Berkeley Davis Hall Water System Earthquake Issues

John Eidinger
U.C. Berkeley M.Eng. 78, M.S. 1982, M.B.A. 1984

EERI
April 15 2024

The Speakers

David Fung, Berkeley Office of Emergency Services

Laurel Mathews, San Francisco

John Eidinger, G&E Engineering Systems

Anne Wein, USGS Moffett Field

Lisl, Berkeley Office of Emergency Services

John Eidinger

- 1971 - 1975: B.S. MIT
- 1975 - 1984: M.Eng, M.S., M.B.A. Berkeley
- 1978 - 1990: ABB
- 1991 - 2024: G&E
- Spent Years in Davis Hall, Room 504

Our SESM Professors, 1975 - 1976

Graham Powell	
Jack Bouwkamp	
Anil Chopra	
Bob Taylor	
Ed Wilson	
Jim Kelly	
Ray Clough	1920-2016
Vic Bertero	1923-2016
Karl Pister	1925-2022
Joe Penzien	1924-2011
Alex Scordelis	1923-2007
Igor Popov	1913-2001
TY Lin	1912-2003
Jerry Raphael	1912-1989
Frank Baron	1914-1994
High McNiven	1922-2009
William Godden	1923-2012
Borris Bresler	1918-2000
Milos Polivka	1917-1987


CAL


University of California
STRUCTURAL ENGINEERING
sesm
STRUCTURAL MECHANICS
BERKELEY

1975-1976 TA Reunion, SESM

Left to Right: John Eidinger, Bruce Maison, John Stanton, Len Cobb, Mark Ketchum, Jon Magnussson, Reinhard Ludke, John Hall

Guests: Ed Ong, Nancy Gavlin


Left to Right: Anil Chopra, Ed Wilson, John Eidinger, Jerry Sackman,
Bruce Maison, Mark Ketchum, John Hall, Reinhard Ludke, Jon
Magnusson, Bob Taylor, Len Cobb, John Stanton, Steve Mahin, Jim Kelly
University of California
STRUCTURAL ENGINEERING
sesm
STRUCTURAL MECHANICS
BERKELEY
CAL
April 27, 2013

Transmission Pipe, Lake Washington, Delivering Water to Mercer Island

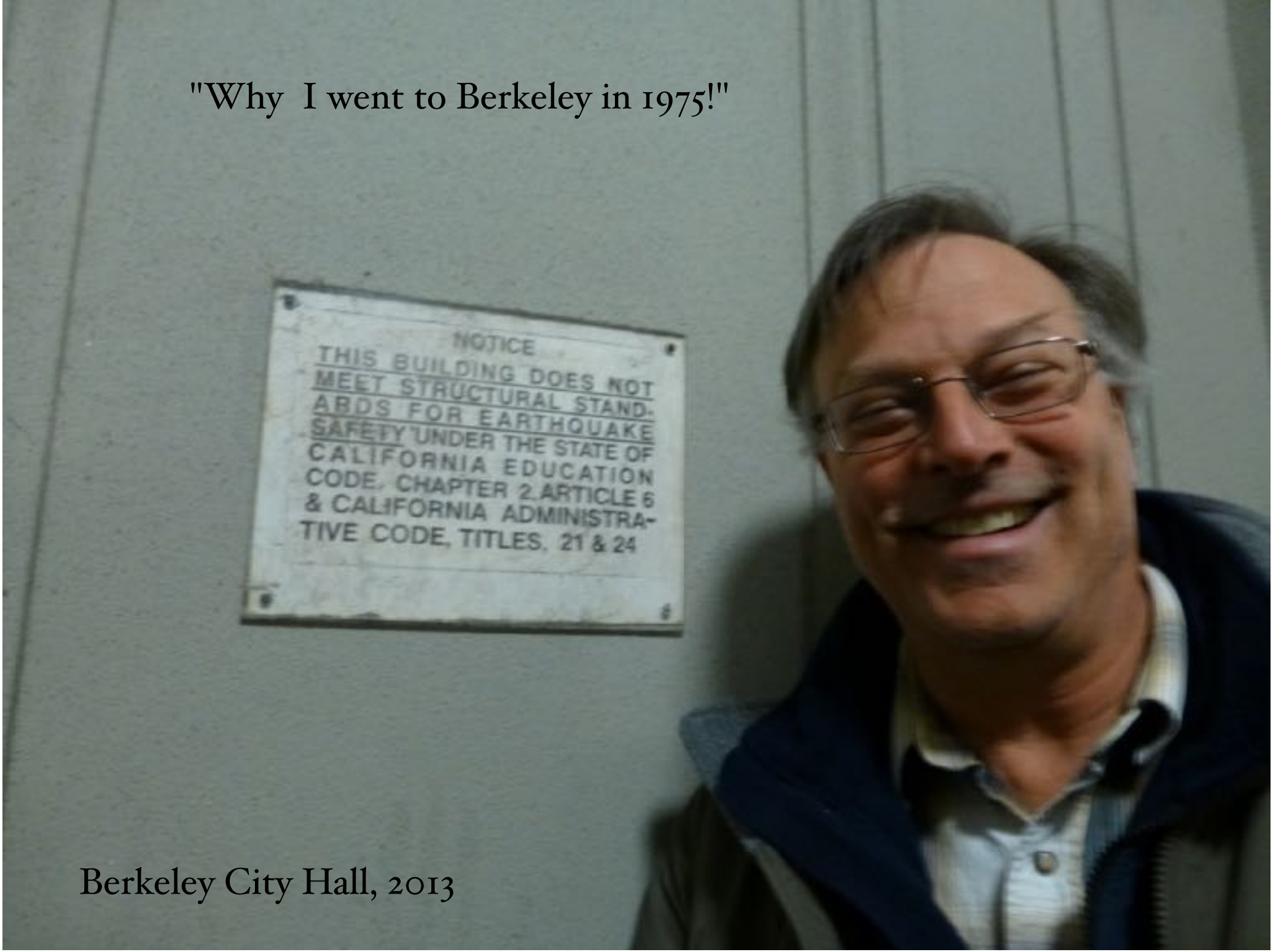
Hetch Hetchy Aqueduct Pipes, 1923 - 1933

The Biggest Hetch Hetchy Aqueduct Pipe, 1965

BDPL 4 Slip Joints at the Hayward Fault

Inside BDPL 4 Inspecting Slip Joints at the Hayward Fault

"Why I went to Berkeley in 1975!"



Berkeley City Hall, 2013

Agenda

- A Quiz
- Is the EBMUD Water System that Delivers Water to Davis Hall "Reliable" After Earthquakes?
- Some pictures to give you an idea

Today's Quiz. Given a nearby Hayward M 7.0, how long will the water be out on Campus at Davis Hall?. Assume Davis Hall has NO damage.

Outage Duration	Number of Students
0 Hours (no outage)	2 (8%)
1 - 4 Hours	2 (8%)
1 - 7 days	7 (29%)
1 week - 2 months	8 (33%)
Up to 1 year	5 (21%)
Total	24 (100%)

What You Should Take Away

- What's seismically weak in the Water grid?
- Is it worthwhile to seismically upgrade the Water grid?
- What can we (you) do about this?

What is the Most Common Type of Pipe that Delivers Water on Campus?


Steel Pipe
Broken Weld. Liquefaction, PGD ~ 4 inches
31.01.2010
Concepcion, Chile M 8.8, 2010


Steel Pipe
Pulled Apart Slip Joints (PGV about 20 cm/sec, no PGDs)
Tohoku, Japan M 9.0, 2011
March 11, 3:26 pm (t + 30 minutes)

Cast Iron Pipe

Kobe, Japan M 6.9, 1995


Asbestos Cement Pipe
Barrel Failure (PGV about 40 cm/sec, Liquefaction PGD about 2-3 inches)
Adapazari, Turkey M 7.7, 1999
9/7/1999

Prestressed Concrete Cylinder Pipe

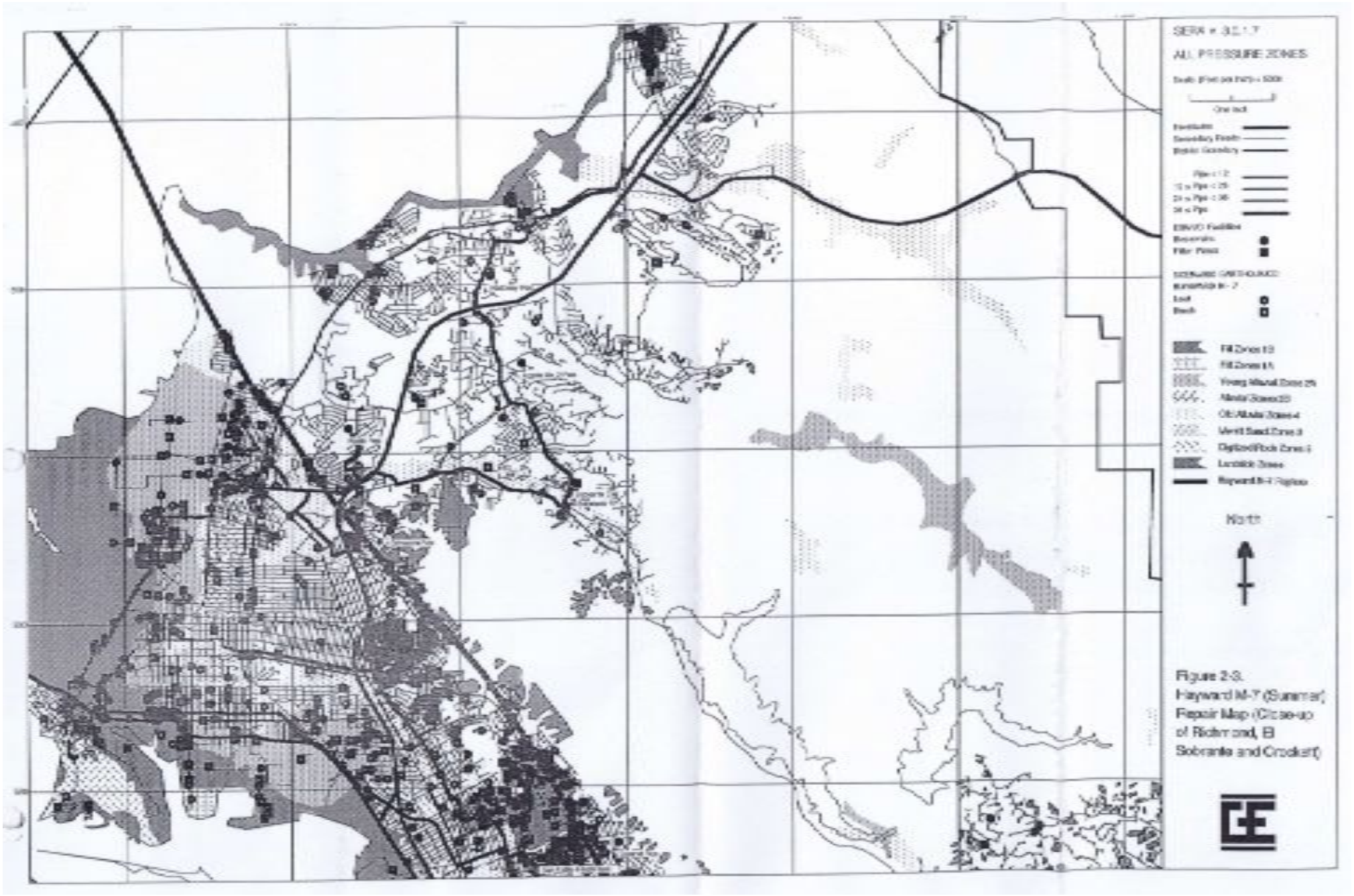
San Diego, Prestressed Wire Failure, No Earthquake

Why? Key Reason:

- Hoop Stress: = *pressure * radius/thickness*
- Longitudinal Stress: = Hoop Stress / 2
- Why divide by 2? Because almost all water pipe codes (AWWA) ignore seismic loads
- This is a HUGE ERROR for seismic design

Berkeley Water System

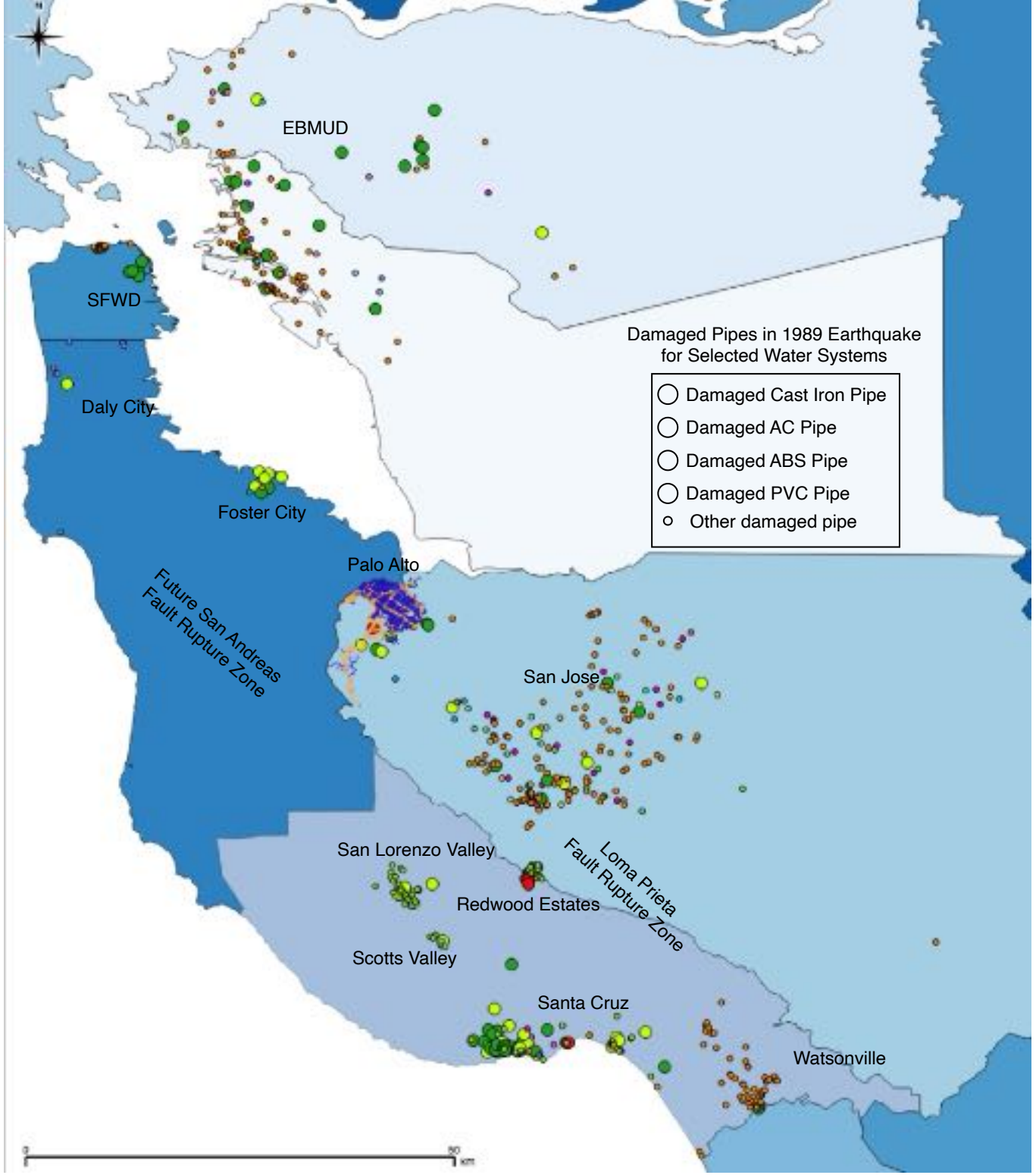
- Part of the East Bay Municipal Utility District (EBMUD)
- Campus Supply: Normally very high quality. Water Treatment Plant in Orinda. Backup (now very rare): San San Pablo / Sobrante (lower quality water).
- Pipes: About 4,200 miles (6" - 87" diameter)
- Most Common Pipes: Cast Iron (> 1,000 miles); Asbestos Cement (> 1,300 miles)
- Other Pipes: Steel (the cheap type), PVC
- Local Storage: 175 Tanks, 125 pump stations, 6 WTPs



