2015년 원자력학회
원전건설 및 운영기술 분과 워크숍

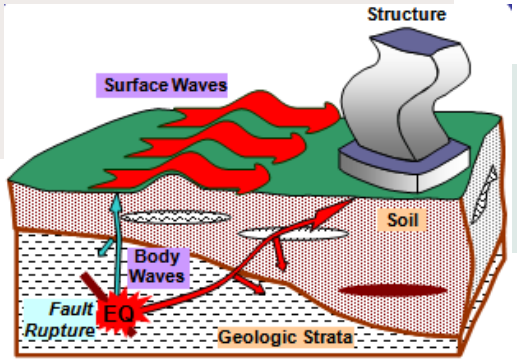
대형지진에 대한 기간시설물의 안전성

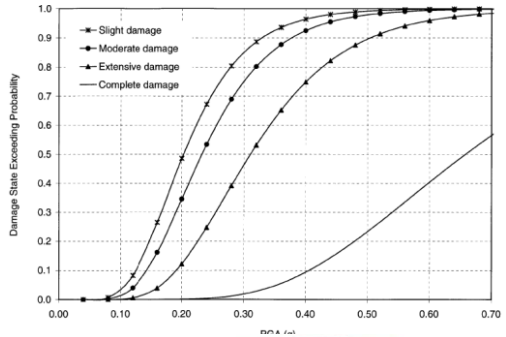
2015년 10월 28일(수)

