

Seismic Effects on Water Infrastructure

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May 8, 2013



Water Infrastructure Elements

- Dams and Reservoirs
- Tanks
- Pipelines
- Treatment Facilities
- Buildings
- Non-structural Components

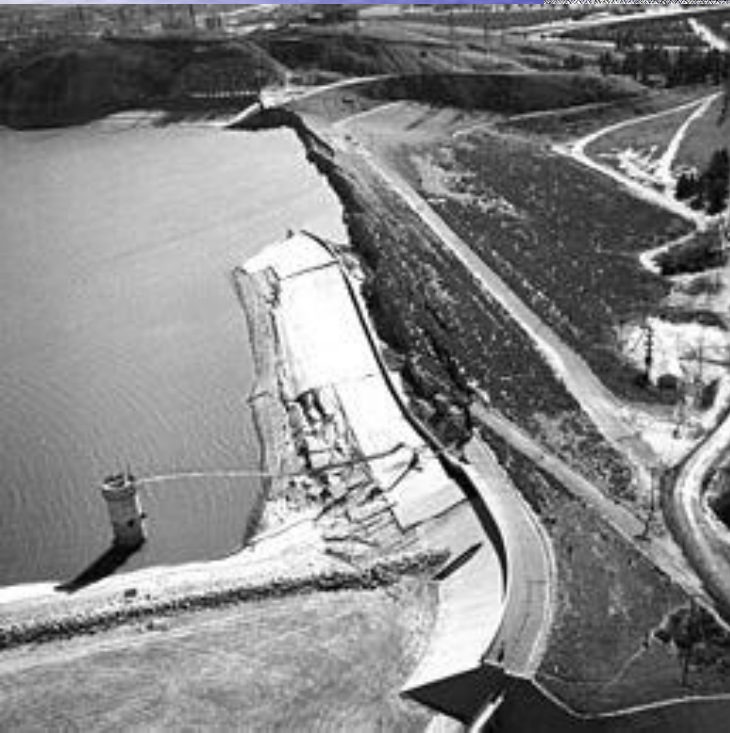
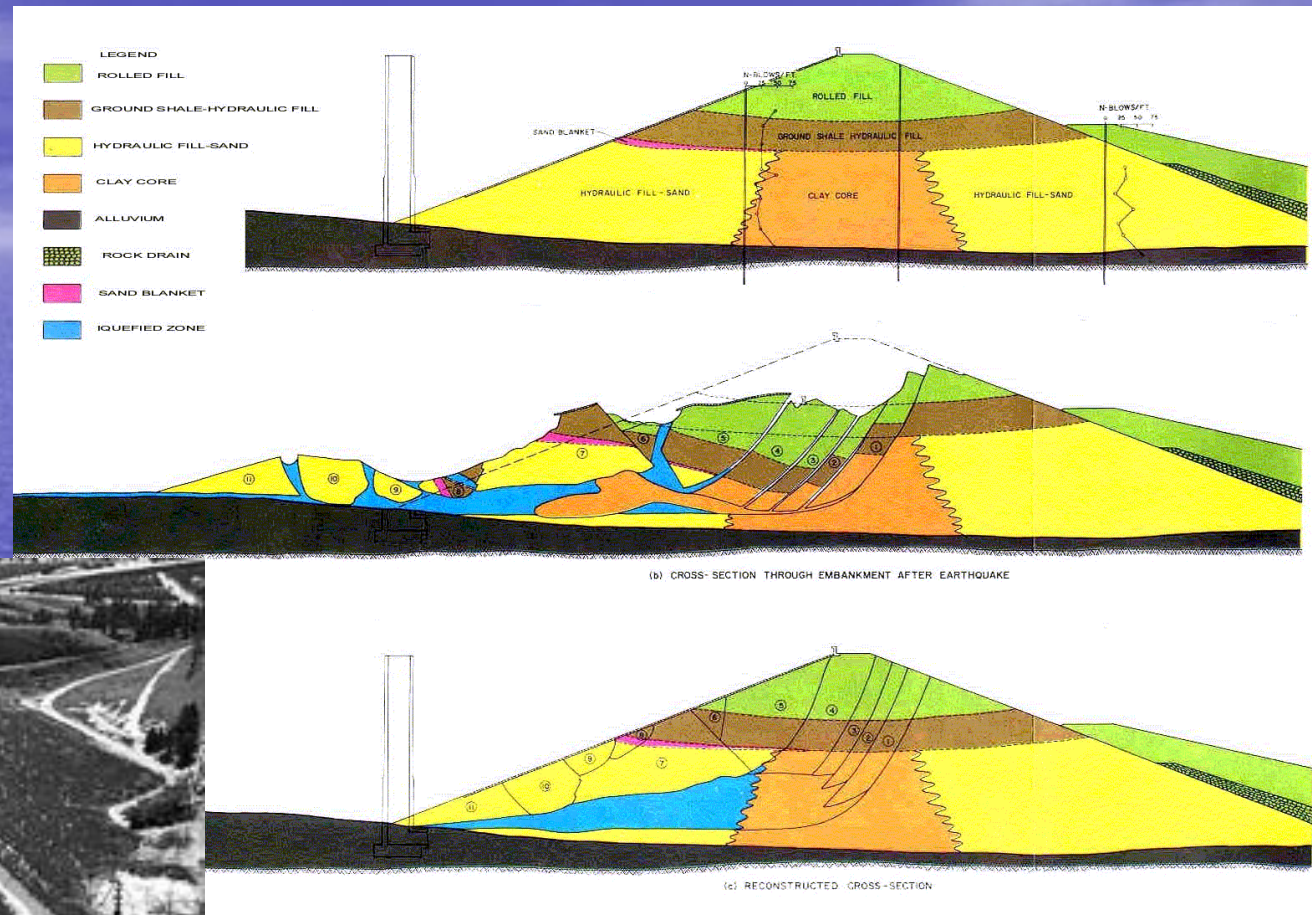
Seismic Hazards

