Report of the ASCE Viaduct Review Committee
December 4, 2006

Introduction

The ASCE Viaduct Review Committee was given the task of providing a technical review of a retrofit proposal submitted by the Viaduct Preservation Group (VPG) to the WSDOT for the Alaskan Way Viaduct. The merits of the proposal have been evaluated by a multi-disciplined team to assess the adequacy and completeness of the proposal
Our Committee was impressed with the efforts by the VPG to provide an immediate fix to the Alaskan Way Viaduct. Their concepts were innovative and, most importantly, focused on a means of conserving public funds.

The Alaskan Way Viaduct is more than 50 years old. It was built in an era when earthquake engineering principles were poorly understood, and when design criteria were largely absent from codes. It should, therefore, be expected that the existing structure contains many details that make it unsuited to resist present day design earthquakes loadings. Detailed studies by various agencies (WSDOT, University of Washington, the special Structural Sufficiency Review Committee, etc.) have demonstrated that this is indeed the case. Deficiencies exist in the structure itself, with respect to both seismic behavior and response to gravity loads, and in the foundations and the supporting soil mass. Furthermore, time has taken its toll on the structure, which now contains cracks, fractured reinforcement, exposed reinforcement, and significant wear and tear from a half century of service.

The findings of the Review committee are summarized in the following Sections of this report.

VPG's proposal

The VPG proposes to retrofit the structure using braces, dampers and grade beams. Such a scheme is indeed likely to improve the seismic performance of the super-structure of the viaduct itself, taken in isolation. However, that alone is an inadequate basis for endorsing the proposal. It must be shown that the proposal addresses all elements of the viaduct sufficiently to merit further, more detailed, study by the WSDOT. Because the WSDOT has already considered the possibility of retrofitting the structure, and because there are significant costs and delays inherent in re-considering that option, the burden of proof that the proposed retrofit is valid must lie with the VPG. Were that not the case, any group could put forward a proposal and demand that the WSDOT take the time and resources to review it. In that way, the project could be held up essentially forever. The state cannot afford to design bridges by referendum.

Evaluation of the VPG's concept was made difficult by the fact that no single document exists that defines exactly what the proposal is and that contains the necessary detailed calculations to back it up. For example, there have been misunderstandings over the configuration of the bracing, whether grade beams form part of the scheme (they appear to be missing from the dynamic analysis conducted by Miyamoto), etc. Had the information been organized and presented in a single report, rather than in a series of partial calculations and submissions, it would have been easier to evaluate. As a second example, the last information from the VPG to the Committee contained a shear friction calculation on a single sheet of paper, with no heading or means of tracing its source. (No title, author, date, reference to earlier calculations, etc.) Presumably, these calculations were intended to demonstrate the adequacy of the shear strength of the cross beams, but it would have been more helpful to have them properly integrated into a comprehensive report. In addition, it appears that the VPG has assumed that ground improvement will render the existing foundation system adequate to resisting loadings imposed by design level seismic events.

Seismic Design Criteria

- WSDOT's selection of the MCEER/ATC 49 Guidelines for seismic design of a replacement structure is appropriate. However, the 2500 year earthquake should not be applied to a retrofitted structure because the probability of its occurrence during the structure's short remaining life estimated as 25 years is remote. A performance objective of life safety for ground motions with a 10 percent probability of exceedance in 50 years (500 year return period) is more appropriate for VPG's retrofit proposal.
- Design-level ground motions (10% in 50 yrs) are much stronger than those produced by previous earthquakes. Therefore, the fact that the viaduct did not collapse during the 1965 or 2001 earthquakes does not guarantee good performance in the design earthquake.

Structural

- The proposed bracing will improve the seismic load-carrying capacity of the parts of the viaduct superstructure on which it is installed.
- However, the seismic forces on the foundations will be increased by the presence of the bracing, even if the seismic input remains the same, i.e. if any soil changes, such as those due to jet grouting, are ignored.
- The present soil conditions are poor. If soil improvement is applied selectively, the ground motion is likely to differ significantly at improved and non-improved locations. Different ground motions at adjacent bents are likely to cause further distress to the structure.
- Details of the bracing system are not clearly stated (e.g. forces, member sizes, damper characteristics, connection details, etc.)
- Many members (cross-beams, longitudinal girders) will remain deficient under gravity loading if not retrofitted.
- Some seismic column shears will still be high. The proposal implies that these can be addressed by jacketing. Placing an effective jacket at the split columns will be extremely difficult. Note that, if the top deck of the Viaduct fails, life safety on the lower deck will be seriously compromised.
- The column rebar splices at ground level are inadequate. As with column shear, while these can theoretically be improved by jacketing, the application of an effective jacket at the split columns is very difficult.