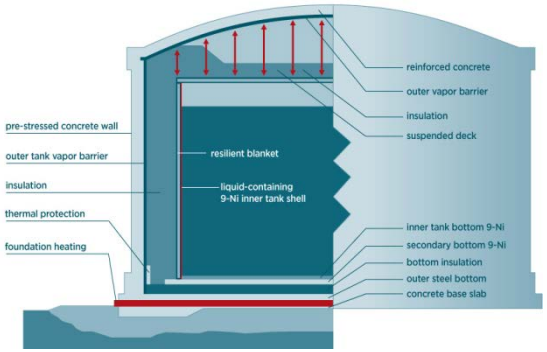
건국대학교 토목공학과
이 태 형

발표 내용

- 구조물의 지진거동과 내진설계
- 사회기반시설의 내진성능
- 기간시설물의 지진취약도 평가
- 대형지진에 대한 원전안전성 사례
- 맺음말

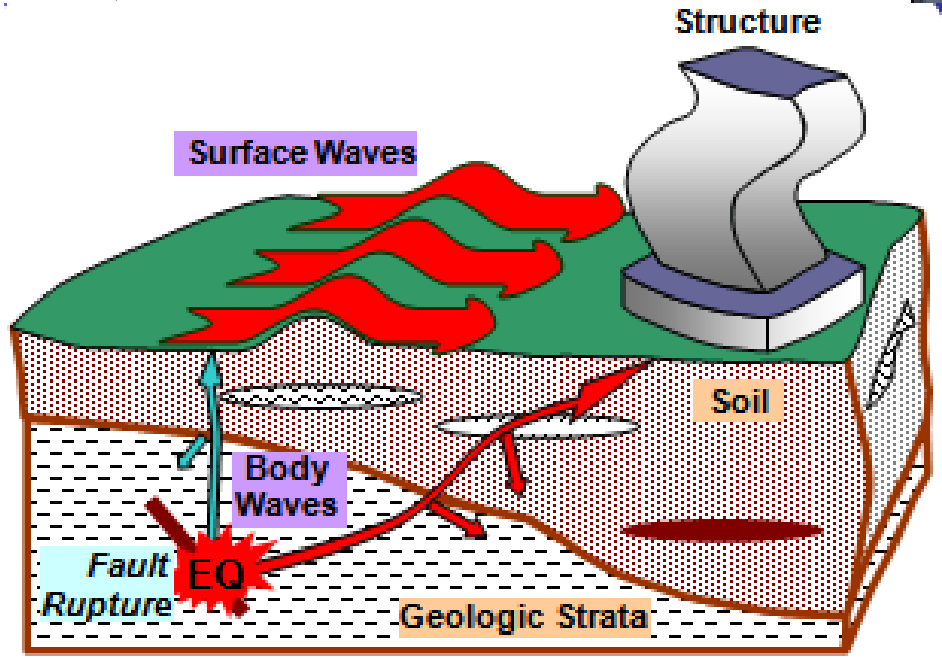


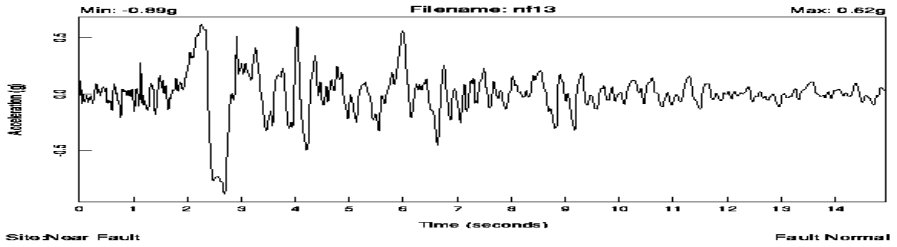




구조물의 지진거동과 내진설계

구조물의 지진거동



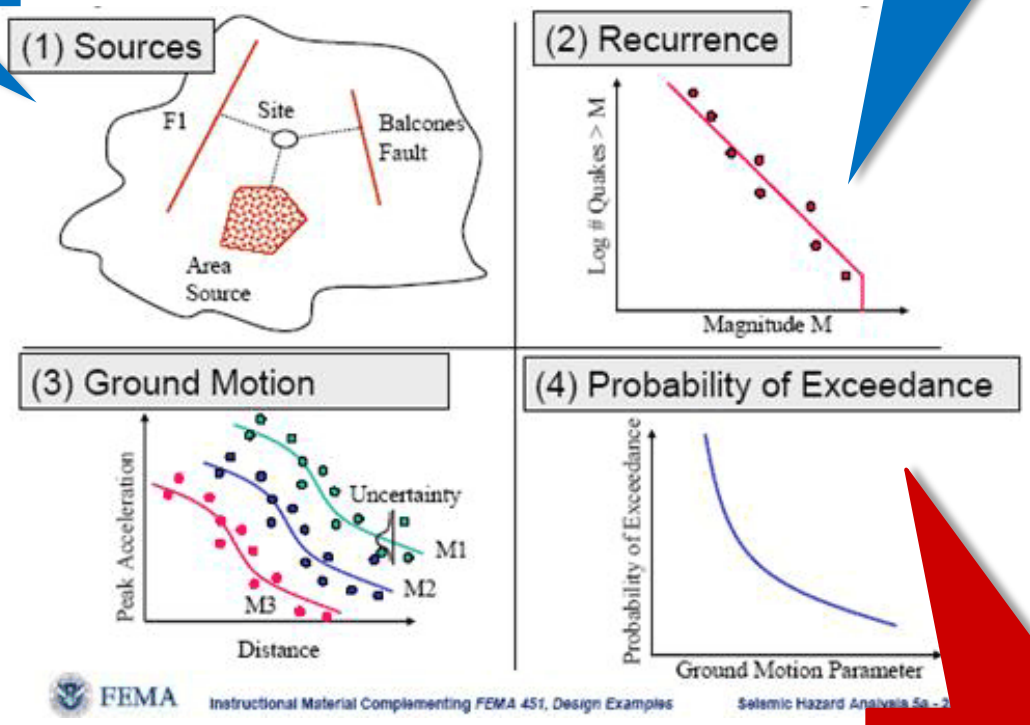


지반가속도

내진설계: 지반가속도 산정

주변의 단층 분포

단층의 확률

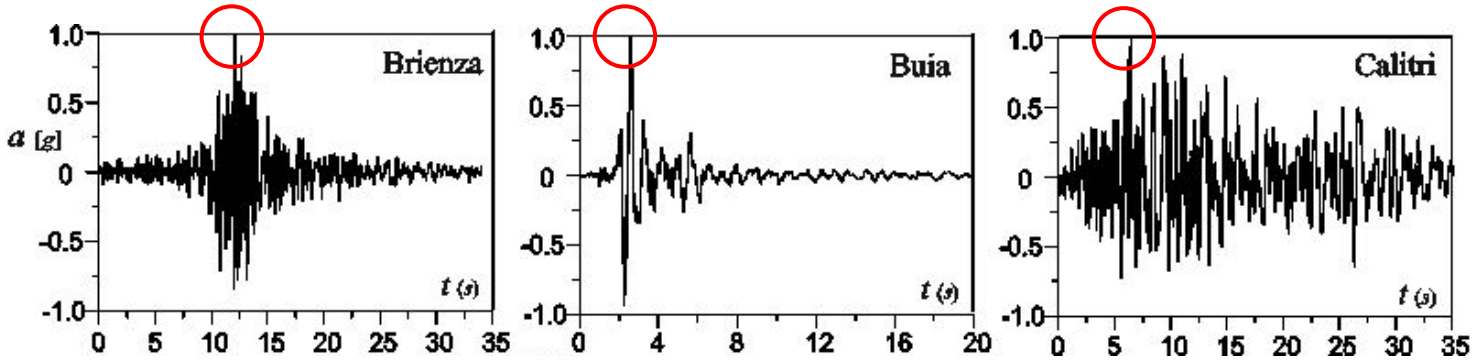


예) 2,400년 재현주기 => 0.20 g (PGA)
1,000년 재현주기 => 0.13 g (PGA)

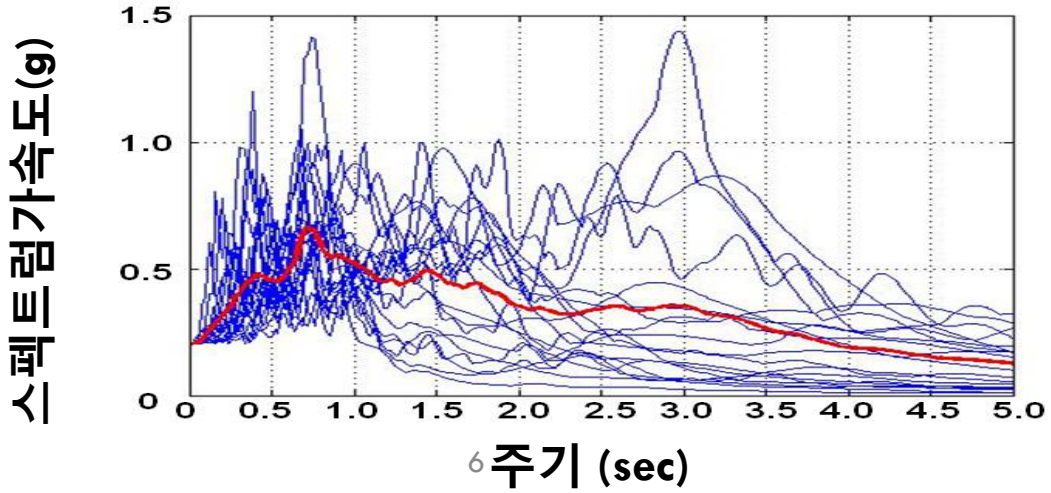
재현주기에 따른 지진의 크기

내진설계: 설계지반가속도

- 최대지반가속도 (PGA, Peak Ground Acceleration)