- Ground Shaking
- Liquefaction
- Fault Rupture
- Landsliding

Dams and Reservoirs

- Liquefaction
 - Collapse of Dam Crest

Lower Van Norman Dam Failure



- Liquefaction of hydraulically placed fill

Dam Failure - Liquefaction



San Fernando Earthquake, 1971

Cracking along the top of the embankment



Lake Youngs, Nisqually Earthquake, 2001

Severe cracking in the Fatehgadh Dam, India 2001



Dams and Reservoirs

- Fault Rupture

Dam failure as a result of fault rupture



Chichi, Taiwan, 1999



Dams and Reservoirs

- Landslides

Slide near Masonry Dam resulted in water quality issue (2001)



Turbidity due to landslide in the Bull Run Reservoir, Portland



Landslide Destroys Access

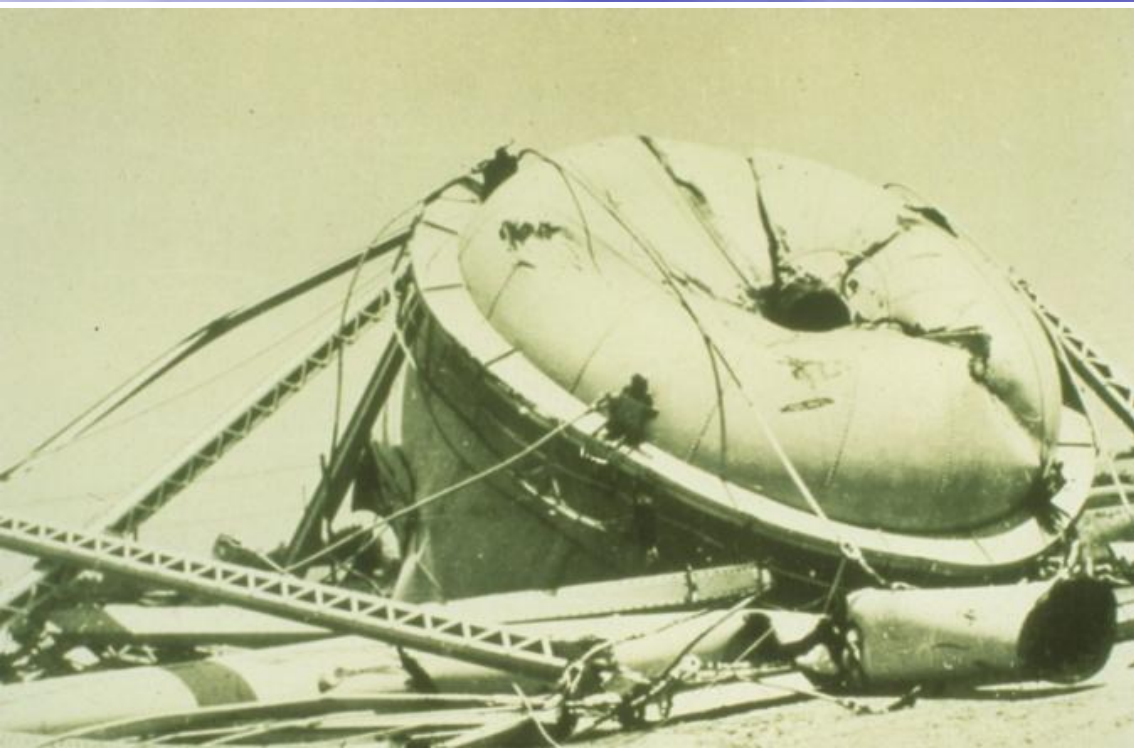
Japan, 2011



Tanks

- Ground Shaking
 - Elevated Tank Collapse
 - Differential Movement between tank and connecting piping
 - Water sloshing

