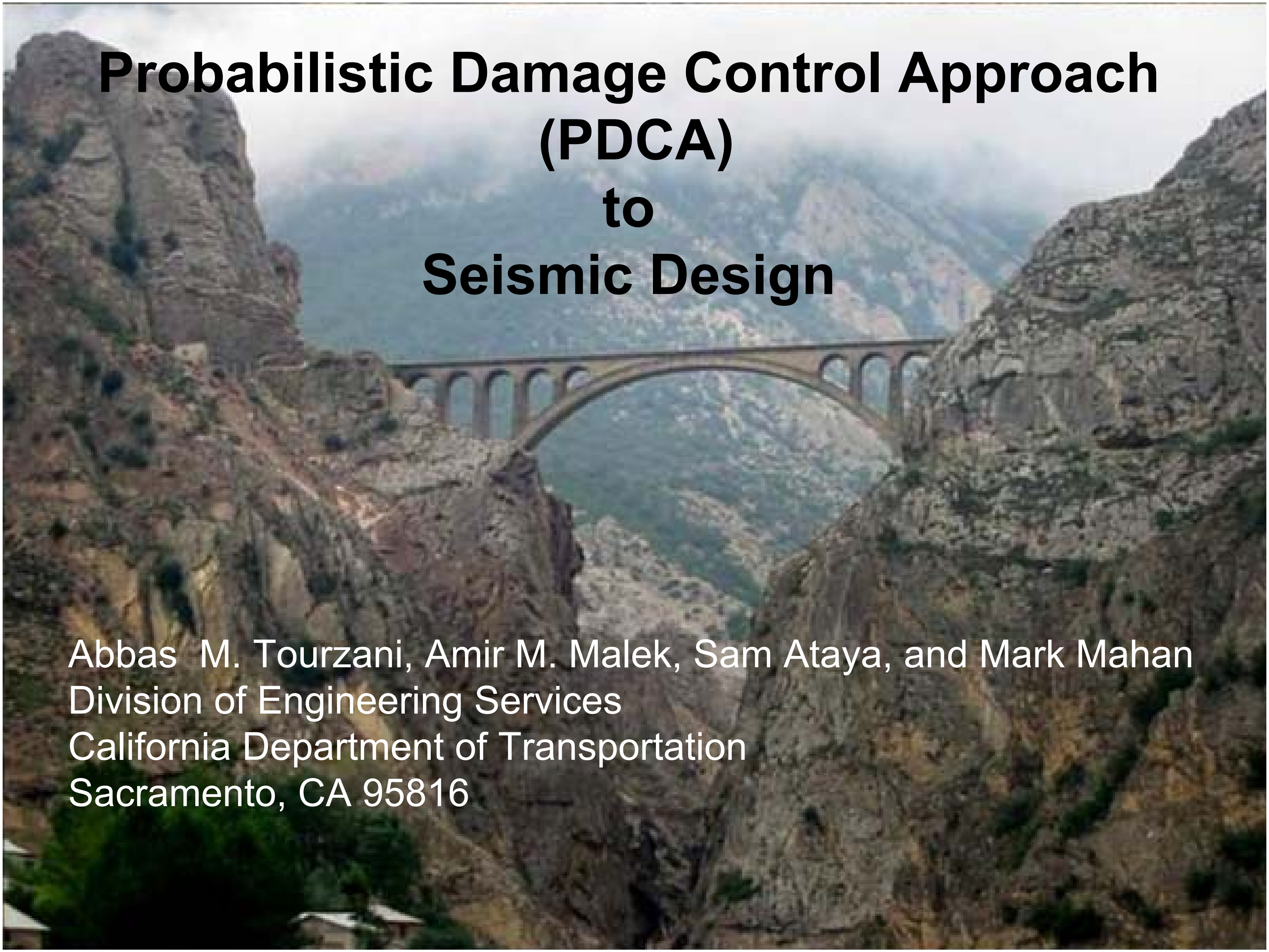
Probabilistic Damage Control Approach (PDCA) to Seismic Design



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Topics of Discussion

- Introduction
- Background
- Probabilistic Damage Control Approach (PDCA)
- Examples of PDCA
- Next Steps
- Questions

Introduction

Bridge Category (Caltrans MTD 20-1):

- Important
  - Life Safety
  - Major Economic Impact
  - Local Emergency Plan
- Ordinary (SDC)

Introduction, cont.

- Seismic Performance Criteria (*Caltrans*):
  - *Functionality*
    - Ordinary Bridges…………… Damage= repairable
    - Important Bridges…………..Damage=Minimal
  - *Safety*
    - Ordinary Bridges……………Damage= Significant
    - Important Bridges…………..Damage= Repairable

Background

- **Conventional Techniques for Safety and Functionality**
  - Strain Reduction (Reducing ultimate strains of concrete and steel to limit damages)
  - Displacement Ductility Reduction (Reducing target displacement ductility demands to smaller values to limit damages)
- **Proposed Technique**
  - **Probabilistic Damage Control Approach (PDCA)**

Probabilistic Damage Control Approach (PDCA)

- *Highlights:*

  - Acceptable level of damage under each excitation depends on probability of occurrence of the earthquake, that is return period (T) of the earthquake
  - Expected Damages at each level of demand can be quantified with Damage Index
  - Level of Damage (*Minimal/Repairable/Significant)* can be related to Damage Index

Damage Index

Level of damage in a column at displacement of "Δ" is represented by Damage Index (DI):

$$DI = \frac{\Delta_D - \Delta_Y}{\Delta_{UC} - \Delta_Y}$$

DI=0, No damage (Elastic)

DI=1, Extensive Damage (at Collapse)

Damage Index, Cont.

Capacity of columns designed based on current requirements for confinement and other considerations is assumed at *DI*~0.5, however tests have shown columns can withstand larger displacements (*DI*~1)

