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FE Modelling approaches for soil-bridge systems towards better emergency response planning

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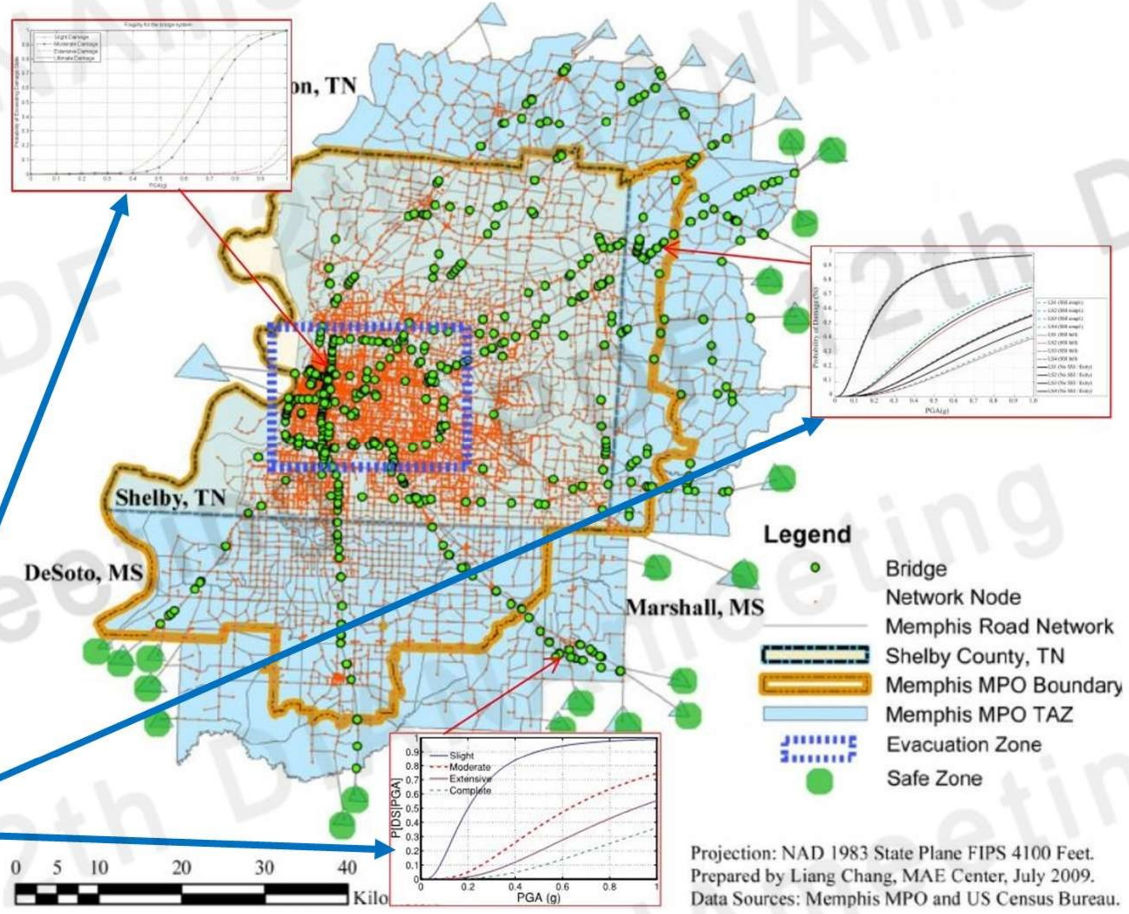
Index

Background

- ☐ Risk analysis in bridge management
  - ✓ Prioritise resources' allocation
  - ✓ Formulate Emergency evacuation plans
- ☐ Fragility curves
  - ✓ Support vulnerability assessment
  - ✓ Formulation by means of the function:

$$P[D>C|\mathrm{IM}] = \Phi\left[\frac{\ln(S_{\mathrm{d}}/S_{\mathrm{c}})}{\sqrt{\beta^2_{\mathrm{D|IM}}+\beta^2_{\mathrm{c}}}}\right]$$



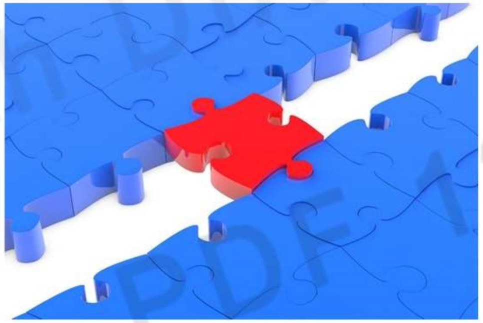
Projection: NAD 1983 State Plane FIPS 4100 Feet.
Prepared by Liang Chang, MAE Center, July 2009.
Data Sources: Memphis MPO and US Census Bureau.

