PEER Workshop on
Seismic Risk Assessment and Management of Transportation Networks Purpose

Analysis of Seismic Performance of Port Facilities

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John A Martin Conference Room
University of California, Berkeley
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- **Socio-Economic Effect of Seismic Retrofit of Concrete Bridges**

  (Zhou, Y., S. Banerjee and M. Shinozuka, "Socio-economic effect of seismic retrofit of bridges for highway transportation networks: A pilot study", Journal of Structure and Infrastructure Engineering, 2009, Published Online)

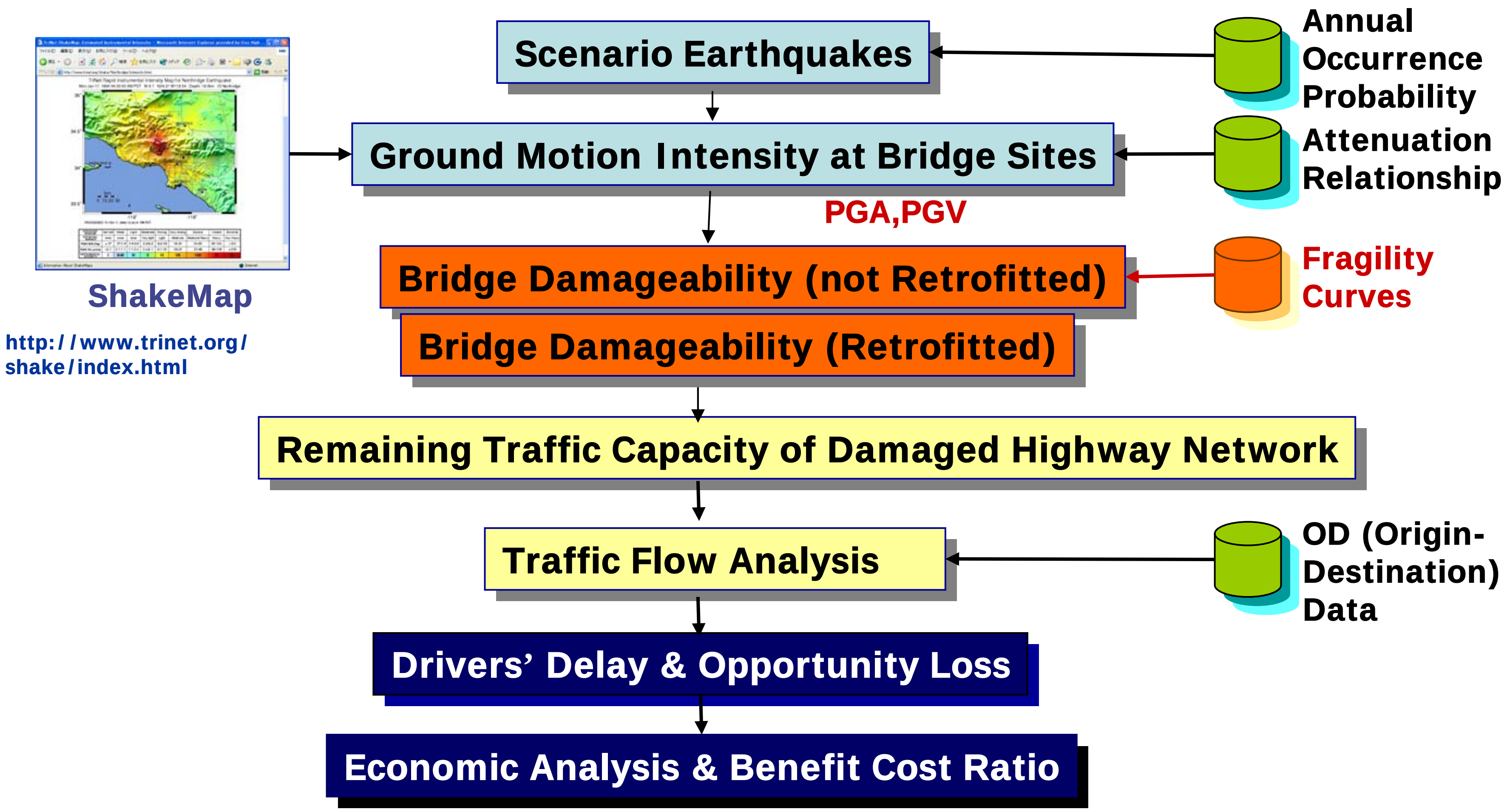
- **Analysis of Seismic Performance of Port Facilities**

  (Ung Jin Na, Samit Ray Chaudhuri and Masanobu Shinozuka, "Probabilistic assessment for seismic performance of port structures", Soil Dynamics and Earthquake Engineering, Volume 28, Issue 2, February 2008, Pages 147-158.

  Na, U.J., Ray Chaudhuri, S., and Shinozuka, M. (2008). "Effects of spatial variation of soil properties on seismic performance of port structures", Soil Dynamic and Earthquake Engineering, Available online.

  Na U.J., Shinozuka M. (2008), "Simulation-based seismic loss estimation of seaport transportation system", Reliability Engineering and System Safety (available online).

Performance of Highway Network



1994 Northridge Earthquake Damage Data

Total Number of Bridges in Damage Data : 2209

Damage State	Number of Bridges
No Damage	1978
Minor Damage	84
Moderate Damage	94
Major Damage	47
Collapse	6

231 damaged

Classified

1st Level (Composite)

The entire sample represents a statistically homogeneous population of bridges.

2nd Level

Divided by
- Span (2 groups)
- Skew (3 groups)
- Soil (3 groups)

3rd Level

Divided by
- Span + Skew (6 groups)
- Span + Soil (6 groups)
- Skew + Soil (9 groups)

4th Level

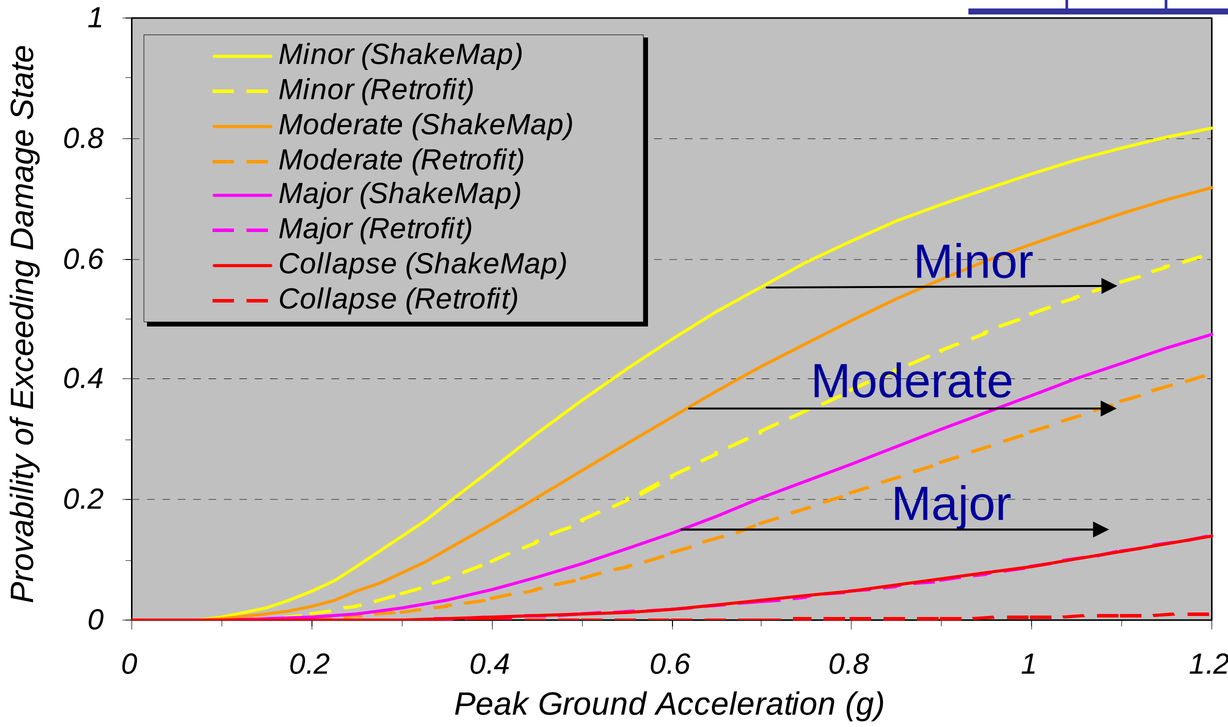
Divided by
- Span + Skew + Soil (18 groups)

Fragility Curve (PGA, Retrofit)

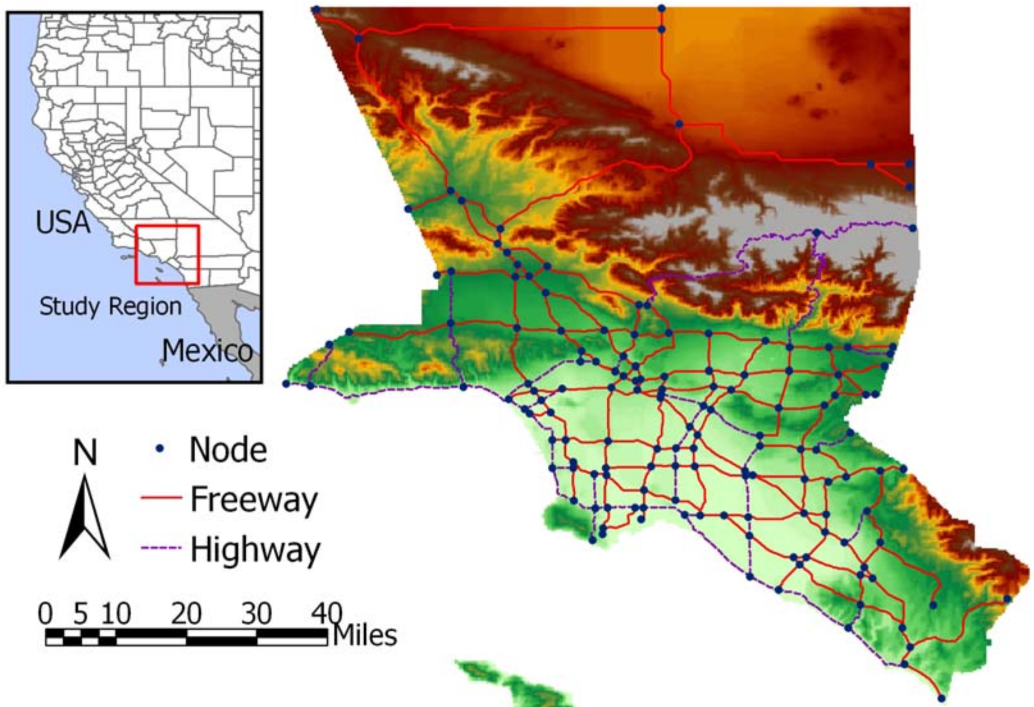
$$F(a) = \phi\left[\frac{\ln(a/C)}{\zeta}\right]$$

a : PGA Value (g)
C : Median (g)
ζ : Log Standard Deviation

	ShakeMap		Retrofit	
	C	ζ	C	ζ
Min	0.64	0.70	0.99	0.70
Mod	0.81		1.40	
Maj	1.25		2.55	
Col	2.55		6.20	



Network Modeling for Los Angeles (2003)

