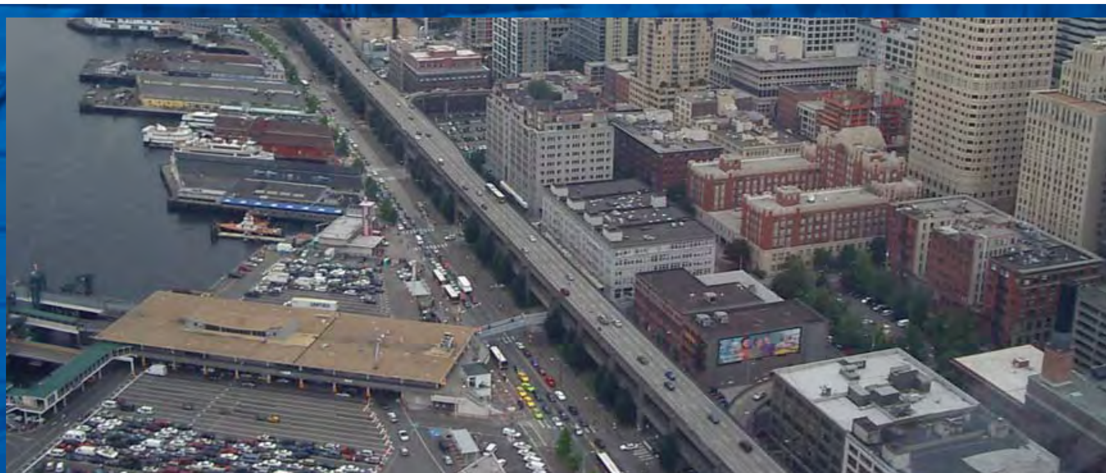
Alaskan Way Viaduct

Independent Project Management Team

Evaluation of Seismic Retrofit Options



September 25, 2008 | Final Report

kpff Consulting Engineers

Evaluation of Seismic Retrofit Options

September 25, 2008

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Executive Summary

SCOPE OF INVESTIGATION

In May 2008, the Tri-Agency Partnership contracted with KPFF Consulting Engineers (KPFF), as part of the Independent Project Management Team, to provide an independent review of seismic retrofit options for the double-deck portion of the existing Alaskan Way Viaduct (AWV) structure along the central waterfront. While many options are under consideration for addressing the aging Alaskan Way Viaduct, including replacement with a new viaduct or tunnel, or demolition without replacement, our study focused exclusively on evaluating seismic retrofit of the existing structure.

In performing this review of retrofit options, we examined existing retrofit evaluation and design documents covering the period from June 2001 to April 2008. These documents are summarized in Table A-1 of Appendix A. The documents in Table A-1 represent the opinions and findings of various advisory panels, consultants, and the Viaduct Preservation Group (VPG). Following evaluation of these documents, we formulated overall findings based on a collective review and comparison of all the documents. A summary of our significant findings based on the reports reviewed is presented in the next section.

The Tri-Agency Partnership has determined certain Guiding Principles that shall be applied to the evaluation of any proposed plan for retrofitting or replacing the Alaskan Way Viaduct:

1. The plan shall improve public safety.
2. The plan shall provide efficient movement of people and goods.
3. The plan shall maintain or improve downtown Seattle, regional, port, and state economic vitality.
4. The plan shall enhance Seattle's waterfront, downtown, and adjacent neighborhoods as a place for people.
5. The plan shall create solutions that are fiscally responsible.
6. The plan shall improve the health of the environment.

Because this evaluation report is primarily technical in nature, and focuses on seismic behavior, it addresses some, but not all, of the Guiding Principles listed above. However, in the discussion below, where applicable, the relevant Guiding Principles are cited. For example, Guiding Principle 5, fiscal responsibility, results in the Tri-Agency Partnership's commitment to providing a long-term rather than short-term solution. Thus, the Tri-Agency Partnership has resolved that a fiscally responsible solution shall have the same life expectancy as a new structure designed according to current American

Association of State Highway and Transportation Officials (AASHTO) and Washington State Department of Transportation (WSDOT) standards: 75 to 100 years.

SUMMARY OF FINDINGS

The existing Alaskan Way Viaduct (including foundations) is in an advanced state of deterioration, and is approaching the end of its functional life. Deterioration of the viaduct is an ongoing process, primarily brought about by long-term intrusion of chlorides (salts) into the concrete, which results in continuing corrosion of steel reinforcing bars (Document 1, pages 13 to 15). A second cause for concern is the compromised condition of some foundation piles following the Nisqually earthquake. In areas with liquefiable soils, the earthquake caused loss of adhesion between the piles and the surrounding soils. This loss of adhesion increased the load carried by the tips of the piles, which reduced the capacity of the piles to resist future settlement. This will lead to long-term settlement of those piles (Document 7, page 4). Indeed, long-term settlement was observed at bents 93 and 94 following the Nisqually earthquake. This settlement was arrested by a foundation retrofit program costing approximately $5 million for those two bents.

The programmed life-span of the viaduct structure was originally 50 years from the date of construction, which would set the replacement date at about 2002. In 1963 the programmed life-span was changed, apparently by decree, to 75 years from the date of construction, which would set the replacement date at about 2027 (Document 1, page 14). These programmed life-spans were established without foreknowledge of actual future damage caused by earthquakes and corrosion, or future advances in earthquake engineering that disclosed shortcomings of 1950s-era seismic design methods for bridges. More recent estimates of the safe remaining life of the viaduct structure range from practically zero (Document 7, pages 3 and 4) to approximately 19 years (Document 1, page 14). If the viaduct were retrofitted, including rebuilding the foundations to resist future settlement, deterioration of the original, underlying concrete structure would continue, due to the presence of chlorides in the concrete (Document 1, page 13). Thus, even with retrofit, the remaining life span of the underlying structure would remain in the range of zero to 19 years. This short life span does not meet the fiscally responsible, long-term solution criterion, Guiding Principle 5.

There exists a significant probability of soil liquefaction along much of the double-deck portion of the viaduct in the event of a significant earthquake. A recent study (Document 15, page 13) stated that widespread soil liquefaction is likely to occur during an earthquake, with about a 1-in-10 chance of occurrence in the next 10 years (an earthquake with an average return period of 108 years). In areas where liquefaction occurs, the soil pressures acting on the seawall will triple (Document 15, page 13), resulting in failure of the seawall. Collapse of the seawall will lead to significant lateral ground movement around the viaduct foundations. According to a geotechnical evaluation of foundation capacities (Document 4), liquefaction would lead to failure of approximately 50 percent of the foundation piles supporting the central portion of the viaduct (the segment from approximately Pike Street to Dearborn Street). Thus, soil liquefaction is a critically important factor in the seismic performance of the seawall and the viaduct foundations. Improvements to both the viaduct foundations and the seawall, to prevent liquefaction-induced failures, must be an integral part of any plan to retrofit or replace the viaduct. Improving the viaduct superstructure, without improving the viaduct foundations and the seawall, would not significantly improve public safety, and would violate Guiding Principle 1.

