The Study of Lifeline Serviceability: Toward More Hazard-Resilient Communities

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Categories of lifelines

- **Energy Facilities**: electric power, gas and liquid fuel facilities
- **Water Supply Facilities**: waterworks, drainage, rivers and dams
- **Transportation Facilities**: roads & highways (including tunnels and bridges), railways, airports, ferries and ports
- **Information Facilities**: tele-communications, mass media (radio, TV, …)

Duke,C. M. and Moran, D. F. 1975, “Guidelines for Evaluation of Lifeline Earthquake Engineering”, Proc. U.S. Nat. Confer. Earthquake Eng., pp.367-376.

Common characteristics of lifelines

- high **publicity** and social responsibility
- service through **transmission** of something (materials, energy, information, etc.)
- huge **economic and social impacts** due to service disruption
- spatially distributed **networks** with many interconnected components
- performance (while damaged) largely affected by the topology and redundancy of system **networking**
- with a hierarchy of various **subsystems and components** for realizing the system functionality
- **system resilience** decided by the integrity, resistance and durability of subsystems and components
- **interdependence** upon one another (exaggeratedly increased in disastrous situations)

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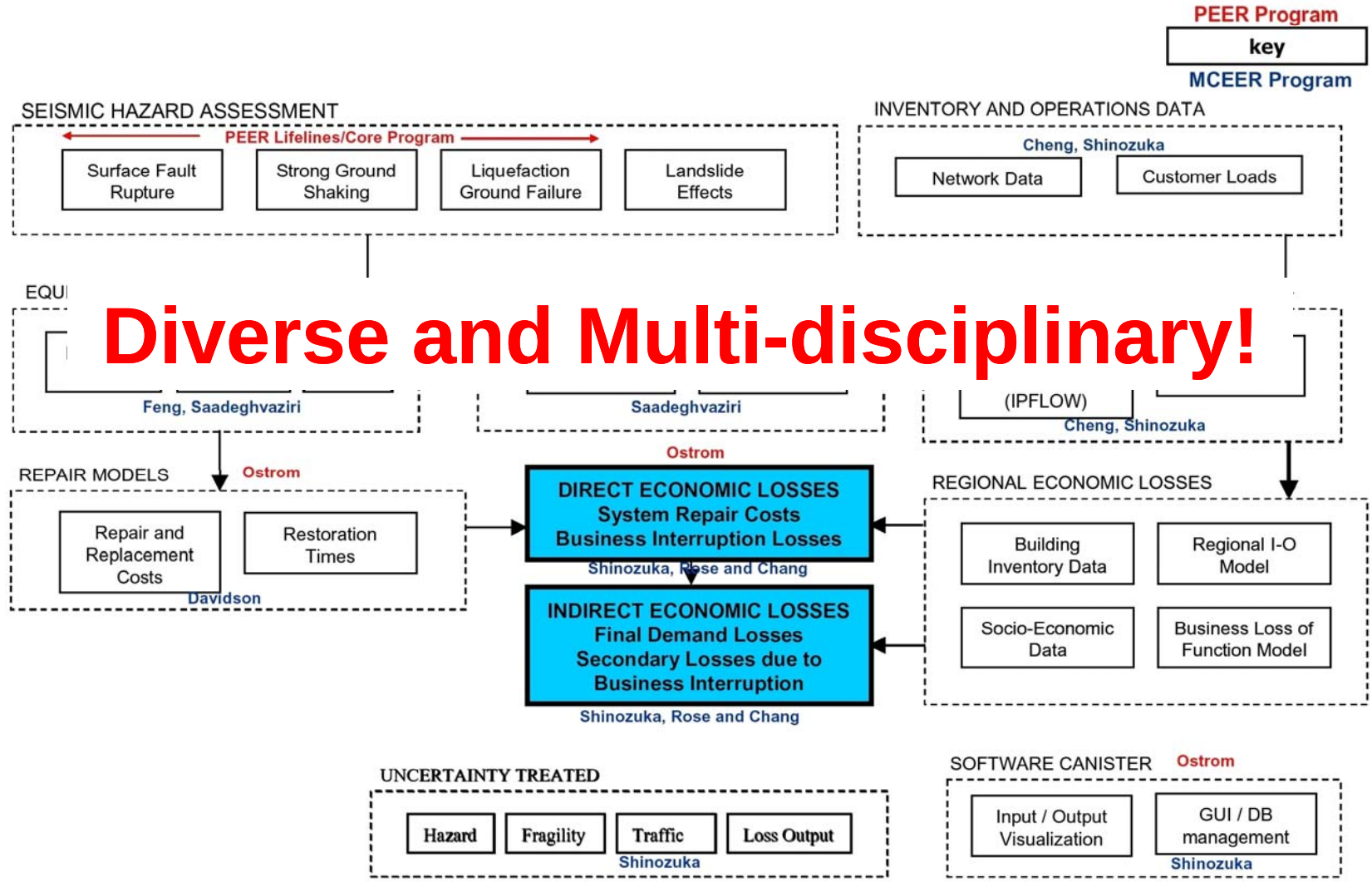
Example of lifeline research framework (electric power systems in US)



Incidents in electric power systems

- **1994 Northridge earthquake**
  - 2.5 million houses affected
  - 93% restored after 24 hours
  - Transients in power system reached Washington State, Idaho, British Columbia and Alberta affected
  - 1 billion US$ loss in power system
- **1995 Kobe earthquake**
  - 2.3 billion US$ loss in power system
  - Causing severe fires after restoration

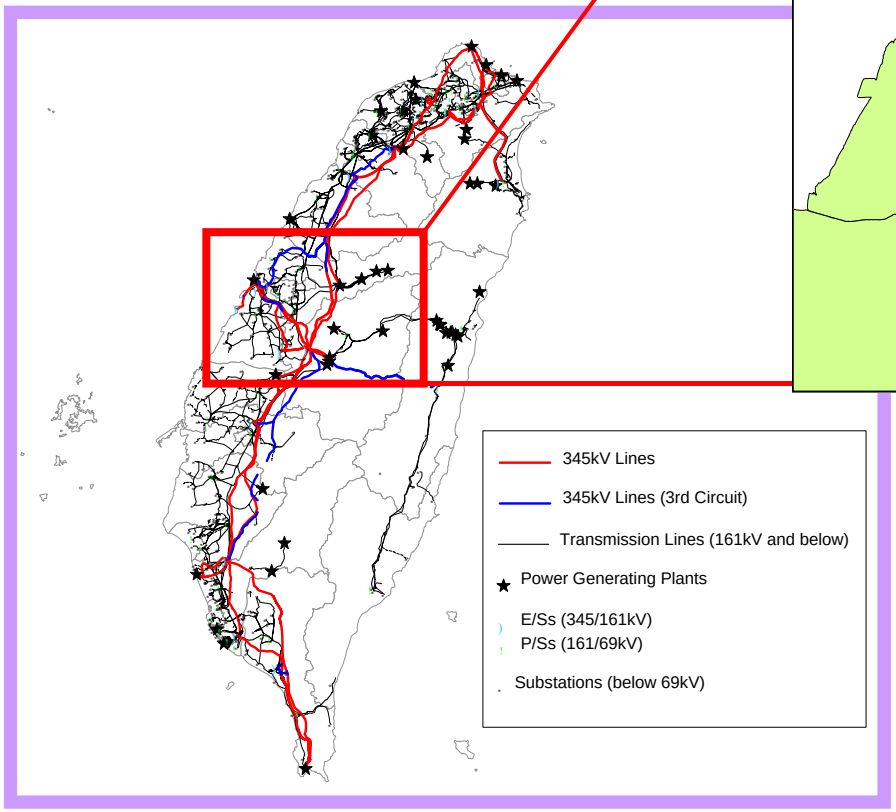
- **August 14, 2003 Great Blackout**
  - 50 million people affected
  - Rotation of suspension continued for 10 days
  - Caused by shorts in 3 circuits contacting with trees
  - 30 billion US$ loss reported
- **Sep. 12, 2005 LA Blackout**
  - 2 million people affected
  - Caused by worker's inadequate actions