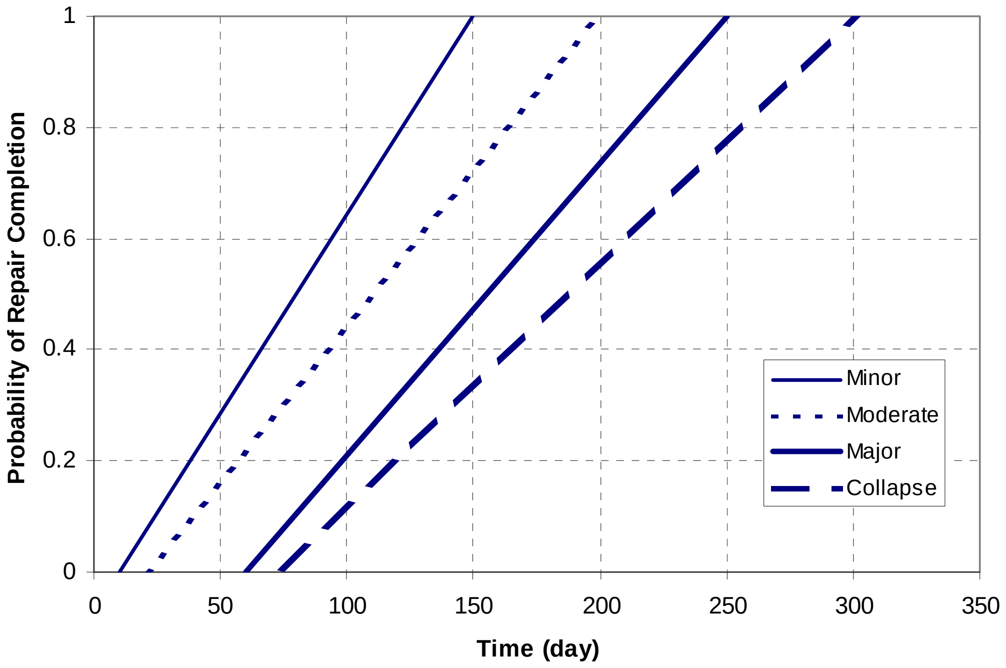


	Traffic Light	Speed Limit (MPH)	Capacity (PCU)
Freeway	×	65	2500
Highway	○	35	1000

Total Number of Nodes =148
Total Number of Links =231

❖ PCU : Passenger Car Unit

Probabilistic Bridge Repair/Restoration Model

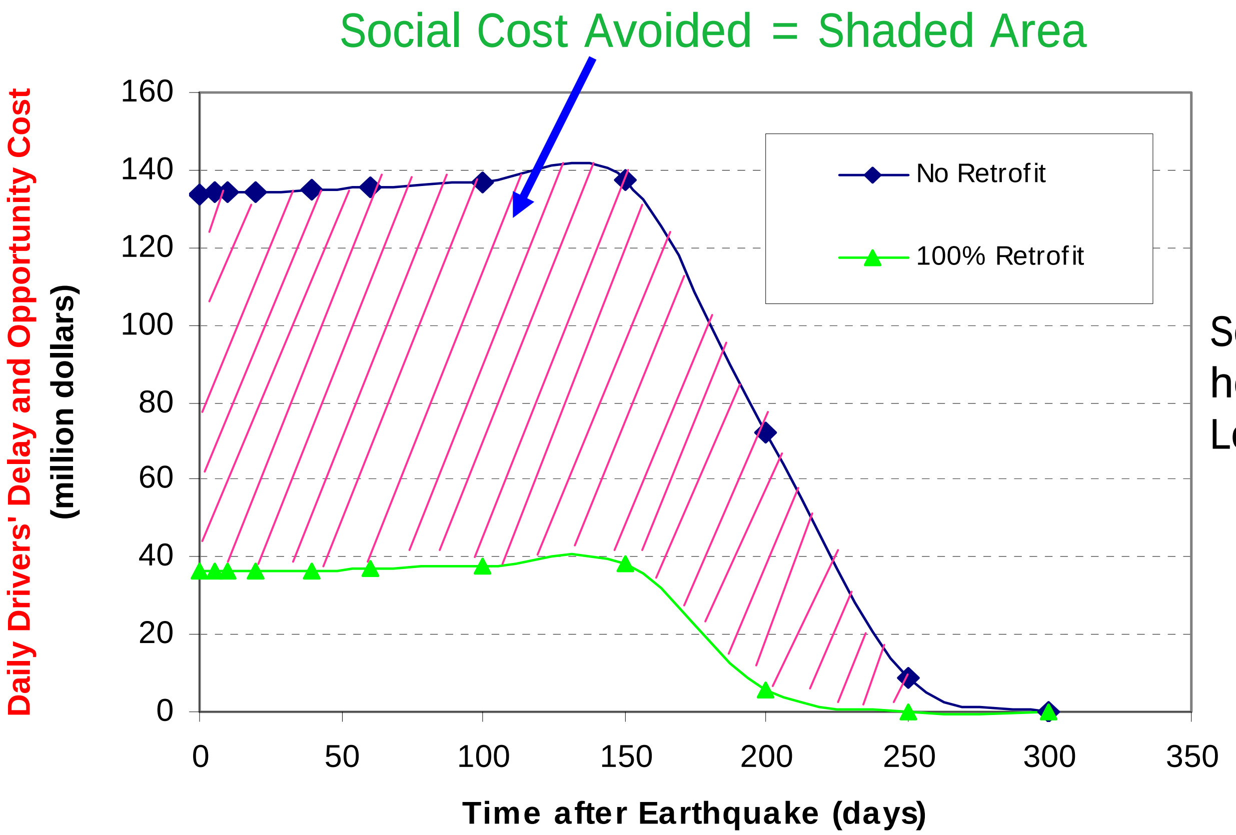


Damage State	Days for Repair Completion	
	Minimum	Maximum
Minor	10	150
Moderate	20	200
Major	60	250
Collapse	75	300

Depends on Preparedness and Resourcefulness

(Shinozuka etc. 2003)

Effect of Bridge Retrofit on System Restoration Curve



Social cost in hour * average hourly wages (~$21.77/h for Los Angeles in 2005 DOL)

(Shinozuka's Bridge Restoration Model, Low Residual Link Capacity Case)

Cost-effectiveness Evaluation Example

Benefit-Cost	Retrofit
Total Social Cost Avoided ($Million) (1)	7,220
Total Bridge Restoration Cost Avoided($Million) (2)	86.7
Total Retrofit Cost($Million) (3)	1,665
Benefit/Cost Ratio in terms of Bridge Restoration Cost Avoided (4)=(2)/(3)	0.052
Benefit/Cost Ratio in terms of Social Cost Avoided (5)=(1)/(3)	4.34
Total Benefit/Cost Ratio (6)=[(1)+(2)]/(3)	4.39

*** Evaluation is based on**
discount rate= 3%; Low link residual capacity;
remaining life of retrofitted bridges T =50 years.

Cost-effectiveness Evaluation Summary

Discount Rate	Benefit/Cost Ratio	Cost-Effectiveness
3%	4.39	Yes
5%	3.12	Yes
7%	2.36	Moderate

R=Benefit/Cost Ratio

No: R<1.5 **Moderate**: 1.5 <= R<2.5 **Yes**:R>=2.5

Conclusions

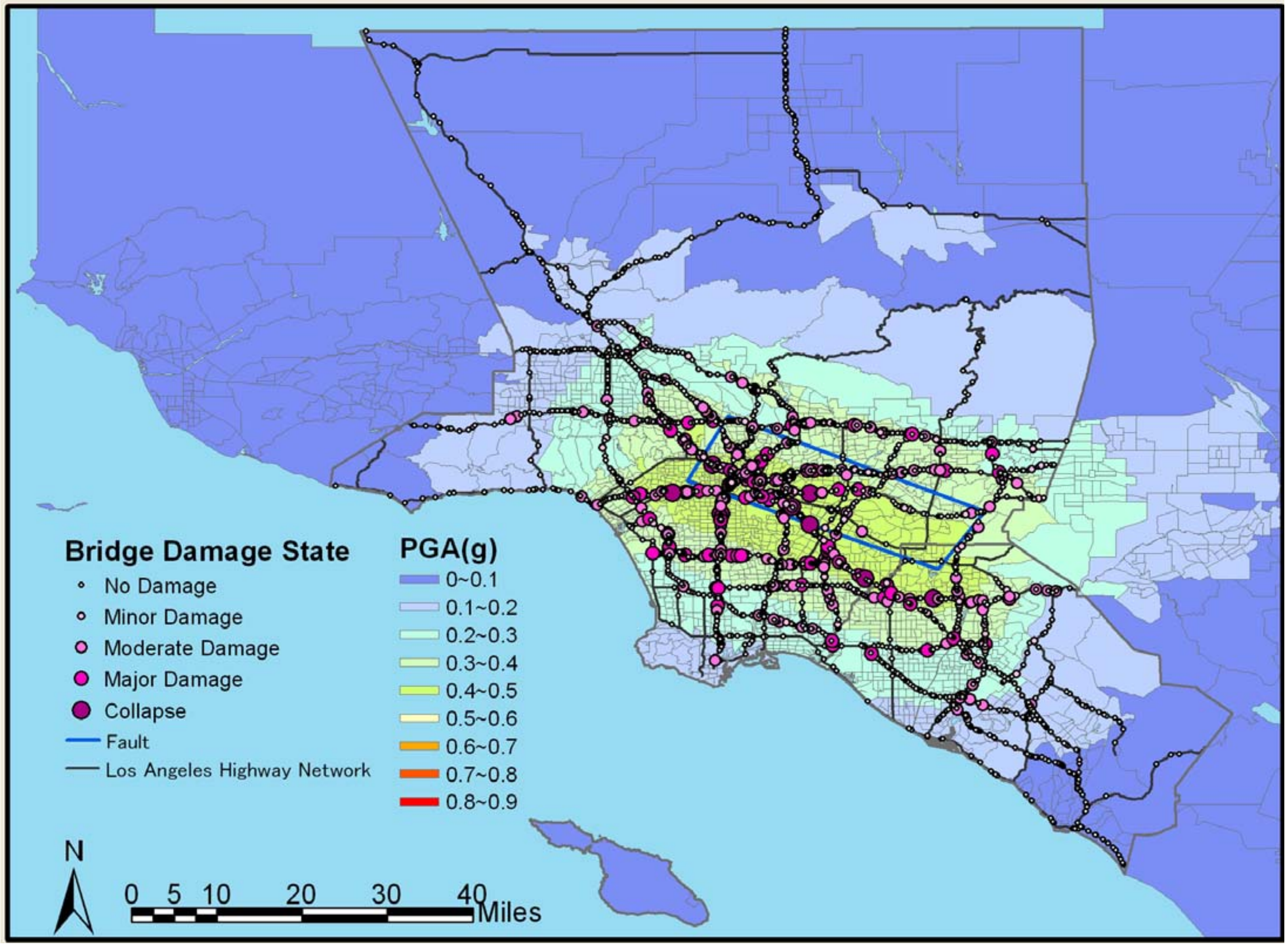
- **Carried out Multidisciplinary Analysis on Cost-Effectiveness of Bridge Retrofit**

- **Developed and Integrated Analytical Models Consisting of Modular Models for Contributing Factors:**
  - **Engineering Seismology:Probabilistic Scenario Earthquakes**
  - **Structural Engineering:Fragility Curves**
  - **Transportation System Analysis:Traffic Assignment**
  - **Socio-Economic Analysis**