Hayward Magnitude 7 Earthquake. Forecast 3,300 to 5,500 water pipe repairs

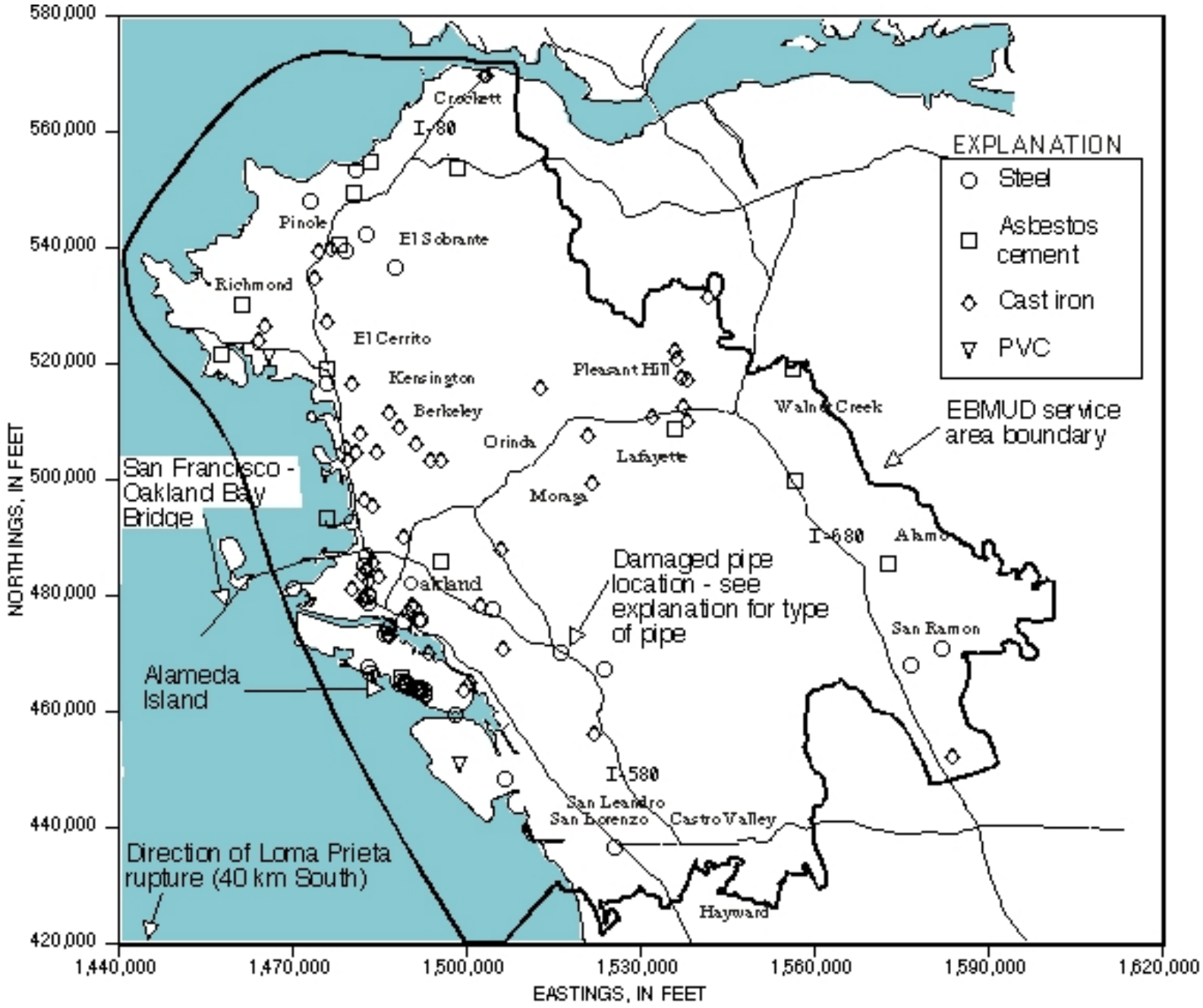
Figure 2-2. Hayward M-7 (Summer) Repair Map (Close up of Berkeley and El Cerrito)

Figure 2-1. Hayward M-7 (Winter) Repair Map (Close-up of Alameda Island, Bay Farm Island, and Downtown Oakland)



Damage to water pipes in the 1989 Loma Prieta Earthquake

Note: this map excludes damage in Santa Clara (>60 pipe repairs), Mountain View, Milpitas, ACWD, Sunnyvale, and some other water districts

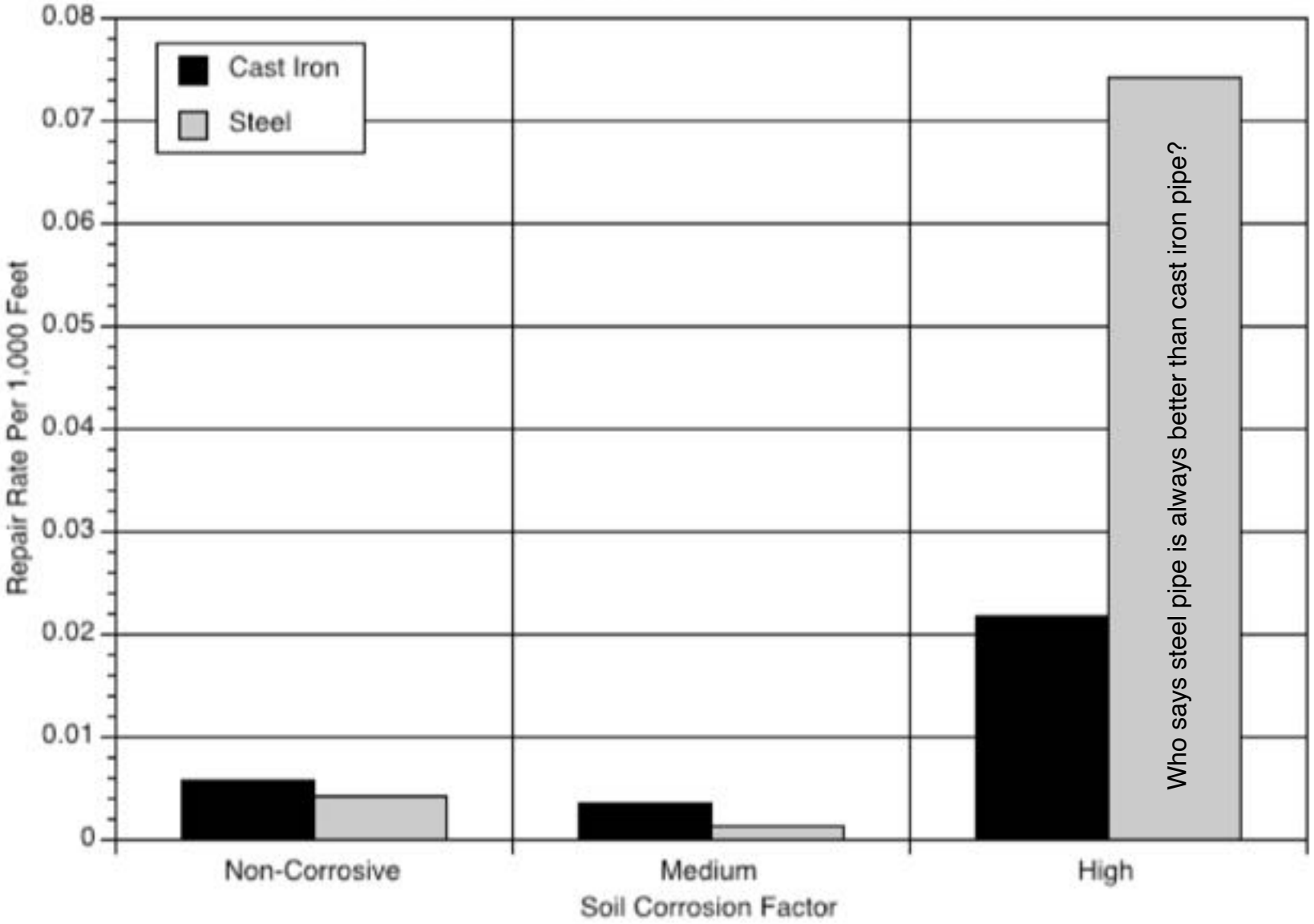


EBMUD Pipe Repairs, 1989 Loma Prieta Earthquake (total 135)

Figure A-3. Location of Pipe Repairs in EBMUD System 1989 Loma Prieta Earthquake (after Eidinger, 1998)

R47.01.02 Rev. 0

LOMA PRIETA 1989 EARTHQUAKE - EMPIRICAL DATA - EBMUD



Size Matters!

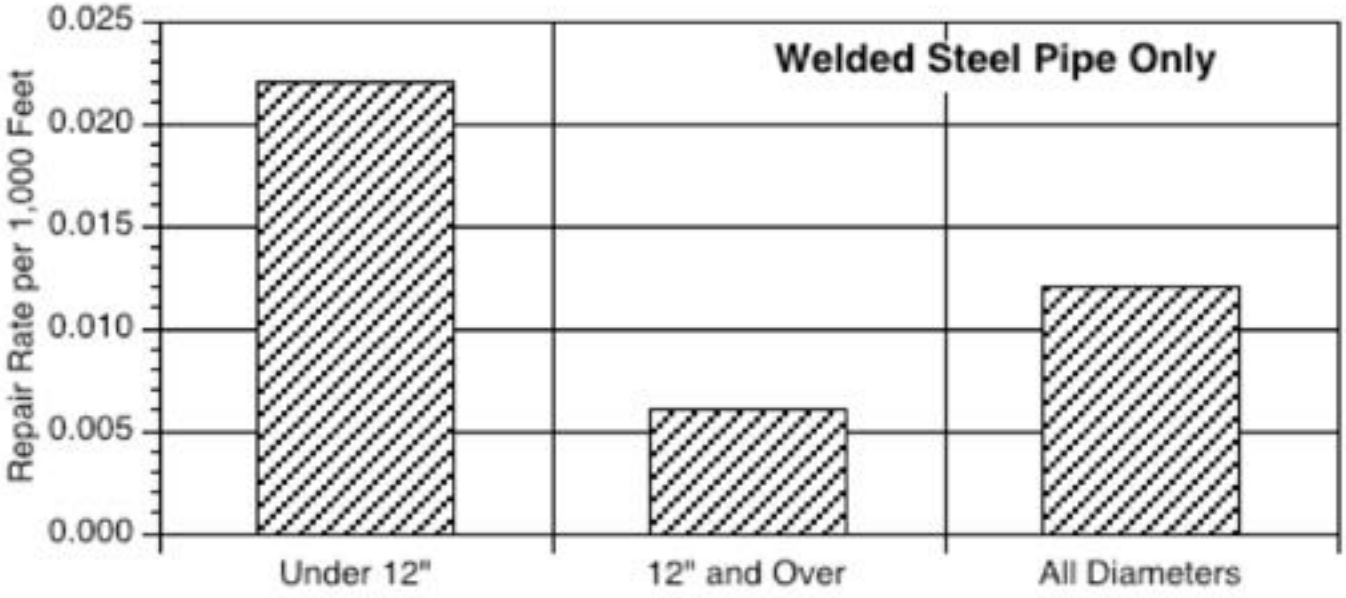
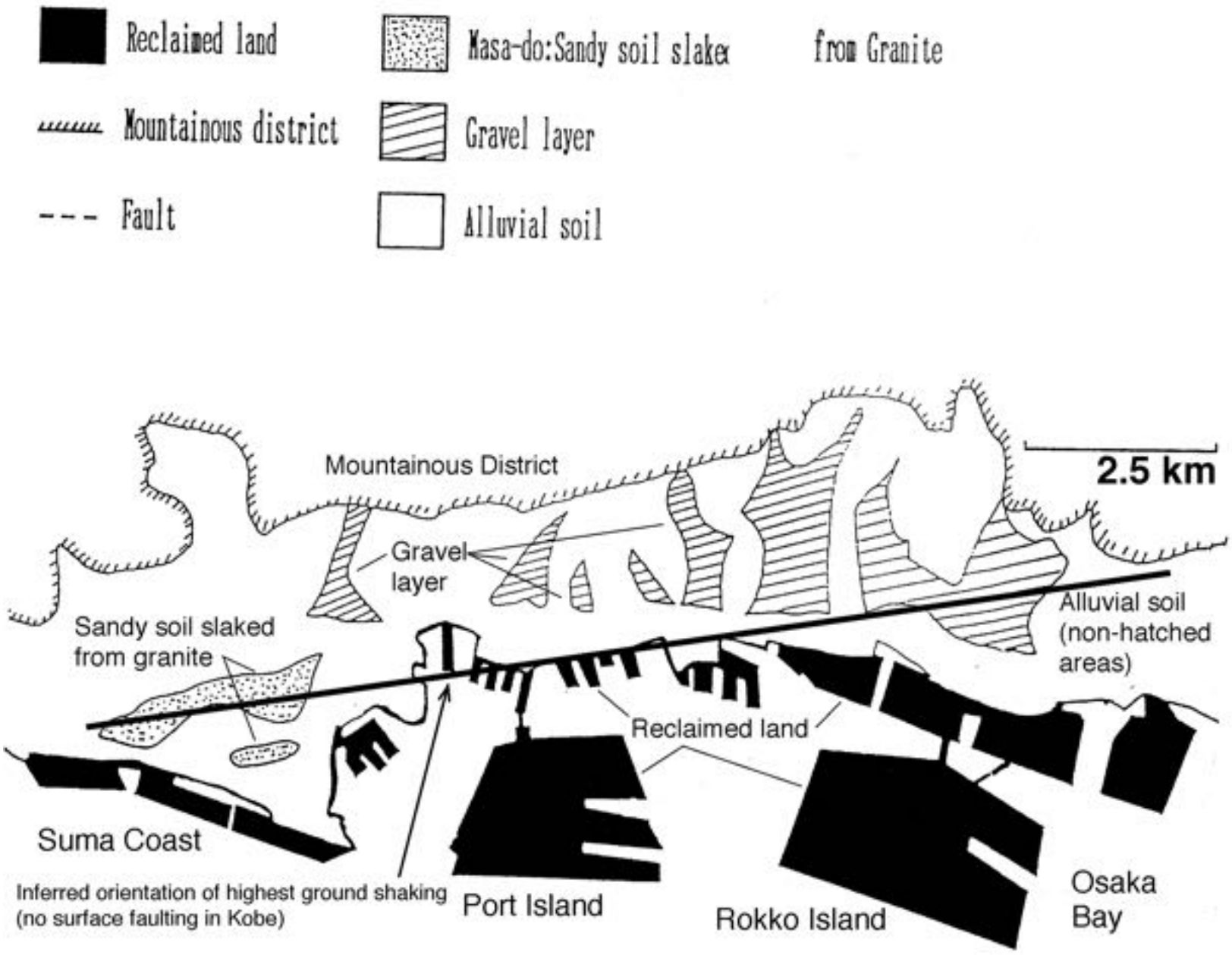


