Innovative
Ductile Seismic Shear Keys (DSSK)

DETAILS AND DESIGN METHODOLOGY

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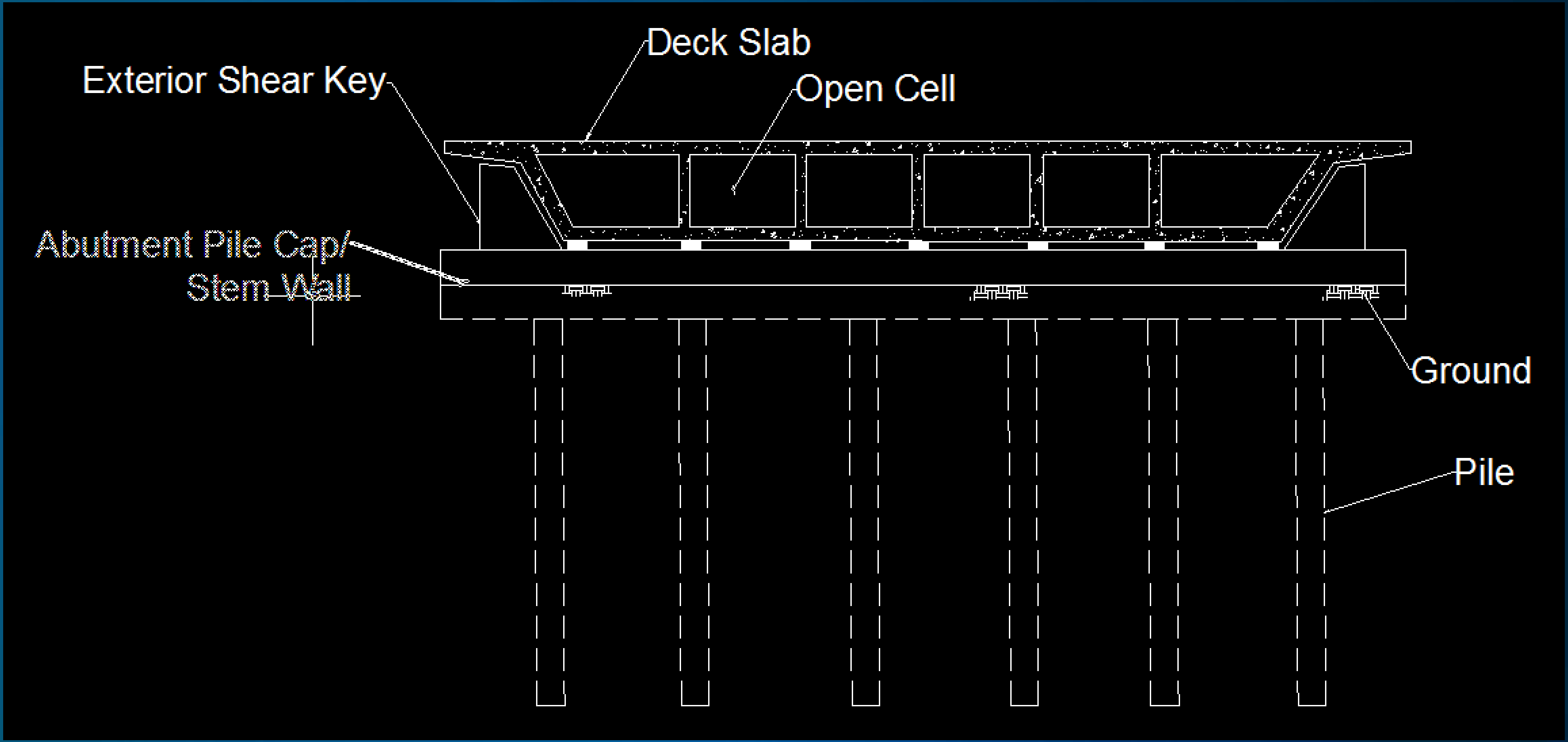
Outline

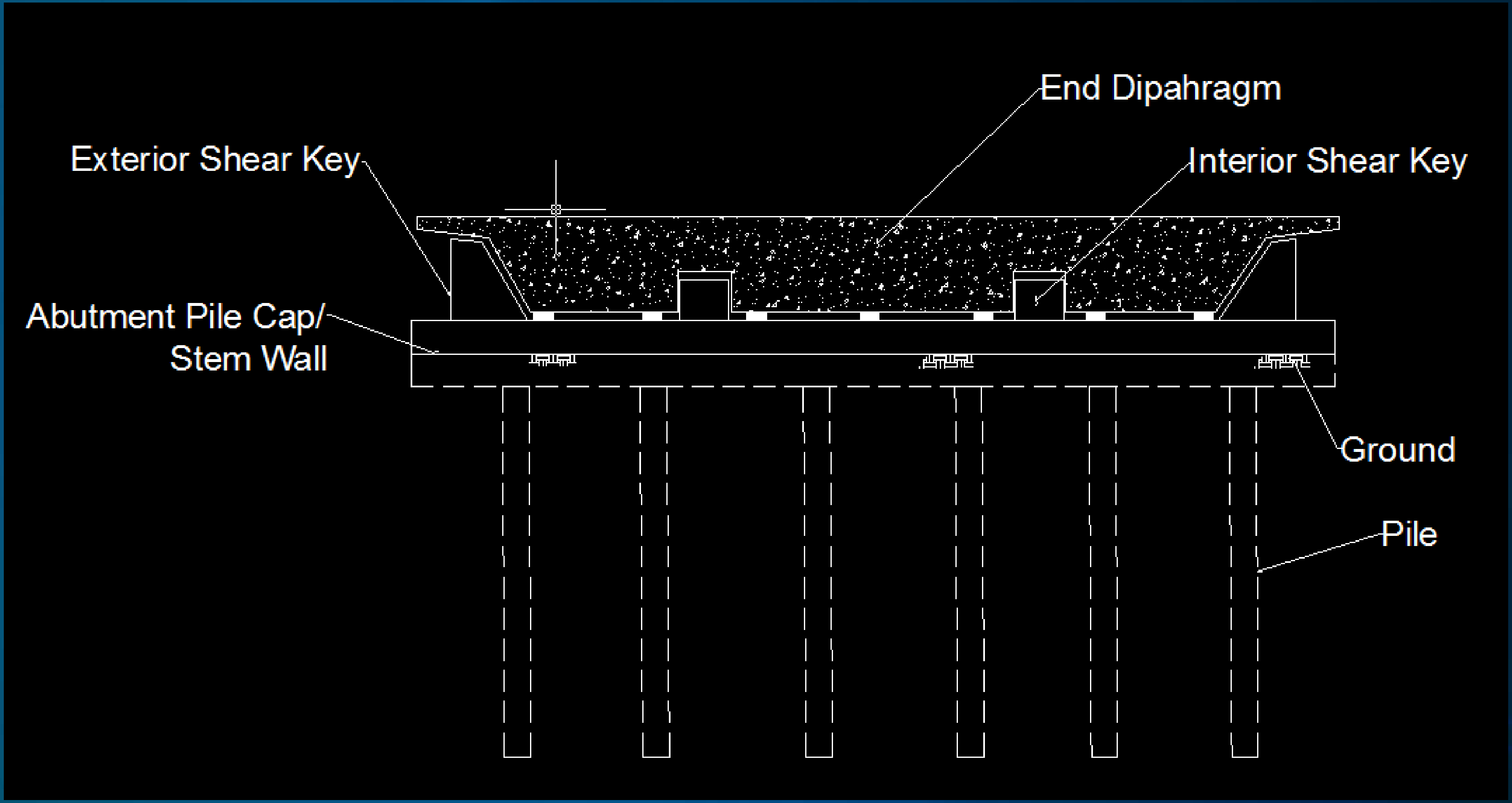
- Background/Common Practice
- Statement of Problem
- Innovative Details
- Design Methodology
- Example
- Conclusion

Background



Typical Shear Key- Abutments

Background



Typical Shear Key- Abutments

Why We Need Shear Keys?

