Washington State Department of Transportation
Bridge and Structures Office

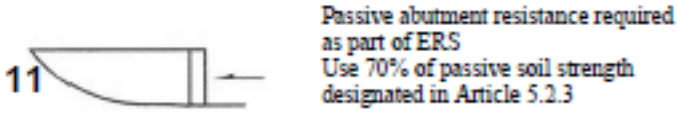
Design Memorandum

TO: All Design Section Staff
FROM: Bijan Khaleghi
DATE: March 1, 2013
SUBJECT: Abutment Participation as Part of Earthquake Resisting System

BDM Update:

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

Modify depict 11 of Figure 3.3-1a as shown:



~~Permissible Upon Approval~~

4.2.11 Abutments

~~Guide Specifications Article 5.2 – Diaphragm Abutment type shown in Figure 5.2.3.2-1 shall not be used for WSDOT bridges.~~

~~With WSDOT Bridge Design Engineer's approval, the abutment may be considered and designed as part of earthquake resisting system (ERS) in the longitudinal direction of a straight bridge with little or no skew and with a continuous deck. For determining seismic demand, longitudinal passive soil pressure shall not exceed 50 percent of the value obtained using the procedure given in Article 5.2.3.3. Participation of the wingwall in the transverse direction shall not be considered in the seismic design of bridges.~~

This design memorandum provides guidance to include abutment participation as part of the Earthquake Resisting System (ERS) for WSDOT Bridges. This memorandum supersedes the requirements of Section 5.2 of the AASHTO Guide Specification for LRFD Seismic Bridge Design, and WSDOT Bridge Design Manual Section 4.2.11. The passive abutment resistance required as part of ERS shall be limited to 70% of passive soil strength as shown in SGS Figure 3.3-1b-10.

The participation of abutment walls in providing resistance to seismically induced inertial loads may be considered in the seismic design of bridges either to reduce column sizes or reduce the ductility demand on the columns. Damage to backwalls and wingwalls during earthquakes may be considered acceptable when considering no collapse criteria, provided that unseating or other damage to the superstructure does not occur. Abutment participation in the overall dynamic response of the bridge system shall reflect the structural configuration, the load transfer mechanism from the bridge to the abutment system, the effective stiffness and force capacity of the wall-soil system, and the level of acceptable abutment damage. The capacity of the abutments to resist the bridge inertial loads shall be compatible with the soil resistance that can be reliably mobilized, the structural design of the abutment wall, and whether the wall is permitted to be damaged by the design earthquake. The lateral load capacity of walls shall be evaluated on the basis of a rational passive earth-pressure theory.

Longitudinal Direction

Under earthquake loading, the earth-pressure action on abutment walls changes from a static condition to one of two possible conditions:

- The dynamic active pressure condition as the wall moves away from the backfill, or
- The passive pressure condition as the inertial load of the bridge pushes the wall into the backfill.

The governing earth-pressure condition depends on the magnitude of seismically induced movement of the abutment walls, the bridge superstructure, and the bridge/abutment configuration.

For semi-integral (Figure 1a), L-shape abutment with backwall fuse (Figure 1b), or without backwall fuse (Figure 1c), for which the expansion joint is sufficiently large to accommodate both the cyclic movement between the abutment wall and the bridge superstructure (i.e., superstructure does not push against abutment wall), the seismically induced earth pressure on the abutment wall shall be considered to be the dynamic active pressure condition. However, when the gap at the expansion joint is not sufficient to accommodate the cyclic wall/bridge seismic movements, a transfer of forces will occur from the superstructure to the abutment wall. As a result, the active earth-pressure condition will not be valid and the earth pressure approaches a much larger passive pressure load condition behind the backwall. This larger load condition is the main cause for abutment damage, as demonstrated in past earthquakes. For semi-integral or L-shape abutments, the abutment stiffness and capacity under passive pressure loading are primary design concerns.

