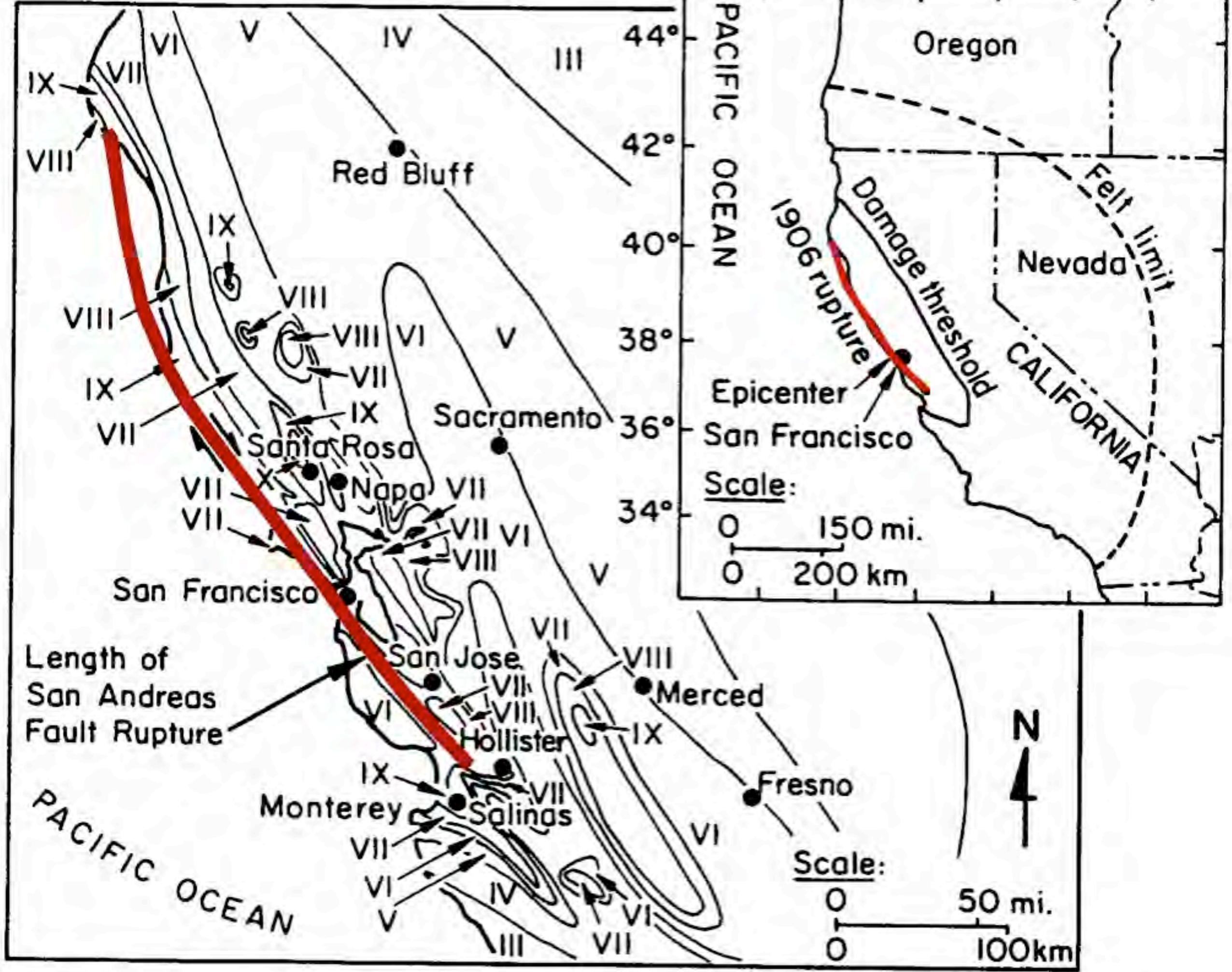


The 1906 San Francisco Earthquake and its Impact on the Water System

John Eiding
G&E Engineering Systems Inc
October 28, 2004

What Happened in 1906?

- M 7.8 Earthquake on San Andreas Fault
- April 18, 5:12 am, 1906



Fire Following Earthquake

285 page book, available
at:

<http://homepage.mac.com/eidinger/>





San Francisco City Hall (Steinbrugge)



Sacramento Street, Approaching Fire (Steinbrugge)



San Francisco 1906





RUINS OF SAN FRANCISCO
MILL IN FOREGROUND
LAWRENCE CAPTIVE AREA
4500 FEET ELEVATION

Photo taken on balloon, May 23, 1906
Looking South to Nob Hill, Union Square

Spring Valley Water Company offices were open on April 18, but burned out later.