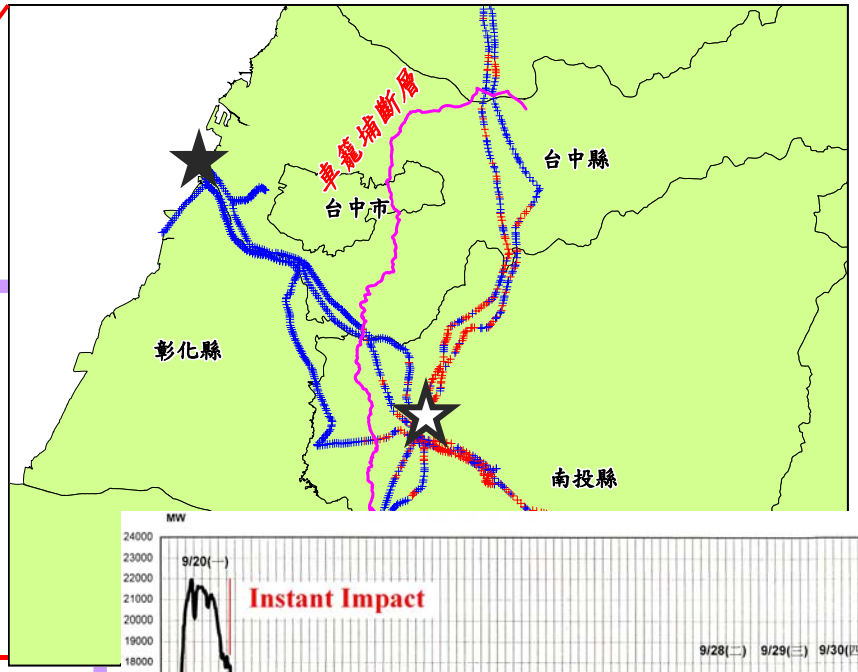
Damage in Taipower system in 1999 Chi-Chi Taiwan EQ

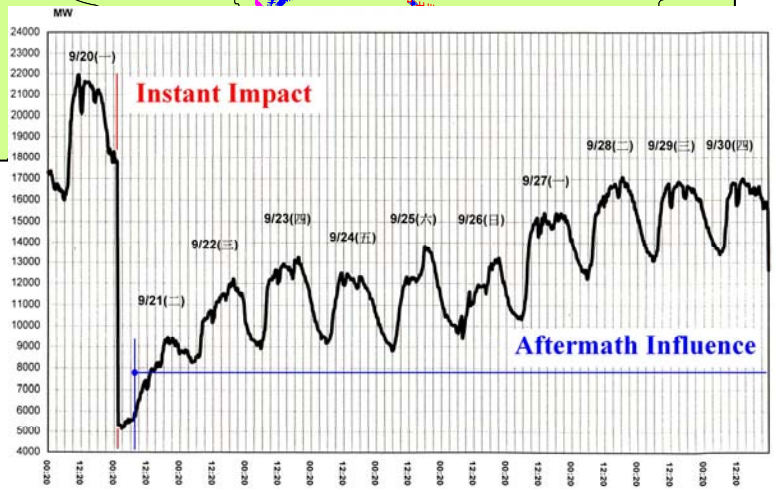
Chung-liaw switch yard ☆

345kV lines and towers

Taichung power plant ★







Power supply during 9/20 – 9/30

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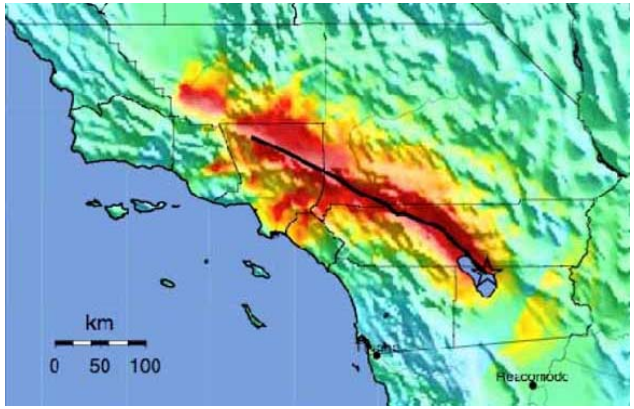
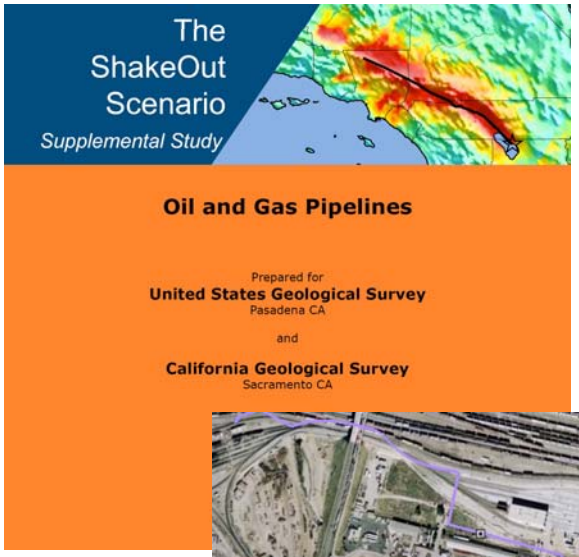
The Great California ShakeOut 2009

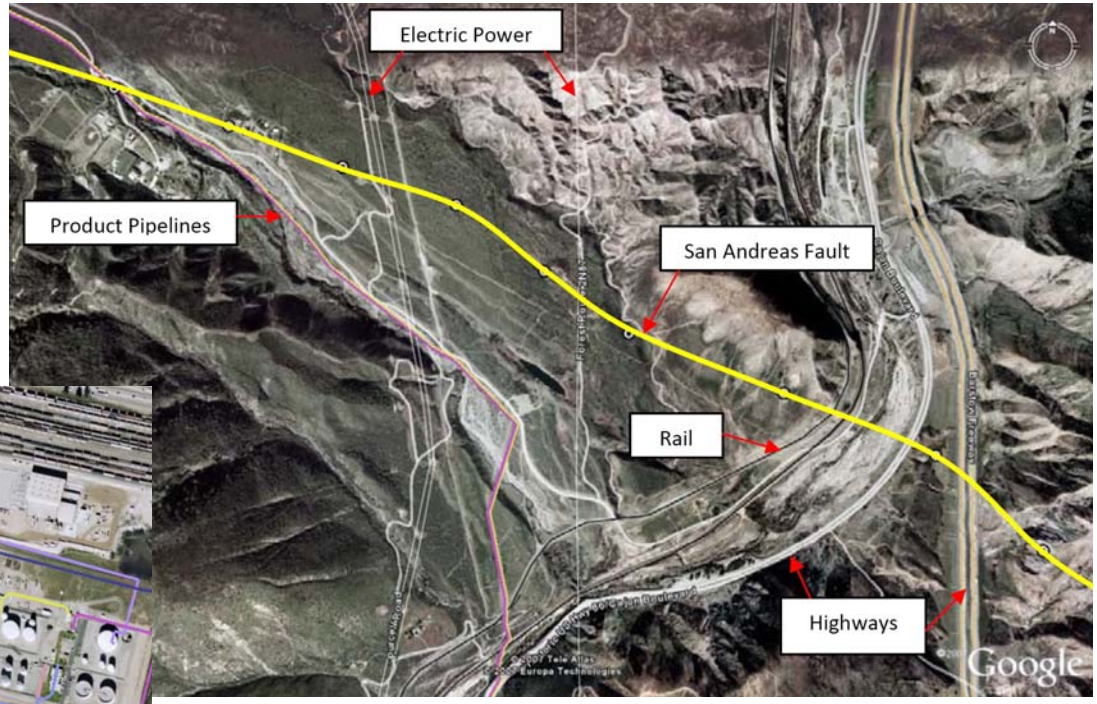
- October 15, 2009
- Over 6.9 million Californians
- The largest earthquake drill ever

