Seismic Resilience in Pipeline Design

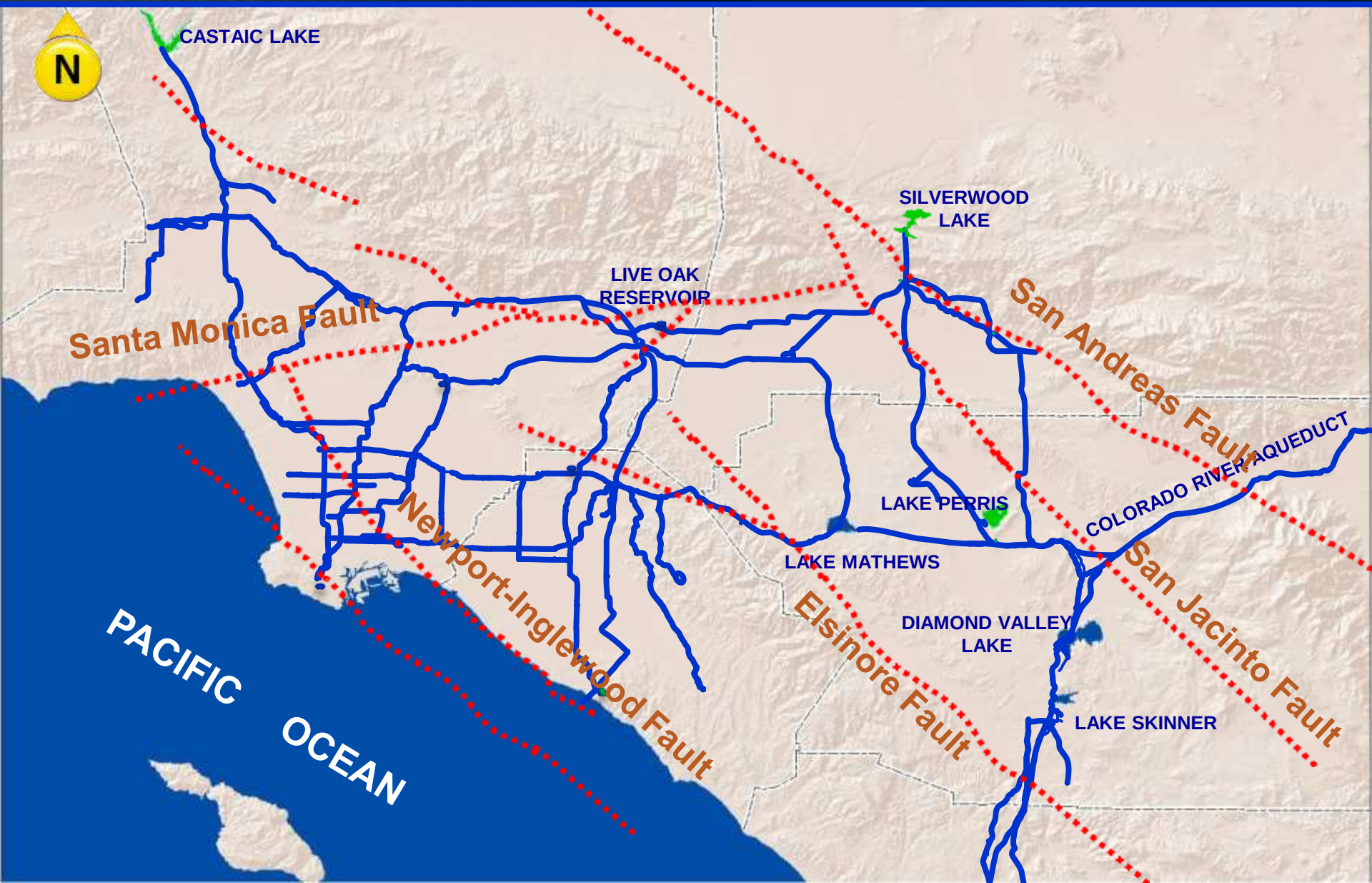
Engineering and Operations Committee
Item 6a, Part 2
November 13, 2017

Outline

- Seismic Setting
- Evolution of Seismic Design
- Recent Technological Advancements
- Planned Design Approach

Background

Faults in Southern California



Seismic Hazards for Buried Pipelines

1971 San Fernando Earthquake

Shaking

Leading to Pipe Joint Failure

Fault Crossing

Leading to Pipe Rupture

1992 Landers Earthquake

Seismic Hazards for Buried Pipelines

1994 Northridge Earthquake

Liquefaction
Leading to Pipe Rupture

Slope Failure
Leading to Pipe Rupture

1989 Loma Prieta Earthquake

Evolution of Seismic Design

- Buildings
  - 1927 - Uniform Building Code (1st edition) contained Seismic Design Appendix
  - 1971 - Metropolitan initiated seismic assessment & upgrade program for individual facilities
- Pipelines
  - 1930's - Metropolitan initiated seismic guidelines
  - 1974 - ASCE Technical Council on Lifeline Earthquake Engineering formed
    - 1984 - ASCE published "Guidelines for Seismic Design of Oil and Gas Pipeline Systems"