- Anchorage of the cross-beam bottom steel into the columns is inadequate.
- The beam-column joints need to be confined. Those on the lower deck are hard to wrap because of the multiplicity of beams and column projecting from the joint.
- The basic modeling of the structure is simplistic, especially at the soil structure interface. Possible modes of failure, such as shear of the piles just below the pile cap, are not represented within the model.
- The proposed traffic deck overlay will increase the load but will not increase the strength. It thus represents a step backwards in strengthening the structure.

Some of the VPG's arguments with respect to the seismic response of the superstructure are open to considerable question. For example:

- The recently submitted shear friction calculations for the crossbeams assume that the standard ACI friction coefficient of 1.0 is applicable. The ACI value is based on a tight crack and is inappropriate when end cracks in beams tend to "walk" open. This occurs as seismic loading is cycled; thereby reducing the aggregate interlock and the ability to carry shear across the crack. This behavior is particularly prevalent when the top and bottom reinforcement are different because, after a negative moment cycle, the crack is open at the top. Subsequent positive bending (bottom bars in tension) then opens the crack at the bottom but does not close the one at the top because the compression resistance of the top bars is larger than the tension strength of the bottom bars. This situation in the viaduct is even more exacerbated by the fact that bottom bars are inadequately anchored.

Soil Liquefaction and Ground Improvement

The impression of VPG that their concepts relative to the foundation system not being a critical factor appears to be based on a reliance that the WSDOT-proposed ground improvement work would be effective to the degree that liquefaction, lateral flow or other ground movements during a design level seismic event would not be damaging to the retrofitted structure. This is an overly optimistic view since there will be major difficulties in accomplishing the ground improvement at best and it is almost certain not the be as highly effective in the upper ten feet or so where lateral restraint of the pile caps will be important . Some key considerations include:

- The consistency of ground improvement results under and around an existing structure is less reliable than for a replacement structure where site access is not impeded.
- Despite ground improvement, some vertical and lateral displacement of the foundation soils should be expected and the retrofitted structure may not be capable of accommodating these displacements without damage.
- Ground improvement will alter the amplitude and frequency components of the ground motions transmitted to the retrofitted structure. The VPG proposal does not model these ground motions correctly.

- The presence and performance of the seawall will influence the retrofitted viaduct. If the seawall were to experience massive failure, progressive slope failure could extend back to the improved soils. This loss of lateral confinement could result in displacements of the stabilized soil block could occur resulting in damage to the viaduct foundations.

Foundation Performance

- Incomplete ground improvement would force pore water to flow from liquefied soils into the dense glacial till that supports the existing piles. The result would be an increase in pore pressure and a decrease in strength of the upper portion of the glacial till. Consequently, some of the more shallowly embedded piles would move downward and cause differential movement of the superstructure.
- The composite piles (timber piles with a cast-in-place section spliced to the butt) that support portions of the existing viaduct are particularly susceptible to bending failure. Failure of the splices could occur at relatively small levels of lateral displacement.

Seawall

- The VPG concept is based upon the assumption that the above ground structure, the foundation, and the seawall can be considered separately. Recent VPG discussions have included proposals for soil improvement by cement jet grouting and also for constructing grade beams for lateral column support; however, the seawall continues to be excluded from the VPG concept. The viaduct and seawall are interrelated in that a significant length of the viaduct is dependant upon continued stability of the seawall. Consequently the corridor solution must address both components and provide a common solution.

Traffic and Operations

- It is unclear whether VPG expects the retrofit to strengthen the viaduct to the level needed so the original design level traffic volume and vehicle sizes can once again use this route. Even if the retrofit were to bring the structure up to that level, the current deficiencies in lane width and other aspects of traffic control and flow will remain.
- We disagree with VPG that the “non-engineering (traffic) issues”, as they have termed them, are not important. “Preserving” the viaduct as proposed gives us no breakdown lane, and does not address the unsafe rail/barrier and decking. The VPG retrofit approach does not allow for improving corridor safety since the current roadway (lanes and shoulders) is maintained. The replacement option (and even the early WSDOT full retrofit option) improves corridor safety by providing adequate lane and shoulder widths, and adding breakdown lanes and traffic control and ramp improvements.

- One of the last VPG comments was related to traffic impacts during construction of an alternative corridor. Traffic disruptions during any construction in a busy metropolitan area are inevitable, even when mitigation measures are implemented. The extent of traffic disruptions during ground stabilization work and installation of the bracing system can be expected to be less that that experienced during a complete rebuild. However, to bring all portions of the other elements of work needed for a proper retrofit are added to the VPG proposal, the duration of traffic disruptions could be significantly longer than suggested by VPG.