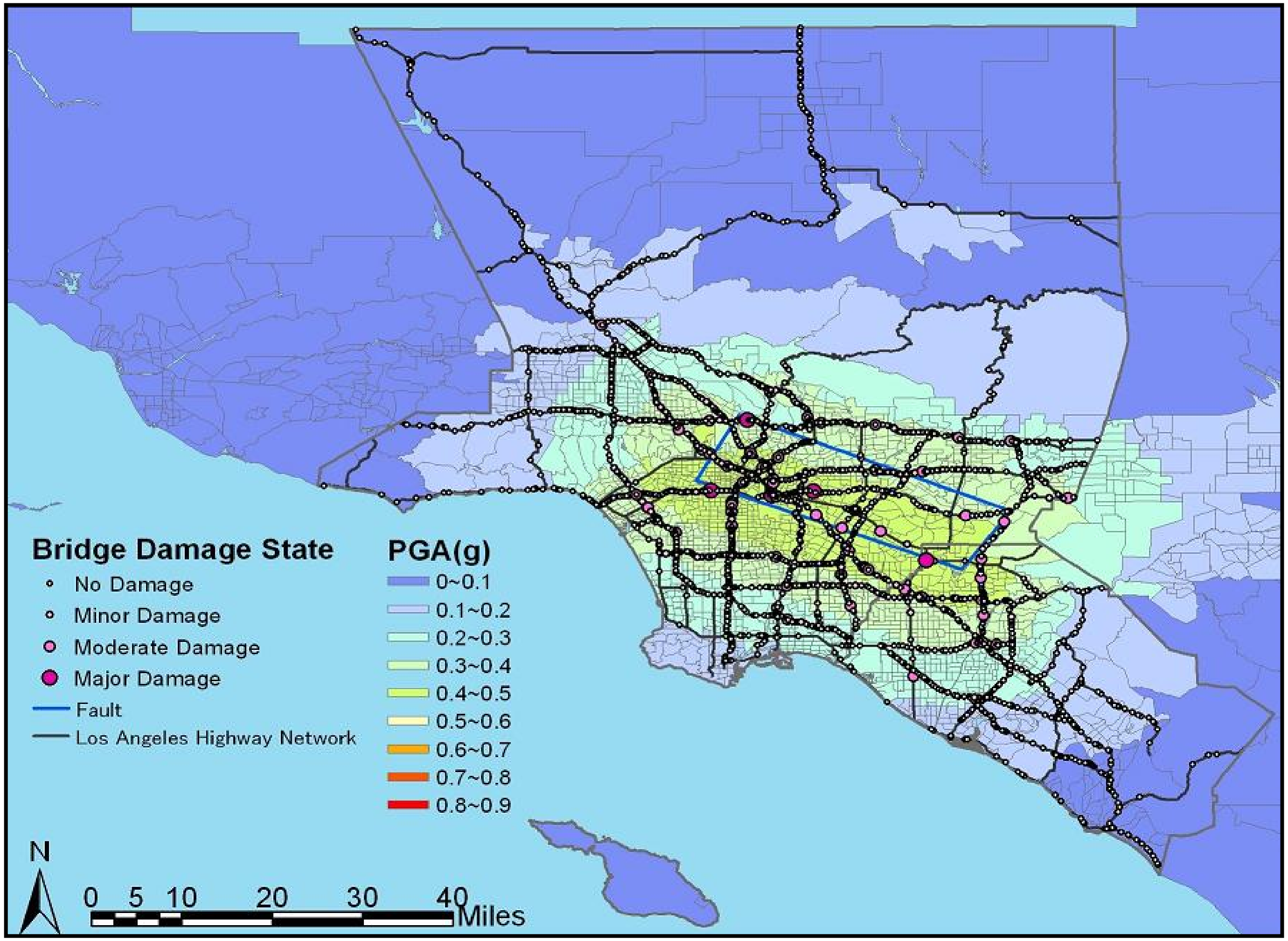
- **Multilayer Monte Carlo Simulation Approach**

- **Found that Bridge Retrofit is Cost-effective if We Take Social Cost into Consideration**

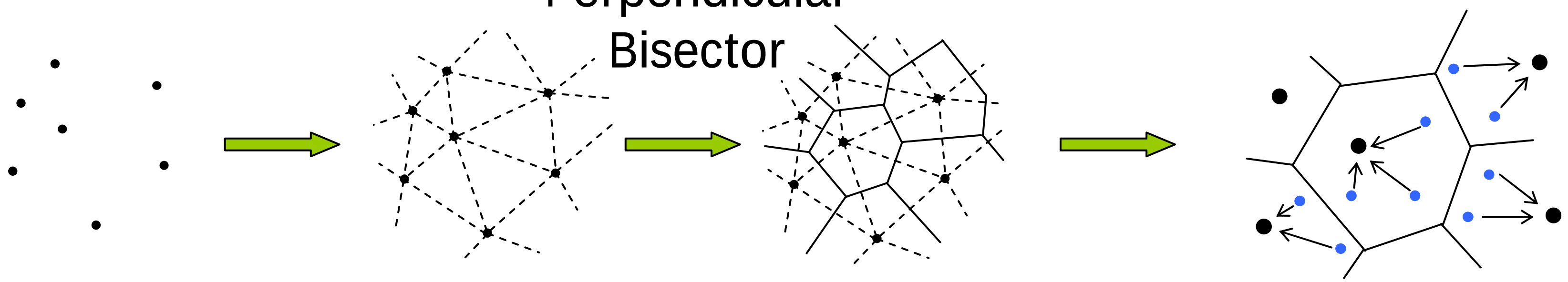
PGA Distribution & Bridge Damage State (1)
-Elysian Park M7.1 (before retrofit)



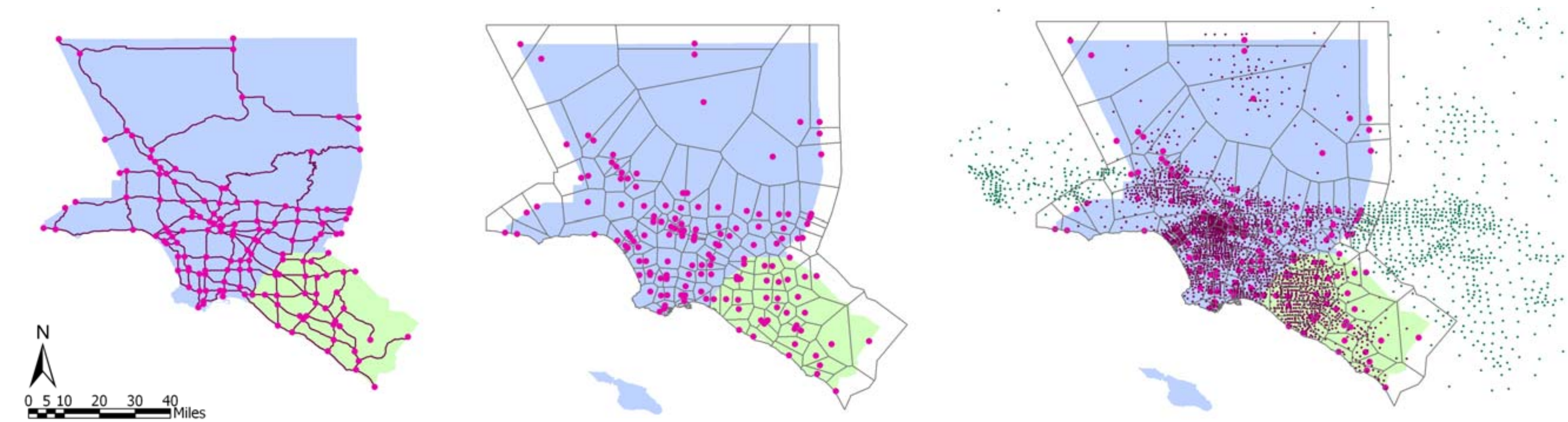
PGA Distribution & Bridge Damage State (2) -Elysian Park M7.1 (after retrofit)



Condensation OD



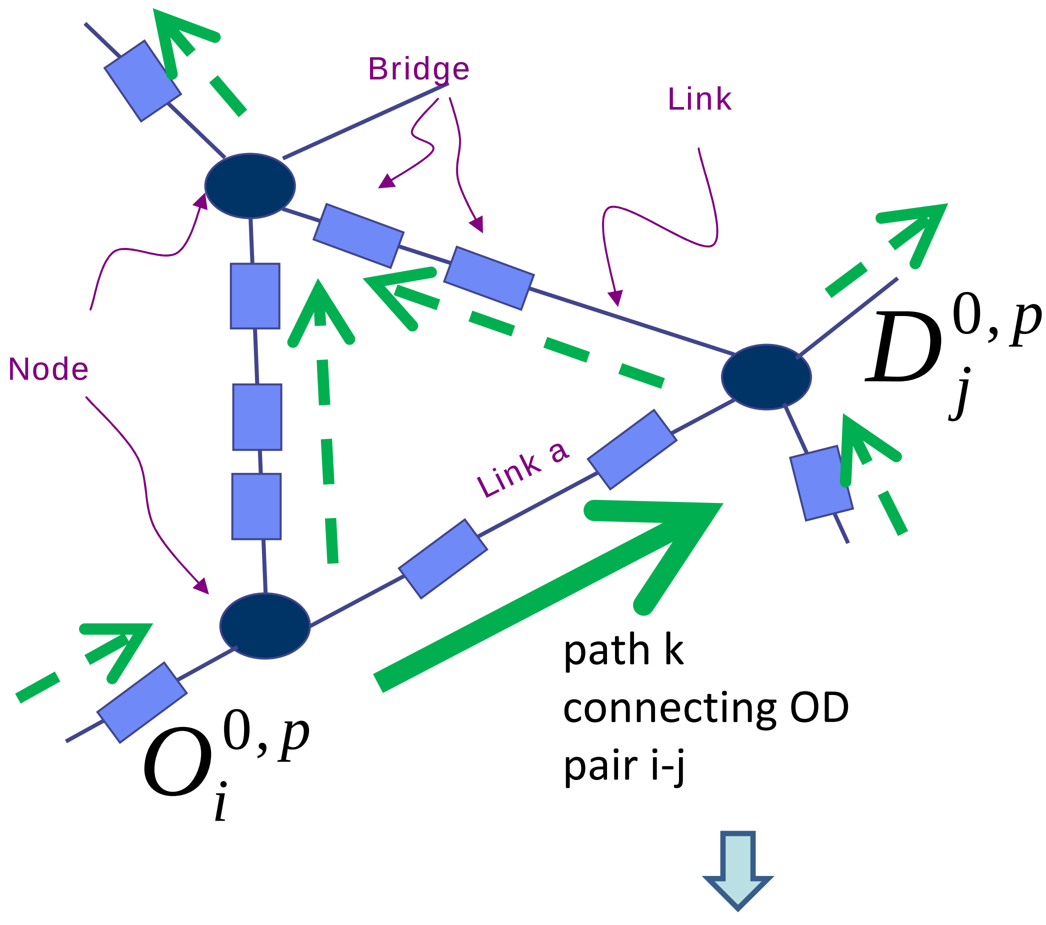
Nodes Tin Thiessen



New Total Number of Traffic Analysis Zones (TAZ) = 148 (Original 2270)

