Bridge reinforced concrete column limit state definition

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Presentation Plan

- Introduction
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  - Qualitative LS – Damage States
  - Quantitative LS
- Chemin des Dalles Bridge Column
  - Sectional Analysis
  - Damage Mechanics Analysis
  - Limit States Definition
  - Fragility Curves
- Conclusion

Introduction

- Performance-based earthquake engineering (PBEE)
  - Service Performance Level - small-magnitude earthquake
  - Intermediary levels
  - No Collapse Performance Level - high-magnitude earthquake
- Seismic Risk Assessment – HAZUS 2003
  - Slight
  - Moderate
  - Extensive
  - Complete

Limit States

❑ Qualitative Limit States

- Basöz 1999

Damage State		Description
0	No damage	No damage to the structure.
1	Minor	Hairline cracks. Cracks at column top and bottom (1.4 to 1.6mm). Spalls at column faces, spalled column flares (flare ratio = < 1/3 or adequate reinforcement exists). Flare is the relation of height and column height. Cracks at bent cap connection.
2	Moderate	Shear cracks. Spalled column flares (flare ratio < 1/3 or inadequate reinforcement exists). Flexural failure (formation of plastic hinges, buckling of longitudinal reinforcement over a length of one column diameter. Cracks exposing core.
3	Severe	Shear failure Flexural failure without formation of plastic hinges due to inadequate confinement (due to steel rupture or broken welds), inadequate anchorage of the steel, inadequate lap splices. Vertical pull of the longitudinal column reinforcement. Ground displacement at column base. Tilting of substructure due to foundation failure.
4	Collapse	Column collapse.

Limit States

- Quantitative Limit States
  - Dutta and Mander 1998

Damage State	Non-seismically defined	Seismically defined
1 First Yield	θ_y	θ_y
2 Cracking, Spalling	0.008	0.010
3 Loss of Anchorage	0.010	0.025
4 Incipient Pier Collapse	0.020	0.050
5 Pier Collapse	0.050	0.075

Limit States

Quantitative Limit States

- EfiCoS

Tension damage (*) index (Dt)	Drift, δ_θ (%)	Qualitative (SEAOC, 1995)
≈ 0	< 0.05	Fully Operational
0.5 to ≈ 1.0 (near to total spalling)	≈ 0.1 to 0.4	Fully Operational

(*): Measured by EFiCoS over the concrete cover response of column.

Compression (**) damage index (D)	Drift, δ_θ (%)	Qualitative (SEAOC, 1995)
≈ 0	< 0.2	Fully Operational
< 0.10	0.2 to 0.5	Operational
0.1 to 0.6	0.5 to 1.5	Life Safety
0.6 to 0.9 (near to total crushing)	1.5 to 2.5	Near Collapse
> 0.9	> 2.5	Collapse

(**): Measured by EFiCoS over the concrete core response of column.

Limit States

❑ Quantitative Limit States

- Hwang 2001

$$\mu_d = \frac{\Delta}{\Delta_{cy1}}$$

Damage State	Displacement ductility ratio	Median Value
Slight	μ_{cy1}	1.0
Moderate	μ_{cy}	1.2
Extensive	μ_{c2}	1.76
Complete	$\mu_{c\text{-}max}$	4.76

Limit States

Quantitative Limit States

- Georgia Institute of Technology

Damage states	Choi (2002)	Choi (2004)	Nielson (2005)	Padgett (2007)
Type	Displacement Ductility	Curvature Ductility	Curvature Ductility	Curvature Ductility
Slight damage	$1.0 <. \mu < 1.2$	$1.0 <. \mu < 2.0$	$1.0 <. \mu < 1.58$	$1.29 <. \mu < 2.10$
Moderate damage	$1.2 <. \mu < 1.76$	$2.0 <. \mu < 4.0$	$1.58 <. \mu < 3.22$	$2.10 <. \mu < 3.52$
Extensive damage	$1.76 <. \mu < 4.76$	$4.0 <. \mu < 7.0$	$3.22 <. \mu < 6.84$	$3.52 <. \mu < 5.24$
Complete damage	$4.76 <. \mu$	$7.0 <. \mu$	$6.84 <. \mu$	$5.24 <. \mu$