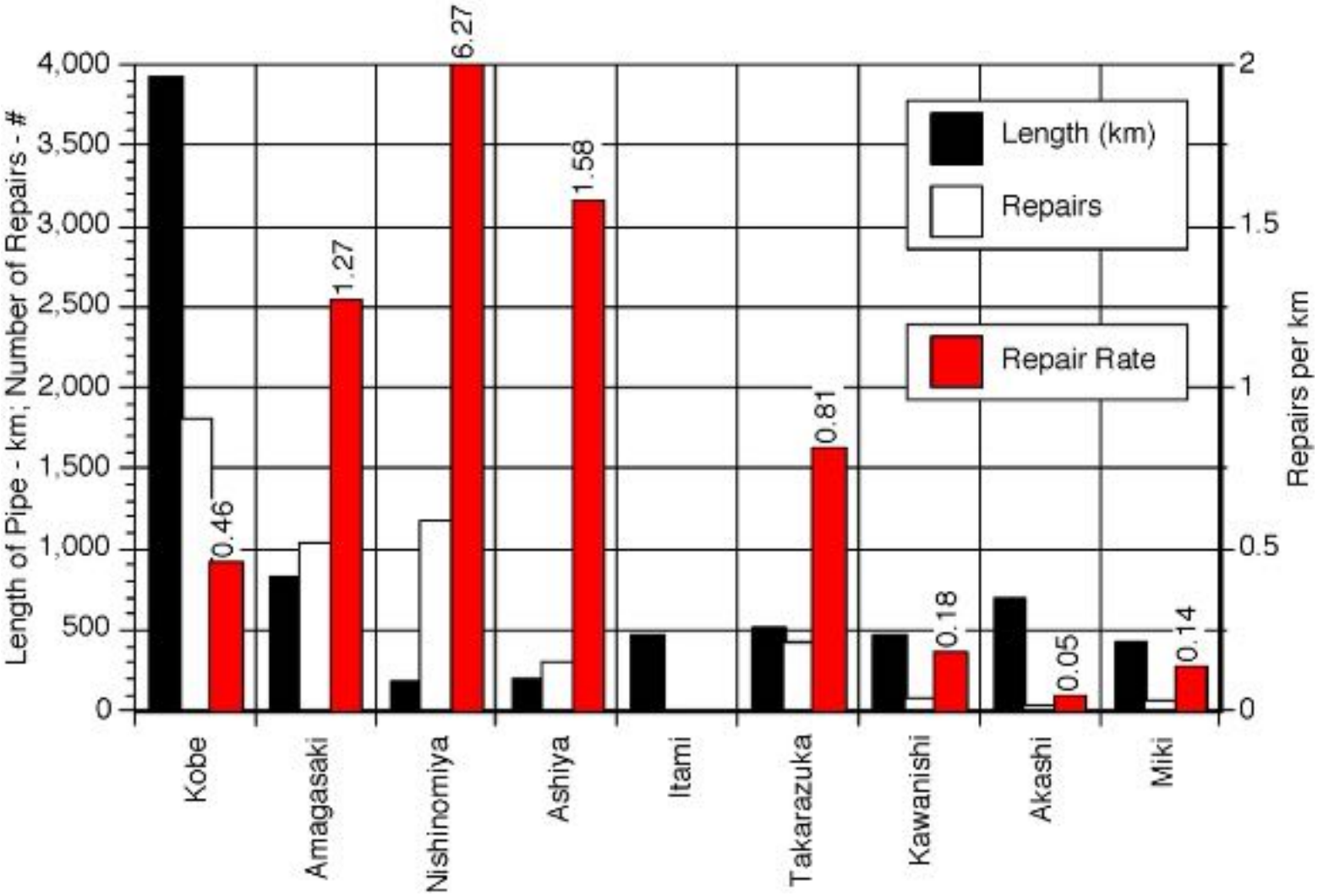
FIGURE 8.2-17. LOMA PRIETA 1989 EARTHQUAKE - EMPIRICAL DATA - EBMUD

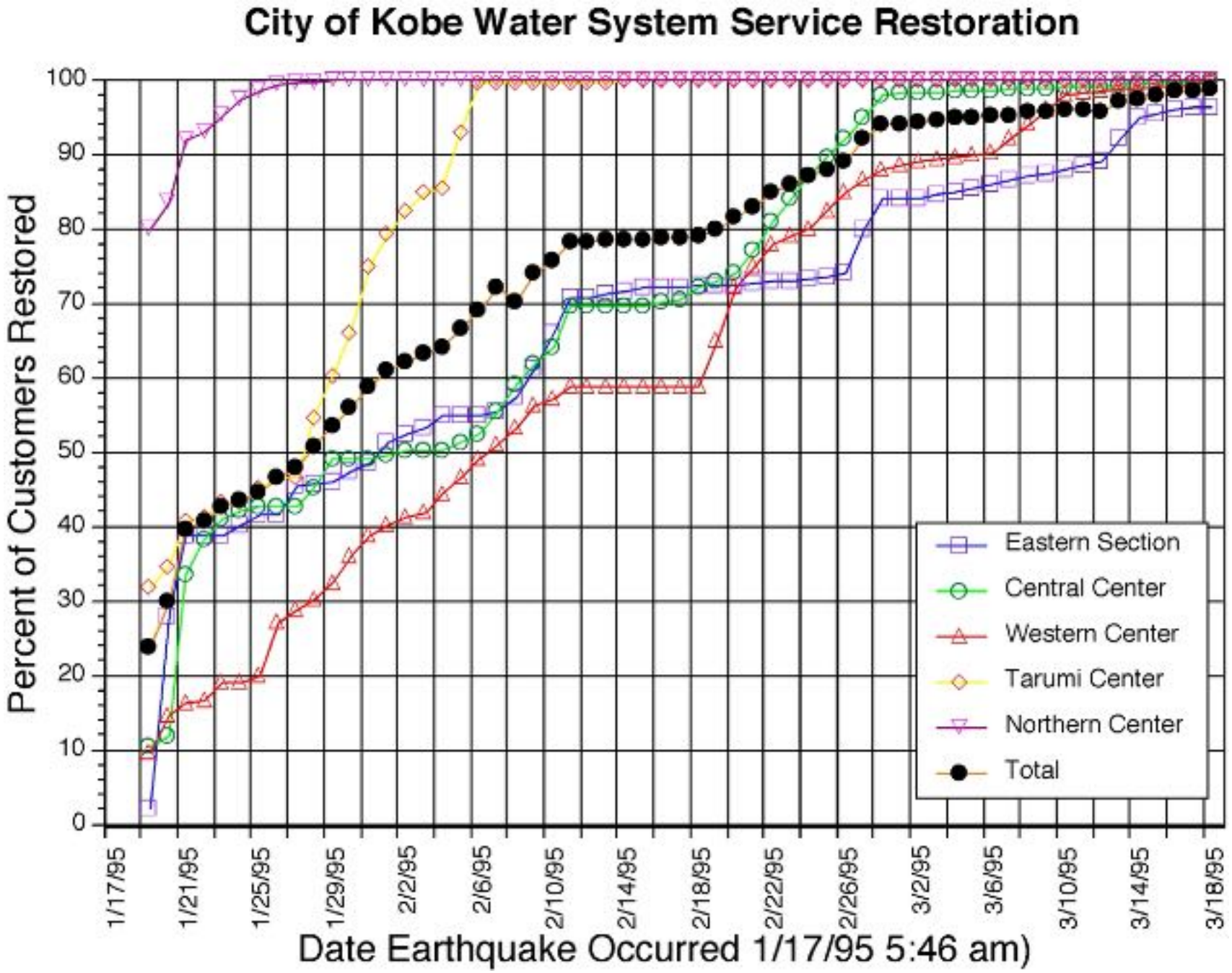
Kobe, Japan
January 17, 1995

Kobe Geotechnical Conditions



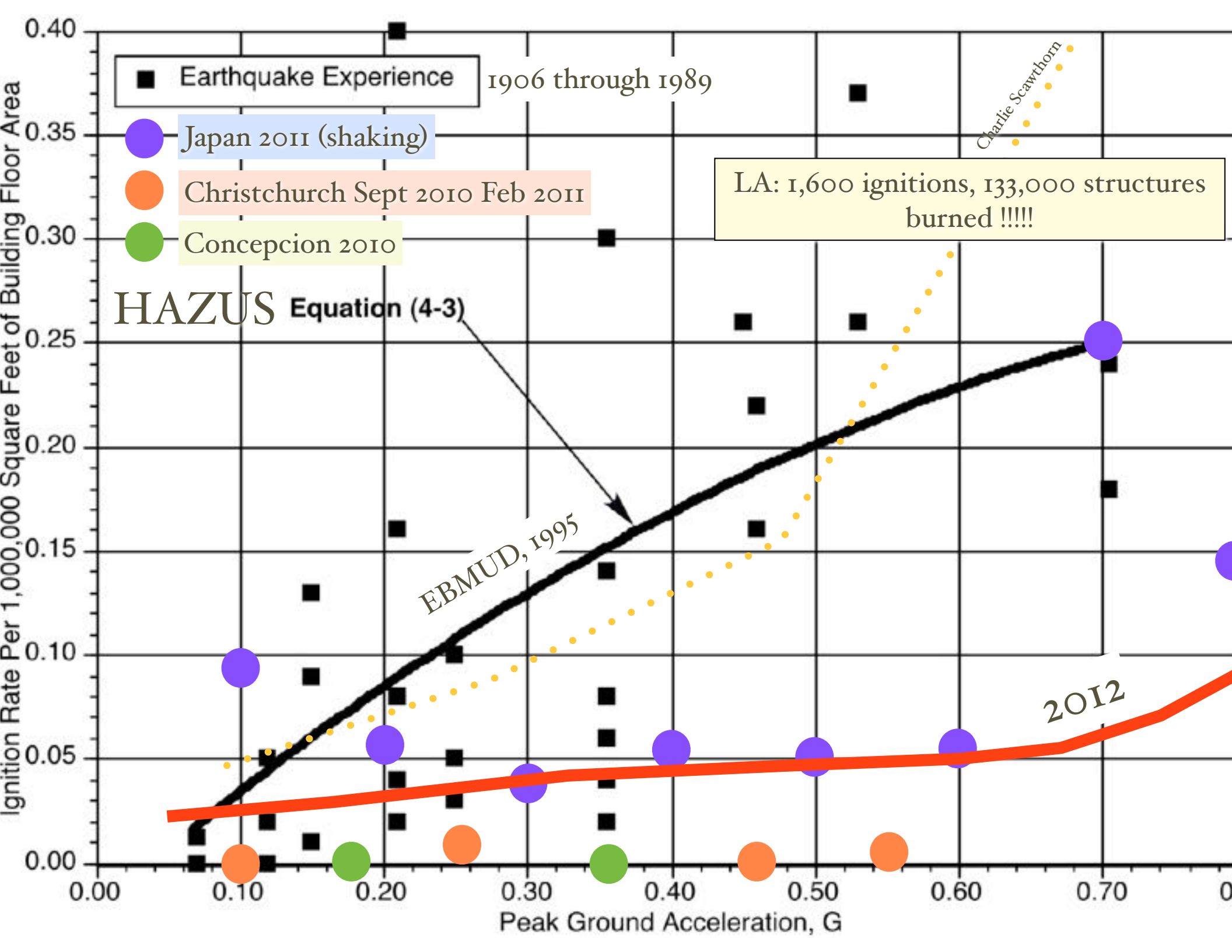
Pipe Repairs, By City




City of Kobe Water System Service Restoration
Percent of Customers Restored
100
90
80
70
60
50
40
30
20
10
0
1/17/95
1/21/95
1/25/95
1/29/95
2/2/95
2/6/95
2/10/95
2/14/95
2/18/95
2/22/95
2/26/95
3/2/95
3/6/95
3/10/95
3/14/95
3/18/95
Date Earthquake Occurred 1/17/95 5:46 am)
Eastern Section
Central Center
Western Center
Tarumi Center
Northern Center
Total