- ShakeOut scenario (USGS)
  - M7.8 earthquake on the southern San Andreas Fault
  - Recurrence Interval ~ 150 years; elapsed time ~ 300 years
  - The great Los Angeles area



Oil, gas and other critical facilities in ShakeOut Scenario





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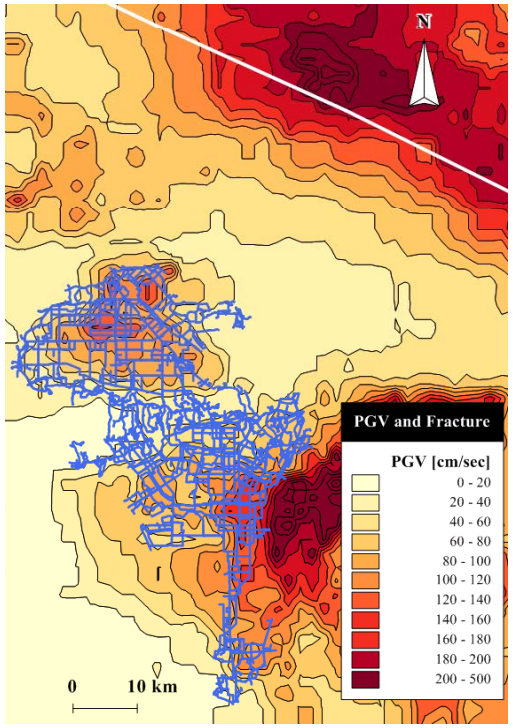
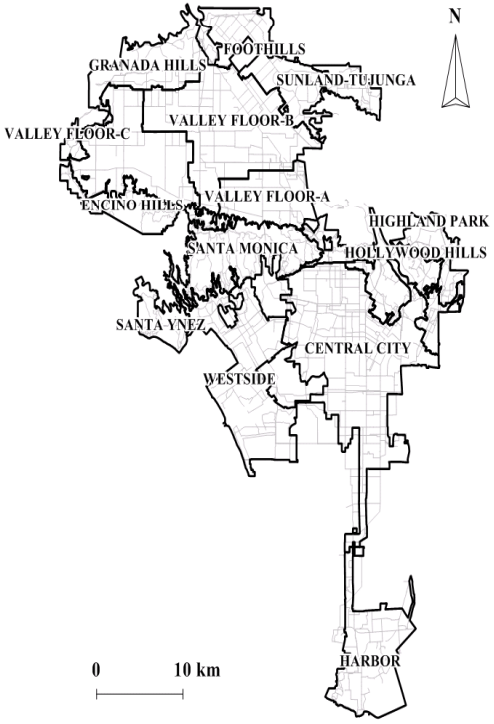
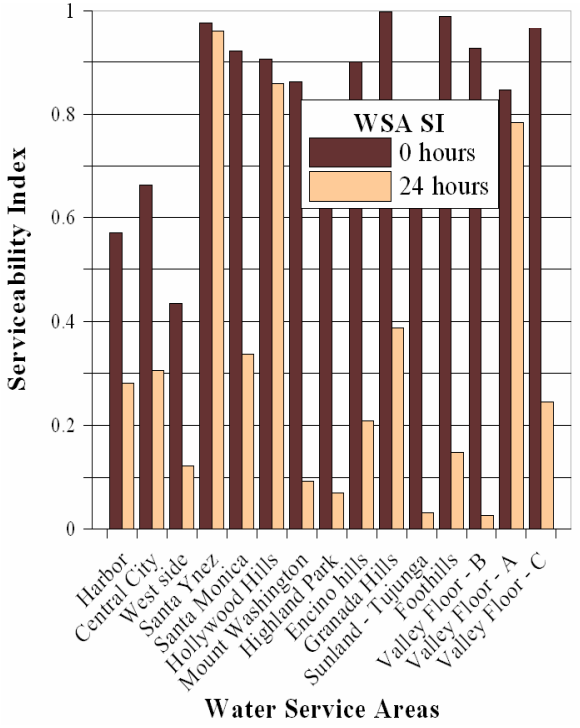
Water system in ShakeOut Scenario

- GIRAFFE (Graphical Iterative Response Analysis of Flow Following Earthquakes) by O'Rourke et al.
- $87 Billion loss from fire, $53 Billion business interruption loss from water

