Abutments

Type Selection

The designer is responsible for the type of abutments selected, taking into account the requirements for structural support, structure movement, drainage, structure approach and earthquakes.

Six types of abutments are used for bridges; the diaphragm abutment, the short seat abutment, the high cantilever abutment, the bin abutment, the strutted abutment, and the rigid frame abutment.

The diaphragm abutment, *Bridge Design Aids*, pages 1-3 and 1-4 and *Bridge Design Details*, pages 6-20 and 6-21, and the short seat abutment, *Bridge Design Aids*, page 1-5, are the most frequently used abutment types. These abutments are usually placed at the top of the approach embankment and have evolved from the desire to present an open appearance to traffic beneath the structure by removing a structural support adjacent to traffic. The essential structural difference is that the seat abutment permits superstructure movement independent of the abutment while the diaphragm abutment does not.

The major benefit of the diaphragm abutment is its initial lower cost to construct, however maintenance problems generally preclude its use except for short structures. See Memo to Designers 5-2 for uses and limitations of the diaphragm abutment.

The short seat abutment is an independent structural component of the bridge and can generally be designed to accommodate all the imposed forces.

The high cantilever abutment, *Bridge Design Aids*, page 1-6 and *Bridge Design Details*, pages 6-50, 6-51, 6-52 and 6-53, the bin abutment , *Bridge Design Details*, pages 6-40 and 6-41, and the strutted abutment, *Bridge Design Details*, page 20-10, are infrequently used, except for bridge widenings in kind, unusual sites or in some geometrically constrained urban locations. Rigid frame abutments are generally used with tunnel type single span connectors and overhead structures which permit passage through a roadway embankment. These abutment types have a high initial cost and present a closed appearance to approaching traffic by placing the structure support adjacent to traffic. At overcrossings, these abutment types usually preclude the widening of the highway below without complete replacement of the bridge.

Design Criteria

Article 7.4.1.2 in the *Bridge Design Specifications* permits using either Service Load Design or Load Factor Design methods to design the abutment.

Supersedes Memo to Designers 5-1 dated September 1988

Until the final implementation of Load Factor Design methods, it is recommended that abutments be designed using Service Load Design methods and static earth pressures, except for the seismic resisting elements. The static earth pressures to be used are specified in Article 3.20 in the *Bridge Design Specifications*. See *Bridge Design Aids*, pages 1-1 and 1-2 for the various non-seismic load cases to be considered to design the abutment.

Earthquake

It is the department's policy to accept abutment damage caused by earthquake action provided the damage does not result in collapse of the bridge.

Damage to abutments from a major earthquake is expected and can be tolerated. Our purpose in evaluating the forces and movements at the abutments is to control the damage to the abutment elements and at the same time obtain a realistic estimate of the displacements at the interior supports. Earthquake action tends to densify both the roadway embankments and the foundation material under the embankment. Because many roadway embankments tend to be granular in nature, significant densification of the embankment can be expected during a major earthquake, which could cause significant damage to the structure. Therefore, the designer should use pile foundations at the abutments when the expected peak rock acceleration is 0.6 g or greater, and the embankment height is 10 feet or greater, or if the bents are on piles and significant densification of the foundation material during an earthquake can be expected. The exception to this recommendation is for abutments under single span bridges, these may have either pile or spread footings.

The number of piles required at abutments shall not be controlled by seismic loads.

The restraining elements of the abutment (shear keys, wingwalls and abutment walls) used to resist seismic forces from the superstructure shall be designed by Load Factor Design methods consistent with the assumptions made in the seismic analysis guidelines outlined in *Bridge Design Aids*, Section 14; and in *Bridge Design Specifications*, Section 3 commentary.

Diaphragm Abutments (Seismic)

The diaphragm abutment engages the adjacent backfill immediately which is very effective in absorbing energy during an earthquake.

The longitudinal resistance for seismic analysis of a diaphragm abutment should be based on mobilizing the backfill equal to the depth of the superstructure plus the shear capacity of the abutment diaphragm. The ultimate passive resistance of the backfill is assumed to be 7.7 kips per square foot. The diaphragm abutment shown in *Bridge Design Aids*, pages 1-3 and 1-4 has been designed so that the flexural reinforcing will yield before a shear failure occurs. It is usually impractical to structurally

size the abutment diaphragm below the soffit to totally mobilize the backfill. When the design earthquake force is greater than these resisting elements, a reduced stiffness should be used in the seismic analysis based on only the soil resistance. Even though the diaphragm below the soffit will experience damage from a major earthquake, the possibility of collapse of the superstructure is remote.