(Chang et. al., 2012)

Gaps in the state-of-art and objectives

☐ Gaps

- ✓ Variances in site conditions are loosely addressed
- ✓ One SSI method used to assess liquefaction
- ✓ Costs associated with different levels of analysis



☐ Objectives

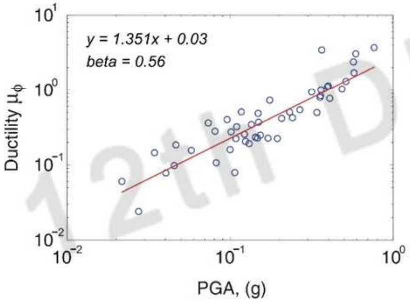
- ✓ Assessment of bridge fragility on 2 different site profiles
- ✓ Effects of soil-structure interaction analysis
- ✓ Cost-benefit analysis associated with different models
- ✓ Bridge deck displacements (value-engineering)

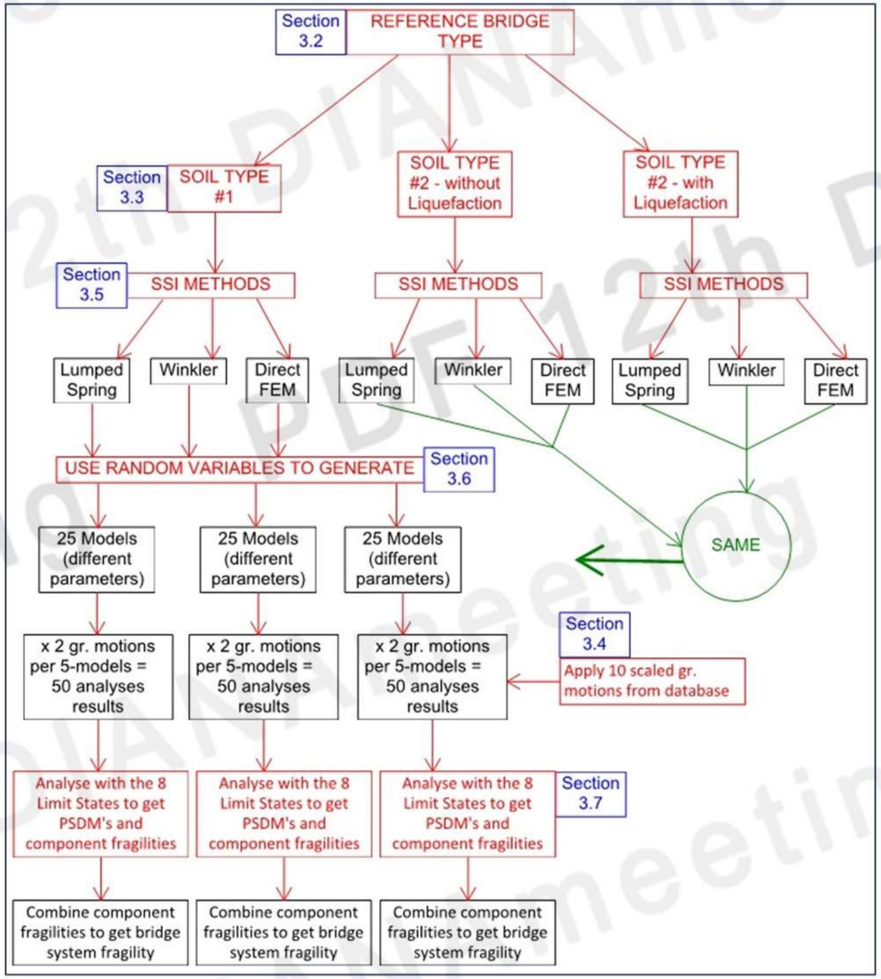
Methodology

- ☐ 3 Types of SSI models (section 3.5)
  - ✓ Winkler spring
  - ✓ Lumped spring
  - ✓ Direct FE method
- ☐ Random variables (section 3.6.1)
  - ✓