Union Square

SVWC

Macy's

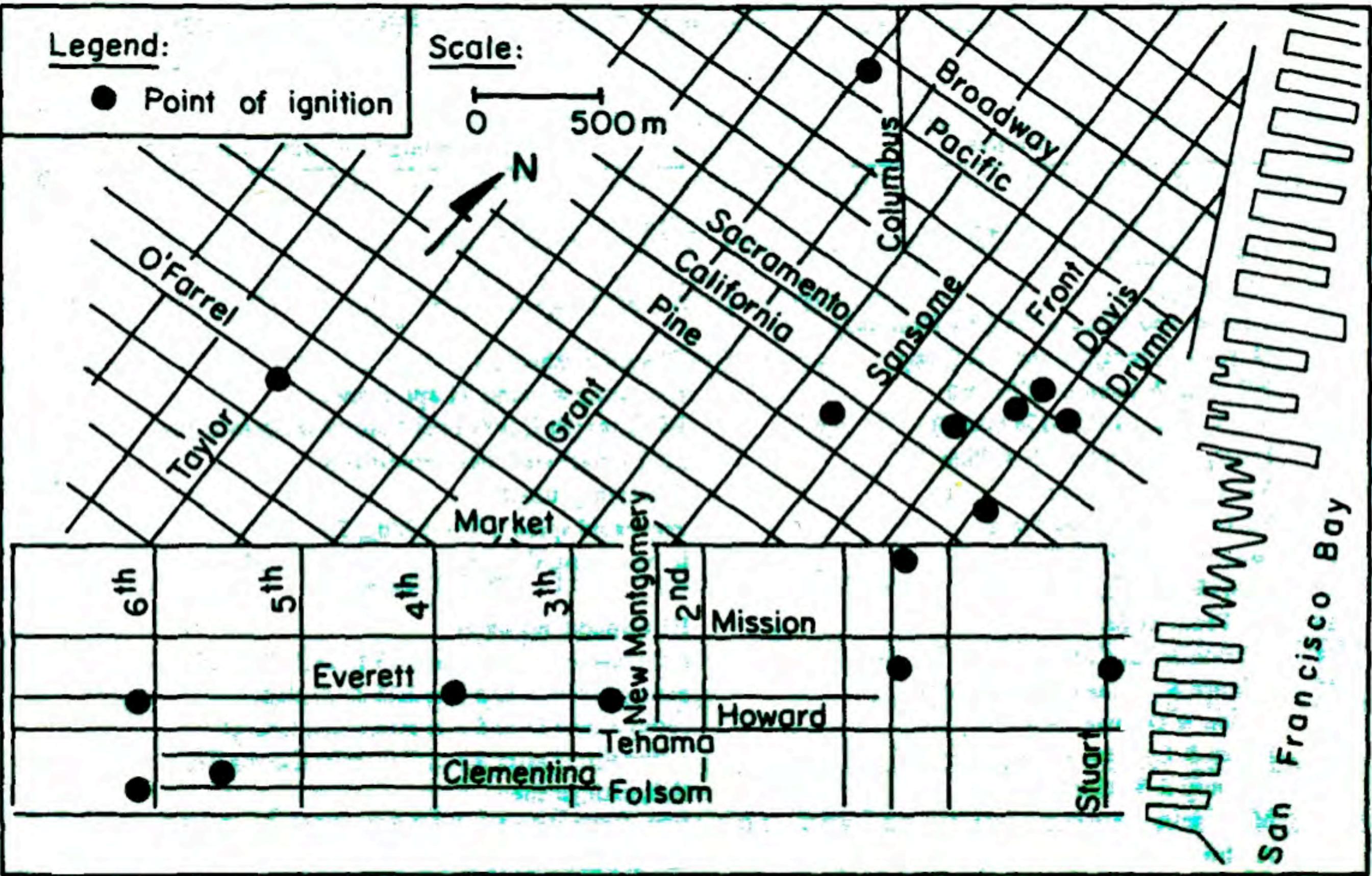


Legend:

● Point of ignition

Scale:

0 500 m



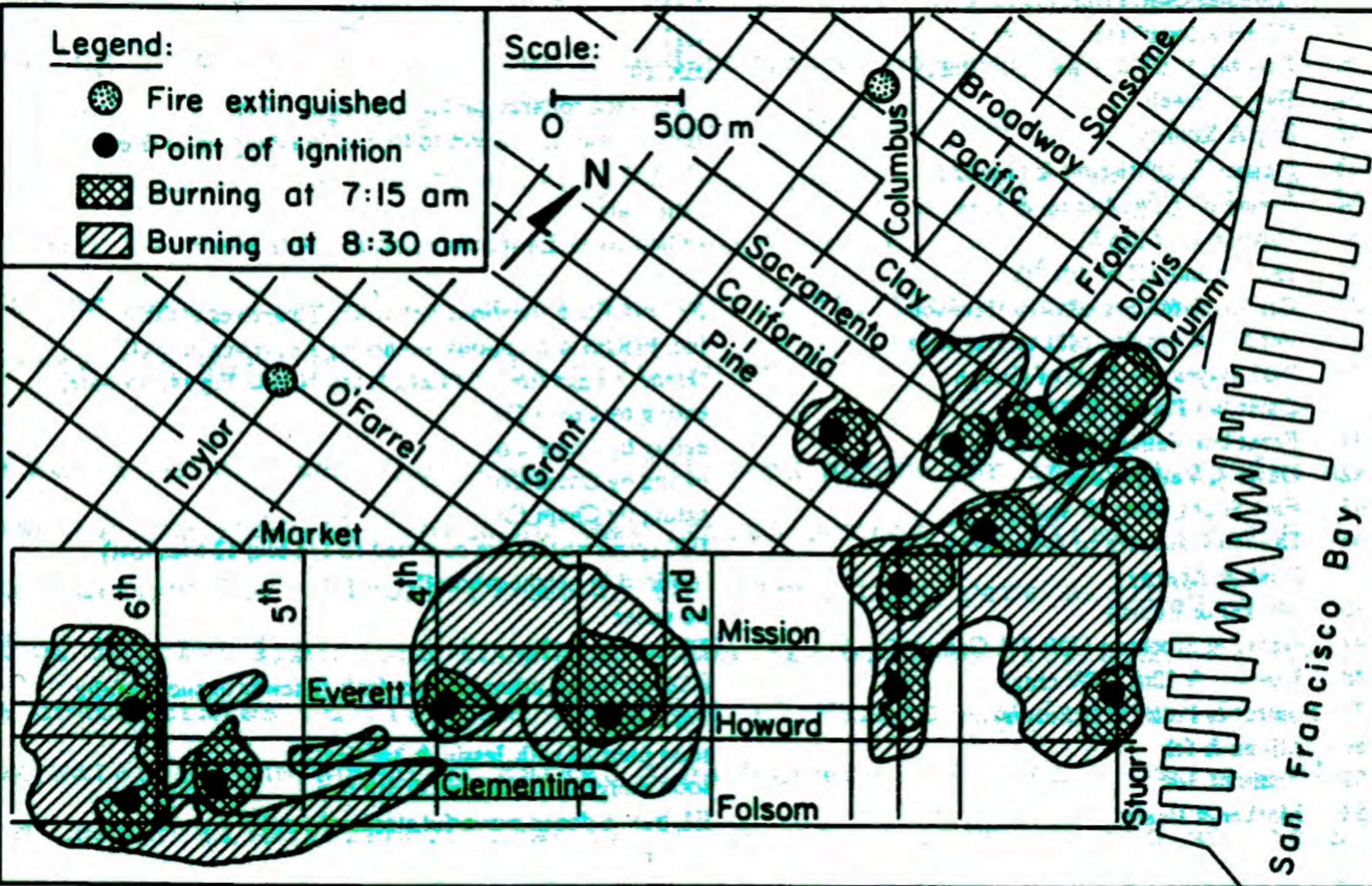
San Francisco Bay

Legend:

- Fire extinguished
- Point of ignition
- ▨ Burning at 7:15 am
- ▧ Burning at 8:30 am

Scale:

0 500 m



San Francisco Bay

The San Francisco Fire

April 18, 19 and 20, 1906

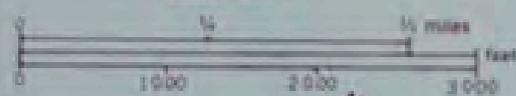
LEGEND



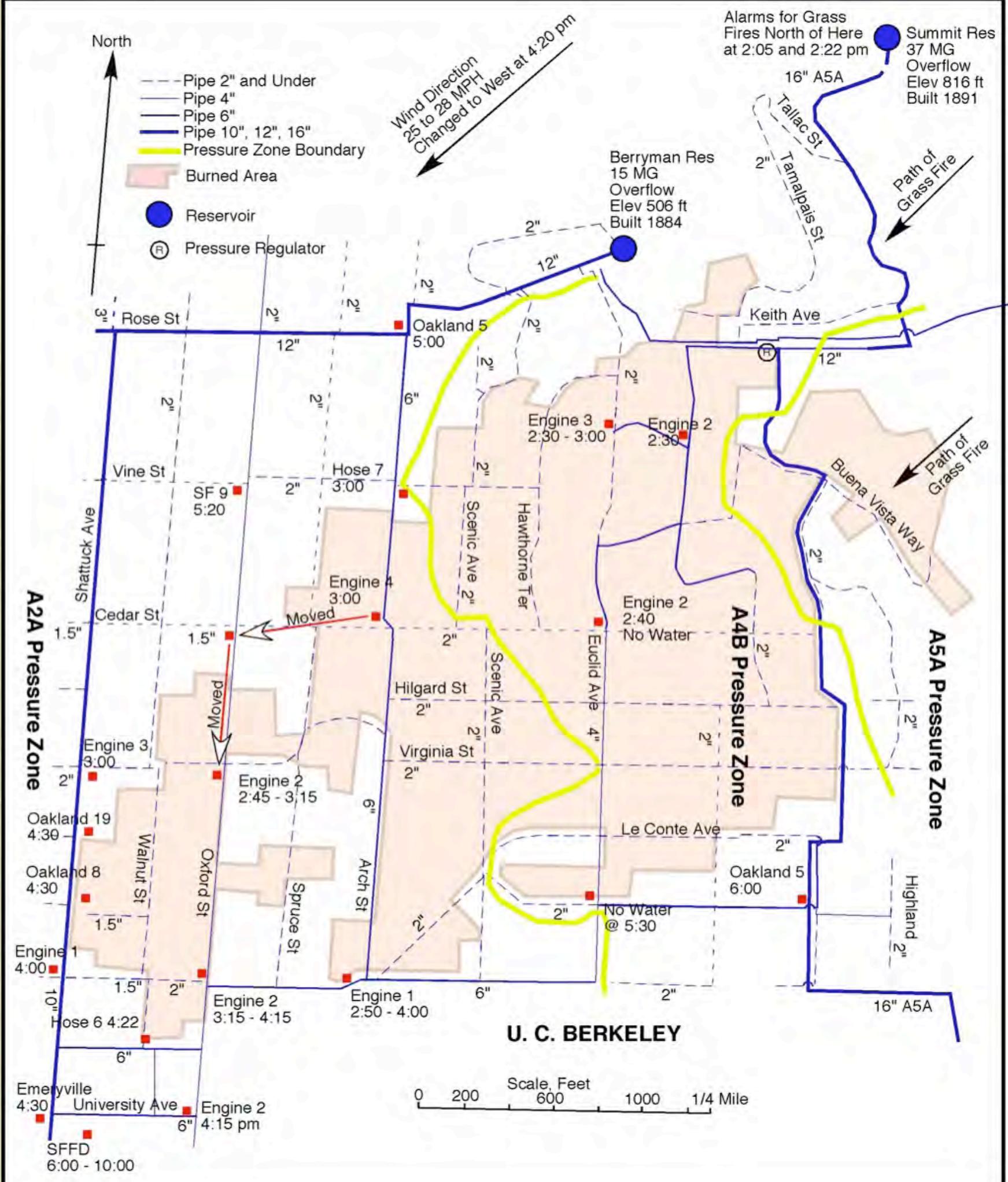
KEY TO NUMBERS ON MAP

- | | | | |
|---------------------|-----------------------|---------------------|---|
| ① Appraiser's bldg. | ⑧ Hall of Justice | ⑮ Old St. Mary's | ★ Points of origin of major fires |
| ② Call building | ⑨ House of the Flag | ⑯ Palace hotel | → Arrows indicate general course and direction of major fires |
| ③ City Hall | ⑩ Lafayette Square | ⑰ Portsmouth Square | |
| ④ Emporium | ⑪ Merchant's Exchange | ⑱ Post Office | |
| ⑤ Fairmont hotel | ⑫ Mills building | ⑲ St. Francis hotel | |
| ⑥ Ferry bldg. | ⑬ Mission Dolores | ⑳ Union Square | |
| ⑦ Flood building | ⑭ Monkey Block | ㉑ U.S. Mint | |