Curvature Ductility:

$$\mu_\phi = 1 + \frac{\mu_\Delta - 1}{3\frac{l_p}{l}\left(1 - 0.5\frac{l_p}{l}\right)}$$

$$l_p = (0.08)l + 9d_b$$

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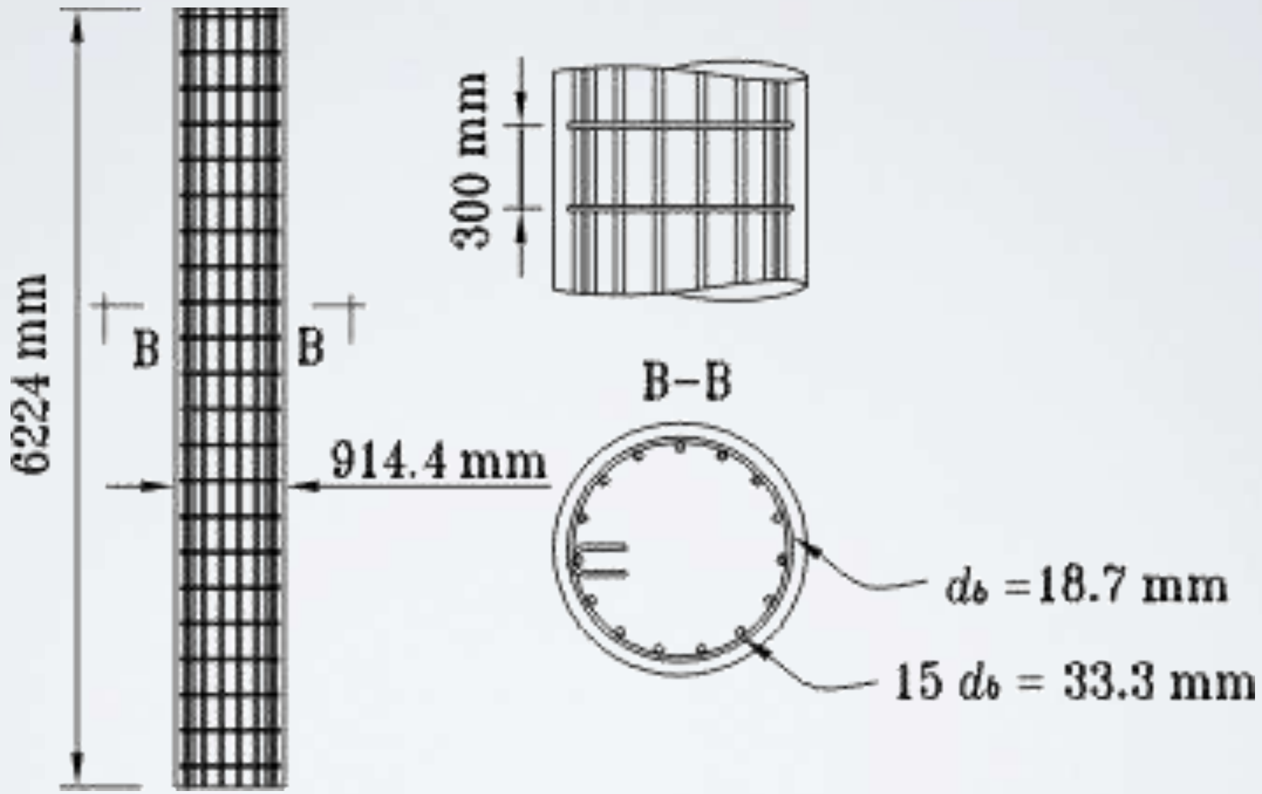
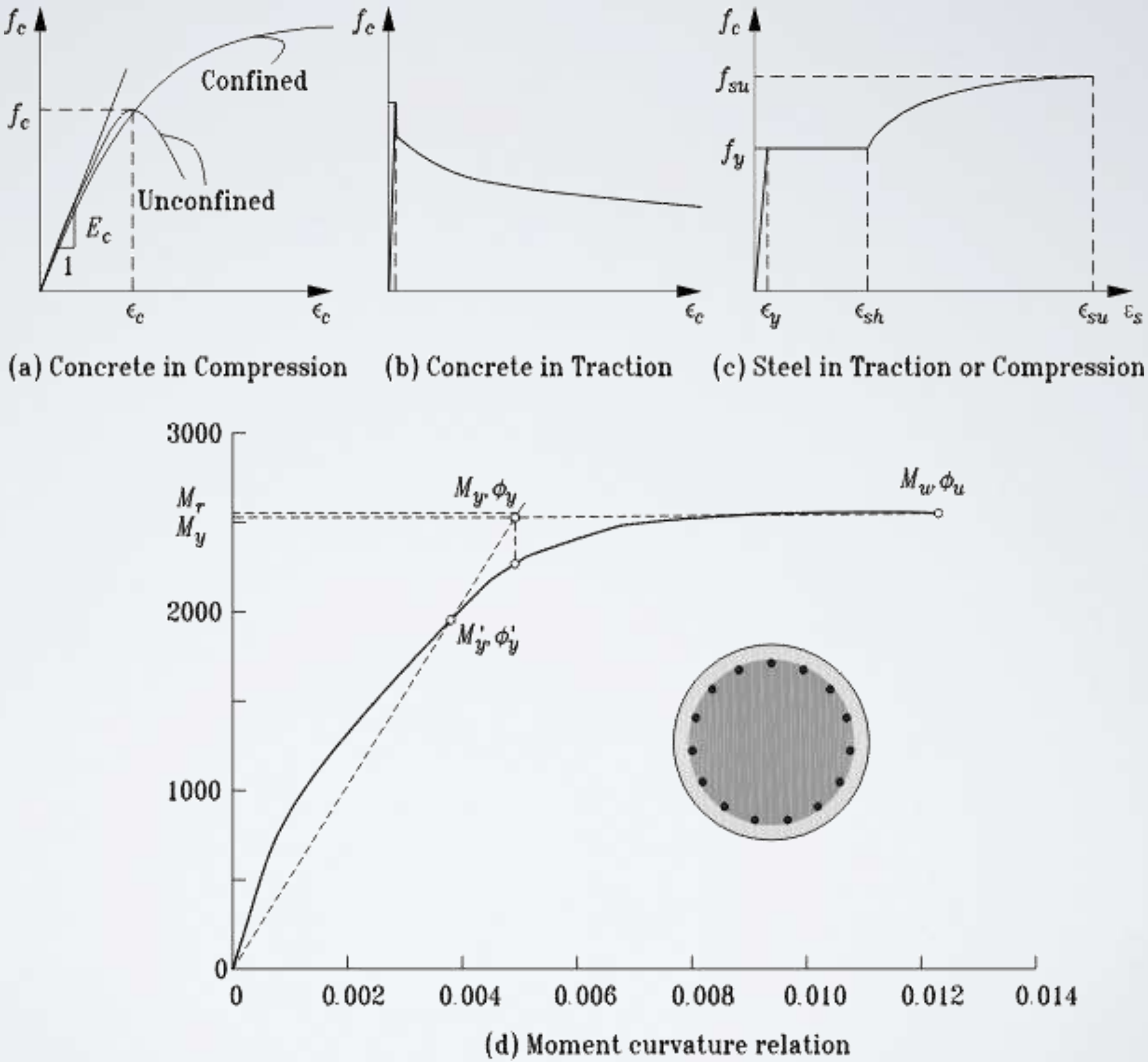
Chemin des Dalles Bridge Column