Design Damage Index (DI) Values

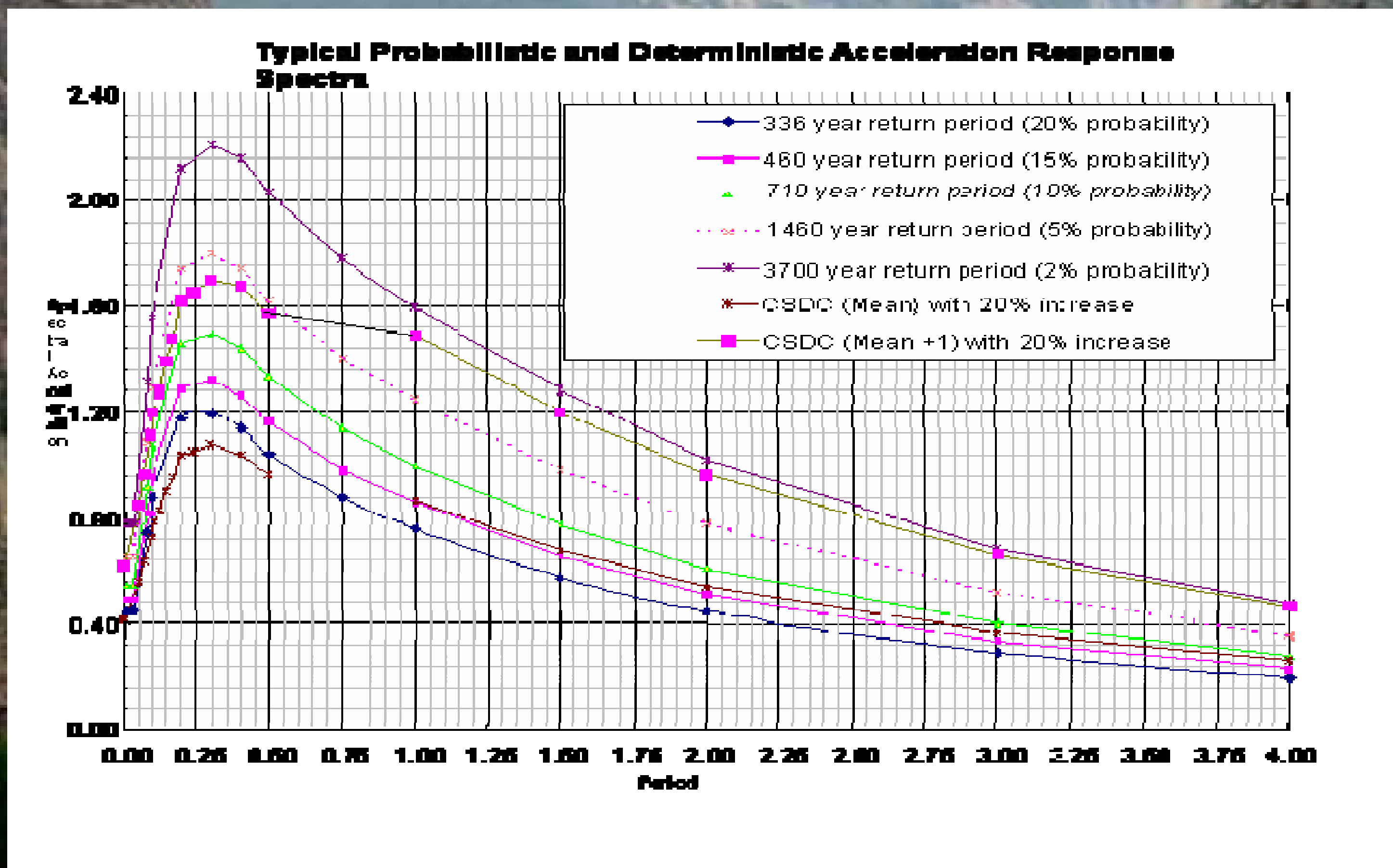
The acceptable level of damage index under each probabilistic ARS curve is design specific, for example it can be:

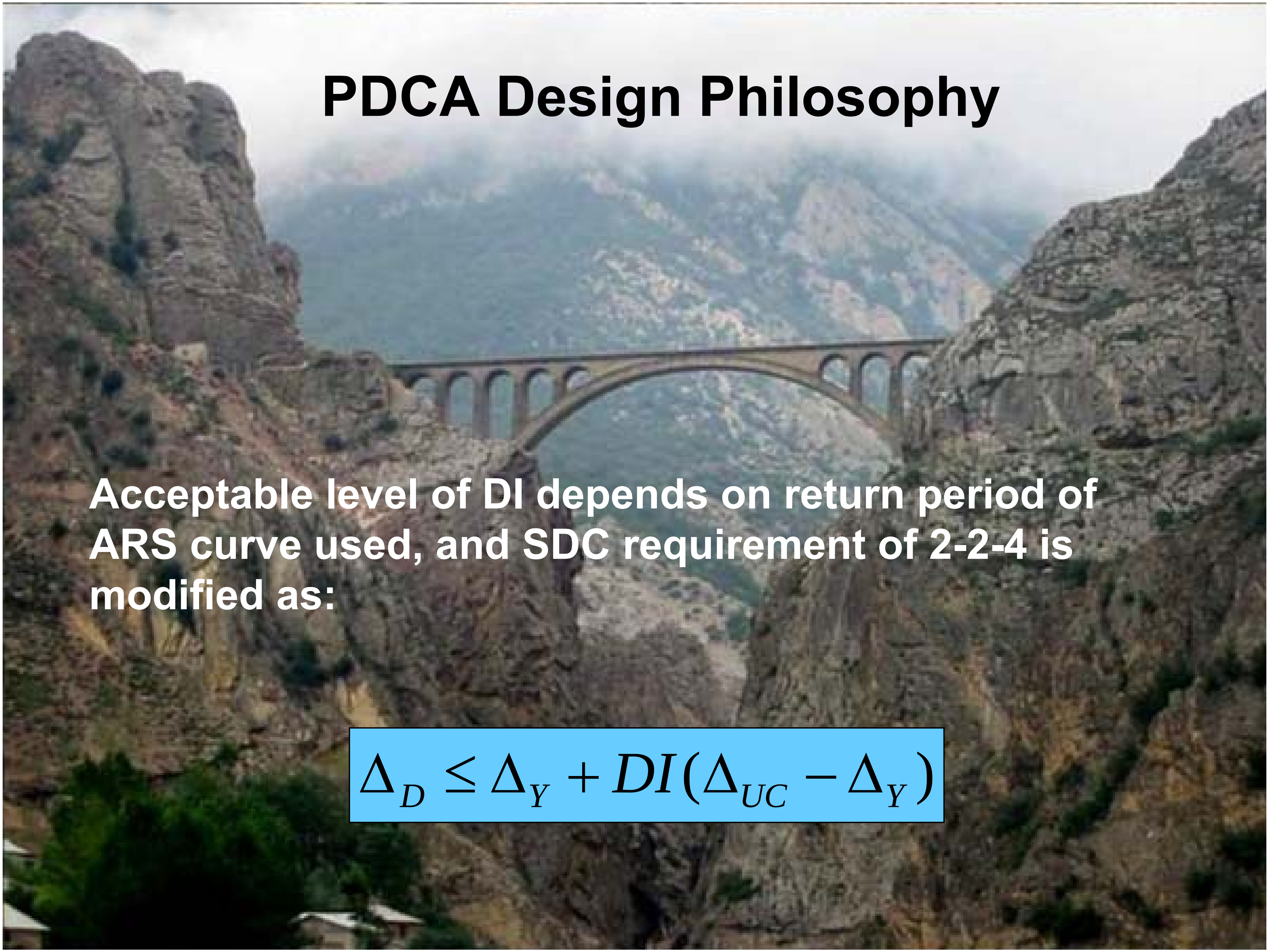
T=710 years* (10% chance of happening in 75 year life): DI=0.5