Fire Following Earthquake

- Kobe: 234 Fire Ignitions within 14 hours
  - 100 Ignitions Immediately After EQ
- Lack of Water, Small Cisterns, Debris Hamper Fire Fighters
- Fire Boats Ineffective > 500 m from Shoreline
- Total: 350-419 fires in Kobe. 1,000,000 sq. m lost (~100 years of normal fire losses)


Earthquake Experience
1906 through 1989
Japan 2011 (shaking)
Christchurch Sept 2010 Feb 2011
Concepcion 2010
HAZUS Equation (4-3)
EBMUD, 1995
Charlie Scawthorn
LA: 1,600 ignitions, 133,000 structures burned !!!!!
2012
Ignition Rate Per 1,000,000 Square Feet of Building Floor Area
Peak Ground Acceleration, G
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70

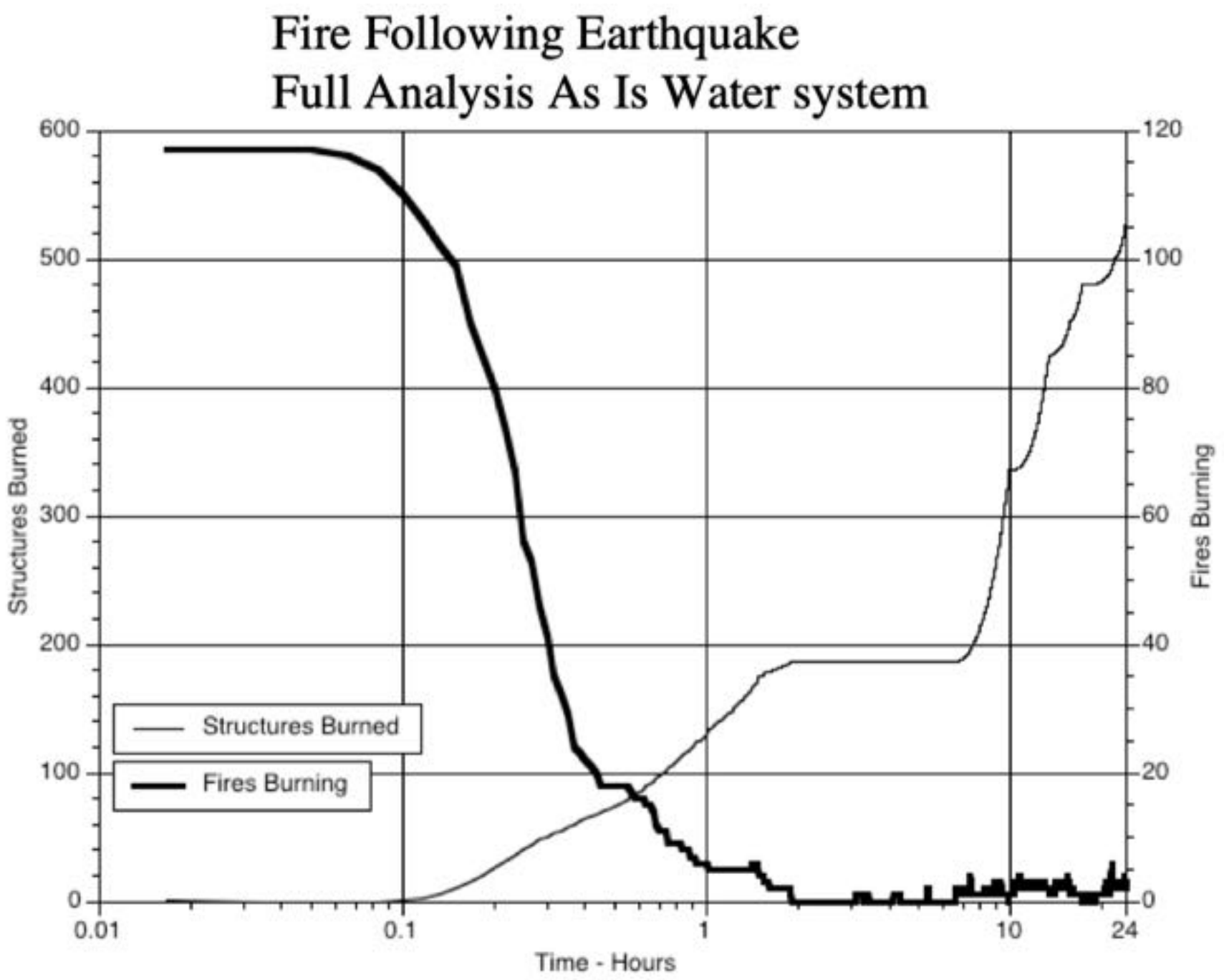
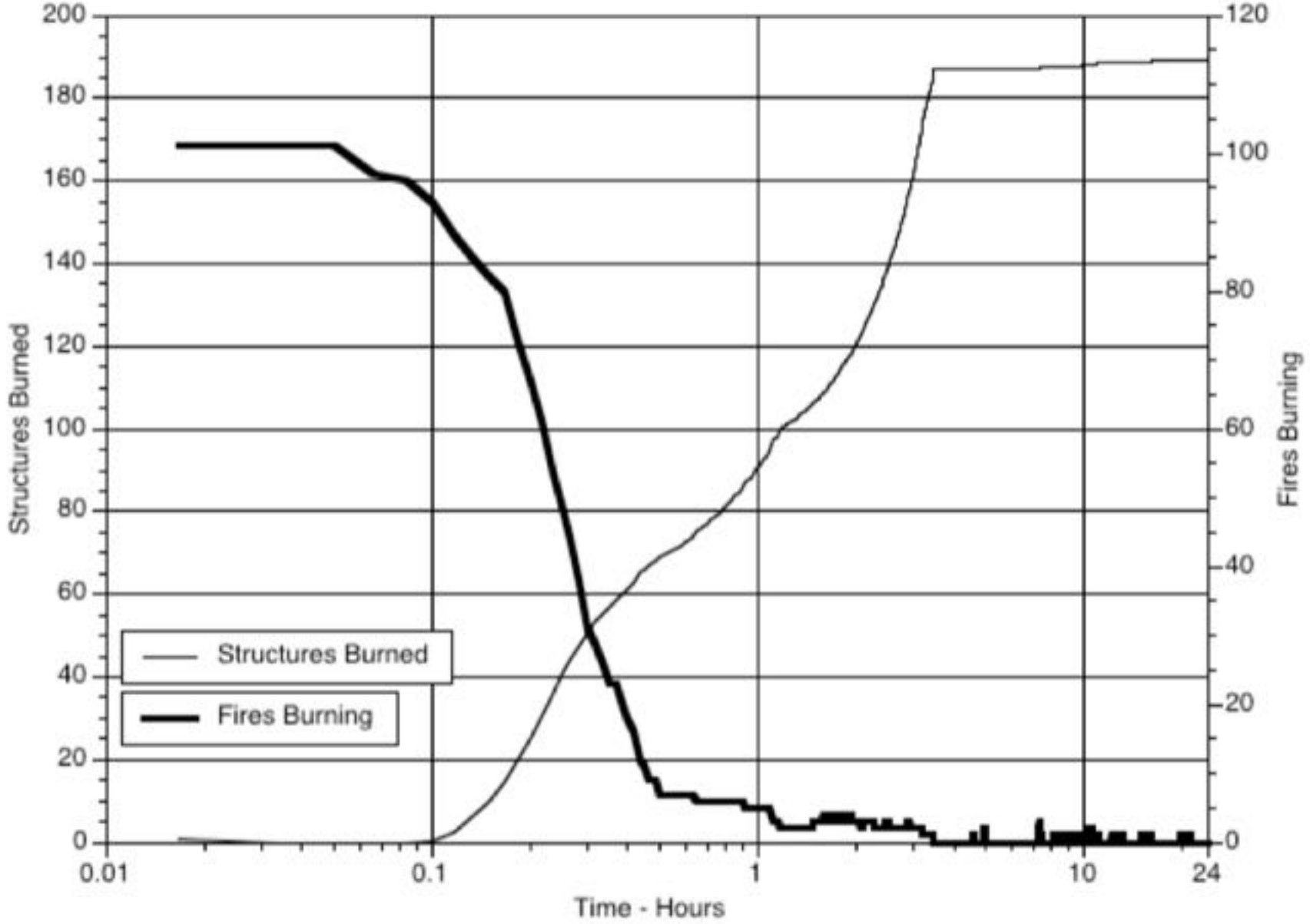

Fire Following Earthquake
Full Analysis As Is Water system
Structures Burned
Fires Burning
Time - Hours
Structures Burned
Fires Burning
600
500
400
300
200
100
0
120
100
80
60
40
20
0
0.01
0.1
1
10
24

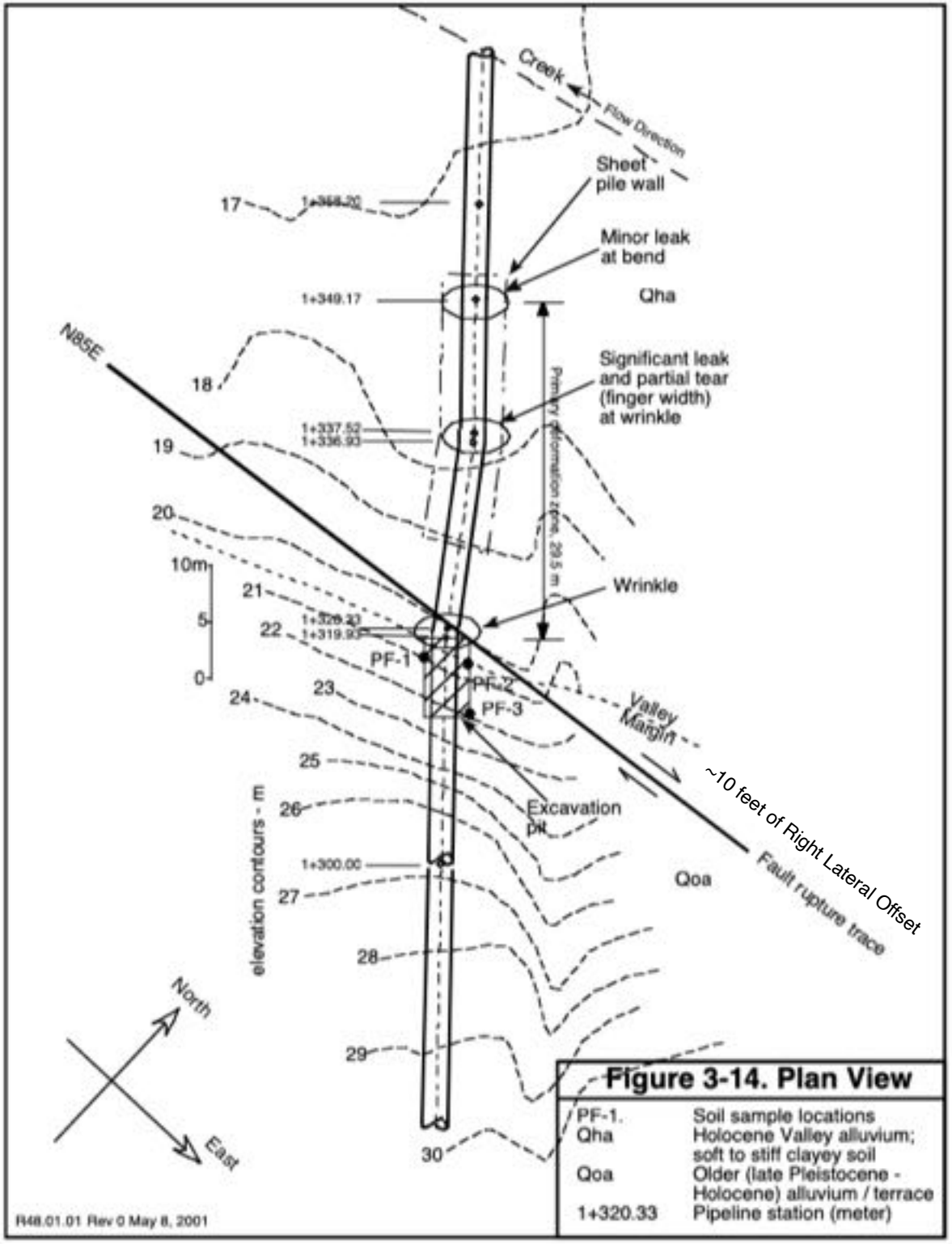
FIGURE 12. Hayward M - 7. Calm Winds. CIP #3