Random variable	Distribution type	Parameter 1	Parameter 2	Units
Steel strength	Lognormal	λ = 6.13	ξ = 0.08	Mpa
Concrete strength	Normal	μ = 33.8	σ = 4.3	Mpa
Deck mass	Uniform	*l* = 0.9	*u* = 1.1	%
Fixed Bearing coefficient of friction	Lognormal	λ = -1.56	ξ = 0.5	
Rocker Bearing coefficient of friction	Lognormal	λ = -3.22	ξ = 0.5	

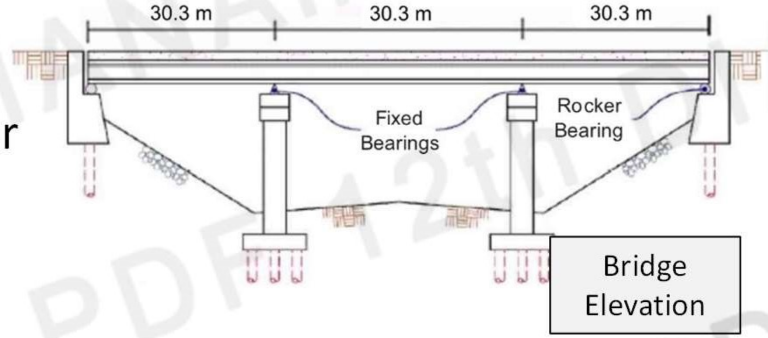
- ☐ Probabilistic Seismic Demand Model (section 4.1)
  - ✓

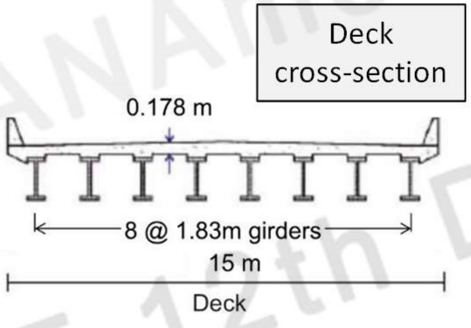




Case study - overview

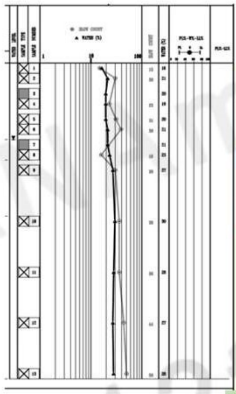
- ☐ Type of Bridge:
  - ✓ Multi Span Continuous Steel Girder
  - ✓ Pile foundations





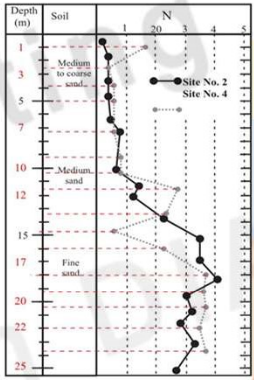
(Nielson, 2005)

- ☐ Type of Soils:



	Depth, z (m)	N_{SPT}	γ (kN/m³)	Seismic Shear Stress τ_e (kN/m²)	σ_{vo}' (kN/m²)	Cyclic Stress Ratio	Result
Stiff Sandy Clayey Silt	0.4	15	16	0.96	2.40	0.40	No Liquefaction
	1	30	19	2.84	9.00	0.32	No Liquefaction
	2.5	23	17	6.35	17.50	0.36	No Liquefaction
	3.5	31	19	9.94	31.50	0.32	No Liquefaction
Stiff Sandy Silt	4	39	19	11.36	36.00	0.32	No Liquefaction
Hard Sandy Clayey Silt	5.5	16	17	13.98	38.50	0.36	No Liquefaction
	6.5	30	19	18.46	58.50	0.32	No Liquefaction
Hard Silty Clay	9.5	36	19	26.98	85.50	0.32	No Liquefaction
	12.5	36	19	35.51	112.50	0.32	No Liquefaction
	15.5	44	19	44.03	139.50	0.32	No Liquefaction
	18.9	50	19	53.69	170.10	0.32	No Liquefaction
							continue last value up to 30m depth