T=1460 Years* (5% chance of happening in 75 year life): DI=0.75

Note: each of these events are represented by an ARS curve

Typical ARS (75-year exposure time)



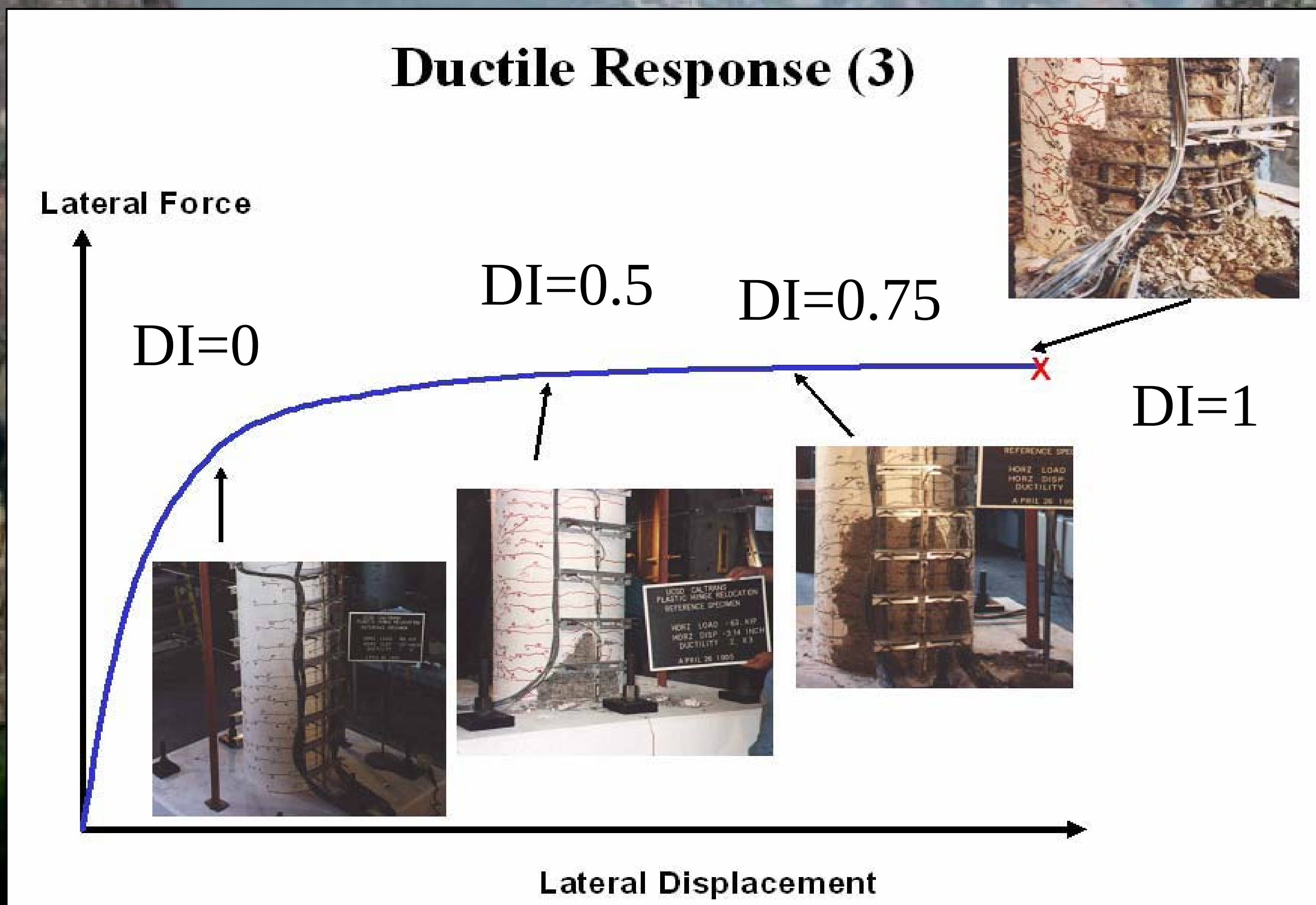


PDCA Design Philosophy

Acceptable level of DI depends on return period of ARS curve used, and SDC requirement of 2-2-4 is modified as:

$$\Delta_D \leq \Delta_Y + DI(\Delta_{UC} - \Delta_Y)$$

Ductile Column Response



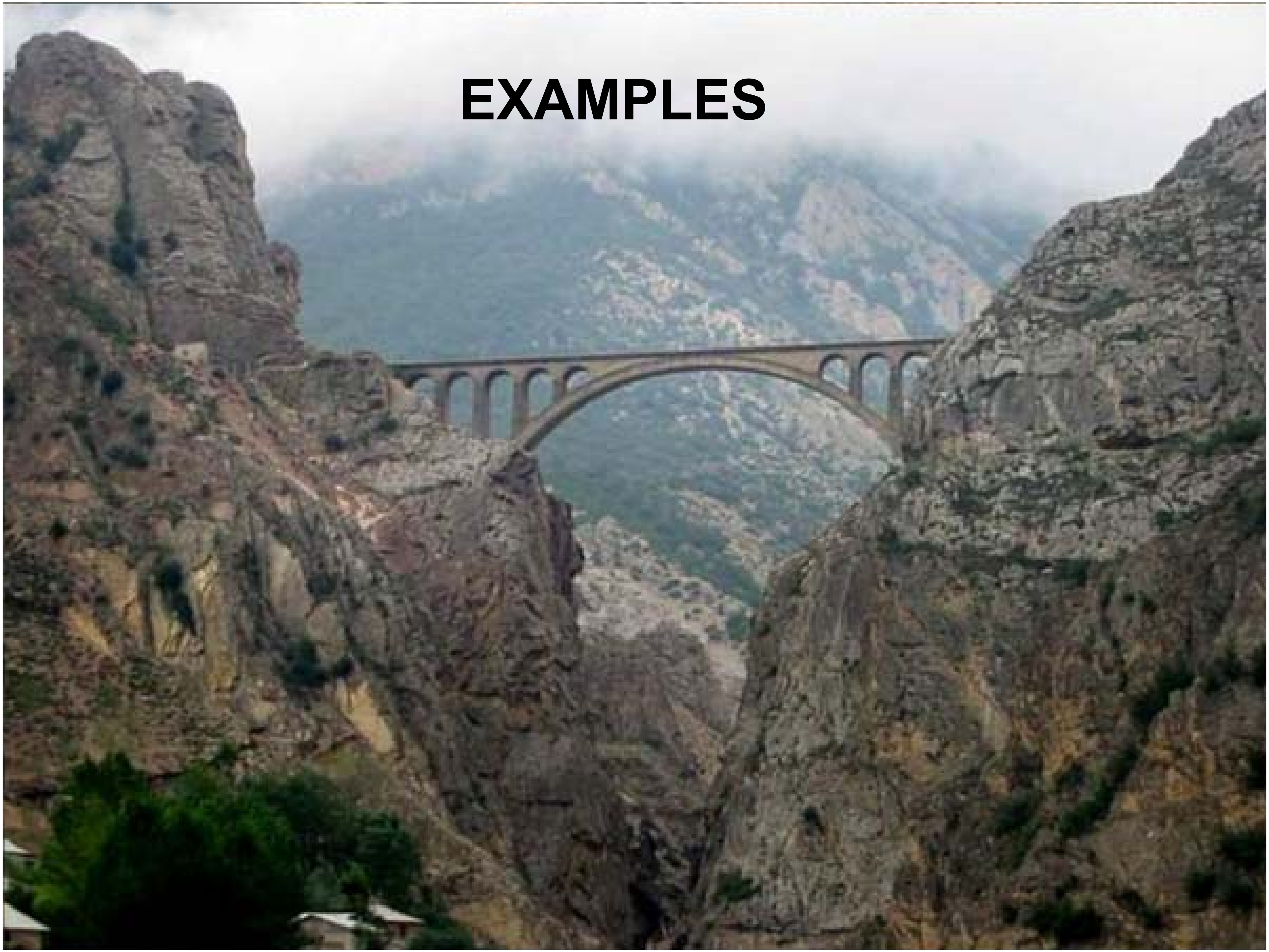
PDCA Advantages

Designer can increase confinement to reduce DI and satisfy design requirements.

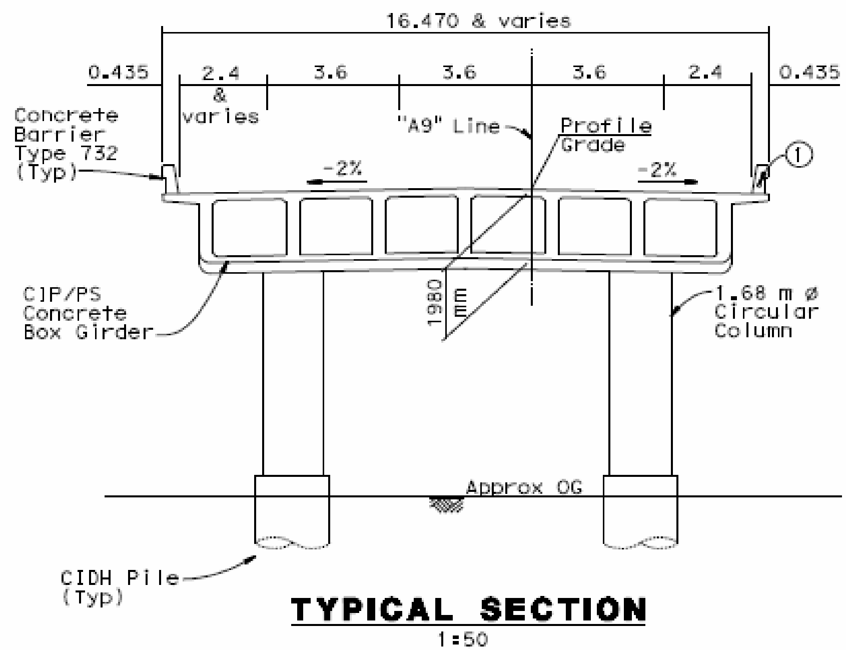
Applicable to all parties involved in a project:

- Bridge Designers
- Bridge Owners (State and Local Agencies)
- Bridge Maintenance personnel (Repair/retrofit)
- Public