Network assignment model

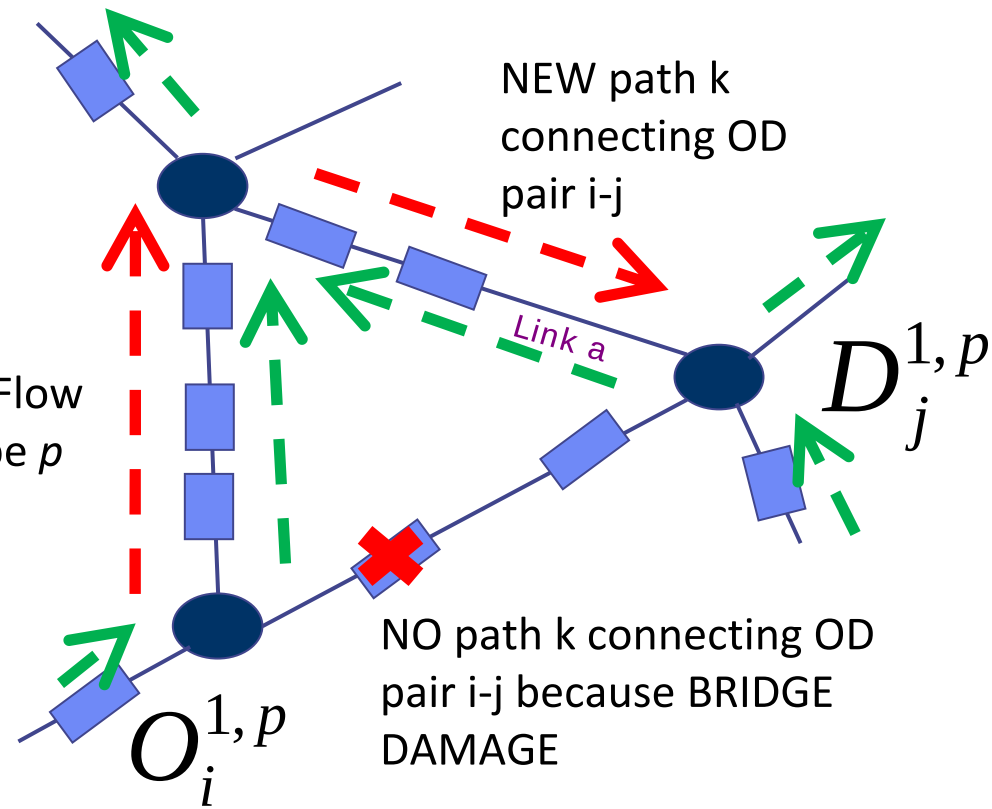
Before earthquake (free flow speed, 100% link capacity, daily OD)



$$f_{ij}^{pk} \geq 0$$ Flow of trip type *p*

Network assignment model

After earthquake (reduced flow speed, reduced link capacity, reduced OD)



path k connecting OD pair i-j changes

⇩

$$f_{ij}^{pk,1} \geq 0$$ Reduced Flow of trip type *p*

⇩

$$\sum_k f_{ij}^{pk,1} = t_{ij}^p$$ Trip rate of type *p*

⇩

Flow on link *a*

$$x_a = \sum_p \sum_{i,j} \sum_k f_{ij}^{pk} \cdot \delta_{ij}^{a,k}$$

1 if link *a* is on path *k* between OD pair *i-j*, 0 other-wise

⇨

Travel time

$$c_{ij} = \sum_a c_a(x_a) \cdot \delta_{ij}^{a,k}$$

Link performance function of link *a*

$$t_a = t_a^0 \left(1 + \alpha \left(\frac{x_a}{c_a} \right)^{\beta} \right)$$

Economic Analysis (1)

Under any earthquake

Bridge Restoration Cost

(repair or replacement)

$$C_{RPj} = \sum_{i=1}^{N} C_i \bullet R(k_{ij})$$

Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Minor	0.03	0.01-0.03
Moderate	0.08	0.02-0.15
Major	0.25	0.10-0.40
Complete	1.00*	0.30-1.00

(HAZUS)

Social Cost in Dollars

$$C_{SC} = T_{SC} * c_{T_{SC}}$$

Social cost in hour * average hourly wages(~$21.77/h for Los Angeles in 2005 DOL)

Economic Analysis (2)

Expected Annual Benefit from Seismic Retrofit

$$\overline{B} = \sum_{i=1}^{M} (C_{RPi}^{0} - C_{RPi}^{R} + C_{SCi}^{0} - C_{SCi}^{R}) \bullet \overline{p}_{i}$$

C_{RPi}^{0} , C_{RPi}^{R} Bridge restoration cost before and after retrofit under earthquake i

C_{SCi}^{0} , C_{SCi}^{R} Social cost before and after retrofit under earthquake i

$\overline{p}_{i}$ Annual frequency of earthquake i

Total Benefit in T years (in present value)

$$B = \sum_{n=1}^{T} \frac{\overline{B}}{(1+i)^{n}} = \overline{B} \bullet \frac{(1+i)^{T} - 1}{i(1+i)^{T}} = \overline{B} \bullet F$$

i:discount rate

Total Bridge Retrofit Cost (in Present Value)

$$C_{R} = \sum_{i=1}^{N} C_{i} * r_{i}$$

Replacement value($120/sq ft) * Retrofit cost ratio(25%) for All retrofitted Bridges

Benefit-Cost Ratio

Future Study

- Improvement of Models for Each Contributing Factor, in particular,
  * System Restoration Process
  * Social Cost

- Better Quantification of Uncertainty associated with Each Contributing Factors
- Risk Definitions Depending on Stakeholders
- Risk and Resilience Assessment under
  – Flood
  – High Wind
  – Wild Fire
  – Tsunami
  – Man made hazards

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Probabilistic Assessment for Seismic Risk of Port Transportation System

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EARTHQUAKE

Why Ports and Harbors ?

- Important nodes of transportation networks
  - Provide shipping and distribution via water
  - Major centers of commerce
  - 97% of international cargo through seaports
  - ➡ Down time results in severe economic loss
- Vulnerable to earthquakes
  - located very near to faults
  - Built on fill or soft natural material (Liquefaction)
  - ➡ High risk of being damaged

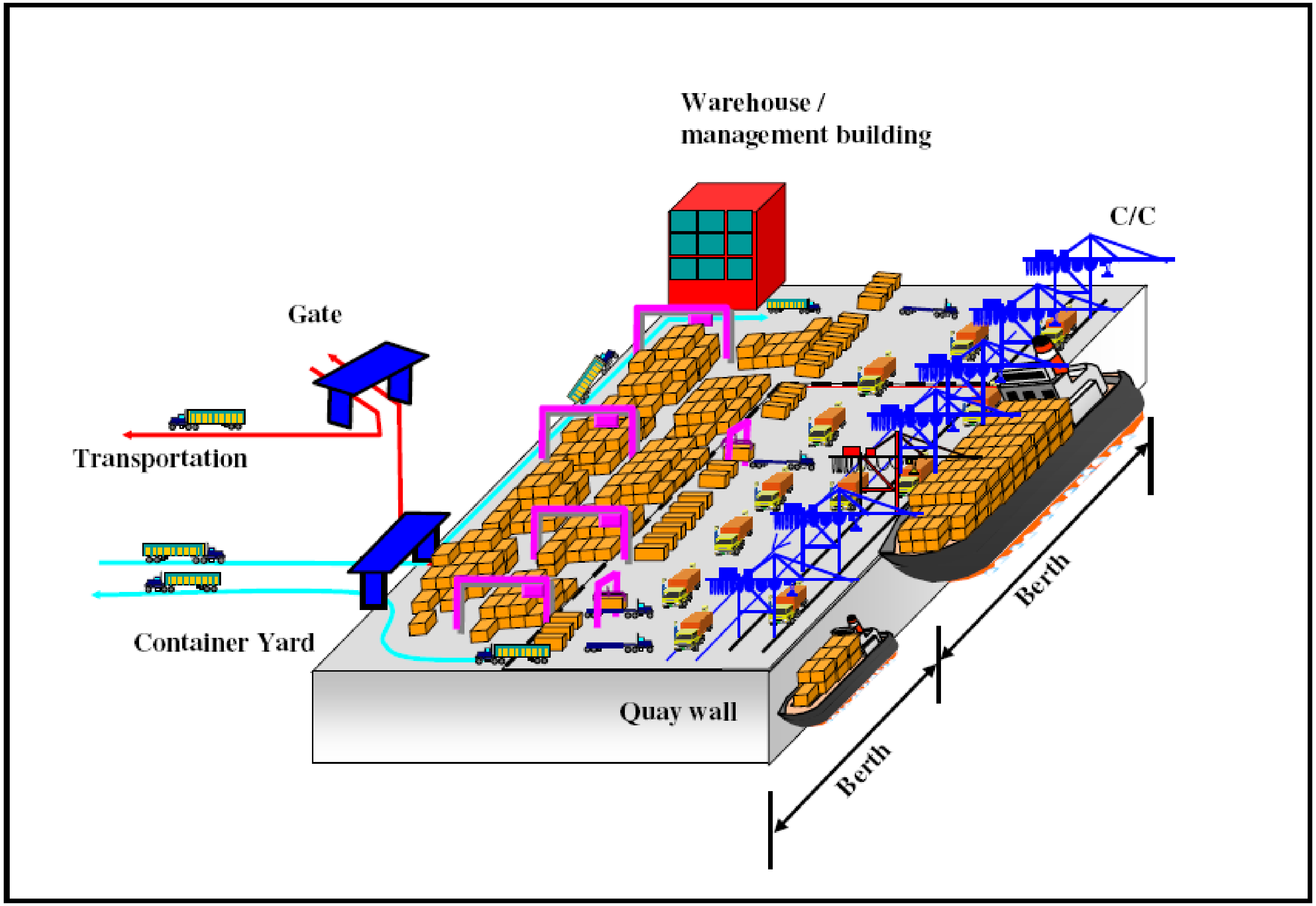
Examples of Economic Loss

- Labor strike (Oakland, LA, Long Beach, 2002)
  - Estimated cost to U.S. : $ 19.4 billion (10days)
- Typhoon (S.Korea, 2003)
  - collapsed 11 cranes : more than 1 year to recover

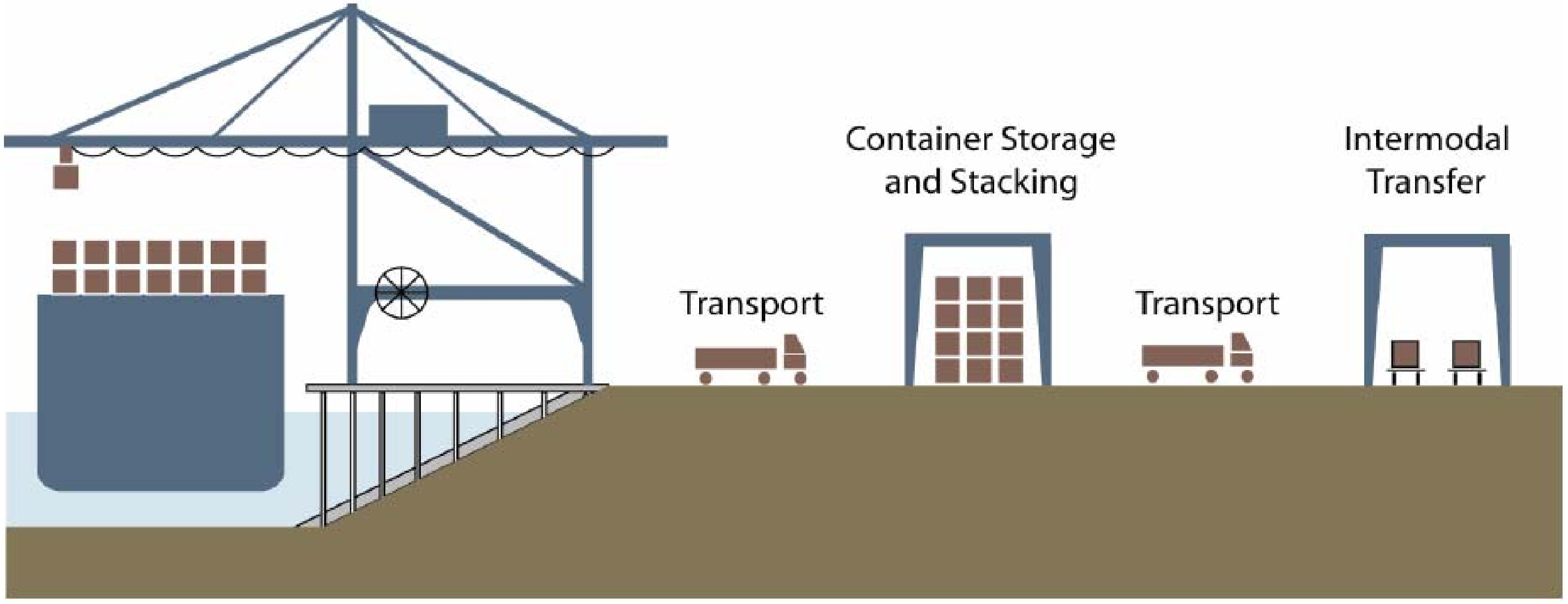
View of the Container Terminal

- View of Busan New Port 2-2 phase (S.Korea)