- 같은 PGA라도 구조물에 영향은 매우 다름
- 지진의 불확실성을 고려하여 **설계지반가속도** 결정



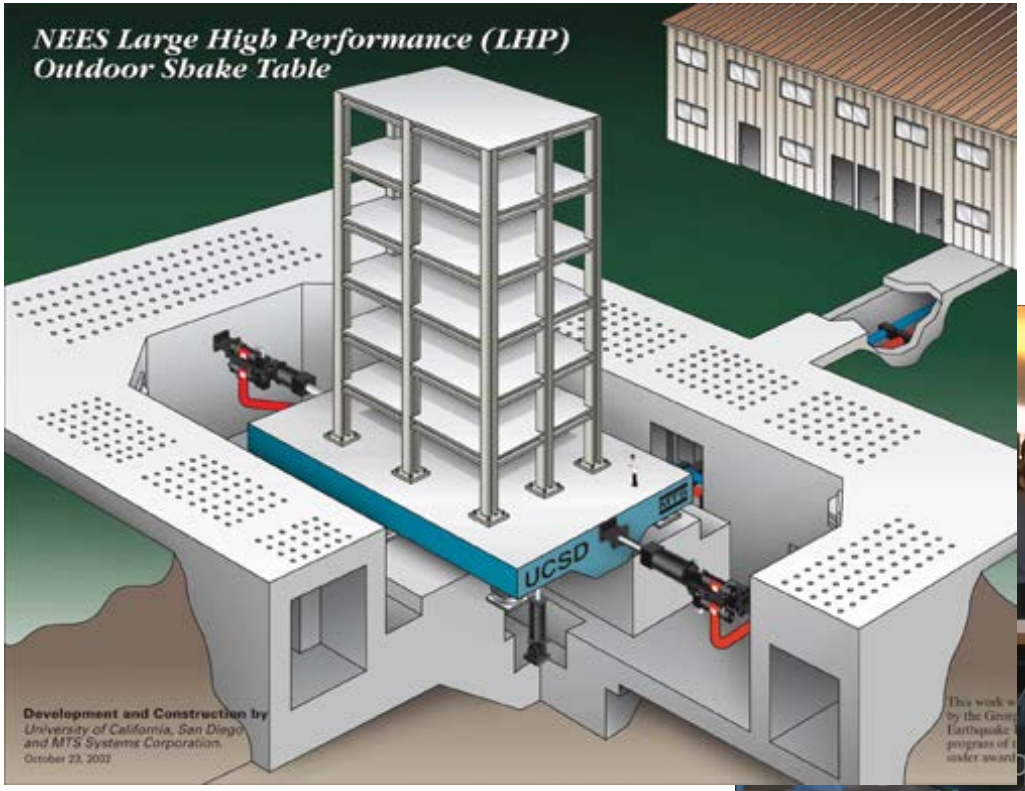
사회기반시설의 내진성능

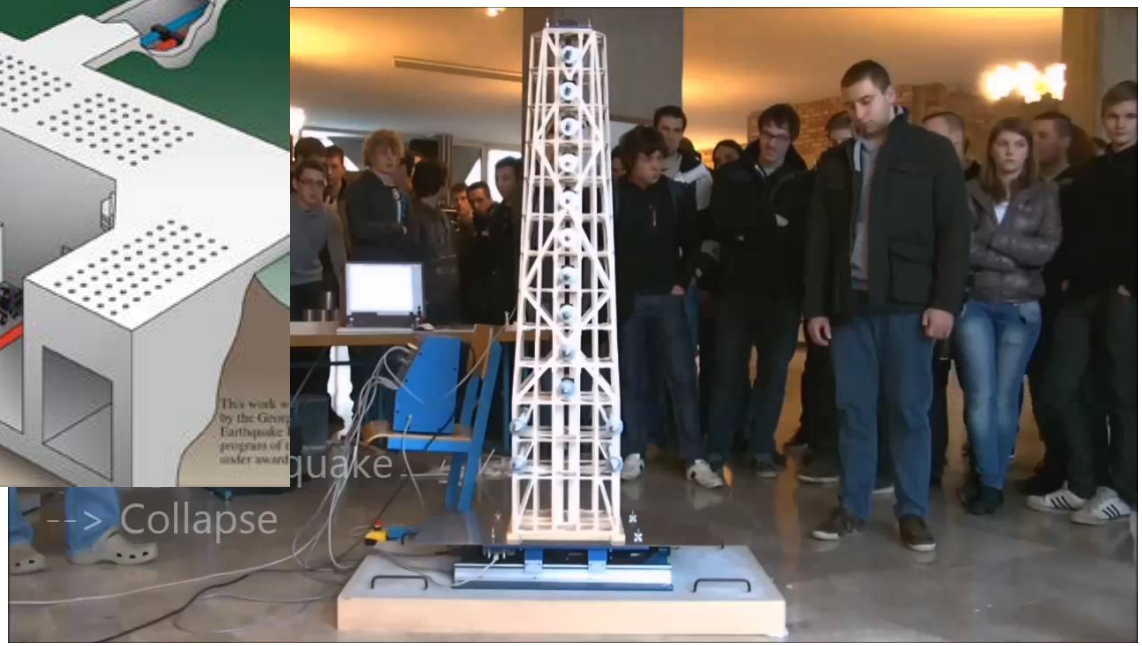
내진설계와 내진성능

- 내진설계의 목표
  - 주어진 수준의 지진에 대해 특정한 성능을 만족하도록 설계함
  - 예: 2,400년 재현주기의 지진이 발생해도 원전을 멈추지 않고 가동할 수 있도록 설계함
- 내진성능 평가
  1. 설계기준을 만족하는지 평가
     - 설계지진하중 작용 시 구조물의 거동을 평가함
  2. 다양한 수준의 지진하중에 대한 구조물의 거동을 평가
     - 지진취약도 평가

내진성능 평가방법 (1)

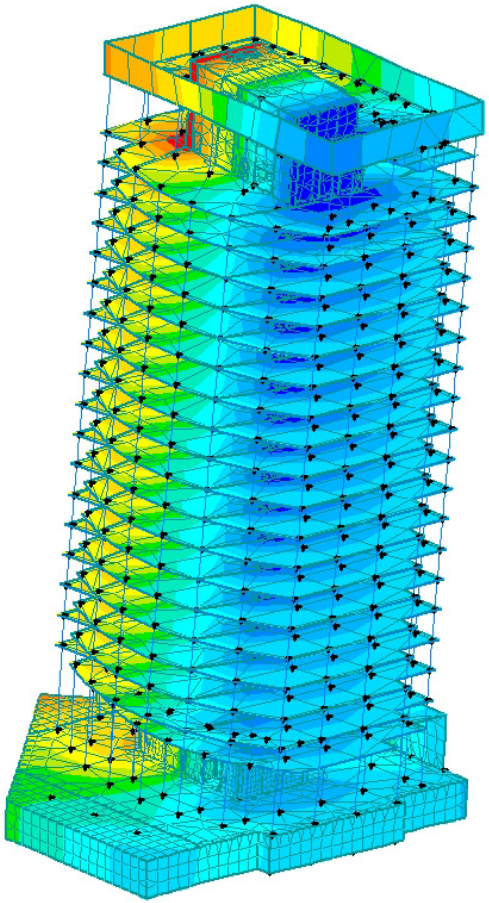
- 실험적 방법: 진동대(shake table) 실험

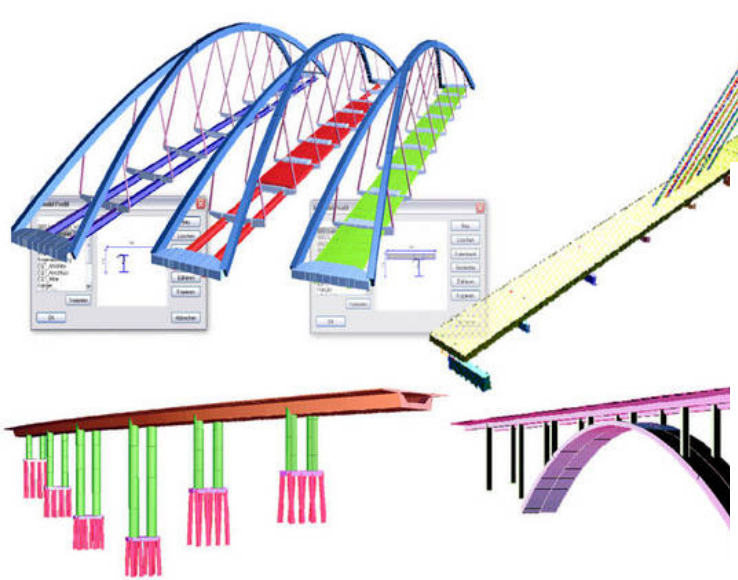


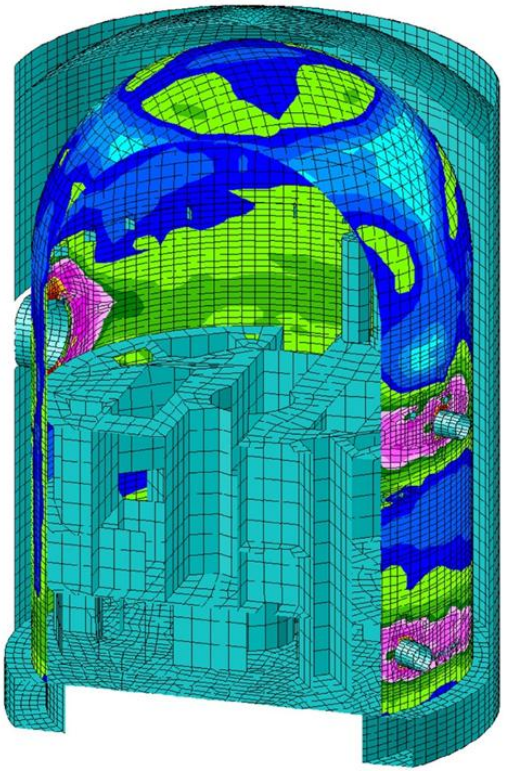


내진성능 평가방법 (2)