An earthquake that would cause partial or complete structural collapse of the existing double-deck portion of the viaduct has the same probability of occurrence as an earthquake that would cause soil liquefaction, seawall collapse, and foundation failure (discussed above): approximately a 1-in-10 chance over the next 10 years.

Thus, the seismic risks associated with catastrophic damage to the existing viaduct structure, foundation, and seawall are all approximately the same: a 1-in-10 chance in the next 10 years of extensive seawall failure, viaduct foundation failure, and partial or complete structural collapse of the double-deck portion of the viaduct. This level of risk far exceeds acceptable levels for public transportation structures. Current design standards for new bridge structures generally adopt an acceptable risk of a 1-in-100 chance in 10 years of severe damage, and the new bridge structure must be designed so that this level of damage will not initiate collapse. This is in sharp contrast to the 1-in-10 chance in 10 years expected collapse performance of the existing viaduct structure, foundations, and seawall in a much smaller, more frequent, seismic event.

If the viaduct were retrofitted, throughout most of the 7 to 8 years required to completely retrofit the superstructure those sections of the viaduct that were not yet retrofitted would remain vulnerable to a high risk of collapse (a 1-in-10 chance over a 10 year period). In contrast, replacing the viaduct could entail complete demolition of the viaduct at an early stage, thereby eliminating the high collapse risk associated with the existing structure. Complete demolition would shorten the construction schedule, compared to phased demolition and replacement. Therefore, because current seismic risks are high, and these risks would remain high during phased retrofit construction, there is a pressing need to demolish, rather than retrofit, the viaduct, in keeping with Guiding Principle 1, “Improve public safety.”

The costs of all retrofit schemes proposed to date are high relative to the cost of completely replacing the viaduct with a new elevated structure. According to WSDOT estimates, the damping retrofit scheme proposed by the Viaduct Preservation Group, and designed through schematic level by T.Y. Lin International (Document 11), would cost approximately 80 percent of the cost of replacing the viaduct (Documents 12 and 14). A retrofitted structure would still have inadequate lane widths, no emergency shoulders, and substandard acceleration and deceleration lanes. A new elevated structure would have a somewhat higher initial cost than a retrofit, but would address the existing functional problems, would provide a structure designed to current AASHTO and WSDOT seismic standards, and would have an expected life of 75 to 100 years. Therefore, retrofit of the existing viaduct structure would not fulfill Guiding Principle 2, "Provide efficient movement of people and goods," or Guiding Principle 5, "Create solutions that are fiscally responsible."

Advocates of seismic retrofit options for the viaduct have often stated that a seismic retrofit could be constructed with minimal disruption to the flow of traffic on the existing viaduct. In fact, this is not the case. Construction of any of the retrofit schemes proposed to date would result in significant and long-term disruptions to traffic both on and around the viaduct. This is because the deteriorated condition of the existing reinforcement and the poor steel reinforcement layout (reinforcement detailing) characteristic of 1950s designs make it necessary to replace or strengthen many of concrete columns, beams, and decks (Document 11). For example, the "knee" and "tee" joints between columns and cross beams are weak, due to deterioration and design practices in the 1950s that are significantly less than today's standards. This would necessitate complete replacement of many of these joints. Replacement of a "knee" or "tee" joint requires temporary support of the cross beams and roadway deck associated with that joint. Similarly, replacement of edge girders, roadway decks, and other major structural elements would require temporary shoring of the remaining structure. In addition, major foundation retrofits are required (Document 11). Temporary structure support and foundation retrofits could not be accomplished without traffic closures both on and around the viaduct. While the total duration of such a closures may be somewhat shorter than the total duration of closures for rebuilding the viaduct (depending on which rebuilding option is selected), for any retrofit option the disruption to traffic on the existing viaduct would be measured in years, not weeks or months.

Considering all of the factors described above, it is clear that retrofitting the viaduct does not meet the guiding principles established by the Tri-Agency Partnership:

- First, estimates of the remaining life of the underlying structure of the viaduct (parts of which would remain, even if retrofit was performed) are in the range of zero to 19 years. This short life span does not meet the fiscally responsible, long-term solution criterion, Guiding Principle 5.
- Second, seismic retrofit of the viaduct superstructure would be of little use without simultaneous retrofit of the viaduct foundations and the seawall. While all retrofit proposals have included reconstruction of the seawall as a necessary component, some retrofit proposals have not fully addressed the necessity of reconstructing the viaduct footings. Neglecting reconstruction of the viaduct footings is not in keeping with Guiding Principle 1, "Improve public safety," and it ignores the significant costs associated with this work, which is not in keeping with Guiding Principle 5, "Create solutions that are fiscally responsible."
- Third, because the risk of collapse of the existing structure is high – approximately a 1-in-10 chance over the next 10 years, the risk of collapse of portions of the viaduct would remain high during most of the retrofit construction period of 7 to 8 years. Thus, there is a safety advantage to

completely demolishing the viaduct in the near future, in anticipation of replacing it with a safer structure. This is in keeping with Guiding Principle 1, "Improve public safety."

- Fourth, the costs of all retrofit schemes proposed to date (provided these estimates include the cost of reconstruction of the viaduct footings) approach the cost of completely replacing the viaduct with a new elevated structure. Furthermore, a retrofitted structure would still have inadequate lane widths, no emergency shoulders, and substandard acceleration and deceleration lanes. A retrofit would not fulfill Guiding Principle 5, "Create solutions that are fiscally responsible," or Guiding Principle 2, "Provide efficient movement of people and goods."
- Fifth, retrofit schemes proposed to date would cause significant traffic disruption, with total closure times not appreciably shorter than closure times required for replacement (depending on which replacement plan was adopted). This is because the existing structure has experienced extensive deterioration, and contains many structural deficiencies when compared to current design standards. Many structural elements must be strengthened or replaced, requiring traffic closures over much of the retrofit construction period. Thus, retrofitting does not present a clear advantage over replacement with respect to Guiding Principle 2, "Provide efficient movement of people and goods."

1. Background Research

DOCUMENTS REVIEWED

The purpose of this investigation was to review and synthesize existing information on retrofit options for the Alaskan Way Viaduct. Therefore, in this study we did not conduct any new research. Instead, we reviewed the findings of prior structural evaluations, planning studies, and construction cost estimates that were conducted by other engineers and planners. A list of the documents that we reviewed appears in Table A-1 of Appendix A.

The documents we reviewed cover the period from June 2001 to April 2008. Collectively, these documents represent varying, and sometimes conflicting, opinions on the advisability of retrofitting the existing Alaskan Way Viaduct. We evaluated each document separately and on its own merits. Following these evaluations, we formulated overall findings based on a collective review and comparison of all the documents.

