Disaster Resilience; A Demonstration for Highway Networks

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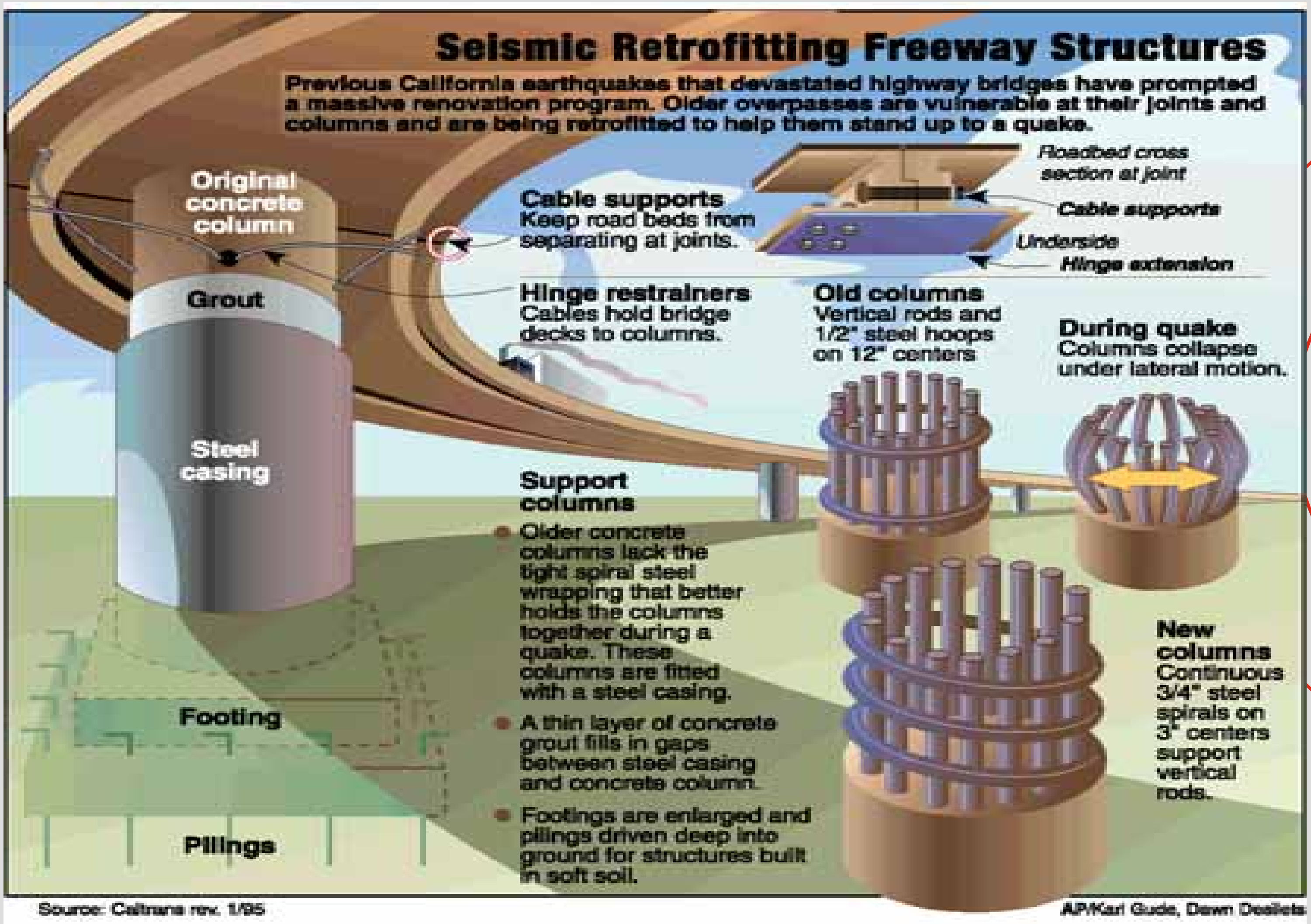
Socio-Economic Effect of Seismic Retrofit of Concrete Bridges



Performance of Highway Network

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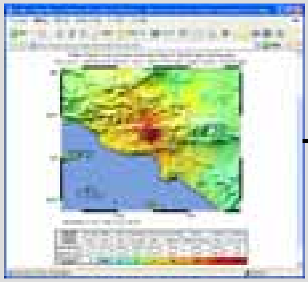


ShakeMap

http://www.trinet.org/shake/index.html

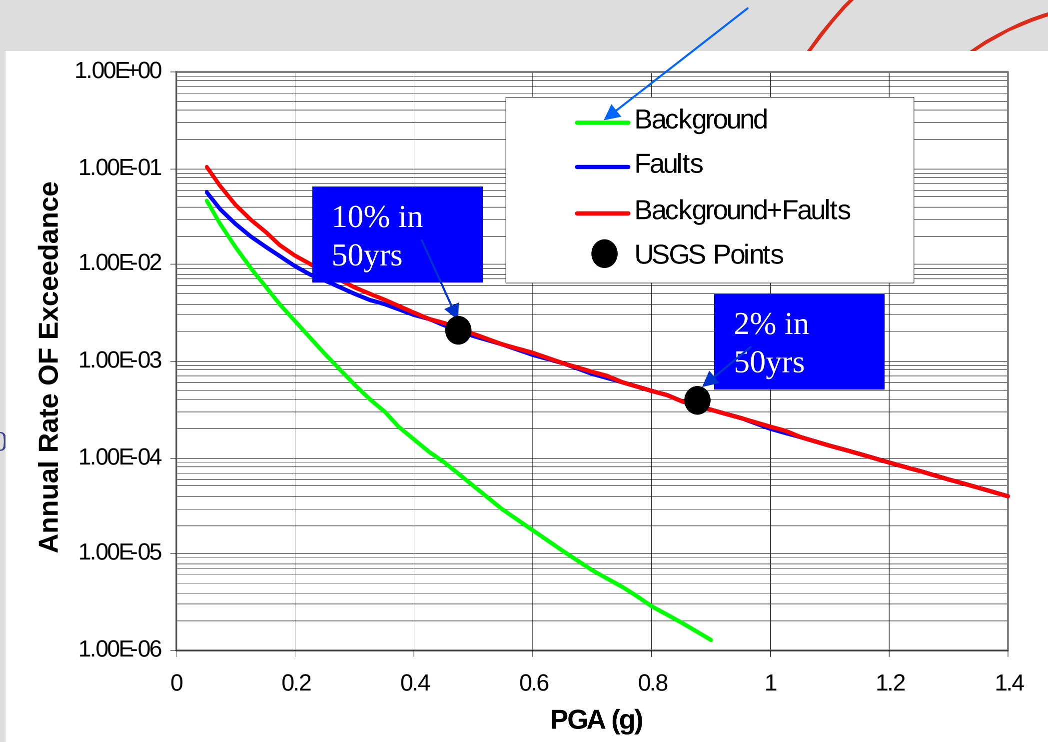
- Scenario Earthquakes ← Annual Occurrence Probability
- ↓
- Seismic Intensity at Bridge Sites ← Attenuation Relationship (← ShakeMap)
- ↓ PGA,PGV
- Bridge Damageability (not Retrofitted) ← Fragility Curves
- Bridge Damageability (Retrofitted)
- ↓
- Remaining Traffic Capacity of Highway Network
- ↓
- Traffic Flow Analysis ← OD (Origin-Destination) Data
- ↓
- Drivers' Delay & Opportunity Loss
- ↓
- Economic Analysis & Benefit Cost Ratio

63 Probabilistic Scenario Earthquakes

- 49 (Char.Faults)+8(Smaller, Faults)+8(Background)=63
- Hazard Curve obtaqind averaging over 4 empirical attenuation relationships

  Sadigh (1997); Abrahamson (1997); Campbell (2003); Boore (1997)

Grid Sites in Study Region



Hazard Comparison at Site 12

1994 Northridge Earthquake Damage Data

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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