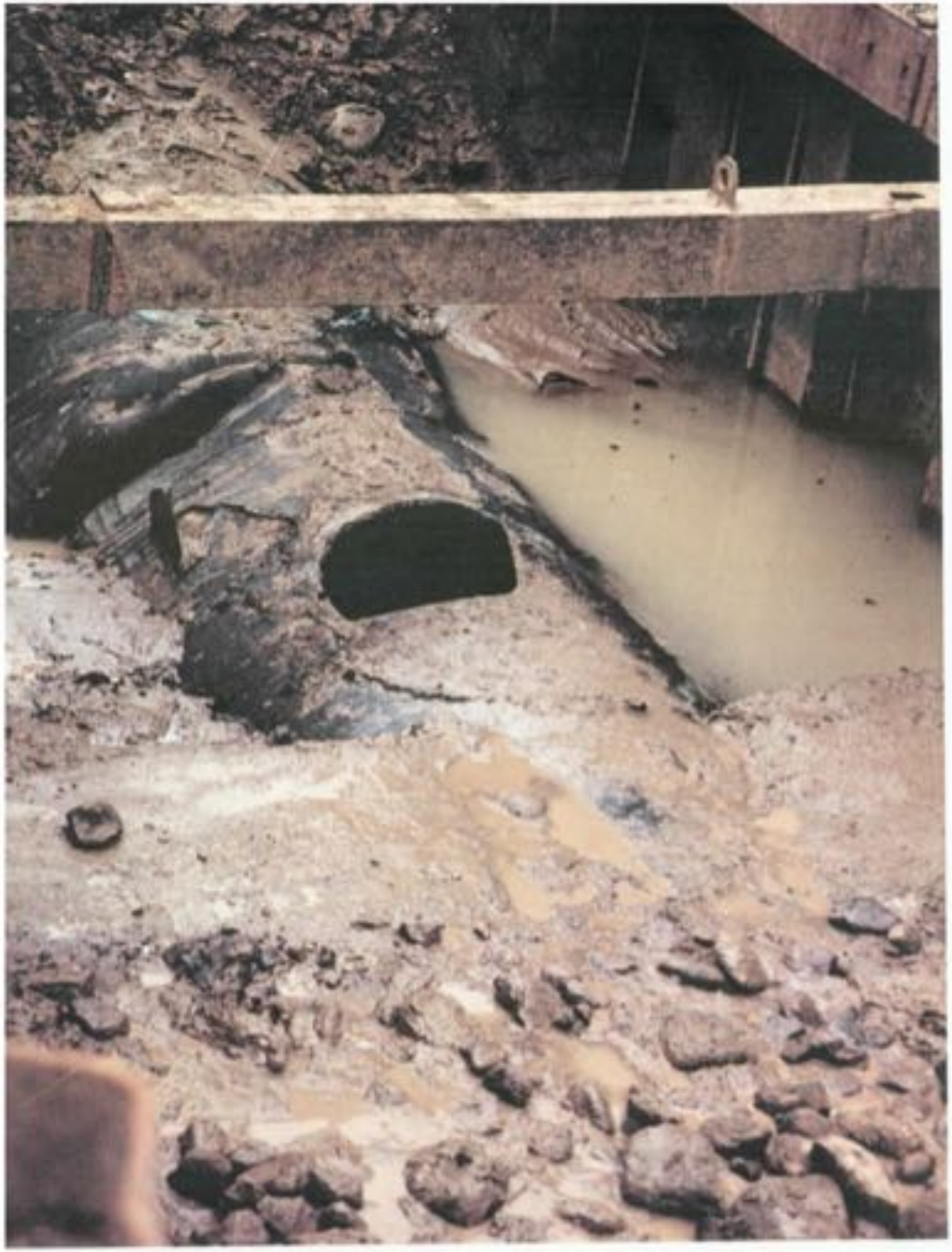


Izmit, Turkey
August 17, 1999

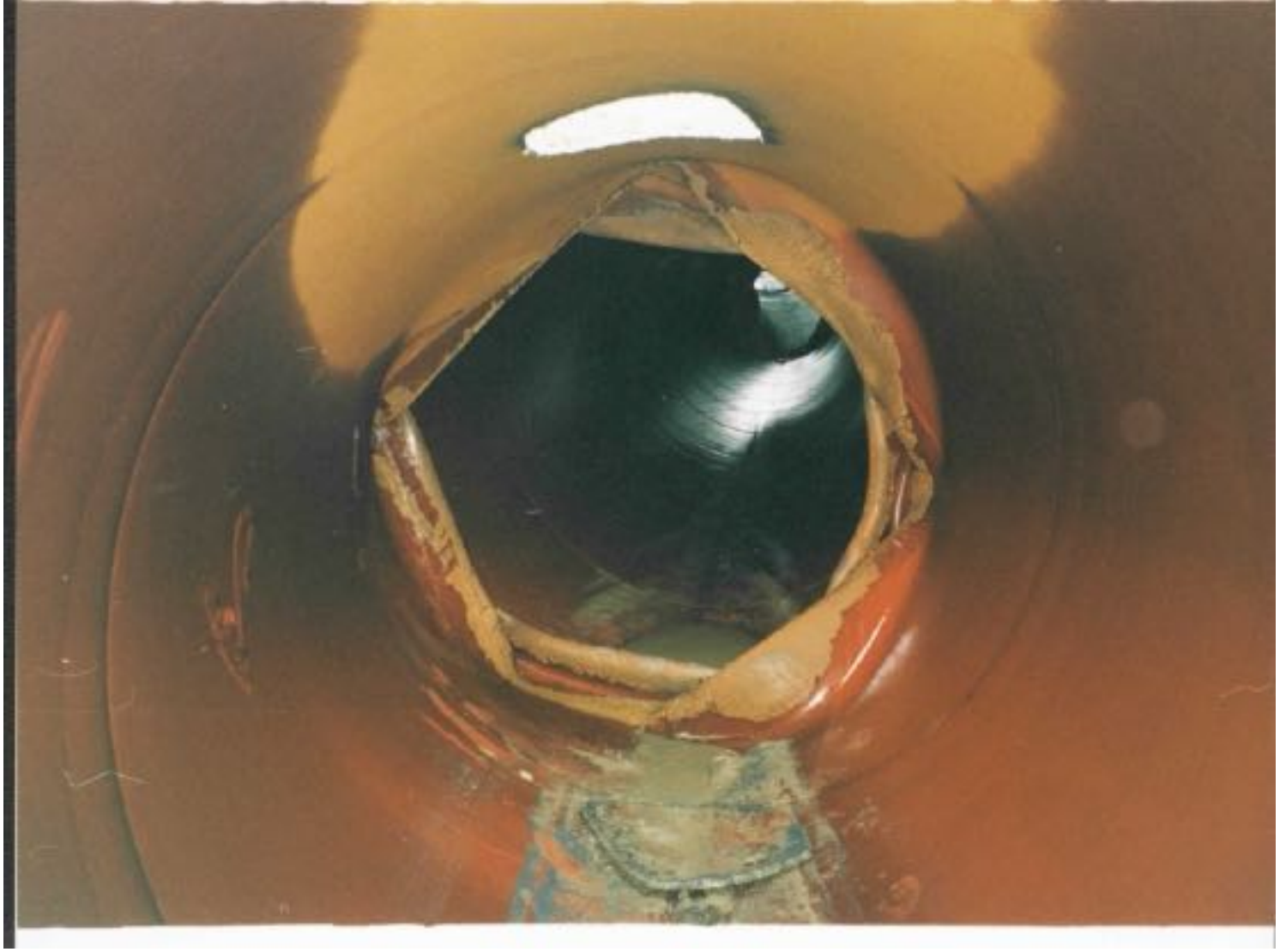
Tilted Building

Ground Rupture

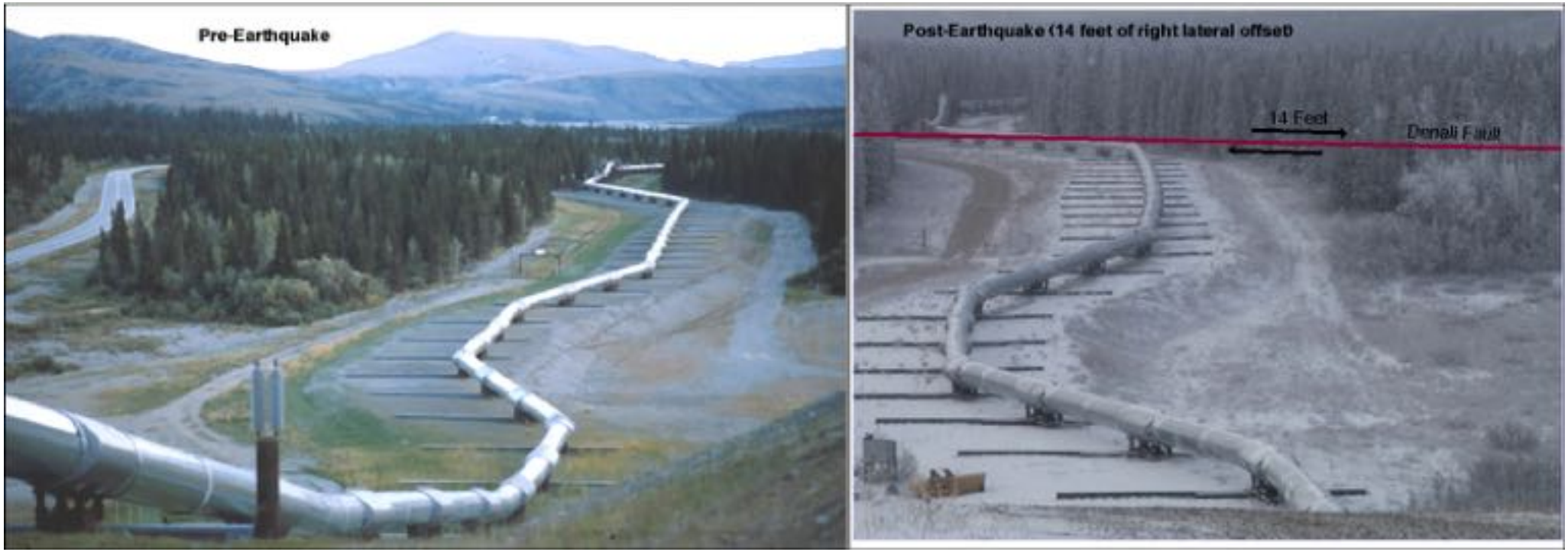

Creek
Flow Direction
Sheet pile wall
Minor leak at bend
Qha
Significant leak and partial tear (finger width) at wrinkle
Primary deformation zone, 29.5 m
Wrinkle
N85E
Valley Margin
~10 feet of Right Lateral Offset
Fault rupture trace
Excavation pit
Qoa
PF-1
PF-2
PF-3
1+368.20
1+349.17
1+337.52
1+336.93
1+329.33
1+319.93
1+300.00
17
18
19
20
21
22
23
24
25
26
27
28
29
30
10m
5
0
elevation contours - m
North
East
R48.01.01 Rev 0 May 8, 2001
Figure 3-14. Plan View
PF-1. Soil sample locations
Qha Holocene Valley alluvium; soft to stiff clayey soil
Qoa Older (late Pleistocene - Holocene) alluvium / terrace
1+320.33 Pipeline station (meter)



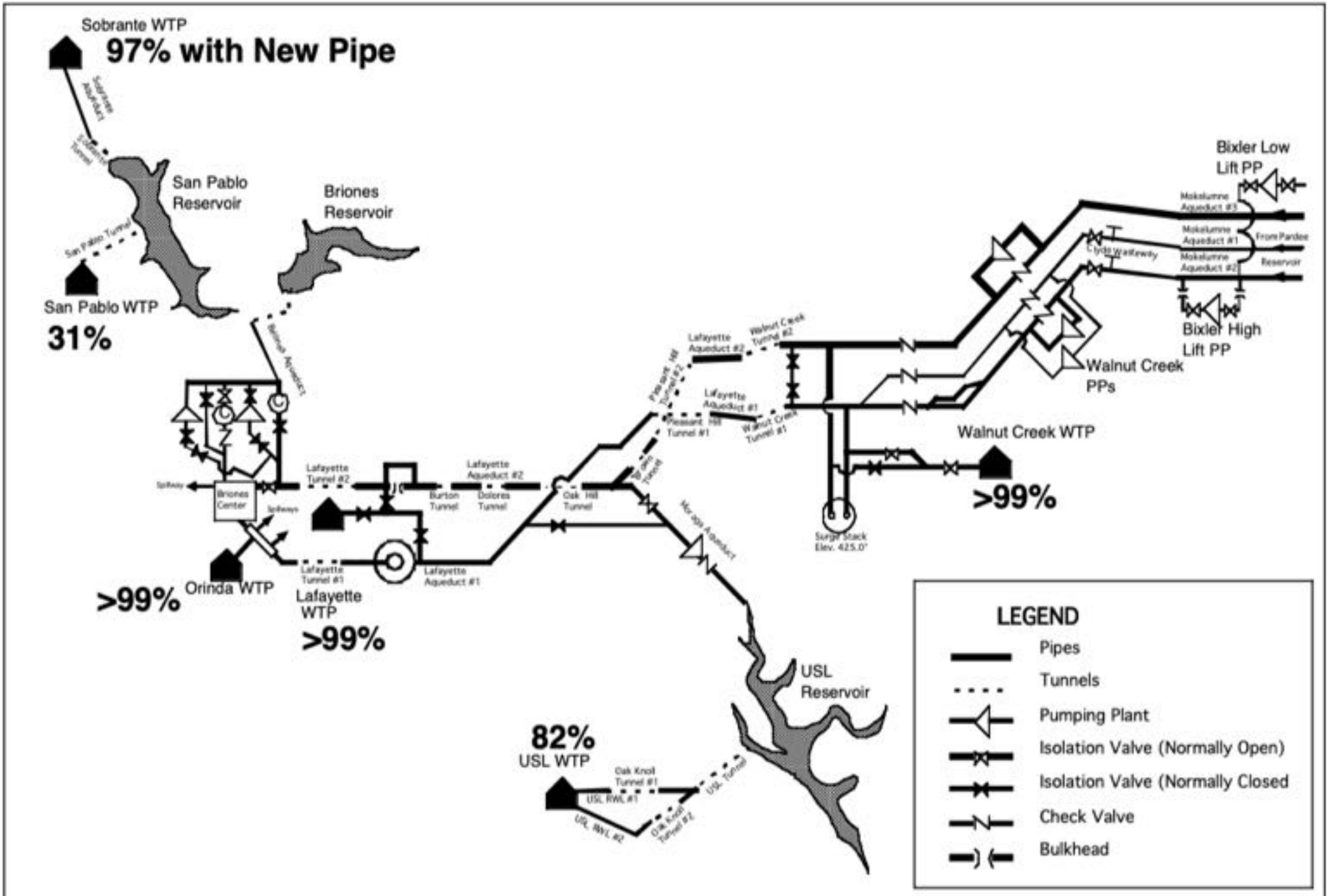
Damaged pipe section - broken out to allow for emptying



