included elongated or broken restrainers, damage to movement joints, and excessive tipping of rocker bearings. Eleven of the damaged bridges sustained one of these types of damage. An example of a damaged bearing is displayed in Fig. 2-7.

Fig. 2-7: Damage to bearing on bridge 005/221 in Chehalis (WSDOT)

3 Damage Analysis

This chapter identifies correlations between the percentage of bridges that were damaged, and the properties of the bridge and ground motion. Specifically, the analysis considered the effects of the year of construction of the bridge, the type of bridge, the distance between the bridge and the epicenter, the estimated peak ground acceleration at the location of the bridge, and the spectral acceleration at the location of the bridge. To express the outcome of these analyses in a consistent manner, the data were normalized by dividing the number of damaged bridges by the total number of bridges in the Washington State Bridge Inventory (WSBI) for each category. A total number of 8,445 bridges are listed in the WSBI. However, in each analysis, only the portion of these bridges that fell within each sorting category was used to normalize the results.

For each analysis, a series of three plots are presented. The first plot shows the total number of bridges listed in the WSBI that fit into the categories that are being analyzed. The second plot reports the number of damaged bridges in each category. The third plot shows the percentage of bridges that were damaged within each category, which corresponds to the values in the second plot divided by the values in the first plot, expressed as a percentage. The damage category "Damage to restrainers, joints, or bearings" could not be expressed in this graphical format, because there was virtually no information in the WSBI on these elements.

3.1 Effect of Year of Construction

Bridges were first sorted by the decade in which each was built. The results of this analysis for the 78 damaged bridges are shown in Fig. 3-1.

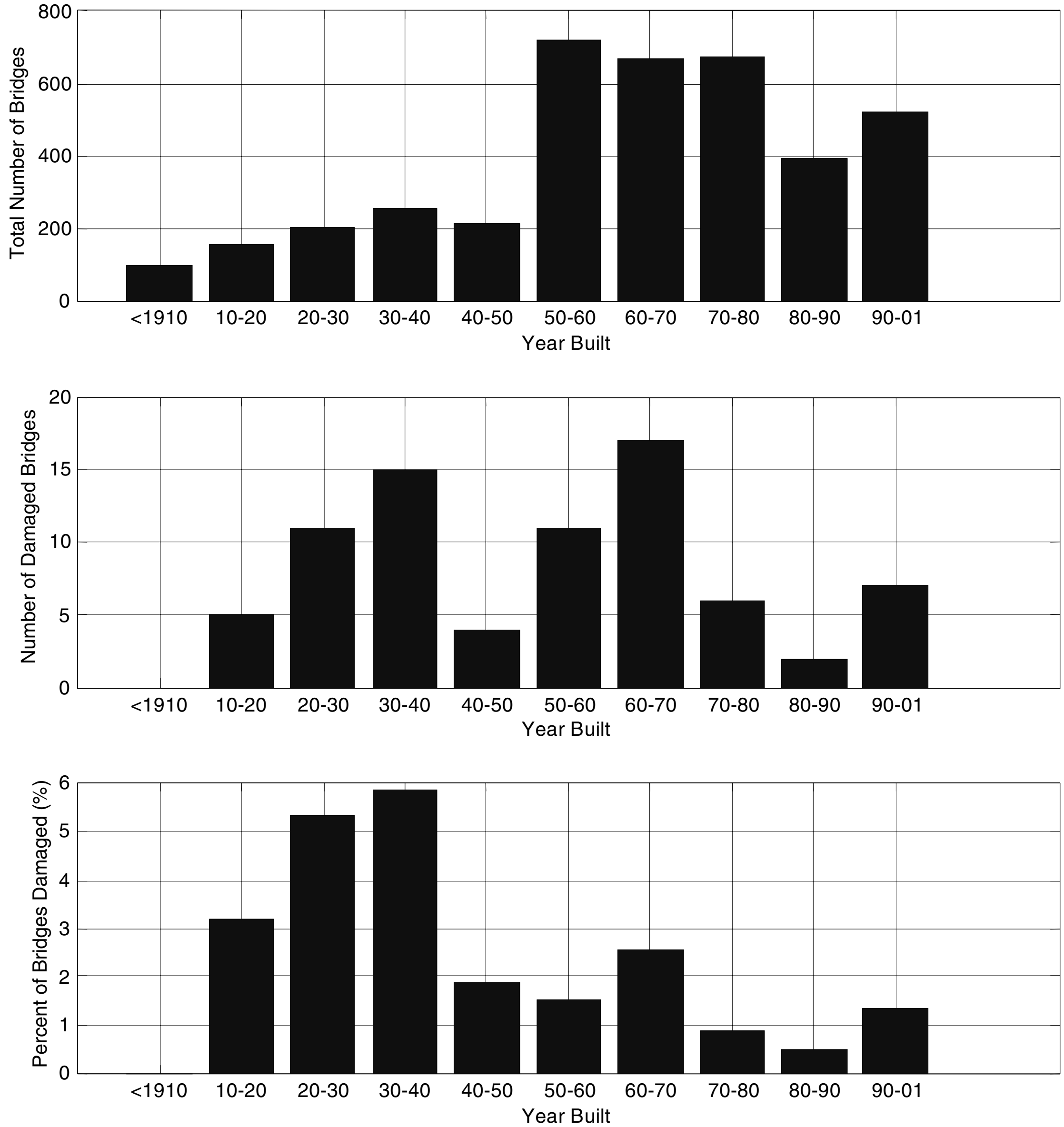


Fig. 3-1: Effect of year of construction, separated into decades

According to Fig. 3-1, the number of bridges constructed increased dramatically at the beginning of the 1950s, and then decreased at the beginning of the 1980s. This range of time coincides with the construction of the interstate highway system. The figure also shows that the percentage of the bridges that were damaged was largest for bridges constructed before 1940, averaging approximately 4.5%. Between 1940 and 1970, the percentage of bridges that were damaged were half that value, averaging approximately 2%. After 1970, this percentage was again reduced in half, averaging approximately 1%. Although the causes of the decline at the beginning of the 1940s are unclear, the drop at the beginning of the 1970s was expected. The San Fernando Earthquake occurred on February 9, 1971, and during the next few years, codes and practices were changed to reduce damage to structures (Moehle and Eberhard 1999).

Because of the dramatic differences between the percentage of bridges that were damaged before 1940 and after 1975, these years will serve to categorize the bridges in upcoming analyses.

3.2 Effect of Epicentral Distance

The distance of the bridge to the epicenter was the second factor considered. The distance was calculated based on the coordinates of both the bridge and the epicenter, following the procedure described in Appendix A. In this analysis, the bridges were grouped into categories that span 15 radial kilometers. The result of this analysis is displayed in Fig. 3-2.