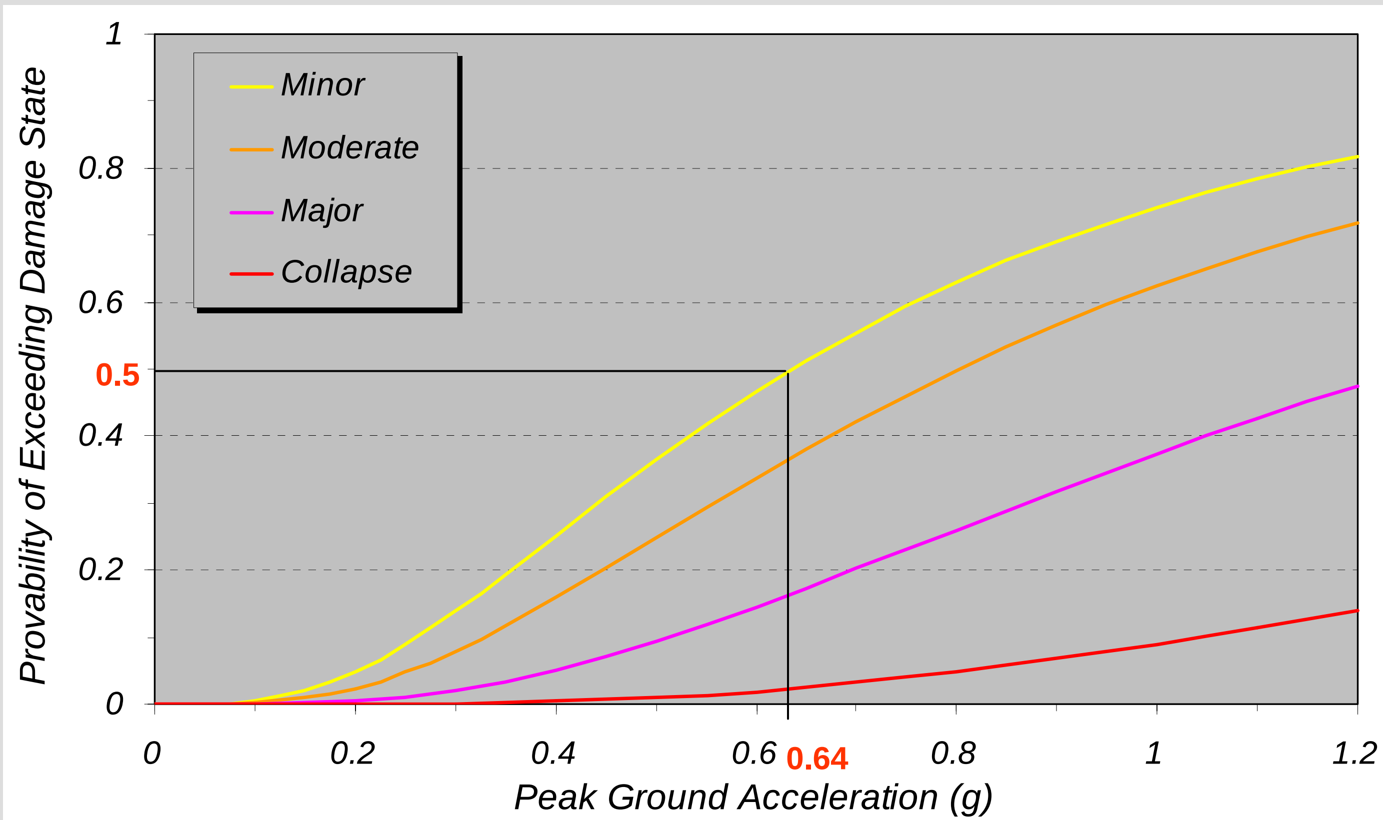
Divided by
- Span + Skew + Soil (18 groups)

Empirical Fragility Curves (Composite, PGA)

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

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

PGA	C	ζ
Minor	0.64	0.70
Moderate	0.81	
Major	1.25	
Collapse	2.55	

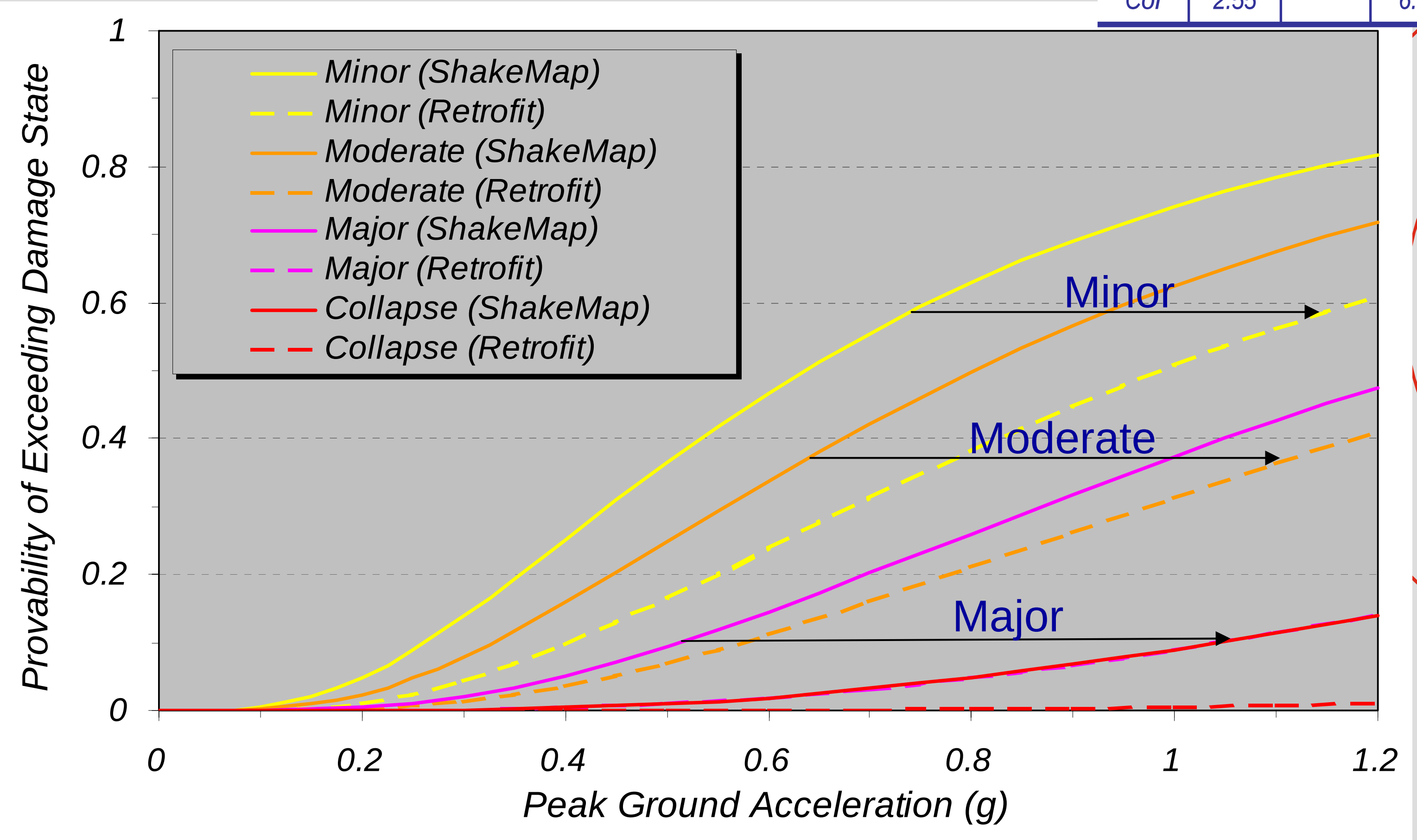


Fragility Curve (PGA, Retrofit)

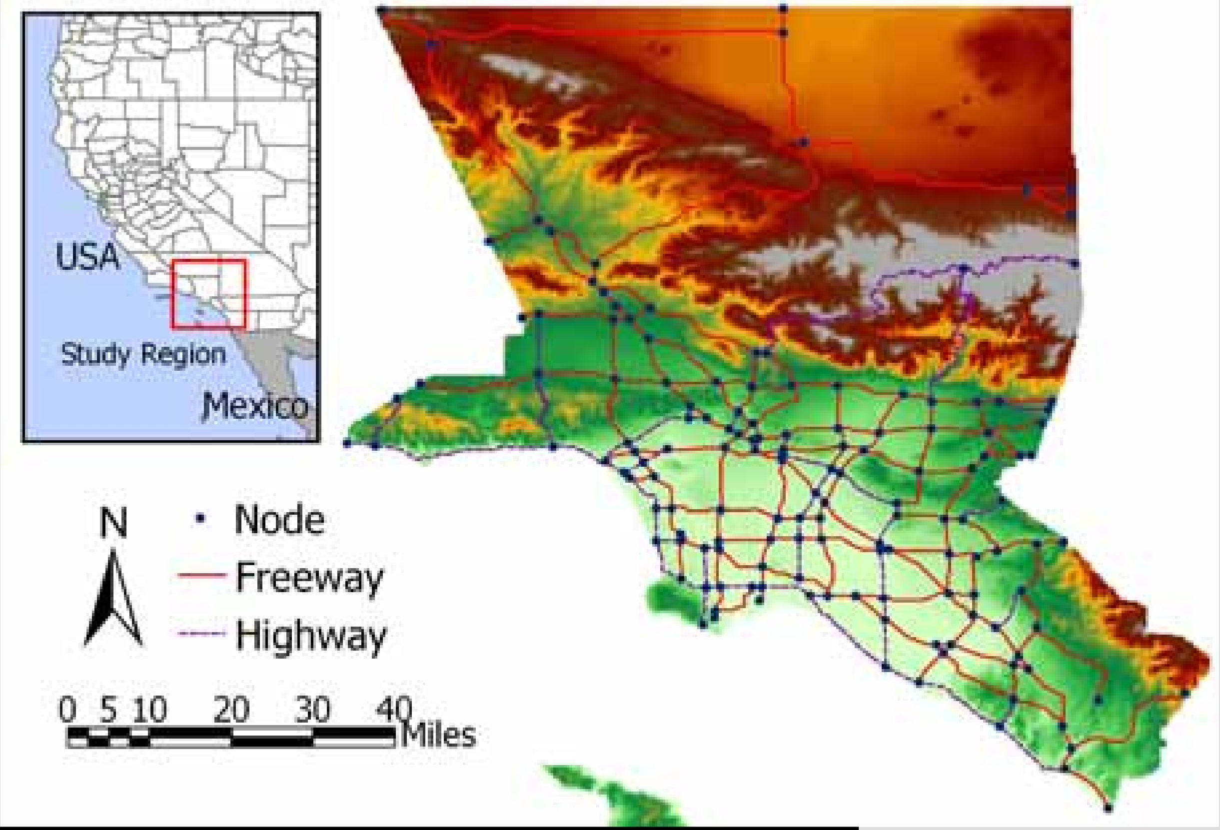
$$F(a)=\phi\left[\frac{\ln(a/C)}{\zeta}\right]$$