Soil #1: Clay, no liquefaction potential



	Depth, z (m)	N_{SPT}	γ (kN/m³)	Seismic Shear Stress τ_e (kN/m²)	σ_{vo}' (kN/m²)	Cyclic Stress Ratio	Result
Medium to coarse sand	1	17	18	2.69	8.00	0.34	Liquefaction
	2.5	4	16	5.98	15.00	0.40	Liquefaction
	3.8	6	16	9.09	22.80	0.40	Liquefaction
	5	6	16	11.96	30.00	0.40	Liquefaction
Medium sand	7.25	6	16	17.34	43.50	0.40	Liquefaction
	9.25	8	16	22.13	55.50	0.40	Liquefaction
	10.4	8	16	24.88	62.40	0.40	Liquefaction
	11.5	27	18	30.95	92.00	0.34	Liquefaction
	13.3	23	18	35.79	106.40	0.34	Liquefaction
	14.7	6	16	35.16	88.20	0.40	Liquefaction
Fine sand	16	23	18	43.06	128.00	0.34	Liquefaction
	18	37	19	51.13	162.00	0.32	No Liquefaction
	19.25	36	19	54.68	173.25	0.32	No Liquefaction
	20.3	37	19	57.66	182.70	0.32	No Liquefaction
	22	35	18	59.20	176.00	0.34	No Liquefaction
	23.7	37	19	67.32	213.30	0.32	No Liquefaction
							continue last value up to 30m depth

Soil #2: Sand, has potential to liquefy

Case study – FE modelling approach

☐ Lumped spring model (*MIDAS software*)

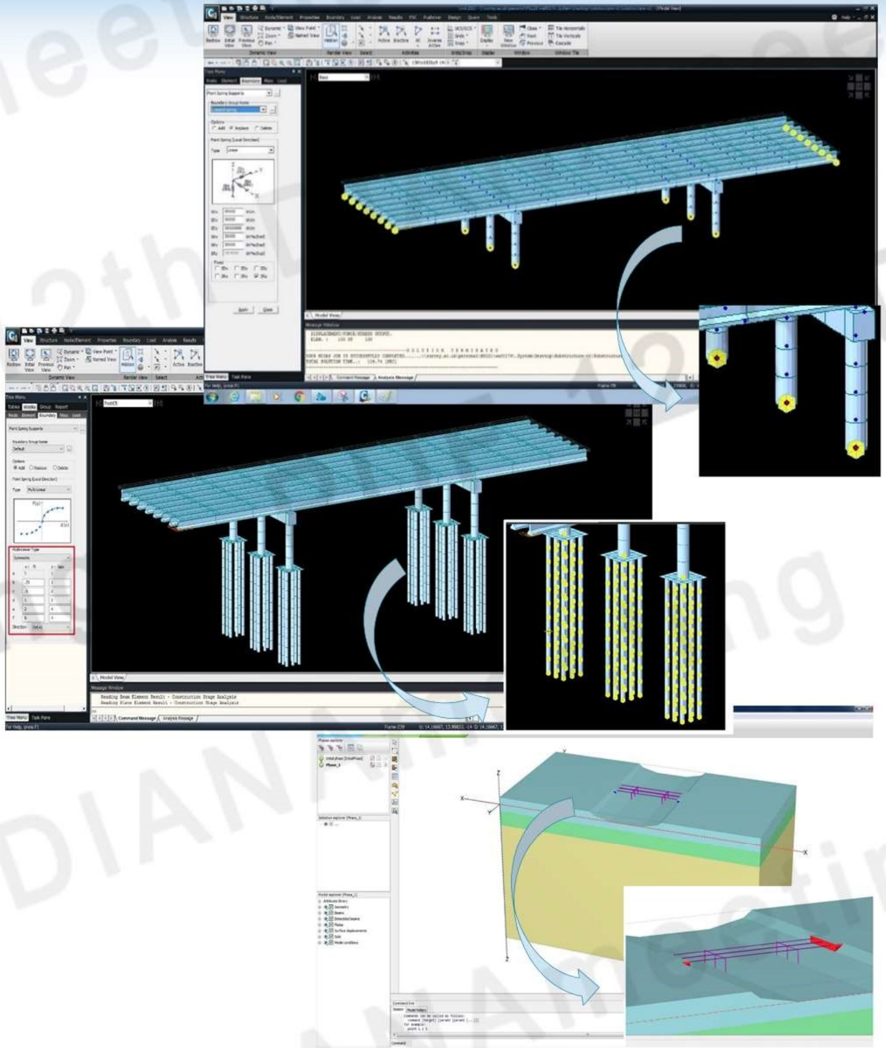
- ✓ Spring parameters from pier & abutment analyses
- ✓ Faster analysis run-time than Winkler (≅ 3 min)
- ✓ Higher level of preparatory work