- **Resistance to Wind Loads**
- **Resistance to Live Loads**

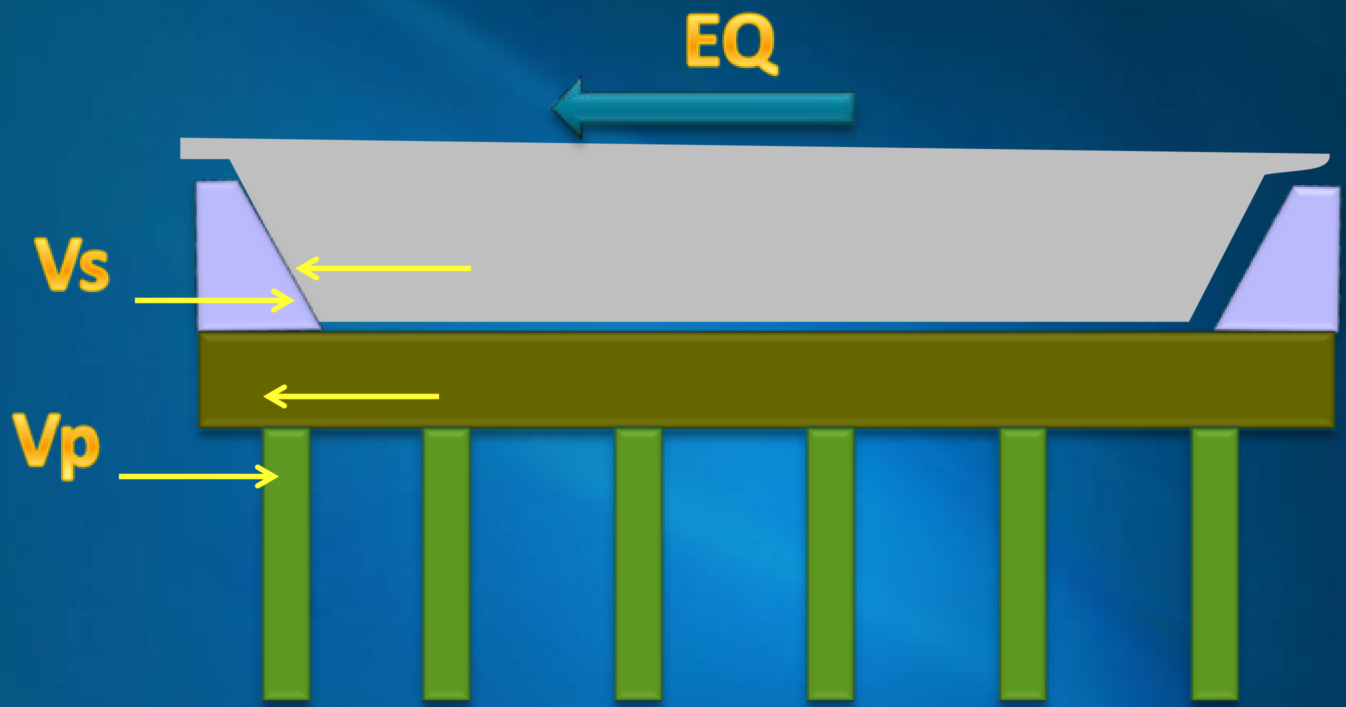
Most important reason (in seismic region):

☐ ***To reduce lateral seismic displacement, thus, reducing displacement demands on substructure***

~~**To protect foundation piles against damage**~~

- **Capacity Protection of piles is only ‘a condition’ for performance-based design criteria not the reason for using shear keys**