In the following sub-sections, we have briefly summarized each document and its significant findings. The document numbers refer to the numbers shown in the first column of Table A-1 of Appendix A.

Document 1: *Alaskan Way Viaduct, Report of the Structural Sufficiency Review Committee*, June 28, 2001

This study was conducted by a committee consisting of John H. Clark, PhD, PE, SE; Ben C. Gerwick, PE; David Goodyear, PE, SE; Paul Grant, PE; Robert Mast, PE, SE; and Professor John Stanton, PhD, PE. Following the February 28, 2001, Nisqually earthquake, this group was asked by the Washington State Department of Transportation Bridge and Structures Office to review the structural condition of the viaduct, and to make recommendations regarding three possible courses of action:

- Option 1: Carry out limited repairs to bridge bents 97 to 100, which were damaged in the Nisqually earthquake. This option was described as “Repair Only – Return to Pre-Nisqually Earthquake Condition.”
- Option 2: Replace the viaduct with a new viaduct as soon as possible. This option was described as “Immediate Replacement.”
- Option 3: Retrofit the viaduct by replacing or strengthening all structural elements (edge beams, transverse frames, footings, and piles), leaving only the original deck slab. This option was described as “Full Retrofit to Current Standards.”

In the Executive Summary of this report, the Structural Sufficiency Review Committee stated (on page 4):

“**As a result of our review, the Committee recommends that WSDOT proceed to replace the Viaduct, which is option 2 in Table 1** [of the committee’s report]. This recommendation is based on our conclusion that even though a comprehensive seismic retrofit [Option 3] might achieve a level of safety comparable to a new structure, the eventual deterioration of the current structure due to aging would exact a greater sum of financial resources for maintenance and be less reliable than a new structure built to current seismic design standards. The least cost alternative – Option 1 – does not begin to satisfy the seismic risk criteria for our study, and will leave the risk of collapse due to earthquake at a level more than twice the risk for a new Viaduct.”

It should be noted that a more recent investigation, in 2007 (Document 15), increased the risk of earthquake collapse of the existing viaduct (which received limited repairs following the Nisqually earthquake) to four times the risk for a new viaduct.

The Structural Sufficiency Review Committee summarized its recommendations (on page 24) as follows.

1. **The Alaskan Way Viaduct should be replaced in kind with a new structure as soon as possible.** This recommendation arises from evaluation of the risks and costs of each of the options considered.
2. The Committee does not recommend retrofitting the Viaduct as a long-term solution. The estimated costs of retrofit are similar to the estimated costs for replacement, and the Committee believes that replacement offers far greater value and reliability that comes with a completely new structure.
3. After repairs for deterioration and all damages incurred in the Nisqually earthquake, the Alaskan Way Viaduct may be operated at an elevated level of risk until replacement of the structure is completed within the recommended time frame [10 years, beginning in 2001]. Control of operations must still be subject to the normal limitations for inspecting, maintaining and load rating of similar structures.

Document 2: *Alaskan Way Viaduct, Phase 1 - Retrofit Option*, April 24, 2002, and cover letter from committee chair Theodore Bell, July 12, 2002.

This study was conducted by the Seattle Section of the American Society of Civil Engineers (ASCE) Viaduct Review Committee (VRC). Members of this committee included Adrian Arnold, David Baska, Theodore Bell, Jack Locke, Dan Mageau, Douglas Myhre, Loren Sand, Joe Scott, Anne Symonds, Jack Tuttle, and Ray Upsahl.

The cover letter from Bell states, “The report evaluates from a technical standpoint the feasibility of several options to retrofit the Alaskan Way Viaduct structure. Mr. Victor Gray and Neil Twelker proposed one of these options and the project team of the City and WSDOT developed the other options."

The retrofit option proposed by Gray and Twelker consisted of installing a base isolation system beneath the existing viaduct. Other retrofit options proposed by the City of Seattle and by WSDOT included elements such as strengthening or replacing structural elements, improving soil conditions, strengthening foundations, and strengthening or replacing the seawall.

Bell goes on to state "Our report concludes that the proposal from Gray and Twelker is not technically sound and the options by the project team are not economically justified. It is not to say that the project team should not continue to evaluate retrofit options, but the options suggested at this time should not be considered further."

The committee report recommended (pages 10 and 11), that:

> "WSDOT and the City of Seattle should proceed with evaluation of options to replace the Alaskan Way Viaduct. Retrofitting the 50 year old facility is not the technically preferred solution since it is doubtful that retrofitting is an effective approach to fully satisfying current design standards. However, retrofitting options should be carried forward for further analysis to allow for options that may be necessary because of funding constraints, implementation strategies, or other interests of WSDOT and the City. The retrofitting of some sections may be necessary as part of the overall staging of the project in order to maintain safety and traffic operations. The plan to retrofit the viaduct as proposed by Gray and Twelker is not considered to be a viable option in any scenario and should not be pursued further."

Document 3*: Rebuild/Retrofit Alternative Report*, August 2002.
This report summarizes a study by Parsons Brinckerhoff Quade & Douglas, Inc. (PBQD, now PB, Inc.), in which the relative merits of rebuilding or retrofitting various portions of the viaduct were considered. In this study, a relatively high level of seismic hazard was considered: an earthquake with a 2 percent probability of exceedence in a 50 year period. This represents an earthquake which, on average, occurs about every 2500 years, commonly referred to as "The 2500-year earthquake."

Subsequent review by WSDOT determined that it would also be useful to assess retrofit and rebuild options for the viaduct using a less demanding design earthquake. This less demanding earthquake was defined as an event with a 10 percent probability of exceedence in a 50 year period. This represents an earthquake which, on average, occurs about every 500 years, commonly referred to as "The 500-year earthquake." PBQD repeated the rebuild/retrofit alternative study, and reported all findings for the 2500-year and 500-year event evaluations in Documents 5 and 6 of Table A-1.

Thus, this report will not be discussed further here, as all relevant findings are discussed under Documents 5 and 6.

Document 4: ***Preliminary Deep Foundation Engineering Analyses, Existing Piles, Alaskan Way Viaduct Project*****, January 17, 2003.**

This memorandum summarizes the findings of a WSDOT study on the capacity of existing deep foundations (pile foundations) supporting bents 54 through 130 of the viaduct. That is, the study investigated the strength of pile foundations supporting the viaduct between approximately Pike Street and Dearborn Street, which is generally considered to be the "Central Waterfront" portion of the viaduct.

This investigation studied the effects of the soil liquefaction that would occur beneath the viaduct during a significant seismic event. Once soil liquefaction occurs, the liquefied soil provides virtually no lateral support to piles, and the vertical load carrying capacity of the piles is greatly reduced, unless the piles are embedded in non-liquefied supporting soil layers below.