Container Terminal System

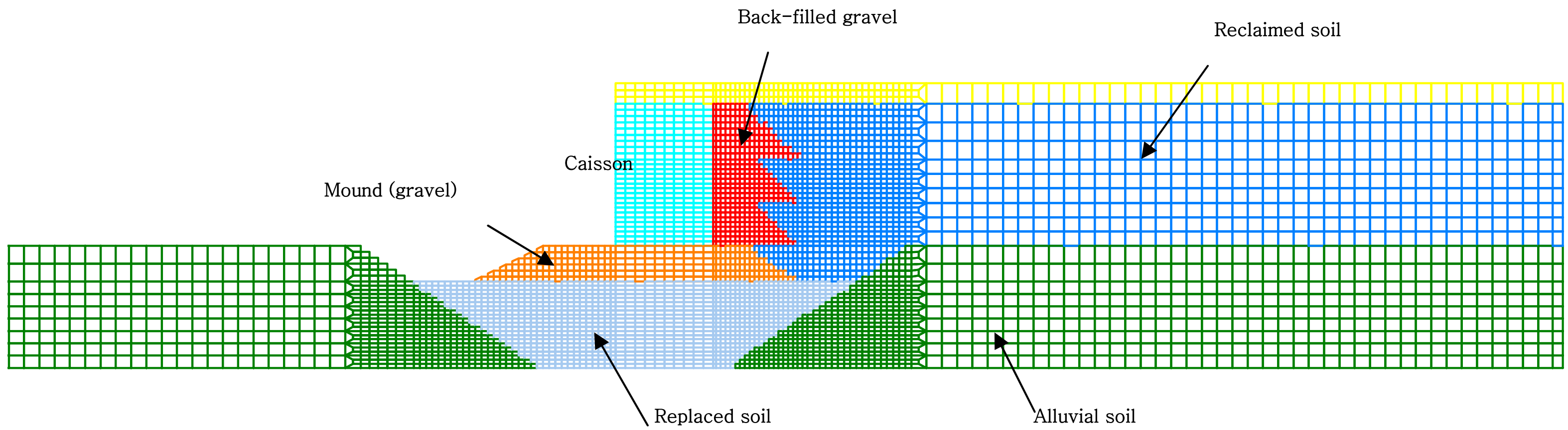


Container Terminal System



Numerical Simulation

- Modeling of the quay wall
  - FLAC (Itasca, 2005)
  - Dynamic analysis for a reference structure (PC1, Kobe)



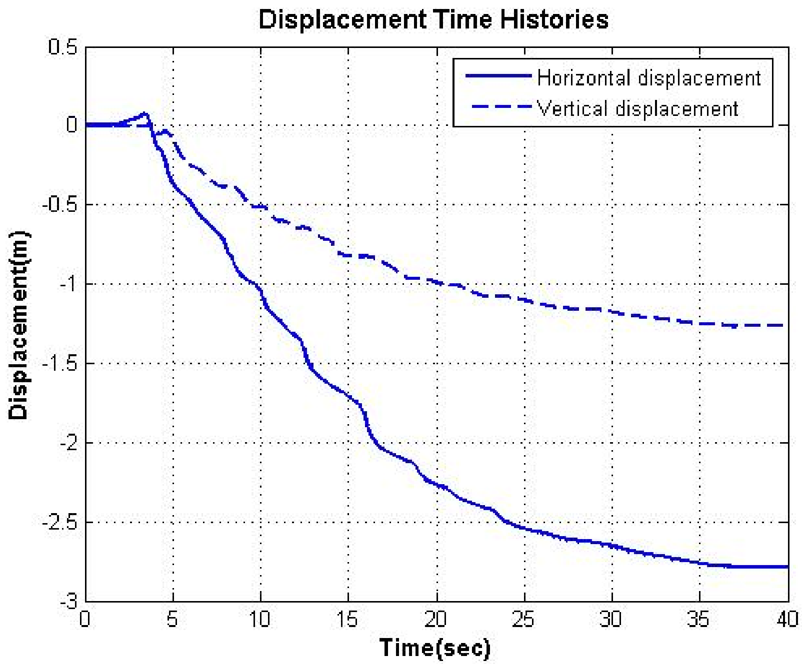
Bed-rock

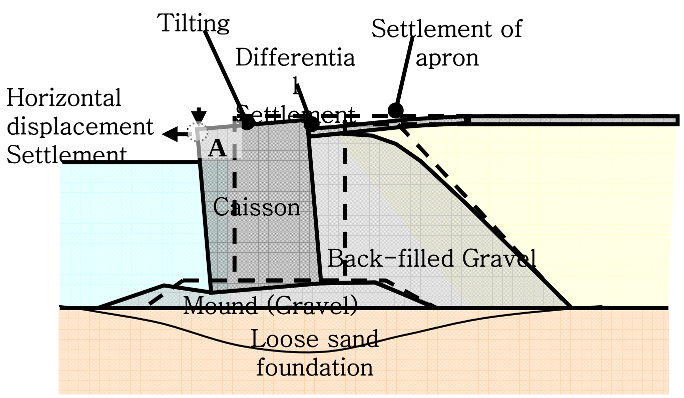
* PC1 berth (Port Island, Kobe)

Numerical Simulation (4)

❑ Analysis results

* Displ. time histories of the upper seaside corner of the caisson

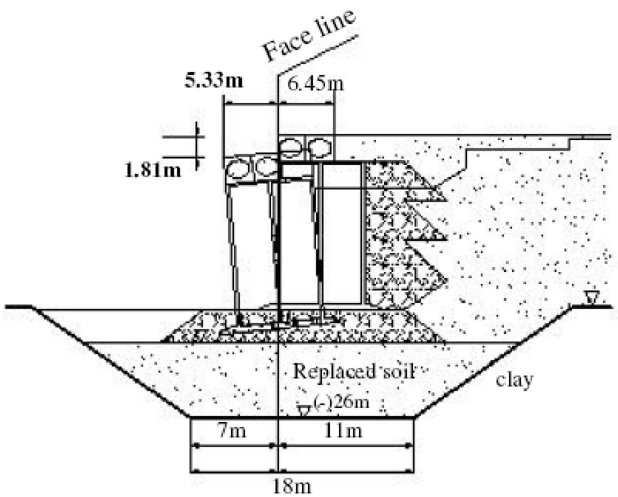




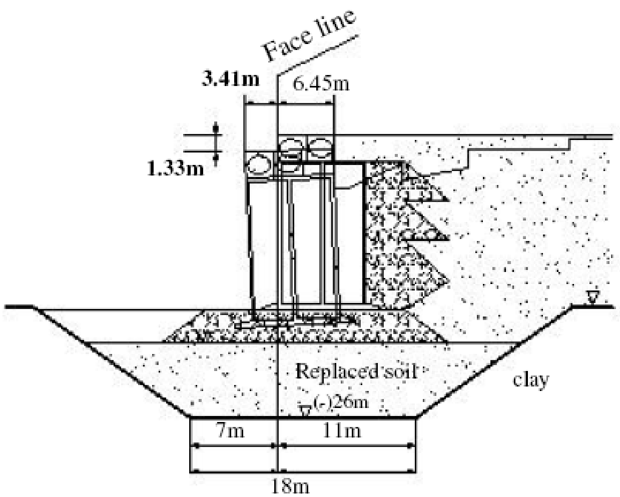
- Field investigation : 2.55 to 2.80m in the horizontal direction
  1.13 to 1.41m vertical settlements

Identification of uncertainty

- Considerable variability in seismic response
  - Identical configuration, located at the same site, with similar seismic intensity and similar soil conditions
  - > experienced different degrees of damage



(a) PL 13 berth



(b) PL 12 berth

* Two identical caissons sitting next to each other showing different degrees of damage (Port Island, Kobe)

Spatial variation of Soil Properties

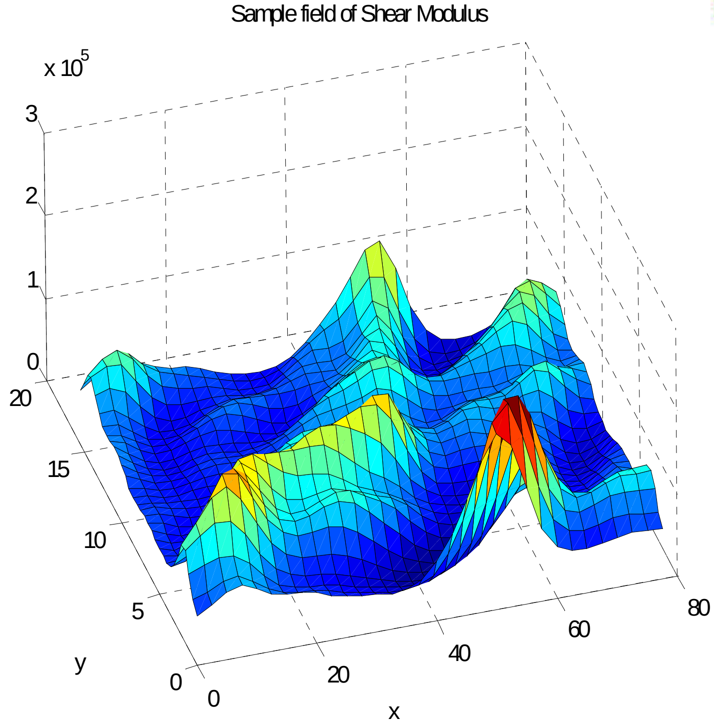
- Spatially variable soil properties
  - Soil properties : generally assumed deterministic
  - Representing spatial variation with random fields
  - Expressed using power spectral density function