- 해석적 방법: computer simulation



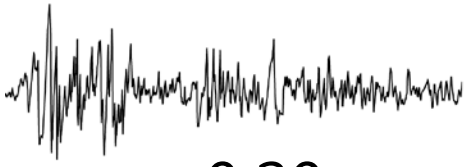




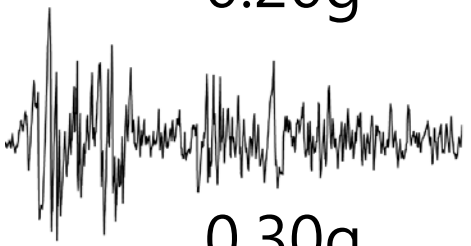
해석적 내진성능평가 절차

최소 7개의 지진파 → **NG 확률**

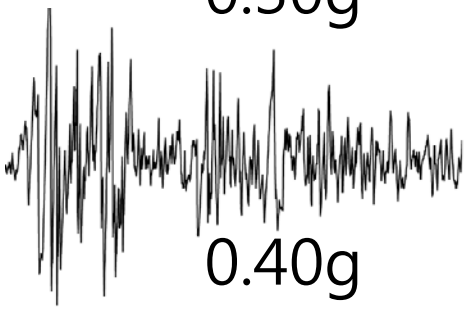
0.10g



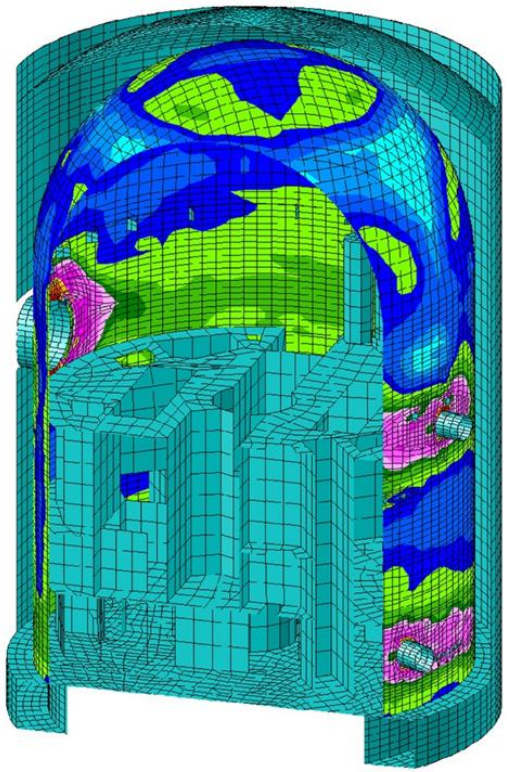
0.20g



0.30g



0.40g



OK or NG

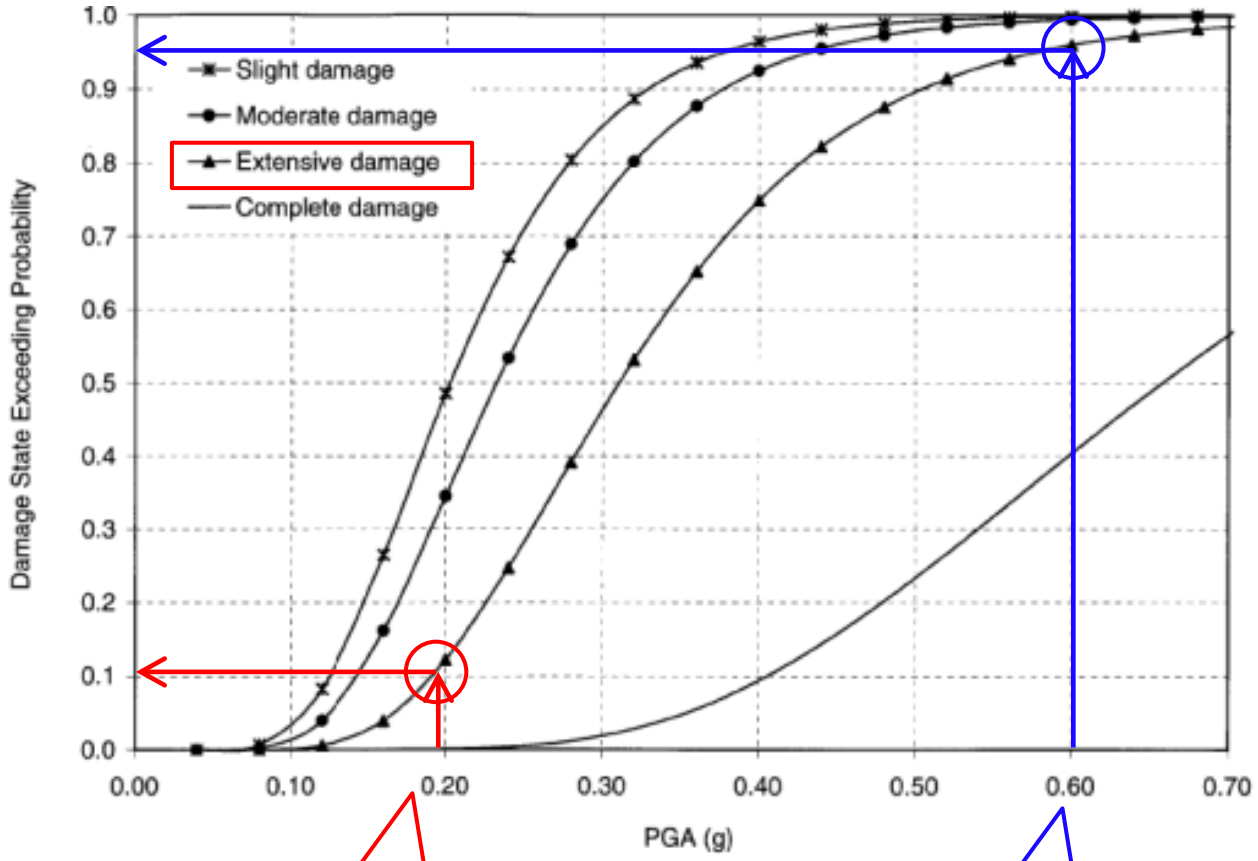
OK or NG

OK or NG

OK or NG

구조물의 지진취약도

- 지진취약도 함수: 손상확률 (불확실한 지진파가 주 원인)