Of the 78 bridge bent foundations studied, it was found that the piles supporting 39 of the bents (50 percent of the bents) would fail under vertical loads if soil liquefaction were to occur during an earthquake. Furthermore, for all 78 bridge bent foundations studied, it was found that the ability of all piles to resist lateral forces, due to horizontal earthquake loads, was questionable and requires further study.

Document 5: ***Rebuild/Retrofit 500 Executive Summary, 500-year Design Earthquake*****, April 2003.**

This is the executive summary for Document 6, discussed below.

Document 6***: Rebuild/Retrofit 500, 500-Year Design Earthquake*****, April 2003**

This was an expansion of the study described in Document 3, above. This study was essentially a repeat of the Document 3 study, but considering a lower seismic hazard, corresponding to a "500-year earthquake," hence the title of this study.

The two studies (Documents 3 and 6) evaluated the relative merits of rebuilding or retrofitting various portions of the viaduct. The findings of both studies are summarized on Page 2 of Document 6, and are reprinted below. Also reproduced below are Table 1 and Figure 2 from Document 6, which are essential to comparing the findings and relative estimated costs for the two levels of seismic hazard considered.

Findings

For this comparison, two locations on the existing viaduct and seawall were chosen as being representative of the typical configurations found on the structures. The only variable was the seismic design earthquake standard with either a 2500-year return period (Rebuild 2500 Plan) or a 500-year return period (Rebuild 500 Plan and Retrofit 500 Plan). The results of this analysis are summarized in Table 1, Figure 2 (Table 1-1 and Figure 1-1 of this report), and following:

- The Rebuild 500 Plan performance is far superior in a seismic event than the Retrofit 500 Plan.

- The Retrofit 500 Plan would receive significant damage; require hundreds of millions of dollars and a long time to repair in an event slightly larger than the Nisqually earthquake.
- The Rebuild 500 Plan has the potential to reduce the total project cost by 5 to 15 percent of the Rebuild 2500 Plan.
- The Rebuild 500 Plan has the potential to reduce the overall construction duration by one year compared to the Rebuild 2500 Plan in a fully funded scenario.
- A rebuild plan allows for a limited funding scenario, but total project cost and duration increase significantly.
- There is little difference in cost or construction impacts between a rebuilt seawall designed to either the 500-year or the 2500-year seismic design standard.
- Utility impact differences between any rebuild and retrofit plan are minor.

Conclusion

One conclusion that can be reached is that the Rebuild 500 plan is far superior to the Retrofit 500 Plan when seismic performance, aesthetics, cost, and risk are balanced. As a result, the facility as a whole does not lend itself to a retrofit approach. However, the exception is a retrofit of the single-level structures between the Battery Street Tunnel and Pike Street, which do perform well. It is also clear due to the variable site conditions along the corridor, in combination with the significance of the facility, that site specific seismic design criteria, while likely to be less than a 2500-year design criteria, should be used for all viaduct replacement plans during preliminary engineering.

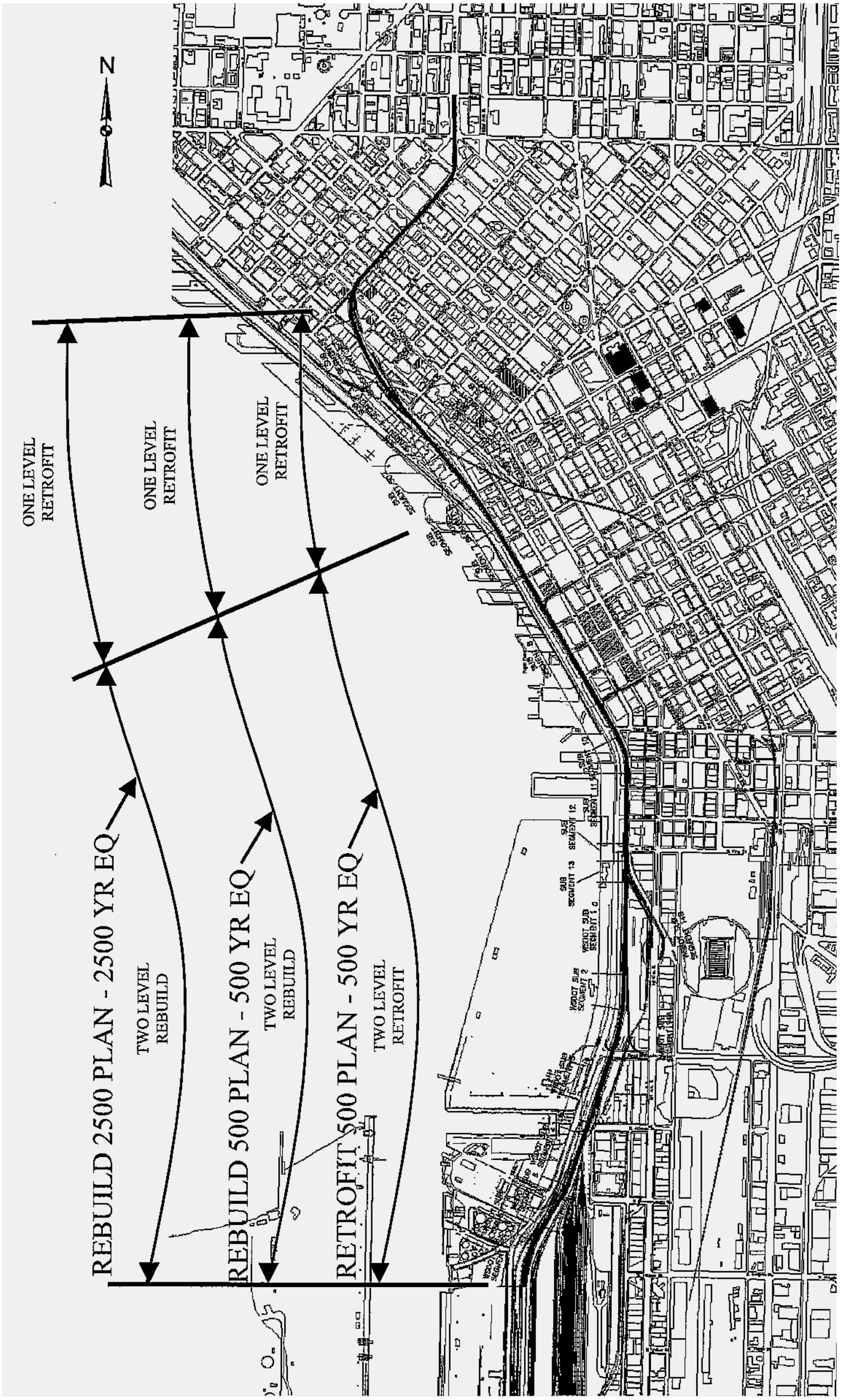

Figure 1-1: Figure 1 of Document 6 “Rebuild 2500 Plan, Rebuild 500 Plan, and Retrofit 500 Plan Location Map”