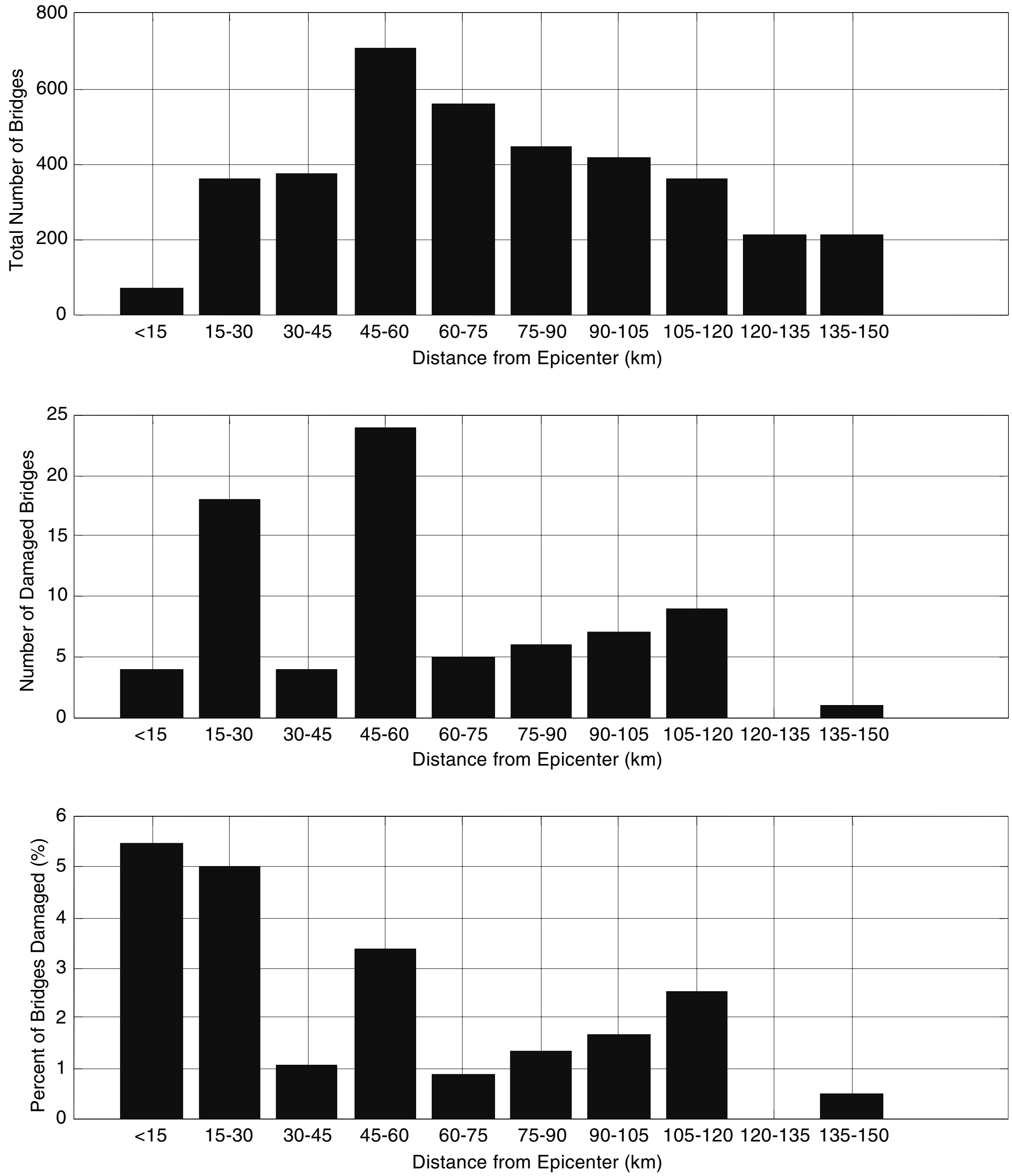


Fig. 3-2: Effect of distance to epicenter

As shown in Fig. 3-2, many bridges were damaged within the ranges of 15–30 km and 45–60 km. The range of 15–30 km corresponds to the distance to the City of Olympia, while the range of 45–60 km corresponds to the distance to the City of Seattle. As expected, the percentage of bridges that were damaged was largest near the epicenter. However, as the distance to the epicenter increased, the damage percentage did not decrease consistently. If the intensity of the earthquake had depended only on the distance from the epicenter, the trend would have been more consistent. The correlation between damage and epicentral distance was weak, because epicentral distance does not account for the local geology. For example, the City of Seattle has a large number of bridges situated on soft soils.

3.3 Effect of Peak Ground Acceleration

To investigate the effect of the estimated peak ground acceleration (PGA), the PGA at every bridge location was estimated from ShakeMaps, as described in Section 1.2. The ground-motion characteristics for seven of the damaged bridges could not be estimated from the ShakeMap, because they were located outside of the boundaries of the map (Section 1.2). Overall, 3,312 bridges (of which 71 were damaged) were located within the range of the ShakeMap, which corresponds to an average damage percentage of 2.1%. The analysis of the percentage of bridges damaged as a function of the PGA is shown in Fig. 3-3. As shown in Fig. 3-4, there is only a weak correlation between the level of the estimated peak ground acceleration and the percentage of bridges that were damaged. From this figure, one can only conclude that bridges with peak ground accelerations above 0.2g were more likely to be damaged than bridges subjected to lower peak accelerations.

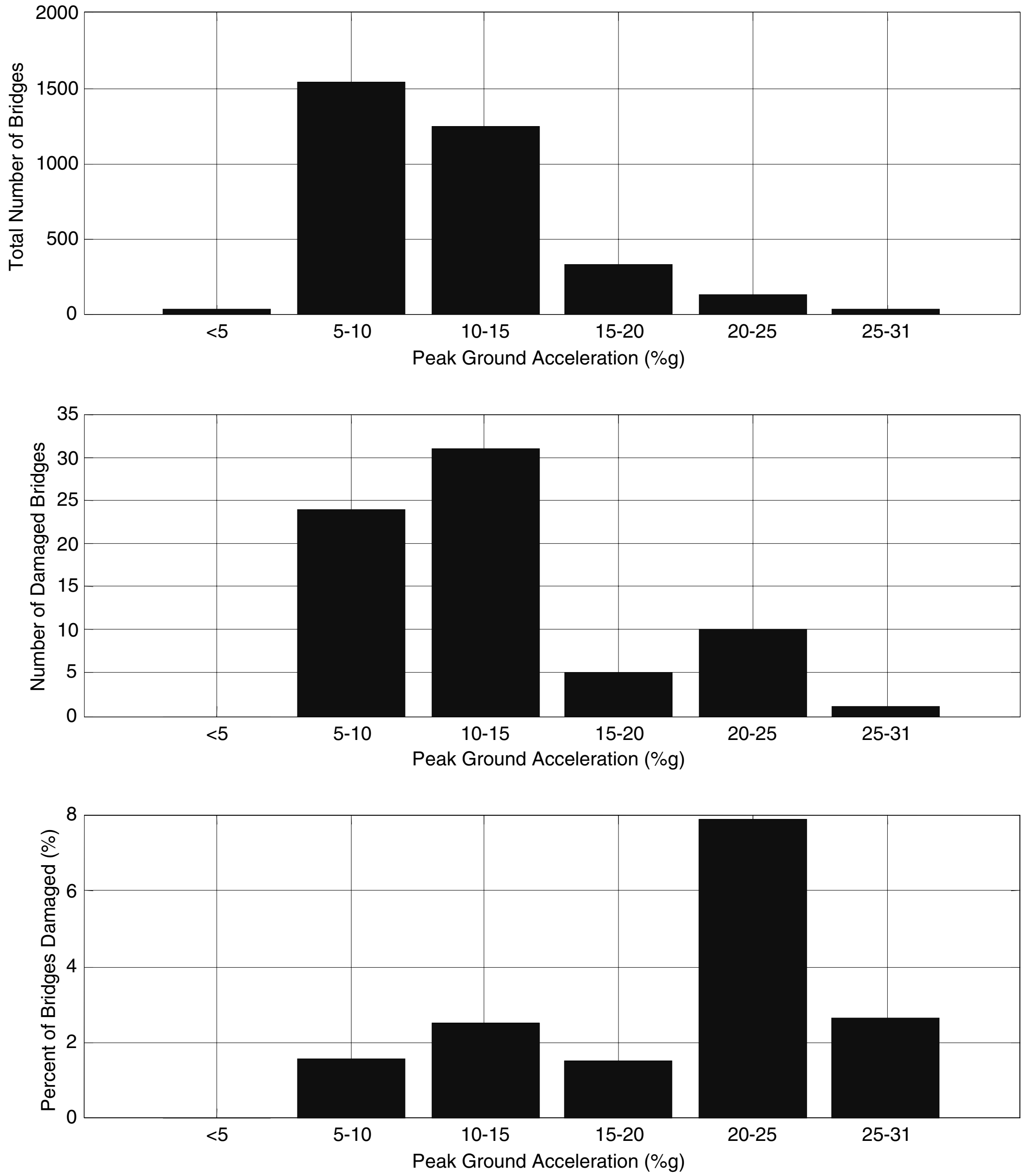


Fig. 3-3: Effect of peak ground acceleration

3.4 Effect of Spectral Acceleration

The correlation between spectral acceleration and damage was also investigated. The PNSN ShakeMap provided data for the spectral acceleration at periods of 0.3, 1.0, and 3.0 s. However, damage frequency did not correlate well with the spectral acceleration at periods of 1.0 and 3.0 s. Therefore, further analysis was performed only on the data for the spectral acceleration at a period of 0.3 s.