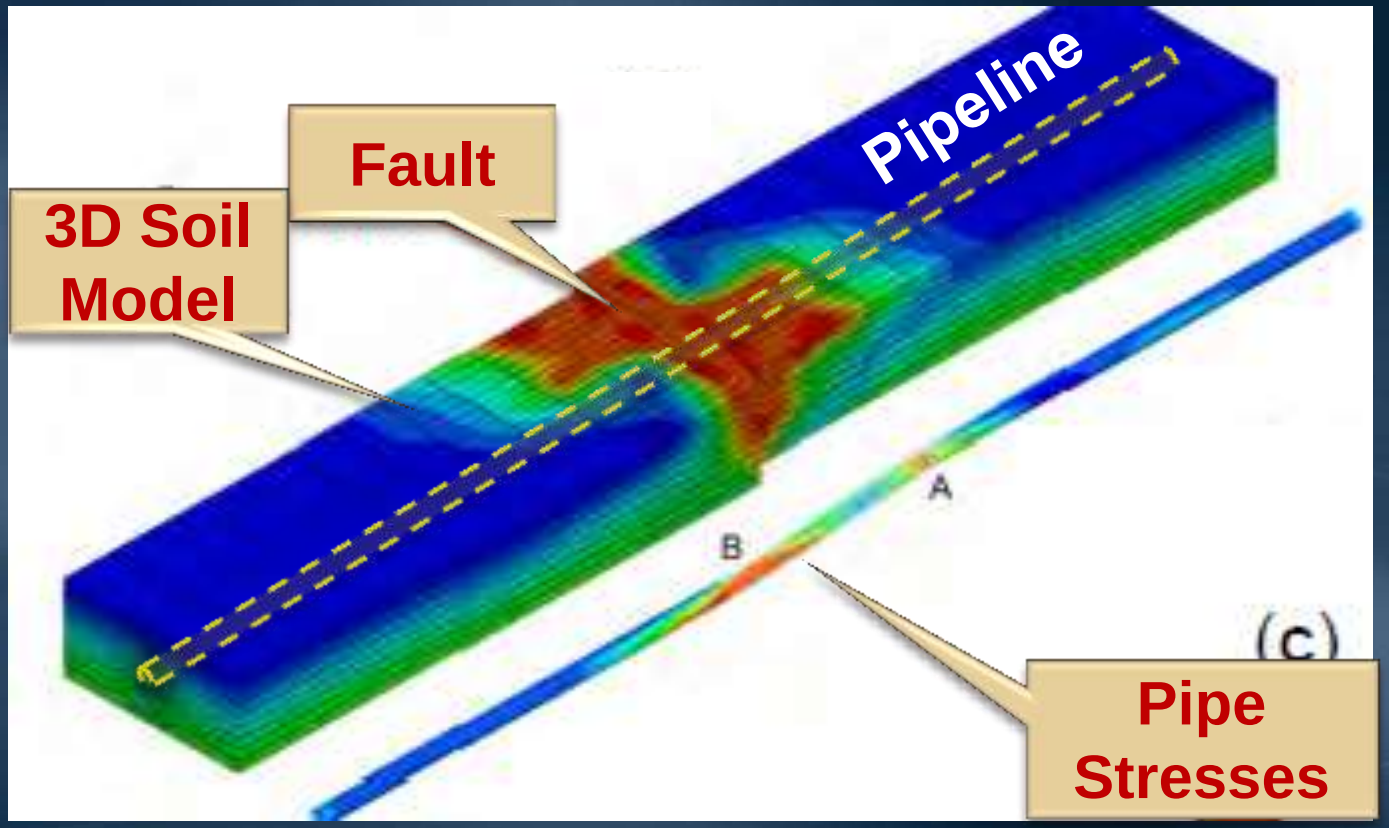
Evolution of Seismic Design

- Pipelines (cont.)
  - Early 2000's – Metropolitan initiated vulnerability assessments of distribution system
    - Expanded seismic upgrade program to vulnerable pipelines
  - Recent developments
    - Improved techniques to analyze response of structures, pipelines & ground shaking
    - Improved assessment & prediction of earthquakes
    - Increased post-earthquake data collection of ground motions & damage observations
    - Development & demonstrated performance of earthquake-resistant pipeline products