Table 1-1: Table 1 of Document 6, "Viaduct Comparison Summary, Rebuild 2500 versus Retrofit 500 versus Rebuild 500"

Description		Double-Level Viaduct			Single-Level Viaduct		Existing Viaduct
		Rebuild 2500 Nov. 2002 Snapshot 2500-Year Earthquake	Rebuild 500 500-Year Earthquake	Retrofit 500 500-Year Earthquake	Rebuild 2500 Nov. 2002 Snapshot 2500-Year Earthquake	Rebuild 500 and Retrofit 500[1] 500-Year Earthquake	
Performance	Overall Earthquake Resistance	Excellent	Very Good	Adequate	Excellent	Very Good	Very Poor
	2500-Year Earthquake	Good	Poor	Very Poor	Good	Poor	Very Poor
	500-Year Earthquake	Very Good	Good	Adequate	Very Good	Good	Very Poor
	Moderately Heavy Earthquakes (stronger than Nisqually)	Excellent	Very Good	Poor	Excellent	Very Good	Very Poor
	Facility Life Expectancy without Earthquake	75 Plus Years	75 Plus Years	75 Years Maximum	75 Plus Years	75 Plus Years	20 Years Maximum Expected
Construction Sequence Duration – Full funded		10 Year	9 Year	8 Year	10 Year	8 Year	N/A

Table 1-1: Table 1 of Document 6 "Viaduct Comparison Summary, Rebuild 2500 vs. Retrofit 500 vs. Rebuild 500"

[1] Rebuild 500 is identical to Retrofit 500 for single-level Viaduct

Document 7: Alaskan Way Viaduct Summary: Safety and Service Limitations of the Alaskan Way Viaduct, 2005

This summary was written by T.Y. Lin International, based on studies of the Alaskan Way Viaduct since it was damaged in the 2001 Nisqually earthquake. The summary cites the findings of the Structural Sufficiency Review Committee (Document 1), then goes on to provide further discussion of limitations of the original design and construction, the effects of age and deterioration, the effects of the Nisqually earthquake, and implications of all these factors for service life of the viaduct, as quoted below:

> Implications for Service of the Viaduct:
>
> The age and associated load rating of the Alaskan Way Viaduct is alone a basis for programming replacement. However, the acute and latent damages caused by the Nisqually earthquake change the need from normal programming to an emergency status. Structural details are replicated throughout the length of the Viaduct, and those that have failed differ from the remainder only in the variance of original construction tolerances – a razor thin margin. The accelerated deterioration of the Viaduct is approaching the point of a zipper effect: subsequent failures of similar details can be expected with future events. Future earthquakes notwithstanding, the accelerated deterioration since the Nisqually earthquake handicaps the serviceability of the Viaduct. From the risks of falling concrete spalls, to the structural deterioration due to bond loss and increased foundation settlement, the current condition of the viaduct is not reliable. As a result, regular closures are required for extensive structural inspections, just to assure that additional latent defects do not unduly compromise public safety. And when the risk of future earthquakes is considered, the Viaduct fails precipitously according to any modern engineering standards.

Document 8: Letter from Victor O. Gray to Washington State Secretary of Transportation Douglas B. MacDonald (Regarding Gray's cost estimate for retrofit), July 27, 2006.

This letter, with cost estimate enclosed, was prepared by the Viaduct Preservation Group (VPG). The letter discusses the viability of the VPG damping retrofit proposal. The VPG cost estimate for the damping retrofit is presented in terms of 21 “work items,” and does not include detailed cost breakdowns for each work item. The VPG estimate totals, as summarized in the cover letter, are as follows:

- $300 million for retrofit of the viaduct
- $200 million for rebuilding the seawall
- $300 million for contingencies

Document 9: ***Proposed Retrofit of Alaskan Way Viaduct Using Fluid Viscous Dampers: Preliminary Phase*****, July 5, 2006.**

This is a preliminary engineering study, conducted by Miyamoto International, Inc., of the feasibility of retrofitting the Alaskan Way Viaduct, primarily through the installation of new steel braced frames and fluid viscous (hydraulic) dampers.

Miyamoto constructed a computer model of a typical three-bay (four-bent) section of the viaduct (within the central portion of the viaduct, originally designed by the Seattle Engineering Department). Miyamoto then subjected the viaduct model to simulated earthquakes, first with the viaduct in its current configuration, and then with the proposed steel braced frames and hydraulic dampers installed. Miyamoto concluded that the proposed damping system significantly improved the seismic performance of the viaduct superstructure.

In this process Miyamoto analyzed only the superstructure and the flexibility of the foundations, (but did not provide details on how this flexibility was modeled). He did not analyze the foundations themselves or the ability of the foundations to carry the imposed loads and deformations. Miyamoto reported on the general configuration of the damping system, but did not provide the engineering properties of the actual dampers used in the computer analysis.

One significant feature of Miyamoto's study was that a single viaduct section (three bays, four bents) was analyzed as a stand-alone structure, separate from other adjacent viaduct sections. That is, the interaction between adjacent viaduct sections was not modeled. The gaps between adjacent viaduct sections are approximately two inches wide. Thus, significant ground shaking will cause adjacent sections to pound against one another. This pounding will have a major influence on the behavior of the viaduct during an earthquake. Miyamoto addressed this behavior by proposing to install hydraulic "Shock Transmission Units" between adjacent viaduct sections, to limit or prevent pounding between sections. While the presence of such shock transmission units may limit or eliminate pounding between units, the forces developed by the shock transmission units themselves will have a major influence on the dynamic response of the viaduct. The influence of the shock transmission units on the seismic performance of the viaduct was not analyzed in Miyamoto's study.

The "Summary and Conclusion" and "Future Investigations" sections of Miyamoto's report (page 22) are reproduced below.

> Summary and Conclusions
>
> Three dimensional time-history analysis of a typical SED [Seattle Engineering Department, now Seattle Department of Transportation] frame in the Alaskan Way Viaduct was conducted to assess the efficacy of retrofitting the frames with dampers. Only the response of the superstructure was evaluated. The design guidelines developed by PBQD 2005 and WSDOT were used in this study. The analysis showed that the dampers materially improved the seismic response of the frame.

The level of deck displacement was reduced such that the retrofitted frame would meet both of the requirements (functionality at EE [Expected Earthquake] level and collapse prevention at RE [Rare Earthquake] event) proposed for retrofit/replacement. Limited evaluation was also conducted to ascertain whether brittle failure would be expected and it was found not to be the case.