The transverse resistance for seismic analysis for a diaphragm abutment should be based on the ultimate shear capacity of one wingwall and all piles. When Class 45, Class 70 or standard 16" CIDH piles are used an ultimate shear capacity of 40 kips per pile may be used.

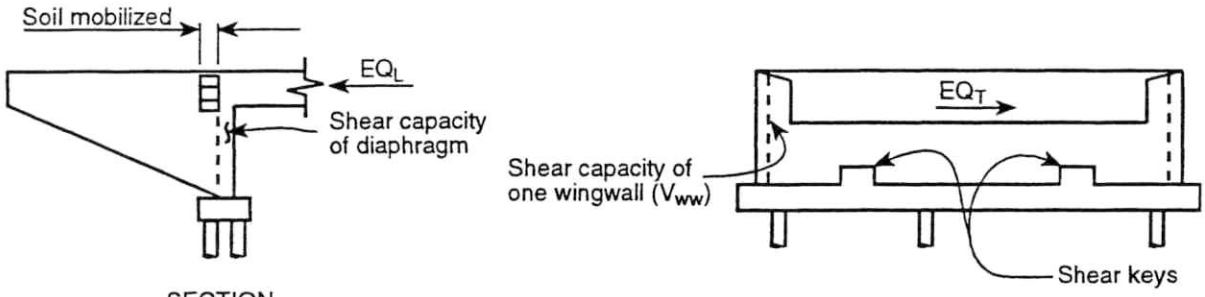
The limiting force for transverse keys for diaphragm abutments on footings is the ultimate shear capacity of the piles. This force represents the maximum force which can be expected to be transmitted through the keys. To reduce possible damage to the piles, transverse keys should be designed for 75% of this limiting force.

When the design transverse earthquake force exceeds the capacity of the wingwall and piles for diaphragms without a footing or the wingwall and transverse keys for diaphragms with a footing, the transverse stiffness for the seismic analysis is zero and a released condition should be used which will result in larger lateral design forces at the adjacent bents.

When spread footings are used the transverse keys shall be designed for a minimum of 75% of the dead load reaction at the bottom of footing. Abutments on spread footings in rock or very stiff material should be given special consideration and designed to receive larger seismic forces.

Diaphragm Abutment

Seismic Resisting Elements



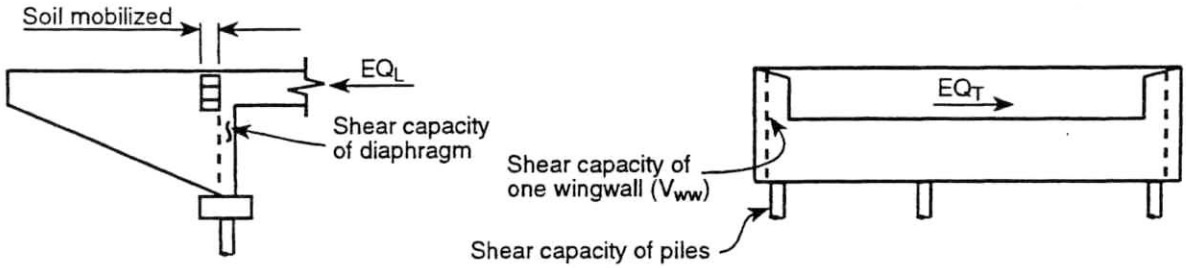
SECTION

$EQ_L \leq R_{soil} + V_{diaphragm}$

$EQ_T \leq V_{ww} + V_{key}$
or else $EQ_T = 0$
$V_{keys} = 0.75\ (V_{piles})$

ELEVATION
or for spread footings
$V_{keys} \approx 0.75$ (Dead load reaction @ bottom of footing)

With Footing



SECTION

$EQ_L \leq R_{soil} + V_{diaphragm}$

ELEVATION

$EQ_T \leq V_{ww} + V_{piles}$
or else $EQ_T = 0$

Without Footing

EQ_L = Longitudinal earthquake force from an elastic analysis.

EQ_T = Transverse earthquake force from an elastic analysis.

R_{soil} = Resistance of soil mobilized behind abutment.

$V_{diaphragm}$ = ϕ times the nominal shear strength of the diaphragm.

