September 26, 2006

Mr. Joe Wizner, Building Official
City of Spokane
Department of Building & Code Enforcement
808 West Spokane Falls Blvd.
Spokane, WA 99201-3343

Re: Review of Final Report
Structural Evaluation
River Park Square Parking Garage
Vehicle Barrier Repairs

Dear Mr. Wizner:

At your request, we have reviewed the referenced final report prepared by Wiss, Janney, Elstner Associates, Inc. (WJE) dated July 18, 2006. The report, as well as copies of original structural drawings and additional background information was provided by your office.

Additionally, we have reviewed construction permit application materials submitted by the contractor for repair work resulting from the WJE final report. The submitted materials were provided to us by your office and consisted of the following:

- *Structural calculations (11 pages total) stamped by Richard A. Dethlefs of Wiss, Janney, Elstner Associates with signature dated 8/25/06.*
- *Drawing sheets A000, S100, and S500, Revision 1, dated 8/21/06, prepared by Wiss, Janney, Elstner Associates, stamped and signed by Richard A. Dethlefs.*

After review of the submitted documents, it is our opinion that the evaluation conducted by WJE and the proposed repairs do not result in a repaired barrier system sufficient to provide safe conditions for future users of the parking garage. We recommend that the City require additional evaluation and repairs as identified in the following paragraphs.

<u>Evaluation of 1974 Panels</u>

The WJE final report investigated panels constructed in 1974 relative to their ability to resist code specified design loads. The report states that the 1970 Uniform Building Code was the applicable code at the time these panels were designed and constructed. WJE asserts that no horizontal force resulting from vehicle impact was required by the 1970 UBC. We do not agree with this assertion.

It is true that the 1970 UBC does not contain a specific 6,000-lb equivalent lateral load for vehicle barriers. This specific load first replaced more general code language in the 1991 edition of the code. However, we find two statements in the 1970 UBC indicating that forces from vehicular impact are to be considered in design of parking garage barriers. Sec. 1109, Open Parking Garages, paragraph (c), states "Adequate curbs and railings shall be provided at every opening." Sec. 2302, Loads, paragraph (a), states "Impact loads shall be considered in the design of any structure where impact loads occur." The magnitude of design forces to address these requirements is not specified, thereby leaving that decision to the judgment of the design professional or building official.

Also, it is apparent that the original design considered a horizontal force allowing for vehicle impact. Had the original barrier panels been designed for applicable wind and gravity loads alone, which the WJE report suggests as appropriate, the reinforcing required would have been notably less than the #6 bars at 12" on center that were provided. Based on our approximate evaluation, the reinforcing provided in the 1974 panels, if properly placed, was designed with sufficient flexural strength to resist a vehicle impact force equal to the current code requirement.

It is incorrect, in our opinion, to assert that vehicle barriers designed under provisions of the 1970 UBC were not required to be designed for any vehicle impact loads. We suggest that the 'Findings' and 'Conclusions and Recommendations' portions of the WJE final report be revised to recognize the requirements of the 1970 UBC noted above. Any impact that these revisions have on recommended repairs should also be incorporated in the repair drawings submitted for permit.

<u>Ductility Evaluation and Repair</u>

The WJE final report evaluates ductility for each barrier panel in the garage facility. Ductility requirements are specifically discussed on page 14 of the report, where the argument is put forward that non-compliance with code-required ductility provisions can be tolerated provided the element has a load carrying capacity sufficiently in excess of design requirements. The report states that sufficiency can be evaluated through the use of reduced phi factors in capacity calculations. We do not think this is an appropriate approach in the case of vehicle barrier panels.

In our opinion, ductile behavior is particularly important in members resisting dynamic impact loads, such as vehicle barriers. Failures in non-ductile elements are sudden and brittle, dissipating considerably less energy than ductile, yielding elements. It is our opinion that this behavior, when considering the dynamic nature of loads resulting from vehicle impact, represents a dangerous and non-compliant condition.