Based on the above findings, a retrofit measure that meets the Department's requirement consist of:

- Add Fluid Viscous [hydraulic] Dampers to interior bays of viaduct frames.
- Add shock-transmission units between the frames in longitudinal direction.
- Increase shear capacity, confinement, and reinforcement splice length of existing columns by wrapping the columns in ductile fiber wraps.
- Increase the shear capacity of joints by either added cap concrete bolsters and drill-and bond reinforcement or by prestressing (Priestley 1996) (Optional).

Future Investigations

The analysis reported herein, was limited in scope. The objective of the investigation was to assess whether FVDs [Fluid Viscous Dampers] can be used to limit the superstructure displacements to meet the design criteria's performance objectives. Geotechnical evaluation as related to the foundations and condition of underlying soil was beyond the scope of the work presented here. The evaluation was limited to structural assessment. No attempt was made to evaluate the remaining service life, local traffic and population forecast and adequacy of the number of lanes for the future development plans. No analysis of maintenance costs was performed. Benefit-to-cost analysis to determine the merits of replacement vs. retrofit was not conducted.

- The results presented here are conceptual and preliminary. It is suggested that the following steps be considered prior to implementation:
- Include the geotechnical data for the frame foundation. Assess substructure condition and investigate soil improvements.
- Investigate the response of a typical WSDOT frame. [A frame designed by the Seattle Engineering Department was investigated in Miyamoto's study]
- Perform material testing to determine the in-situ concrete and reinforcement properties.
- Conduct independent nonlinear static analysis to determine the response of a typical two-dimensional bay. Include flexural, shear, foundation, and joint nonlinear limit states.
- Refined nonlinear behavior: Develop three two-component site specific acceleration histories to be used for analysis, incorporate soil-structure interaction.

- Verification studies: Conduct comprehensive nonlinear time history analysis incorporating material and damper nonlinearity.
- Proof of concept testing: Construct a scaled model test frame and seismically conduct tests of existing and retrofitted frames a EE [Expected Earthquake] and RE [Rare Earthquake] levels.

Document 10: Letter from Ronald J. Paananen, WSDOT Project Director, Alaskan Way Viaduct and Seawall Replacement Project to Victor O. Gray, July 27, 2006

This letter is a response by WSDOT, on behalf of Governor Gregoire's office, to a July 9, 2007, letter from Victor O. Gray. The letter describes how the Alaskan Way Viaduct and Seawall Replacement Project has responded to prior requests for information from Victor O. Gray. The letter includes Attachment A, which describes "36 letters of correspondence or meetings the project team has documented with you and the Viaduct Preservation Group since 2001." The letter contains responses to specific statements and requests contained in Gray's July 27, 2006, letter.

Document 11: *Alaskan Way Viaduct, Evaluation of Gray's Retrofit Proposal*, July 31, 2006.

This is an engineering study and schematic design for a damping retrofit of the viaduct, based on the concepts presented by the Viaduct Preservation Group (VPG). Although the earlier study of the damping retrofit proposal, conducted by Miyamoto International, Inc., (Document 9) provided a conceptual framework for a damping retrofit, the Miyamoto study was not carried to a stage of design that would allow estimation of the total scope of work and project costs. Thus, WSDOT commissioned T.Y. Lin International to conduct further engineering analyses and preliminary design, up through the schematic design level.

The proposed VPG damping retrofit scheme was analyzed and designed for two levels of seismic hazard: a 500-year event (approximately a 10 percent chance of exceedence in 50 years), and a 2500-year event (approximately a 2 percent chance of exceedence in 50 years). The Executive Summary of this study is reproduced below.

> Executive Summary
>
> Victor Gray et al. have proposed retrofitting the Alaskan Way Viaduct with a shoring system comprised of auxiliary structural steel frames and dampers. This report to the Washington State Department of Transportation (WSDOT) summarizes the results of an independent evaluation of the effectiveness of Gray's proposal. Gray's proposal did not include the dimensions of the structural steel frames, or the sizes of their component members. In order to conduct this review, the sizes of members were determined by successive trials to be reasonably effective in reducing the demands on the existing structure, without being extremely large. Additional amended proposals submitted by Gray are reviewed in Appendices to this report.

The evaluation focuses on a design earthquake with a return period of 500 years, and a maximum considered earthquake with a return period of 2500 years. Victor Gray has stated that his proposal is designed to deal with the 500 year event, which is considered the minimum seismic standard for design. To put these values in perspective, the Nisqually earthquake of February 28, 2001 has been estimated to correspond to a return period of about 150 years, so it was less intense than the design earthquake considered in this report. A return period of 500 years is the minimum hazard used by the WSDOT (and AASHTO) for the seismic retrofit of ordinary structures. A return period of the order of 2500 years is commonly used for the seismic retrofit of critical structures, and is the design standard for new lifeline structures, including any replacement for the current Viaduct.

The design standard in the rare 2500 year event is to prevent collapse and loss of life. This event corresponds to a 2 percent chance of being exceeded over a 50 year life of the structure. For the more modest 500 year design event, the standard is to limit the effects to a condition of repairable damage. Repairable damage will include major cracking and some spalling, which may require the Viaduct to be out of service for repairs, but closures should be brief and the structure should not approach collapse. The 500 year event corresponds to a 10 percent chance of being exceeded over a 50 year life of the structure. The classification of severe damage noted below is reserved for foundations, and represents a structural failure condition, but one which should not result in immediate collapse since the failure is in the foundation unit. The standard for repairable damage does not extend to the foundation structures hidden below grade. Those elements are expected to survive the Design Earthquake without structural damage that would necessitate repairs.

With the auxiliary frames and dampers from the Gray proposal in place, the estimated damage to the structure in the two major earthquake events is summarized in the following table. (See Section 5 (of the T.Y. Lin report] for other results).

Table 1-2: Earthquake Event

Element	Design (500 year)	Rare (2500 year)
Columns	Repairable	Failure
Floor Beams	Repairable	Significant
Joints	Repairable	Significant
Piles	Significant	Severe
Footings	Severe	Severe

The summary indicates that the foundations of the Viaduct would remain particularly vulnerable to earthquake damage even after the Gray retrofit for the lower minimum design event. In the case of the rare event, the Viaduct may still collapse without further retrofit. In the minimum design event piles would fail in cyclic tension and compression, and footings would fail in shear. While ground improvement could lessen the risk of an abrupt collapse of the structure, the foundation failures would either render the Viaduct unusable for an extended period of time, or require total replacement.

The practical conclusion is that major additional structural retrofit would be required beyond what is included in the Gray proposal in order to meet current minimum design standards for seismic safety.