V_{WW} = ϕ times the nominal shear strength of the wingwall.

V_{piles} = ϕ times the nominal shear strength of the piles.

V_{key} = ϕ times the nominal shear strength of the transverse keys in the direction under consideration.

Seat Abutments (Seismic)

The seat abutment gives the designer more control over the amount of earthquake force the abutment will resist, but introduces the potential for the superstructure becoming unseated leading to a collapse of the end span. The superstructure is restrained longitudinally in one direction by the abutment backwall and approach embankment, and transversely by shear keys built into the abutment.

Shear keys for seat abutments that are highly skewed, offer limited resistance in restraining the superstructure from rotating and moving away from the embankment. If possible, the designer should reduce the skew of the abutment, even at the expense of increasing the bridge length. This recommendation is especially pertinent for long connector structures where large earthquake displacements and forces are anticipated at the abutments.

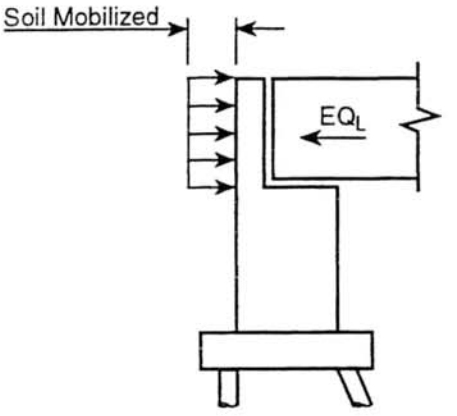
The longitudinal earthquake force required to mobilize the backfill for the full height of the abutment is generally much larger than a practical sized backwall can be designed to resist. Therefore, the backwall is designed to fail before damaging forces can be transmitted to the lower portion of the abutment. The longitudinal stiffness assumed for the seismic analysis should be based on mobilizing only the soil equal to the depth of the superstructure. This stiffness will result in larger earthquake forces at the adjacent bents, than would occur if the total stiffness were mobilized. Longitudinal displacements will also increase, however these results are generally unavoidable and are preferred to introducing excessive damage to the abutment below the soffit level. The effects of larger displacements and forces at the bents must be considered in the design.

For seat abutment transverse keys, the limiting transverse earthquake force may be approximated by adding the ultimate shear capacity of one wingwall plus the ultimate shear capacity of the piles. This force is the maximum force which can be expected to be transmitted through the keys. To reduce possible damage to the piles, transverse keys should be designed for the ultimate shear capacity of one wingwall plus 75% of the ultimate shear capacity of the piles.

When spread footings are used the keys shall be designed for a minimum of 75% of the dead load reaction at the bottom of the footing. Abutments on spread footings in rock or very stiff material should be given special consideration and designed to receive larger seismic forces.

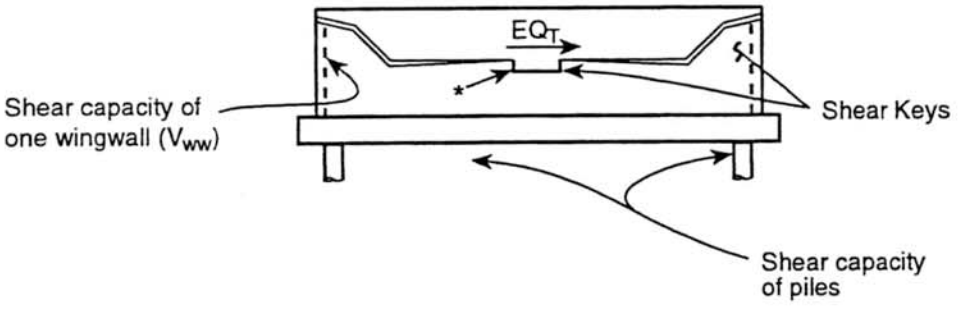
When the transverse earthquake force exceeds the capacity of the keys, the transverse stiffness for the seismic analysis is zero and a released condition should be used in the seismic analysis. This release will result in larger design lateral forces at the adjacent bents.