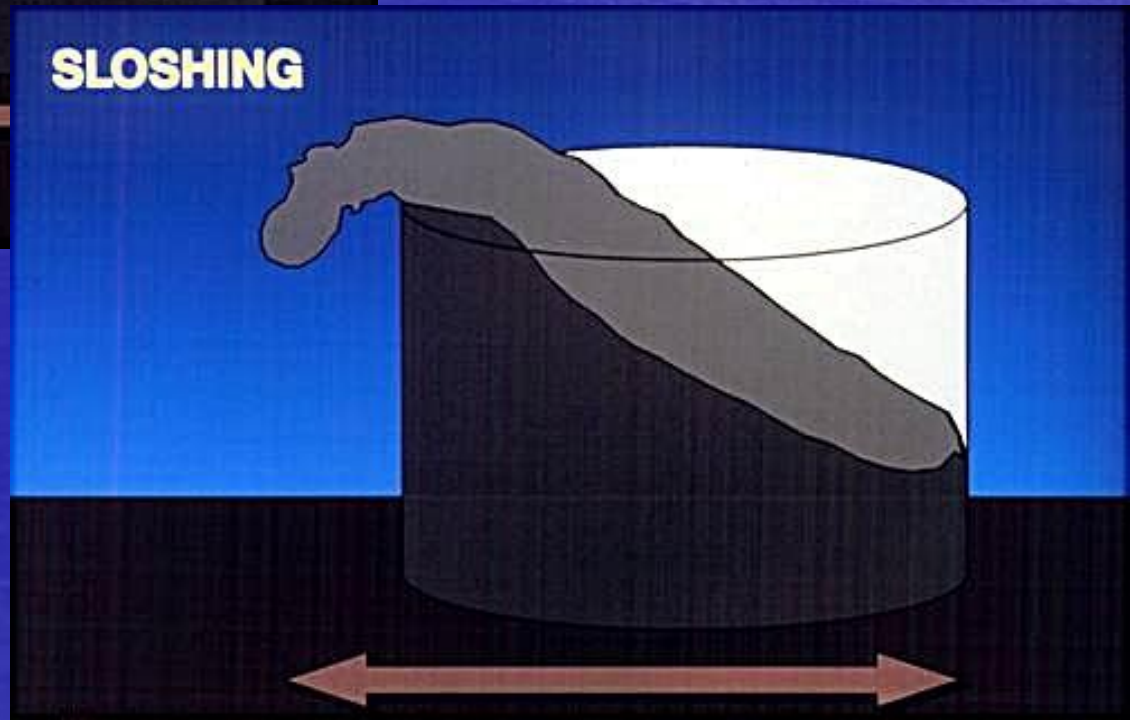
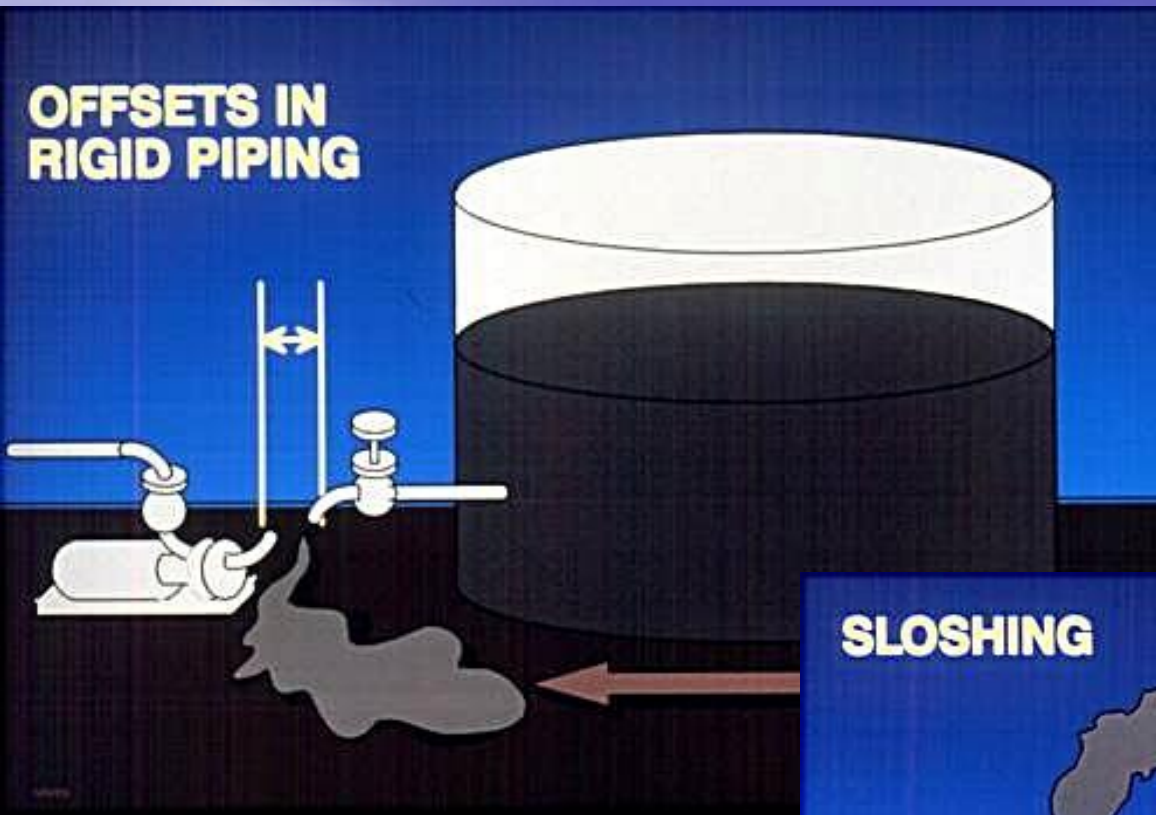
Elevated Tanks Collapse