Interacting Forces



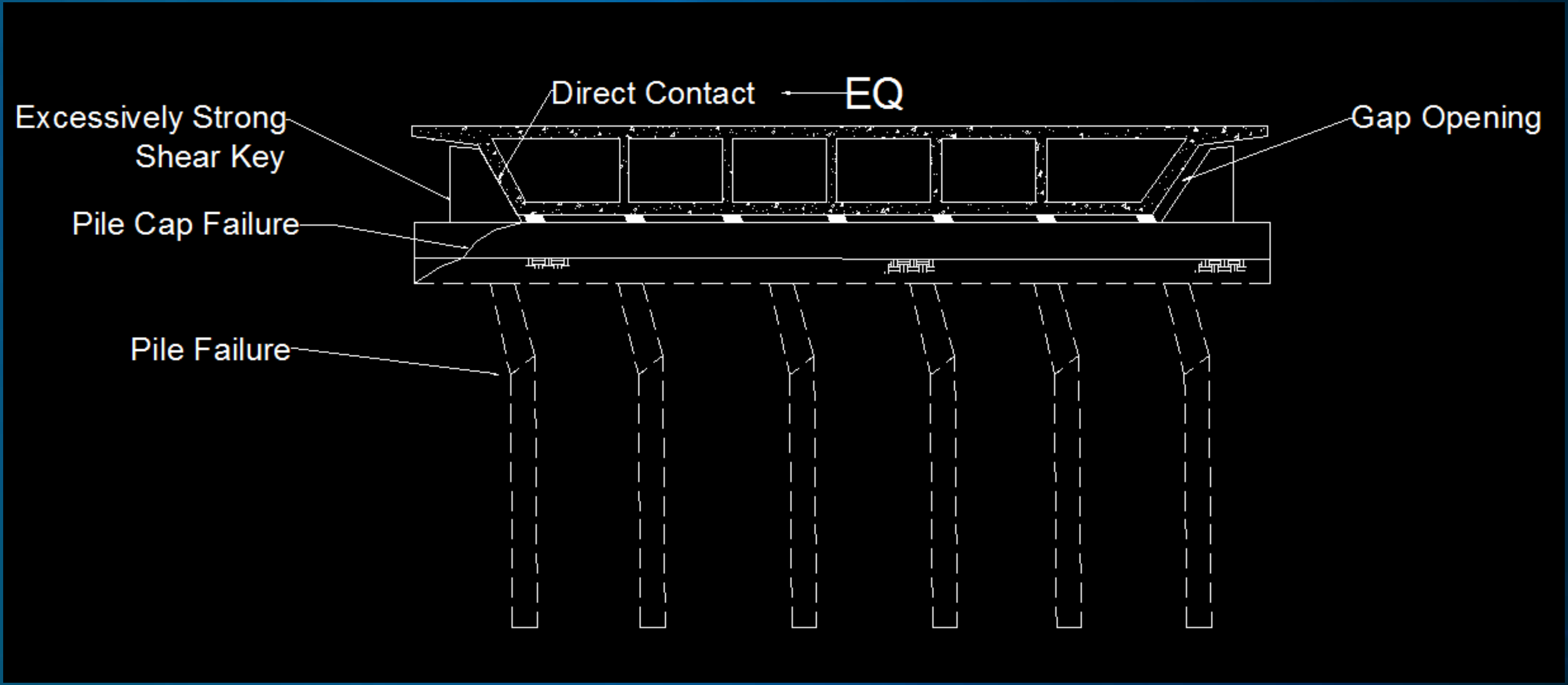
Vs ≥ Vp Pile Failure

Vp ≥ Vs Shear Key Failure

Vp : Resistance of pile group

Vs: Resistance of shear Key

Undesirable Failure Mode



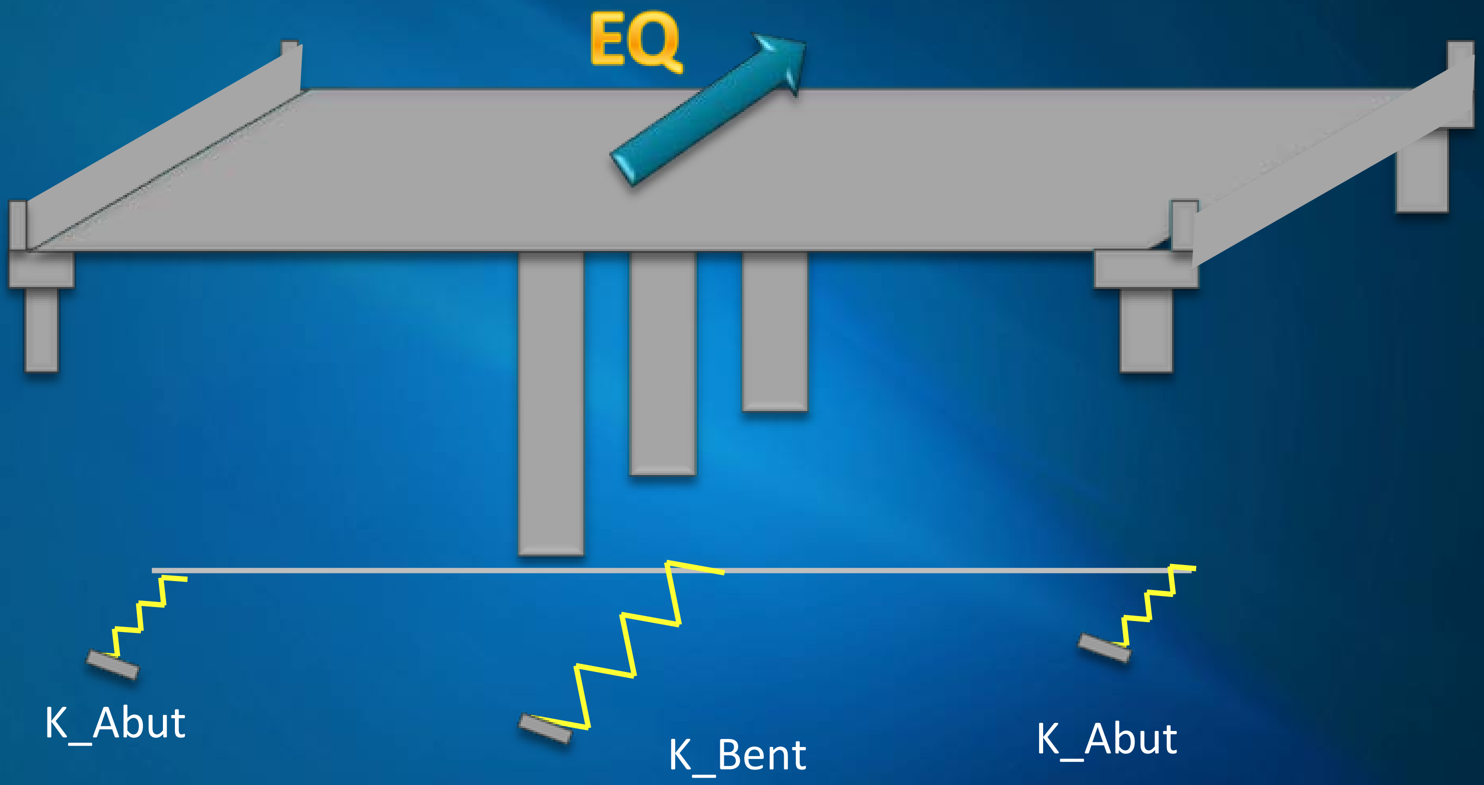
Problem Areas

1- Modeling Assumptions

2- Design Criteria Issues

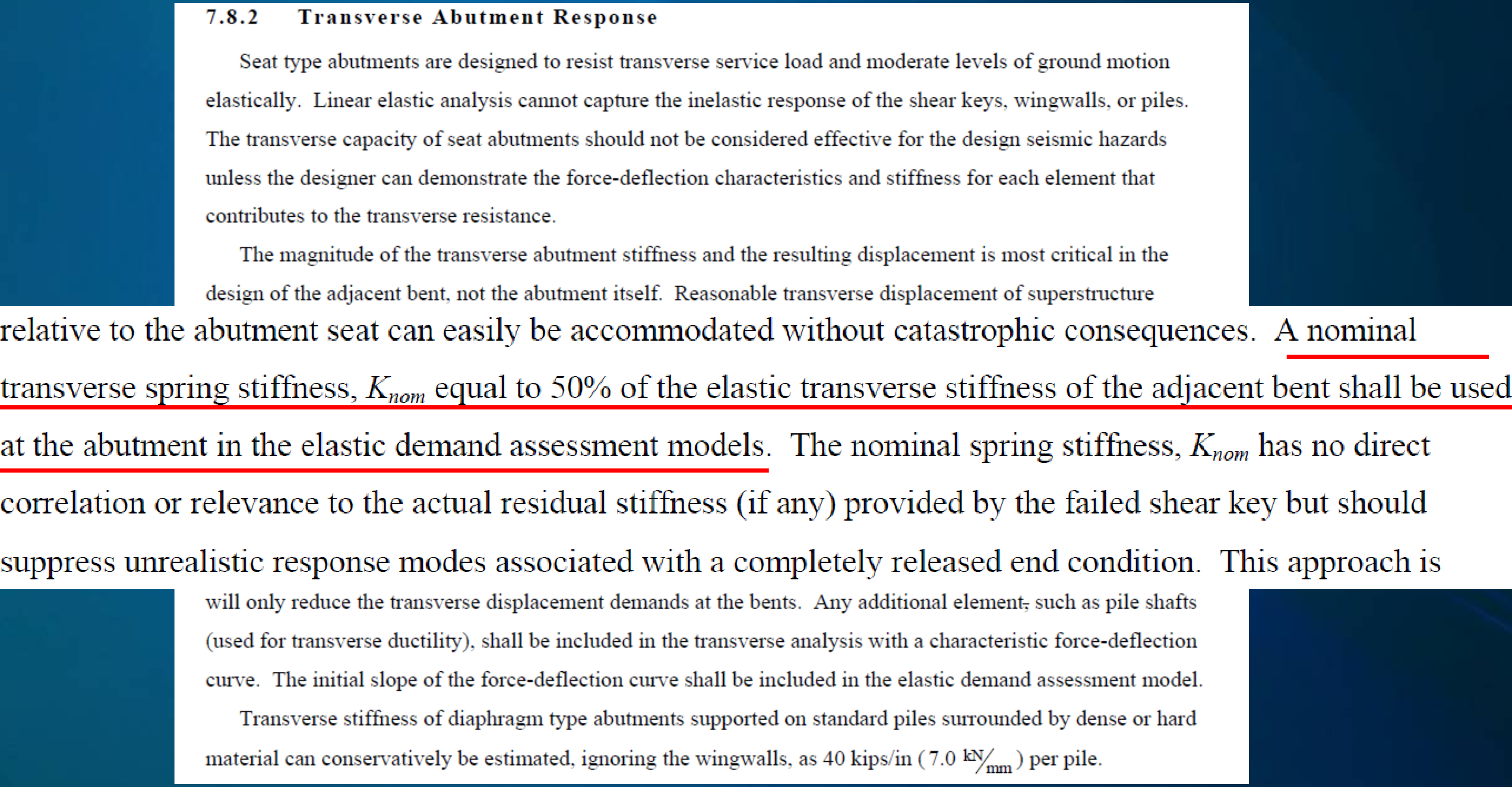
3- Performance of Shear Keys (Testing of Existing and Modified)

1-Modeling Issues



1-1 Modeling Issues

- Simplified Approach (Caltrans Seismic Performance Criteria, SDC 1.6)



7.8.2 Transverse Abutment Response

Seat type abutments are designed to resist transverse service load and moderate levels of ground motion elastically. Linear elastic analysis cannot capture the inelastic response of the shear keys, wingwalls, or piles. The transverse capacity of seat abutments should not be considered effective for the design seismic hazards unless the designer can demonstrate the force-deflection characteristics and stiffness for each element that contributes to the transverse resistance.

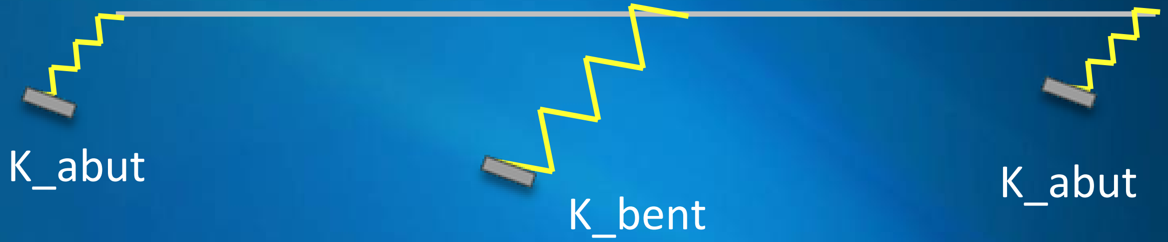
The magnitude of the transverse abutment stiffness and the resulting displacement is most critical in the design of the adjacent bent, not the abutment itself. Reasonable transverse displacement of superstructure relative to the abutment seat can easily be accommodated without catastrophic consequences. A nominal transverse spring stiffness, K_{nom} equal to 50% of the elastic transverse stiffness of the adjacent bent shall be used at the abutment in the elastic demand assessment models. The nominal spring stiffness, K_{nom} has no direct correlation or relevance to the actual residual stiffness (if any) provided by the failed shear key but should suppress unrealistic response modes associated with a completely released end condition. This approach is

will only reduce the transverse displacement demands at the bents. Any additional element, such as pile shafts (used for transverse ductility), shall be included in the transverse analysis with a characteristic force-deflection curve. The initial slope of the force-deflection curve shall be included in the elastic demand assessment model.

Transverse stiffness of diaphragm type abutments supported on standard piles surrounded by dense or hard material can conservatively be estimated, ignoring the wingwalls, as 40 kips/in (7.0 $^{\text{kN}}/_{\text{mm}}$) per pile.