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 (Model 2003)

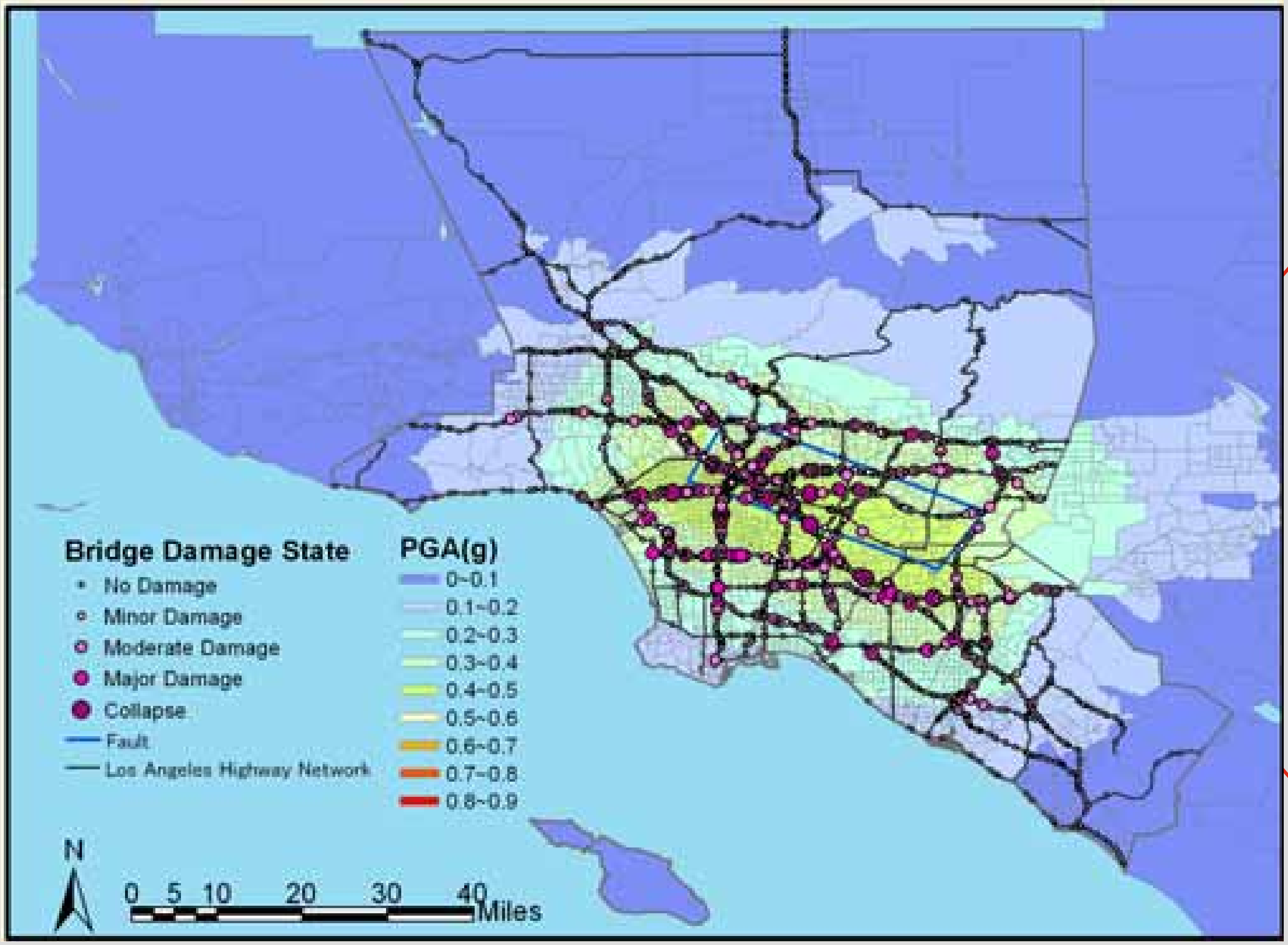


	Traffic Light	Speed Limit (MPH)	Capacity (PCU)
Freeway	×	65	2500
Highway	○	35	1000

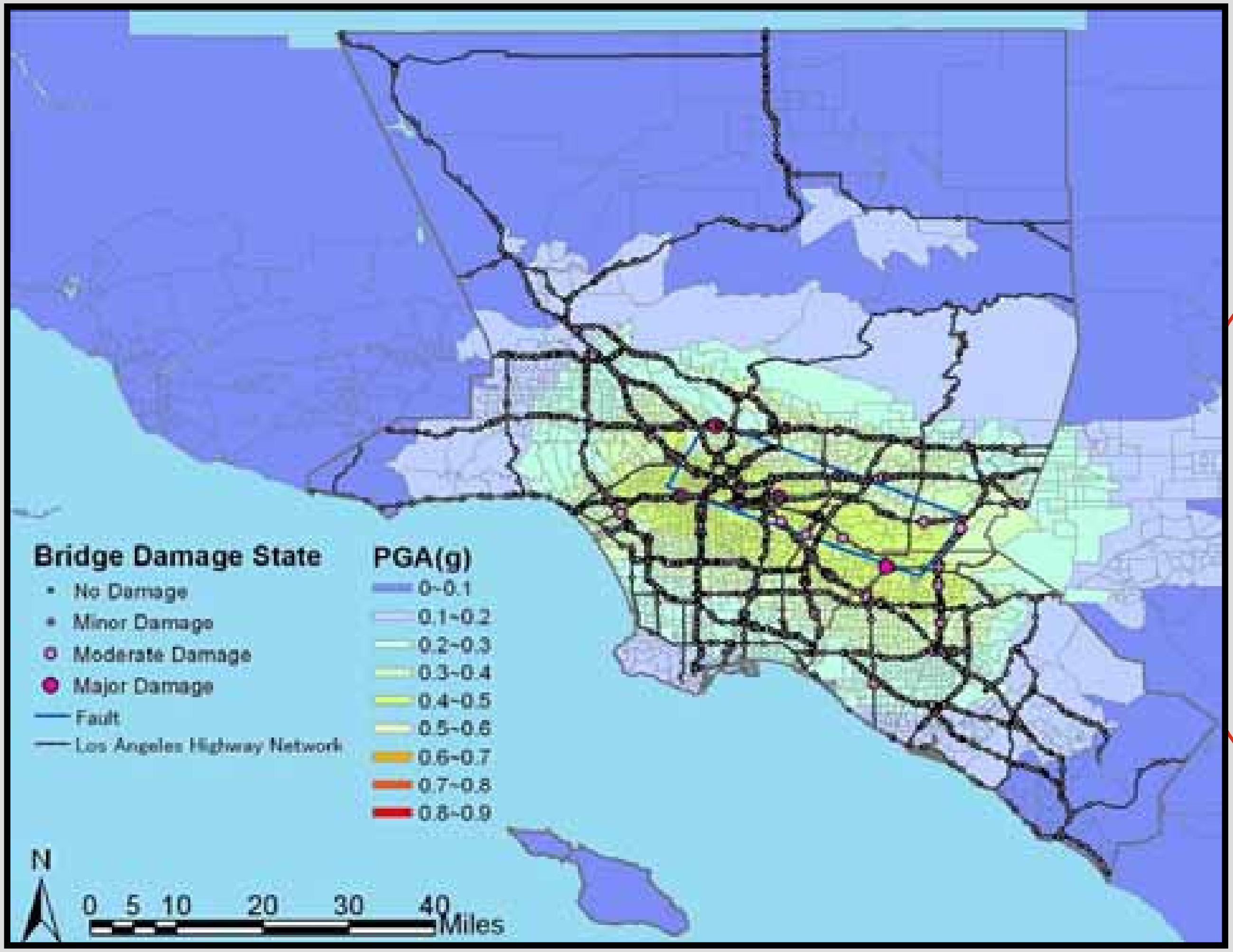
Total Number of Nodes =148
Total Number of Links =231