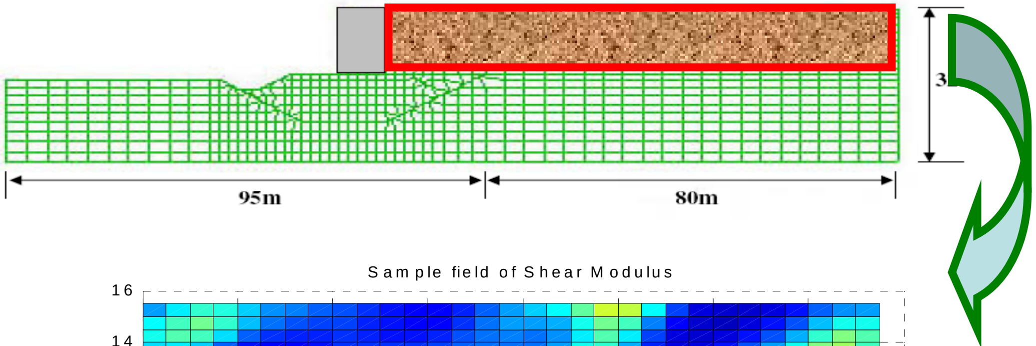
- random field simulation

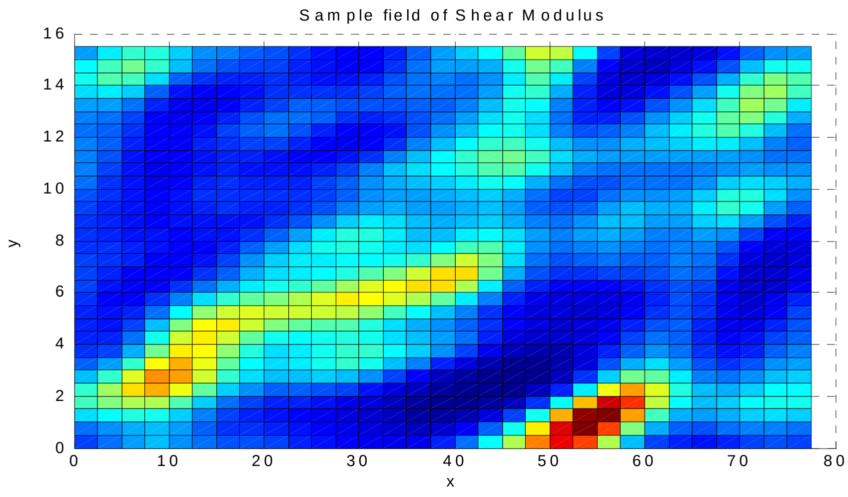
  : 2D non-Gaussian random field

  : Shear Modulus of backfill soil is focused

Random field simulation

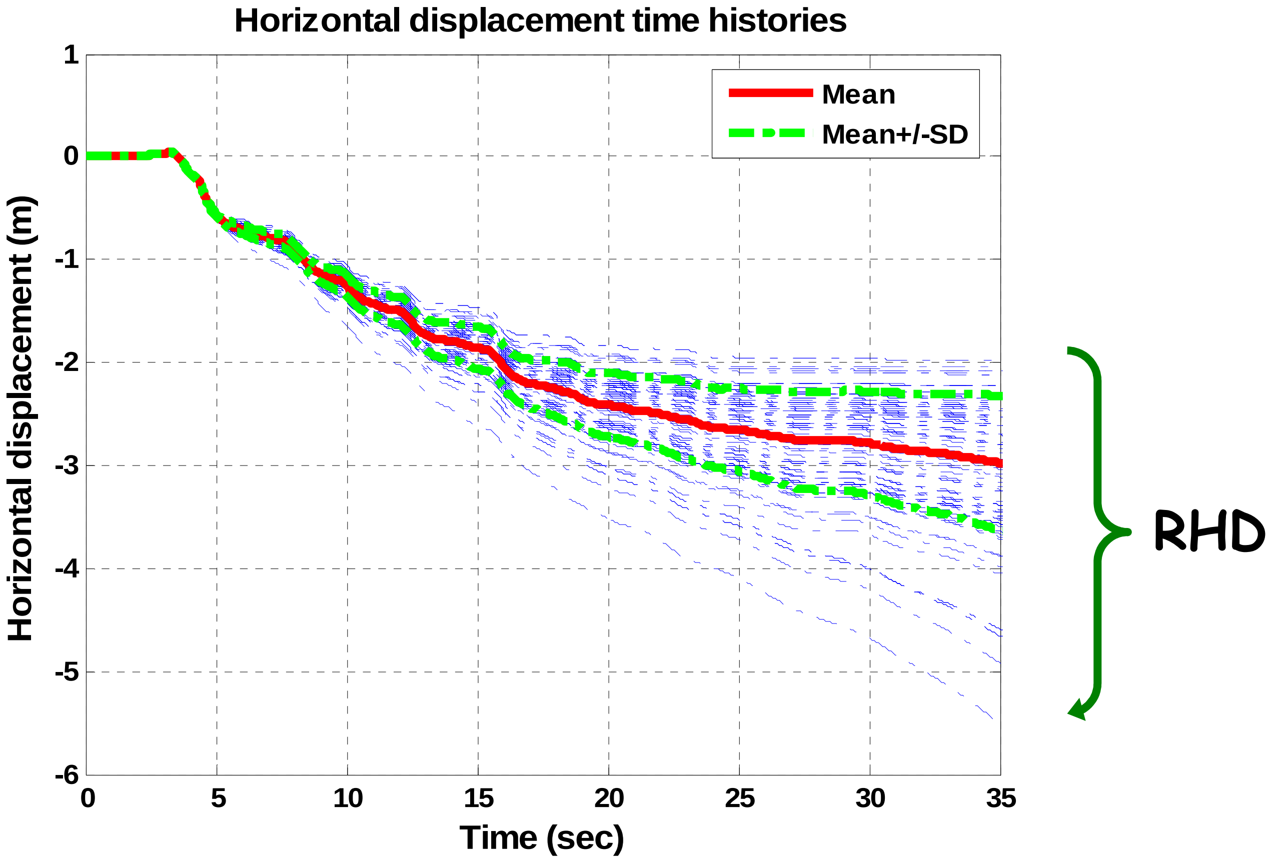






Effects of Spatial Variation

- Time histories for 130 samples (Kobe EQ)



Damage Level

- Damage state proposed by PIANC(2001)
  - Based on Serviceability and Structural damage modes

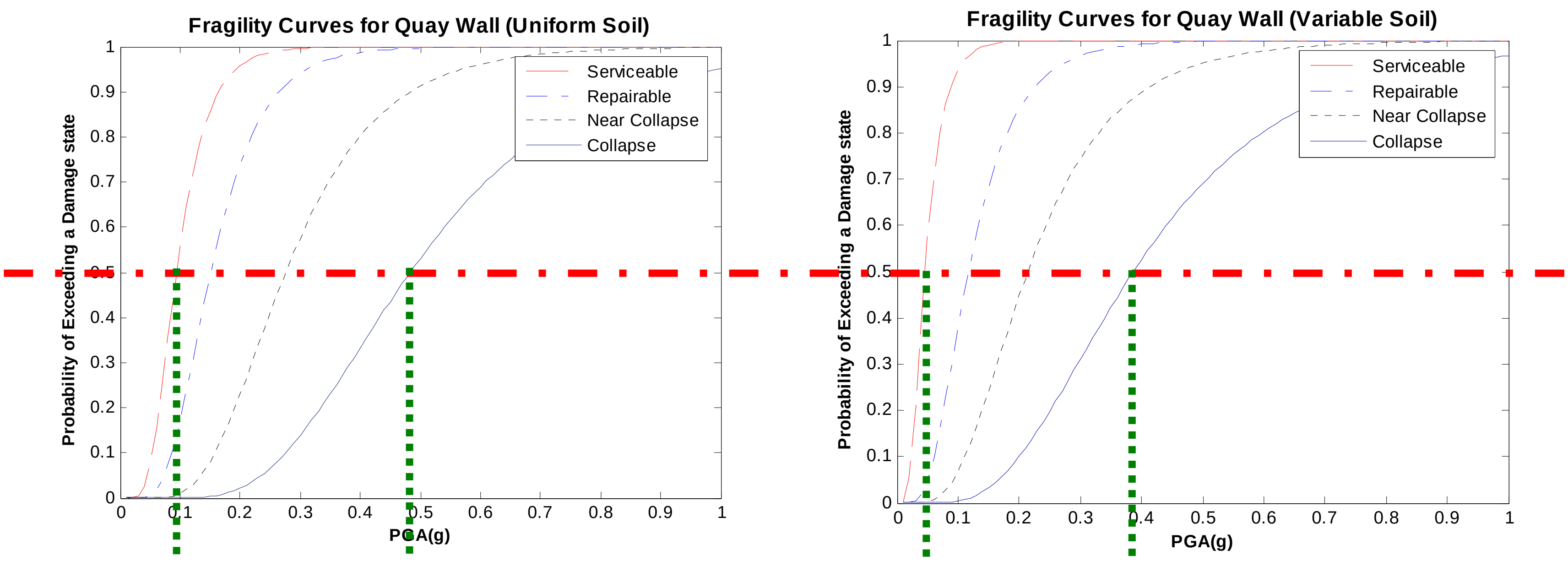
Table 1. Proposed damage criteria for gravity quay walls

Level of Damage		Degree Ⅰ	Degree Ⅱ	Degree Ⅲ	Degree Ⅳ
Gravity Wall	Normalized Residual Horizontal displ.	~1.5%	1.5~5%	5~10%	10%~
	Residual tilting	~3°	3~5 °	5~8 °	8 °~
Apron	Differential settlement	~0.1m	N/A	N/A	N/A

* Highest damage degree among different criteria is the final result of the evaluation.

Fragility Analysis

- Fragility curves obtained from analysis
  - **Comparison between no-spatial variation / variation**



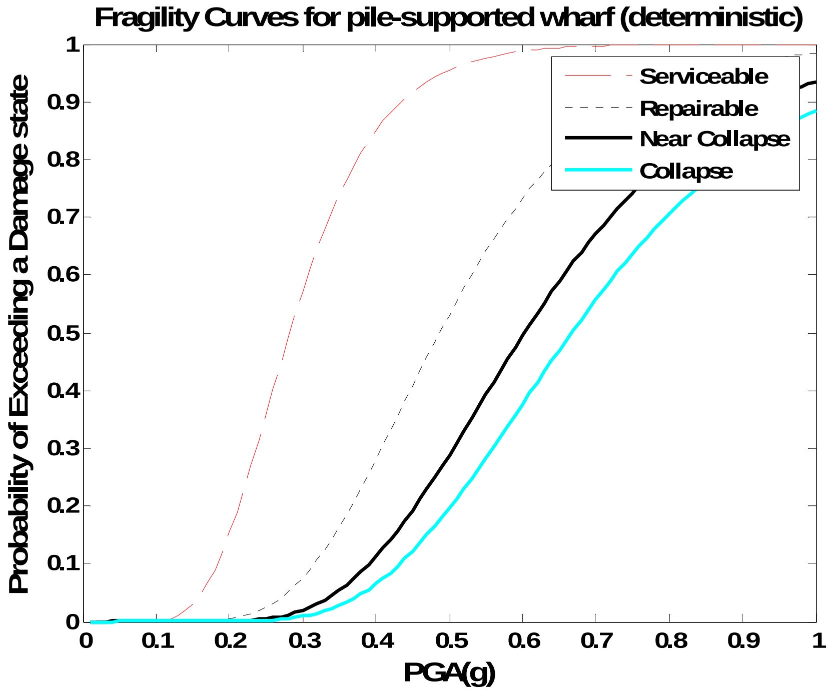
Damage Level

- Damage state proposed by PIANC(2001)
  - **Based on Serviceability and Structural damage modes**