1-2 Modeling Issues

Simplified Approach (Caltrans Seismic Performance Criteria, SDC 1.6)



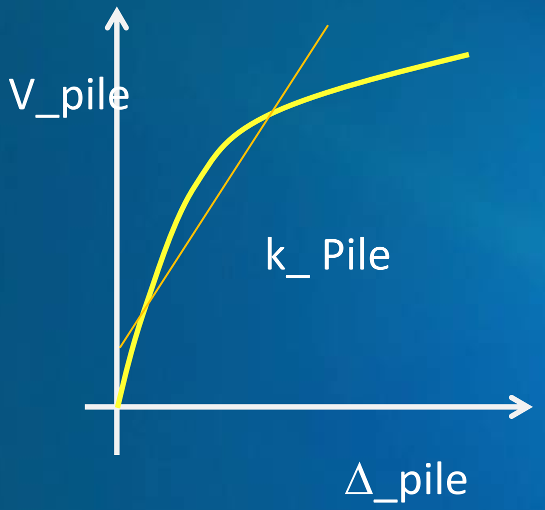
$K_{abut} = K_{nom} = \frac{1}{2} K_{bent}$

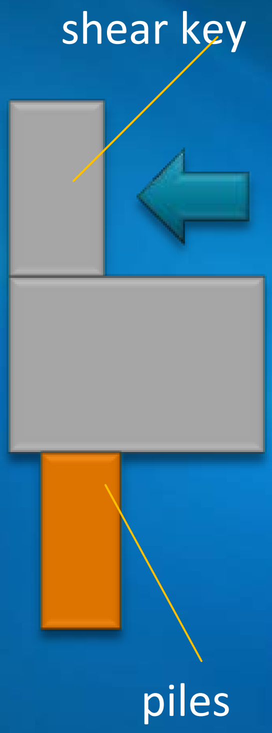
$K_{tot} = 2 K_{bent}$

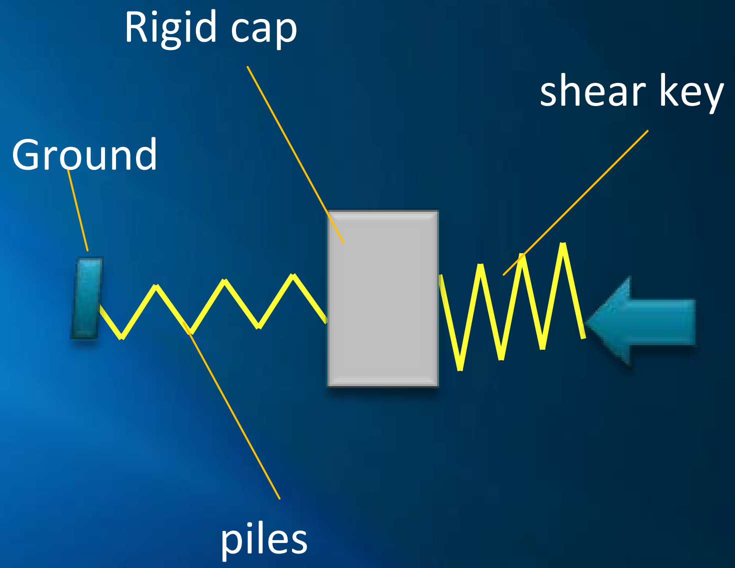
- Neither displacement nor forces are checked
- Stiffness used does not represent the designed shear key

1-3 Modeling Issues

Alternative Modeling Approach





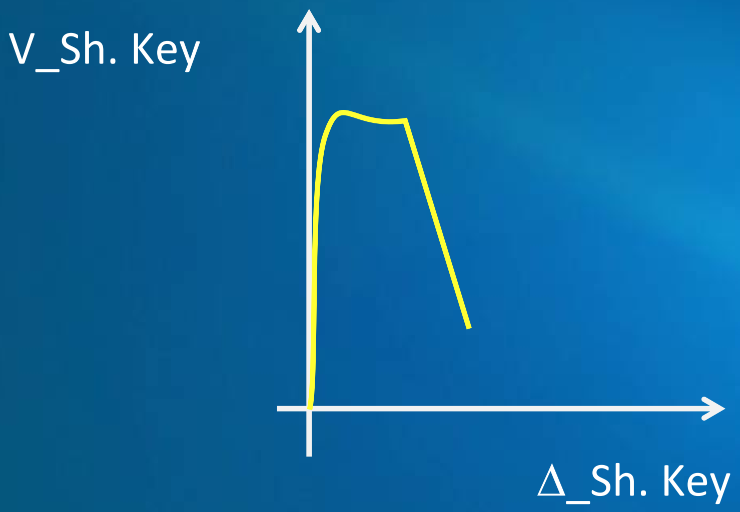


k_ Pile ≅ 40 k/in/ Pile

1/K_abut = 1/ (K_shear key) + 1/ (k_ Piles)

1-4 Modeling Issues

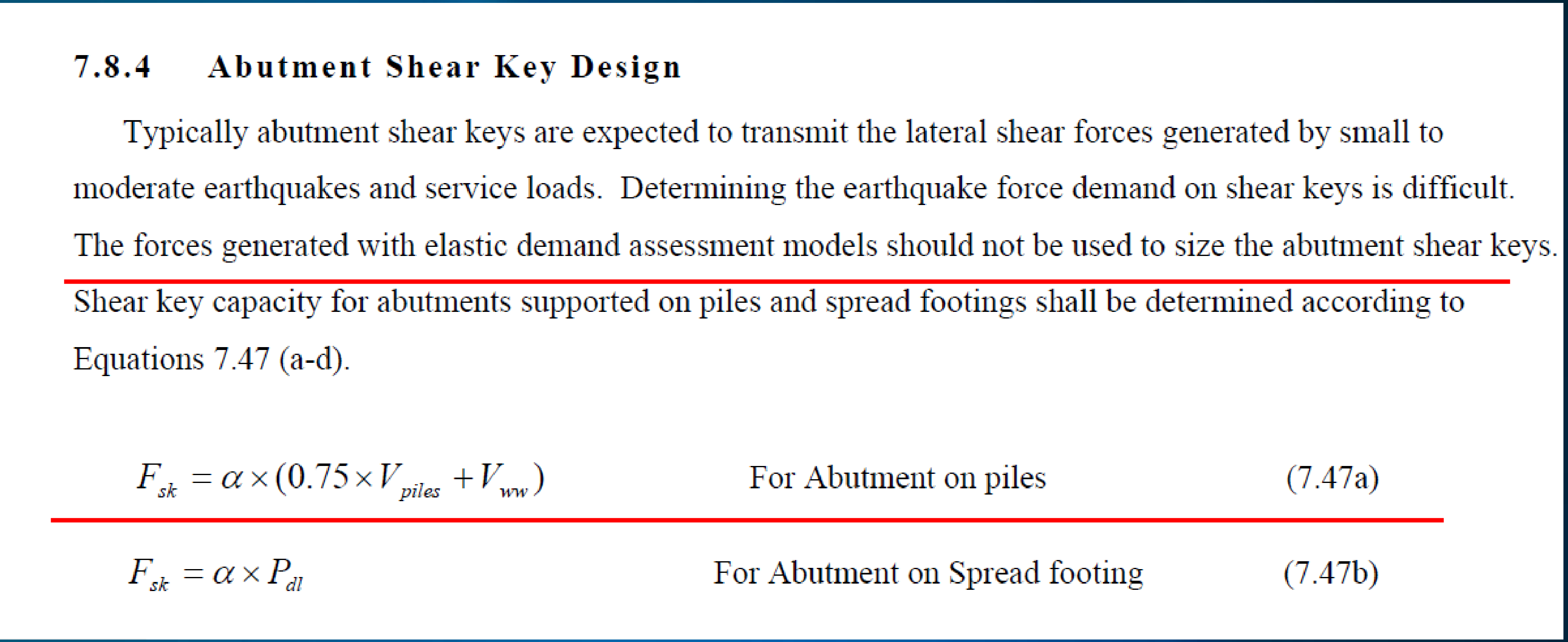
Conventional Shear Key Stiffness?