❖ PCU : Passenger Car Unit

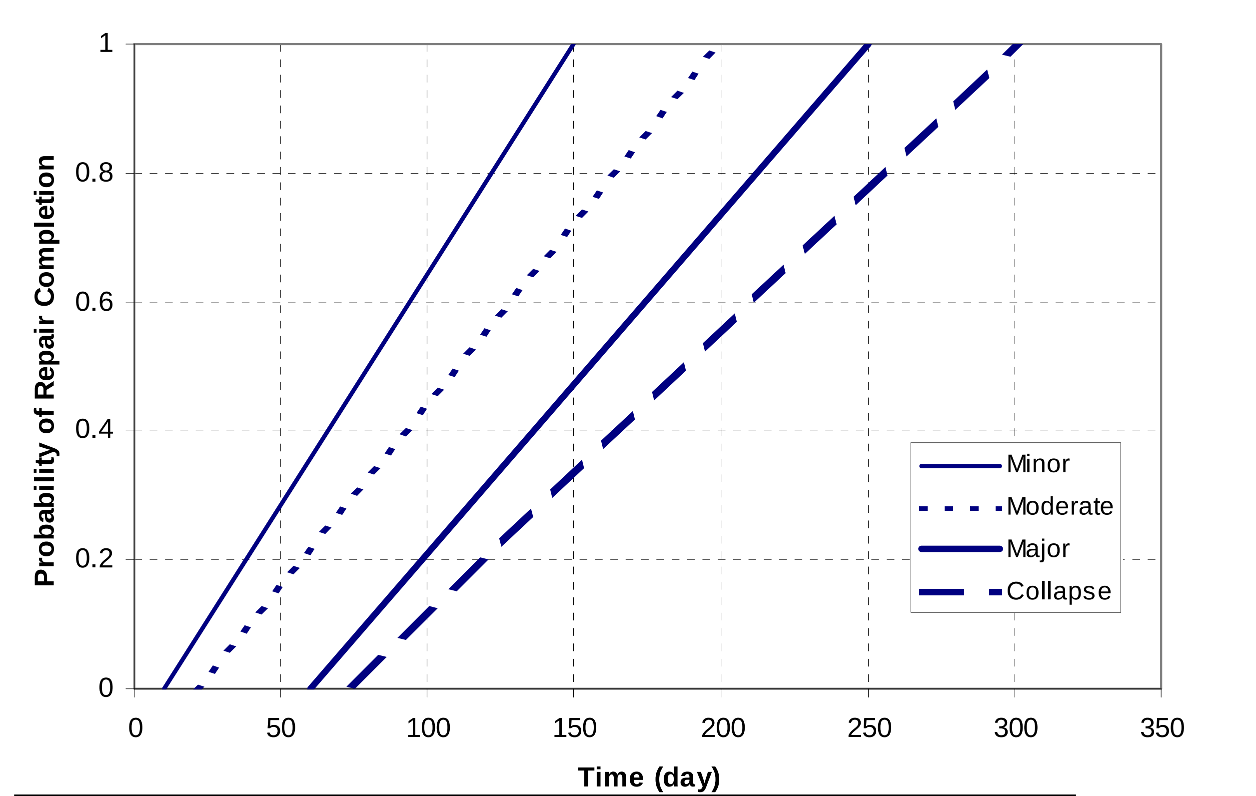
PGA Distribution & Bridge Damage State (1) -Elysian Park M7.1(before retrofit)



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



Probabilistic Bridge Repair/Restoration Model



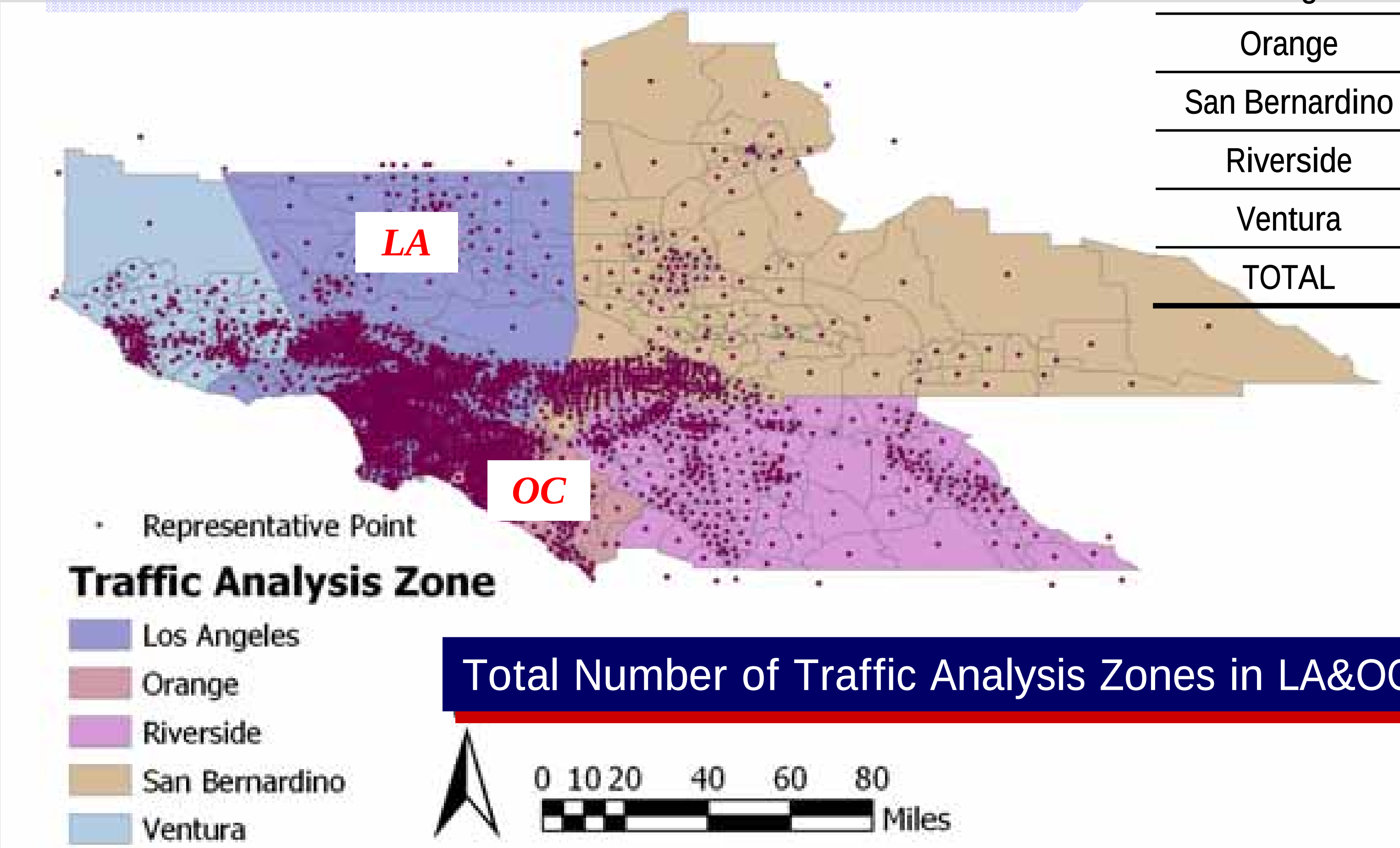
Damage State	Days for Repair Completion	
	Minimum	Maximum
Minor	10	150
Moderate	20	200
Major	60	250
Collapse	75	300

(Shinozuka etc. 2003)