0.2g 일 때,
손상확률 10%

0.6g 일 때,
손상확률 95%

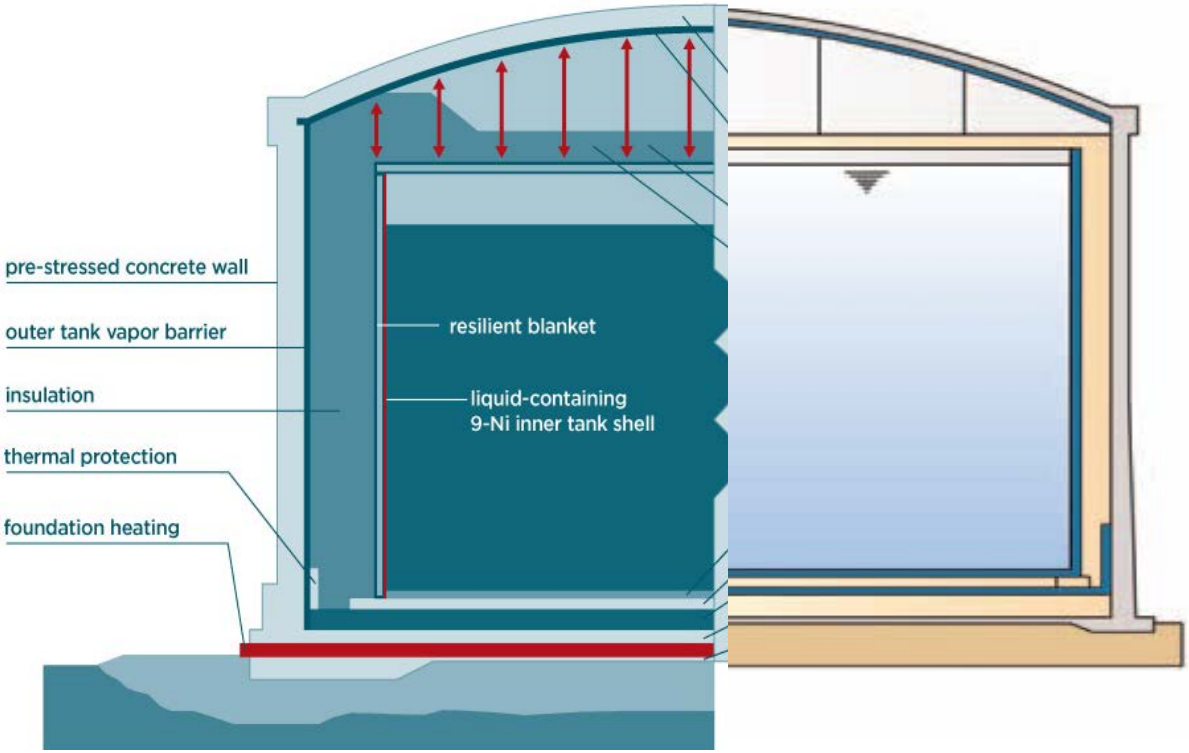
일기예보

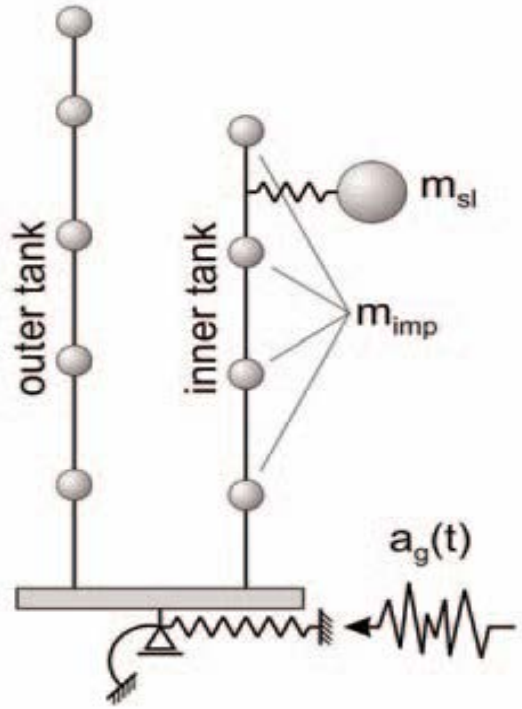
- LNG 저장탱크
- 송전철탑

기간시설물의 지진취약도

LNG 저장탱크의 지진취약도

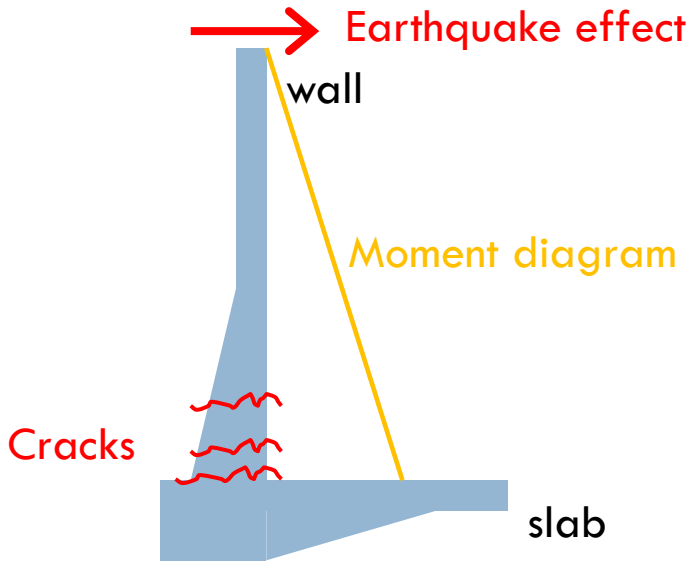
- 국내 LNG저장탱크
- 설계지진: 0.2 g (SSE)





Tuning Fork Model

LNG 저장탱크의 지진취약도(2)

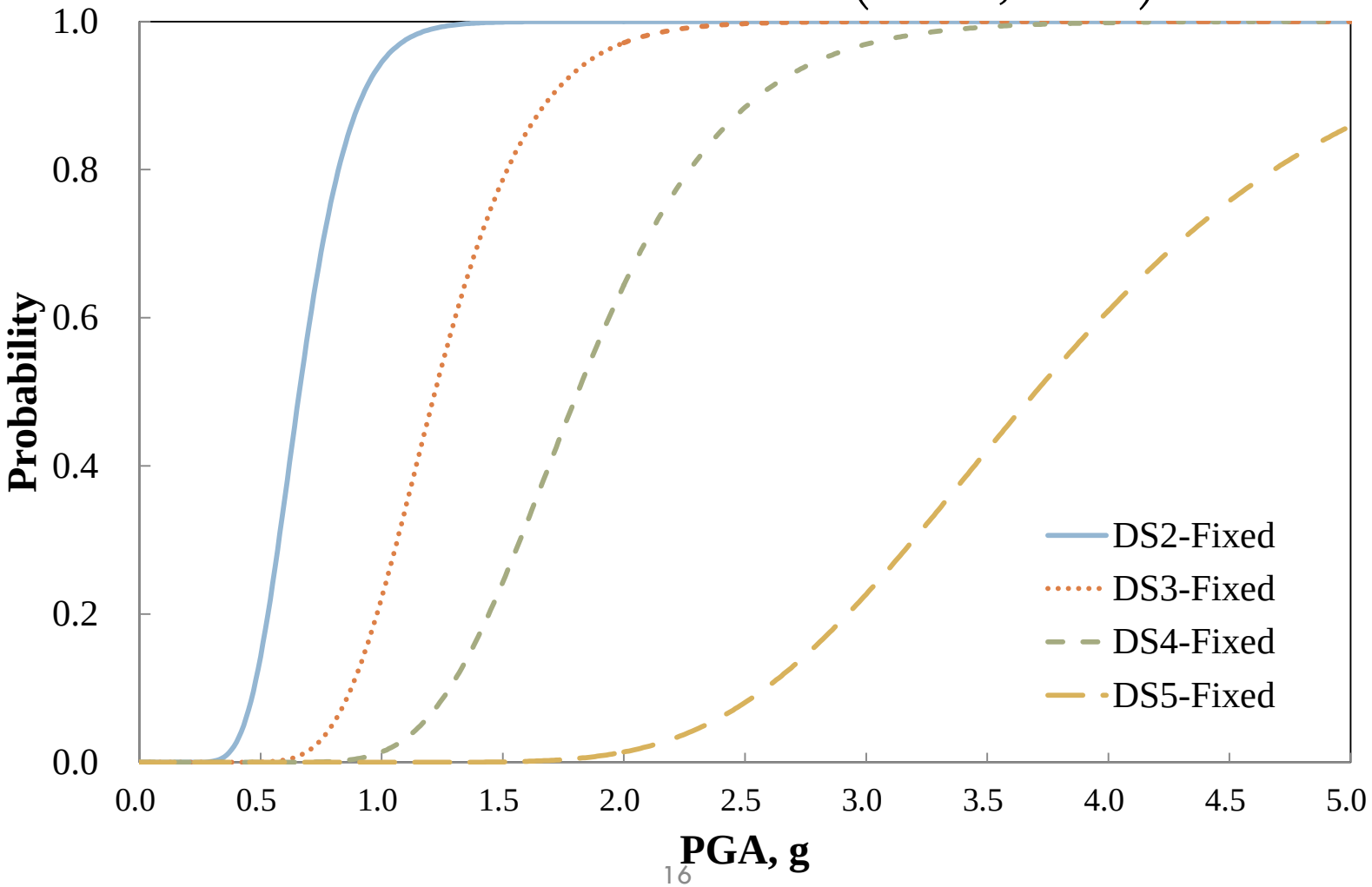


- According to Hurlbut (1985)
- Crack initiation @ 125με
- Limit state defined by concrete strain

Limit State	Damage Level	Concrete Strain
DS1	No damage	< 125με
DS2	Minor damage	125με
DS3	Moderate damage	250με
DS4	Major damage	375με
DS5	Complete damage	500με

LNG 저장탱크의 지진취약도(3)

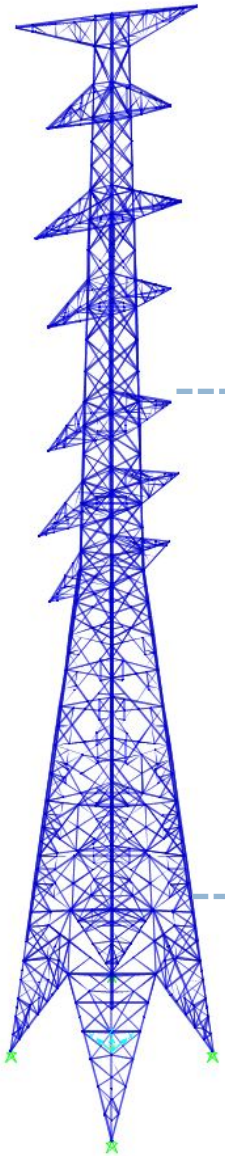
- Lognormal assumption $P = \Phi\left(\frac{\ln PGA - \ln c}{\zeta}\right)$



송전철탑의 지진취약도

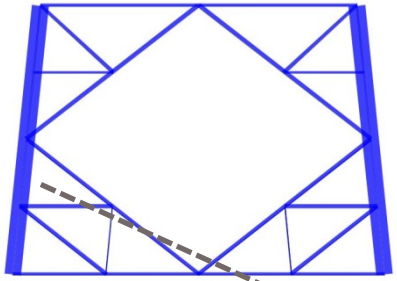
Sichuan Earthquake (2008)