SEAT ABUTMENT
Seismic Resisting Elements



$EQ_L \leq R_{soil}$

Section



$EQ_T \leq V_{keys}$
or else $EQ_T = 0$

Elevation

$V_{key} = V_{ww} + 0.75\ (V_{piles})$
or for spread footings
$V_{key} = V_{ww} + 0.75$ (Dead load reaction @ bottom footing)

* Internal shear keys shall be avoided if possible

Note: For notations, see "DIAPHRAGM ABUTMENT (Seismic Resisting Elements)"

Support Width of Abutments (Seismic)

It is recommended that the bearing support width for abutments be equal to the displacements resulting from a seismic elastic analysis or from the following expression, whichever is greater:

$$N = (12 + 0.03L + 0.12H)\left(1 + \frac{S^2}{8,000}\right)^*$$

where

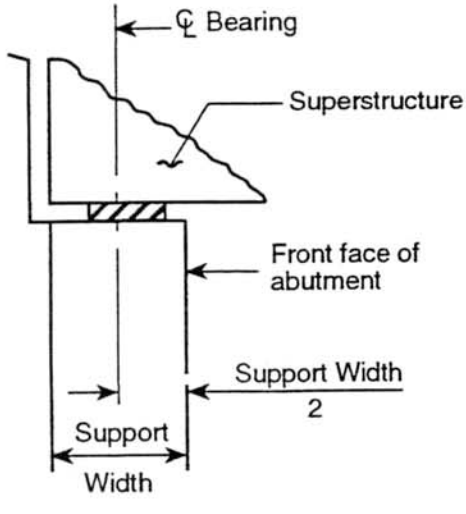
N = Support width in inches, measured normal to the centerline of bearing. Minimum width, 2'-6".

L = Length in feet, of the bridge deck from the abutment to the adjacent expansion joint, or to the end of the bridge deck. For simple span bridges, L equals the length of the bridge deck.

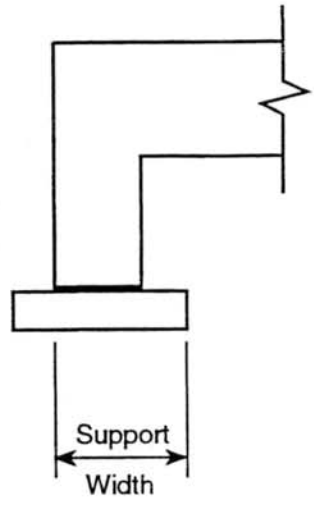
H = Average height in feet of columns or piers supporting the bridge deck from the abutment to the next expansion joint. H = 0 for single span bridges.

S = Skew of abutment in degrees.

*1983 AASHTO Design Guide Specifications and modified for skew by Caltrans.



Seat Abutment

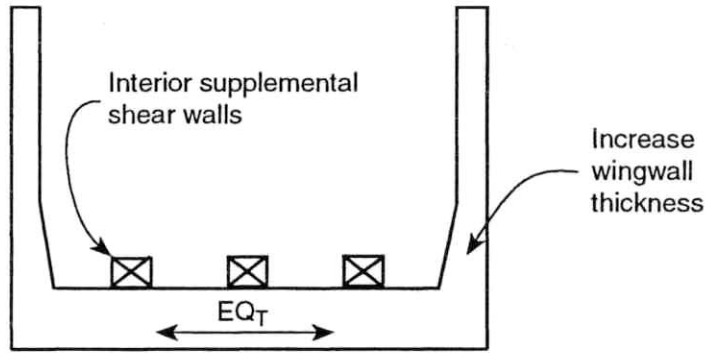


Diaphragm Abutment on Footing

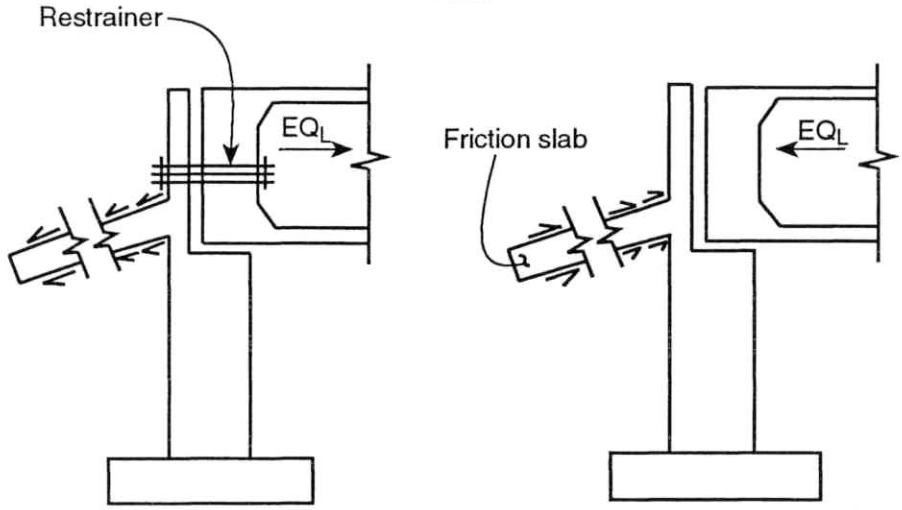
Abutment Enhancements (Seismic)