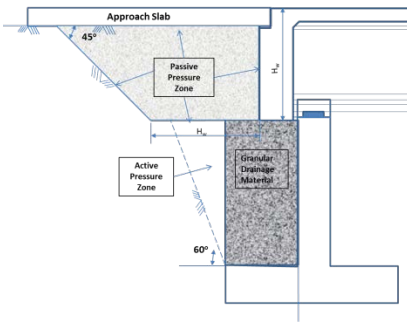


Fig. 1a: Semi-integral Abutment

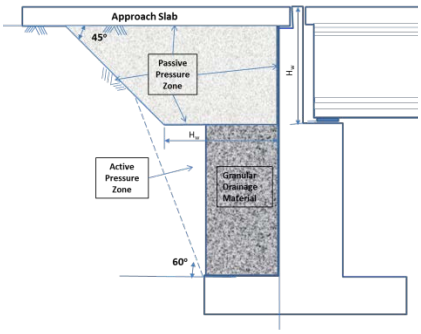


Fig. 1b: L-shape Abutment Backwall Fuses

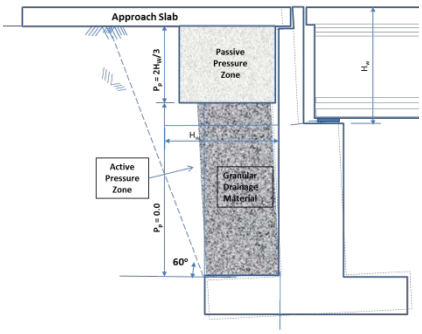


Fig. 1c: L-shape Abutment Backwall Does Not Fuse

Figure 1: Abutment Stiffness and Passive Pressure Estimate

Where the passive pressure resistance of soils behind semi-integral or L-shape abutments will be mobilized through large longitudinal superstructure displacements, the bridge may be designed with the abutments as key elements of the longitudinal ERS. Abutments shall be designed to sustain the design earthquake displacements. When abutment stiffness and capacity are included in the design, it should be recognized that the passive pressure zone mobilized by abutment displacement extends beyond the active pressure zone normally used for static service load design. This is illustrated schematically in Figures 1a and 1b. Dynamic active earth pressure acting on the abutment need not be considered in the dynamic analysis of the bridge.

Abutment Stiffness and Passive Pressure Estimate

Abutment stiffness, K_{eff} in kip/ft, and passive capacity, P_p in kips, should be characterized by a bilinear or other higher order nonlinear relationship as shown in Figure 2a and 2b. When the motion of the back wall is primarily translation, passive pressures may be assumed uniformly distributed over the height (H_w) of the backwall or end diaphragm. The total passive force may be determined as:

$$P_p = p_p H_w W_w$$

where:

p_p = passive lateral earth pressure behind backwall or diaphragm (ksf)

H_w = height of back wall or end diaphragm exposed to passive earth pressure (ft)

W_w = width of back wall or diaphragm (ft)

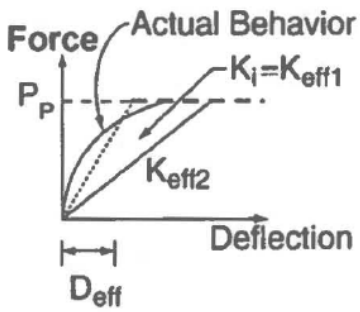


Fig. 2a: Semi-integral Abutment

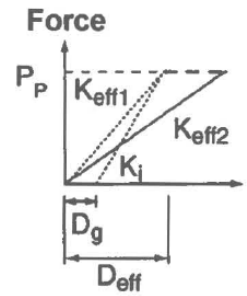


Fig. 2a: L-shape Abutment

Figure 2: Characterization of Abutment Capacity and Stiffness

Calculation of Best Estimate Passive Pressure P_p

If the strength characteristics of compacted or natural soils in the "passive pressure zone" are known, then the passive force for a given height, H_w, may be calculated using accepted analysis procedures. These procedures should account for the interface friction between the wall and the soil. The properties used shall be those indicative of the entire "passive pressure zone" as indicated in Figure 1. Therefore, the properties of backfill present immediately adjacent to the wall in the active pressure zone may not be appropriate as a weaker failure surface can develop elsewhere in the embankment.

For L-shape abutments where the backwall is not designed to fuse, H_w shall conservatively be taken as the depth of the superstructure, unless a more rational soil-structure interaction analysis is performed.

If presumptive passive pressures are to be used for design, then the following criteria shall apply:

- Soil in the "passive pressure zone" shall be compacted in accordance with WSDOT Standard Specification Section 2-03.3(14)I, which requires compaction to 95-percent maximum density for all “Bridge Approach Embankments”.

- For cohesionless, nonplastic backfill (fines content less than 30 percent), the passive pressure p_p may be assumed equal to $2H_w/3$ ksf per foot of wall length.

For other cases, including abutments constructed in cuts, the passive pressures shall be developed by a geotechnical engineer.

Calculation of Passive Soil Stiffness

Equivalent linear secant stiffness, K_{eff} in kip/ft, is required for analyses. For semi-integral or L-shape abutments initial secant stiffness may be determined as follows:

$$K_{eff1} = \frac{P_p}{(F_w H_w)}$$

where:

P_p = passive lateral earth pressure capacity (kip)

H_w = height of back wall (ft)

F_w = the value of F_w to use for a particular bridge may be found in Table C3.11.1-1 of the AASHTO LRFD Bridge Design Specifications.