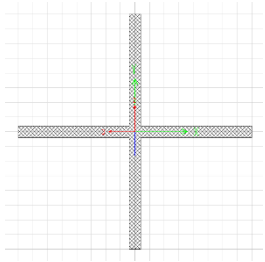
송전철탑의 지진취약도

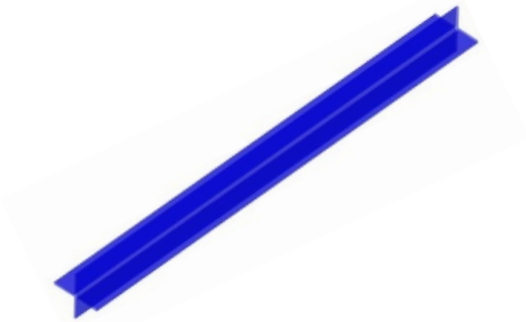


345kV Angle type

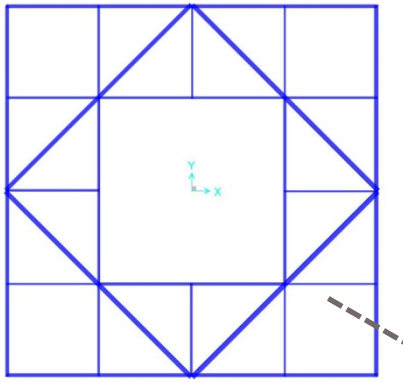
Scale : 122.8m / 19.8m

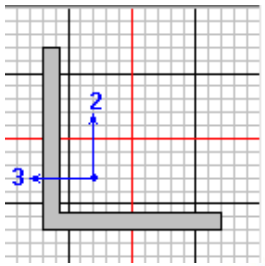


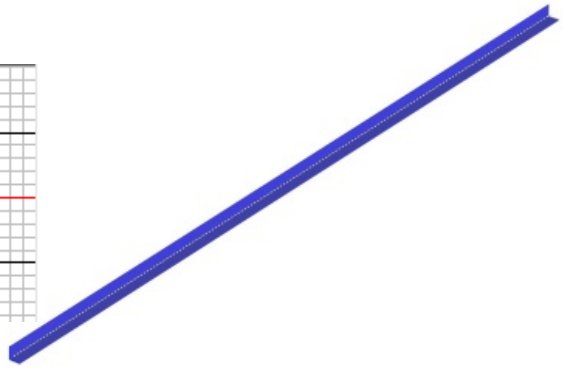




Main frame (cross) : Beam



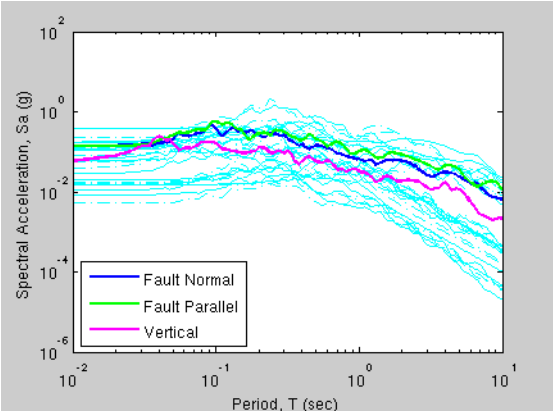




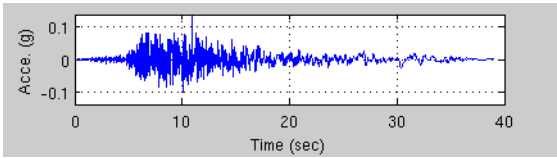
Brace (angle) : Truss

송전철탑의 지진취약도

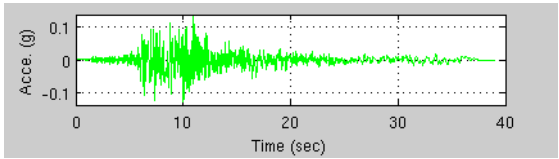
PEER NGA Strong Motions



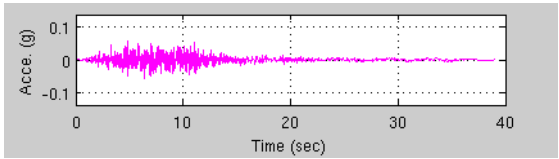
Global X-dir

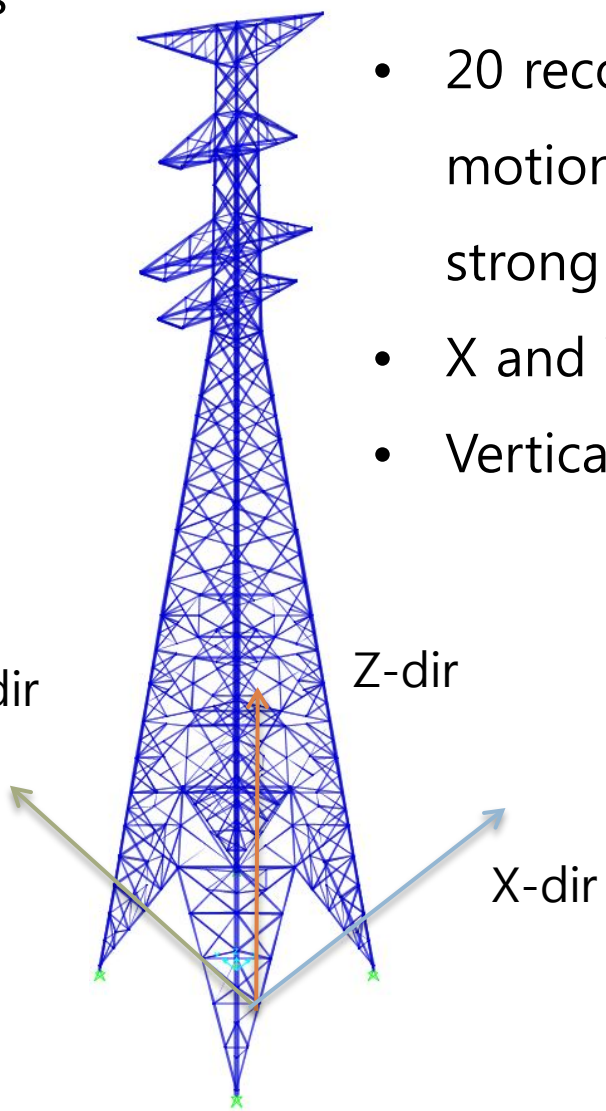


Global Y-dir



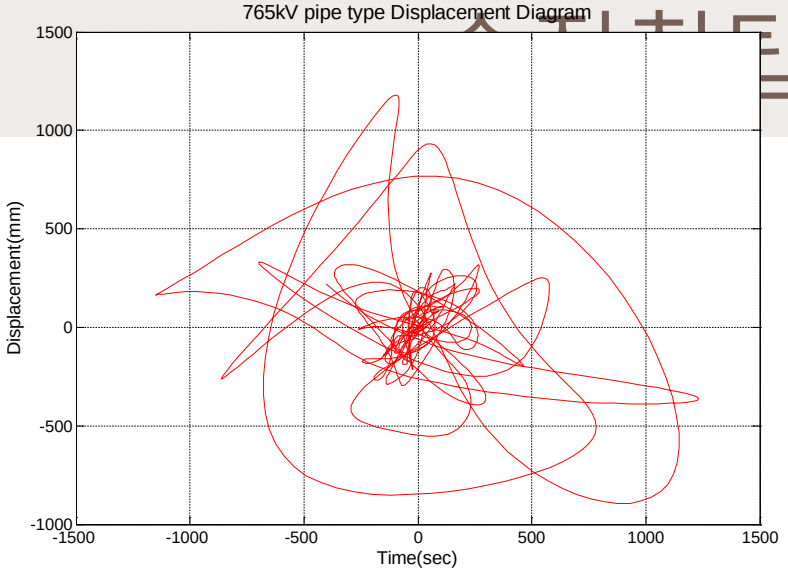
Global Z-dir.