Baseline Origin-Destination (OD) Data

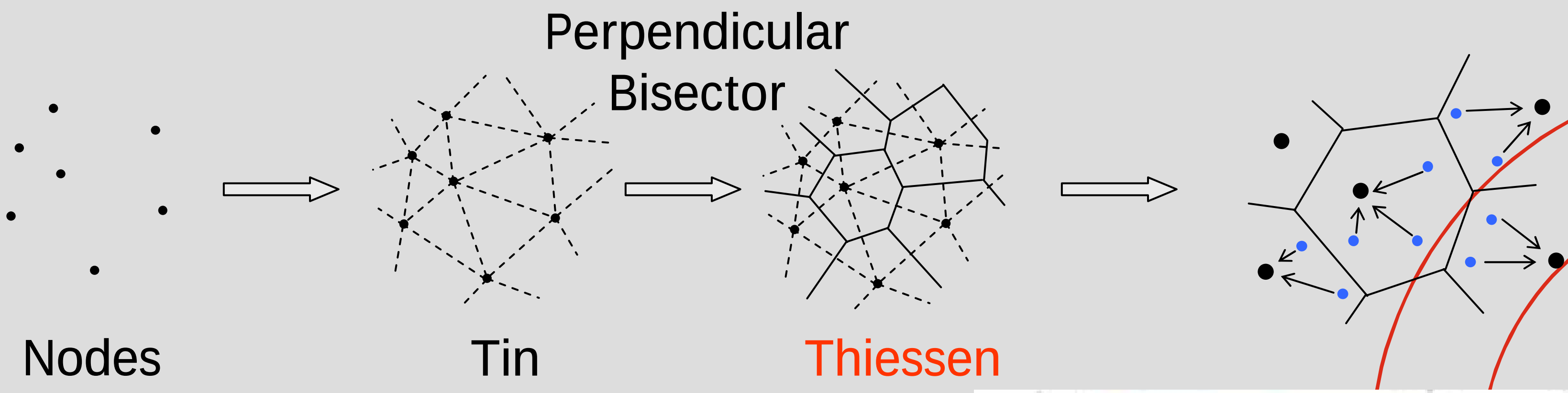
1996 Southern California Origin-Destination Survey

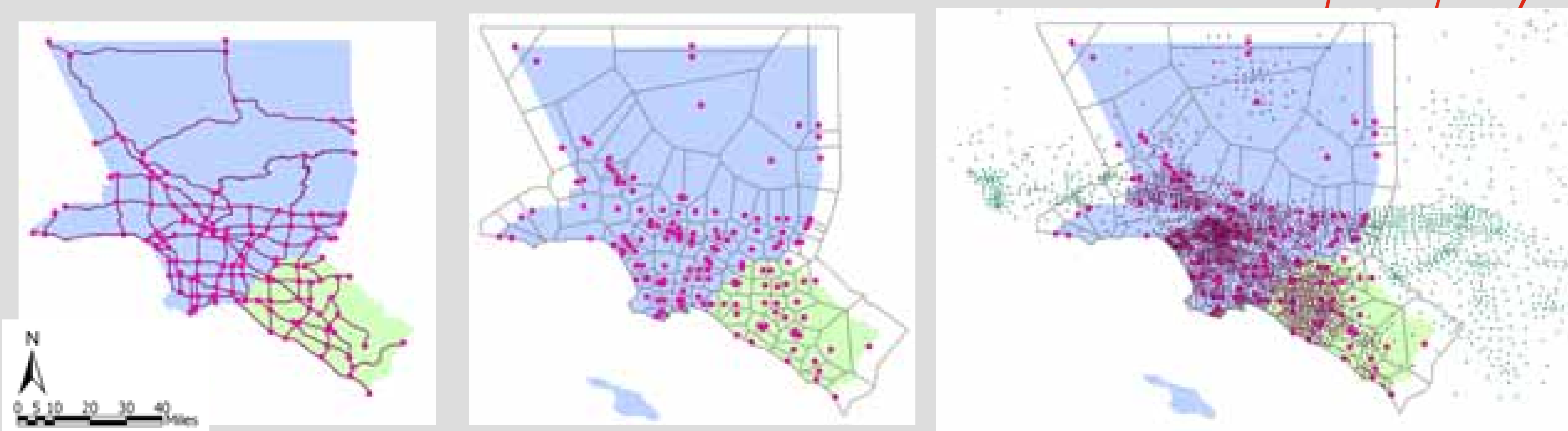
Number of Zone	
Los Angeles	1,721
Orange	549
San Bernardino	375
Riverside	347
Ventura	199
TOTAL	3,191