When it becomes necessary to increase the longitudinal resistance of abutments to reduce the displacements at the bents, force dissipating elements such as a friction slab connected to the abutment backwall along with restrainers connected to the superstructure should be considered.

To increase the transverse resistance of the abutment, interior supplemental shear walls attached to the abutment or increasing the wingwall thickness should be considered.



Plan



Elevation

Jerry A. McKee

Floyd L. Mellon

TPJ:dm

5-1 ABUTMENTS

Type Selection

The designer is responsible for the type of abutments selected, taking into account the requirements for structural support, structure movement, drainage, structure approach and earthquakes.

Six types of abutments are used for bridges; the diaphragm abutment, the short seat abutment, the high cantilever abutment, the bin abutment, the strutted abutment, and the rigid frame abutment.

The diaphragm abutment, *Bridge Design Aids*, pages 1-3 and 1-4 and *Bridge Design Details*, pages 6-20 and 6-21, and the short seat abutment, *Bridge Design Aids*, page 1-5, are the most frequently used abutment types. These abutments are usually placed at the top of the approach embankment and have evolved from the desire to present an open appearance to traffic beneath the structure by removing a structural support adjacent to traffic. The essential structural difference is that the seat abutment permits superstructure movement independent of the abutment while the diaphragm abutment does not.

The major benefit of the diaphragm abutment is its initial lower cost to construct, however maintenance problems generally preclude its use except for short structures. See Memo to Designers 5-2 for uses and limitations of the diaphragm abutment.

The short seat abutment is an independent structural component of the bridge and can generally be designed to accommodate all the imposed forces.

The high cantilever abutment, *Bridge Design Aids*, page 1-6 and *Bridge Design Details*, pages 6-50 through 6-53, the bin abutment, *Bridge Design Details*, pages 6-40 and 6-41, and the strutted abutment, *Bridge Standard Detail Sheets*, XS-22-01, are infrequently used, except for bridge widenings in kind, unusual sites or in some geometrically constrained urban locations. Rigid frame abutments are generally used with tunnel type single span connectors and overhead structures which permit passage through a roadway embankment. These abutment types have a high initial cost and present a closed appearance to approaching traffic by placing the structure support adjacent to traffic. At overcrossings, these abutment types usually preclude the widening of the highway below without complete replacement of the bridge.

Memo converted to metric.

Design Criteria

Article 7.4.1.2 in the *Bridge Design Specifications* permits using either Service Load Design or Load Factor Design methods to design the abutment.

Until the final implementation of Load Factor Design methods, it is recommended that abutments be designed using Service Load Design methods and static earth pressures, except for the seismic resisting elements. The static earth pressures to be used are specified in Article 3.20 in the *Bridge Design Specifications*. See *Bridge Design Aids*, pages 1-1 and 1-2 for the various non-seismic load cases to be considered to design the abutment.

Earthquake

It is the department's policy to accept abutment damage caused by earthquake action provided the damage does not result in collapse of the bridge.

Damage to abutments from a major earthquake is expected and can be tolerated. Our purpose in evaluating the forces and movements at the abutments is to control the damage to the abutment elements and at the same time obtain a realistic estimate of the displacements at the interior supports. Earthquake action tends to densify both the roadway embankments and the foundation material under the embankment. Because many roadway embankments tend to be granular in nature, significant densification of the embankment can be expected during a major earthquake, which could cause significant damage to the structure. Therefore, the designer should use pile foundations at the abutments when the expected peak rock acceleration is 0.6 g or greater, and the embankment height is 3 meters or greater, or if the bents are on piles and significant densification of the foundation material during an earthquake can be expected. The exception to this recommendation is for abutments under single span bridges, these may have either pile or spread footings.

The number of piles required at abutments shall not be controlled by seismic loads.