Sapporo Brewery



Tank Failure Modes



Tank Moves and Breaking Connection Piping



Landers 1992

Roof Damage from Sloshing



1 MG Tank, Calexico, 2010



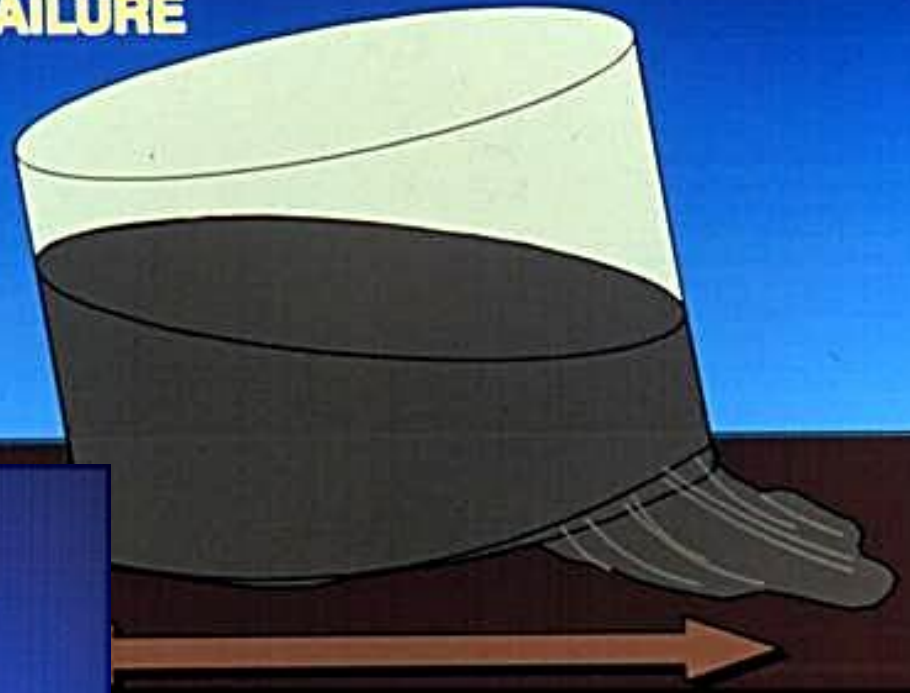
Contents Sloshing out



Chile, 2011

Tank Failure Modes

**FLOOR-SHELL
JOINT FAILURE**



**SHELL
BUCKLING**



Tank Damage – Elephant Foot Buckling

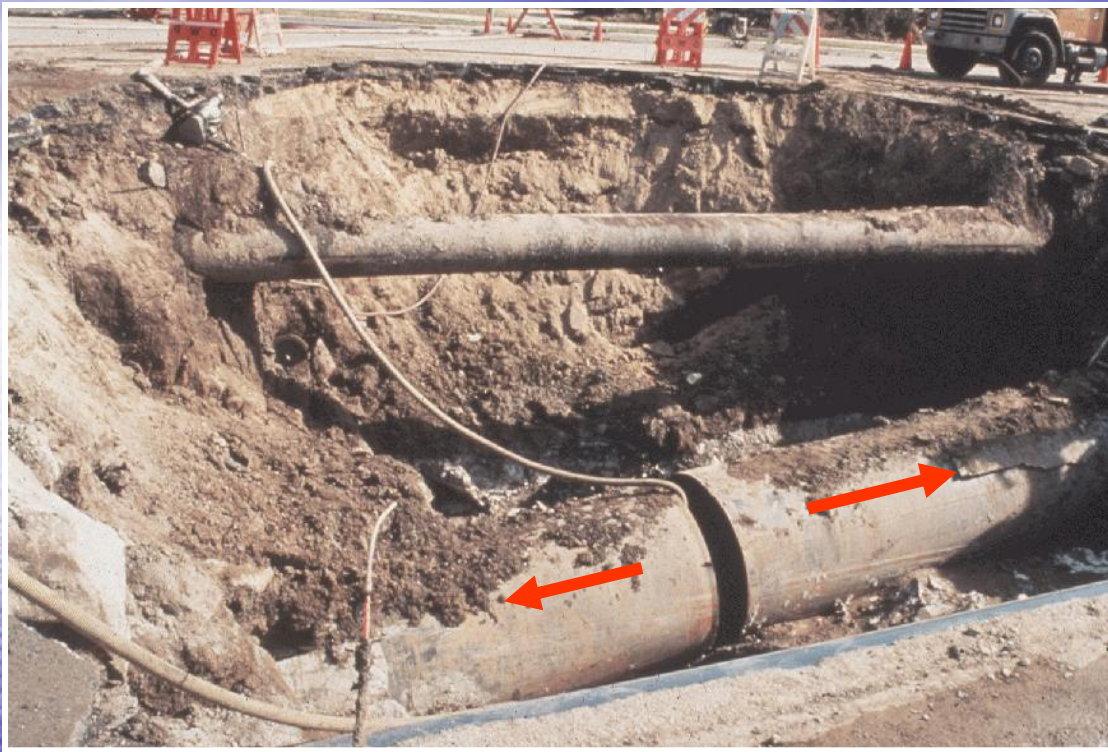


Pipelines

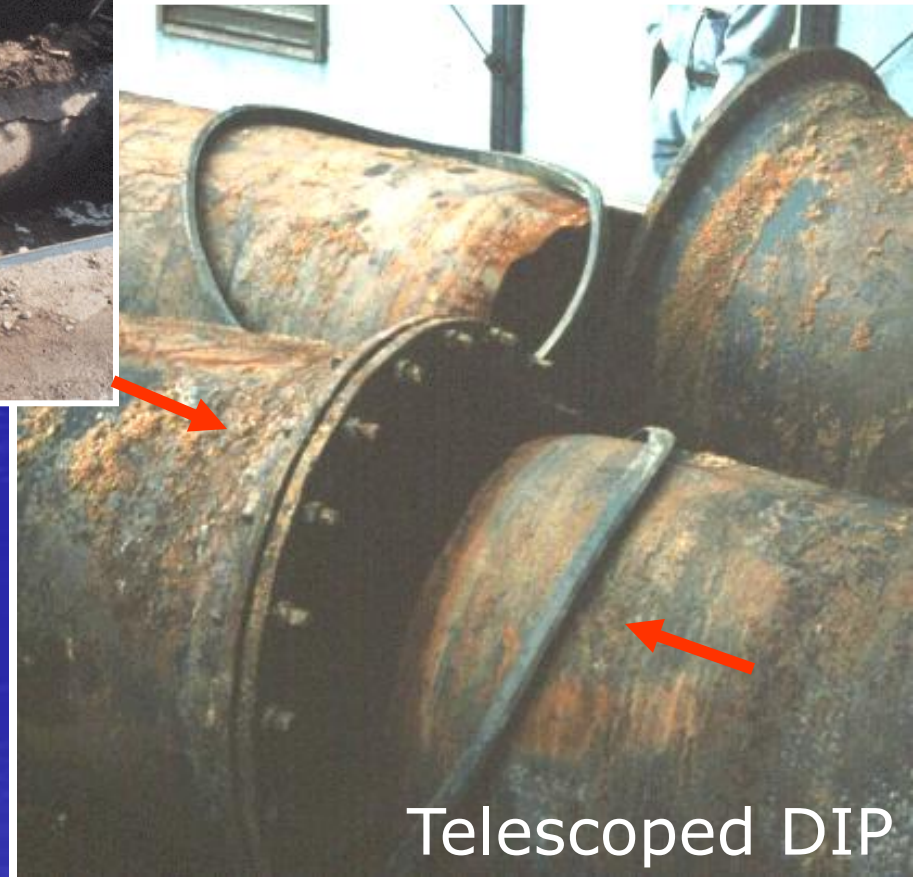
- Liquefaction, Ground Motion
 - Joint Pull Apart
 - Pipe shear
 - Pipe Telescoping

Joint Failure Mechanisms

Kobe, Japan 1995



Northridge, 1998



Telescoped DIP

Joint Pull Out - Kobe, Japan, 1995

Over 1/2 of the failures were due to joint pull out. Pipeline damage rates for the Kobe earthquake are shown in the table below.