Total Number of Traffic Analysis Zones in LA&OC= 2270

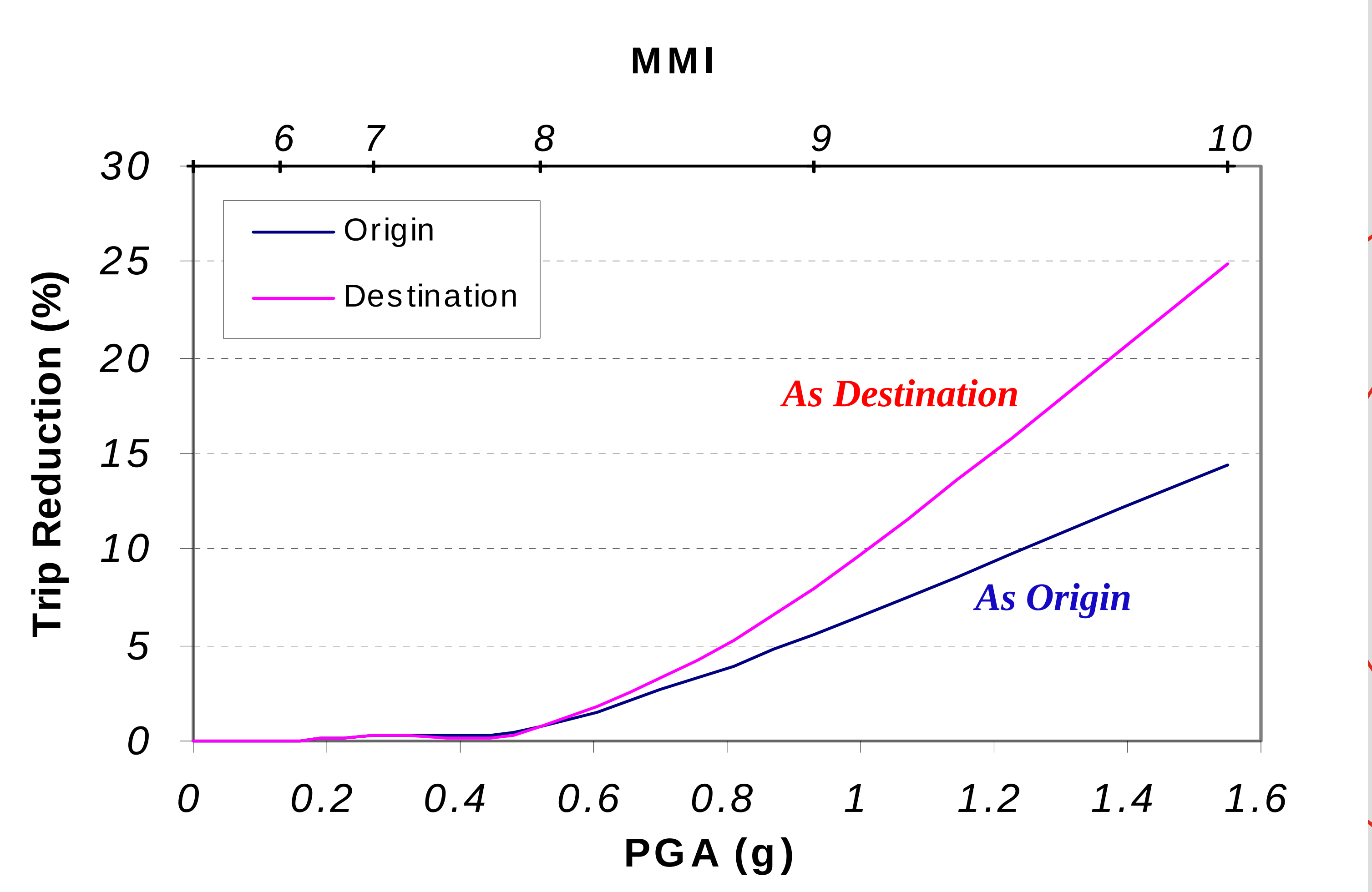
Compressed Origin-Destination (OD) Data





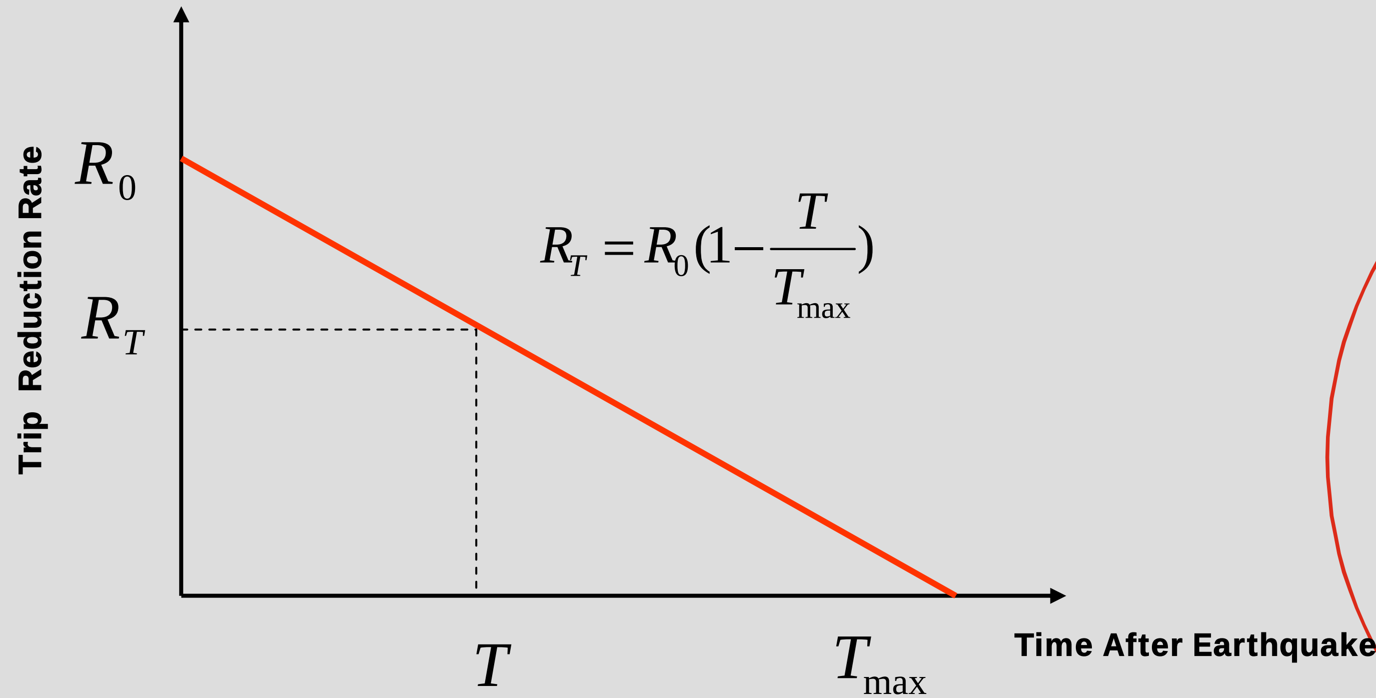
New Total Number of Traffic Analysis Zones = 148

Variable OD (1): Trip Reduction Due to Earthquake



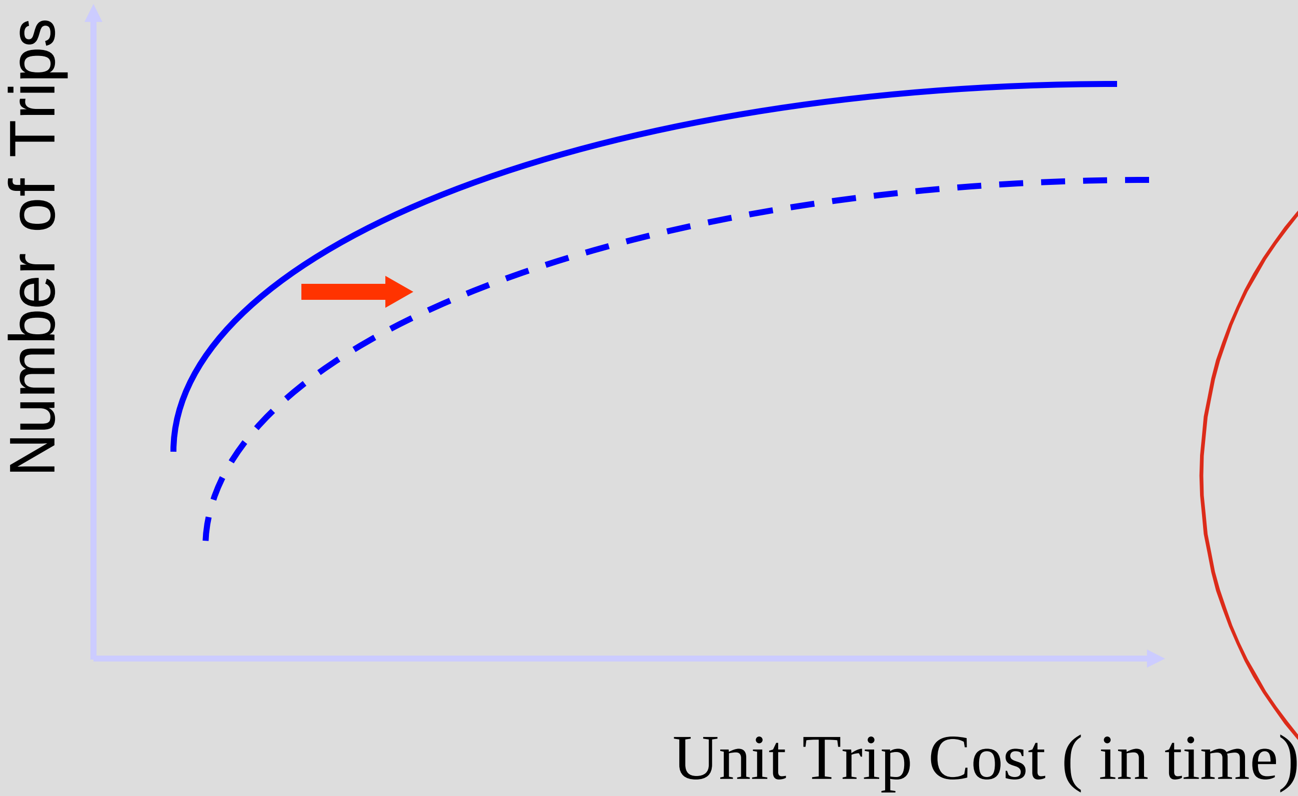
(Origin: trip production Destination: trip attraction)

Variable OD (2): Trip Recovery



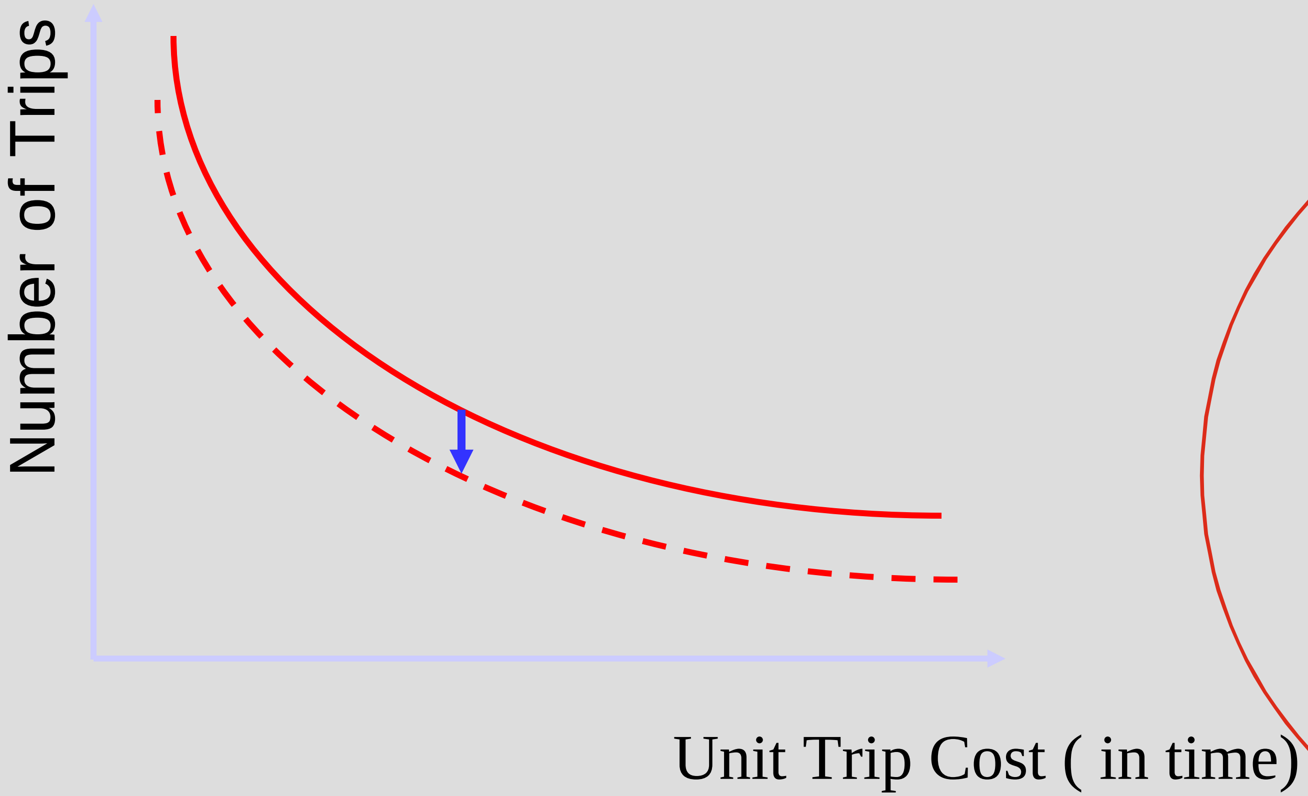
$$T_{max} = \frac{365}{10 - MMI} \qquad MMI<10$$