Scale of map



Berkeley 1923



Berkeley 1923

Panorama from Virginia Street and Scenic Avenue Looking Northerly



Berkeley 1923



Northridge
1994



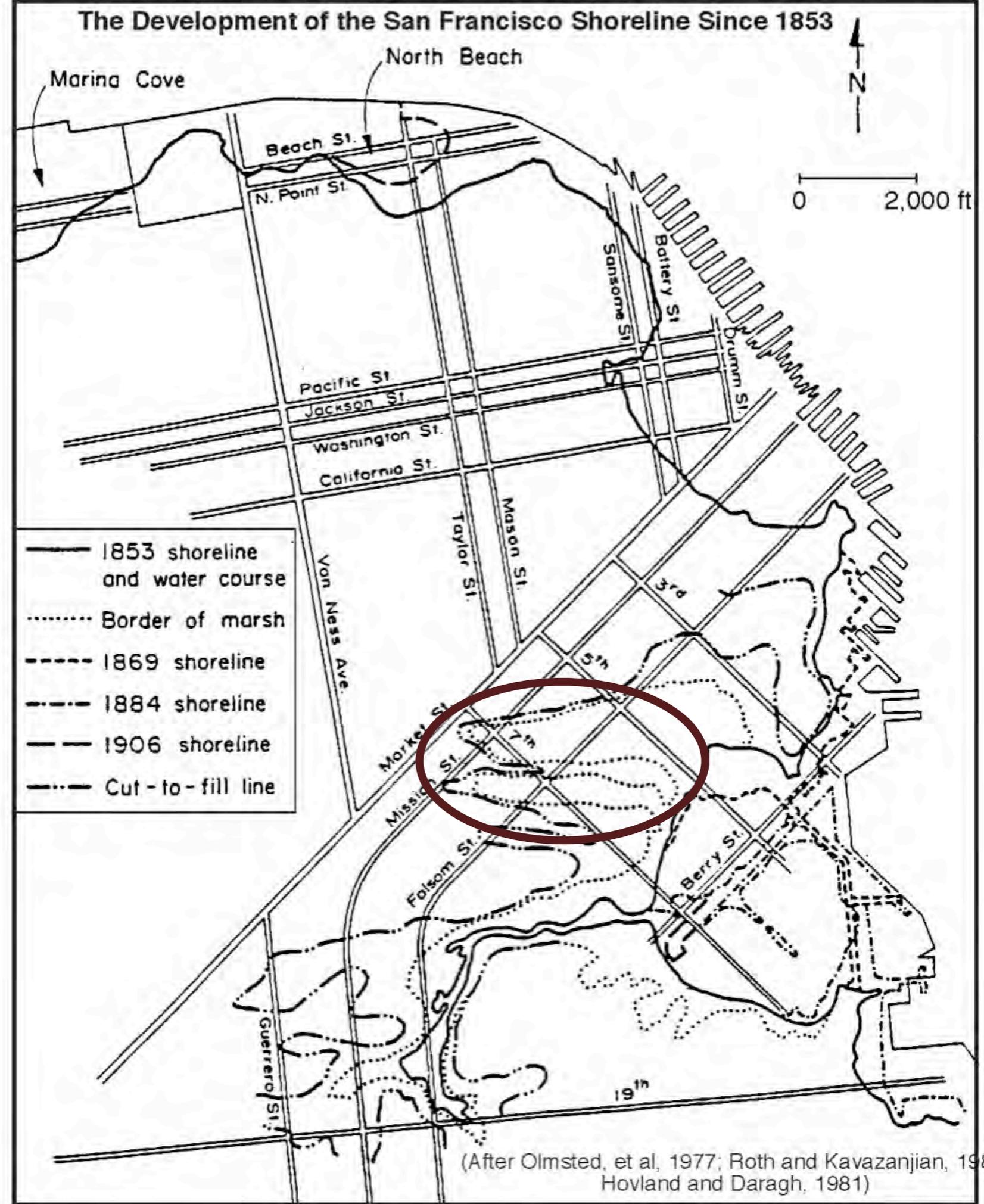
Kobe 1995



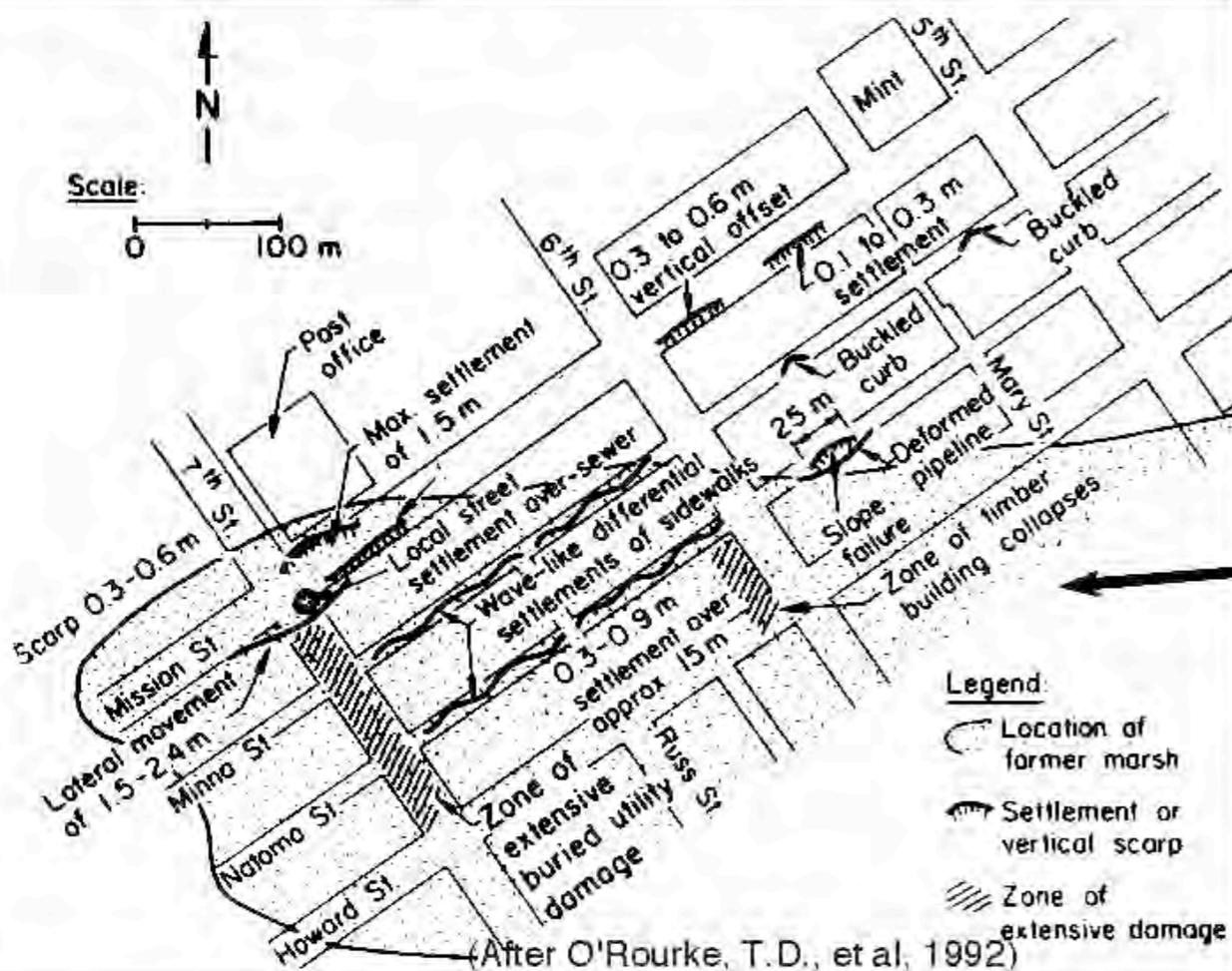
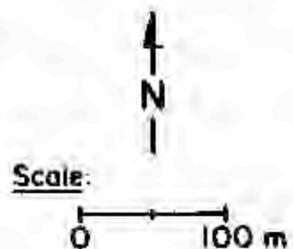
City Pipes