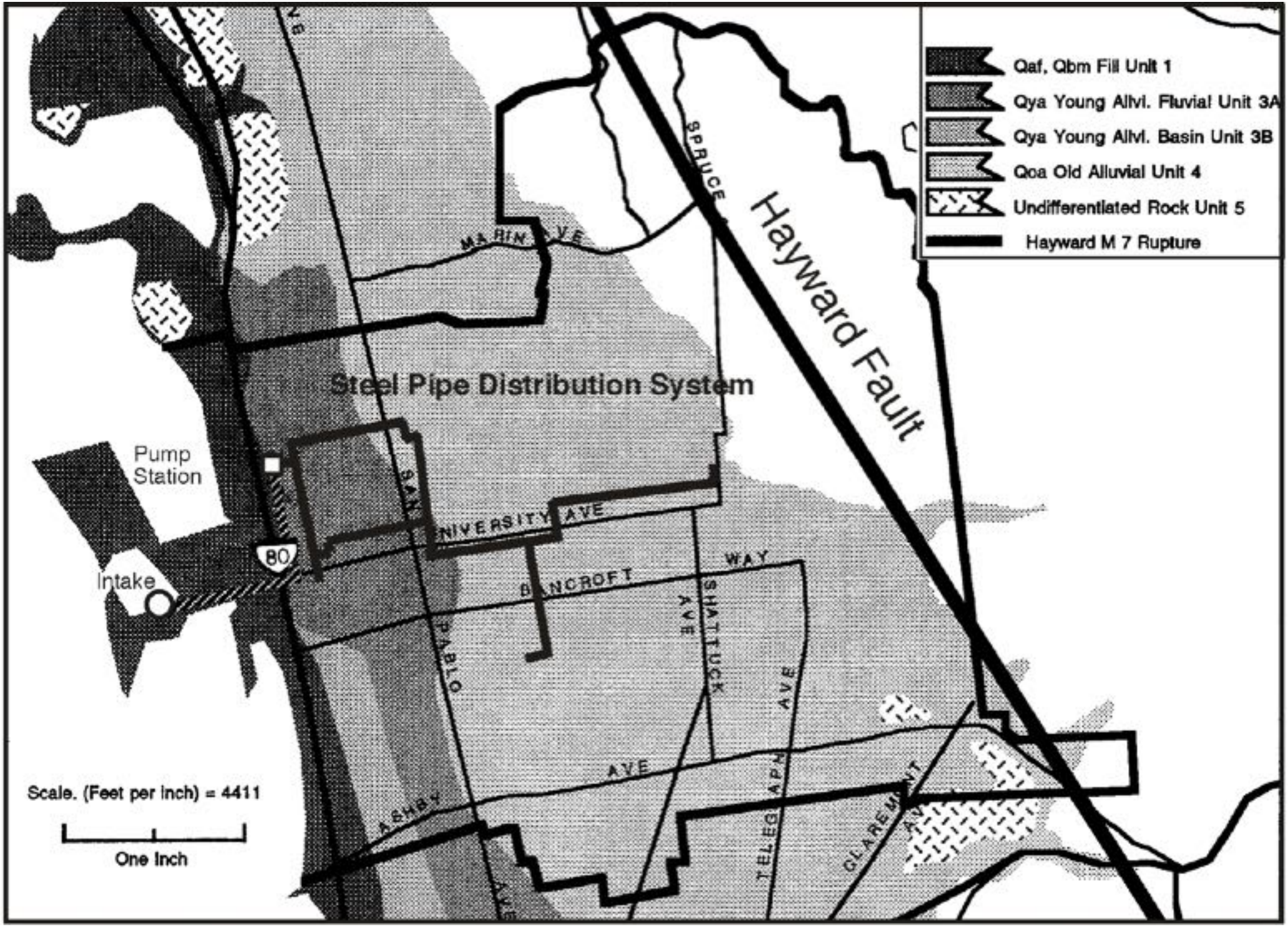
Picture taken at approximately Station 1+400, looking south.
The wrinkle in the foreground is at station 1+337.
The hole at the top of the pipe is a manhole cut into the pipe to allow inspection;
the steel plate at the floor of the pipe is the steel from the hole cut at the top of the pipe.
The wrinkles are as much as 200 mm deep from the original diameter of the pipe.
The internal epoxy lining has been stripped away from the pipe at the wrinkle location.
The wrinkle in the background is at station 1+320.
There is a change in direction of the pipe at both wrinkled locations.

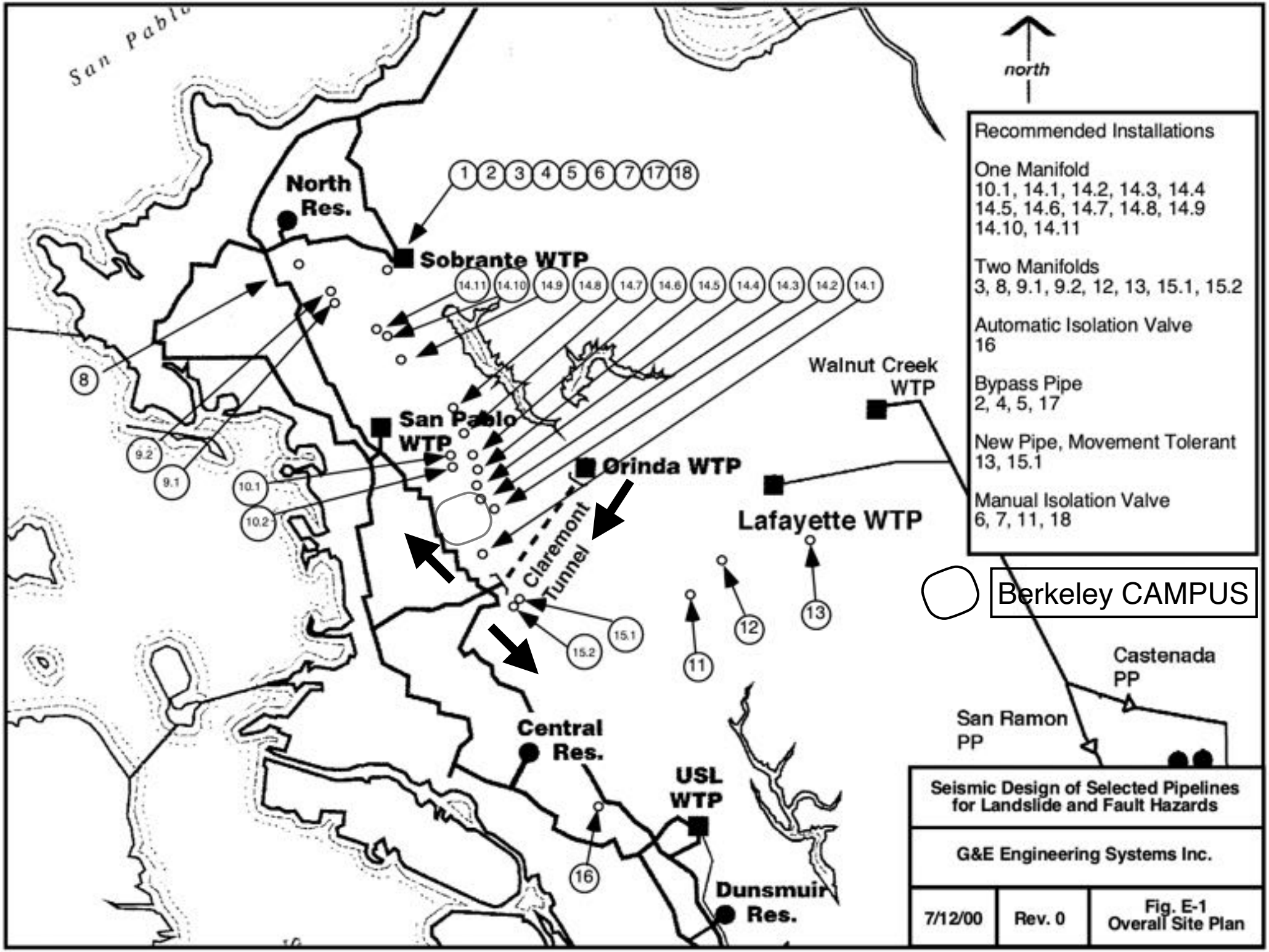


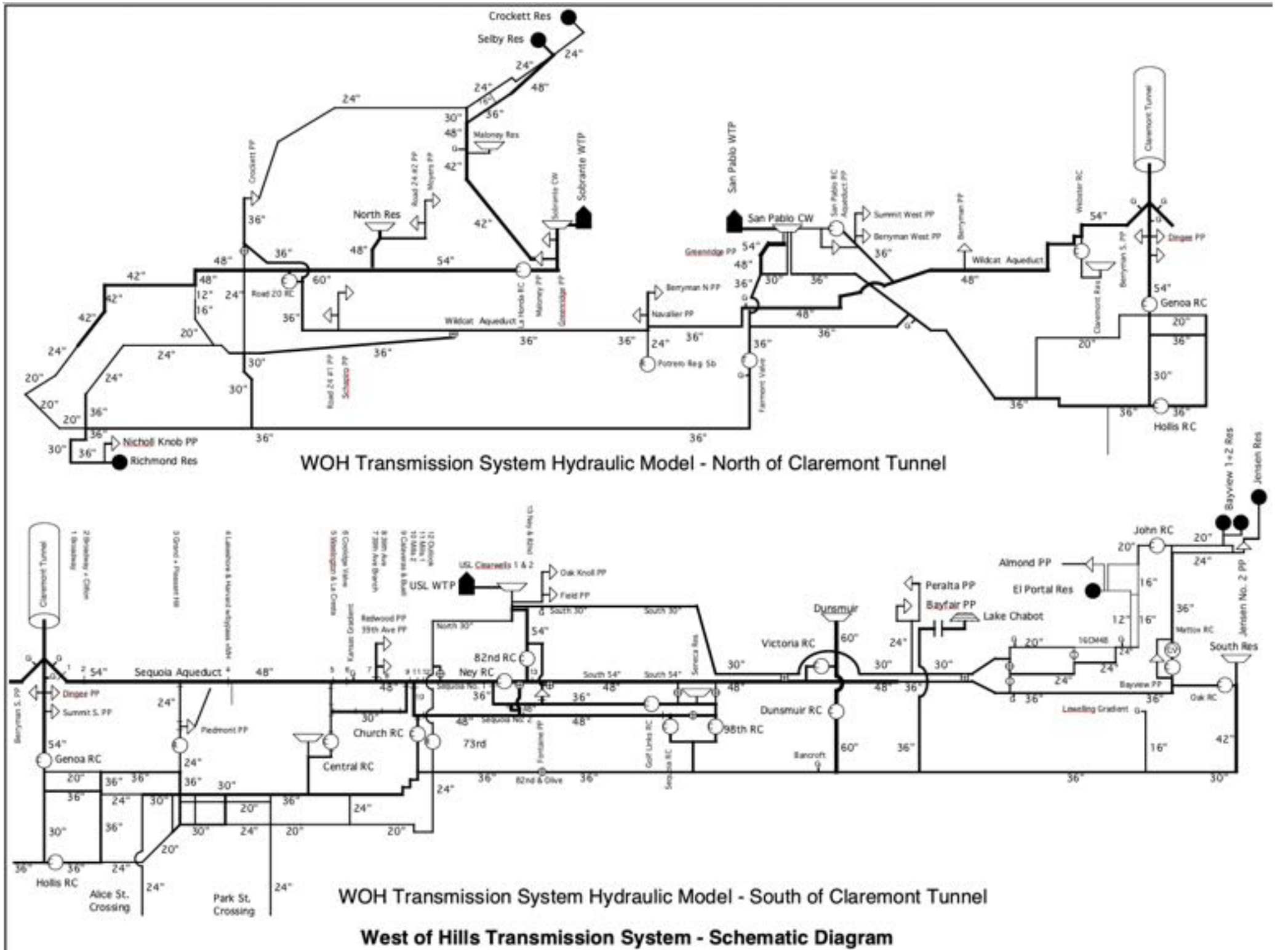
Seismic Design by Ed Keith c. 1970. Designed for 20 feet of right lateral offset. Designed to remain elastic assuming using El Centro 1940 motion (PGA = 0.33g)



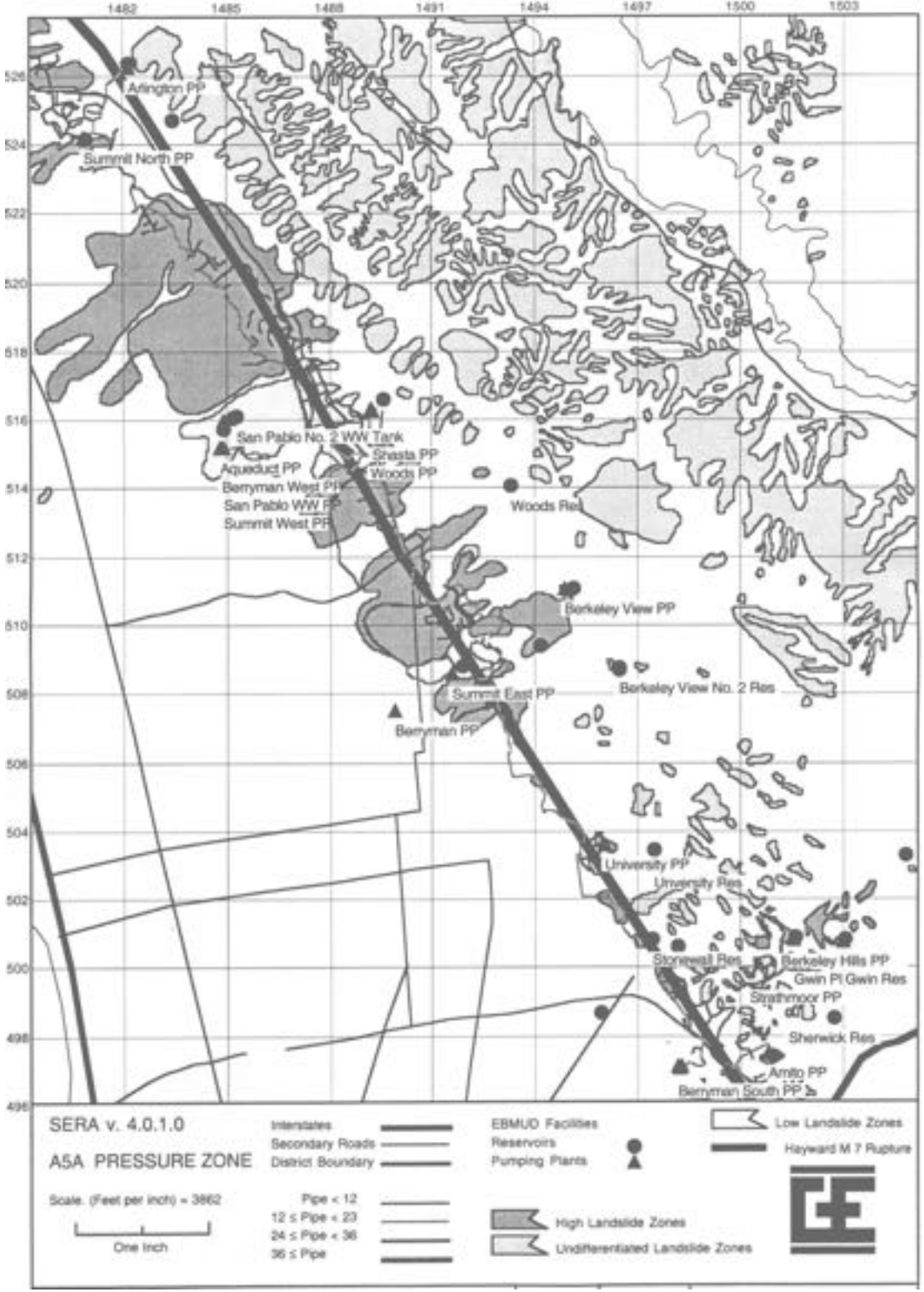
Raw Water Supply to WTPs - Hayward M 7 - Time = 0