Document 12: Cost Report: AWV - TY Lin Retro, November 11, 2006.
This is a detailed construction cost estimate for the damping retrofit scheme proposed by the Viaduct Preservation Group (VPG). This estimate is based on the results of the analysis and schematic design of the VPG damping retrofit that was conducted by T.Y. Lin International (Document 11). The estimate is carried for one double-deck viaduct segment, consisting of three deck spans and four column bents. These cost figures were then used, (along with cost estimates for retrofitting other portions of the viaduct) in preparing overall cost estimates for the entire viaduct project (Document 14).

Document 13: Report of the ASCE Viaduct Review Committee, December 4, 2006.
The Washington State Department of Transportation (WSDOT) asked the Seattle Section of the American Society of Civil Engineers (ASCE) to provide a technical review of the damping retrofit scheme proposed by the Viaduct Preservation Group (VPG). The Review Committee examined key aspects of the VPG proposal, including seismic design criteria, structural performance, soil liquefaction and ground improvement, foundation performance, interaction with the seawall, traffic and operations, and the costs of retrofitting or rebuilding the viaduct. The findings of the ASCE Viaduct Review Committee are reproduced below.

Conclusion

With all of the above factors in mind our committee concludes that the relatively narrow difference in costs between the choice of retrofit or rebuild weighs heavily in favor of rebuilding. The cost differential between the two choices is expected to narrow when considering the higher life cycle maintenance costs, short life span and substandard operations geometry of a retrofitted structure. As such, we do not view the retrofit option as presented by the Viaduct Preservation Group as a viable option.

Document 14: Summary of Cost estimate revisions by Victor O. Gray for Gray's retrofit concept, December 20, 2006.

This is a summary of WSDOT cost estimates for two Alaskan Way Viaduct options:

- Complete replacement of the viaduct with a new, elevated structure, including wider lanes, roadway shoulders, improved acceleration and deceleration lanes, and seismic design according to current AASHTO and WSDOT standards.
- Retrofit of the viaduct according to the Viaduct Preservation Group (VPG) damping proposal. The estimate is based on the analysis and schematic design by TY Lin International (Document 11).

In addition, Victor O. Gray has commented on the WSDOT estimate of the costs of the VPG proposal, and provided his own, line by line, revisions to the WSDOT estimate. Gray does not provide detailed cost breakdowns for the proposed revision, but he does provide statements of general rationale for the revisions.

Document 15: *Seismic Vulnerability Analysis Report*, November 2007.

This study, conducted by PB, Inc., and Jacobs Engineering, is a reassessment of the seismic vulnerability of the viaduct, considering new information on earthquake hazards in the Seattle area.

The most important conclusion of this study is that the new earthquake hazards information doubled the probability of partial or complete collapse of the viaduct during the next ten years. Whereas previous estimates of seismic vulnerability placed the chance of collapse over the next ten years at 1 in 20. the new study increase this probability to 1 in 10. That is, during the next ten years there is a one-in-ten chance that an earthquake will occur that will cause partial or complete collapse of the viaduct.

The Executive Summary of this report is reproduced below.

> Executive Summary
>
> The risk of an earthquake causing the Alaskan Way Viaduct to fall down is significantly higher than was previously thought. Until now, it was estimated that it would take seismic ground motions with a 210-year return period to initiate collapse of the Viaduct. In practical terms, this translates to an approximate 1-in-20 chance in the next ten years of an earthquake sufficient to cause portions of the Viaduct to collapse. We found that an earthquake capable of initiating collapse of the Viaduct has a much shorter expected return period of 108 years. This translates to approximately a 1-in-10 chance in the next ten years of an earthquake that would cause portions of the Viaduct to collapse, or roughly double the previously identified risk. This change in risk is based on new geotechnical information and a better understanding of local and regional seismic behavior.
>
> This review was prompted by new data on the frequency and distribution of earthquakes in the region. To better understand how the Viaduct would react during an expected seismic event, we

used advanced structural analysis techniques to reexamine the interaction of local soil conditions and the Viaduct structure that could cause its collapse.

The evaluation of the Viaduct's structural capacity largely verified previous studies. Therefore, the higher collapse potential for the Alaskan Way Viaduct is primarily based on the expectation of increased seismic demands on the structure.

Document 16: "The Viaduct: A Stakeholders Marathon" letter to Stakeholders Advisory Committee, with attachments, April 24, 2008.

This is a letter, with attachments, from Victor O. Gray, representing the Viaduct Preservation Group (VPG). The letter is addressed to the Stakeholders Advisory Committee (SAC). The letter urges the SAC to re-consider the retrofit option proposed by the VPG, which is the damping retrofit described and studied in Documents 8 to 14. The letter describes a number of disagreements that the VPG has regarding the evaluation of the VPG proposal by the three transportation agencies and the SAC. A partial list of these disagreements includes the evaluation of costs for the VPG retrofit proposal, the duration of construction and the extent of traffic disruption caused by the various viaduct replacement options vs. the VPG retrofit proposal; and the remaining service life of the viaduct if the VPG retrofit proposal were carried out

Documents attached to the letter include two artist's renderings of the completed VPG retrofit proposal, and a position paper titled "The Case for Retrofitting the Viaduct," dated April 24, 2008. This position paper covers many of the same concerns expressed in Victor O. Gray's cover letter, and states additional figures on the estimated duration of various viaduct replacement options and estimated costs.

2. Discussion

STRUCTURAL DEFICIENCIES OF THE VIADUCT AND SEAWALL

There are several common themes that emerge from many of the studies described in Documents 1 to 16.

- The advanced state of deterioration of the viaduct, including the foundations, leads to the conclusion that the viaduct is approaching the end of its functional life. Estimates of the safe remaining life of the viaduct structure under gravity loads only (*not considering* the possibility of collapse due to earthquake loads) range from practically none (Document 7, pages 3 and 4) to approximately 19 years (Document 1, page 14). When originally constructed, the planned replacement date of the viaduct was 2002. In 1963, this replacement date was extended, apparently by decree, to 2027 (document 1, page 14).
- The viaduct continues to deteriorate due to long-term intrusion of chlorides (salts) into the concrete. The presence of chlorides in the concrete, due partly to long-term exposure to a marine environment, leads to corrosion of the embedded steel reinforcing bars. Concrete samples taken from the deck indicate chloride contents greater than two pounds per cubic yard, which exceeds the threshold (1.4 pounds per cubic yard) required to cause reinforcing bar corrosion (Document 1, page 14). In addition, hundreds of locations on the viaduct have been observed where concrete has spalled (flaked away) due to corroding reinforcing. Cracking of concrete structural members under gravity loads and lateral loads (such as earthquakes) leads to water intrusion, which causes reinforcing bar corrosion. This corrosion causes concrete to spall, due to the expansion of rust around the reinforcing bar.
- A second cause for concern is the compromised condition of some foundation piles following the Nisqually earthquake. In areas with liquefiable soils, the earthquake caused loss of adhesion between the piles and the surrounding soils. This loss of adhesion increased the load carried by the tips of the piles. Because the pile tips have a limited capacity to support load, the net result of loss of adhesion between the piles and the surrounding soils is a reduction in the overall ability of the piles to resist future settlement. This will lead to long-term settlement of those piles (Document 7, page 4).
- There exists a significant probability of soil liquefaction over much of the double-deck portion of the viaduct in the event of a significant earthquake. A recent study (Document 15, page 13) stated that widespread soil liquefaction is likely to occur during an earthquake with a 1-in-10 chance of occurrence in the next 10 years. In areas where liquefaction occurs, the soil pressures acting on the seawall will triple (Document 15, page 13), resulting in failure of the seawall. Collapse of the seawall will lead to significant lateral ground movement around the viaduct foundations. According to a geotechnical evaluation of foundation capacities (Document 4), liquefaction would lead to failure of approximately 50 percent of the foundation piles