The restraining elements of the abutment (shear keys, wingwalls and abutment walls) used to resist seismic forces from the superstructure shall be designed by Load Factor Design methods consistent with the assumptions made in the seismic analysis guidelines outlined in *Bridge Design Aids*, Section 14; and in *Bridge Design Specifications*, Section 3 Commentary.

Diaphragm Abutments (Seismic)

The diaphragm abutment engages the adjacent backfill immediately which is very effective in absorbing energy during an earthquake.

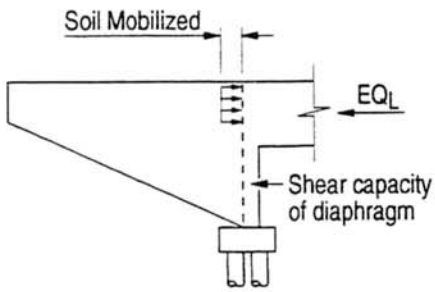
The longitudinal resistance for seismic analysis of a diaphragm abutment should be based on mobilizing the backfill equal to the depth of the superstructure plus the shear capacity of the abutment diaphragm. The ultimate passive resistance of the backfill is assumed to be 370 kPa (kilopascals). The diaphragm abutment shown in *Bridge Design Aids*, pages 1-3 and 1-4 has been designed so that the flexural reinforcing will yield before a shear failure occurs. It is usually impractical to structurally size the abutment diaphragm below the soffit to totally mobilize the backfill. When the design earthquake force is greater than these resisting elements, a reduced stiffness should be used in the seismic analysis based on only the soil resistance. Even though the diaphragm below the soffit will experience damage from a major earthquake, the possibility of collapse of the superstructure is remote.

The transverse resistance for seismic analysis for a diaphragm abutment should be based on the ultimate shear capacity of one wingwall and all piles. When Class 400, Class 625 or standard 400 mm CIDH piles are used an ultimate shear capacity of 180 kN (kilonewtons) per pile may be used.

The limiting force for transverse keys for diaphragm abutments on footings is the ultimate shear capacity of the piles. This force represents the maximum force which can be expected to be transmitted through the keys. To reduce possible damage to the piles, transverse keys should be designed for 75% of this limiting force.

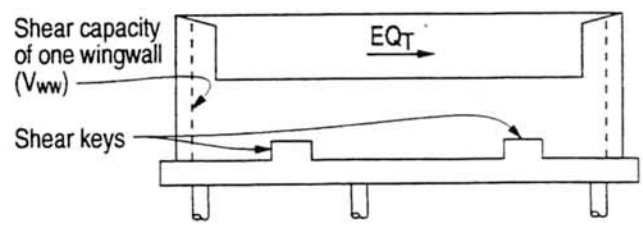
When the design transverse earthquake force exceeds the capacity of the wingwall and piles for diaphragms without a footing or the wingwall and transverse keys for diaphragms with a footing, the transverse stiffness for the seismic analysis is zero and a released condition should be used which will result in larger lateral design forces at the adjacent bents.

When spread footings are used the transverse keys shall be designed for a minimum of 75% of the dead load reaction at the bottom of footing. Abutments on spread footings in rock or very stiff material should be given special consideration and designed to receive larger seismic forces.



SECTION

$EQ_L \leq R_{soil} + V_{diaphragm}$



ELEVATION

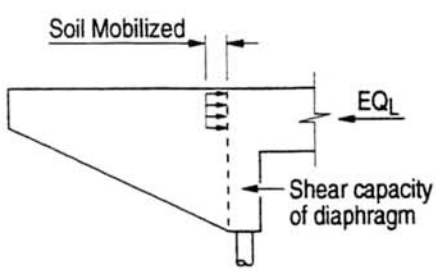
$EQ_T \leq V_{ww} + V_{key}$ or else $EQ_T = 0$

$V_{keys} = 0.75\ (V_{piles})$

or for spread footings

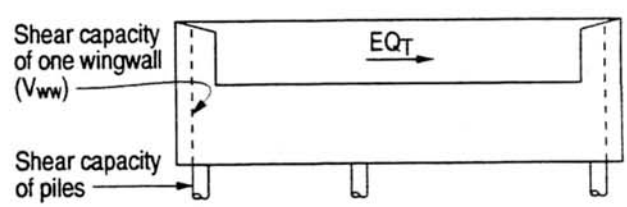
$V_{keys} \approx 0.75$(Dead Load reaction @ bottom of footing)