Failure Mode	Failure Rates/km - Number of Failures									
	DIP		CIP		PVC		Steel		AC	
PipeLength (km)	1874		405		232		30		24	
Barrel	0	9	0.63	257	0.38	88	0.33	10	1.24	30
Fitting	0	1	0.31	124	0.17	40	0.03	1	0.04	1
Pulled Joint	0.47	880	0.49	199	0.33	76	0	0	0.37	9
Joint Failure	0	2	0.06	25	0.5	115	0.07	2	0.08	2
Joint Intrusion	0	5	0	1	0.01	3	0	0	0	0



Kobe - Lateral Spread Resulting in Pulled Joint

Lateral spreading resulted
in DIP joint separation



Pipe Failure Mechanisms



Pipe shortening



Pipe Failure Mechanisms



Kobe Japan, 1995

Sheared steel pipe

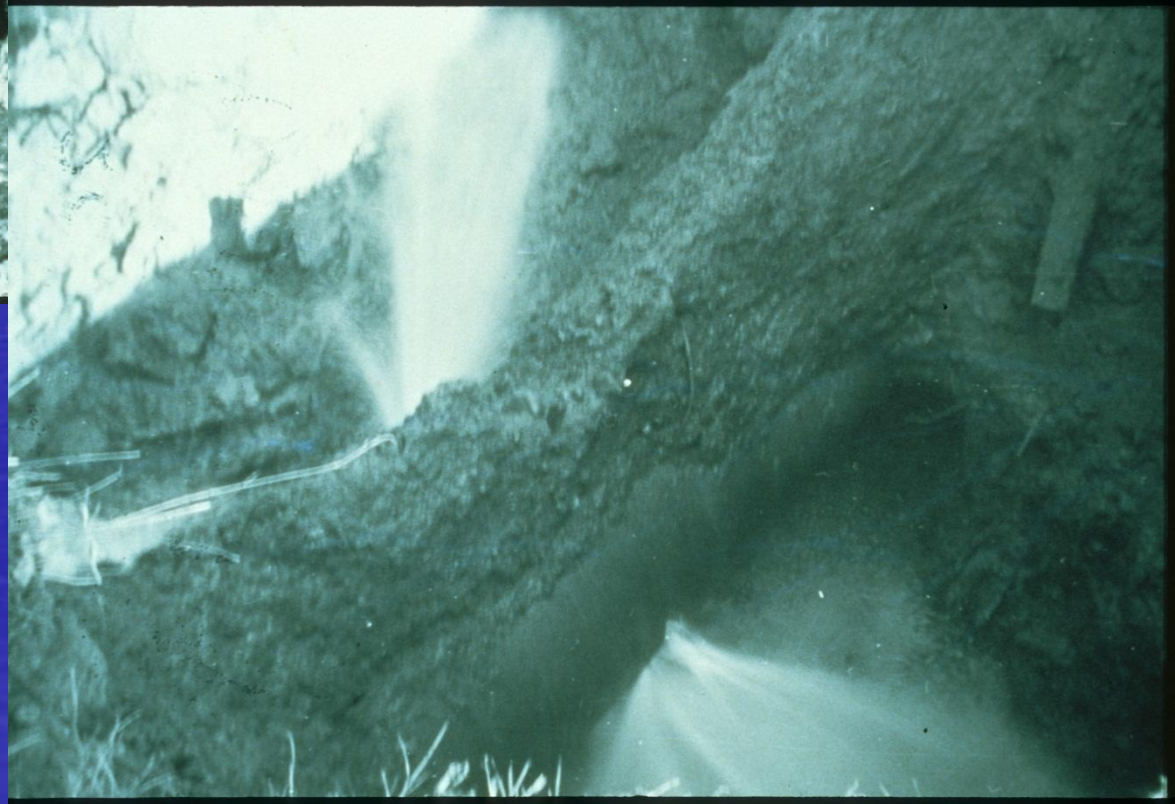


Burst CIP

20" CI Main at Western & Spring



36" CCP on East Side Supply Line



Pipe on Bridges



Chile, 2011



Due to bridge collapse or settlement of abutment.



Wells

- Liquefaction induced lateral spreading bends casings
- Settlement of soil around casing
- Loss of power
- Pump damage
- Connecting pipe damage