☐ Winkler spring model (*MIDAS software*)

- ✓ P-y curves derived using ALP software
- ✓ Abutment spring parameter from separate analysis
- ✓ Relatively fast analysis run-time (≅ 15 min)

☐ Direct FE model (*PLAXIS software*)

- ✓ Soil modelled as linear strain elements
- ✓ Boundary distances affect analysis results
- ✓ Relatively long analysis run-time (≅ 30 min)



Case study – FE modelling approach

- ☐ Lumped spring model (*DIANA software*)
  - ✓ Spring parameters from pier & abutment analyses
  - ✓ Faster analysis run-time than Winkler
  - ✓ Higher level of preparatory work
- ☐ Winkler spring model (*DIANA software*)
  - ✓ P-y curves derived using ALP software
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  - ✓ Soil modelled as linear strain elements
  - ✓ Boundary distances affect analysis results
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Case study: Results I – bridge components

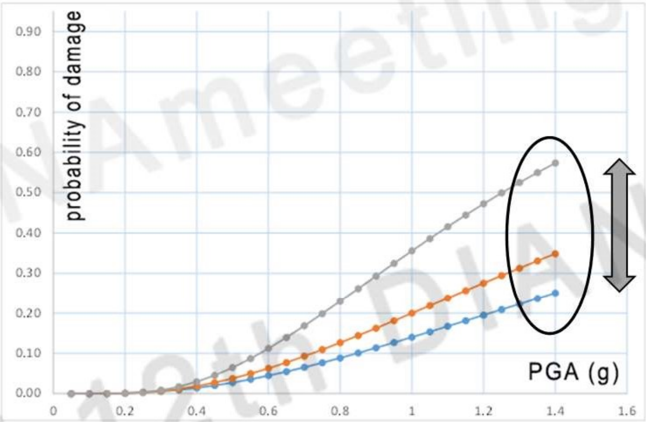
- ☐ As a function of the type of the SSI model approach:

	Column/Pier	Fixed bearings	Rocker bearings	Abutments
Highest probability of failure	Lumped Spring	Lumped Spring	Direct FE Method	Direct FE Method
	Winkler Spring	Winkler Spring	Lumped Spring	Lumped Spring
Lowest probability of failure	Direct FE Method	Direct FE Method	Winkler Spring	Winkler Spring

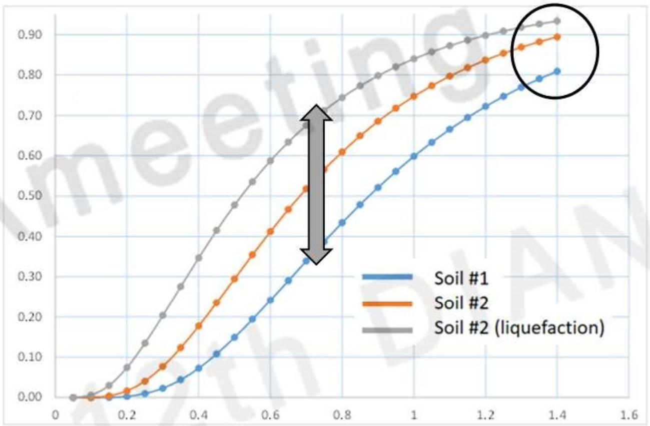
Legend:

- 🟨 Highest values for Direct FE
- 🟥 Highest values for Lumped spring

- ☐ As a function of the type of soil:



Complete damage – Column (Winkler spring)