Although we question the approach utilized in WJE evaluations, we have noted that all panels failing to meet ductility requirements, of either 1974 or 1999 vintage, are indicated to receive repairs in the submitted repair drawings. We believe this is a sound decision and is an appropriate response to applicable code requirements. Specific

concerns regarding the repair details proposed for these panels are presented in subsequent paragraphs.

Values Used in Calculations

Evaluations of panel capacity and ductility presented in the WJE final report considered conditions at the panels' critical section, that point where panel thickness reduces from 6 inches to 5 inches. Because this is a narrow section with minimal rebar depth 'd', accurate measurement of material properties and dimensions are crucial for an accurate evaluation. Fractions of inches in such narrow sections can significantly affect member strength and ductility. It is apparent in reviewing the WJE final report that a high level of care was taken in acquiring measured properties with accuracy.

Concrete compressive strengths used in panel analysis by WJE were based on 20 concrete specimens removed from the barrier panels and laboratory tested. Results of these tests are discussed and presented on pages 8 and 9 of the final report. For both the 1974 and the 1999 panels, compressive strengths in excess of the required f'c (5,000 psi) resulted and were used in WJE calculations.

The report does not cite any testing to determine actual strength of the reinforcing steel present in the vehicle barrier panels. We assume that the steel strength called for in original construction drawings (fy = 60 ksi) was used by WJE in their analyses. Because steel yield strength above that specified (fy = 60 ksi)is not unlikely and would have an adverse affect on ductility, we recommend that the City require testing to determine actual yield strength of reinforcing steel in the barrier panels. Testing to determine actual reinforcing steel yield strength is much less common than testing of concrete strengths, and is often not significant in strength evaluations. However, given the sensitivity of panel evaluation to minor variations of measured properties discussed above, it is a prudent consideration in our opinion. Because reinforcing steel is typically accessible only after selective concrete removal, it may be practical to only test rebar that is readily accessible, such as the reinforcing in the recently failed panel.

The WJE final report indicates that a Hilti Ferroscan meter was used to determine actual locations of reinforcing bars in the 5" deep horizontal legs of the vehicle barrier panels. Based on the manufacturer's technical literature, we understand that meter readings should be considered accurate within plus or minus 0.1 to 0.2 inches. The data presented in Appendix E of the WJE final report provides reinforcing depths ('d') based on Ferroscan meter readings in hundredths of an inch. The report does not mention the accuracy factor regarding readings and it is not clear whether WJE calculations accounted for meter accuracy. If the tabulated average cover in Appendix E is increased by 0.1inches to allow for meter accuracy limitations, calculated strength and ductility will be reduced by 5 to 10%.

We suggest that the WJE final report be revised as necessary to address variability of rebar depth readings and yield strength and to clarify whether these accuracy variables have been considered in panel evaluations and reported capacities. Corresponding

revisions to the submitted repair drawings as may result should also be made and submitted.

Typical Plate Repair at Panel Joints

Details 5, 6, and 7 on sheet S500 depict a proposed steel plate repair. This repair is to occur at 67 panels as indicated on sheet S100. Calculation pages 6 through 9 present the design and analysis for this connection. Referring to the detail sketch on page 7, a moment in the horizontal plane is induced in the end of the supporting panel 'B'. This moment results from the bolt tension force 'T' and the concrete compression force 'C', acting as a couple in resisting the applied force from the adjacent supported panel 'A'. Horizontal panel reinforcing is not developed at these panel edges, and the capacity to resist this horizontal moment is correspondingly minimal. Referring to the calculations on page 7, the magnitude of this applied moment can be calculated as:

M_h *= T x 5.33" = 21k x 5.33" = 112 in-k = 9.33 ft-k.*

When the supporting panel is one identified in the WJE report as non-ductile, the submitted drawings indicate that this panel will be strengthened with a pair of HSS tube frames. Frames are located 2'-6" from each panel vertical edge. Submitted calculations do not assess any bending stresses in the concrete panel which will develop in transferring the applied load at the panel edge to the HSS frame.