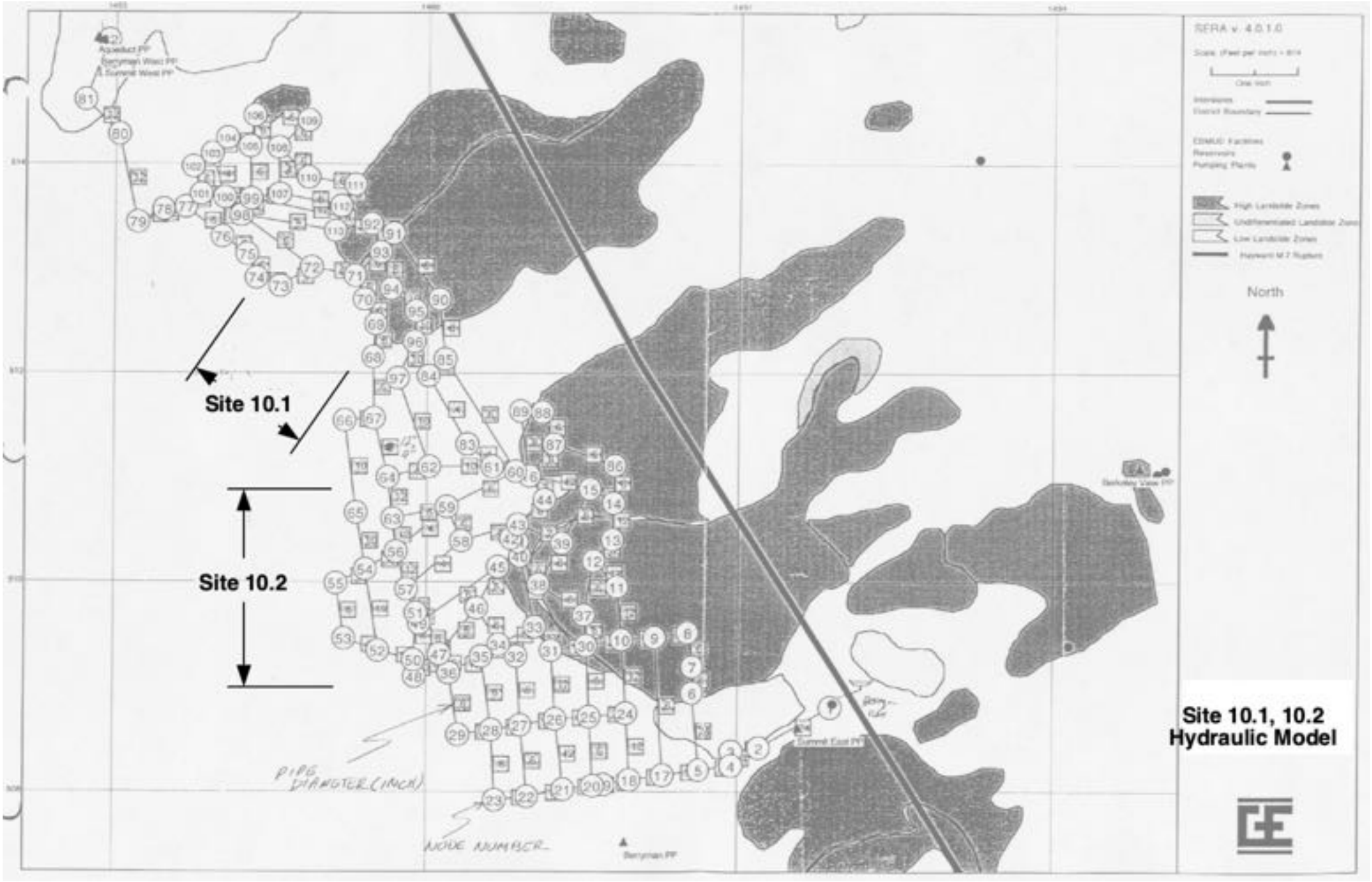

Qaf, Qbm Fill Unit 1
Qya Young Alivi. Fluvial Unit 3A
Qya Young Alivi. Basin Unit 3B
Qoa Old Alluvial Unit 4
Undifferentiated Rock Unit 5
Hayward M 7 Rupture
Hayward Fault
Steel Pipe Distribution System
Pump Station
Intake
80
SPRUCE
MARIN AVE
UNIVERSITY AVE
BANCROFT WAY
SHATTUCK AVE
PABLO AVE
ASHBY AVE
TELEGRAPH AVE
CLAREMONT AVE
Scale. (Feet per inch) = 4411
One Inch


north
Recommended Installations
One Manifold
10.1, 14.1, 14.2, 14.3, 14.4
14.5, 14.6, 14.7, 14.8, 14.9
14.10, 14.11
Two Manifolds
3, 8, 9.1, 9.2, 12, 13, 15.1, 15.2
Automatic Isolation Valve
16
Bypass Pipe
2, 4, 5, 17
New Pipe, Movement Tolerant
13, 15.1
Manual Isolation Valve
6, 7, 11, 18
Berkeley CAMPUS
North Res.
Sobrante WTP
San Pablo WTP
Orinda WTP
Walnut Creek WTP
Lafayette WTP
Claremont Tunnel
Central Res.
USL WTP
Dunsmuir Res.
Castenada PP
San Ramon PP
1 2 3 4 5 6 7 17 18
14.11 14.10 14.9 14.8 14.7 14.6 14.5 14.4 14.3 14.2 14.1
8
9.2
9.1
10.1
10.2
15.1
15.2
11
12
13
16
Seismic Design of Selected Pipelines for Landslide and Fault Hazards
G&E Engineering Systems Inc.
7/12/00
Rev. 0
Fig. E-1
Overall Site Plan

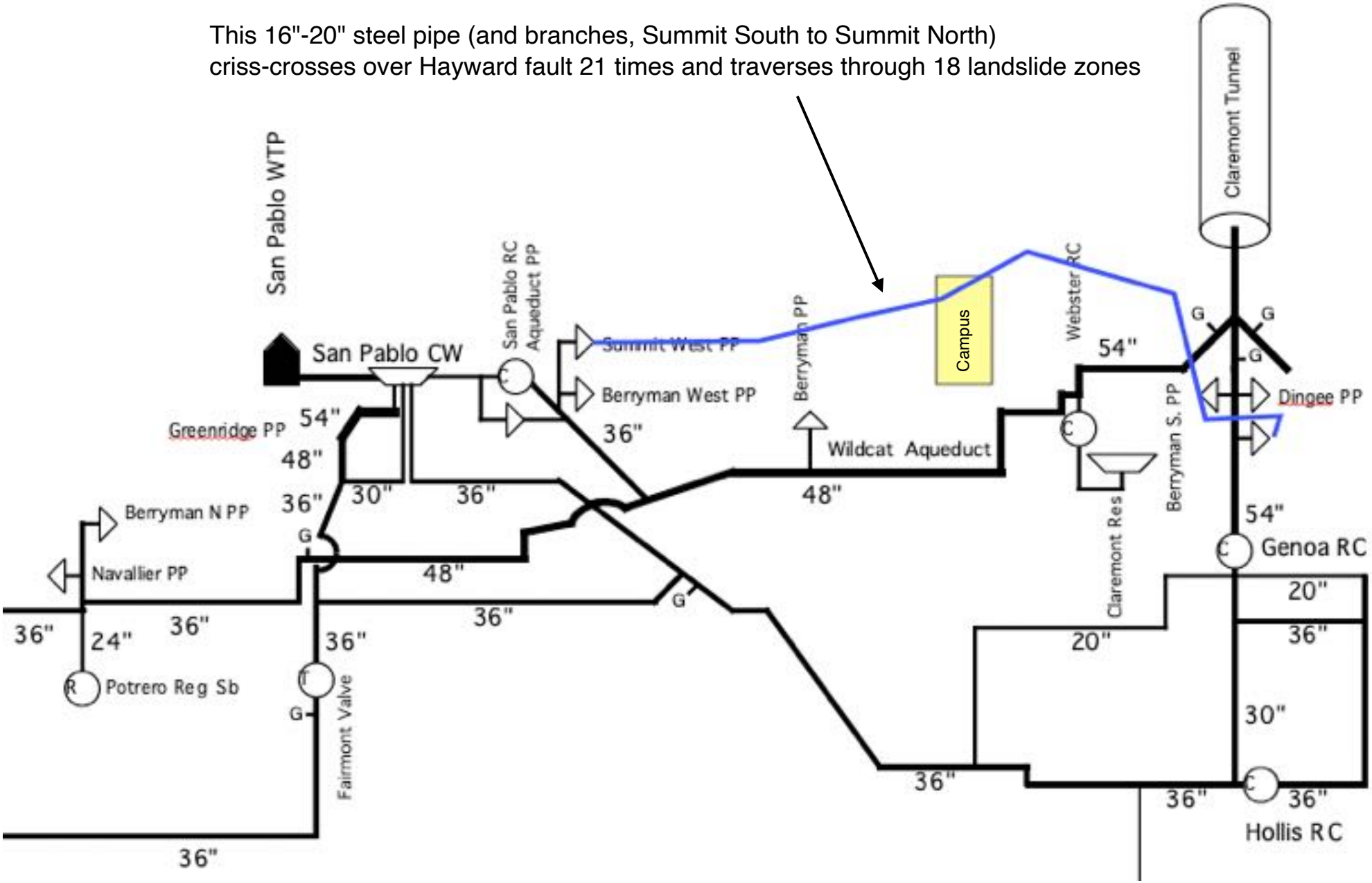


West of Hills Transmission System - Schematic Diagram

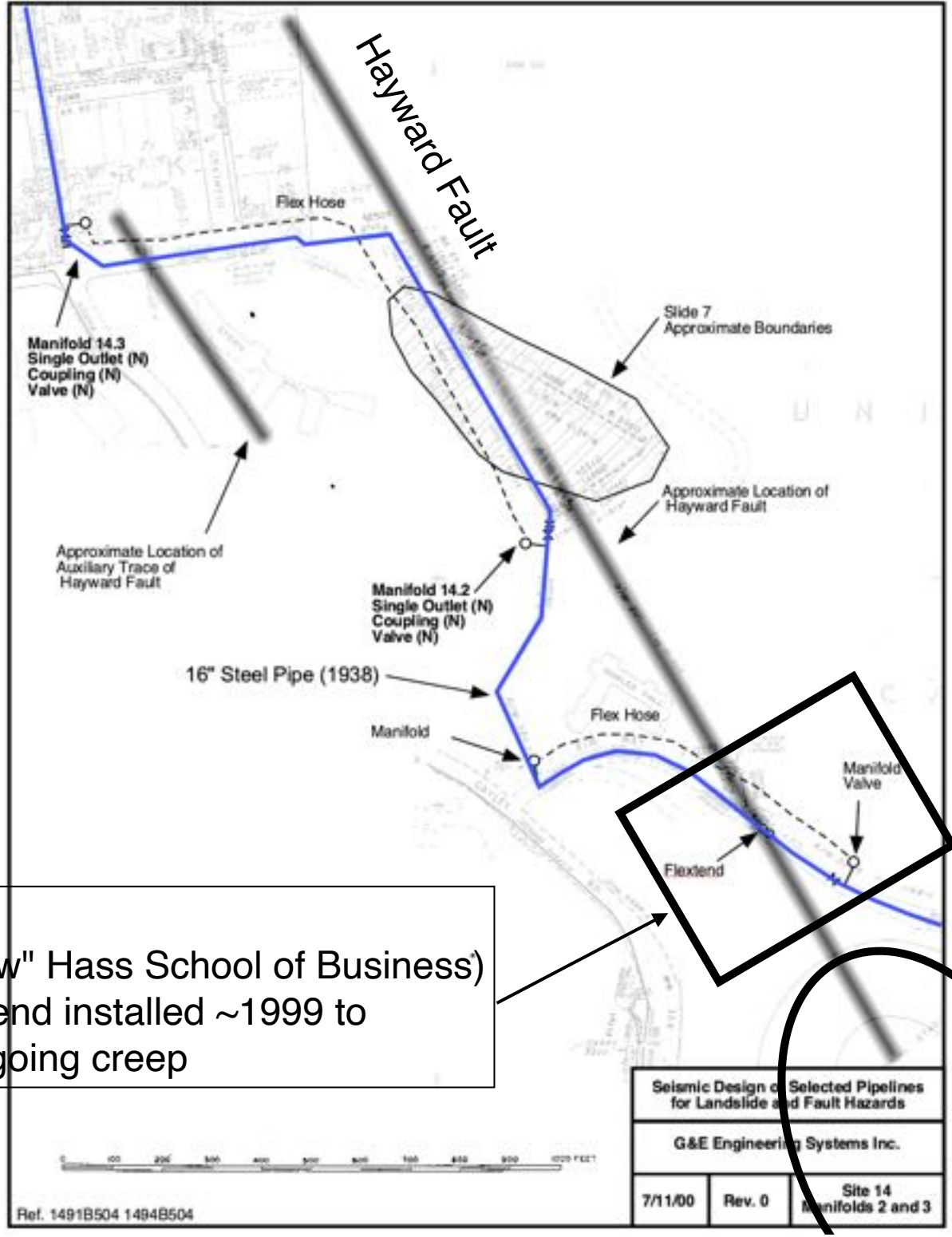

1482
1485
1488
1491
1494
1497
1500
1503
526
524
522
520
518
516
514
512
510
508
506
504
502
500
498
496
Arlington PP
Summit North PP
San Pablo No. 2 WW Tank
Shasta PP
Aqueduct PP
Woods PP
Berryman West PP
San Pablo WW PP
Summit West PP
Woods Res
Berkeley View PP
Summit East PP
Berkeley View No. 2 Res
Berryman PP
University PP
University Res
Stonewall Res
Berkeley Hills PP
Gwin Pl Gwin Res
Strathmoor PP
Sherwick Res
Arrillo PP
Berryman South PP
SERA v. 4.0.1.0
A5A PRESSURE ZONE
Scale. (Feet per inch) = 3862
One Inch
Interstates
Secondary Roads
District Boundary
Pipe < 12
12 ≤ Pipe < 23
24 ≤ Pipe < 36
36 ≤ Pipe
EBMUD Facilities
Reservoirs
Pumping Plants
High Landslide Zones
Undifferentiated Landslide Zones
Low Landslide Zones
Hayward M 7 Rupture