For L-shape abutments, the expansion gap should be included in the initial estimate of the secant stiffness as specified in:

$$K_{eff1} = \frac{P_p}{(F_w H_w + D_g)}$$

where:

D_g = width of gap between backwall and superstructure (ft)

For SDCs C and D, where pushover analyses are conducted, values of P_p and the initial estimate of K_{eff1} should be used to define a bilinear load-displacement behavior of the abutment for the capacity assessment.

Modeling Passive Pressure Stiffness in the Longitudinal Direction

In the longitudinal direction, when the bridge is moving toward the soil, the full passive resistance of the soil may be mobilized, but when the bridge moves away from the soil no soil resistance is mobilized. Since passive pressure acts at only one abutment at a time, linear elastic dynamic models and frame pushover models should only include a passive pressure spring at one abutment in any given model. Secant stiffness values for passive pressure shall be developed independently for each abutment.

As an alternative, for straight or with horizontal curves up to 30-degrees single frame bridges, and compression models in straight multi-frame bridges where the passive pressure stiffness is similar between abutments, a spring may be used at each abutment concurrently. In this case, the assigned spring values at each end need to be reduced by half because they act in simultaneously, whereas the actual backfill passive resistance acts only in one direction and at one time. Correspondingly, the actual peak

passive resistance force at either abutment will be equal to the sum of the peak forces developed in two springs. In this case, secant stiffness values for passive pressure shall be developed based on the sum of peak forces developed in each spring. If computed abutment forces exceed the soil capacity, the stiffness should be softened iteratively until abutment displacements are consistent (within 30 percent) with the assumed stiffness.

Transverse Direction

Transverse stiffness of abutments may be considered in the overall dynamic response of bridge systems on a case-by-case basis upon Bridge Design Engineer approval. Upon approval, the transverse abutment stiffness used in the elastic demand models may be taken as 50-percent of the elastic transverse stiffness of the adjacent bent.

Girder stops are typically designed to transmit the lateral shear forces generated by small to moderate earthquakes and service loads and are expected to fuse at the design event earthquake level of acceleration to limit the demand and control the damage in the abutments and supporting piles/shafts. Linear elastic analysis cannot capture the inelastic response of the girder stops, wingwalls or piles/shafts. Therefore, the forces generated with elastic demand assessment models should not be used to size the abutment girder stops. Girder stops for abutments supported on a spread footing shall be designed to sustain the lesser of the acceleration coefficient, A_s, times the superstructure dead load reaction at the abutment plus the weight of abutment and its footing or sliding friction forces of spread footings. Girder stops for pile/shaft-supported foundations shall be designed to sustain the sum of 75% total lateral capacity of the piles/shafts and shear capacity of one wingwall.

The elastic resistance may be taken to include the use of bearings designed to accommodate the design displacements, soil frictional resistance acting against the base of a spread footing-supported abutment, or pile resistance provided by piles acting in their elastic range.

The stiffness of fusing or breakaway abutment elements such as wingwalls (yielding or non-yielding), elastomeric bearings, and sliding footings shall not be relied upon to reduce displacement demands at intermediate piers.

Unless fixed bearings are used, girder stops shall be provided between all girders regardless of the elastic seismic demand. The design of girder stops should consider that unequal forces that may develop in each stop.

When fusing girder stops, transverse shear keys, or other elements that potentially release the restraint of the superstructure are used, then adequate support length meeting the requirements of Article 4.12 of the Guide Specifications for LRFD Seismic Bridge Design must be provided. Additionally, the expected redistribution of internal forces in the superstructure and other bridge system element must be considered. Bounding analyses considering incremental release of transverse restraint at each end of the bridge should also be considered.

Curved and Skewed Bridges

Passive earth pressure at abutments may be considered as a key element of the ERS of straight and curved bridges with abutment skews up to 20 degrees. For larger skews, due to a combination of

longitudinal and transverse response, the span has a tendency to rotate in the direction of decreasing skew. Such motion will tend to cause binding in the obtuse corner and generate uneven passive earth pressure forces on the abutment, exceeding the passive pressure near one end of the backwall, and providing little or no resistance at other end. This requires a more refined analysis to determine the amount of expected movement. The passive pressure resistance in soils behind semi-integral or L-shape abutments shall be based on the projected width of the abutment wall normal to the centerline of the bridge. Abutment springs shall be included in the local coordinate system of the abutment wall.

The participation of the bridge approach slab in the overall dynamic response of bridge systems to earthquake loading and in providing resistance to seismically induced inertial loads may be considered permissible upon approval from both the Bridge Design Engineer and the Geotechnical Engineer.

When the presence of the abutment backfill may be uncertain, as in the case of slumping or settlement due to liquefaction below or near the abutment, participation of the abutment in the ERS should be carefully evaluated with the Geotechnical Engineer and the Owner.