EXAMPLES

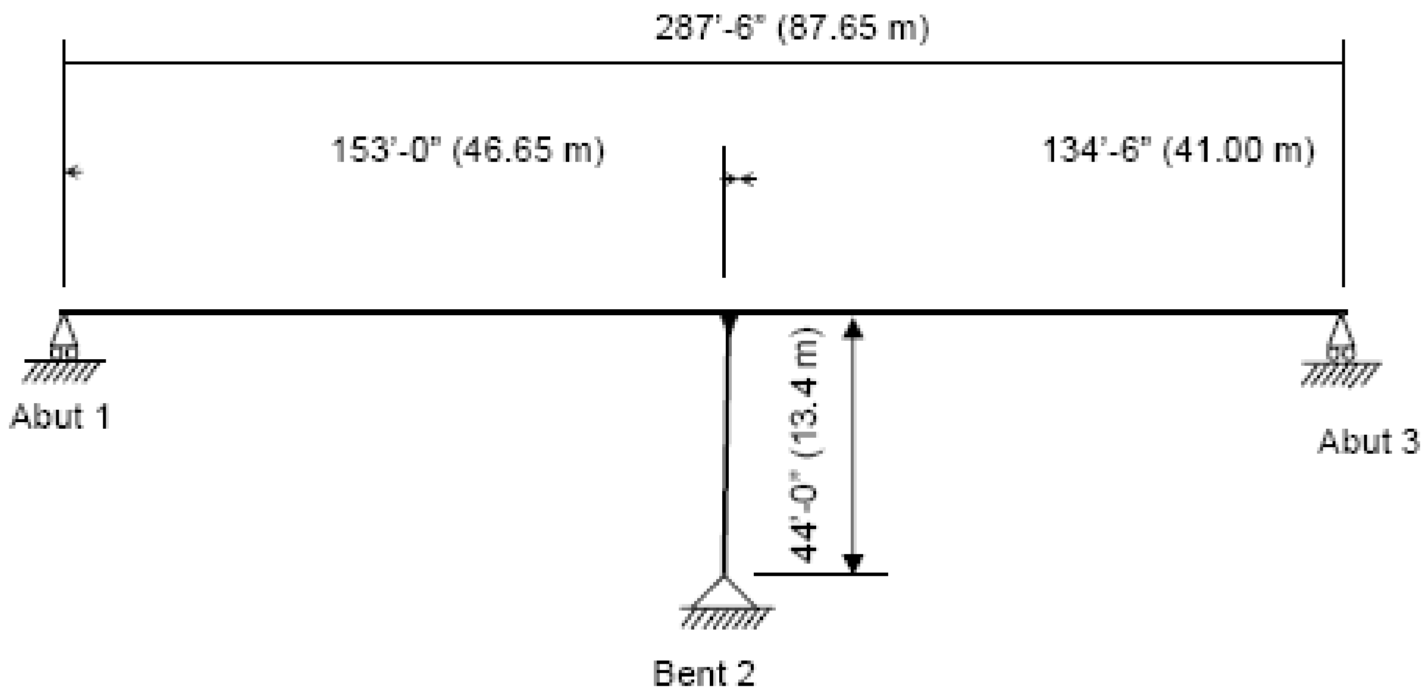


EXAMPLE # 1

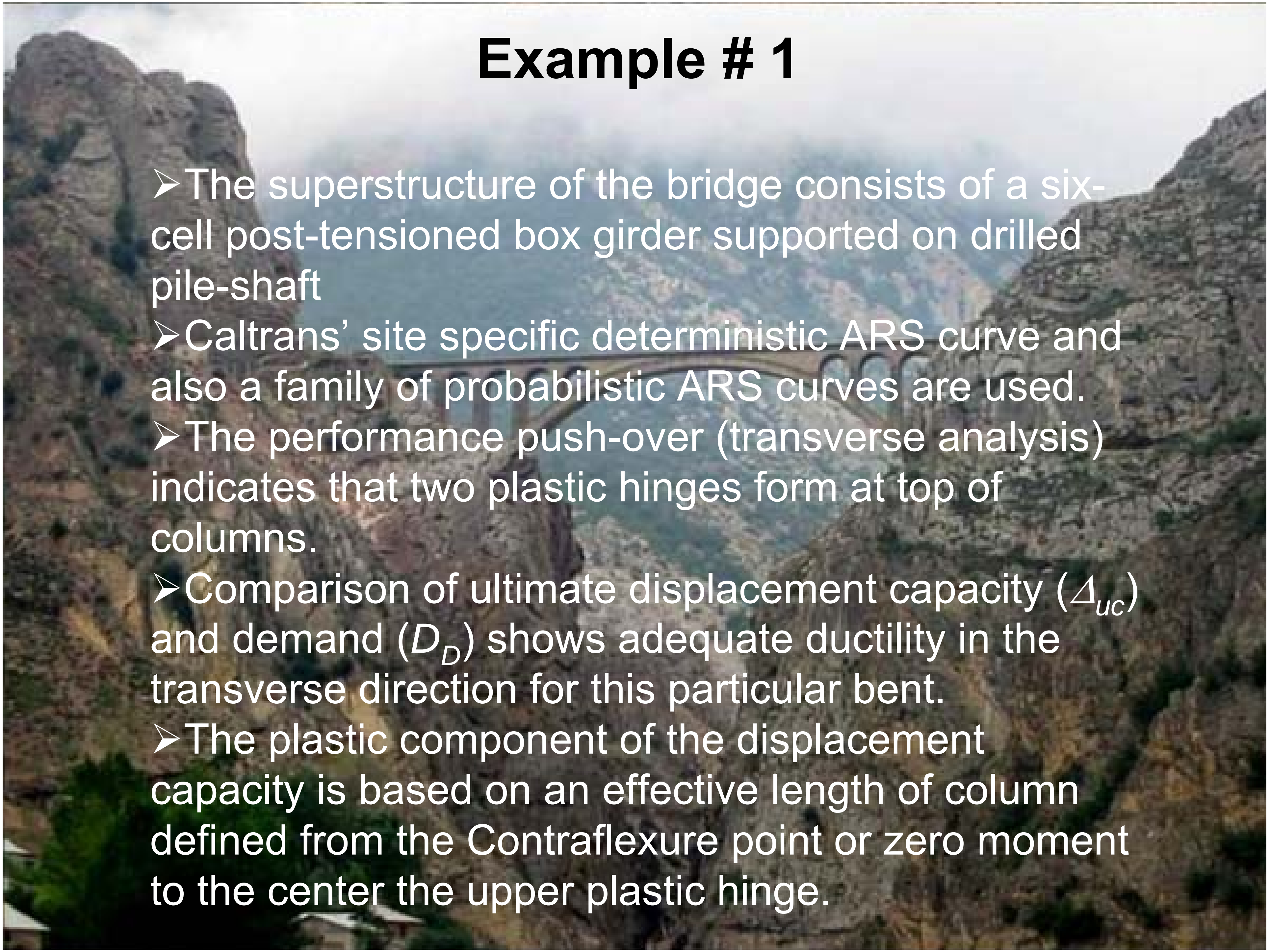


16.470 & varies
0.435
2.4 & varies
3.6
3.6
3.6
2.4
0.435
Concrete Barrier Type 732 (Typ)
"A9" Line
Profile Grade
-2%
-2%
1
CIP/PS Concrete Box Girder
1980 mm
1.68 m ø Circular Column
Approx OG
CIDH Pile (Typ)
TYPICAL SECTION
1:50

EXAMPLE # 1



Example # 1



- The superstructure of the bridge consists of a six-cell post-tensioned box girder supported on drilled pile-shaft
- Caltrans' site specific deterministic ARS curve and also a family of probabilistic ARS curves are used.
- The performance push-over (transverse analysis) indicates that two plastic hinges form at top of columns.
- Comparison of ultimate displacement capacity (Δ_{uc}) and demand (D_D) shows adequate ductility in the transverse direction for this particular bent.
- The plastic component of the displacement capacity is based on an effective length of column defined from the Contraflexure point or zero moment to the center the upper plastic hinge.