Recent Technological Advancements

Advanced Seismic Analysis

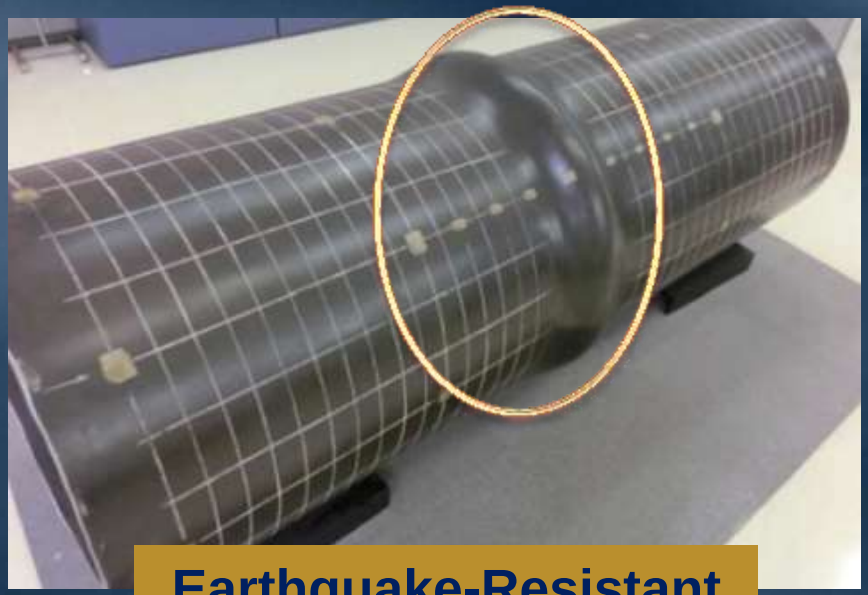
- Finite element modeling techniques
- Integrated soil-structure 3D modeling



Recent Technological Advancements

Earthquake-Resistant Pipe

- Absorbs energy during seismic events
- Has large deformation capacity to protect pipe & joint
- Supports pipeline after ground loss

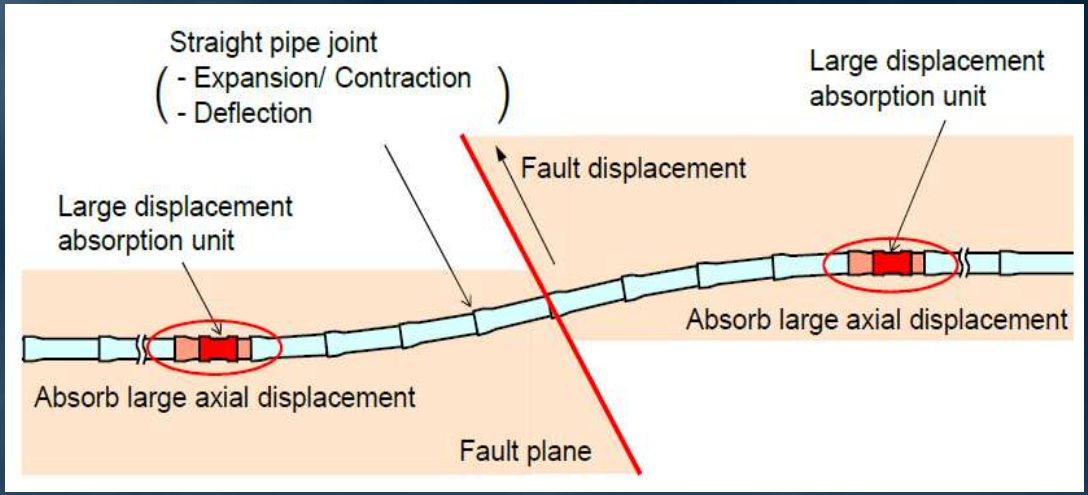


Earthquake-Resistant Steel Pipe by JFE

Earthquake-Resistant Ductile Iron Pipe by Kubota

Recent Technological Advancements

Earthquake-Resistant Pipe



Earthquake-Resistant Ductile Iron Pipe

Recent Technological Advancements

Earthquake-Resistant Pipe Installations

Santa Clara Valley Water District Seismic Retrofit

Load Test of 72-inch Pipe Joint

Recent Technological Advancements

Testing of Earthquake-Resistant Pipe System

Courtesy of Cornell University

Recent Technological Advancements

Testing of Earthquake Resistant Pipe System

Courtesy of Cornell University

Planned Design Approach

- New pipelines
  - Establish performance criteria
  - Identify seismicity & ground conditions along entire alignment
  - Design pipeline to:
    - Resist ground shaking
    - Accommodate ground deformation (such as fault displacement & liquefaction)
  - Consider earthquake-resistant pipe
  - Develop pipeline seismic design standards

Planned Design Approach

- Rehabilitation of exist. pipelines
  - Assess seismic risk of vulnerable pipelines
  - Incorporate seismic resilience as a component of rehabilitation programs
    - Evaluate each upgrade individually to balance risk, performance & cost
    - Enhances pipeline reliability economically over the long-term


THE METROPOLITAN WATER DISTRICT OF
SOUTHERN CALIFORNIA
1928