Network Capacity Reduction and recovery



After earthquake, the network capacity will be reduced, and causing degradation of system performance, so the unit cost for given trips is higher than pre-earthquake

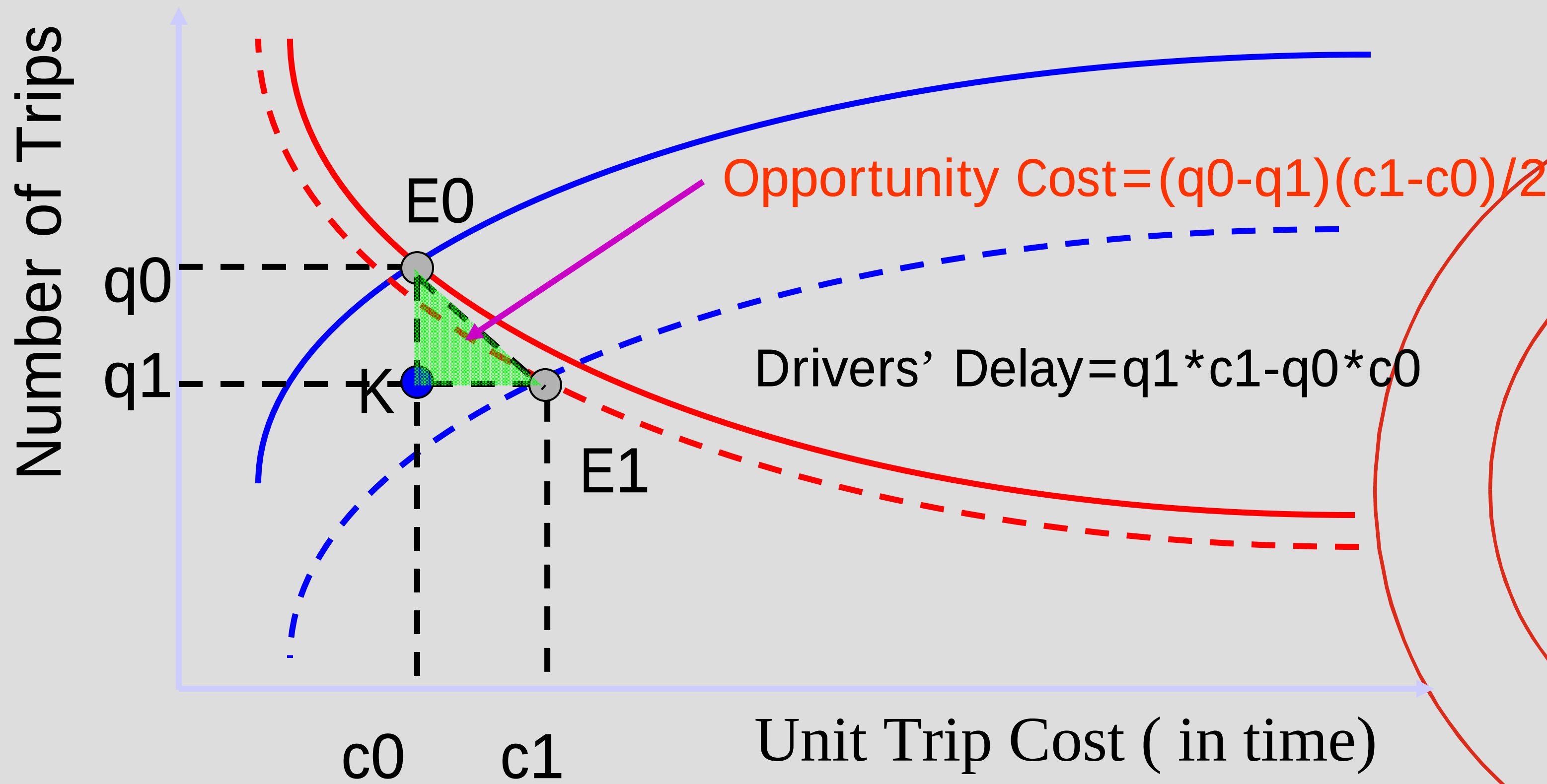
Travel Demand Reduction and Recovery



After earthquake, the travel demand also decreases due to damages to the activity systems (job site, residential damage)

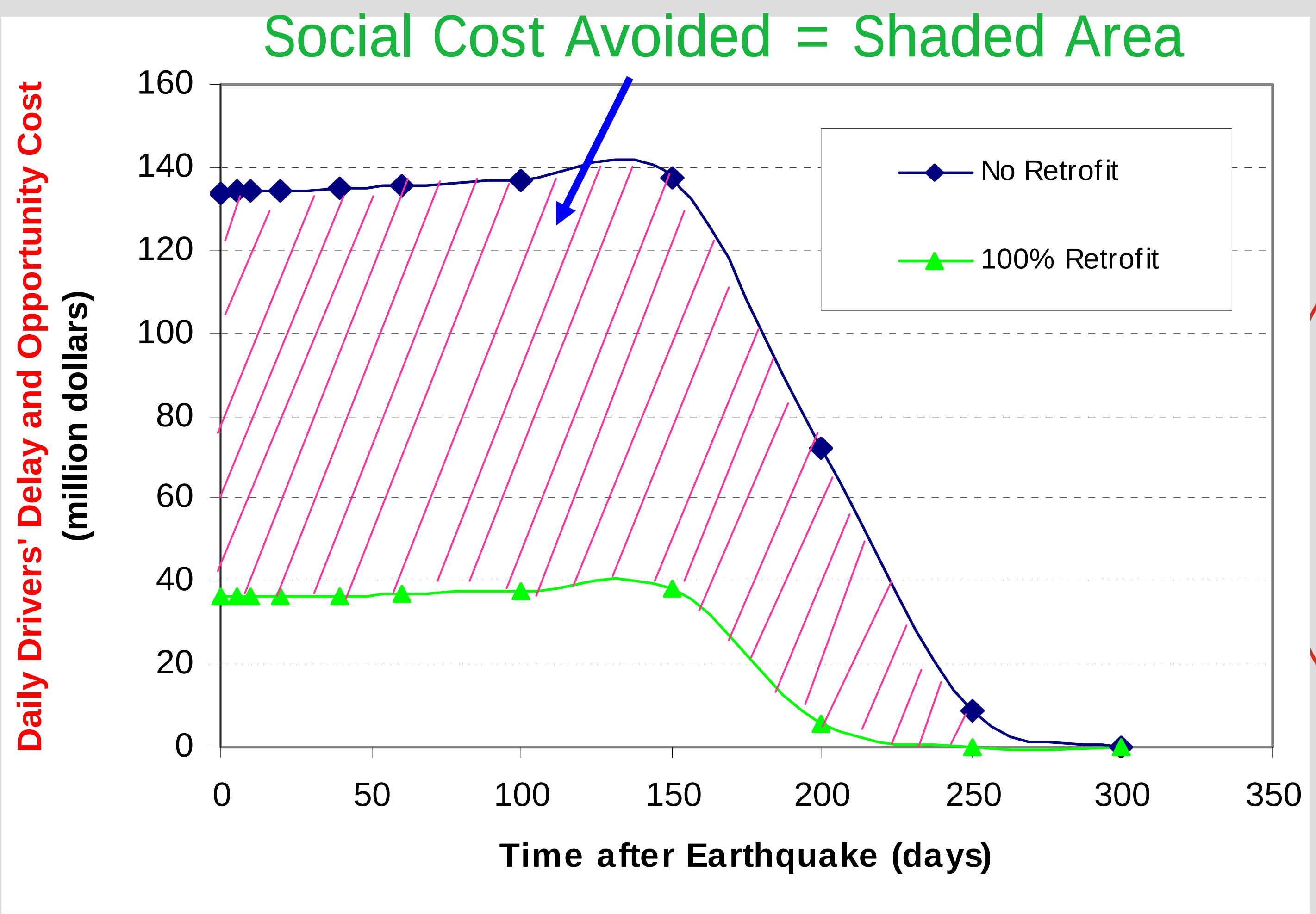
Equilibrium Conditions (Pre- and Post-Earthquake)