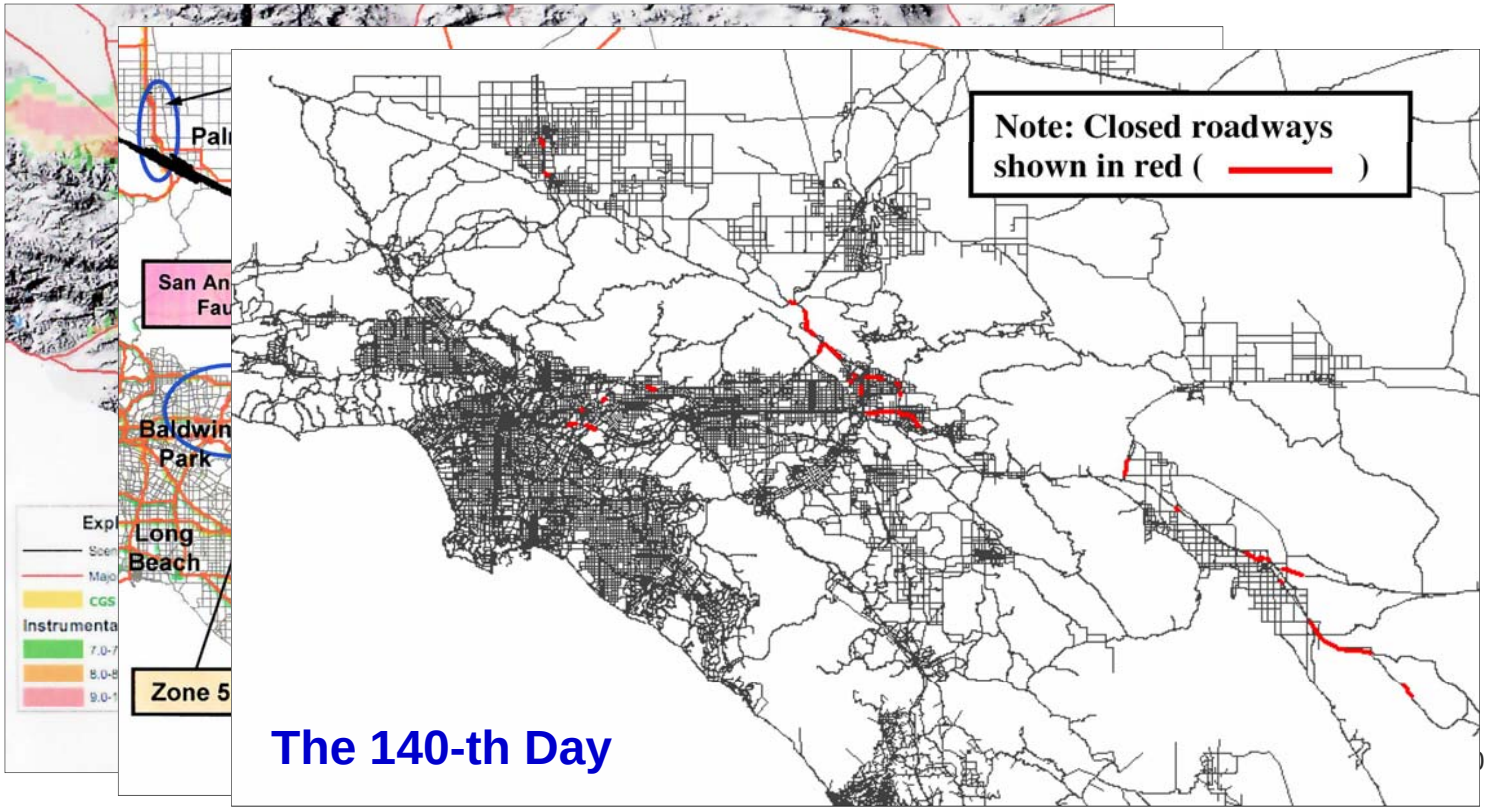






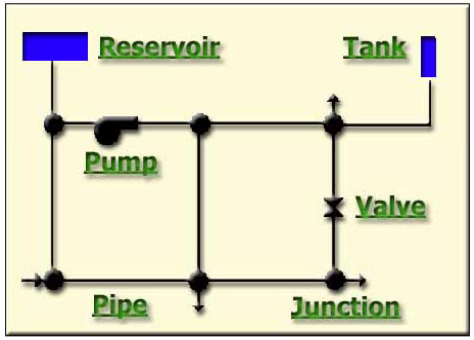
Highway system in ShakeOut Scenario

- REDARS™ 2 (Risks from Earthquake DAmage to Roadway Systems) by Federal Highway Bureau

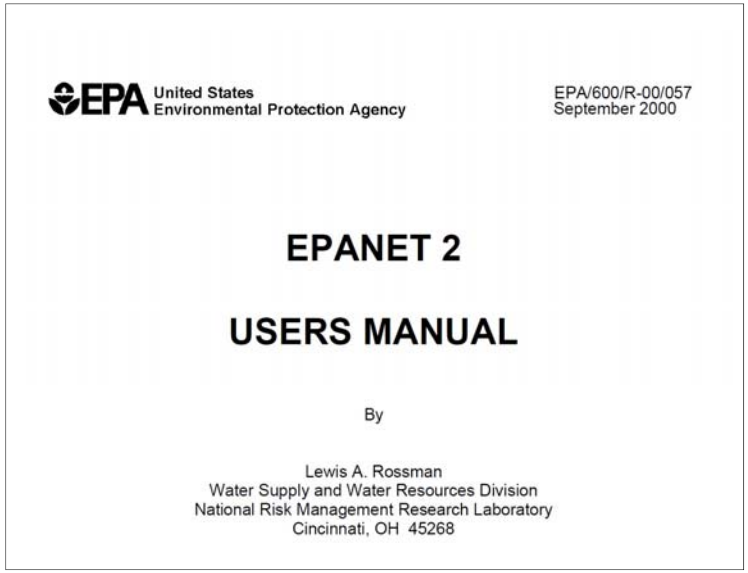


Hydraulic analysis of pressurized pipe flows for water systems

- **Unknowns**
  - Nodal heads: h_i (no. = N)
  - Pipe flows: q_{ij} (no. = N_P)
- **Governing equations**
  - Continuity (no. = N, linear in q_{ij})
  - Flow headloss relation: the change in the heads of two end nodes of a pipe (no. = N_P, nonlinear in q_{ij})



N nodes + N_P pipes


EPA United States Environmental Protection Agency

EPA/600/R-00/057
September 2000

EPANET 2

USERS MANUAL

By

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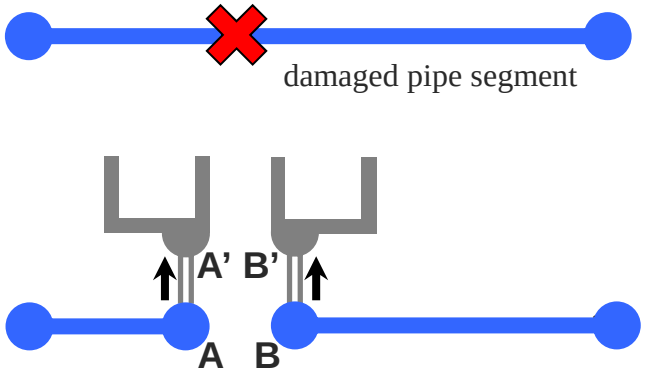
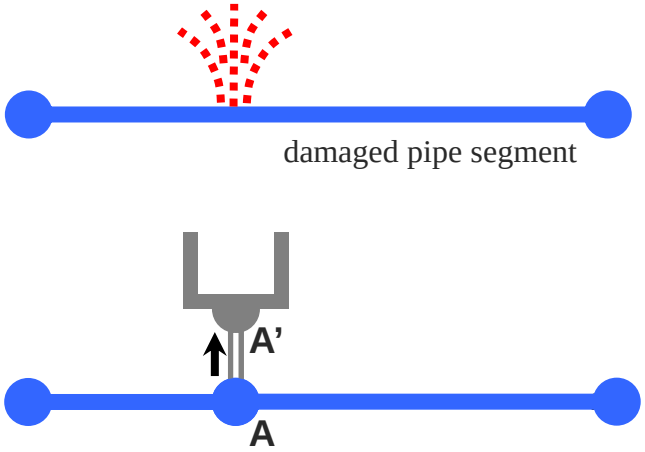
Modeling a pipe break

1. Decide the location and elevation of pipe break point
2. Remove the original link (pipe segment)
3. Add two new nodes A and B at the location of pipe break point
4. Add two new links connecting the original pipe segment ends to A and B, respectively
5. Add two new nodes A’ and B’ with the elevation of pipe break point and designate them as reservoirs
6. Add two new links connecting A-A’ and B-B’ and specify them with one-way check valves, respectively