Table. Proposed damage criteria for pile-supported wharf

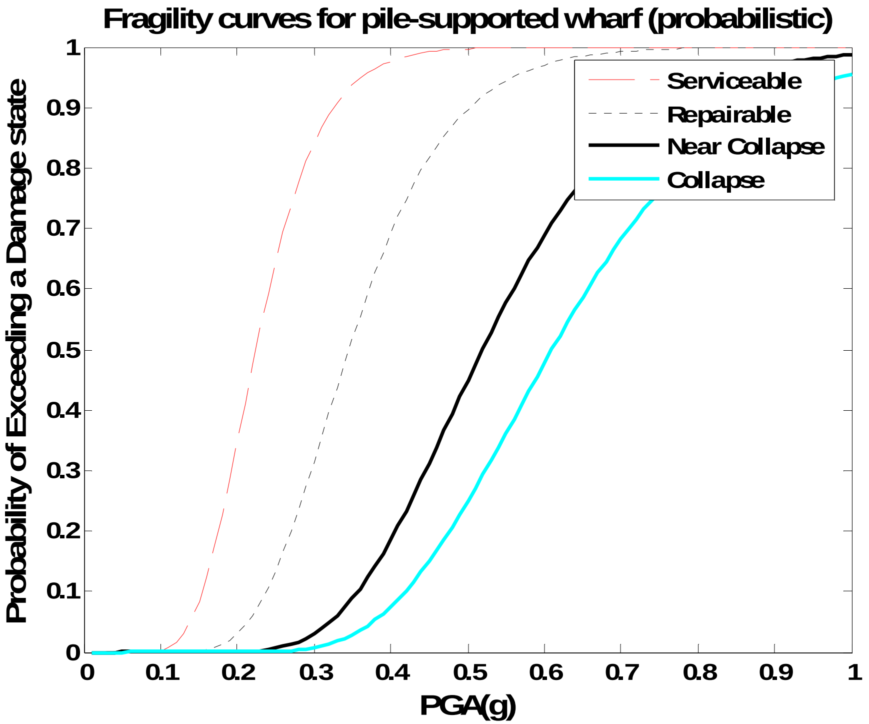
Level of Damage		Degree I	Degree II	Degree III	Degree IV
Pile & Deck	Differential Settlement	~0.1m	0.1-0.3m	N/A	N/A
	Peak response of pile	elastic	No residual deform	repairable	Plastic hinge
Dike/ slope	Normalized Residual Horizontal displ.	~1.5%	1.5~5%	5~10%	10%~

Fragility Curves



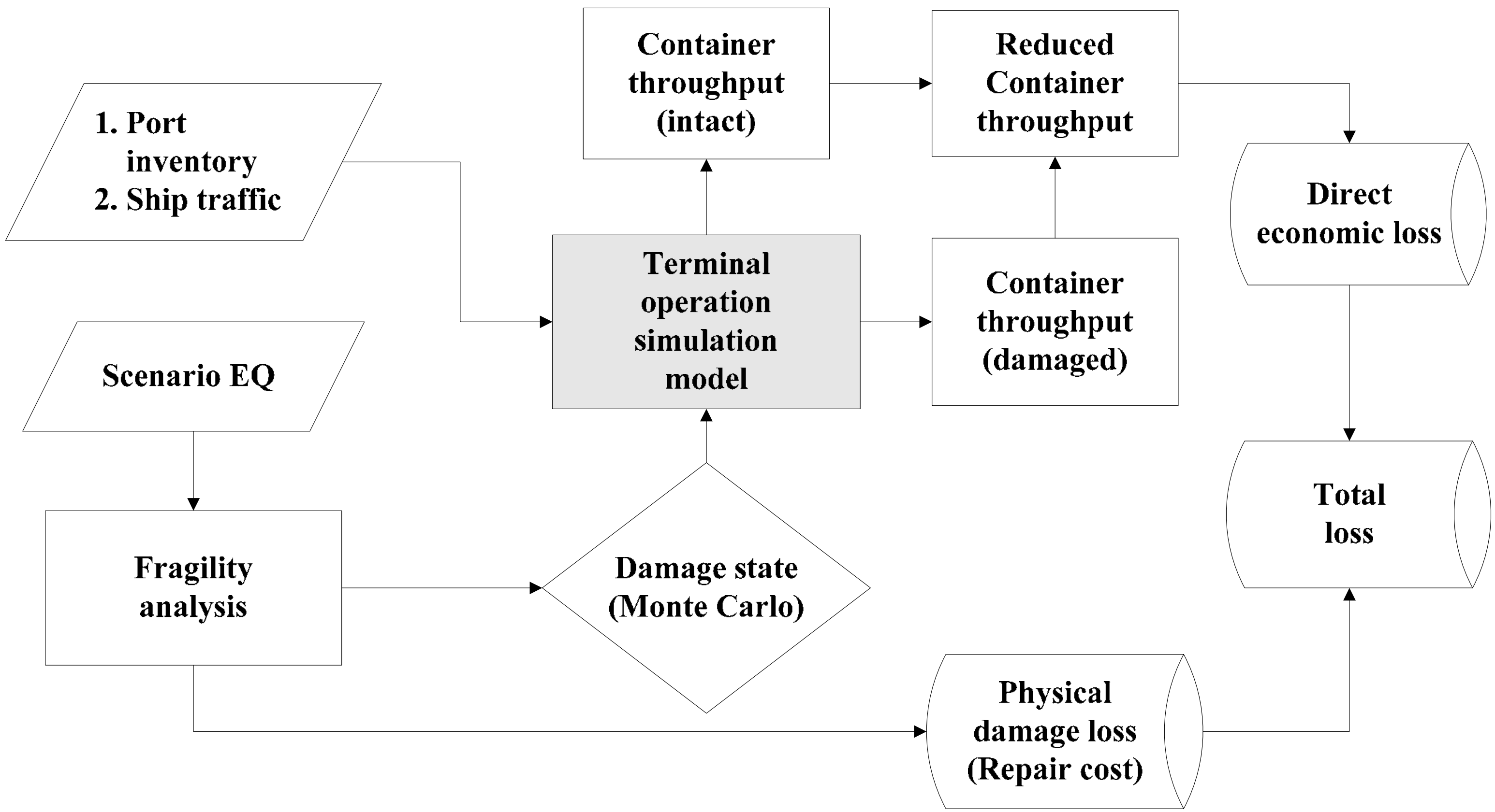
(Deterministic)

(Probabilistic)

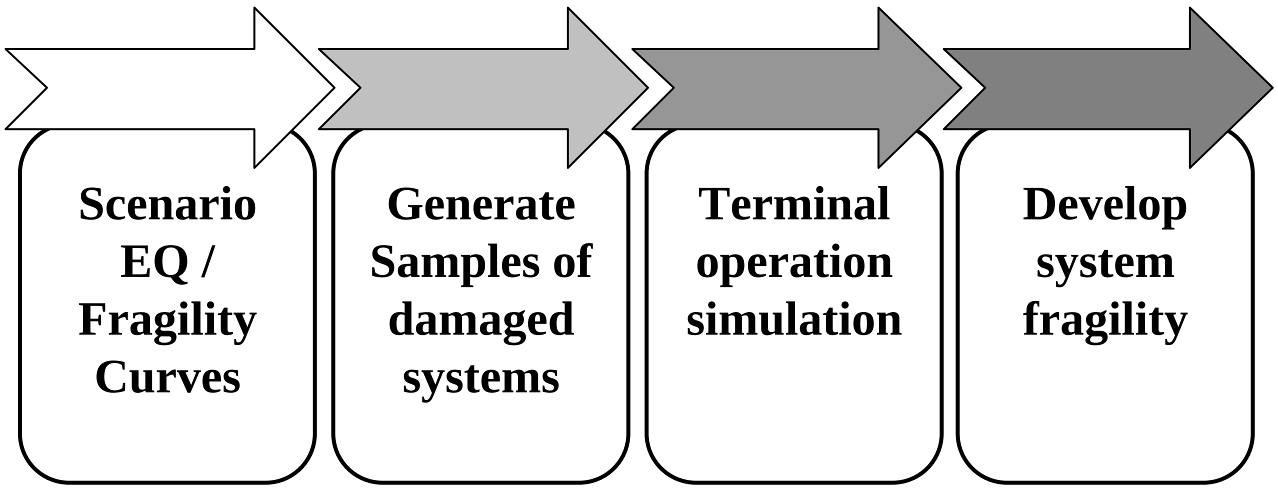


Risk Assessment

Overview of the Loss Estimation Methodology



System Fragility Curves



- System failure

$$\frac{TEU_{\text{intact}} - TEU_{\text{damaged}}}{TEU_{\text{intact}}} > f_{cr}$$

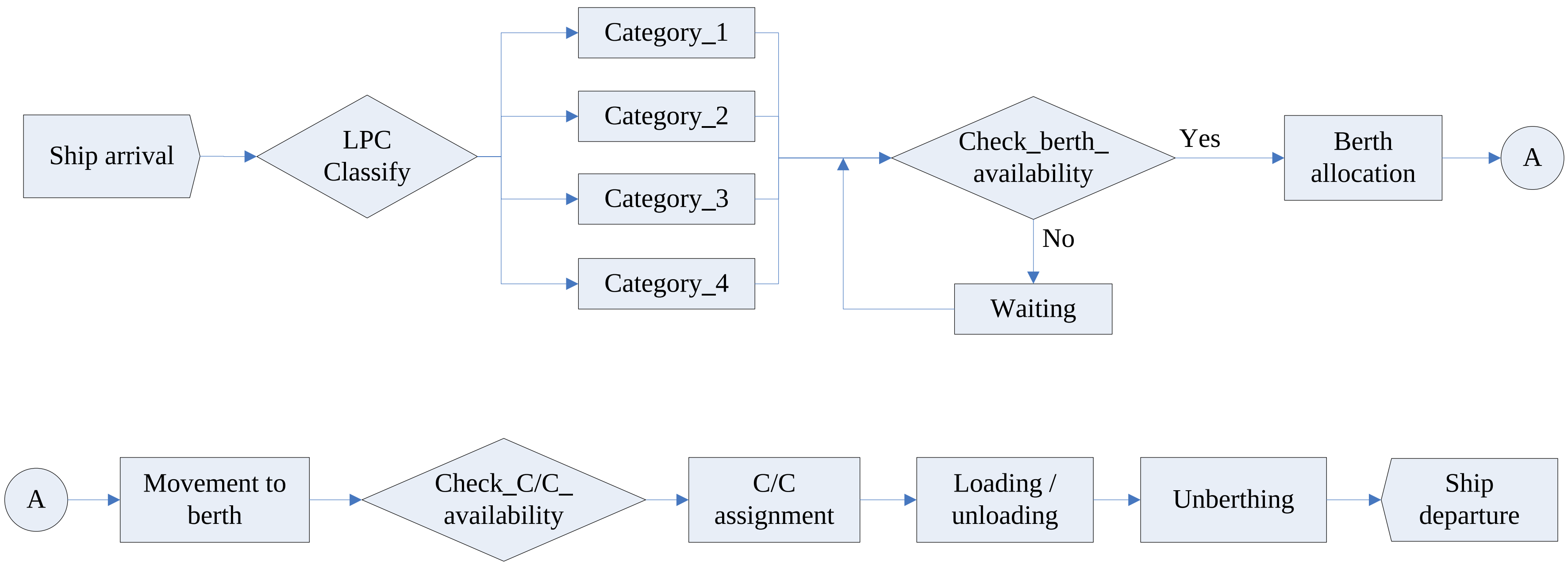
· f_{cr} : failure criteria (5, 10, 30, and 50%)