The submitted calculations do not indicate that thermal stresses were considered at the proposed repair plates. Existing panel joints currently free to move are restricted from thermal expansion and contraction by the proposed repair plates.

Additional calculations addressing localized and distributed stresses in the supporting barrier panels, including those mentioned here should be submitted to demonstrate that this repair is sufficient.

Permit Application Materials

We have reviewed the submitted drawings and calculations as forwarded to us by your office. In addition to comments and recommendations discussed above, which could significantly affect the submitted design; we have prepared the following list of specific items that should be considered in processing the permit application.

1. *Sheet A000 should be revised to include a listing of design loads used, consistent with the requirements of IBC section 1603.*
2. *The Key Table on sheet S100 refers to repair detail 1, sheet S501. We do not know of a sheet S501 being submitted. Should this reference be to details 1, 2, and 3 on sheet S500? The key table also refers to end plate repairs per detail 3/S500. This detail does not illustrate plate repairs at panel ends. Should the reference instead be to detail 5/S500? The drawing should be revised to clarify these detail references.*

3. *By our count, the building elevations on sheet S100 indicate a total of 261 panels on the exterior of the parking garage, 249 on the north elevation and 12 on the south. Of these, the drawing indicates 146 panels receiving no repairs, 48 receiving a panel repair per detail 1/S501 (1,2,3/S500?), and 67 panels to be repaired with end plates per detail 3 (5?)/S500. Comparing this drawing with Appendix E of the WJE final report, it appears that there are several panels analyzed as insufficient that are not receiving repairs. These panels are listed below and are identified in the report as 1970 panels meeting ductility requirements but having Demand/Capacity ratios exceeding 100%. We understand that these panels are not proposed to be repaired because they have satisfactory Demand/Capacity ratios when original design loads are considered. As discussed in a previous paragraph, however, we believe the WJE report incorrectly identifies original design loads, and the panels listed below will need to be repaired. Sheet S100 should be revised to include repairs for these panels.*
    - *Floor 2/3: panel 10*
    - *Floor 3/4: panel 32*
    - *Floor 4/5: panels 29 and 32*
    - *Floor 6S: panels 3, 4, and 5*
    - *Floor 6/7: panels 12, 14, 21, 25, and 28*
    - *Floor 7S: panels 1and 4*
4. *On sheet S100, panel 15 is indicated as receiving a steel plate repair. According to the WJE report, this is the panel that failed and was destroyed in the recent accident. Repair at this panel is not practical; a replacement panel should be included in the repair project at this location.*
5. *Detail 3 on sheet S500 calls for '…non-shrink grout or shims under HSS…'. It is our opinion that this may not be durable and vandal-resistant over time. We recommend a more permanent and stable component, such as a welded shim plate, at this location.*
6. *The HSS members indicated on sheet S500 should be provided with welded, galvanized end plates to prevent detrimental rusting or corrosion from occurring inside the HSS members over time and to limit debris accumulation. Each HSS tube should be provided with a vent hole in the bottom of the horizontal leg. This will facilitate the hot dip galvanizing process and will help prevent water vapor accumulation inside the tubes over time.*
7. *Detail 3 on sheet S500 should be revised to include the required weld between the new 4" x 8" x 3/8" plate to the HSS Members. Detail 4 should similarly be revised to specify the required size of the flare bevel welds indicated.*

The observations and recommendations provided in this letter report are forwarded with the intent of facilitating vehicle barrier repairs that will improve public safety in the River Park Square Parking Garage to acceptable standards. As representatives of the Department of Building and Code Enforcement, we have attempted to be diligent in our review efforts and maintain public safety and code compliance as our primary considerations. It is hoped that our recommendations will contribute to a successful

repair project. If you have any questions or concerns regarding this letter report, or if we can be of any additional service, please feel free to contact us.

Sincerely,

LSB Consulting Engineers, PLLC

Randall J. LaPlante, P.E.

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