- It is actually not 100% rigid but assumed rigid
- Difficult to quantify stiffness

K_abut = k_ Piles

2- Design Issues, Criteria



7.8.4 Abutment Shear Key Design

Typically abutment shear keys are expected to transmit the lateral shear forces generated by small to moderate earthquakes and service loads. Determining the earthquake force demand on shear keys is difficult. The forces generated with elastic demand assessment models should not be used to size the abutment shear keys. Shear key capacity for abutments supported on piles and spread footings shall be determined according to Equations 7.47 (a-d).

$$F_{sk} = \alpha \times (0.75 \times V_{piles} + V_{ww}) \qquad \text{For Abutment on piles} \qquad (7.47a)$$

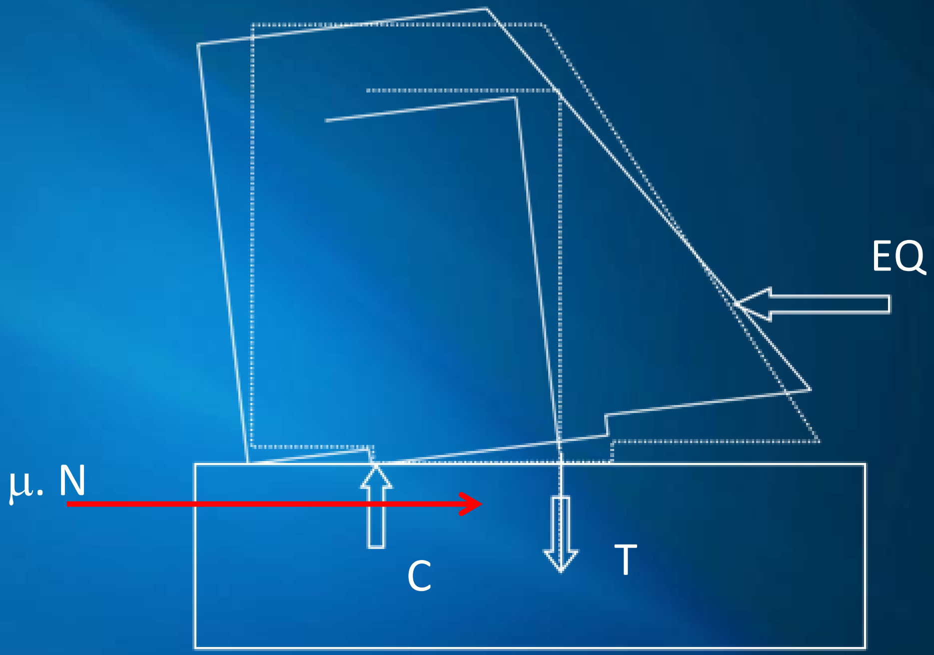
$$F_{sk} = \alpha \times P_{dl} \qquad \text{For Abutment on Spread footing} \qquad (7.47b)$$

- Only upper bound of shear strength considered
- No consideration of ductility/displacement demands

Performance of Conventional Shear Keys

Conventional Shear Keys designed based on shear-friction failure mechanism

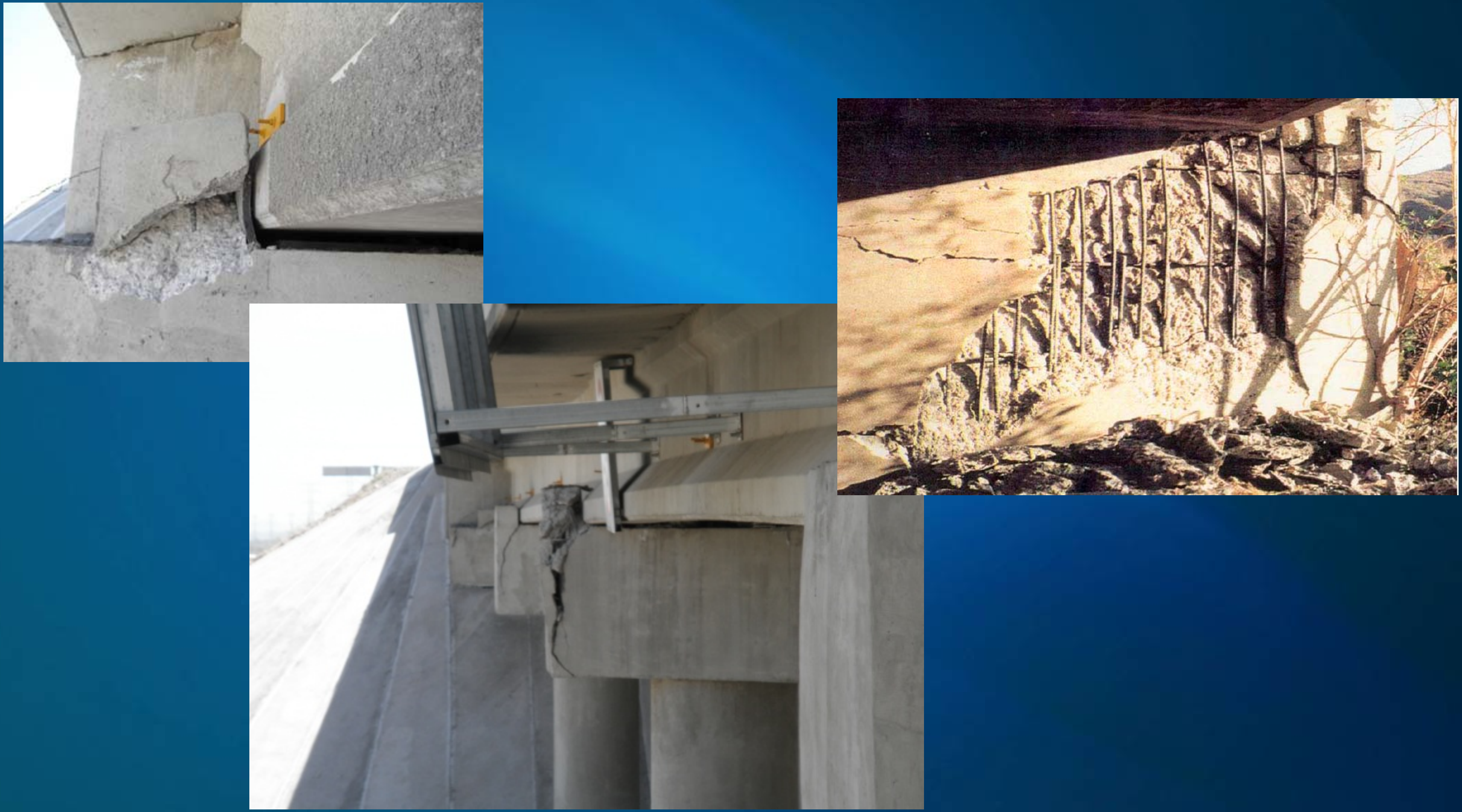
μ. N = μ. C. = μ. T
μ. T= μ. As. Fy



- **Significant overstrength, variability**
- **Lack of sufficeint ductility**
- **Cannot Establish its displacement capacity**
- **Not a reversible mechanism**