Analyses were conducted to identify: the effect of spectral acceleration; the combined effects of spectral acceleration and year of construction; and the combined effects of spectral acceleration and bridge type.

The percentage of the bridges that were damaged correlated well with the magnitude of the spectral acceleration at 0.3 s, as shown in Fig. 3-4. An exception to this trend was the decrease at the highest range of the spectral acceleration. This anomaly is most likely attributable to the small number of bridges in each category.

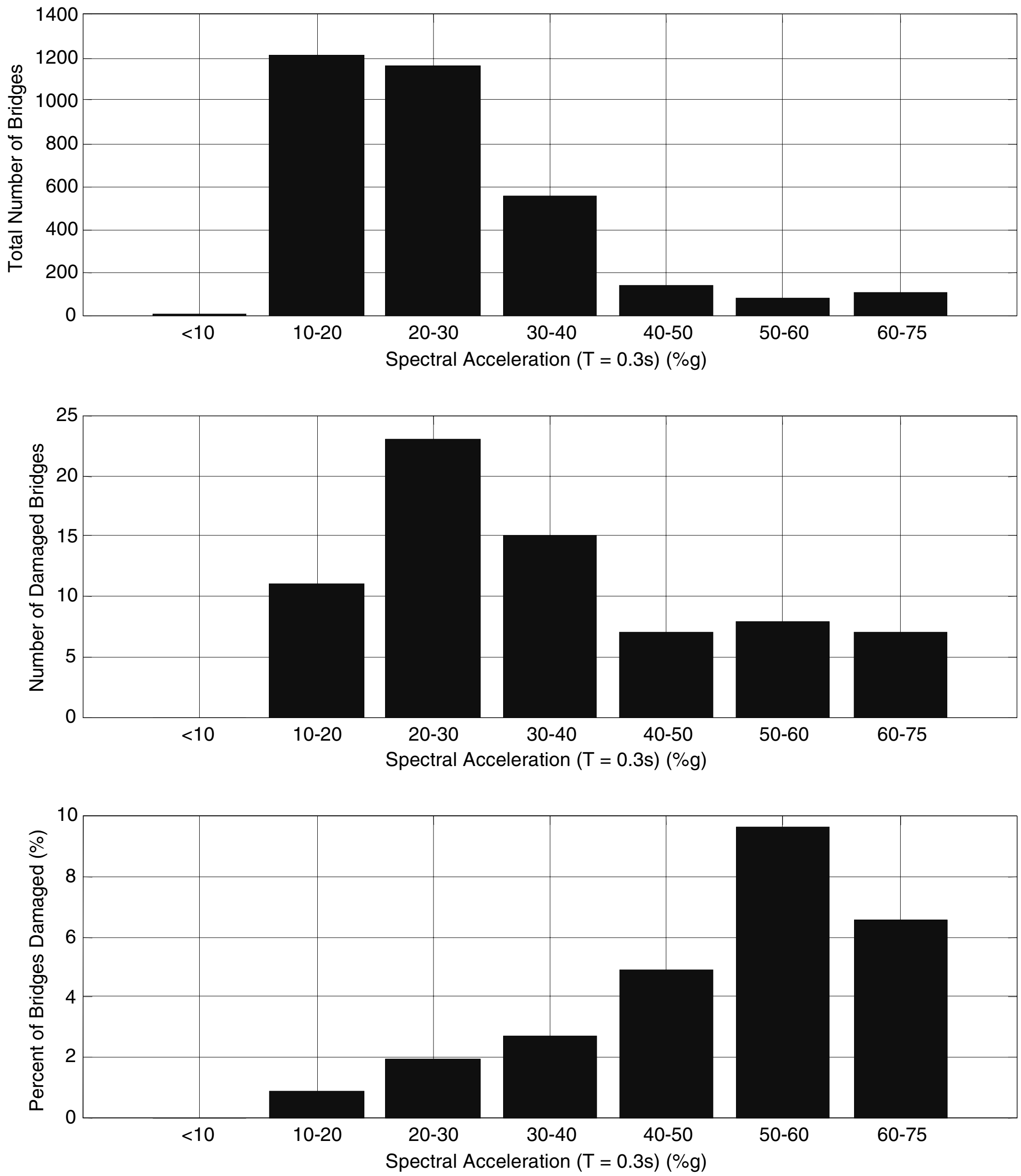


Fig. 3-4: Effect of spectral acceleration at a period of 0.3 s

3.4.1 Combined effect of spectral acceleration and year constructed

Taking into account the year of construction further refined the spectral-acceleration analysis. As discussed in Section 3.1, bridges were classified into three categories according to the year of construction: before 1940, 1940–1975, and after 1975. The results of this analysis are displayed in Fig. 3-5.

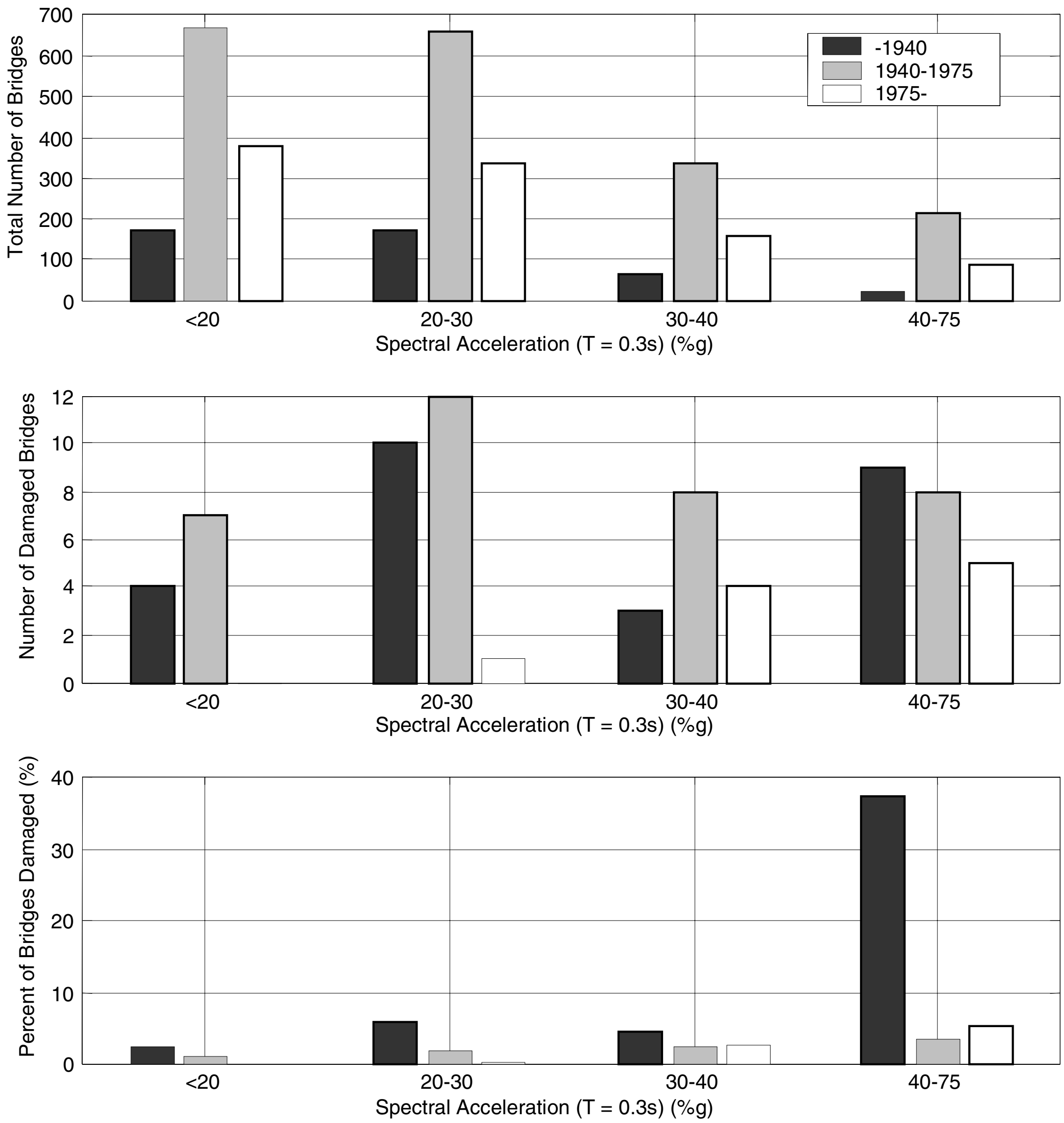


Fig. 3-5: Combined effect of spectral acceleration and year of construction

As noted before, the bridges with high spectral accelerations were more likely to be damaged. Moreover, at each level of spectral acceleration, the bridges that were built before 1940 had the highest percentage of damaged bridges, and in general, those built after 1975 were the least likely to be damaged.