- Column Description
  - N=2054kN



Chemin des Dalles Bridge Column

- Sectional Analysis



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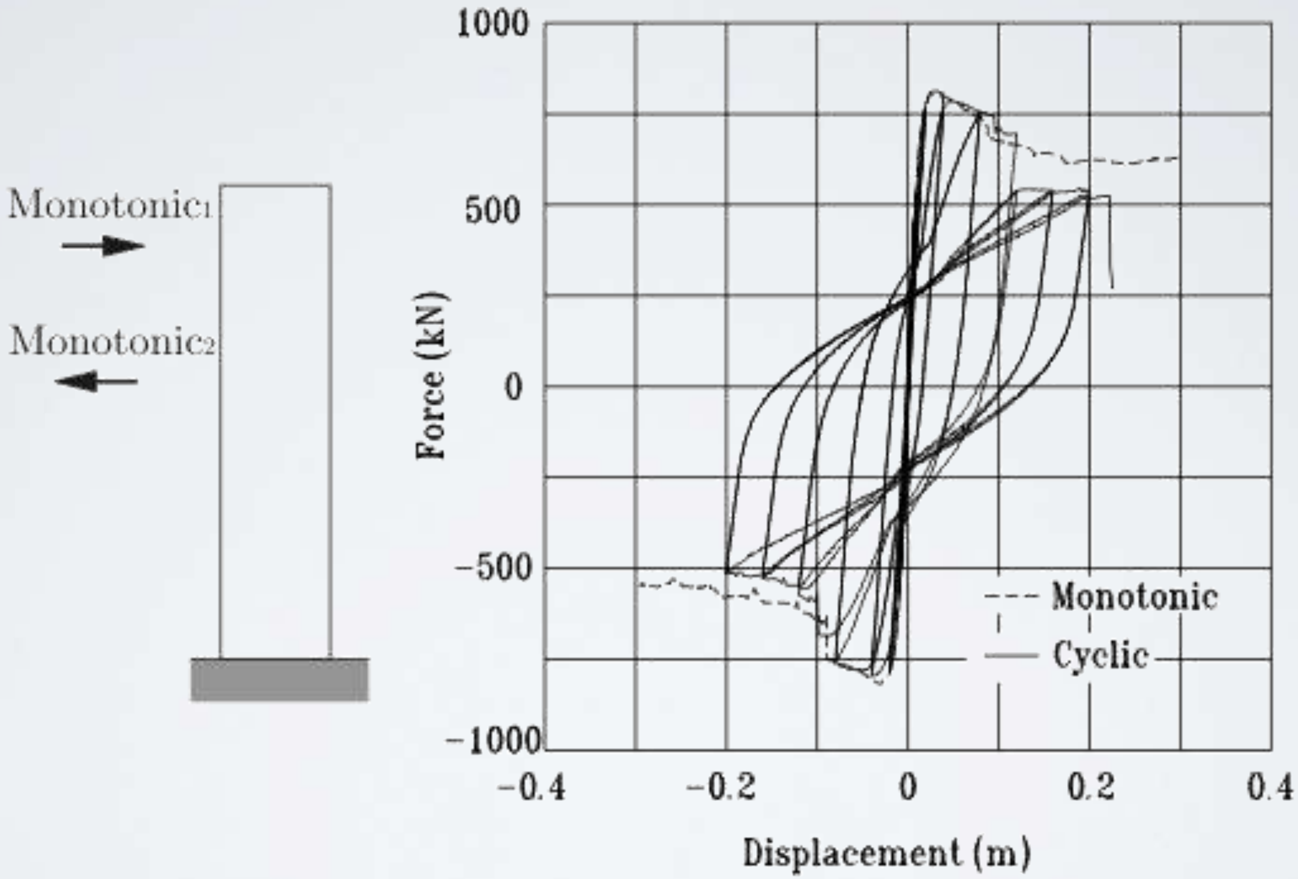
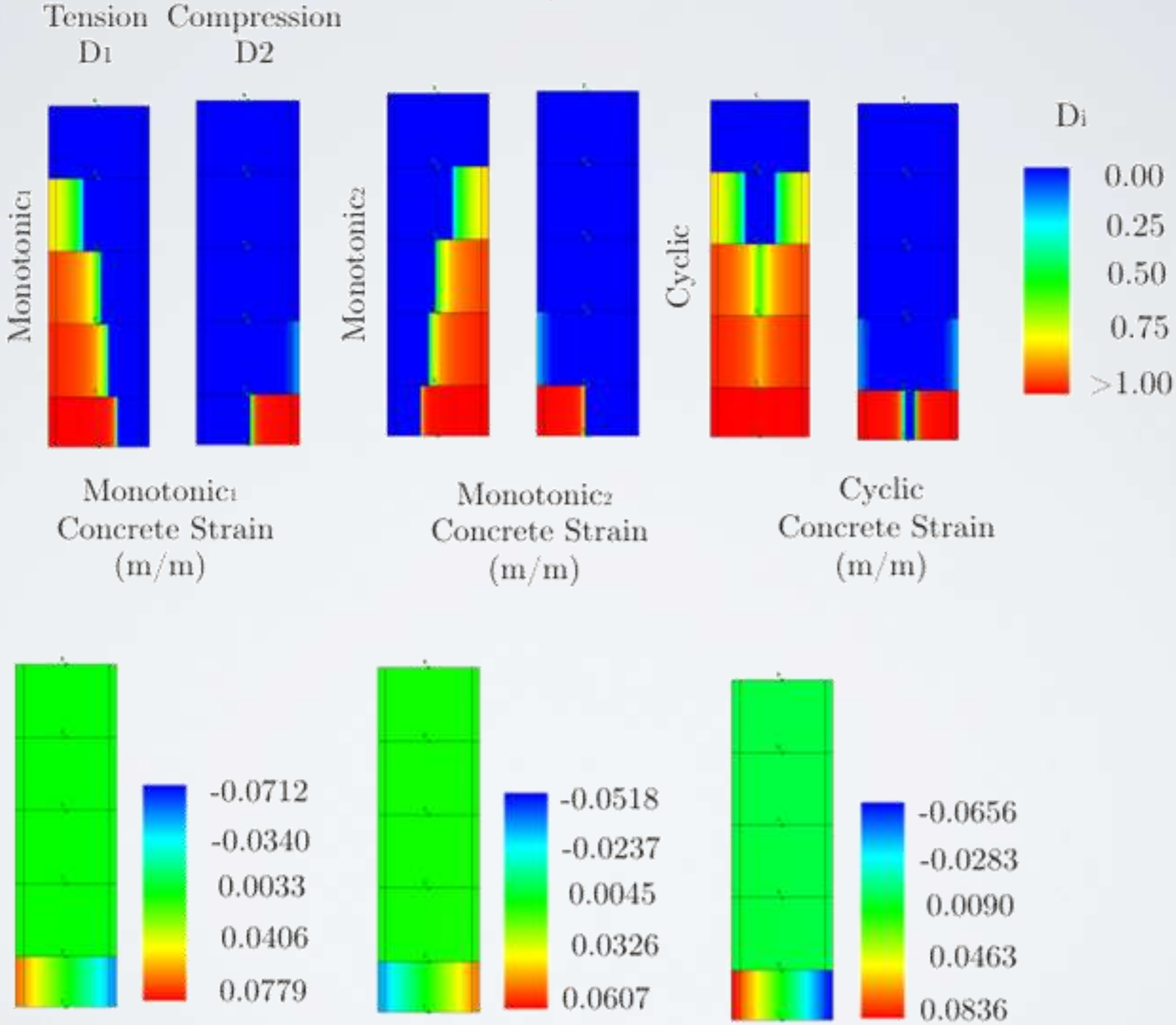
Chemin des Dalles Bridge Column