Terminal Operation Model

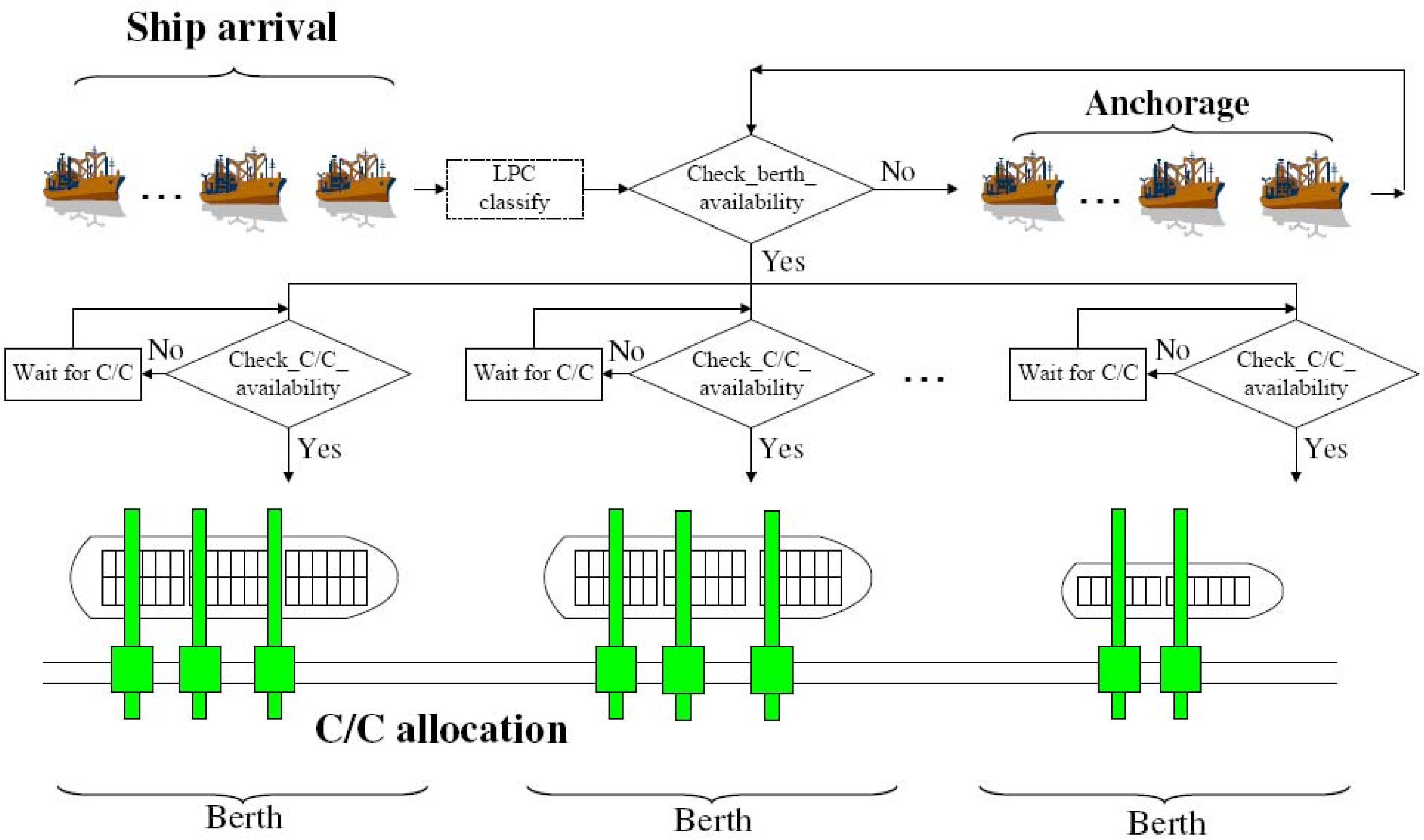
- Simulation Software : ARENA
  - discrete-event simulation : ship arrival, container movement, etc

- Actual Operation Data
  - 15 container terminals' operation records
    - Ship's arrival
    - Lift Per Call (LPC, the num. of container boxes handled at each ship)
    - The number of assigned C/C
    - Handling time per Lift

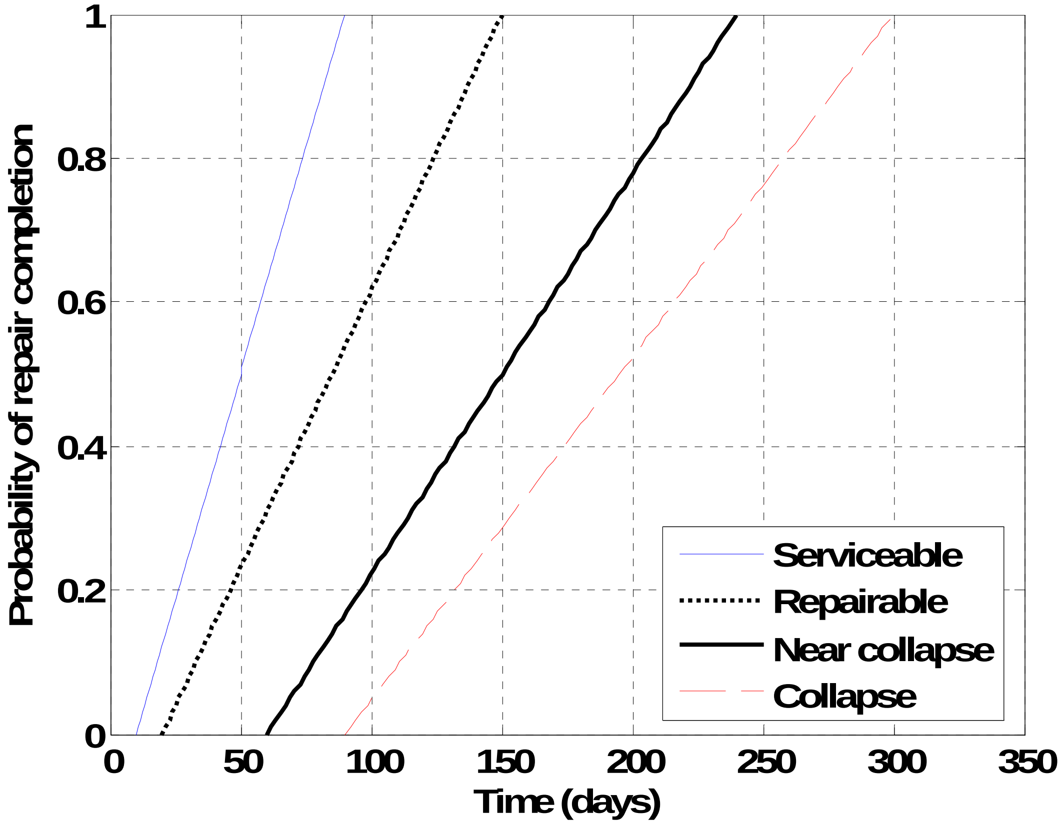
Container Terminal System



Container Terminal System



Probabilistic Restoration Curves

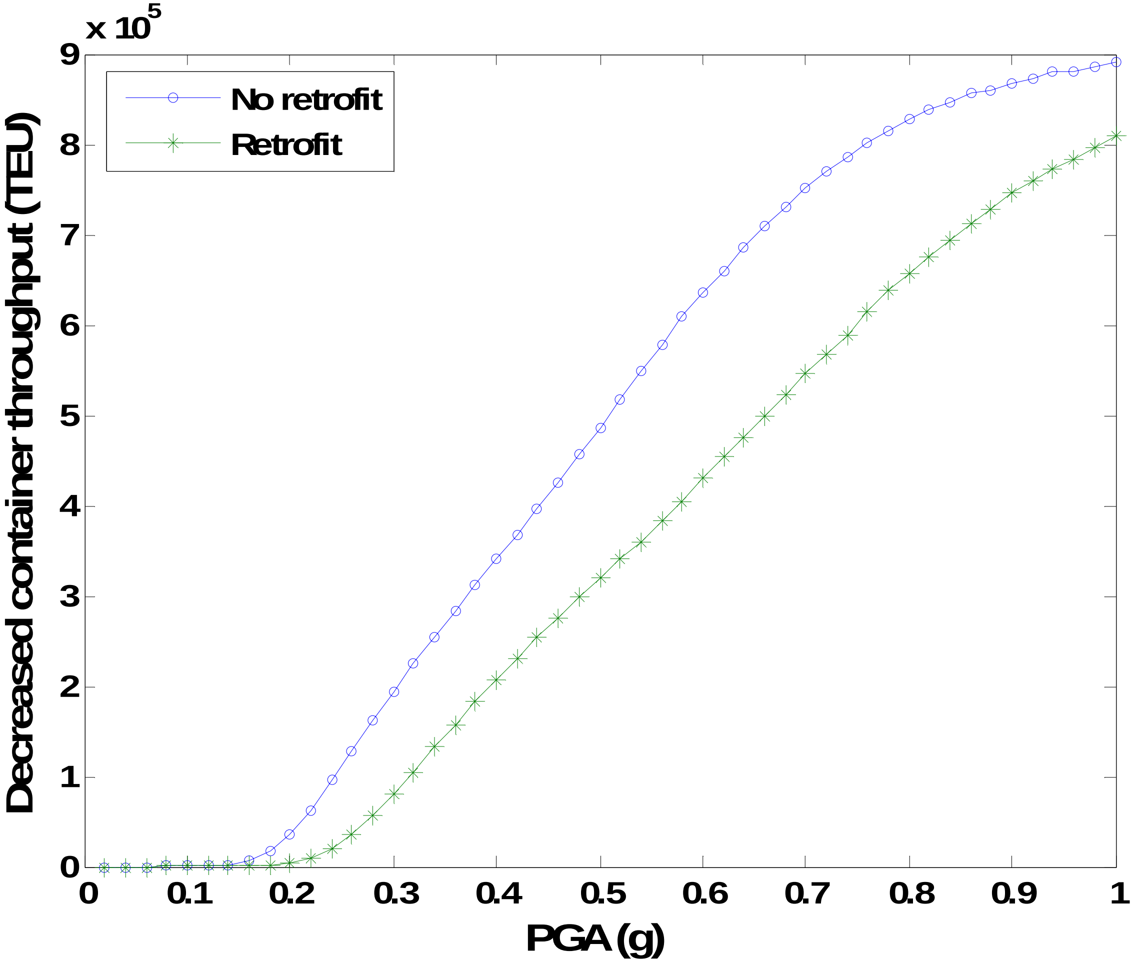


Decreased TEU (based on Simulation)

(a) In case of PGA 0.2 *g*

Sample number	Berth 1		Berth 2		Berth 3		Berth 4		Decreased Throughput (TEU)
	Damage state	Repair (days)	Damage state	Repair (days)	Damage state	Repair (days)	Damage state	Repair (days)	
1	-	0	-	0	-	0	I	39	2,365
2	-	0	I	57	-	0	I	66	79,804
3	-	0	-	0	-	0	-	0	-
4	-	0	-	0	I	83	-	0	5,074
5	I	15	I	17	-	0	-	0	2,113
6	I	76	-	0	-	0	I	86	109,180
7	-	0	II	111	-	0	-	0	6,774
8	I	43	-	0	I	47	-	0	61,034
9	-	0	I	24	I	60	-	0	36,299
10	I	53	-	0	-	0	-	0	3,248

Decreased Container TEU



Thank you