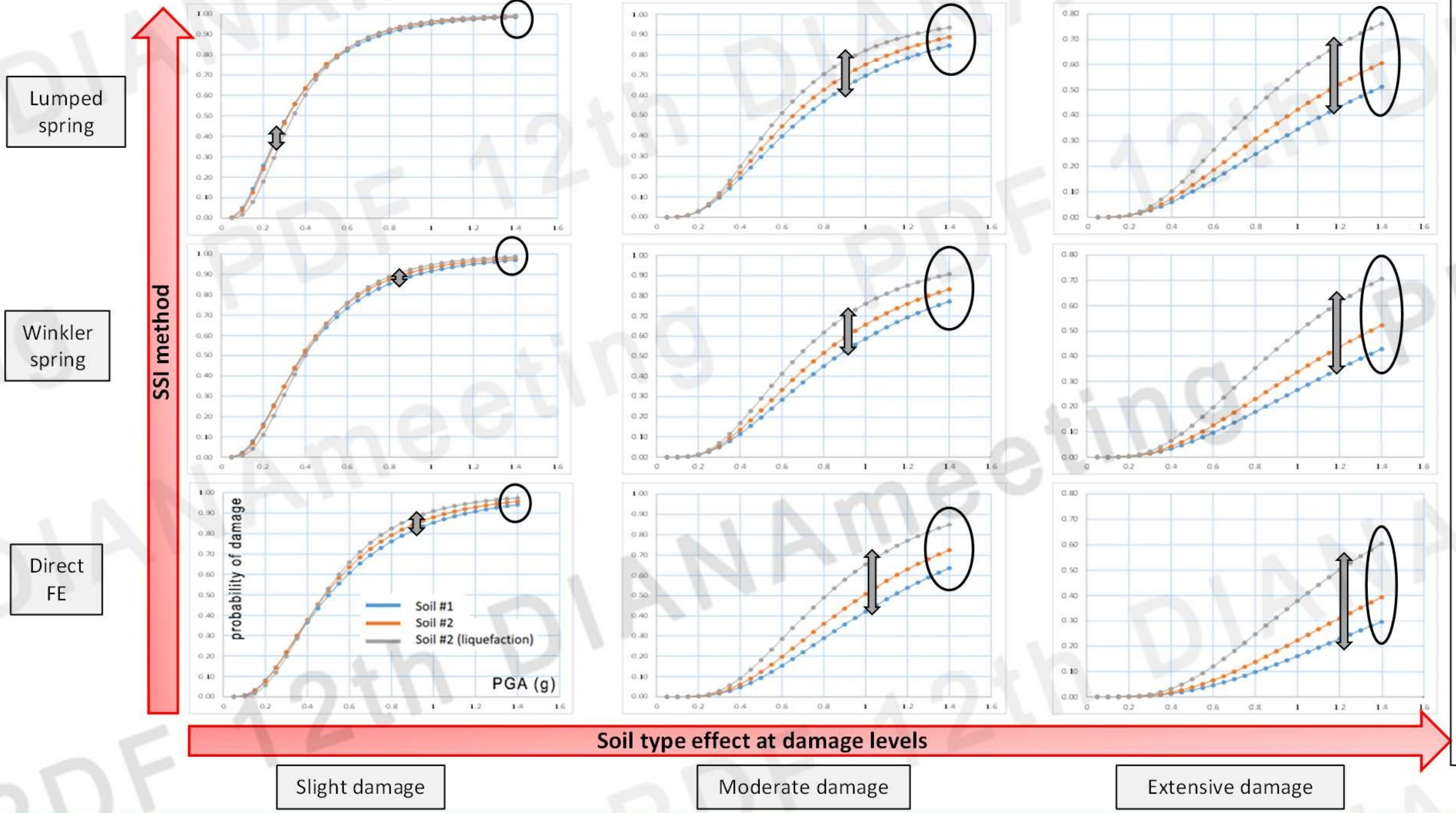
Moderate damage – Bearing (Direct FE)

∴ Fragility curves show:

- ✓ High scatter between different soil profiles,
- ✓ Different patterns observed depending on the bridge component,
- ✓ Soil #2 (with liquefaction) has the highest probability,
- ✓ Soil #1 has lowest probability.