With Footing



SECTION

$EQ_L \leq R_{soil} + V_{diaphragm}$



ELEVATION

$EQ_T \leq V_{ww} + V_{piles}$ or else $EQ_T = 0$

Without Footing

Diaphragm Abutment (Seismic Resisting Elements)

EQ_L	=	Longitudinal earthquake force from an elastic analysis.
EQ_T	=	Transverse earthquake force from an elastic analysis.
R_{soil}	=	Resistance of soil mobilized behind abutment.
$V_{diaphragm}$	=	ϕ times the nominal shear strength of the diaphragm.
V_{WW}	=	ϕ times the nominal shear strength of the wingwall.
V_{piles}	=	ϕ times the nominal shear strength of the piles.
V_{key}	=	ϕ times the nominal shear strength of the transverse keys in the direction under consideration.

Seat Abutments (Seismic)

The seat abutment gives the designer more control over the amount of earthquake force the abutment will resist, but introduces the potential for the superstructure becoming unseated leading to a collapse of the end span. The superstructure is restrained longitudinally in one direction by the abutment backwall and approach embankment, and transversely by shear keys built into the abutment.

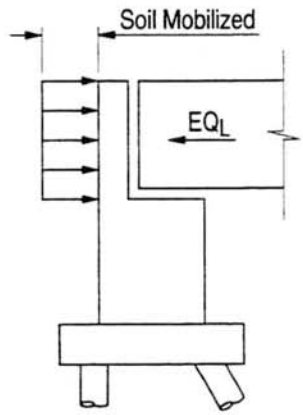
Shear keys for seat abutments that are highly skewed, offer limited resistance in restraining the superstructure from rotating and moving away from the embankment. If possible, the designer should reduce the skew of the abutment, even at the expense of increasing the bridge length. This recommendation is especially pertinent for long connector structures where large earthquake displacements and forces are anticipated at the abutments.

The longitudinal earthquake force required to mobilize the backfill for the full height of the abutment is generally much larger than a practical sized backwall can be designed to resist. Therefore, the backwall is designed to fail before damaging forces can be transmitted to the lower portion of the abutment. The longitudinal stiffness assumed for the seismic analysis should be based on mobilizing only the soil equal to the depth of the superstructure. This stiffness will result in larger earthquake forces at the adjacent bents, than would occur if the total stiffness were mobilized. Longitudinal displacements will also increase, however these results are generally unavoidable and are preferred to introducing excessive damage to the abutment below the soffit level. The effects of larger displacements and forces at the bents must be considered in the design.

For seat abutment transverse keys, the limiting transverse earthquake force may be approximated by adding the ultimate shear capacity of one wingwall plus the ultimate shear capacity of the piles. This force is the maximum force which can be expected to be transmitted through the keys. To reduce possible damage to the piles, transverse keys should be designed for the ultimate shear capacity of one wingwall plus 75% of the ultimate shear capacity of the piles.

When spread footings are used the keys shall be designed for a minimum of 75% of the dead load reaction at the bottom of the footing. Abutments on spread footings in rock or very stiff material should be given special consideration and designed to receive larger seismic forces.

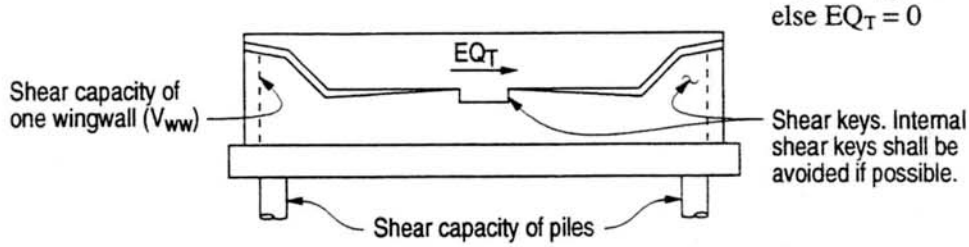
When the transverse earthquake force exceeds the capacity of the keys, the trans-verse stiffness for the seismic analysis is zero and a released condition should be used in the seismic analysis. This release will result in larger design lateral forces at the adjacent bents.