Dagupan, Philippines, 1990

Damage from Adjacent Utilities

Floating Sewer facilities
break adjacent water mains



Christchurch,
2011

Sendai, 2011



Liquefaction – Flotation

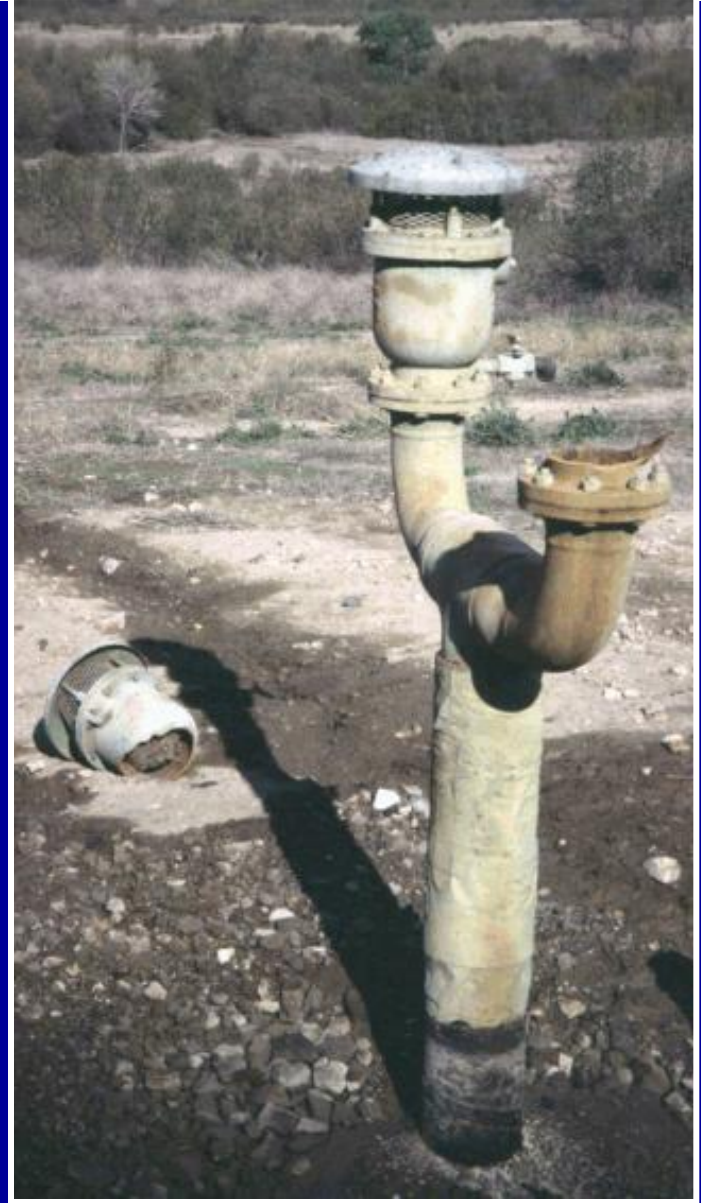


Trench liquefies,
native does not,
sewer main floats,
water services
break

Pipelines

- Hydraulics
 - Water Hammer
 - Vacuum collapse

Water Hammer



Pipe Collapse



Pipe collapse due to internal vacuum.