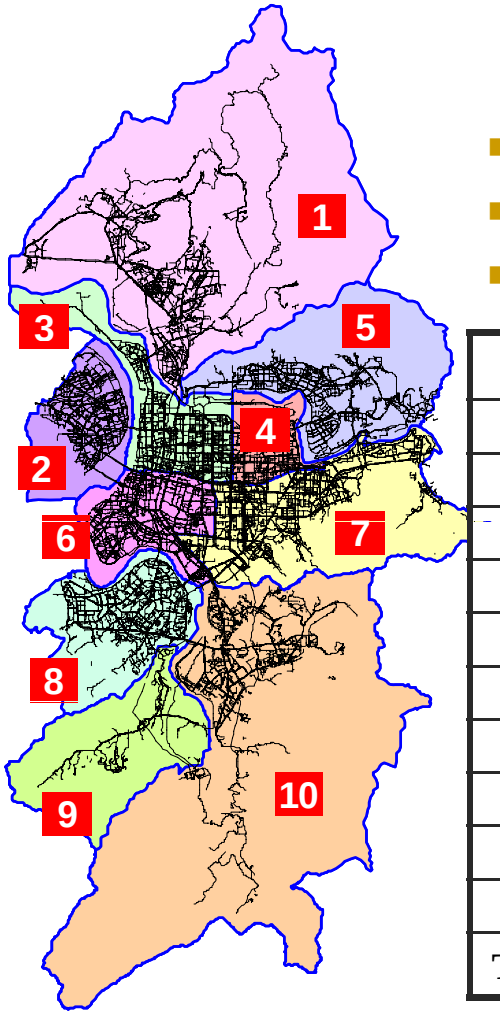


Modeling a pipe leak

1. Decide the location and elevation of pipe leak point
2. Remove the original link (pipe segment)
3. Add a new node A at the location of pipe leak point
4. Add two new links connecting the original pipe segment ends to A
5. Add a new node A’ with the elevation of pipe leak point and designate it as a reservoir
6. Add a new link connecting A and A’ and specify it (1) as a fictitious pipe with a diameter of corresponding pipe leak model, and (2) with a one-way check valve



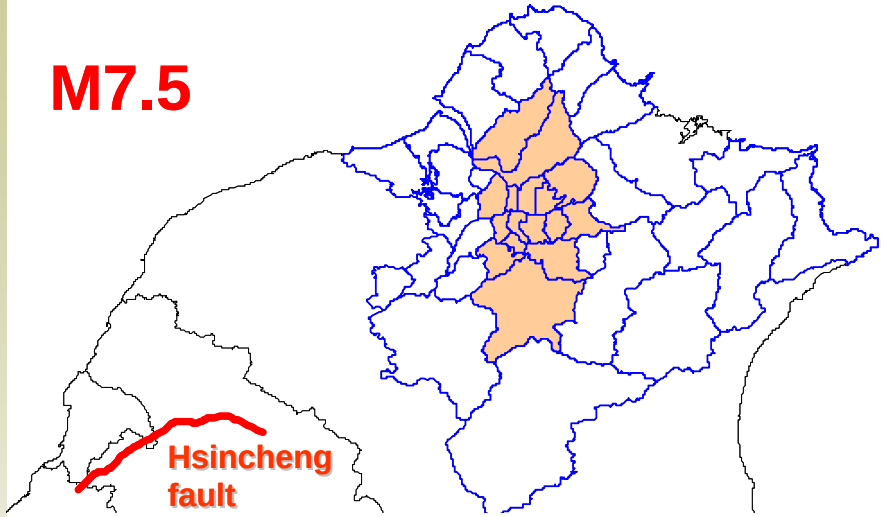
The water system of the Taipei Water Department (TWD)

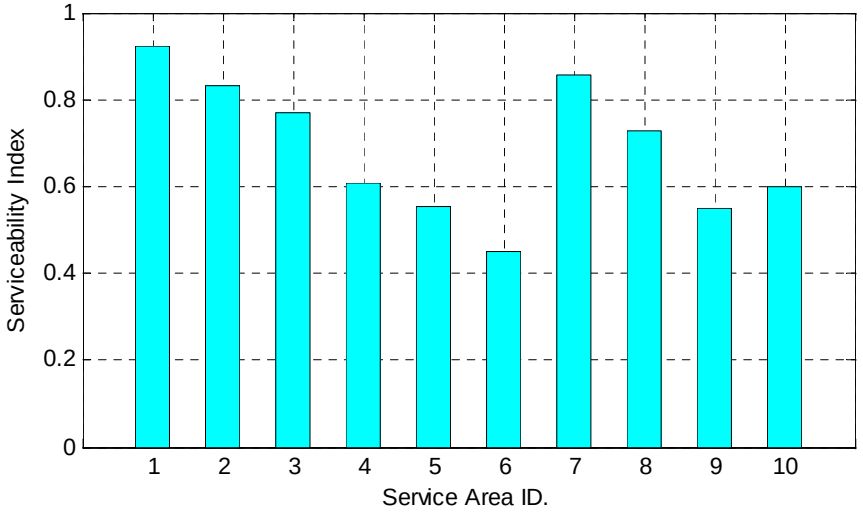


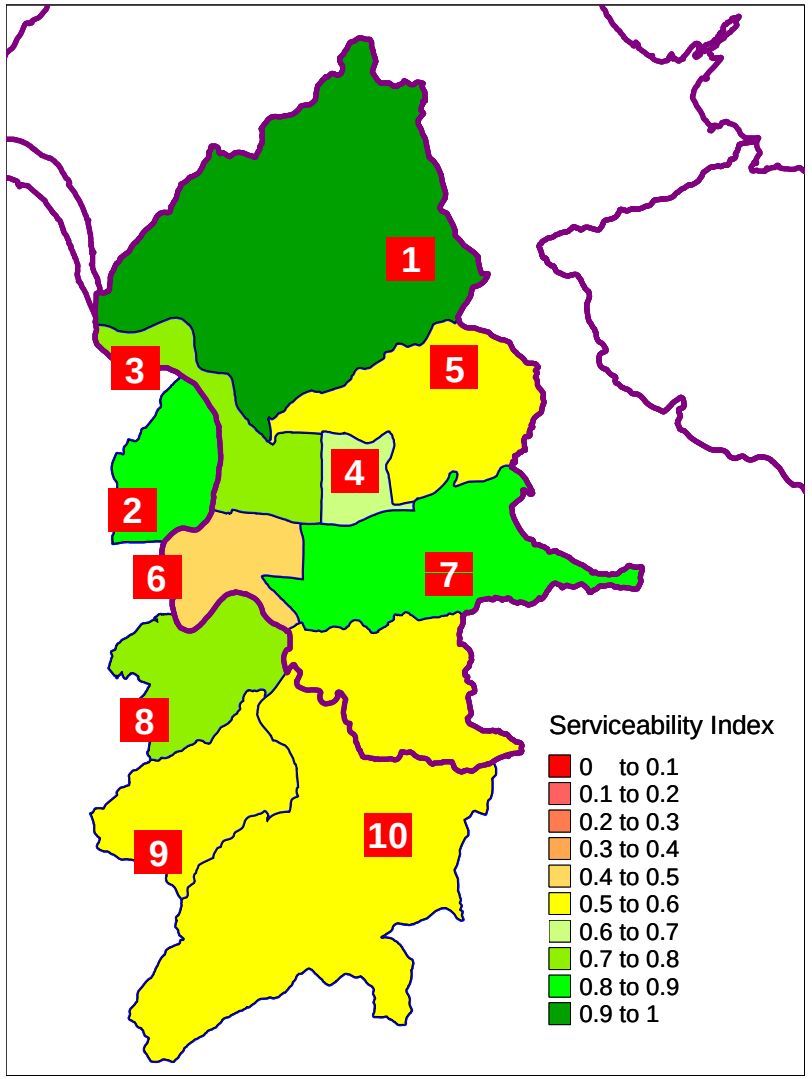
- Service region: 434 square kilometer, including the whole Taipei City plus 4 most populated cities of the Taipei County, divided into 10 service areas
- Serving 1.51 million customers or 3.85 million people
- Daily water supply: 2.5 million tons
- Total pipe length: 7,153 Km (including customer pipes)