$EQ_L \leq R_{soil}$

SECTION

$EQ_T \leq V_{keys}$ or
else $EQ_T = 0$



ELEVATION

$$V_{key} \approx V_{ww} + 0.75(V_{piles})$$

or for spread footings

$$V_{key} \approx V_{ww} + 0.75(\text{Dead Load reaction @ bottom footing})$$

Seat Abutment (Seismic Resisting Elements)

NOTE: For notations, see "Diaphragm Abutment (Seismic Resisting Elements)"

Support Width of Abutments (Seismic)

It is recommended that the bearing support width for abutments be equal to the displacements resulting from a seismic elastic analysis or from the following expression, whichever is greater:

$$N = (12 + 0.03L + 0.12H)\left(1 + \frac{S^2}{8{,}000}\right) \quad *$$

$$= (200 + 0.0017L + 0.0067H)\left(1 + \frac{S^2}{8{,}000}\right)$$

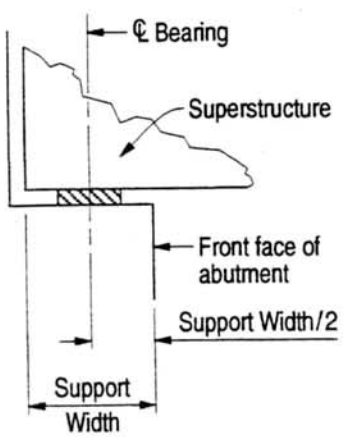
where

N = Support width in millimeters, measured normal to the centerline of bearing. Minimum width, 750 mm.

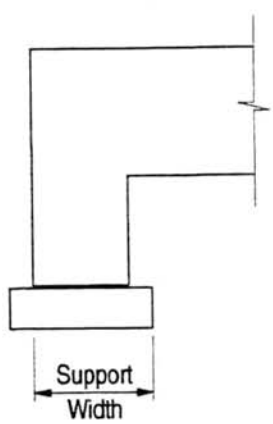
L = Length in millimeters, of the bridge deck from the abutment to the adjacent expansion joint, or to the end of the bridge deck. For simple span bridges, L equals the length of the bridge deck.

H = Average height in millimeters of columns or piers supporting the bridge deck from the abutment to the next expansion joint. H = 0 for single span bridges.

S = Skew of abutment in degrees.



SEAT ABUTMENT



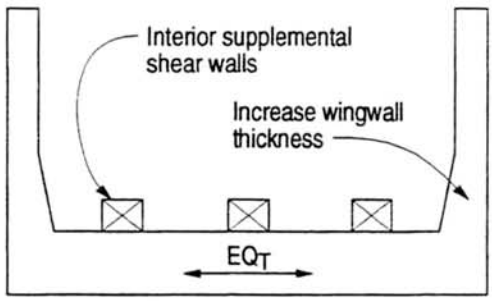
DIAPHRAGM ABUTMENT ON FOOTING

*1994 AASHTO LRFD Bridge Design Specifications.

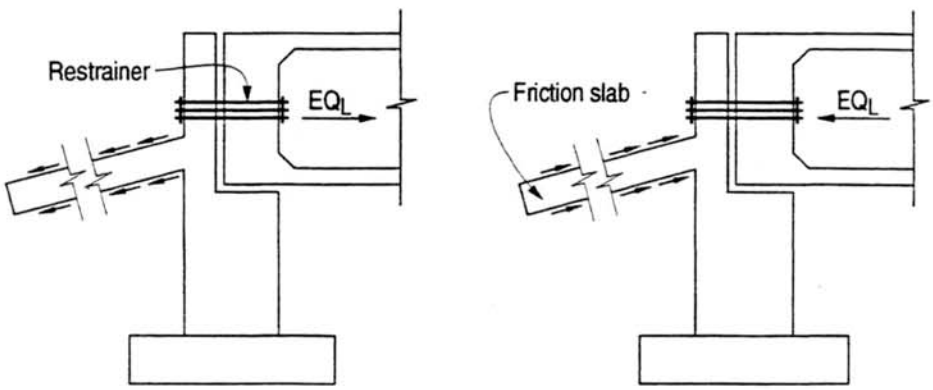
Abutment Enhancements (Seismic)

When it becomes necessary to increase the longitudinal resistance of abutments to reduce the displacements at the bents, force dissipating elements such as a friction slab connected to the abutment backwall along with restrainers connected to the superstructure should be considered.

To increase the transverse resistance of the abutment, interior supplemental shear walls attached to the abutment or increasing the wingwall thickness should be considered.



PLAN



ELEVATION

Richard D. Land

Shannon H. Post

TPJ:jgf/jlw