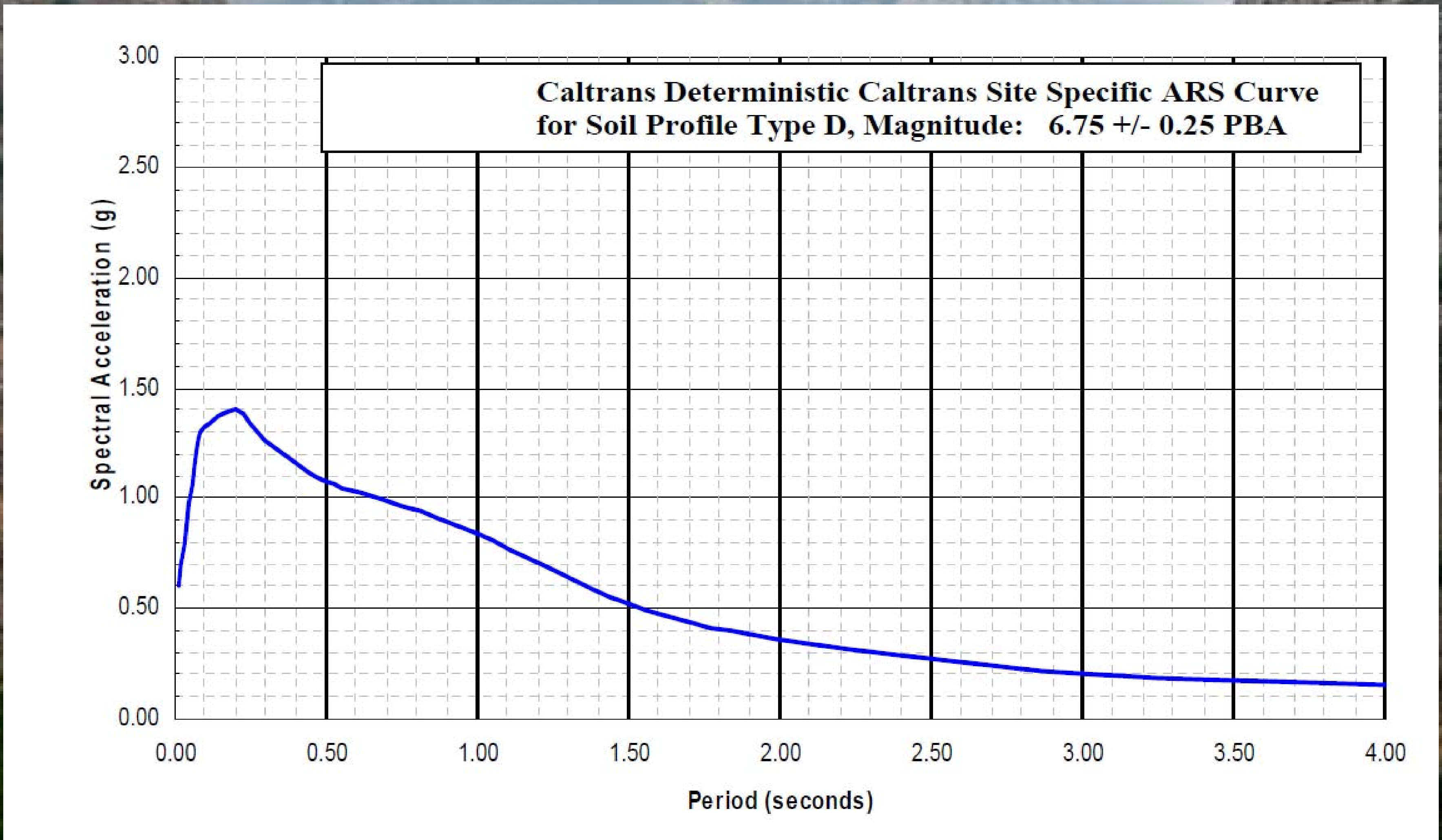
EXAMPLE # 1

- The longitudinal bars in the column consists of 36 No. 11 bars, the confinement consists of No. 8 hoops @ 4 inches spacing in the plastic hinge region. The plastic moment and curvature were calculated using sectional fiber analysis software
- The over-turning effects increased the axial load from 2034 kips to 2911 kips in the compression column; however, the increase in plastic moment was only 8.4%. There is additional reserved capacity in the cap beam to easily meet the higher column moments.

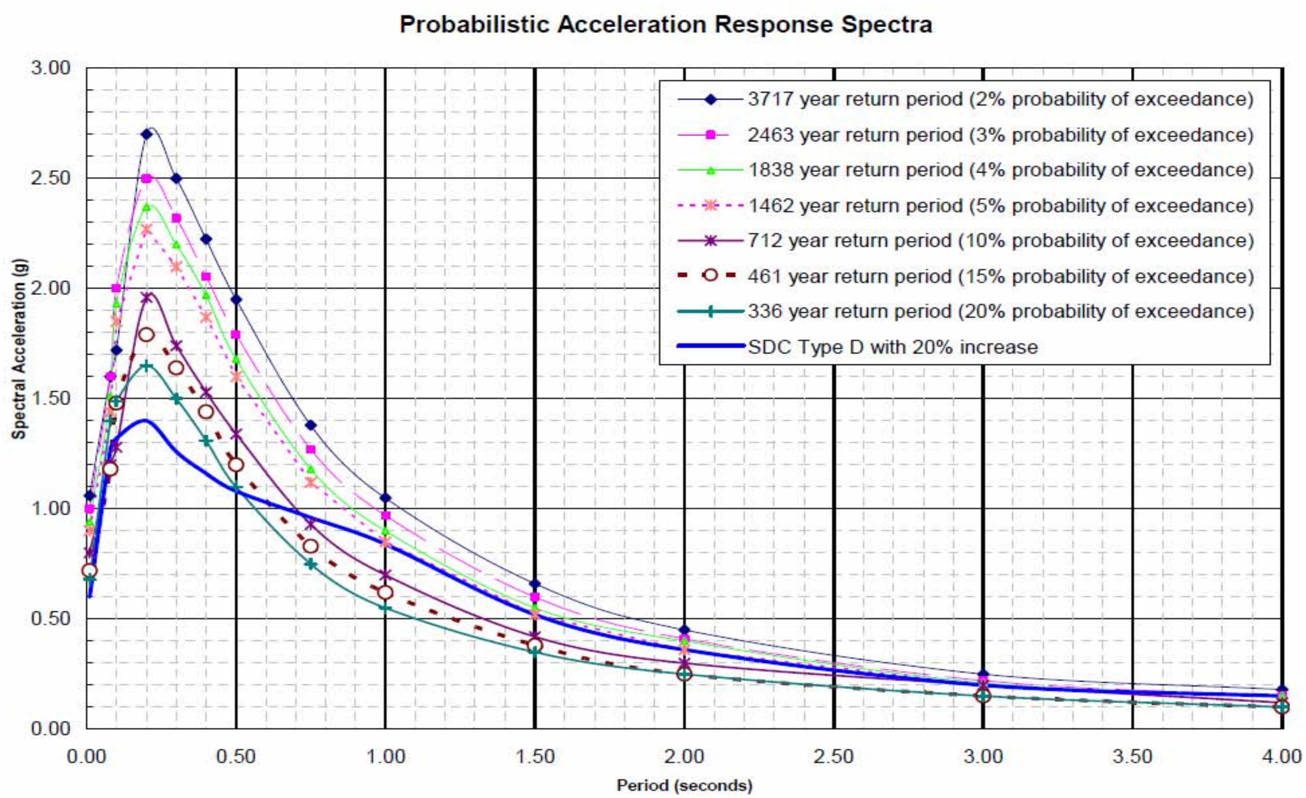
COLUMN PROPERTIES PDCA

D	P (kips)	Mp (K-ft)	Єcu	Φp (rad/in)	Icr (ft^4)	Ec (ksf)	f'c (ksi)
5.5 ft Circle	2034	12935	0.0348	0.00187	19.98	580000	5