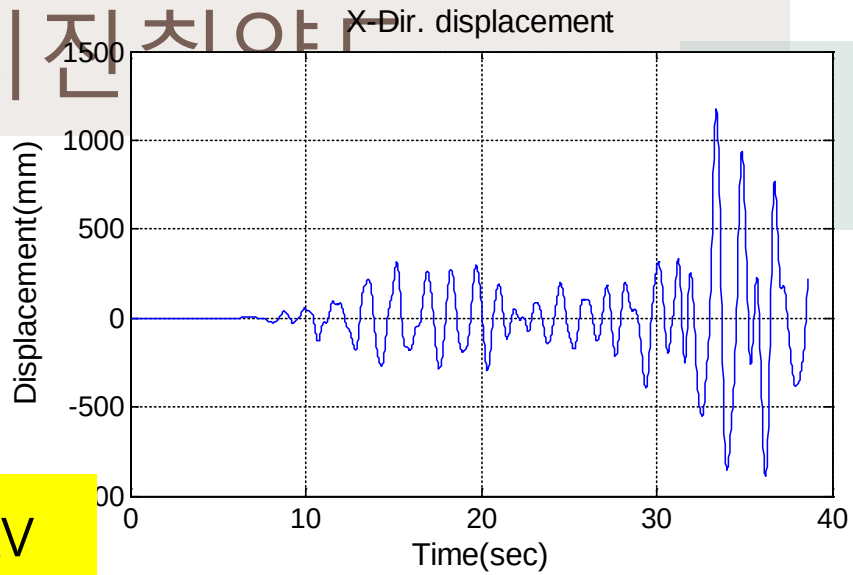


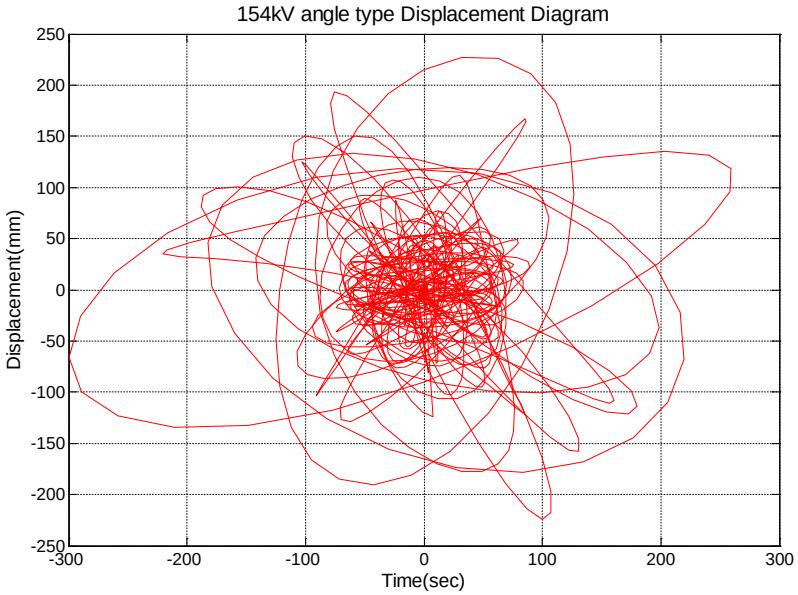
- 20 recorded ground motions from PEER NGA strong motion database
- X and Y directions in plane
- Vertical motion