3.4.2 Combined effect of spectral acceleration and bridge type

The movable bridges were the most vulnerable type of bridge. Of the 42 movable bridges within the boundaries of the ShakeMap, six were damaged, resulting in an average damage percentage of 14%. Fig. 3-6 shows that the percentage of damaged movable bridges tended to increase with spectral acceleration. For example, of the nine bridges with estimated spectral accelerations above 0.4g, three (33%) were reported to have suffered damage. There was a notable exception to this trend. None of the eight movable bridges with estimated spectral accelerations in the range 0.30g to 0.40g were reported to suffer any damage. Such exceptions should be expected for small data sets.

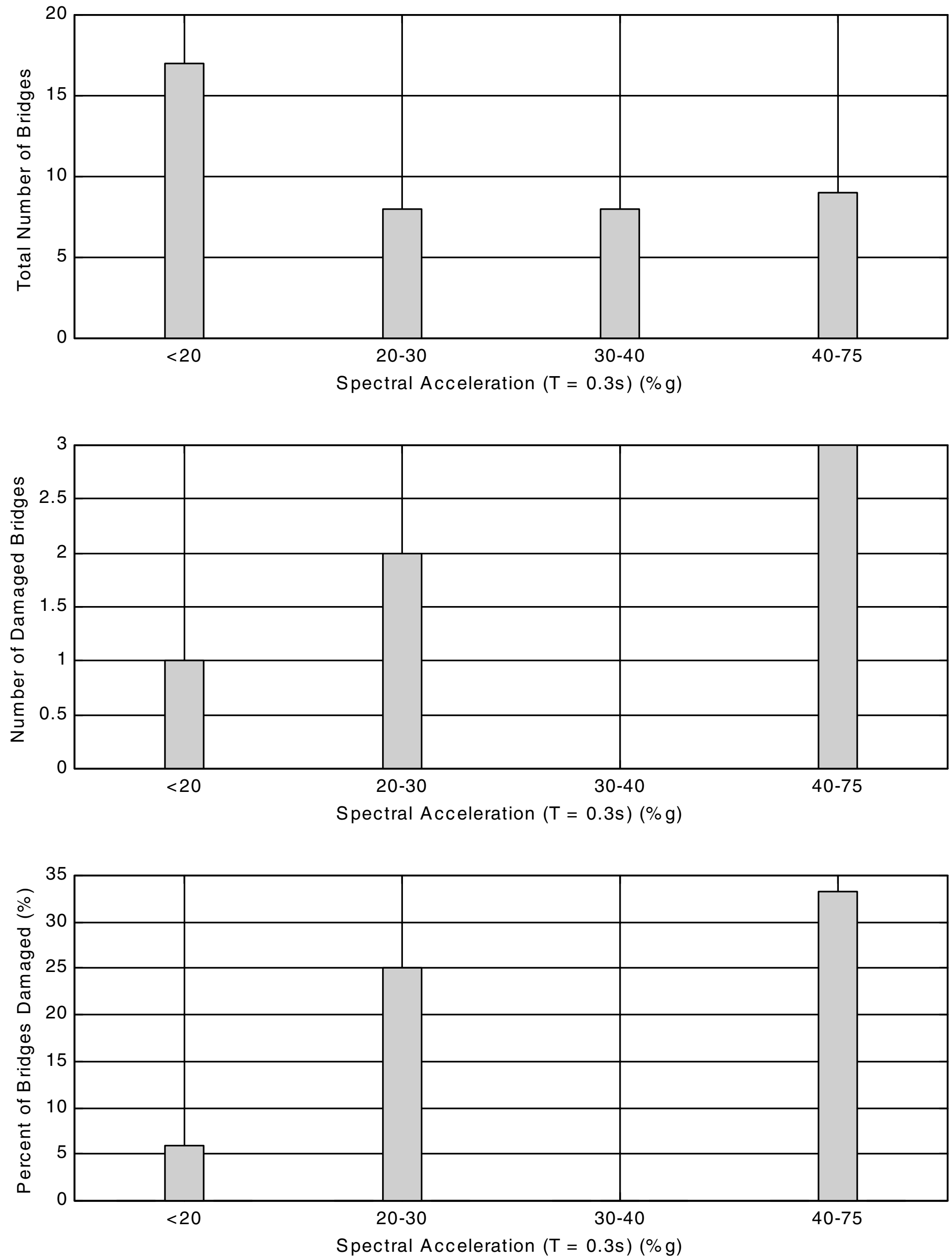


Fig. 3-6: Effect of spectral acceleration on movable bridges

Damage to the three types of immobile bridges (reinforced concrete, prestressed concrete and steel) were analyzed as a function of spectral acceleration. Settlement damage would not be expected to depend on bridge type. As a result, movable bridges (6), bridges with settlement (7), and bridges outside the limits of the ShakeMap (7) were not considered in this analysis. The results of the analysis for the remaining 58 bridges are reported in Fig. 3-7.