EXAMPLE # 1

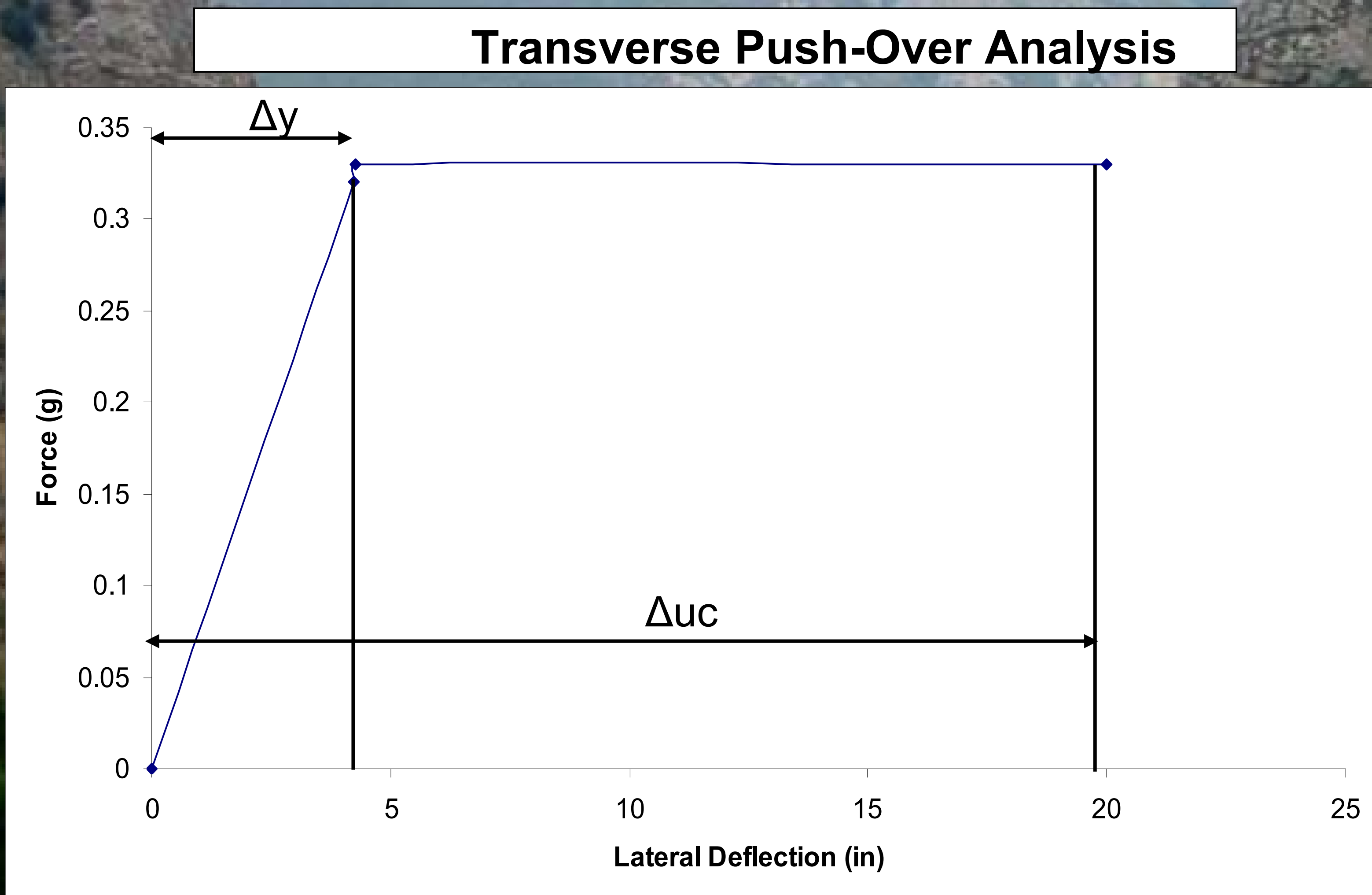

Caltrans Deterministic Caltrans Site Specific ARS Curve
for Soil Profile Type D, Magnitude: 6.75 +/- 0.25 PBA
Spectral Acceleration (g)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Period (seconds)

EXAMPLE # 1



Probabilistic Acceleration Response Spectra
Spectral Acceleration (g)
Period (seconds)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
3717 year return period (2% probability of exceedance)
2463 year return period (3% probability of exceedance)
1838 year return period (4% probability of exceedance)
1462 year return period (5% probability of exceedance)
712 year return period (10% probability of exceedance)
461 year return period (15% probability of exceedance)
336 year return period (20% probability of exceedance)
SDC Type D with 20% increase

EXAMPLE # 1



Transverse Push-Over Analysis
Δy
Δuc
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Force (g)
0
5
10
15
20
25
Lateral Deflection (in)

EXAMPLE # 1

Safety Evaluation:

The bridge is evaluated for safety when exposed to deterministic design earthquake. Following is summary of displacement demand and capacity calculations for safety evaluation of Bent 2.

$$k_i = \text{initial slope} = \frac{\text{Lateral Force}}{\text{Yield Displacement}} = \frac{0.32W}{\Delta_y} = \frac{0.32x4064 \text{ kips}}{4.22''} = 308.4 \text{ k/in}$$

$$T = 0.32\sqrt{\frac{W}{k_i}} = 0.32\sqrt{\frac{4064}{308.4}} = 1.16 \text{ sec onds}$$

From CSDC (Mean) ARS curve is calculated as 0.75g.

$$\Delta_D = \frac{F}{k_i} = \frac{0.75x4064}{308.4} = 9.90 \text{ inches}$$

$$\Delta_{uc} = \Delta_P + \Delta_y \text{ for the plastic hinge}$$

$$l_P = \text{Length of plastic hinge} = 0.08L_1 + 10.2d_b$$

$$l_p = 0.08x20x12 + 10.2x1.63 = 35.83''$$

$\theta_p = l_p \varphi_p$, and l_p is the plastic curvature capacity at top of column from sectional analysis.

$$\theta_p = 35.83'' x0.00187 = 0.0670 \text{ radians}$$

$$\Delta_p = \theta_p * (L_1 - l_P/2) = 0.0670x(20 \text{ ft } (12) - 35.83''/2) = 14.88''$$

$$\Delta_{uc} = 14.88 + 4.22 = 19.10'' > \Delta_D = 9.90'' \quad \therefore \text{OK}$$

<u>Damage Index</u>

$$DI = \frac{\Delta_D - \Delta_y}{\Delta_{uc} - \Delta_y} = \frac{9.90 - 4.22}{19.10 - 4.22} = 0.38 < 0.5 \quad \therefore \text{OK}$$

EXAMPLE # 1

Functionality Evaluation:

The bridge is evaluated for functionality when exposed to the family of probabilistic ARS curves. The Bent # 2 sample calculations of displacement demand and capacity for probabilistic ARS Curve with 10% probability of exceedance is summarized as:

$$k_i = \text{initial slope} = \frac{\text{Lateral Force}}{\text{Yield Displacement}} = \frac{0.32g}{\Delta_y} = \frac{0.32x4067 \text{ kips}}{4.22"} = 308.4 \text{ k/in}$$

$$T = 0.32\sqrt{\frac{W}{k_i}} = 0.32\sqrt{\frac{4067}{308.4}} = 1.16 \text{ seconds}$$

From 10% ARS Curve spectral acceleration is calculated as 0.60g.

$$\Delta_D = \frac{F}{k_i} = \frac{0.60x4064}{308.4} = 7.91 \text{ inches}$$

Similarly, $\Delta_{uc} = \Delta_P + \Delta_y$

$$\Delta_{uc} = 14.88 + 4.22 = 19.10" > \Delta_D = 7.91" \quad \therefore \text{OK}$$