- Damage Mechanics Analysis
  - EFiCoS



Chemin des Dalles Bridge Column

- Damage Mechanics Analysis
  - EFiCoS



Chemin des Dalles Bridge Column

Damage Mechanics Analysis

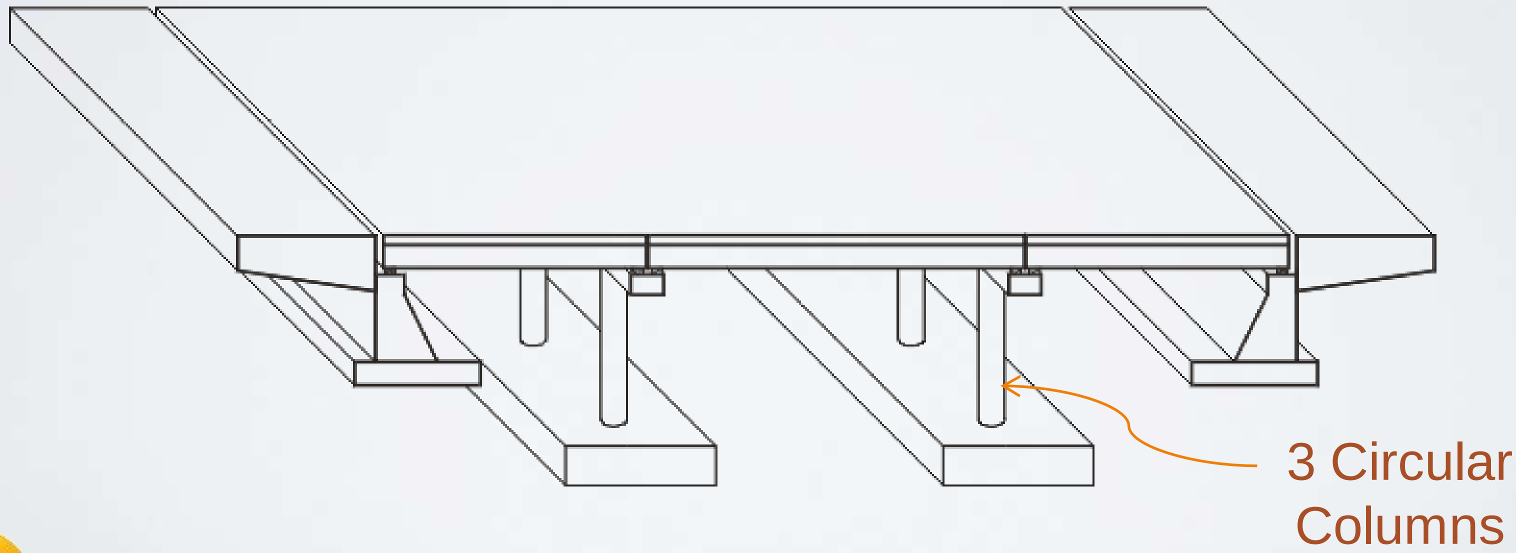
- EFiCoS

Qualitative Parameter	Load Case – Displacement at half height of the real Column (m)		
	Monotonic (→)	Monotonic (←)	Cyclic
Concrete first cracking	0.002	0.002	0.002
Concrete significant spalling, (DT > 0.5)	0.003	0.003	0.003
Concrete significant compression damage (+), (DC > 0.5)	0.034	0.034	0.036
Reinforcement rebar yielding	0.013	0.014	0.013
Reinforcement rebar buckling	0.086	0.088	0.095

