Washington State Department of Transportation
Bridge and Structures Office

Design Memorandum

TO: All Design Section Staff
FROM: Bijan Khaleghi
DATE: November 14, 2013
SUBJECT: Elastic Design In Lieu of Overstrength Forces for Capacity Protection

This Design Memorandum describes WSDOT policy for use of elastic design forces in lieu of design using overstrength plastic hinging forces for capacity protection for members intended to remain essentially elastic at the displacement demand. Elastic response in this case means no inelastic action in any of the reinforcement.

With the approval of the Bridge Design Engineer, for Type 1 ERS for SDC C or D, if columns or pier walls are considered an integral part of the energy-dissipating system but remain elastic at the demand displacement, the forces to use for capacity design of other components are to be a minimum of 1.2 times the elastic forces resulting from the demand displacement in lieu of the forces obtained from overstrength plastic hinging analysis. Because maximum limiting inertial forces provided by yielding elements acting at a plastic mechanism level is not effective in the case of elastic design, the following constraints are imposed. These may be relaxed on a case-by-case basis with the approval of the Bridge Design Engineer.

1. Unless an analysis that considers redistribution of internal structure forces due to inelastic action is performed, all substructure units of the frame under consideration and of any adjacent frames that may transfer inertial forces to the frame in question must remain elastic at the design ground motion demand.
2. Effective member section properties must be consistent with the force levels expected within the bridge system. Reinforced concrete columns and pier walls should be analyzed using cracked section properties. For this purpose, a moment of inertia equal to one-half that of the uncracked section shall be used.
3. Foundation modeling must be established such that uncertainties in modeling will not cause the internal forces of any elements under consideration to increase by more than 10 percent.
4. When site-specific ground response analysis is performed, the response spectrum ordinates must be selected such that uncertainties will not cause the internal forces of any elements under consideration to increase by more than 10 percent.
5. Thermal, shrinkage, prestress or other forces that may be present in the structure at the time of an earthquake must be considered to act in a sense that is least favorable to the seismic load combination under investigation.
6. P-Delta effects must be assessed using the resistance of the frame in question at the deflection caused by the design ground motion.

7. Joint shear effects must be assessed with a minimum of the calculated elastic internal forces applied to the joint.
8. Detailing as normally required in either SDC C or D, as appropriate, must be provided.

It is permitted to use expected material strengths for the determination of member strengths for elastic response of members.

The use of elastic design in lieu of overstrength plastic hinging forces for capacity protection described above shall only be considered if designer demonstrates that capacity design of Article 4.11 of the AASHTO Guide Specifications for LRFD Bridge Seismic Design is not feasible due to geotechnical or structural reasons.

Background

In some cases, because of architectural considerations or for other reasons, columns or pier walls intended to act as an integral part of the energy-dissipating system, have cross-sections that are larger than that required to resist the applied seismic loading. As such, the overstrength plastic moment capacity of these elements can be greater than the unreduced elastic forces. Consequently, capacity design based on the forces obtained from overstrength analysis tends to be overly conservative and potentially excessively expensive. However, certain modes of failure in columns or pier walls, such as shear, may be brittle in nature and are thus sensitive to input force levels. Therefore, the internal design forces should be conservatively determined, and a number of constraints are imposed to ensure that design is appropriately conservative. The constraints are intended to address uncertainties in the response and require the designer to conservatively estimate internal forces.

It is good practice to identify and check the lateral load path to ensure that no portions of the load path are weaker than the elements that establish the plastic capacity of the substructure (e.g., plastic hinging in the columns). Therefore, checks of the load path are suggested, but full capacity design using plastic overstrength forces is not required.

The design of substructures using the elastic forces associated with the design ground motion is permitted in SDC B, although not encouraged, because potentially larger ground motions could produce undesirable performance, including collapse or partial collapse of the bridge. Use of ductile design with capacity design principles provides margin against poor performance in ground motions larger than the design level due to the inherent displacement capacity in a suitably ductile structure.

If you have any questions regarding these issues, please contact Chyuan-Shen Lee at 360 705-7441 (LeeCh@wsdot.wa.gov) or Bijan Khaleghi at 360-705-7181 (KhalegB@wsdot.wa.gov) .

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<u>BDM Revision:</u>

Revise the first paragraph of BDM Article 4.2.2as follows:

4.2.2 Earthquake Resisting Systems (ERS) Requirements for SDCs C and D

With the approval of the Bridge Design Engineer, for Type 1 ERS for SDC C or D, if columns or pier walls are considered an integral part of the energy-dissipating system but remain elastic at the demand displacement, the forces to use for capacity design of other components are to be a minimum of 1.2 times the elastic forces resulting from the demand displacement in lieu of the forces obtained from overstrength plastic hinging analysis. Because maximum limiting inertial forces provided by yielding elements acting at a plastic mechanism level is not effective in the case of elastic design, the following constraints are imposed. These may be relaxed on a case-by-case basis with the approval of the Bridge Design Engineer.

1. Unless an analysis that considers redistribution of internal structure forces due to inelastic action is performed, all substructure units of the frame under consideration and of any adjacent frames that may transfer inertial forces to the frame in question must remain elastic at the design ground motion demand.
2. Effective member section properties must be consistent with the force levels expected within the bridge system. Reinforced concrete columns and pier walls should be analyzed using cracked section properties. For this purpose, a moment of inertia equal to one-half that of the uncracked section shall be used.
3. Foundation modeling must be established such that uncertainties in modeling will not cause the internal forces of any elements under consideration to increase by more than 10 percent.
4. When site-specific ground response analysis is performed, the response spectrum ordinates must be selected such that uncertainties will not cause the internal forces of any elements under consideration to increase by more than 10 percent.
5. Thermal, shrinkage, prestress or other forces that may be present in the structure at the time of an earthquake must be considered to act in a sense that is least favorable to the seismic load combination under investigation.
6. P-Delta effects must be assessed using the resistance of the frame in question at the deflection caused by the design ground motion.
7. Joint shear effects must be assessed with a minimum of the calculated elastic internal forces applied to the joint.
8. Detailing as normally required in either SDC C or D, as appropriate, must be provided.

It is permitted to use expected material strengths for the determination of member strengths for elastic response of members.

The use of elastic design in lieu of overstrength plastic hinging forces for capacity protection described above shall only be considered if designer demonstrates that capacity design of Article 4.11 of the AASHTO Guide Specifications for LRFD Bridge Seismic Design is not feasible due to geotechnical or structural reasons.