- 400 Miles of CI pipe in 1906
- 300 repairs to mains after 3 months
- Repairs to distribution pipe in areas with many fallen buildings required digging through the rubble to close all the broken service connections
- Repairs to distribution pipe in areas with large settlements took many months to complete

Marshes in
South of
Market Area
and
1906 Shoreline

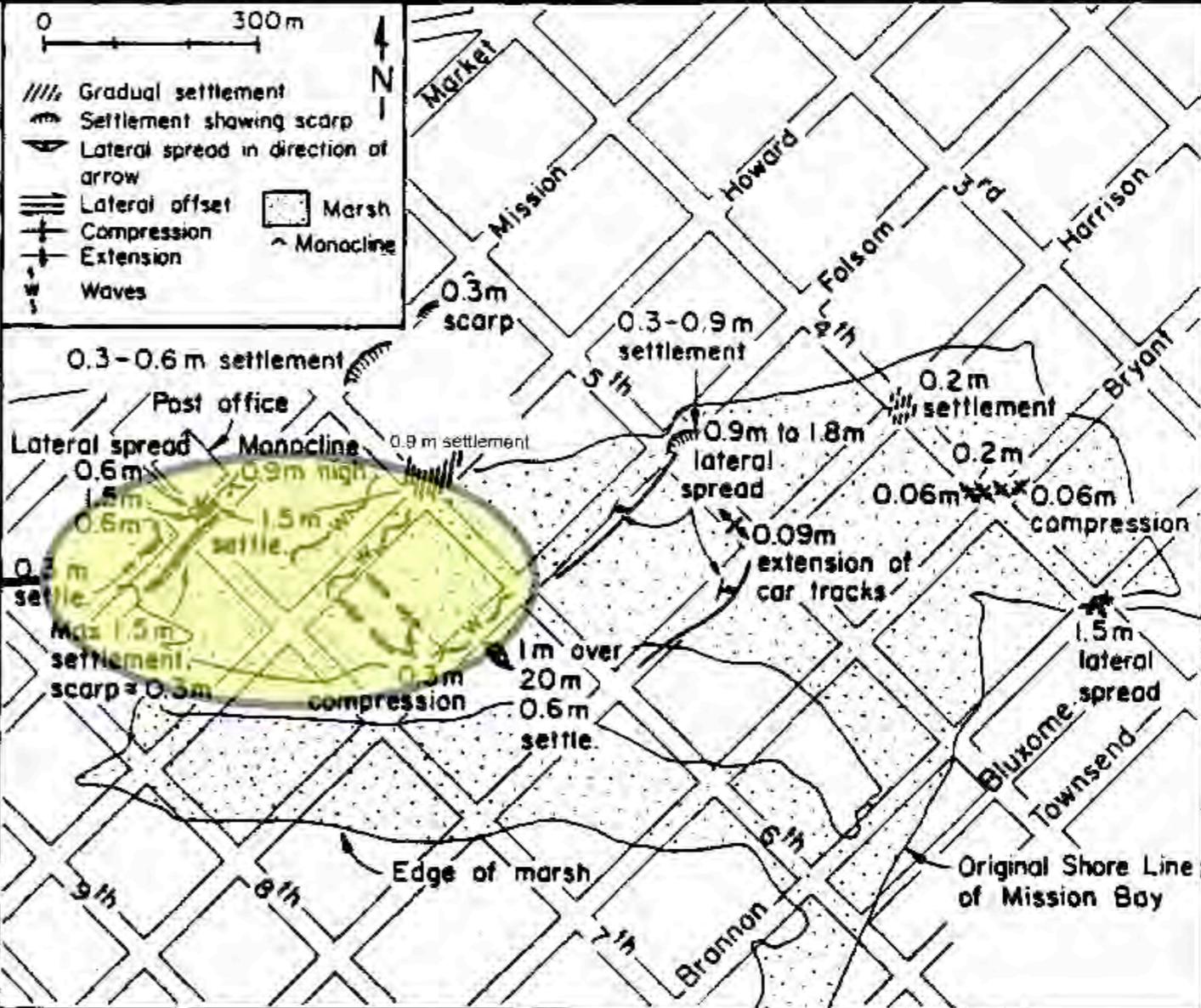
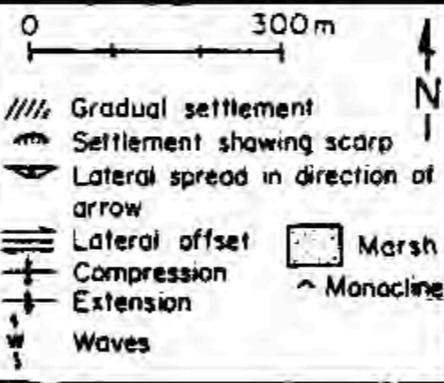