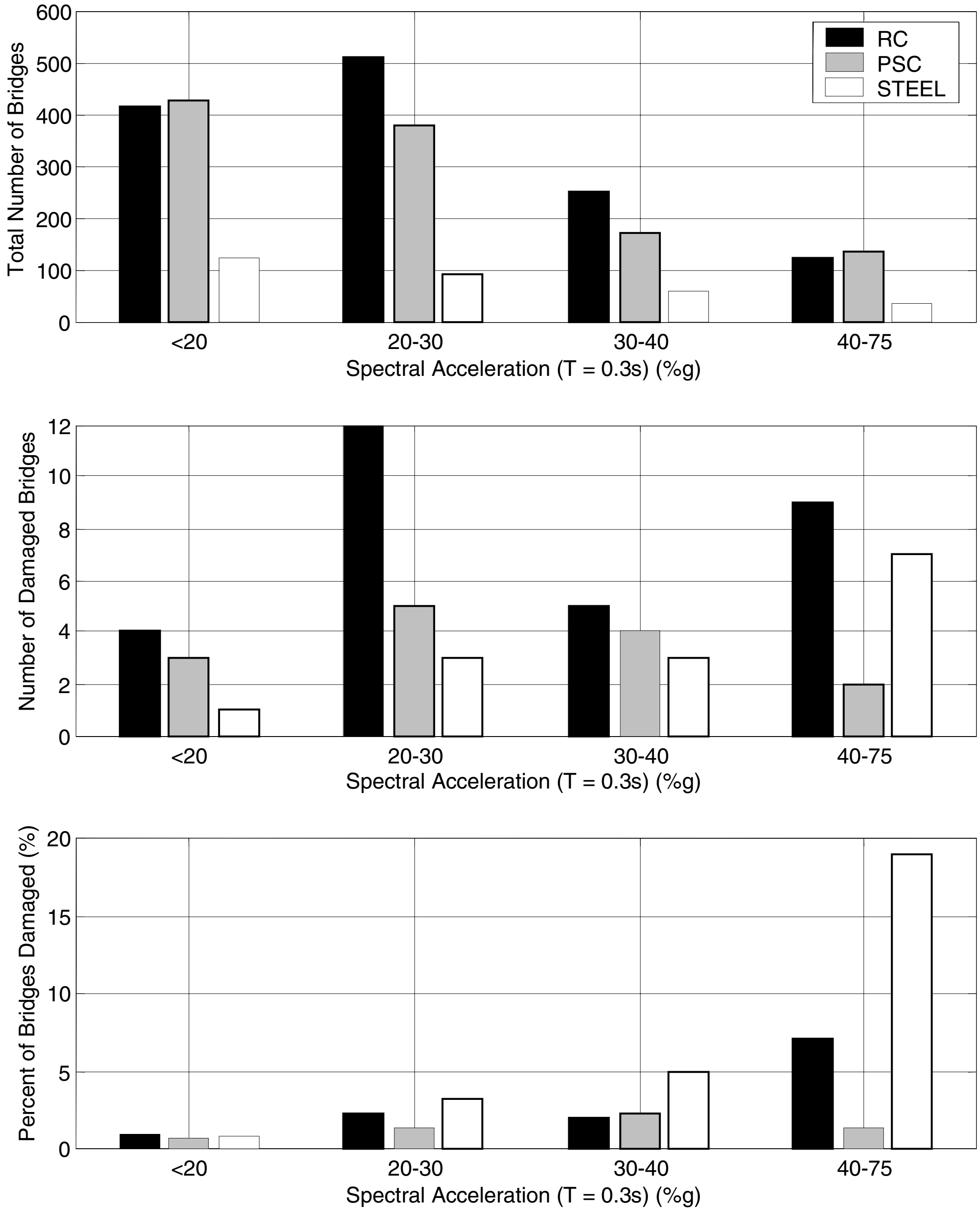


Fig. 3-7: Combined effect of spectral acceleration and bridge type

Despite the small number of damaged bridges in each category, Fig. 3-7 shows a clear correlation between the percentage of bridges that were damaged and the level of spectral acceleration. Based on this breakdown, it appears that the steel bridges were more vulnerable than those constructed of reinforced or prestressed concrete. However, this observation is not attributable solely to the type of bridge, but to the year that the bridges were constructed, as shown in Fig. 3.8. As shown in this figure, both reinforced concrete and steel bridges that were constructed before 1940 were much vulnerable than bridges constructed later. In addition, 40% of the damage to steel bridges consisted of damage to the reinforced concrete substructure (Fig. 2-1).

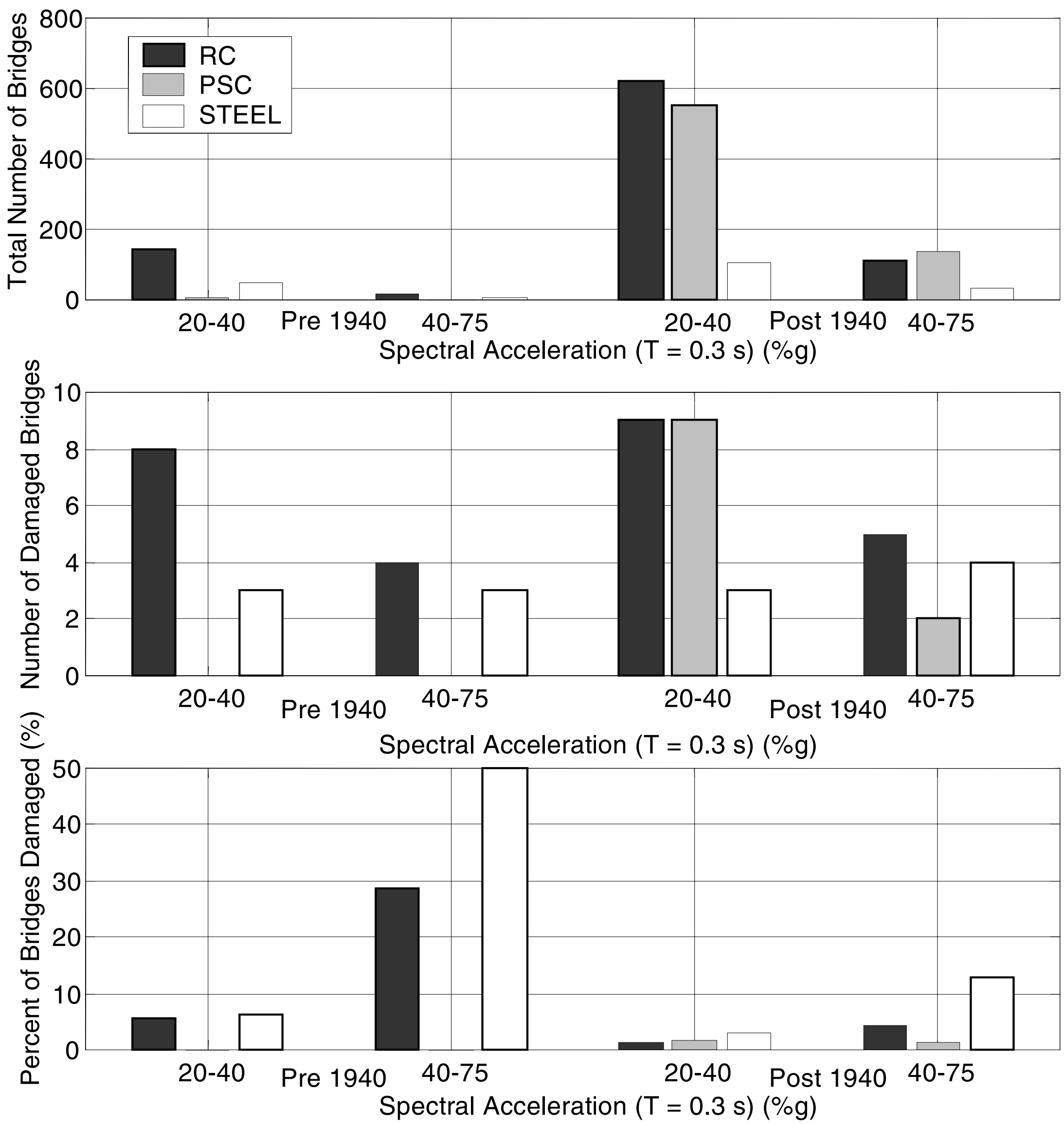


Fig. 3-8: Combined effects of spectral acceleration, year of construction, and bridge type

4 Conclusions

The 2001 Nisqually earthquake damaged at least 78 bridges, of which 68 had slight or mild damage, and 10 had moderate damage. The most common type of reported damage (48 bridges) consisted of concrete cracking and spalling.

Reports of bridge damage were combined with the Washington State Bridge Inventory and ShakeMaps produced by the Pacific Northwest Seismic Network to identify factors that made bridges most vulnerable. If ShakeMaps were available immediately after an earthquake in the future, the results of this study could be used to prioritize post-earthquake inspections.

The percentage of bridges that were damaged did not correlate well with the distance from the bridge to the epicenter or the estimated peak ground acceleration at the bridge site. The estimated spectral acceleration at 0.3 s was a better indicator of the likelihood of bridge damage.

The year in which the bridge was constructed and the type of bridge were also important factors, with the highest percentages of damage reported for bridges that were built before 1940 and those that were movable. For estimated spectral accelerations above 0.4g, damage was reported to 33% of the movable bridges, 29% of the reinforced concrete bridges built before 1940, and 50% of steel bridges built before 1940. Although the damage percentage for bridges with a steel main span was generally higher than for other types of bridges, the number of such bridges was small, and the most common type of damage in these bridges was not to the steel superstructure, but rather, to the reinforced concrete substructure.

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Appendix A: Distance Calculation

The distance from each bridge to the earthquake epicenter was calculated based on their respective latitudes and longitudes. By knowing the approximate radius of the earth, as well as the latitude and longitude of the point, it is possible to construct the spherical coordinates of this location on the earth's surface. These can then be converted into Cartesian coordinates by the following set of equations.

$$\begin{aligned} x &= R\cos\phi\cos\theta \\ y &= R\cos\phi\sin\theta \\ z &= R\sin\phi \end{aligned} \quad \textbf{(A-1)}$$

where R is the radius of the earth, ϕ is the latitude and θ is the longitude. ϕ is positive above the equator, and θ is considered positive if east of the International Date Line.

From the rectangular coordinates, the vector formed by connecting the origin to the point on the earth's surface can be determined.

$$P_1 = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} \qquad P_2 = \begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} \quad \textbf{(A-2)}$$

P_1 denotes the location of the epicenter, and P_2 denotes the location of the bridge.