Case study: Results II – bridge system

❑ Type of the SSI model approach vs. the type of soil:

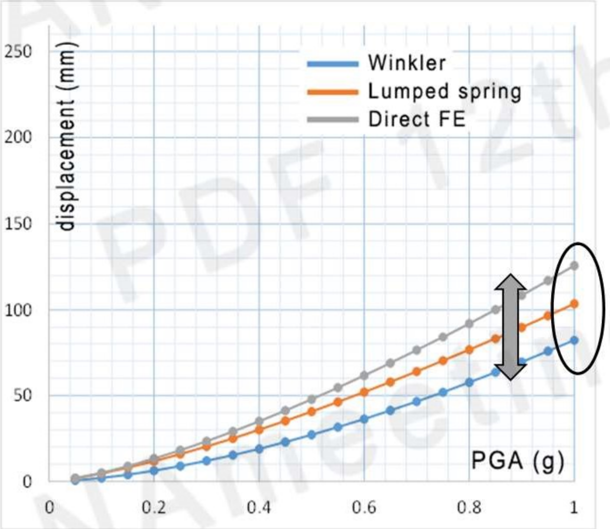


∴ Fragility curves show:

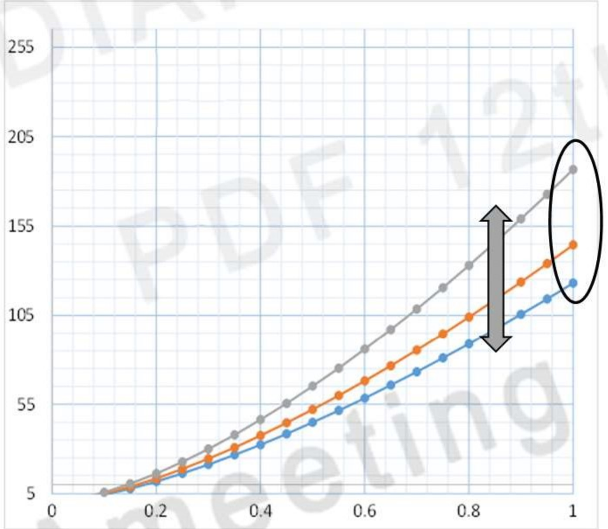
- ✓ Consistent patterns between different SSI approaches,
- ✓ Lower probability of failures as the SSI approach becomes more refined,
- ✓ Soil type has more effect at higher levels of damage,
- ✓ Lumped-spring method produced highest probabilities, followed by Winkler-spring and Direct-method.

Case study: Results III – deck displacements

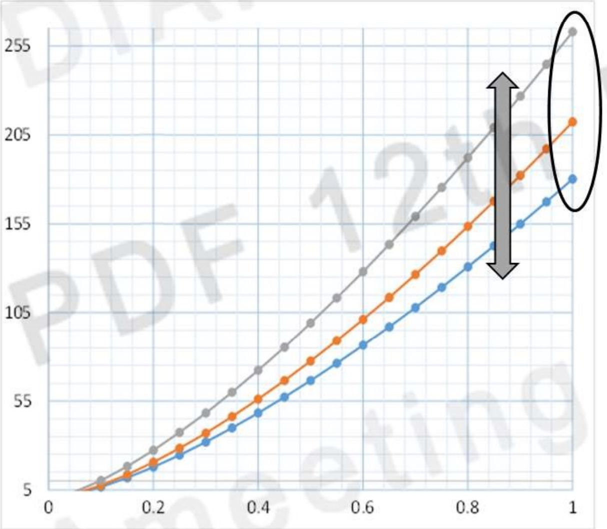
❑ As a function of both the SSI model approach and the type of soil :



Soil Profile #1



Soil Profile #2 – no liquefaction



Soil Profile #2 – liquefaction

∴ Displacement curves show:

- ✓ Consistent patterns between different SSI approaches
- ✓ Scatter increases as the soil properties becomes weaker
- ✓ Direct FE leads to higher displacements

Conclusions

❑ Impact of SSI modelling on fragility curves

- ✓ Greater effect at the bridge component level (important for retrofitting decisions)
- ✓ Consistent patterns between different SSI approaches at the bridge system level
- ✓ Scatter increases between results from different SSI models as the soil properties becomes weaker
- ✓ Lumped-spring method produced highest probabilities of failure but it is the fastest method
- ✓ Direct FE leads to higher displacements

❑ Comparison of modelling methods

- ✓ A more comprehensive SSI approach may not always be the most efficient approach
- ✓ The Winkler spring method provides acceptable results, on a comparative basis
- ✓ Define requirements (e.g. probability of failure, displacements, etc) before selecting a method of analysis

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THANK YOU!

☺

11th October 2018, University of Porto, Porto, Portugal