1906 Earthquake-Induced Ground Deformations



- Legend**
- Location of former marsh
 - Settlement or vertical scarp
 - Zone of extensive damage

(After O'Rourke, T.D., et al, 1992)



- Gradual settlement
- Settlement showing scarp
- Lateral spread in direction of arrow
- Lateral offset
- Compression
- Extension
- Waves
- Marsh
- Monocline

Pressure Zones

- University Mound (lowest level). Rapidly depressurized due to breaks in supply mains. No water for fighting fires.
- College Hill (medium level). Rapidly depressurized due to ruptured mains. College Hill Res (14 MGD) did not empty until April 19. Supply restored 62 hours later at 6 MGD rate
- La Honda (upper level). Lake Merced pumps had only a broken steam gate; this was replaced and pumps started April 18 3 pm providing 3 MGD (6 MGD later) rate to La Honda Res.

City Reservoirs

- University Mound (37 MG): Good order to the reservoir itself. No water supply as CS #1 was ruptured (thrown from trestles across marshes, 30 days for repair). Empty by April 20. Still empty May 4. Refill started May 18.
- College Hill (14 MG). Empty by April 20, Refilled once San Andreas pipe fixed in 62 hours.
- Lake Honda (33 MG). The earthquake cracked the bottom and sides of the liner. Taken out of service for a month. Lake Merced water bypassed the reservoir to serve the upper zone, but at 40 psi lower than water originally from Pilarcitos.
- Small reservoirs / tanks. Empty by April 20. Presidio Heights had no water until UM/CH water could be restored to Black Point pumps (16 days). Clarendon Heights restored once SA pipeline restored to CH reservoir.

Pumping Plants

- Only damage was a broken steam pipe, easily fixed. However, no water to pump.
- Lack of water in University Mound zone meant no water to Black Point or Clarendon Heights pumping plants.

Liquefaction in the City

- Most damage to Pipe occurred in filled areas
- Mostly, in the South of Market Area