The distance between these two points can be calculated as an arc along the earth's surface, or as a straight line (chord) beneath the earth's surface. Because the waves of an earthquake do not follow either of these exactly, and because both calculations would yield approximately the same answer, the arc-based measurement was chosen to estimate epicentral distances.

The angle between the two vectors can be determined by using the equation

$$P_1 \cdot P_2 = \| P_1 \| * \| P_2 \| \cos\beta \quad \textbf{(A-3)}$$

where β is the angle between the two vectors. Since both the points lay on the Earth's surface, $\|P_1\| = \|P_2\| = R$. Solving for β,

$$\beta = \cos^{-1}\left(\frac{P_1 \cdot P_2}{R^2}\right) \qquad \textbf{(A-4)}$$

Once the angle between the two vectors is known, the arc length between the two points can be determined by the equation

$$D = R\beta \qquad \textbf{(A-5)}$$

where D is the distance between the epicenter and the point of interest. Combining Equations A-1, A-2, A-4 and A-5,

$$D = R\cos^{-1}\frac{\begin{bmatrix} R\cos\phi_1\cos\theta_1 \\ R\cos\phi_1\sin\theta_1 \\ R\sin\phi_1 \end{bmatrix} \cdot \begin{bmatrix} R\cos\phi_2\cos\theta_2 \\ R\cos\phi_2\sin\theta_2 \\ R\sin\phi_2 \end{bmatrix}}{R^2} \qquad \textbf{(A-6)}$$

Simplifying the above equation, and using the trigonometric identity

$$\cos(A - B) = \cos A\cos B + \sin A\sin B$$

the epicentral distance can be calculated as follows.

$$D = R\cos^{-1}\left[(\cos\phi_1\cos\phi_2)(\cos(\theta_1 - \theta_2)) + \sin\phi_1\sin\phi_2\right] \qquad \textbf{(A-7)}$$

With this equation, the distance from the epicenter to the point of interest can be directly linked to the latitude and longitude of the two points.

Appendix B: Data Collection Inquiry Form

Contact
Name:
Agency:
Phone Number:
Fax Number:

AGENCY INFORMATION

Total Number of Bridges in Agency ______________________________

Total Number of Damaged Bridges in Agency ______________________________

BRIDGE IDENTIFICATION

Bridge Name ____________________ Bridge Number/Designation________________

Latitude ____________ Longitude ___________ Year of Construction_________

National Bridge Inventory Number ______________________________________

Physical Description of Location ______________________________________

____

BRIDGE DAMAGE

Description of Damage ______________________________

____

____

Have Photograph of Bridge (Y/N) Have Photograph of Damaged Section (Y/N)

CONSEQUENCES OF DAMAGE

Duration of Closure ______________________________

Average Daily Traffic ______________________________

Repair Date (Actual or Anticipated) ______________________________

Cost of Repair ______________________________

Bridge Value ______________________________

Please return care of
Marc O. Eberhard or R. Tyler Ranf
University of Washington Department of Civil Engineering.
Fax: (206) 543-1543 Phone: (206) 543-4815

Appendix C: Characteristics of Damaged Bridges

KEY

PGA = Estimated peak ground acceleration

PSA03 = Estimated spectral acceleration at a period of 0.3 s

PSA10 = Estimated spectral acceleration at a period of 1.0 s

PSA30 = Estimated spectral acceleration at a period of 3.0 s

Damage level = amount of damage ($) sustained by the bridge

1 = $30,000 and under

2 = $30,001 - $100,000

3 = more than $100,000

Damage category = the type of damage that the bridge sustained

1 = Settlement damage

2 = Concrete damage

3 = Steel damage

4 = Damage to restrainers, bearings, or joints

5 = Damage to movable bridges

Main Span Material = the material for the load bearing member of the main span is made

2 = Reinforced concrete

4 = Steel

6 = Prestressed concrete

Main Span Design = the type of bridge

1 = Slab

2 = Stringer/multi-beam or girder

3 = Girder and floor beam system

4 = tee beam

5 = box beam/box girder – multiple

6 = Box beam/box girder – single or spread

7 = Rigid frame

8 = Orthotropic

9 = Truss – deck

10 = Truss – through

11 = Arch – deck

12 = Arch – through

13 = Suspension

14 = Stayed girder

15 = Movable – lift

16 = Movable – bascule

17 = Movable – swing

#	Bridge Designation	Agency	Agency Bridge #	Washington State Bridge Inventory	Lat	Lon	distance to epicenter (km)	PGA	PSA03	PSA10	PSA30	Year Con	Damage Description	ADT	Estimated Repair Cost	damage level	damage category	Main Span Mat	Main Span Des
1	002/35	WSDOT-NW	2/36	000000OA	47.8383	-121.6433	110.79	11.80	25.95	12.75	1.27	1963	Open (4" drop @ approach, filled w/ACP by region)	8935		1	1	4	3
2	090/10EB & 90/10E-S	WSDOT-NW	90/10 E-S	000000OC	47.5933	-122.3200	57.33	11.79	31.93	17.81	2.36	1991	Closed. Damaged Bearings at joint connecting both bridges.	4406		1	4	6	6
3	004/208	WSDOT-SW	004/208	0001442A	46.1917	-123.1350	111.07	0.00	0.00	0.00	0.00	1930	Spalls on columns	3994		1	2	2	1
4	004/209	WSDOT-SW	004/209	0001442B	46.1917	-123.1350	111.07	0.00	0.00	0.00	0.00	1930	Spalls on columns	3994		1	2	4	2
5	101/217 HOH River	WSDOT-OLYMPIC	101/217	0001457A	47.8083	-124.2483	135.62	0.00	0.00	0.00	0.00	1931	Open (Banged against abut.)	1770		1	2	4	9
6	101/418 Skokomish R.	WSDOT-OLYMPIC	101/418	0001604A	47.3117	-123.1750	38.54	10.93	28.18	12.39	2.79	1932	Fractured corbel at exp. Jt. Main pier ahead on stationing, right side of bridge.	4758		1	2	4	10
7	012/15 Aberdeen Viaduct	WSDOT-OLYMPIC	012/15	0001679A	46.9583	-123.7917	83.75	6.37	21.98	5.53	0.90	1994	Bent #3 SW column spall	20146		1	2	2	4
8	002/37	WSDOT-NW	2/37	0001706A	47.8333	-121.6417	110.50	8.91	20.04	7.76	0.72	1933	Open… EQ restrainers elongated ~2" at pin/hanger locations of span 2. (4 locations)	6726	$15,000	1	4	4	2
9	002/39	WSDOT-NW	2/39	0001706C	47.8167	-121.5967	111.77	11.55	25.00	13.05	1.37	1933	EQ restrainers @ P3 have 2-3" gap between plates.	6726		1	4	2	4