Chemin des Dalles Bridge Column

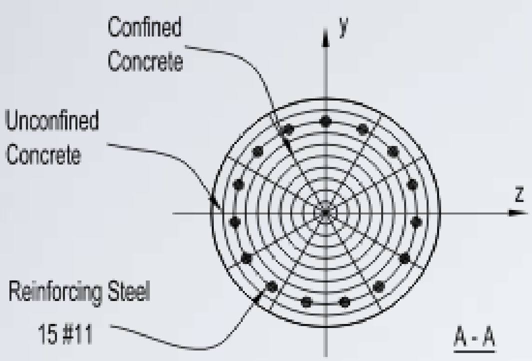
❑ Limit States Definition

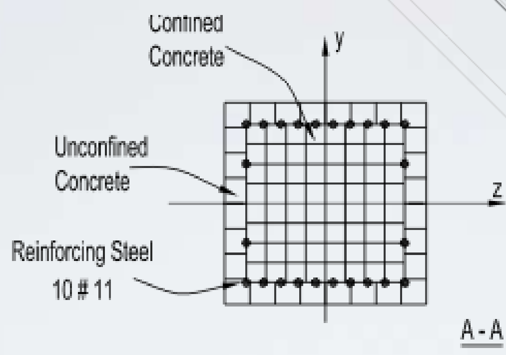
Damage State	Service Level	Damage Index Comp. and Tension	Drift, δ_θ	Displacement Ductility	Curvature Ductility
Slight	Fully Operational	DC = 0.1 DT≈0.0	0.005	1.0	1.0
Moderate	Operational	DC = 0.2	0.007	1.15	1.50
Extensive	-	DC = 0.5 DT=0.5	0.011	1.76	3.22
Complete	Stability	DC = 0.9 DT=0.9	0.030	3.0	6.84