Pipelines

- Landslides

Pipeline damaged by landslide



Treatment Facilities

- Ground Shaking
- Sloshing

Treatment Facilities – Tilt-Up Buildings



Northridge, 1994

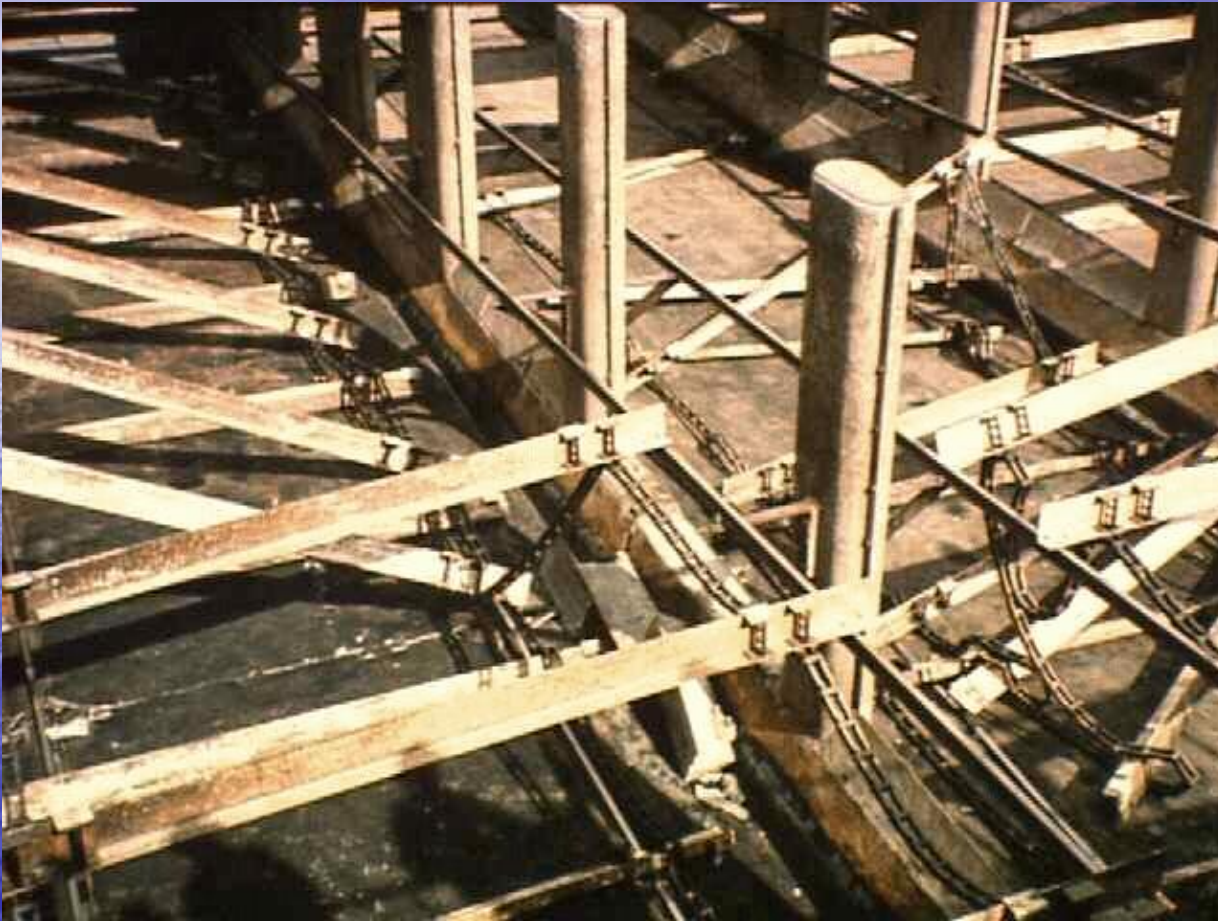
Treatment Facilities – Basins



Jensen WTP 1994
Sedimentation Tank
Damage

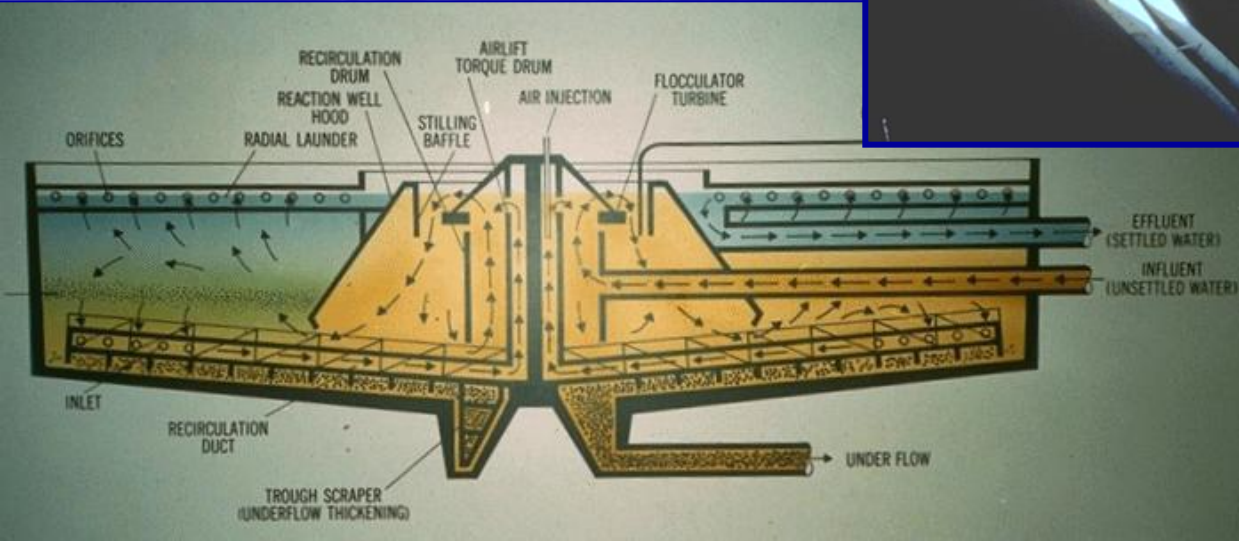
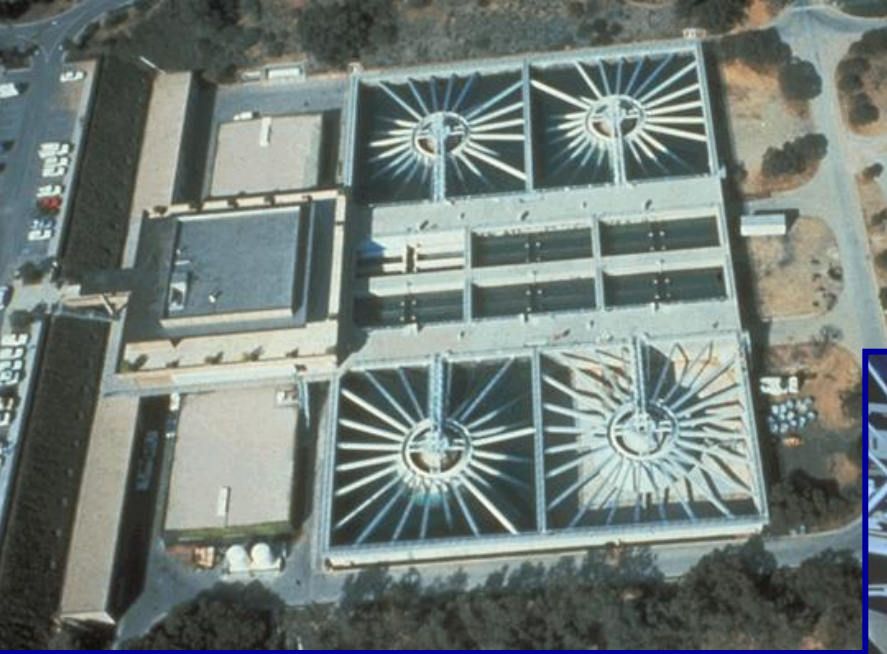


Treatment Facilities – Submerged Equipment



Sedimentation tank
sludge scrapers
dislodged.
Higashinada
WWTP, Japan 1995

Treatment Facilities – Submerged Equipment



Rinconada
Treatment Plant
SCVWD, 1989

Treatment Facility and Non-Structural Elements

- Liquefaction

Treatment Facility - Liquefaction



Kanigawa WTP,
Tohoku, 2011

Site Piping Sheared Off

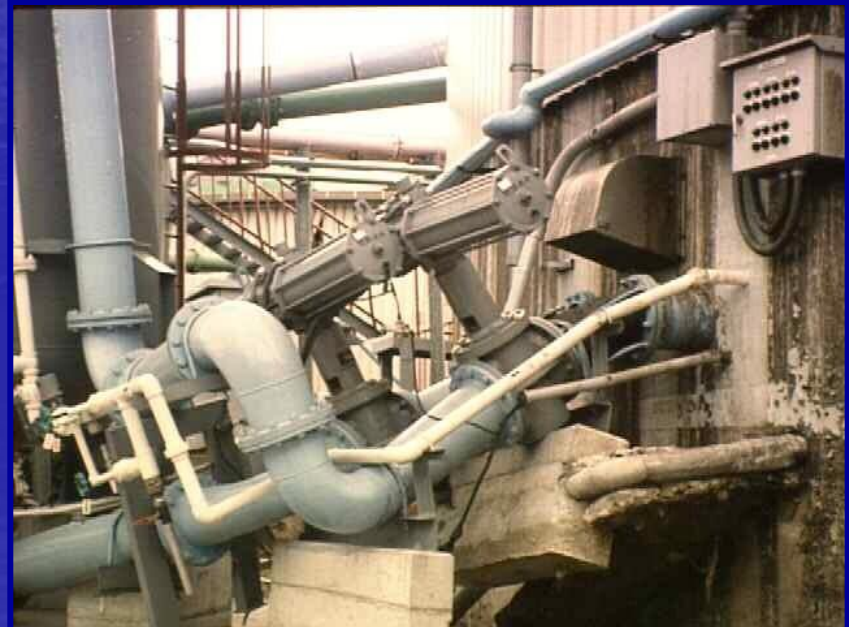


Treatment Facility - Liquefaction



Higashinada WWTP, KObe Japan, 1995.
2 meters lateral and 1 meter vertical movement