10	002/45 BN RR OC	WSDOT-NW	2/45	0002059A	47.8033	-121.5167	115.42	9.35	18.97	9.06	1.14	1936	Open. One broken longitudinal restrainer sheared off horizontal restrainer- sprung 23" horizontally.	5308		1	4	2	4
11	005/345E Nisqually	WSDOT-OLYMPIC	5/345E	0002069A	47.0717	-122.7033	9.04	14.91	60.68	32.62	12.93	1937	Open. Bent and broken cross frames, minor spalling to catcher blocks. Chipped paint around bearing shoes and pins. (see photos)	45830	$50,000	2	3	4	10
12	012/12N Wishkah R.	WSDOT-OLYMPIC	12/12N	0002311A	46.9767	-123.8083	84.46	6.72	24.08	6.23	0.98	1925	Paint pops around entrance portal sway brace rivets	15125		1	5	4	16
13	Hylebos Waterway Bridge	Tacoma	F04	0002376A	47.2778	-122.3930	28.24	8.93	27.24	15.25	3.02	1939	Damage to leafs, temporary support required		$5,000	1	5	4	16
14	016/110 Tacoma Narrows	WSDOT-OLYMPIC	16/110	0003418A	47.2617	-122.5400	18.15	8.10	28.68	10.65	2.94	1949	Cable impact to anchor gallery penetration and minor spalling at impact area.	75337	$50,000	2	3	4	13
15	303/4A Manette	WSDOT-OLYMPIC	303/4A	0003531A	47.5700	-122.6217	46.85	18.28	44.47	11.04	1.24	1930	Damage to gusset span 7, pier 7	7300	$50,000	2	3	4	10
16	433/1 Lewis and Clark	WSDOT-SW	433/1	0003760A	46.0983	-122.9683	118.35	0.00	0.00	0.00	0.00	1929	Open. Temporary wooden blocks rotated and cracked.	17871		1	3	4	10
17	099/540 Alaska Way Viaduct	WSDOT-NW	99/540NB	0003935A	47.6000	-122.3383	57.26	13.32	39.58	23.03	2.59	1952	099_540\99_540 EQ damage and repair.doc	35997	$400,000	3	2	4	2
18	005/308W	WSDOT-OLYMPIC	5/308W	0004544B	46.8967	-122.9600	33.67	12.26	26.02	9.52	3.35	1954	Spalling of pier	25289		1	2	2	4
19	005/321 Capital lake	WSDOT-OLYMPIC	5/321	0005090A	47.0233	-122.9017	19.84	14.78	40.47	18.65	6.52	1956	Broken E.Q. Restrainers. Repair transverse stops at north abutment.	45733	$100,000	2	4	2	6
20	005/322 Capitol Blvd	WSDOT-OLYMPIC	5/322	0005152A	47.0250	-122.8983	19.53	14.78	40.47	18.65	6.52	1956	Bracing broken, bent bearing stiffeners. Damaged end Cross-frames & bottom lateral bracing @ Tumwater end	14771	$100,000	2	3	4	11

21	109/6 Grass Creek	WSDOT-OLYMPIC	109/6	0005197A	47.0067	-123.9917	97.35	9.15	19.56	8.92	1.79	1956	Pier 5 pinched at expansion joint, spalled with exposed rebar	4318		1	2	2	1
22	509/5A Murray Morgan	WSDOT-OLYMPIC	509/5A	0005452A	47.2550	-122.4467	23.49	6.58	19.68	7.72	1.67	1911	Roadway open, but closed to Marine traffic. Counterweights dislodged.	12567	$150,000	3	5	4	15
23	101/132	WSDOT-OLYMPIC	101/132	0005534A	47.0333	-123.9183	91.40	7.52	18.59	6.41	1.24	1957	Repair Required. Open cracks at the pier 3 piles to pile cap interface. Piles 3A thru 3H. Soil movement at the NE corner of the br.	6000		1	2	2	1
24	512/1 I-5 OC	WSDOT-OLYMPIC	512/1	0005655A	47.1633	-122.4783	18.23	7.88	26.70	12.22	2.95	1958	Cracks in concrete at barrier retaining wall interface.	59642		1	2	2	1
25	099/538 Spokane St Viaduct	WSDOT-NW	99/538	0005758A	47.5700	-122.3383	54.41	20.06	60.22	47.43	4.39	1959	Bearing damage and grout failure @ pier 25 for all 8 bearings. Failure of earthquake restrainers	41733	$300,000	3	4	4	2
26	101/130	WSDOT-OLYMPIC	101/130	0005808A	46.9950	-123.8950	90.41	8.22	22.57	8.04	1.46	1958	Repair required. Rocker bearings at south abutment tipped excessively. Need to be reset.	7941		1	4	2	1
27	101/432W	WSDOT-OLYMPIC	101/432W	0006383A	47.0967	-123.0867	28.36	12.43	33.83	15.53	4.06	1960	Suggest to region to monitor approach roadway settlement and repair pavement.	8275		1	1	2	1
28	512/6 Park Ave bridge	WSDOT-OLYMPIC	512/6	0007024C	47.1600	-122.4367	21.35	10.03	27.66	14.83	2.85	1963	Crack on span	70880		1	2	2	1
29	005/599W	WSDOT-NW	5/599W	0007071B	47.7783	-122.3167	75.65	7.13	17.45	9.34	0.83	1963	Open, Pier 2 and 3 cracks in cold joints.	68033		1	2	6	2
30	005/599NBCD	WSDOT-NW	5/599NCD	0007071C	47.7783	-122.3167	75.65	7.13	17.45	9.34	0.83	1963	Open, Pier 2 and 3 cracks in cold joints.	21678		1	2	6	2

31	012/50S Satsop River	WSDOT-OLYMPIC	12/50S	0007612E	46.9983	-123.4967	61.08	12.54	35.27	16.66	4.39	1965	Open. Pier 5 piles 4,5,6 have full perimeter cracks 4' above groundline. Pier 4 pile 2 similar, with minor spalling.	8511		1	2	2	1
32	005/539.5 Holgate	WSDOT-NW	5/539.5	0007686B	47.5867	-122.3183	56.77	20.49	50.88	41.66	5.06	1966	Open (P2 column damage)	2690	$20,000	1	2	2	6
33	512/10S Golden Givens	WSDOT-OLYMPIC	512/10S	0007769A	47.1598	-122.4151	22.97	10.03	27.66	14.83	2.85	1966	Open. Cracks in center span closure pour and spalled diaphragm	26276		1	2	6	2
34	512/10N Golden Givens	WSDOT-OLYMPIC	512/10N	0007769B	47.1644	-122.4151	22.99	8.90	25.33	13.06	2.57	1966	Open. Cracks in center span closure pour and spalled diaphragm	26276		1	2	6	2
35	002/6S-W	WSDOT-NW	2/6S-W	0007923A	47.9767	-122.1500	100.79	7.58	18.62	11.61	1.73	1967	Soil liquefaction around columns of piers 2,3,&4. Sink holes up to 8' deep around columns.	500		1	1	2	2
36	162/6 Puyallup River	WSDOT-OLYMPIC	162/2	0008102C	47.2033	-122.2283	37.44	14.33	26.78	27.43	2.53	1967	Next Inspection- crack in first diagonal from NE corner, 3/16" open 7 feet long.	14009		1	2	6	2
37	005/345W Nisqually	WSDOT-OLYMPIC	5/345W	0008116A	47.0717	-122.7033	9.04	14.91	60.68	32.62	12.93	1967	Open. Bent and broken cross frames, minor spalling to catcher blocks.	45830	$50,000	2	3	4	10
38	204/2 S-W	WSDOT-NW	204/2 S-W	0008176B	47.9783	-122.1383	101.32	7.58	18.62	11.61	1.73	1967	East ramp, north restrainer had broken grout pad. Anchor bolts were bent.	9062		1	4	2	1
39	512/15S Waller bridge	WSDOT-OLYMPIC	512/15S	0008437A	47.1578	-122.3888	24.95	11.00	27.95	16.09	2.68	1969	8" vertical crack, 1/8" wide on girder G, outside face, diaphragm, pier 2	24522		1	2	6	2
40	512/15N Waller bridge	WSDOT-OLYMPIC	512/15N	0008437B	47.1522	-122.3888	24.94	11.00	27.95	16.09	2.68	1969	6" vertical crack on outside diaphragm @ P2 girder G	24522		1	2	6	2
41	518/14 N-W	WSDOT-NW	518/14N-W	0008902A	47.4367	-122.3650	41.26	16.78	46.11	21.08	1.78	1971	Column and joint spalls at abutment.	3430		1	2	6	6
42	104/104	WSDOT-NW	104/104	0009021A	47.8100	-122.3733	77.35	7.00	16.98	9.11	0.96	1971	1/8" cracking and minor spalling in backwalls.	10197	$3,000	1	2	6	2