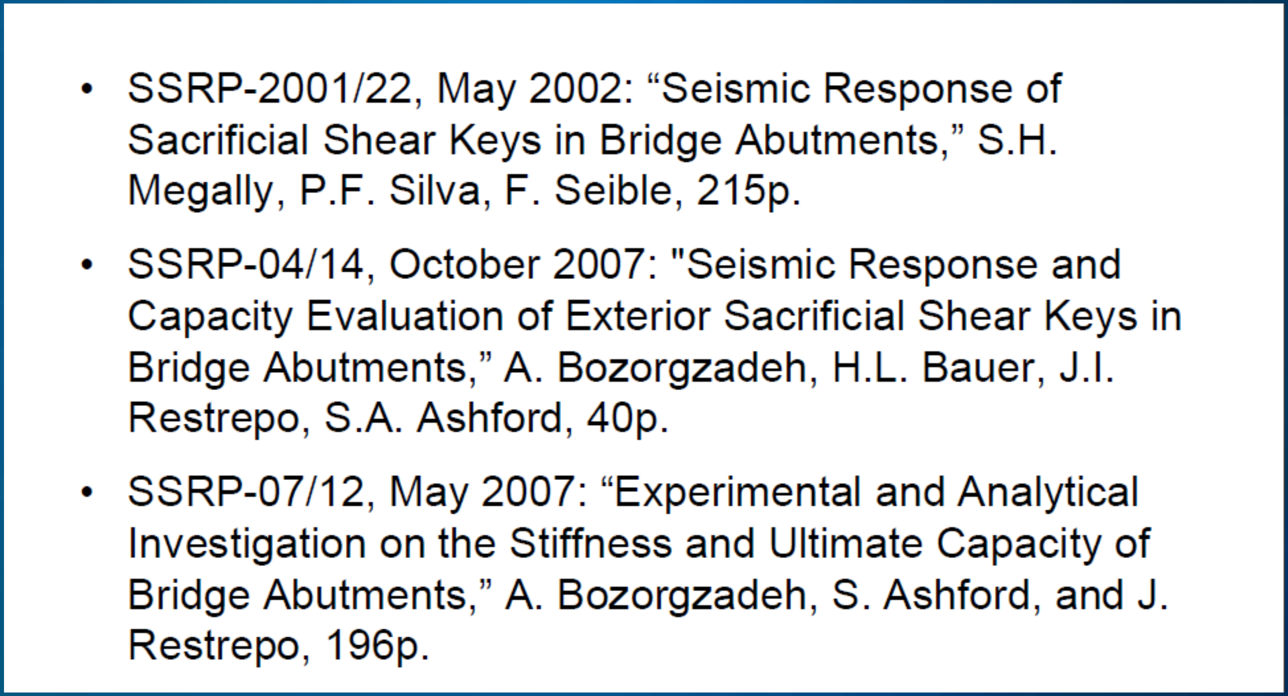
Performance of Traditional Shear Keys

- **Abutment and pile damaged during past earthquakes**



3- Performance of Traditional Shear Keys

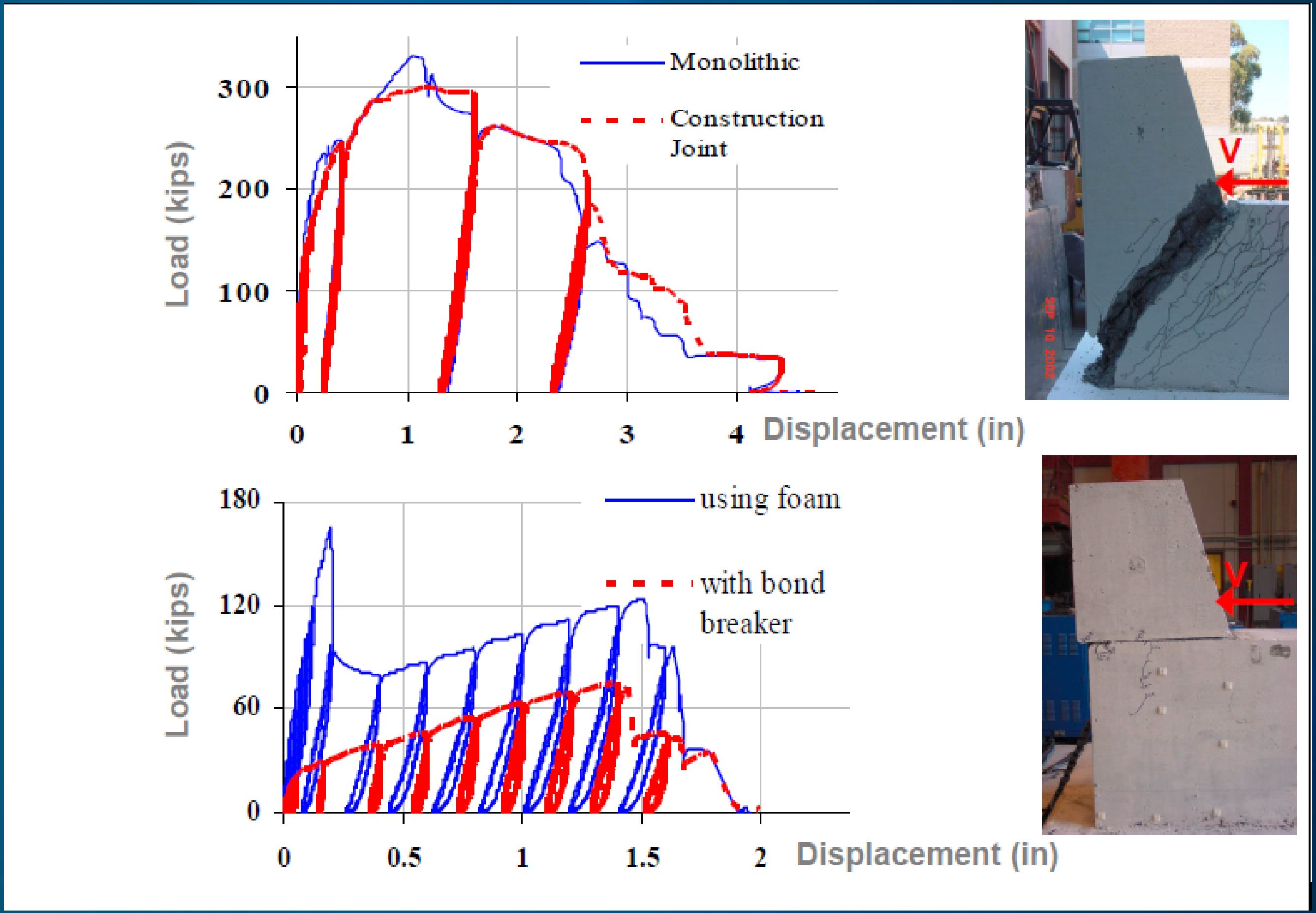
- Many research projects conducted at UCSD
- Testing confirmed deficiencies



- SSRP-2001/22, May 2002: “Seismic Response of Sacrificial Shear Keys in Bridge Abutments,” S.H. Megally, P.F. Silva, F. Seible, 215p.
- SSRP-04/14, October 2007: "Seismic Response and Capacity Evaluation of Exterior Sacrificial Shear Keys in Bridge Abutments,” A. Bozorgzadeh, H.L. Bauer, J.I. Restrepo, S.A. Ashford, 40p.
- SSRP-07/12, May 2007: “Experimental and Analytical Investigation on the Stiffness and Ultimate Capacity of Bridge Abutments,” A. Bozorgzadeh, S. Ashford, and J. Restrepo, 196p.

3-Performance of Traditional Shear Keys

- **Tests at UCSD (Traditional and improved shear keys)**



Statement of Problems

1- The current practice does not account for:

- Shear key stiffness
- Shear ductility
- Shear key displacement capacity

2- Shear friction mechanism is not dependable yielding or repeatable/reversible) mechanism

Most Importantly:

3- Premature shear key failure even though as sacrificial component cause excessive demands on substructures

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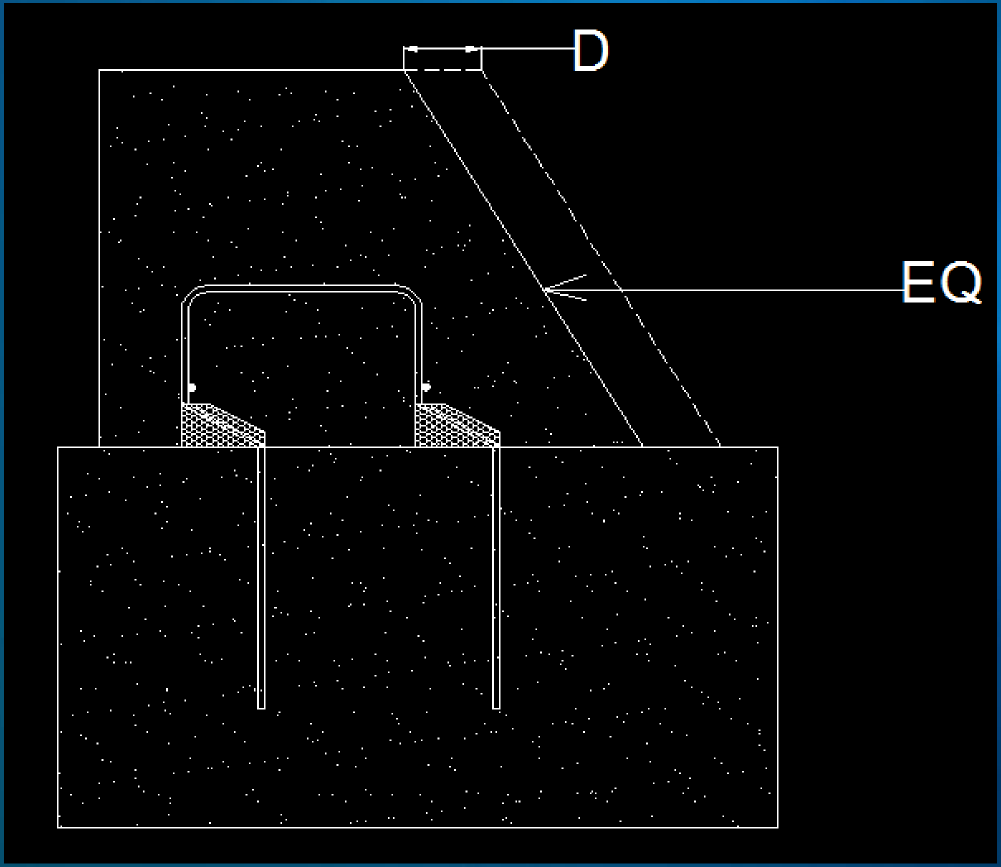
Ductile Seismic Shear Keys , DSSK

Patent Pending (US 2010/0319271)