	Nodes	Pipes	Pumps	Tanks	Reservoirs	Pipe Length (m)
01	3,254	3,376	40	10	0	171,359
02	2,289	2,366	18	3	0	102,684
03	4,288	4,421	27	2	0	143,565
04	1,769	1,822	18	2	0	68,446
05	2,591	2,673	10	2	0	116,349
06	3,691	3,796	17	2	0	142,553
07	4,985	5,127	32	3	1	193,524
08	2,338	2,394	5	1	0	98,039
09	587	601	12	2	0	28,829
10	2,716	2,799	20	3	0	130,933
Total	28,508	29,375	199	30	1	1,196,281

M7.5 Hsincheng fault scenario



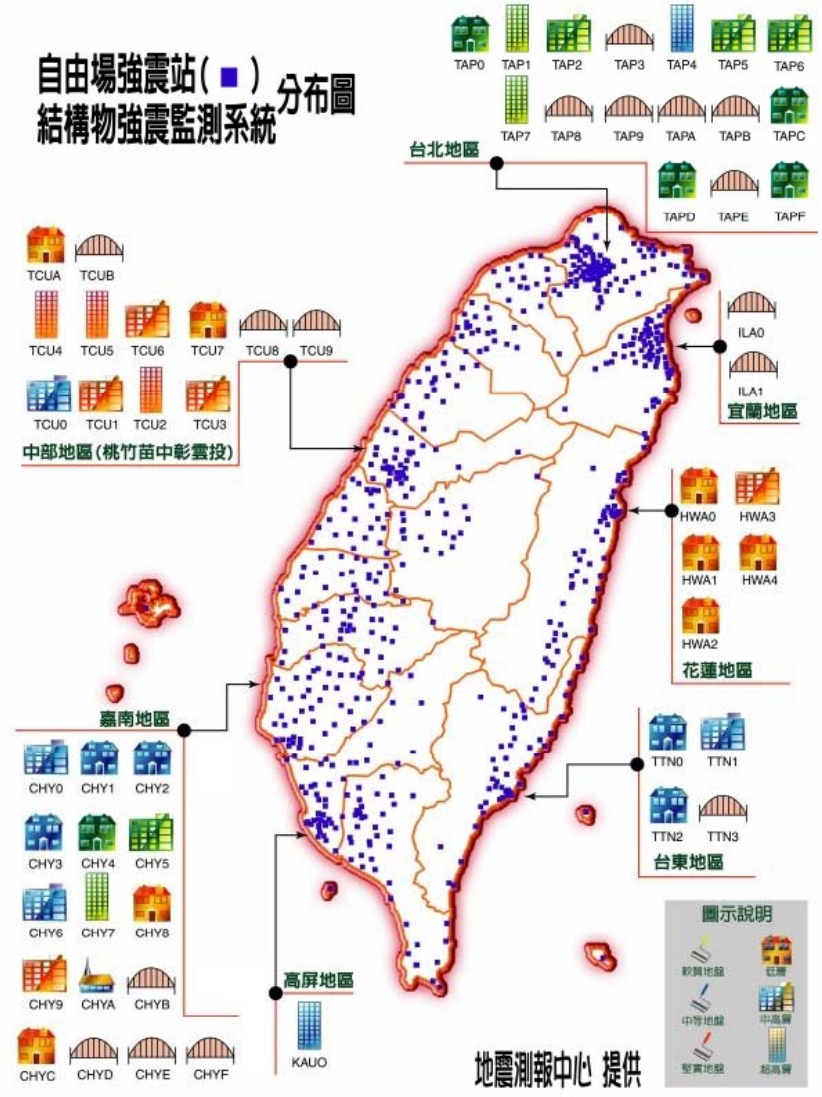




Taiwan Strong Motion Instrumentation Program (TSMIP)

Started in 1990, CWB has installed and maintained more than 700 strong-motion stations around Taiwan:

- **109 real-time stations**
- **650 free-field strong motion stations**
- **51 monitored structures**
- **digital instrumentation**



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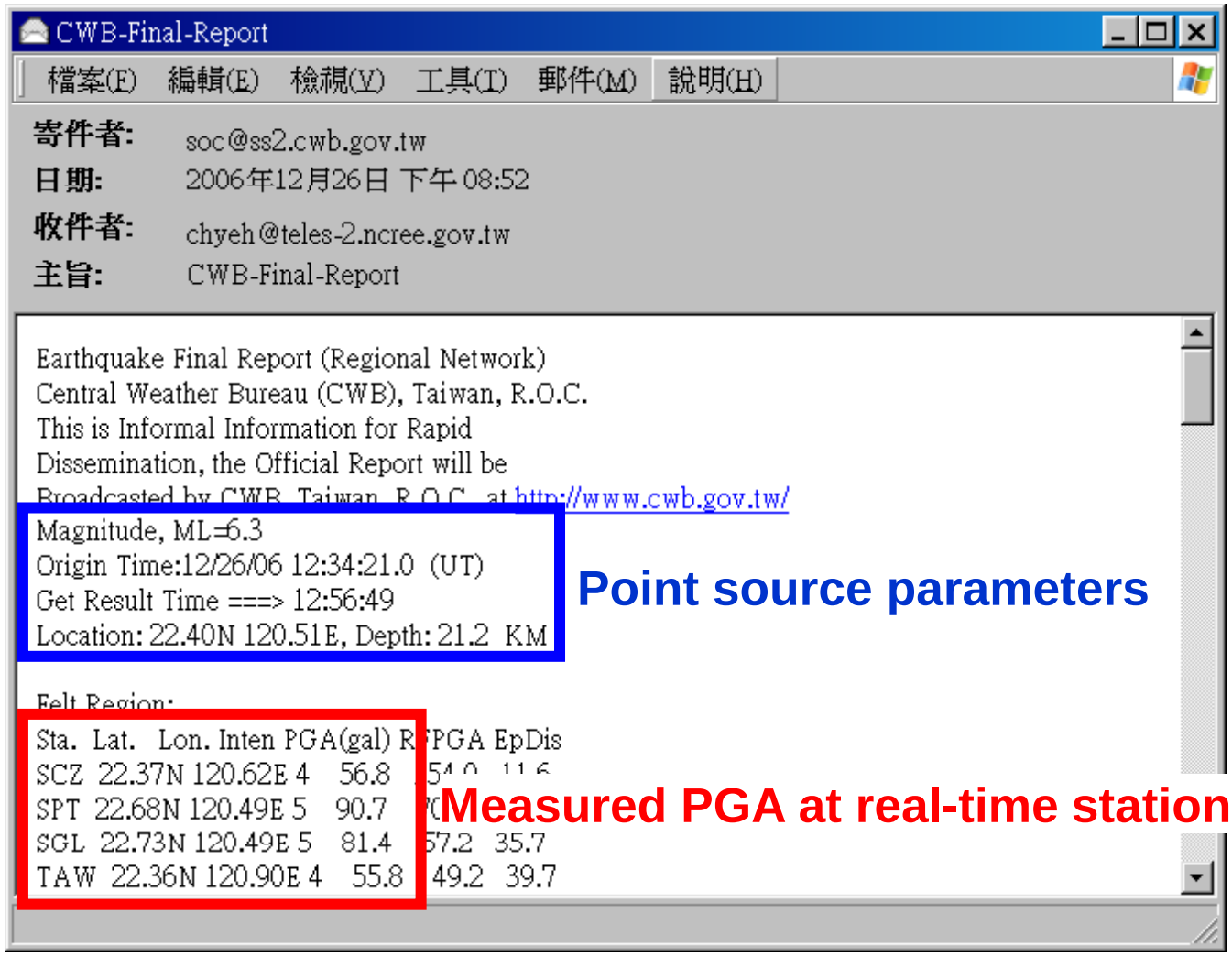
Early Seismic Loss Estimation (ELSE)