43	432/10	WSDOT-OLYMPIC	432/10	0009100A	46.1067	-122.8967	116.69	0.00	0.00	0.00	0.00	1973	Rail minor damage	15971		1	2	4	10
44	005/133 E&W	WSDOT-SW	005/133	0009580A	46.2600	-122.8867	99.73	0.00	0.00	0.00	0.00	1975	Vertical cracking in P2 diaphragm	21459		1	2	6	2
45	005/221	WSDOT-SW	5/221	0012597A	46.6517	-122.9717	58.69	16.41	31.77	19.26	5.85	1954	Spalled Concrete	52208	$1,200,000	3	4	4	2
46	099/530W First Ave S (new bridge)	WSDOT-NW	99/530W	0014459A	47.5417	-122.3317	52.05	22.53	53.13	37.25	3.65	1996	Closed to marine, Open to vehicle (Centerlock damage)	16500	$1,000,000	3	5	4	16
47	099/530E First Ave. S (old bridge)	WSDOT-NW	99/530N-E	0014962A	47.5431	-122.3339	52.09	22.53	53.13	37.25	3.65	1998	Transition Span damaged anchor bolts.	47000	$200,000	3	4	2	6
48	Hartstene Island Bridge	Mason County	3E+08	07996900	47.2461	-122.9267	18.72	12.40	37.56	15.24	4.45	1969	Top foot of abutment damaged, bridge oriented east-west	1588		1	2	2	3
49	Silverbrook Bridge	Lewis County	2.1E+08	08112700	46.3733	-121.9067	106.15	0.00	0.00	0.00	0.00	1934	Leaching cracks in the exterior beams near mid-span opened up.	501	$540,000	1	2	2	4
50	McLane Cove Bridge	Mason County	9.61E+08	08159200	47.3163	-122.8670	21.27	13.73	39.09	15.37	4.51	1953	100 yards of approach gave way 30 ft from bridge. Width of approximately 12 ft.	766		1	1	2	1
51	Reservation Rd. Bridge	Thurston County	R-1	08222100	47.0406	-122.7067	12.44	15.28	57.70	31.40	12.17	1993	Minor spalling @ caps due to girder movement	4099	$1,500	1	2	6	2
52	Teitzel Bridge	Lewis County	2.1E+08	08234300	46.5036	-121.9253	93.81	7.76	13.62	5.80	1.36	1922	Settlement of 1/2" to 5/8". Approach damage only	819	$7,782	1	1	4	10
53	Tolt Hill Road Bridge	King County	1834A	08265100	47.7092	-121.9941	82.26	8.23	16.75	8.11	1.00	1922	Damage to concrete double tees near the bearings	3500	$15,000	1	2	4	10
54	Chambers Creek Bridge	University Place	29202A	08395200	47.1917	-122.5717	11.97	7.76	32.79	12.75	4.02	1946	No damage to actual bridge. Damage to approach on University Place side.	4752		1	1	2	1
55	South Park Bridge	King County	3179	08433700	47.5298	-122.3141	51.73	30.04	74.25	36.72	2.82	1931	Spalling, shear cracking to South and North approach. Lateral Shifting on Baxcule Towers	25000	$750,000	3	5	4	16

56	Hylebos Creek - East-West Rd	Tacoma	F23		08494200	47.2593	-122.3560	29.83	8.82	24.80	17.29	3.09	1967	Crack in conc. Pile cap (1st cap south of north abutment, westside)	23058	$5,000	1	2	2	1
57	4th Ave S., Jackson to Airport	SEATTLE	31		08505000	47.5993	-122.3278	57.59	11.79	31.93	17.81	2.36	1910	Spalls between building and sidewalk, also near Bent 30. Rails pulled apart.	22600	$30,000	1	2	2	1
58	2ND AVE SOUTH EXTENSION	SEATTLE	7		08505100	47.5994	-122.3303	57.51	11.79	31.93	17.81	2.36	1928	Spalls and cracks in the north west abutment	13000	$60,000	2	2	4	2
59	South Main St	SEATTLE	35		08505600	47.6001	-122.3277	57.67	11.79	31.93	17.81	2.36	1982	East abutment cracked and spalled	2070	$30,000	1	2	6	2
60	E. Marginal Way at @ S. Horton St.	SEATTLE	100		08508600	47.5757	-122.3381	54.96	20.06	60.22	47.43	4.39	1931	Settlement and cracking, sand boils and lateral spreading to the west.	13300	$250,000	3	1	2	1
61	E. 26th St. Bridge	Tacoma	E19		08512000	47.2318	-122.4303	23.50	6.79	20.53	9.19	1.97	1931	Cracks on first bent east of west abutment	9079	$5,000	1	2	2	4
62	E. 34th St. Bridge	Tacoma	E07		08512200	47.2306	-122.4311	23.40	6.79	20.53	9.19	1.97	1937	Spalled concrete on column No. 1	3400	$10,000	1	2	2	11
63	Admiral Way N & S	SEATTLE	17		08516700	47.5813	-122.3809	53.90	12.85	46.52	27.56	1.97	1927	Cracks and spalling of the concrete rail.	11800	$100,000	2	2	2	9
64	Ballard Bridge	SEATTLE	20		08517800	47.6599	-122.3749	61.90	10.33	22.53	17.49	2.23	1917	Cracks and spalling at expansion joints, outside edge beams.	52100	$60,000	2	2	2	3
65	Emerson St. Viaduct	SEATTLE	46		08519300	47.6536	-122.3749	61.26	17.86	51.11	28.16	9.76	1949	Seismic joint between 15th Ave W Interchange and Emerson St. Viaduct damaged.	21300	$100,000	2	4	4	2
66	4th Avenue Bridge	Olympia		1	08522600	47.0446	-122.9075	18.54	20.49	50.88	41.66	5.06	1920	Vertical and shear cracks in column carrying expansion joint	22400		1	2	2	11
67	Spokane St Viaduct	SEATTLE	90		08526200	47.5722	-122.3190	55.39	22.53	53.13	37.25	3.65	1941	Cracks & spalling at expansion joints	69500	$70,000	2	2	2	2

68	Fremont Bridge	SEATTLE	12	08528200	47.6477	-122.3484	61.55	22.53	53.13	37.25	3.65	1917	Cracks & spalls in main members. Crack in column cap at bent 21	33100	$60,000	2	2	2	0
69	East Duwamish Waterway, South Bridge	SEATTLE	68	08529800	47.5425	-122.3346	52.00	12.32	33.45	21.66	2.56	1975	Damaged transverse shear block, spalling of cap beams	53600	$50,000	2	2	6	4
70	West Seattle Highrise Bridge	SEATTLE	131	08530600	47.5717	-122.3441	54.35	11.79	31.93	17.81	2.36	1984	Spalling at transverse shear blocks, with rebar exposed. Non-structural cracks in column fins		$100,000	2	2	6	2
71	AIRPORT / ARGO	SEATTLE	6	08535800	47.5546	-122.3205	53.71	12.85	46.52	27.56	1.97	1928	Expansion joint damage, PC TT girder with shear cracks	13200	$60,000	2	2	4	3
72	Magnolia	SEATTLE	23	08540800	47.6338	-122.3747	59.29	12.85	46.52	27.56	1.97	1929	Lateral bracing has failed at 12 bents	14500	$3,500,000	3	2	2	9
73	Marion St Ped. Bridge	SEATTLE	40	08555200	47.6032	-122.3364	57.64	20.06	60.22	47.43	4.39	1976	Failed expansion joint seals	8000	$20,000	1	2	2	1
74	Harbor Ave Bridge B	SEATTLE	5B	08570100	47.5716	-122.3694	53.38	11.54	30.08	12.77	1.46	1927	Spall & crack of girder shear block		$20,000	1	2	2	0
75	Harbor Ave Bridge D	SEATTLE	5D	08570200	47.5716	-122.3694	53.38	10.33	22.53	17.49	2.23	1927	Crack and spall of East abutment and approach		$30,000	1	2	2	0
76	South Jackson St., 4th to 5th	SEATTLE	33	08578600	47.5994	-122.3270	57.63	9.40	25.47	14.87	1.78	1910	Crossbeam has recracked and new cracks have formed	13100	$100,000	2	2	2	2
77	Spokane St. Swing Bridge	SEATTLE	2	08594400	47.5717	-122.3440	54.35	20.06	60.22	47.43	4.39	1991	Docking Bearing/Shims failed, railing and expansion joint damage	8033	$2,100,000	3	5	6	17
78	Lakemont Boulevard Bridge	Bellevue	BELLEVU11	08621100	47.5550	-122.1221	63.27	11.79	31.93	17.81	2.36	1990	Cracks	120		1	2	2	11

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