SERA v. 4.0.1.0
North
Site 10.1
Site 10.2
Site 10.1, 10.2
Hydraulic Model
PIPE DIAMETER (INCH)
NODE NUMBER

This 16"-20" steel pipe (and branches, Summit South to Summit North)
criss-crosses over Hayward fault 21 times and traverses through 18 landslide zones



Davis Hall



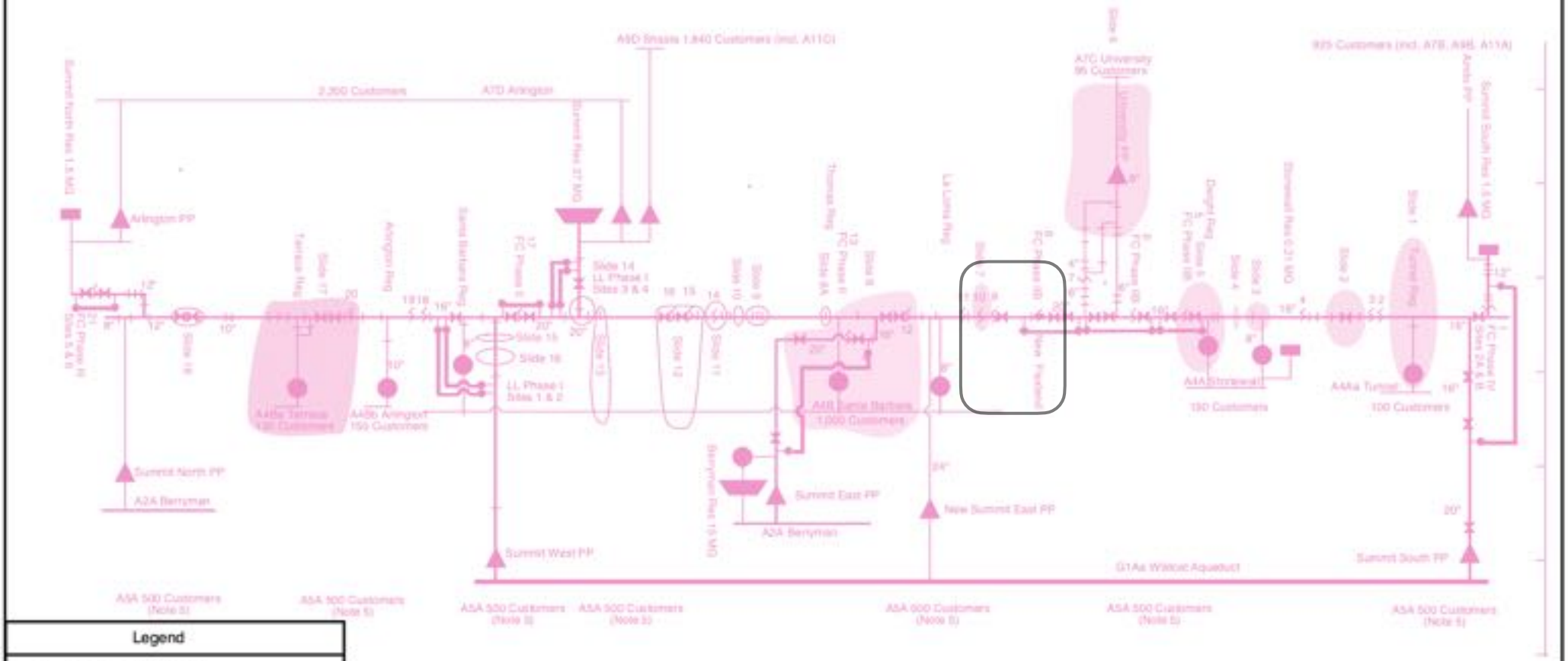
Memorial Stadium

8 Pipe Failures
(1 flooded the "new" Hass School of Business)
A 6-foot long flextend installed ~1999 to
accommodate ongoing creep

Notes:
1. Hazards shown for A5A Zone backbone pipes
2. Some hazards shown for regulated zones A4Ba, A4Bb, A4B, A4A, A4Aa
3. Some hazards shown for pumped zone A7C
4. No hazards shown for pumped zones (A7D, A9D, A11C, A7B, A9B, A11A)
5. Number of customers shown to approximate geographic locations

Campus

21 Fault Crossings
18 Landslide Zones



Legend

- Open Cut Reservoir
- Circular Tank Reservoir
- Pumping Plant
- Backbone Pipe with Gate or Butterfly Valve
- Flex Hose Connection (Shows two single outlet manifolds and hose)
- Pressure Regulator Valve Station
- New pipes for Summit East PP
- Flex-tend Hardward in Pipe

Hazards

- Fault Crossing (FC 1 to 21)
- Landslide Zone (Slide 1 to 18)

Site 14 - Summit Pressure Zone - Schematic Diagram

Seismic Design of Selected Pipelines for Landslide and Fault Hazards		
G&E Engineering Systems Inc.		
7/8/00	Rev. 0	Figure 14.2 Site 14 - Upgraded

Upgraded in 2021 (Identified in 1991.... 30 years from initial concept to final implementation... still more phases in the future)

Angus Flex Hose at EBMUD Fault Crossing

- Original Application
- 3 hoses, 12", 10" and 8" diameter
- Provides parallel capability to a 24" pipe across the Hayward fault, near Castro Valley
- Design features abandoned: above grade elbows, steel elbows, 10" and 8" diameter hose


ANGUS
ANGUS
FLEX

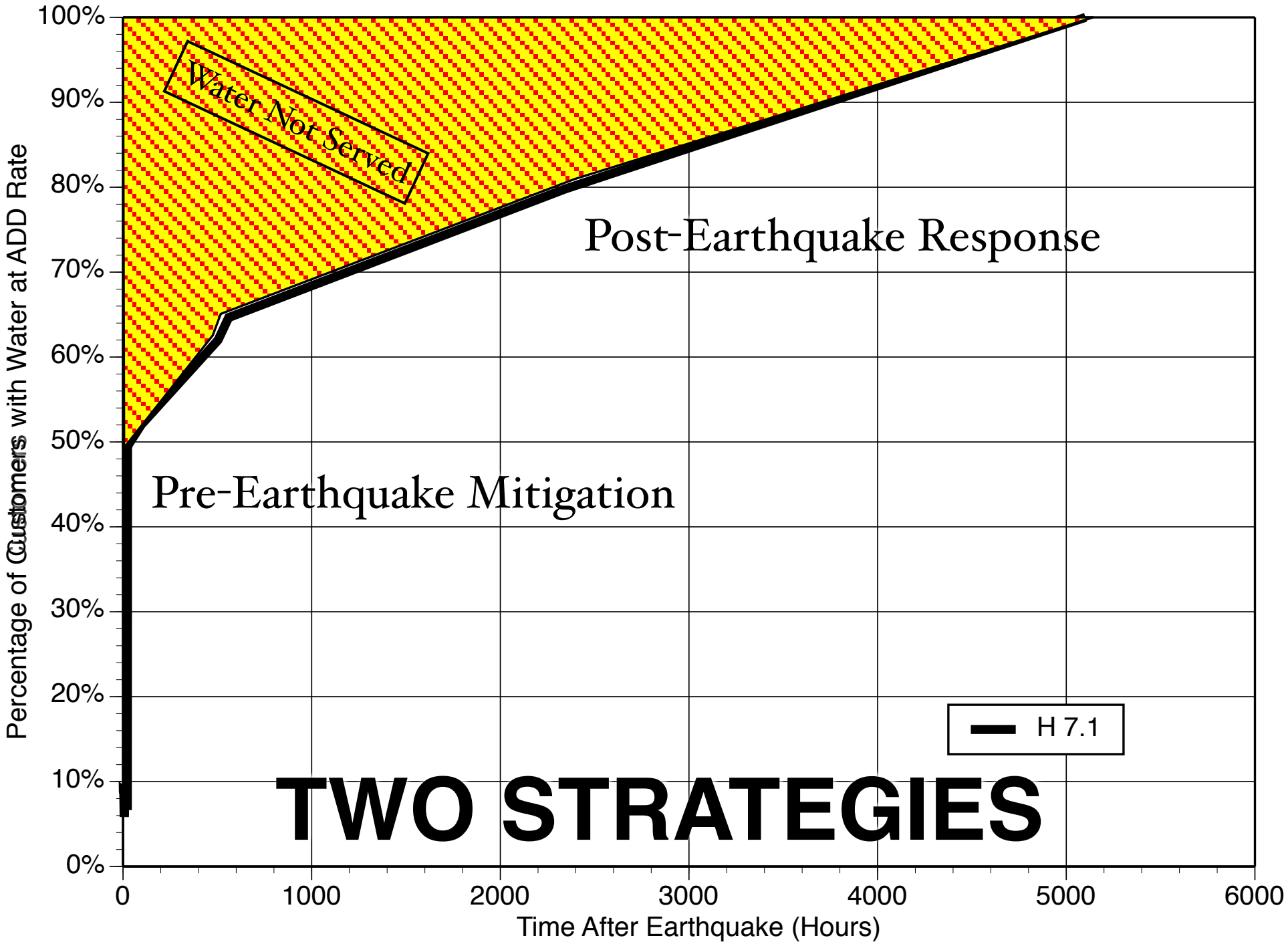

ANGUS


ANGUS

HDPE Application

- Light Weight
- Fused Fittings
- Flanged Fittings
- Can easily accommodate ±10% Strain

As Is


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of Customers with Water at ADD Rate
Water Not Served
Post-Earthquake Response
Pre-Earthquake Mitigation
H 7.1
TWO STRATEGIES
0
1000
2000
3000
4000
5000
6000
Time After Earthquake (Hours)

Performance Goals

4 Seismic Improvement Plans

(Part of CIP)

Service Goal	Description	As Is	SIP-1	SIP-2	SIP-3	SIP-4
1	Minimal secondary damage and risk to the public	■	■	●	●	●
2	Limit extensive damage to system facilities	■	■	■	■	●
3	All water introduced into the distribution system minimally disinfected	■	■	■	●	●
4	Provide limited fire service at fire hydrants for first 24 hours after the earthquake.	■	■	■	●	●
5	Normal fire service to all hydrants within 10 days	■	■	■	●	●
6	Hospitals, Critical Care, Emergency Relief Facilities: Potable water via distribution system or truck within 1 day.	■	●	●	●	●
7	Hospitals, Critical Care, Emergency Relief Facilities: Impaired service within 2 days	■	●	●	●	●
8	Hospitals, Critical Care, Emergency Relief Facilities: Normal service within 5 days	■	■	●	●	●
9	Other Users: Impaired service within 7 days	■	■	■	●	●
10	Other Users: Normal service within 10 days	■	■	■	●	●
	Goals Met	0	2	4	9	10

Can We Do Better?

- Option 1. Spend $202 million. DONE, 1991-2004. Fix tanks. Fix 81 pipes at landslides / faults. EXCLUDES pipe replacement. $3.60 charge for 20 years added to bi-monthly water bill.
- Option 2. Replace 3,000 miles of pipe with earthquake-resistant water pipe. Cost: $9 Billion. (or about $6,700 per student)
    - Benefit: 99%+ no water outage for first 2 days post-earthquake. Increase rent (3 person apartment) by $2,250 per year ($62 per student per month).
- Option 3. Do nothing. Some customers have LONG water outages.

How to Solve?

- Better pipes in liquefaction / FX / landslide PGD zones
  - HDPE (fusion / couplings). Kubota Chained pipes. Welded steel per ALA 2005, but not per AWWA M11 (D/t < 95)
- Tanks: updated D100 D110 ACI 350.3 ASCE 7 (R ≤ 2; Vertical EQ). R=3.25, 3.5, 4.5, 6 are dubious.
- Wells, WTPs, Tanks: Design all for PGDs
- Until then: preparedness, but this will not be of much help if too many fires break out

THE DAILY CALIFORNIAN

AX STOLEN!

Classes Will Be Excused At 10 o'Clock

Bear Crews Will Depart For Seattle

Ancient Ax Rivalry Climaxed by Successful Stanford Raid on Guards of Armored Car; Highways Filled by Avenging Californians