Other Considerations

Other considerations that need be taken into account in measuring the cost/benefit value of a retrofitted structure versus a replacement structure have been raised by our committee.

- We agree with the Structural Sufficiency Review Committee's conclusion that "even though a comprehensive seismic retrofit might achieve a level of safety comparable to a new structure (i.e., 500 year return period), the eventual deterioration of the current structure due to ageing would exact a greater sum of financial resources for maintenance and be less reliable than a new structure built to current seismic design standards."
- We also agree with this statement from the Structural Sufficiency Review Committee, "A retrofit/rehab would be less reliable than a replacement…The ductility designed into a new structure will result in damage and perhaps temporary closure of a new structure, but not structural collapse, at the design event. In contrast, due to the lack of ductile reinforcing details, the existing viaduct can be expected to suffer more catastrophic and sudden collapse, typical of a brittle structure."
- After a major seismic event, replacement of a retrofitted viaduct may be necessary at a time when the entire region will need both operational traffic routes and emergency funding. For this reason, it would be better to replace the viaduct now.
- Replacement now would aid in post-earthquake recovery for the region when a major seismic event does occur, because the route would be usable immediately by emergency vehicles and later by other traffic.
- Replacement increases the life expectancy over that of a retrofit.
- The cost of repair and/or replacement of utilities throughout the work limited work space under the viaduct will be costly, probably more so than estimated by the VPG.

Retrofit Scope Modifications

To complete our evaluation we indicated to WSDOT that it would be desirable to define the extent and nature of repair work needed in addition to that proposed by VPG. WSDOT retained T.Y. Lin do the additional analyses to quantify the work needed to mitigate the structural deficiencies of the viaduct in areas not addressed by VPG in order to provide a structure that will meet the basic roadway loading standards. T.Y. Lin's study is consistent with the Viaduct Preservation Group proposal to not change the lane or geometric configuration of the existing viaduct. Their analyses are based on achieving a 25-year life for the retrofitted structure.

A major element not considered in the original retrofit proposal was the foundations. The new analysis includes additional piling and greatly enlarged foundation bases. This design will restrict the structure from rocking. Further it will eliminate the uncertainty of the condition of the existing foundation systems.

Poor anchorage of the bottom bars at the lower floor beam at the columns was not addressed in the retrofit proposal. To improve the connection high-strength rods would be installed by coring through the column and into the floor beams. These rods would be stressed by post-tensioning to improve the behavior of the tee joints by inducing horizontal compressive stresses in the joints.

The upper knee joints would be replaced between the columns and the upper floor beams. The calculated stresses in these joints are not extreme, however, analyzed joints were for a straight section of the viaduct and stresses will be higher in a curved or less regular section. The knee joints in the sections of the viaduct designed by the Seattle Engineering Department are even more vulnerable.

The retrofit recommendations of the Viaduct Preservation Group Proposal as amended or added in the T. Y. Lin study are as follows:

1. Fiber wrap all columns, both upper and lower levels.
2. Place longitudinal structural steel frames between the middle bents of each unit of the viaduct, consisting of horizontal, vertical and bracing members. The bracing members are connected to the horizontal members of the structure using dampers.
3. Transverse structural steel braces will be placed at the middle bents of each unit, connected to the lower floor beams through dampers.
4. Stabilize the foundation system for the viaduct by cement grouting of soils underneath the viaduct.
5. Add of new piles at each footing.
6. Enlarge footing to engage the new piles.
7. Strengthen the lower floor beam/column tee joints.
8. Replace the upper floor beam/column knee joints.

Replacement of the seawall as necessary to protect the integrity of the viaduct structure has also been included in the plan recommended by our committee.

The above-described retrofit program would provide a structure adequately protected in an earthquake to meet the criteria identified in the first of this addendum and capable of handling the standard highway loadings for 25-years.

Cost-Retrofit vs. Rebuild

In order to assess the economic benefits of the rescoped retrofit proposal we asked WSDOT to prepare a cost estimate. This estimate was prepared on a basis consistent with WSDOT procedures used in estimating the costs of other options for this project.

The resulting estimate by WSDOT indicates that cost of rehabilitating the viaduct to have a 25-year life without modifying have the dimensional deficiencies of the present structure would be about 82 percent of the cost of a completely rebuilt viaduct with a 50-year life with improved operational configuration. In addition, the costs of maintaining the retrofitted structure can be expected to be significantly more than a new structure built to present-day design standards.

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.