Higashinada WWTP Liquefaction



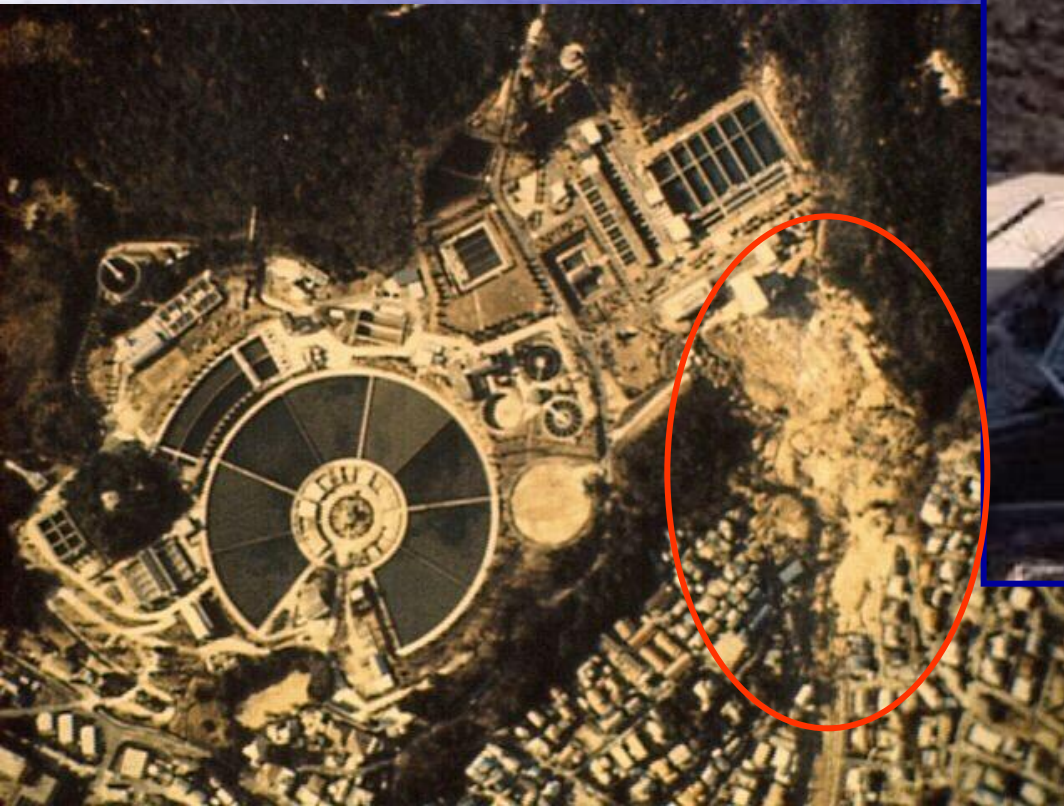
Higashinada WWTP Liquefaction

Pile failure under end of aeration
basin



Treatment Facilities - Landslides

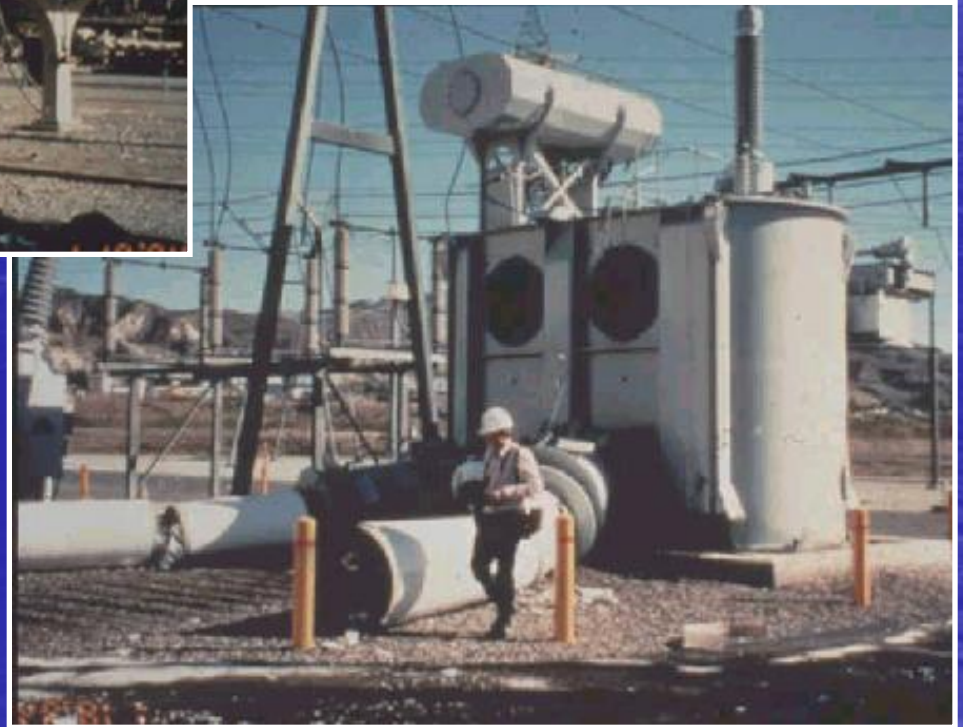
Hanshin WTP Kobe
Japan, 1995



Non Structural Elements

- Ground Shaking

Electrical Equipment



Electrical Equipment – Motor Control Centers



Vibration Isolators



Battery Racks



Storage Overhead



Shelving





Questions ?