- **TREIRS (Taiwan Rapid Earthquake Information Release System) by CWB**
  - Obtain point-source parameters (M, E_x, E_y, D) within seconds
  - Send earthquake alerts to all clients
- **ESLE by NCREE**
  - Auto-trig after receiving email from CWB
  - Obtain estimation results within seconds
    - Dispatch short messages through mobile phones to emergency personnel
    - Send email to provide more information
  - Auto-output useful maps and tables

CWB email service by TREIRS

(Taiwan Rapid Earthquake Information Release System)

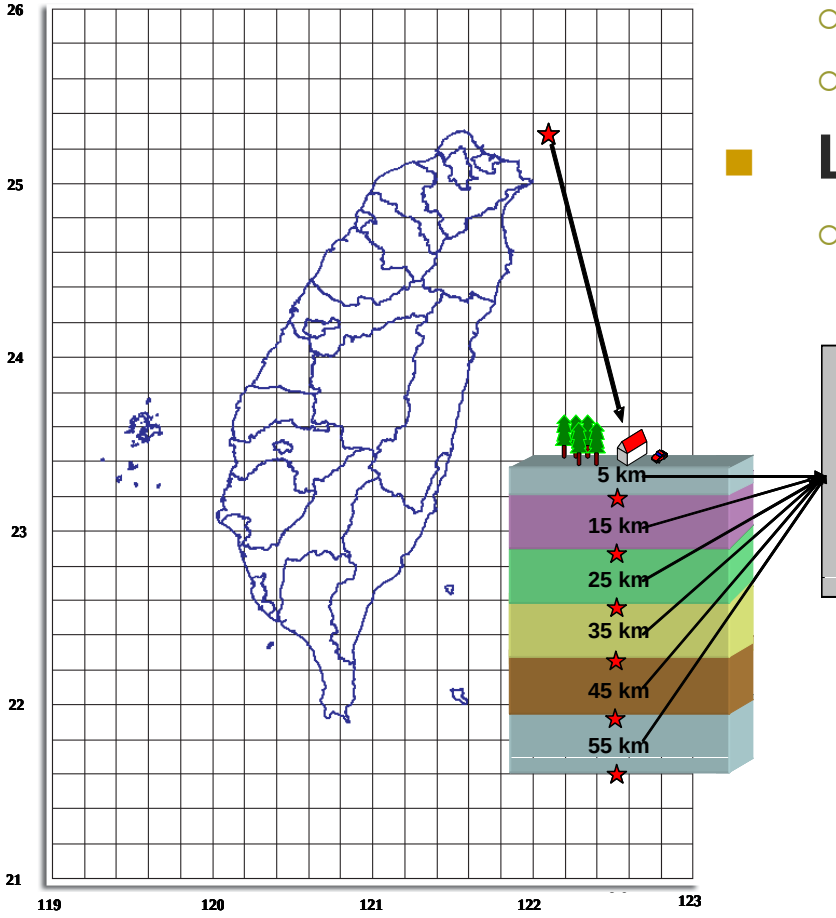


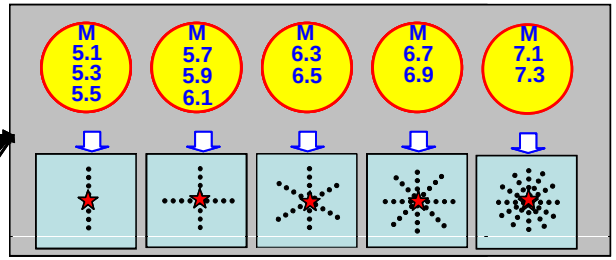
Point source parameters

Measured PGA at real-time stations

Pre-calculated Seismic Scenario Database (SSD)

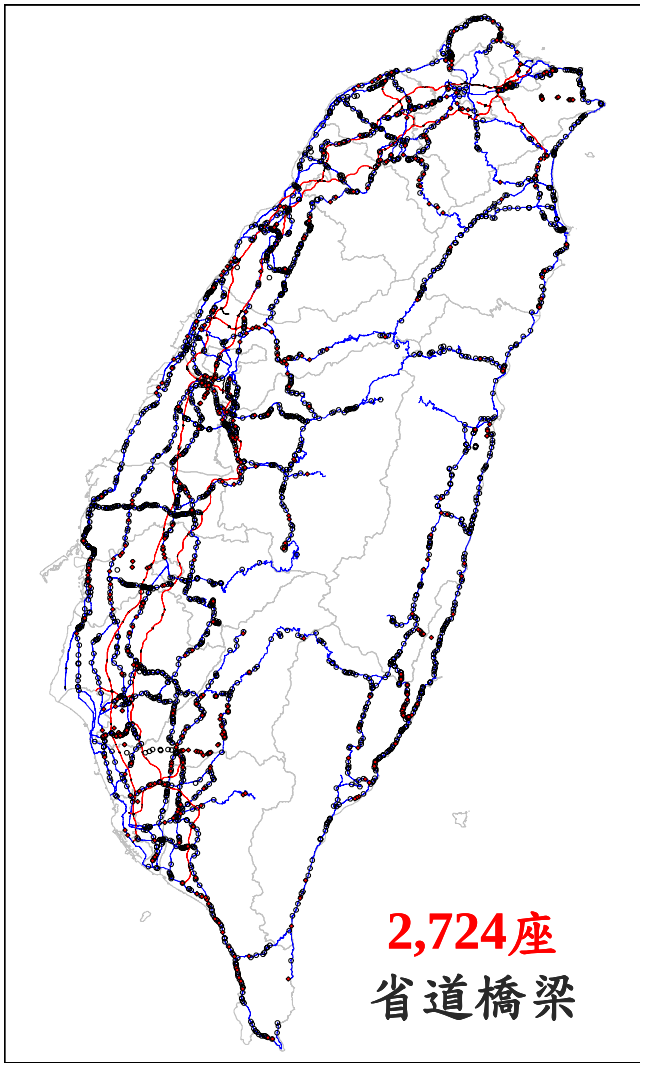
- **Source locations:**
  - E119˚-123˚, N21˚-26˚
  - Grid size: 0.2˚×0.2˚
  - Focal depth: 5, 15, 25, 35, 45, 55km
- **Line source model**
  - 35 combinations of (M, Orientation)