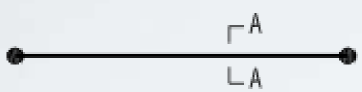


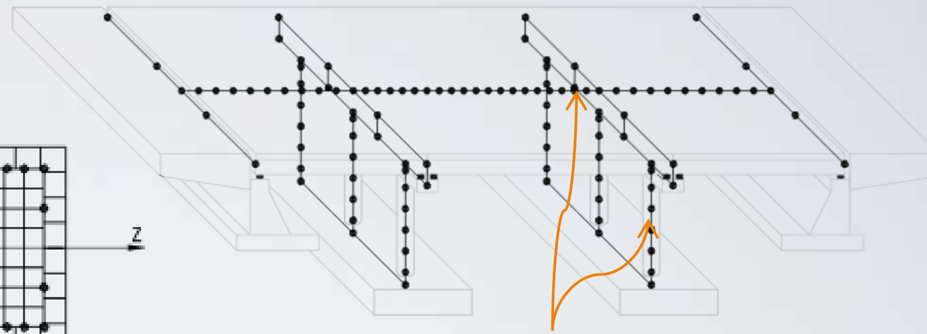
Chemin des Dalles Bridge Column

❑ Fragility Curves Development

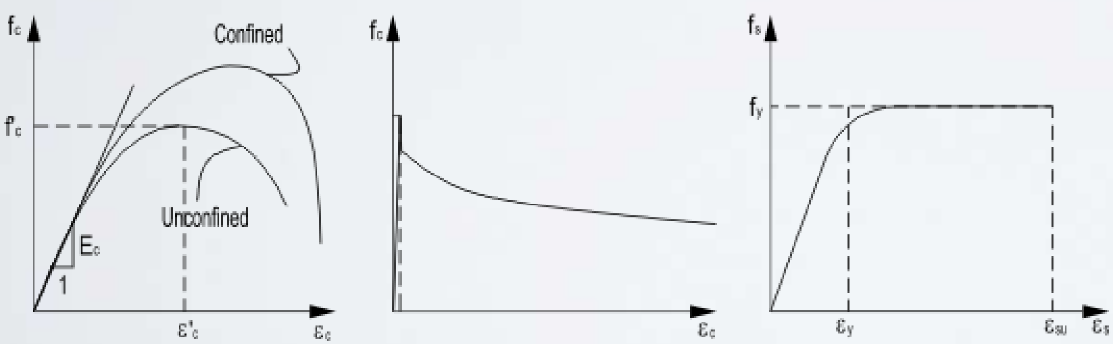








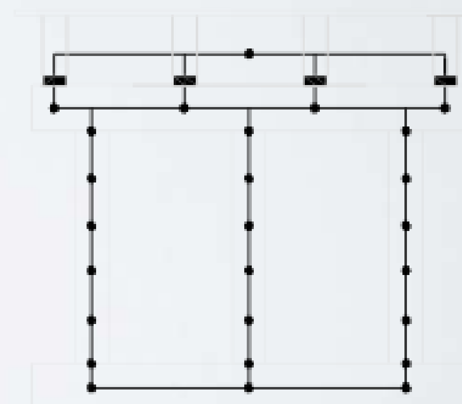
Non-linear Beam-Column Elements



Concrete in Compression

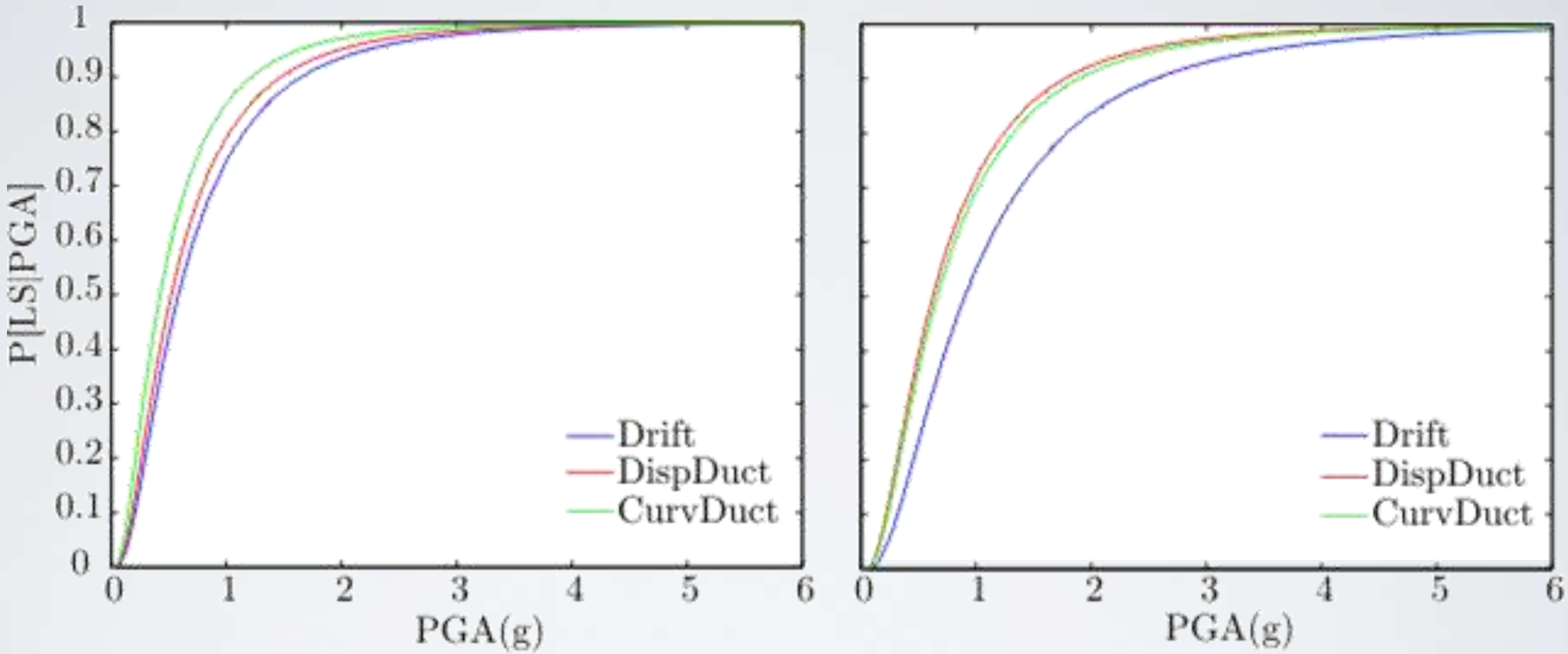
Concrete in Traction

Steel in Traction or Compression



Chemin des Dalles Bridge Column

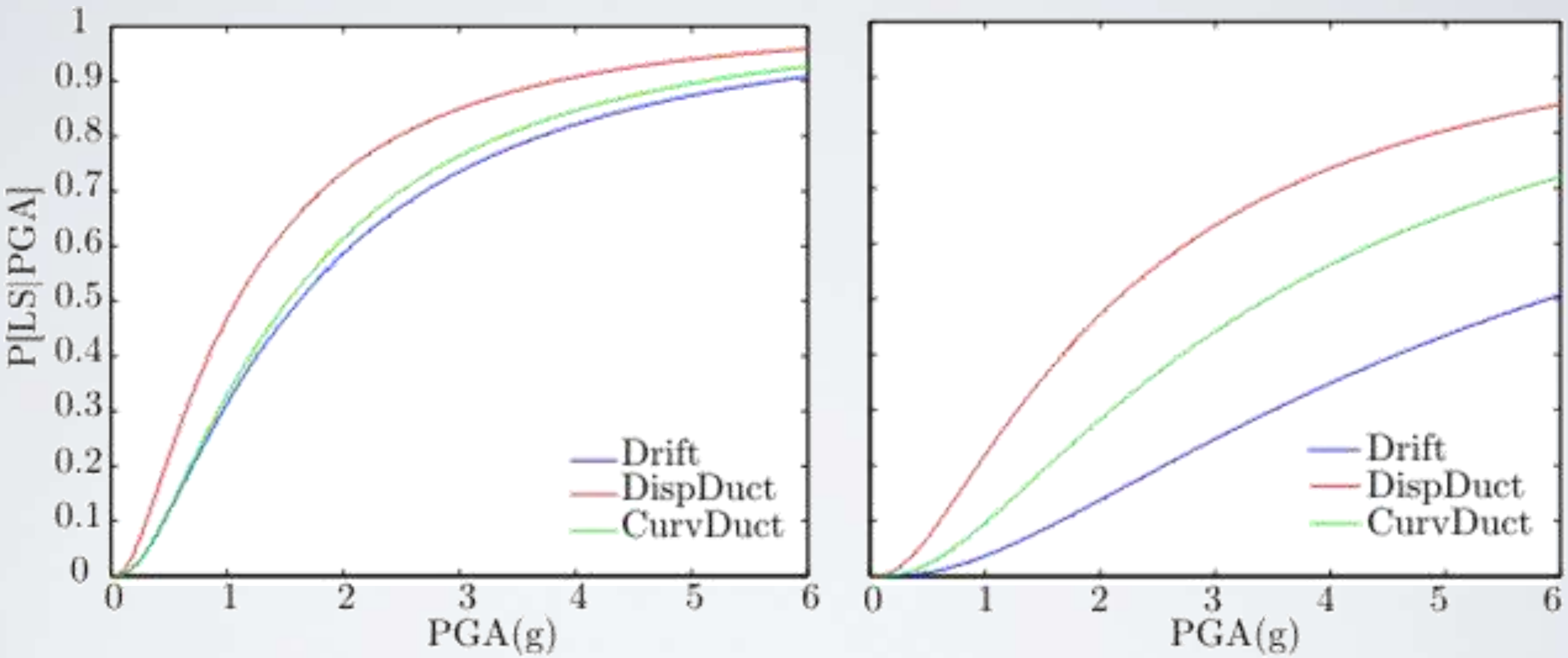
- Fragility Curves Development



(a) Slight (b) Moderate

Chemin des Dalles Bridge Column

- Fragility Curves Development



(c) Extensive

(d) Complete

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Conclusion

- Three quantitative LS were defined for the *Chemin des Dalles* Bridge column.
- To evaluate the effectiveness of these LS, fragility curves were constructed for this column.
- The LS defined in this study are similar to those defined in the literature for slight and moderate damage
- But these values tend to differ for the intermediate values. Even less agreement can be found in the definition of the complete damage state
- From the fragility analysis all three LS were found to properly represent the capacity of the bridge.

Conclusion

- Due to practical reasons, the LS related to displacements are easier to be implemented than the curvature ductility.
- In the case of one bridge, drift and displacement ductility are found to represent the capacity in the same way
- But, the drift LS are found to be more suitable than the displacement ductility when the fragility analysis involves bridges with different columns sections.
- Most of the inconsistencies were found in the complete limit state, as it was expected due to the complexity of the failure mechanisms.

Questions?

Thank you!
Obrigada!

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