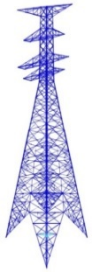
철탑의 지진응답



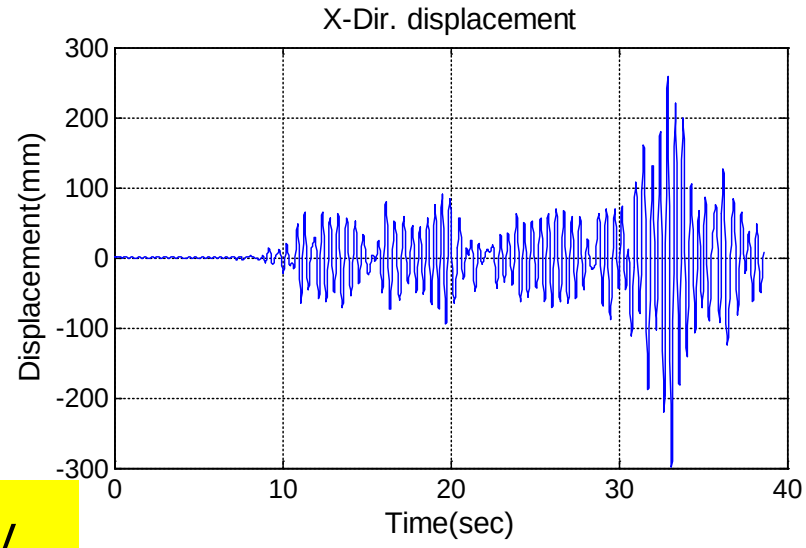
345 kV



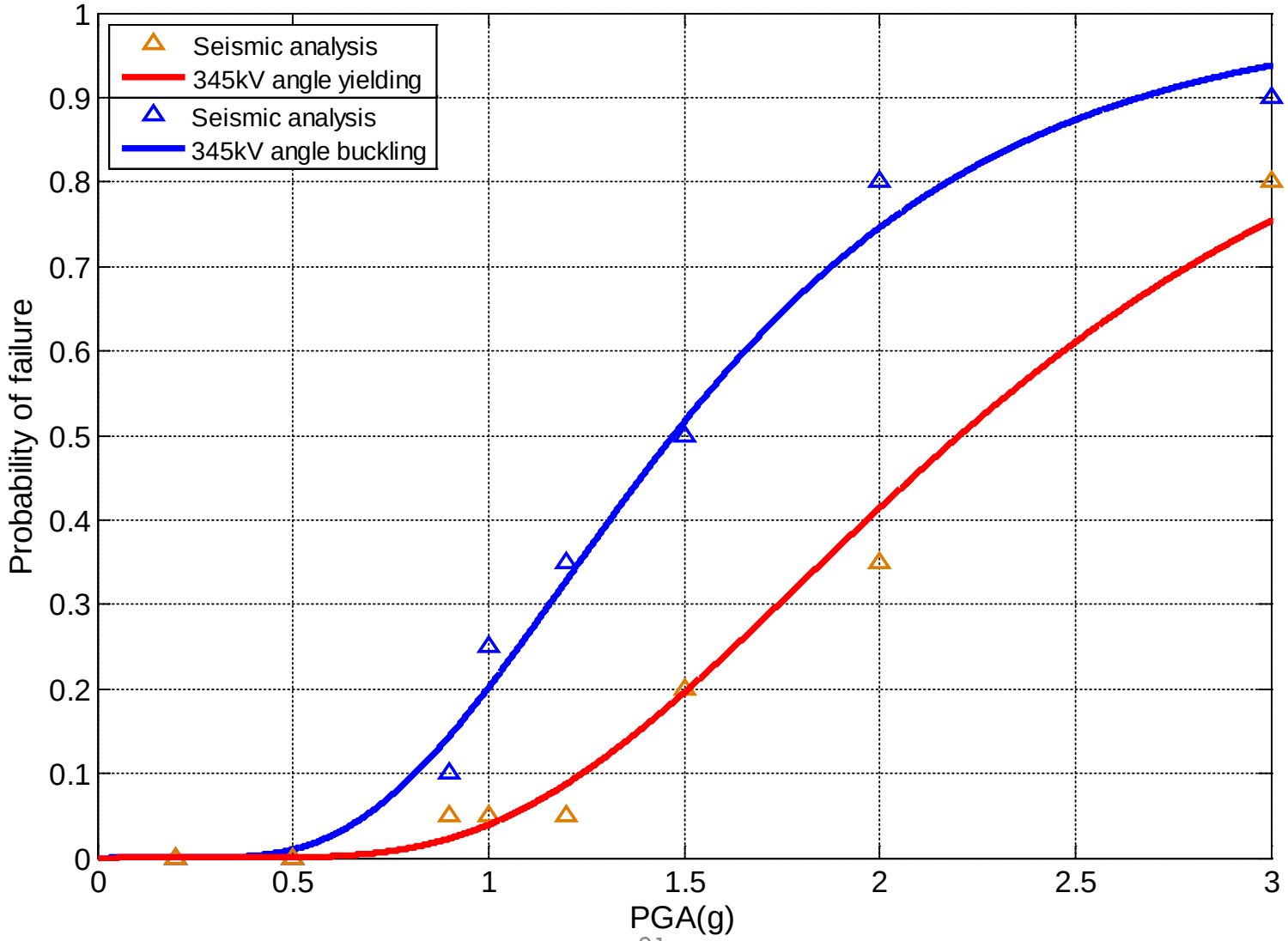




154 kV



송전철탑의 지진취약도

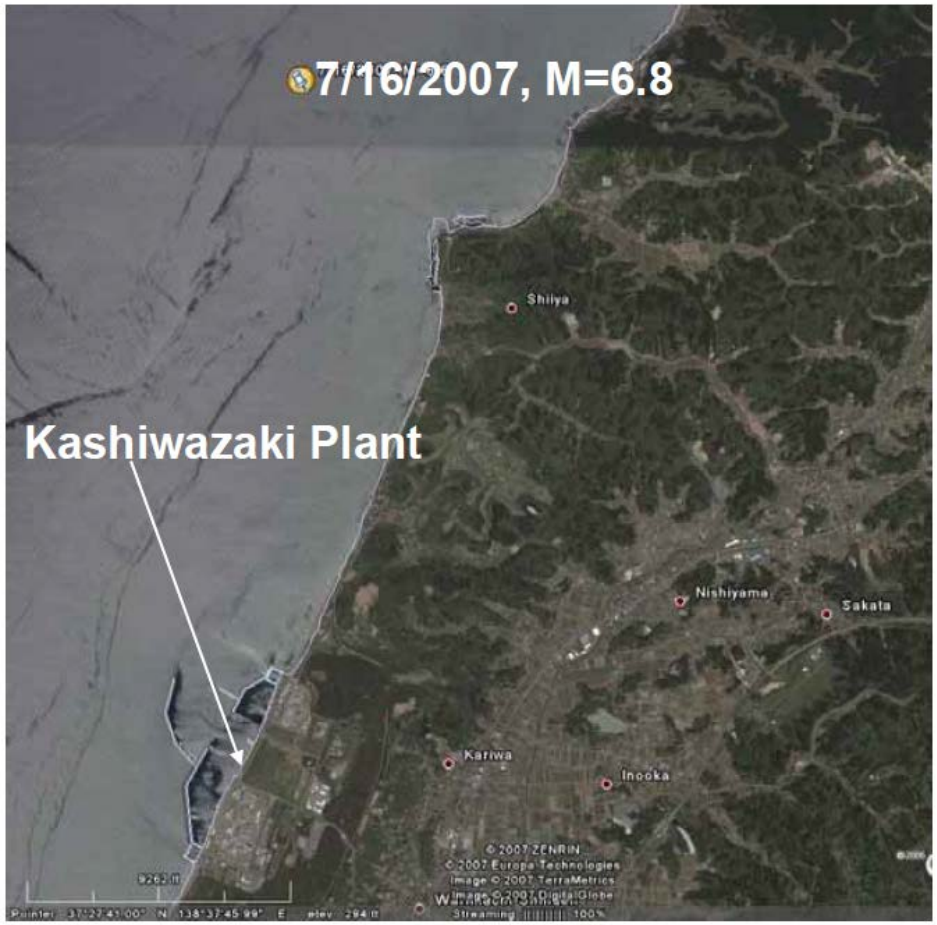

Seismic analysis
345kV angle yielding
Seismic analysis
345kV angle buckling
Probability of failure
PGA(g)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5
3

일본 가시와자키 가리와 원전 사례

대형지진에 대한 원전안전성 사례

일본 가시와자키 가리와 원전 사례

- 지진 발생
  - 발생시각: 2007년7월16일
  - 규모: 6.8 추정
  - 진앙지: 가시와자키 가리와 원전에서 16 km



일본 가시와자키 가리와 원전 사례

- The maximum observed at K-1: 680 gal against the design value of 273 gal.

(Preset level of reactor scram: horizontal: 120Gal, vertical: 100Gal)

unit	Commercial Operation / reactor Type / Rated Power (MWe)	Status prior to the Earthquake	Observed Gal / Design base (at the lowest level of R/B)		
			South-North	East-West	Vertical
K-1	Sep.'85 / BWR5 / 1100	In an outage	311 / 274	680 / 273	408 /(235)
K-2	Sep.'90 / BWR5 / 1100	Starting up	304 /167	606 / 167	282 /(235)
K-3	Aug.'93 / BWR5 / 1100	Operating	308 /192	384 / 193	311 /(235)
K-4	Aug.'94 / BWR5 / 1100	Operating	310 / 193	492 / 194	337 /(235)
K-5	Apr. '90 / BWR5 / 1100	In an outage	277 / 249	442 / 254	205 /(235)
K-6	Nov.'06 / ABWR / 1356	In an outage	271 / 263	322 / 263	488 /(235)
K-7	July '07 / ABWR / 1356	Operating	267 / 263	356 / 263	355 /(235)

- 1호기 부지에 설계기준 대비 2.5배의 지진동이 발생함, 그 외 호기에서도 설계기준을 초과하는 지진동이 부지에 발생함 (2호기에서는 최대 3.6배까지 발생)

일본 가시와자키 가리와 원전 사례

KK Plant Independent Seismic Peer Review

- **Peer Review Team - October 2007 KK Plant Review and Walkdown**
- **Mr. Greg Hardy** – Peer Review Team Leader, Earthquake Experience, Seismic Margins, SPRA
- **Mr. Jerry Kernaghan** – EPRI Project Manager, Nuclear Systems, Components, Plant Start-Up
- **Dr. Jim Johnson** – Seismic Design, Analysis and Response
- **Mr. Bill Schmidt** – Seismic Experience, Nuclear Plant Engineering, EPRI 6695 Author

✓ 미국 EPRI 주도의 점검 결과 (1호기 및 7호기): 안전관련 SSC에는 손상이 발생하지 않음

– **No Significant Damage Found for Any of the Safety Related SSCs Reviewed – Robust Seismic Designs**

일본 가시와자키 가리와 원전 사례

✓ 지진 발생후 발전소의 자체점검 결과 : 안전정지, 비상전력, 냉각, 격납기능은 정상적으로 작동되었으며 관련 SSC에는 손상이 없음

- Internal and external experts visually inspected the buildings, structures, and components related to "**shutdown**" "**cooling**" and "**containment**."
- After the Completion of the above, emergency diesel generators and emergency core cooling pumps were confirmed functionally operable

R/B Walkway, Unit 1

R/B Operating Floor, Unit 1

EDG, Unit 3

No damage that impaired functions was found.

맺음말

- 기간시설물의 지진취약도 평가 사례
  - LNG 저장탱크
  - 송전철탑
- 대형지진에 대한 원전안전성 사례
  - 가시와자키 가리와 원전의 사례
- 내진설계된 기간시설물은 설계기준 초과지진에 대해서도 내진성능을 보유할 가능성이 있음
- 대형지진에 대한 기간시설물의 내진성능은 전문가의 정밀한 해석에 근거해야만 함