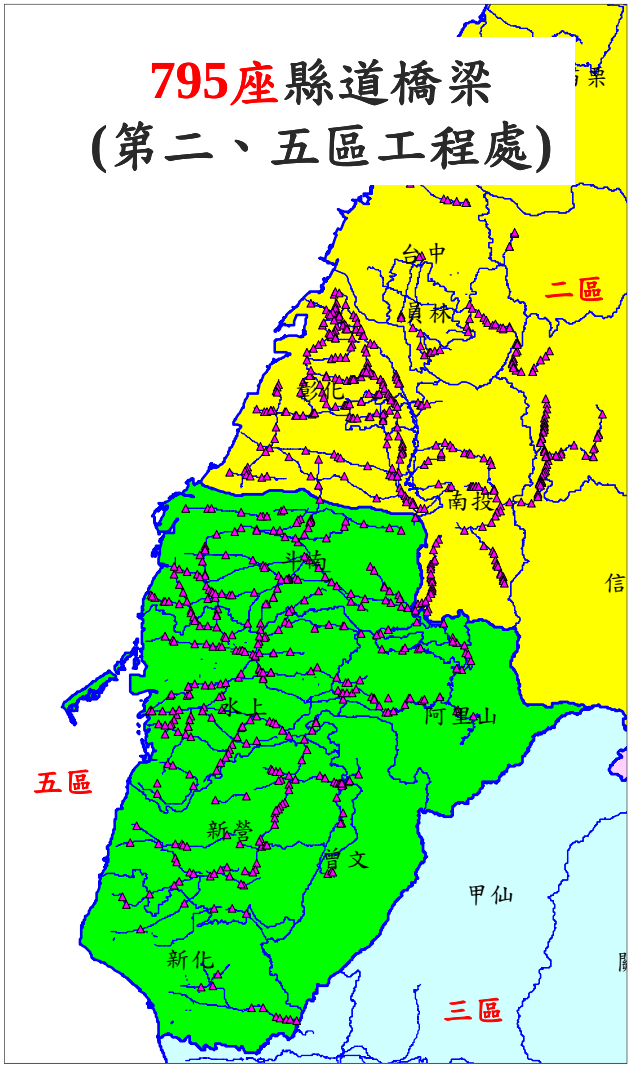




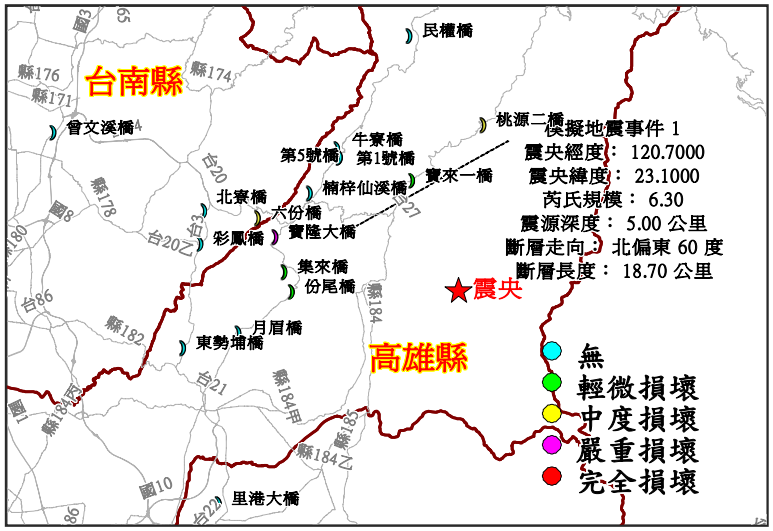
斷層開裂方向
(1) 0度
(2) 0、90度
(3) 0、60、120度
(4) 0、45、90、135度
(5) 0、30、60、90、120、150度

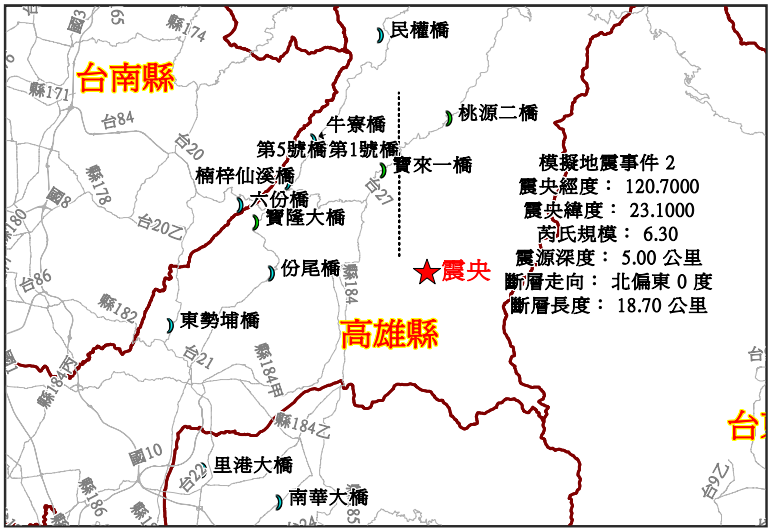
Application of Early Seismic Loss Estimation (ESLE) to highway bridges

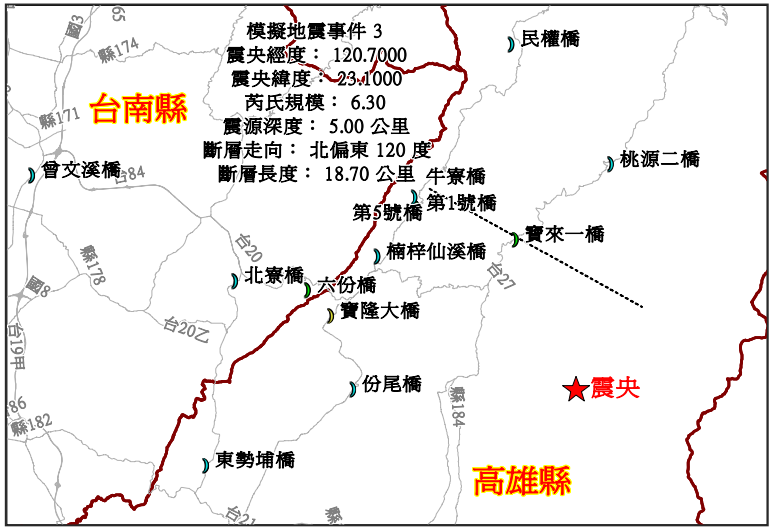




Example of ESLE Application: M6.3 EQ on March 4, 2010







Landslide-induced high turbidity of raw water in watershed areas

- **Aere typhoon** in 2004
- **No physical damage** to water system
- **3.2 million people** in Taoyuan area out of water for **17 days!**

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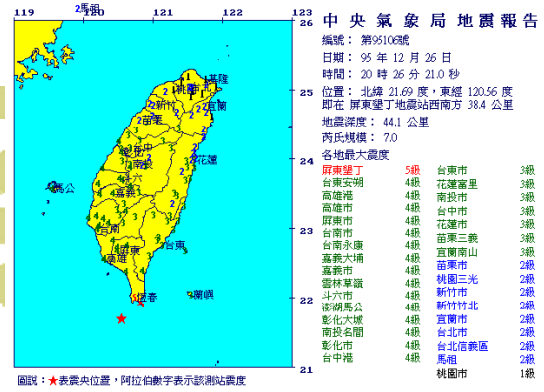
2008 Chinese winter storms (meteorological hazard)

- Jan. 25 to Feb. 6
- 300,000 troops and 1.1 million reservists deployed for relief efforts
- transportation and electricity badly affected

Undersea cables: new type of damage/disaster

Heng-Chun EQ
Dec. 26, 2006



Concluding remarks

- Key issues in hazard-related lifeline research
- Cases of lifeline performance under hazardous condition
- **Barriers in the way:**
  - **lessons not learnt**
  - **cross-disciplinary gaps not filled**
  - **knowledge of rare and extreme events and their consequences limited**

Thanks for your attention!