supporting the central portion of the viaduct (the segment from approximately Pike Street to Dearborn Street). Thus, soil liquefaction is a critically important factor in the seismic performance of the seawall and the viaduct foundations. Improvements to viaduct foundations and the seawall must be an integral part of any plan to retrofit or replace the viaduct.

- Recent geotechnical and structural studies by Parsons Brinckerhoff, Inc. (in the process of publication) show that an earthquake that would cause partial or complete structural collapse of the existing double-deck portion of the viaduct has the same probability of occurrence as the earthquake that would cause soil liquefaction, seawall collapse, and foundation failure (discussed above): approximately a 1-in-10 chance over the next 10 years

COST AND FUNCTIONAL CONSIDERATIONS

Studies of the scope and costs of seismic retrofit, and the functional limitations that would remain after completion of a seismic retrofit, conclude that a seismic retrofit would not be a responsible use of transportation funds.

- The costs of all retrofit schemes proposed to date are high relative to the cost of completely replacing the viaduct with a new elevated structure. According to WSDOT estimates, the damping retrofit scheme proposed by the Viaduct Preservation Group, and designed through a schematic level by T.Y. Lin, International, would cost approximately 80 percent of the cost of replacing the viaduct (Documents 12 and 14). A retrofitted structure would still have inadequate lane widths, no emergency shoulders, and substandard acceleration and deceleration lanes. A new elevated structure would have a somewhat higher initial cost than a retrofitted structure, but would address the existing functional problems, would provide a structure designed to current AASHTO and WSDOT seismic standards, with an expected life of 75 to 100 years.
- Construction of any of the retrofit schemes proposed to date would result in significant and long-term disruptions to traffic both on and around the viaduct. This is because the deteriorated condition of the existing reinforcement and the poor steel reinforcement layout (reinforcement detailing) characteristic of 1950s designs make it necessary to replace or strengthen the majority of concrete columns, beams, and decks (Document 11). For example, the “knee” and “tee” joints between columns and cross beams are weak, due to deterioration and design practices in the 1950s that are significantly less than today’s standards. This would necessitate complete replacement of many of these joints. Replacement of a “knee” or “tee” joint requires temporary support of the cross beams and roadway deck associated with that joint. Similarly, replacement of edge girders, roadway decks, and other major structural elements would require temporary shoring of the remaining structure. In addition, major foundation retrofits are required (Document 11). Temporary structure support and foundation retrofits could not be accomplished without blocking traffic both on and around the viaduct for a length of time totaling years. While the total duration of such a closures may be somewhat shorter than the total duration of closures for rebuilding the viaduct (depending on which rebuilding option is selected), for any retrofit option, the disruption to traffic on the existing viaduct would be measured in years, not weeks or months.

Appendix A

Documents Reviewed

Table A-1: Documents Reviewed

No.	Date	Title	Author(s)	Pages	Notes
1	28-Jun-01	Alaskan Way Viaduct, Report of the Structural Sufficiency Review Committee	Clark, Gerwick, Goodyear, Grant, Mast, Stanton	37	
2	24-Apr-02	Alaskan Way Viaduct, Phase 1 - Retrofit Option, April 24, 2002; and cover letter from committee chair Theodore Bell, July 12, 2002	ASCE Expert Team: Arnold, Baska, Bell, Locke, Mageau, Myhre, Sand, Scott, Symonds, Tuttle, Upsahl	11	
3	Aug-02	Rebuild/Retrofit Alternative Report	Parsons Brinckerhoff Quade and Douglas, Inc.	47	Superseded by "Rebuild/Retrofit 500 report" April 2003
4	17-Jan-03	Preliminary Deep Foundation Engineering Analyses, Existing Piles, Alaskan Way Viaduct Project	Shannon & Wilson	12	Memorandum from S&W to PBQD and Jacobs Civil
5	Apr-03	Rebuild/Retrofit 500 Executive Summary, 500-year Design Earthquake	Parsons Brinckerhoff Quade and Douglas, Inc.	8	
6	Apr-03	Rebuild/Retrofit 500, 500-Year Design Earthquake	Parsons Brinckerhoff Quade and Douglas, Inc.	76	
7	2005	Alaskan Way Viaduct Summary: Safety and Service Limitations of the Alaskan Way Viaduct	T.Y. Lin International	5	
8	6-Jun-06	Letter from Victor O. Gray to WA State Secretary of Transportation Douglas B. MacDonald (Re: Gray's cost estimate for retrofit)	Victor O. Gray	8	
9	5-Jul-06	Proposed Retrofit of Alaskan Way Viaduct Using Fluid Viscous Dampers: Preliminary Phase	Miyamoto International, Inc.	23	
10	27-Jul-06	Letter from Ronald J. Paananen, WSDOT Project Director, Alaskan Way Viaduct and Seawall Replacement Project to Victor O. Gray	Ronald J. Paananen	8	

11	31-Jul-06	Alaskan Way Viaduct, Evaluation of Gray's Retrofit Proposal (with November 2006 addendum, Additional Retrofit for Gray's Modified Proposal)	T.Y. Lin International	168	Technical evaluation of Gray's original proposal
12	11-Nov-06	Cost Report: AWV - TY Lin Retro	Ken Fiorentino, Jacobs Civil	16	Detailed cost estimate for TY Lin/Gray retrofit
13	4-Dec-06	Report of the ASCE Viaduct Review Committee	ASCE Viaduct Review Committee	24	Review of Gray's revised proposal
14	20-Dec-06	Summary of Cost estimate revisions by Victor O. Gray for Gray's retrofit concept	PB, Inc.	6	Compares WSDOT ERP Review, E-C1, 9/06, WSDOT estimate for Gray's proposal, and Gray's comments on estimates
15	Nov-07	Seismic Vulnerability Analysis Report	PB, Inc.	82	
16	24-Apr-08	"The Viaduct: A Stakeholders Marathon" letter to Stakeholders Advisory Committee, with attachments	Victor O. Gray	8	