Social Cost = Drivers' Delay + Loss of Opportunity Cost



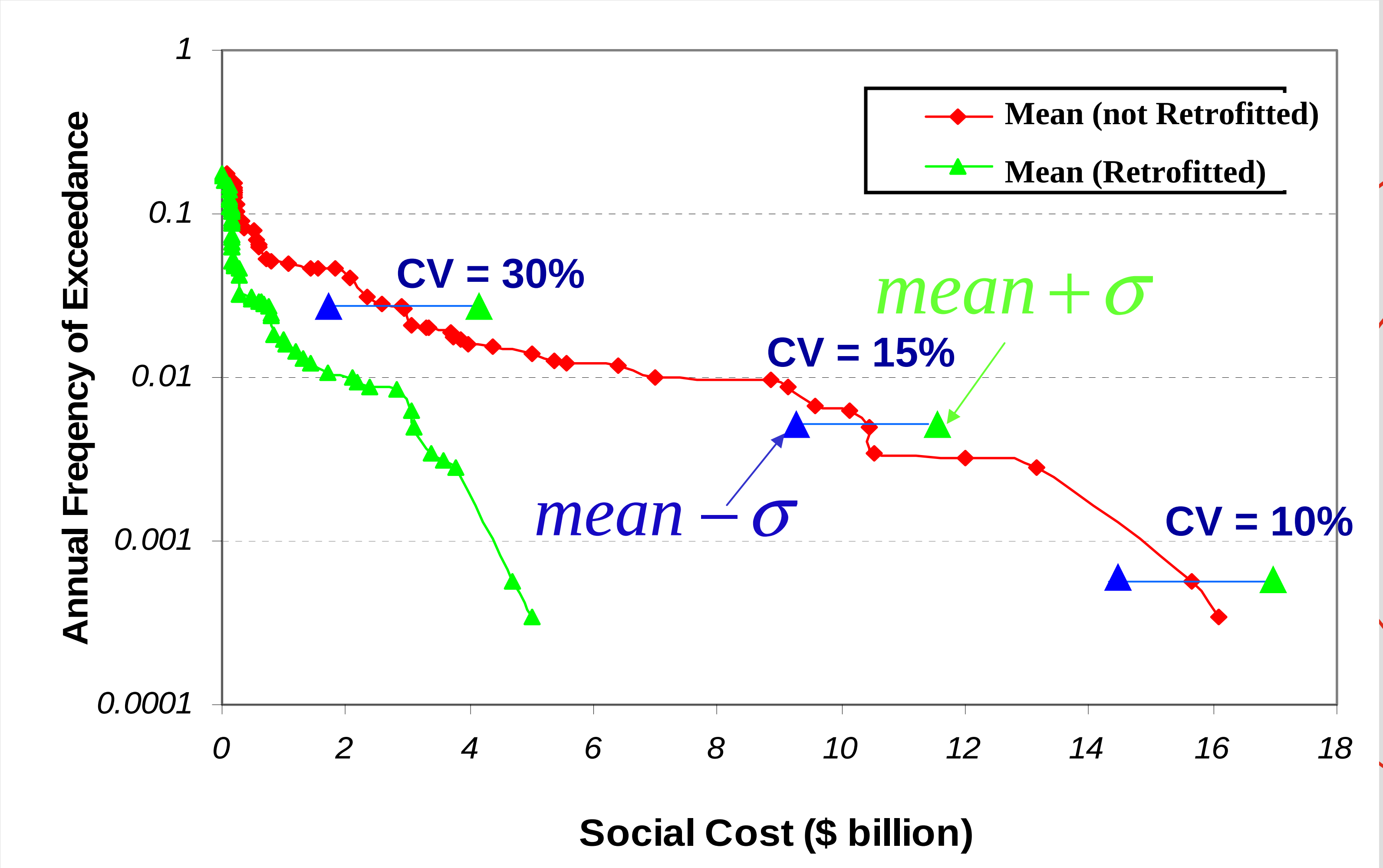
1. **New equilibrium condition reaches at the intersection(E1) of Post-Earthquake network capacity supply curve and travel demand curve.**
2. **Drivers' delay is defined as the difference of the total travel time at post-earthquake and pre-earthquake equilibrium conditions.**
3. **Opportunity cost is calculated as the triangle area E0-K-E1.**

Effect of Bridge Retrofit on System Restoration Curve



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

System Risk Curve in terms of Total Social Cost (before and after Retrofit)



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

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
Slight	0.03	0.01-0.03
Moderate	0.08	0.02-0.15
Extensive	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

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

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

$\bar{p}_i$ Annual frequency of earthquake i

Total Benefit in T years (in present value)

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

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

$$R = B / C_R$$

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

Future Study 1

- Improvement of Models for Each Contributing Factors, in particular,

  * System Restoration Process

  * Social Cost

- Better Quantification of Uncertainty associated with Each Contributing Factors
- Risk Definitions Depending on Stakeholders

Future Study 2

- Risk and Resilience Assessment under
  - Flood
  - High Wind
  - Wild Fire
  - Tsunami
  - Man made hazards

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

- Mutilayer Monte Ccarlo Simulation Approach
- Found that Bridge Retrofit is Cost-effective if We Take Social Cost into Consideration

Contributors

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- Multidisciplinary Center for Earthquake Engineering Research (MCEER)
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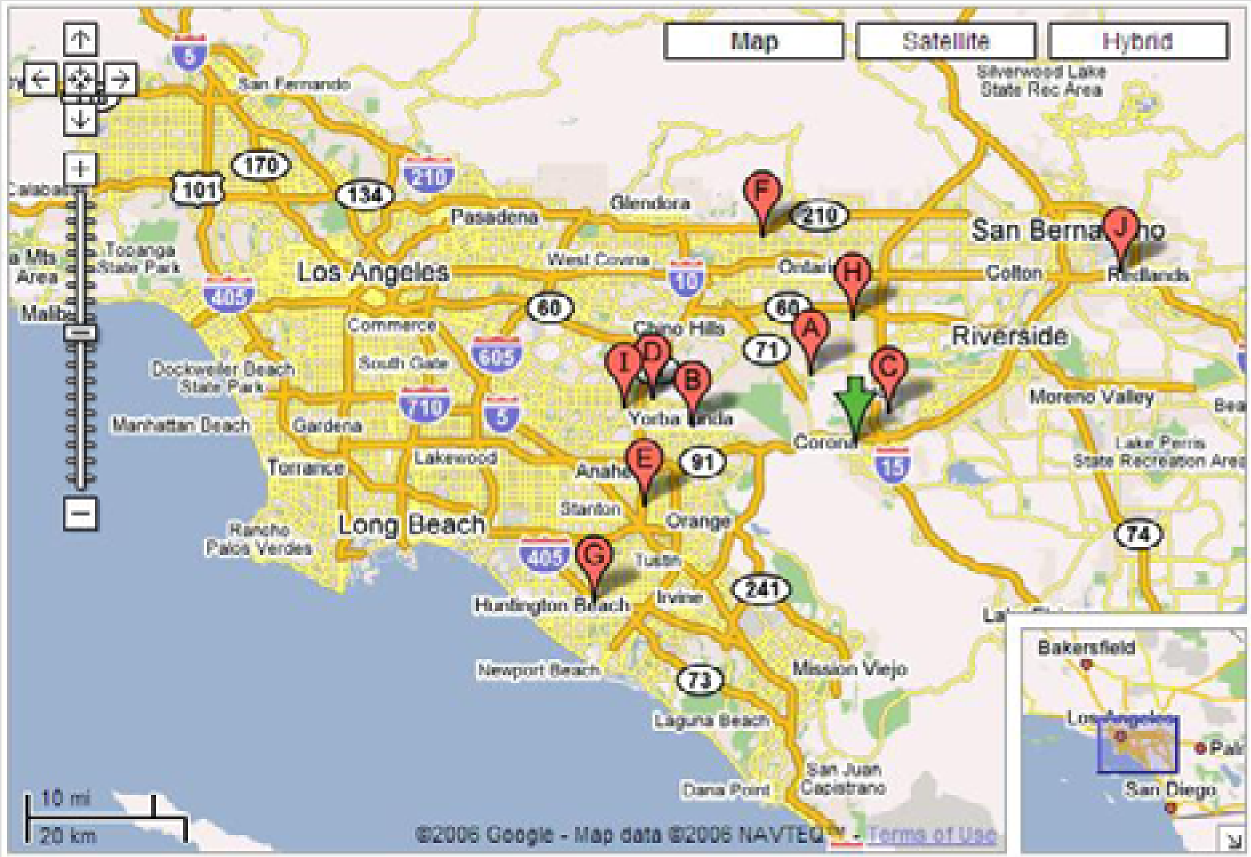
Location of Prado Dam



Hypothetical failure of Prado Dam ,

which just last year was found leaking.

Simulated by Francis Salcedo and Sanders, UCI (2006).

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