- Exterior key

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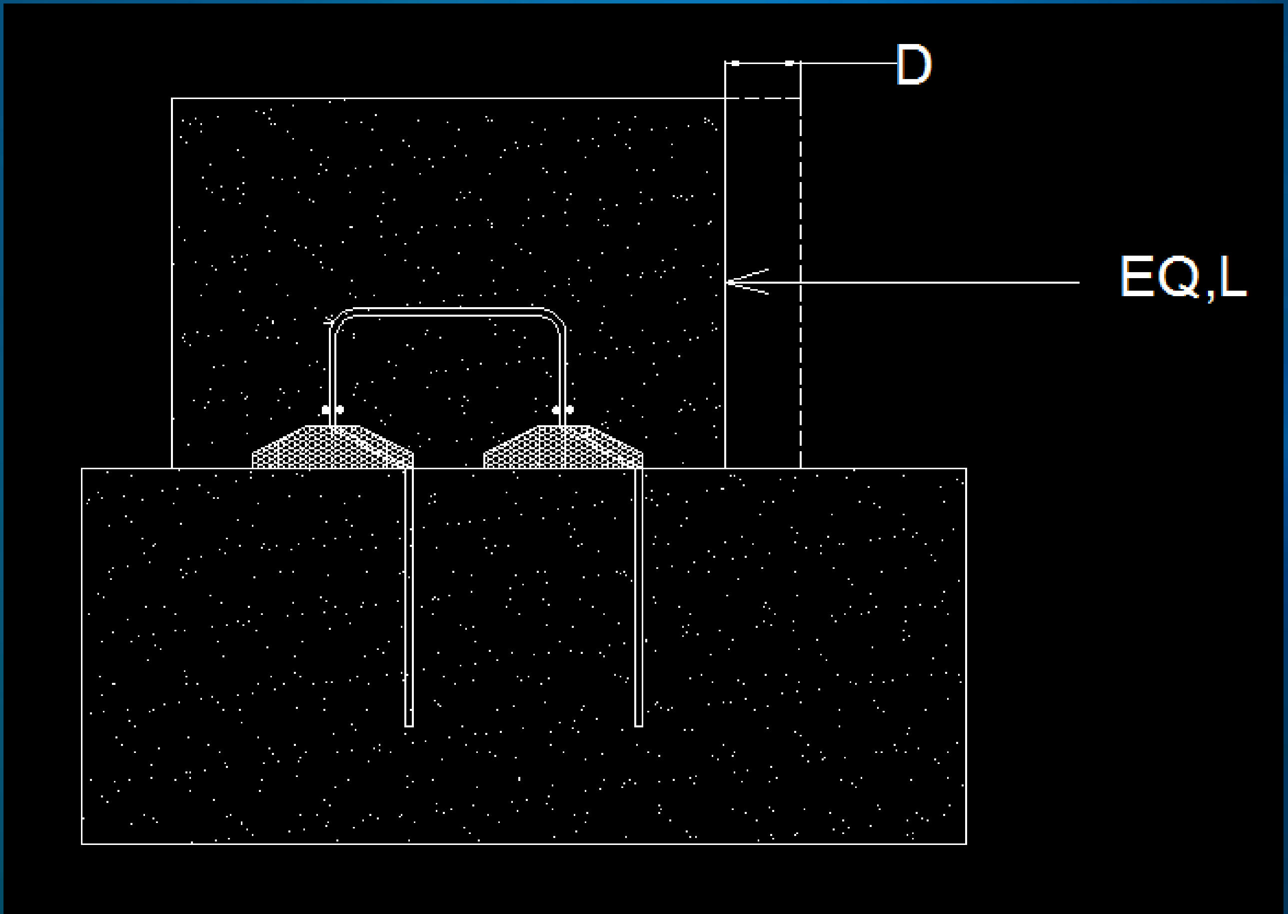

- Interior key

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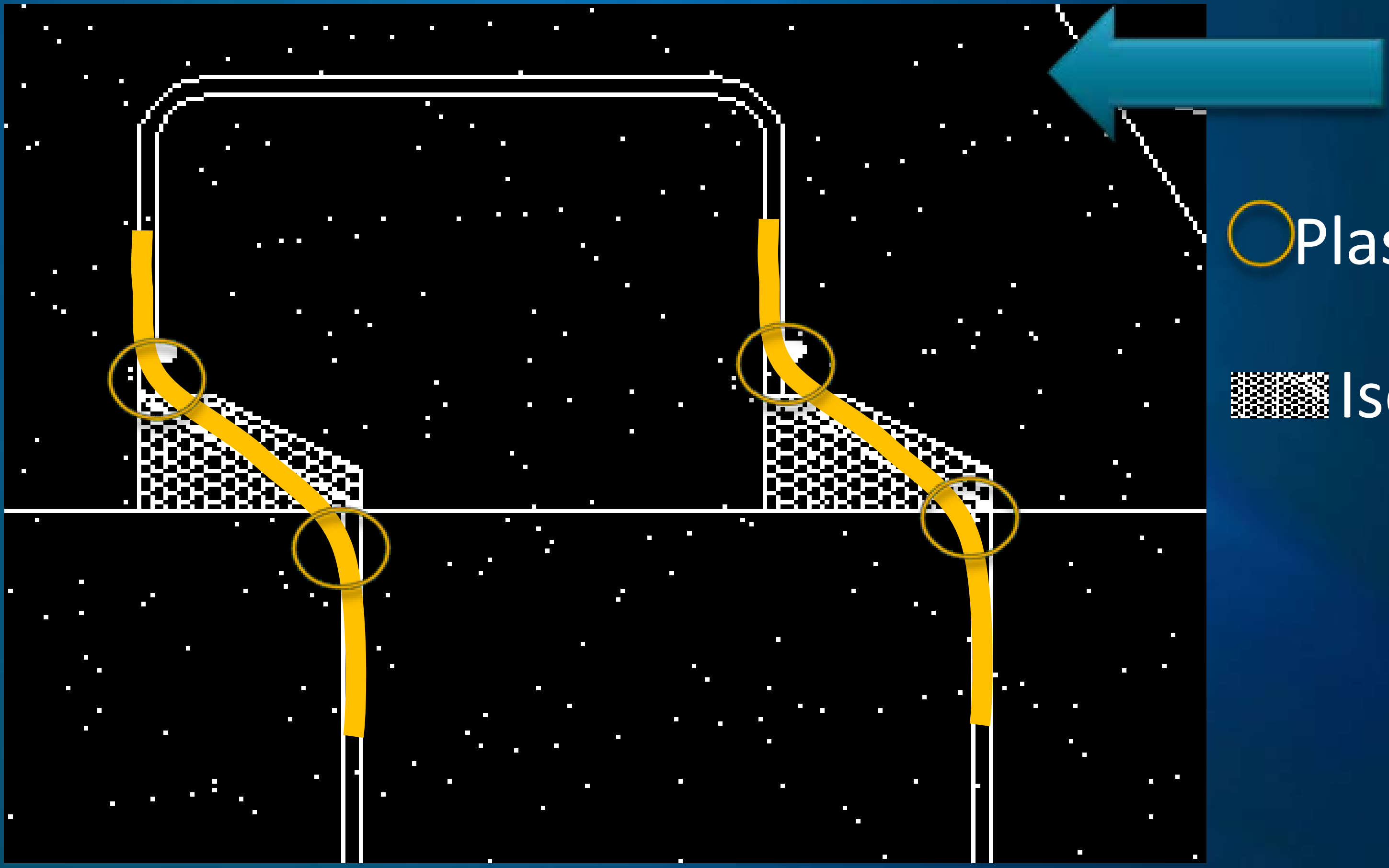
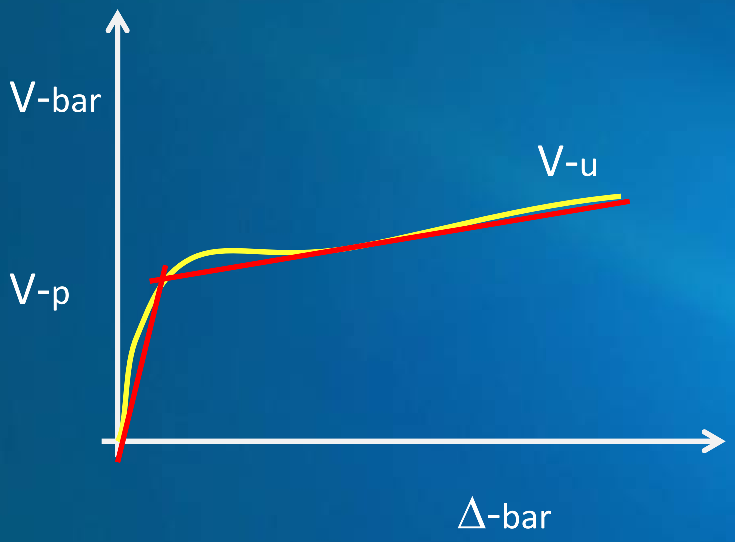
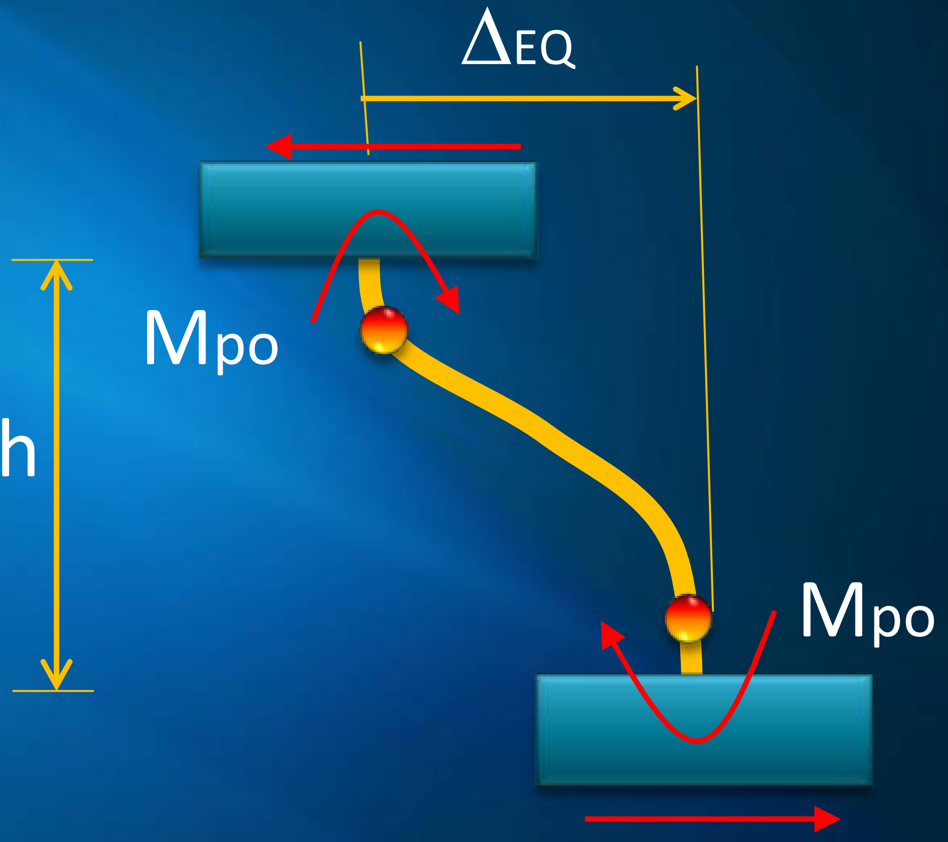