<u>Damage Index</u>

$$DI = \frac{\Delta_D - \Delta_y}{\Delta_{uc} - \Delta_y} = \frac{7.91 - 4.22}{19.10 - 4.22} = 0.25$$

EXAMPLE # 1

DAMAGE INDEX

Column Code	Δ_p (in)	Δ_y (in)	T sec	a (ARS) (g)	Δ_D (in)	Δ_{uc} (in)	Damage DI	Acceptable DI (2 Cols)	Comment Good/NG
Caltrans Type D (0.5g)	14.88	4.22	1.16	0.47	9.90	19.10	0.38	0.6	Good
Example Bridge 20%	14.88	4.22	1.16	0.30	6.26	19.10	0.14	0.3	Good
Example Bridge 15%	14.88	4.22	1.16	0.33	7.25	19.10	0.20	0.4	Good
Example Bridge 10%	14.88	4.22	1.16	0.38	7.91	19.10	0.25	0.5	Good
Example Bridge 5%	14.88	4.22	1.16	0.48	9.90	19.10	0.38	0.8	Good
Example Bridge 4%	14.88	4.22	1.16	0.49	10.28	19.10	0.41	0.9	Good
Example Bridge 3%	14.88	4.22	1.16	0.53	11.08	19.10	0.46	1	Good
Example Bridge 2%	14.88	4.22	1.16	0.58	12.13	19.10	0.53	1	Good

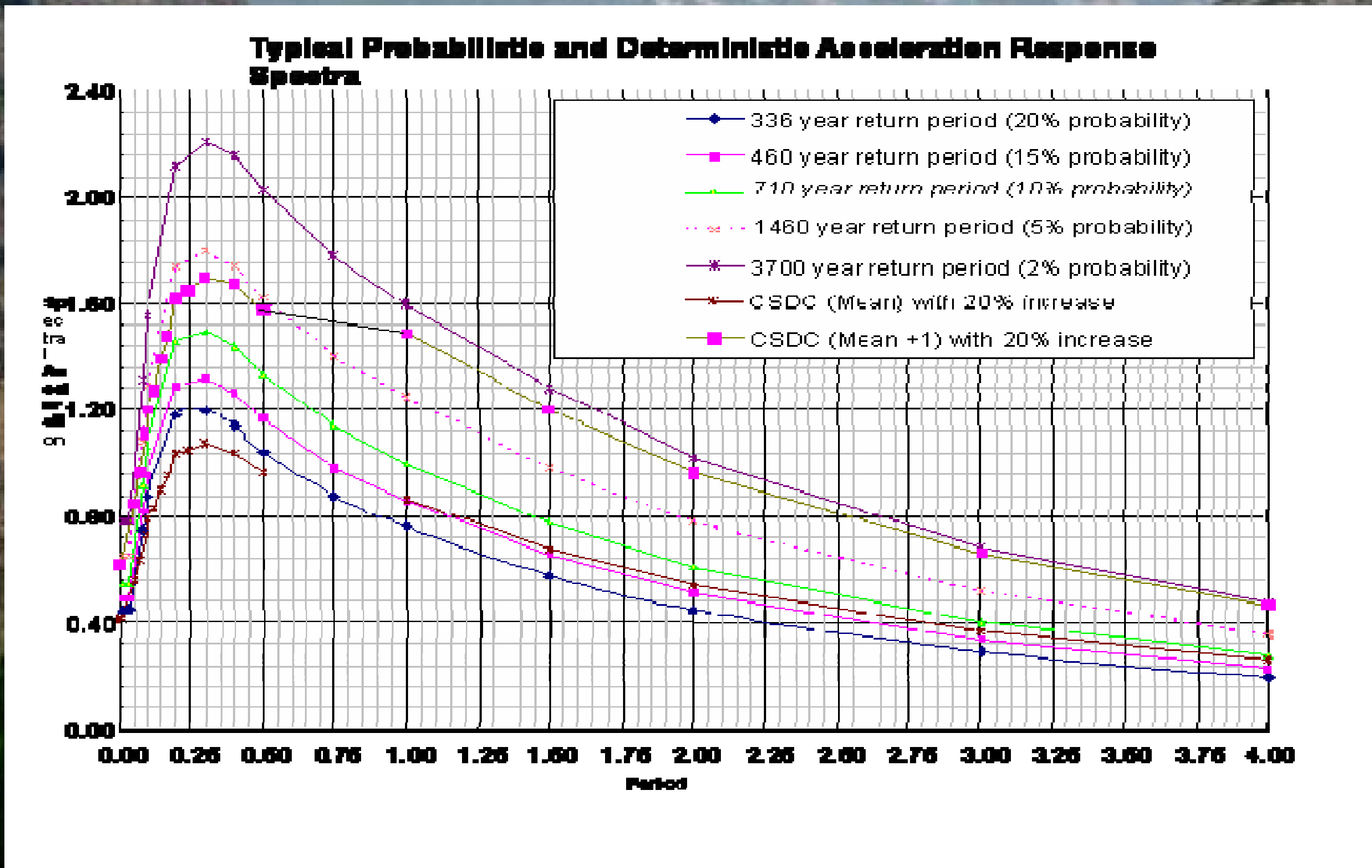
Therefore, the bridge complies with limits proposed for DI values under different probabilistic excitations.

EXAMPLE # 2

6 Foot Column Diameter/CIDH Test Specimen (UCLA)

EXAMPLE # 2

Probabilistic Acceleration Response Spectra San-Francisco the Bay Area Region Marina



EXAMPLE # 2

Analytical Study of 6 Foot Circular Column/CIDH

Assuming *10% f’c Ag Axial Load*

DAMAGE INDEX

ARS risk of Occurrence (%)	Return Period (Yrs)	Δ_p (in)	Δ_y (in)	T sec	a (ARS) (g)	Δ_D (in)	Δ_{uc} (in)	Damage DI
(Mean)	N/A	57.73	9.86	2.22	0.52	25.2	68.00	0.26
(Mean +1)	N/A	57.73	9.86	2.22	0.92	44.60	68.00	0.60
20	336	57.73	9.86	2.22	0.40	19.38	68.00	0.16
15	460	57.73	9.86	2.22	0.47	22.77	68.00	0.22
10	710	57.73	9.86	2.22	0.54	26.16	68.00	0.28
5	1460	57.73	9.86	2.22	0.72	34.88	68.00	0.43
2	3700	57.73	9.86	2.22	0.96	46.51	68.00	0.63

Next Steps…

- Calibration of *DI* using data from tests and post-event observations
- Development of a reliability index covering damage and probabilistic demand
- Local vs. Global *DI* (redundancy)
- Extension of *DI* application to repair projects in order to facilitate communication between maintenance and design


Questions
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