○ Plastic Hinge

▨ Isolation Key

Ductile Seismic Shear Keys Design Methodology





Advantages of DSSK

1-Simple mechanism, can easily establish:

- Stiffness
- Strength
- Ductility

2-Simple to incorporate to modeling and analysis

3- True performance design (based logically established displacement/ductility demands and capacity of the keys)

Advantages of DSSK

- Stiffness

  K = 12 EI_bar/h ^3

- Strength

  $V_{bar} = 2\ M_{po}/h$

- Ductility
  Can be established based on steel ultimate strain

  Ɛ max_bar = 80% Ɛu_st = 0.06

Design Process for DSSK

1- Establish Upper Bound Shear Capacity (Foundation pile Capacity Protection)

2- Establish DSSK Yield Strength

3- Assume Bar Dia., and Est. Bar Height, h

4- Calculate No of bars, n

5- Calculate D.S.S.K stiffness

6- Perform EDA to find D.S.S.K seismic displacement

7- Revise Design Parameter (n, h, Dia.)

Design Equations for DSSK

Number of Dowels, n_{bars}:

$$n_{bar} = \frac{V_{EQ}.h}{24D^3}$$

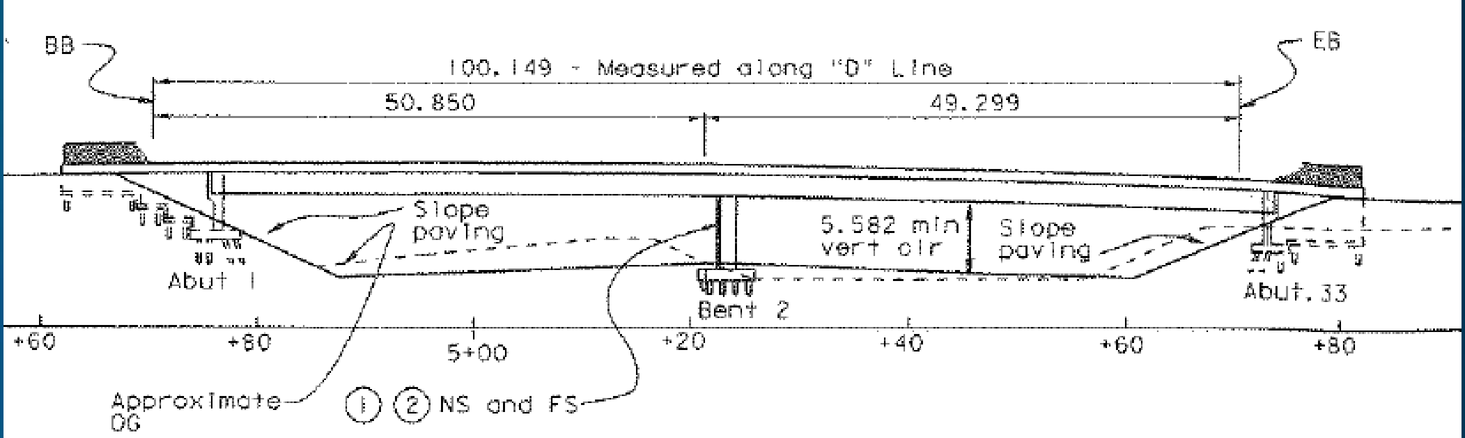
Based on strength equation

Bar Height Equation, h:

$$h = 60\ D\left(-1 + \sqrt{1 + \frac{0.24\ \Delta Eq}{D}}\right)$$

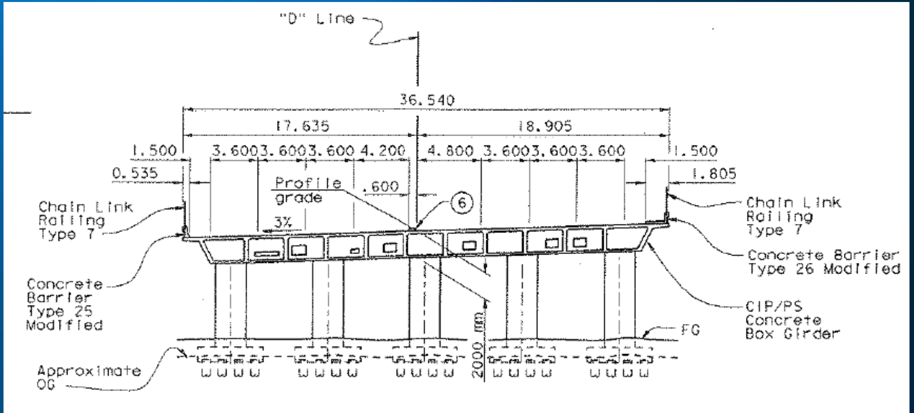
Based on limiting strain of deformed bar

Design Example (Dixon Landing Rd OC)



ELEVATION

1:400



TYPICAL SECTION

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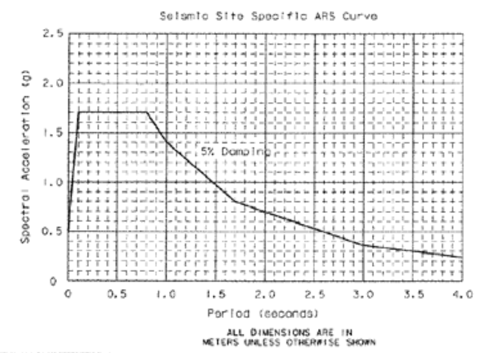
Design Example SAP2000, EDA



ΔEq = 17.0 in (w/o key)

ΔEq = 12.0 in (w DSSK)

30% Nearly Reduction in Displacement Demands in substructure

Conclusions

- Innovative DSSK offers unique simplicity and consistency with fundamentals of performance based design and incorporates all important parameter:
- Stiffness
- Strength
- Ductility/Displacement
- DSSK stiffness is easily incorporated in analytical models to correctly predict displacement demands in substructure