67. East side of Howard Street between 17th and 18th showing effect on buildings



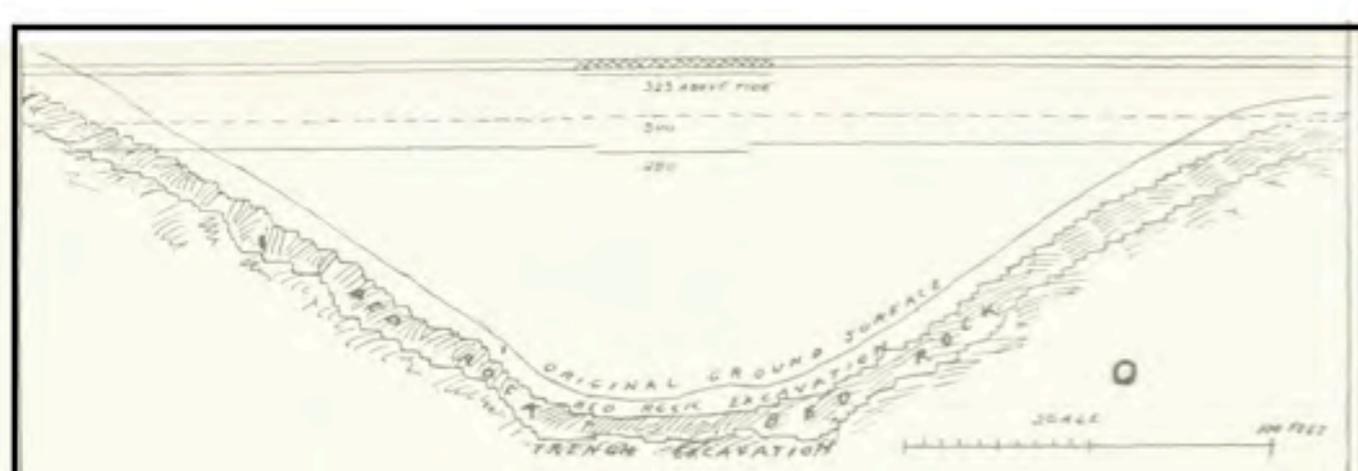
70. Howard Street at 7th. 16" pipe badly fractured



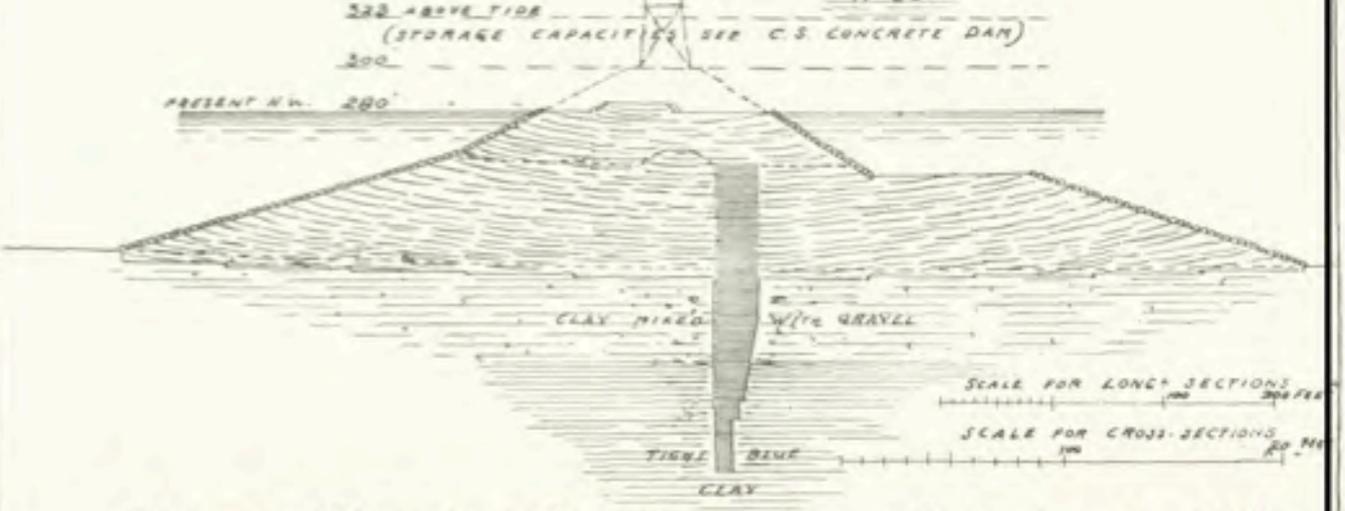
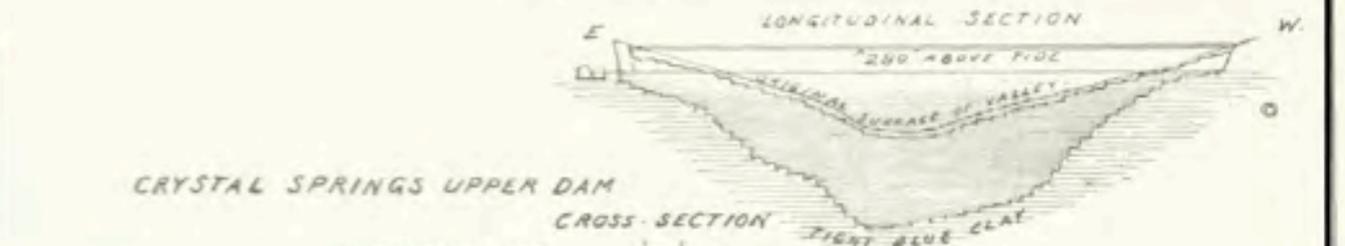
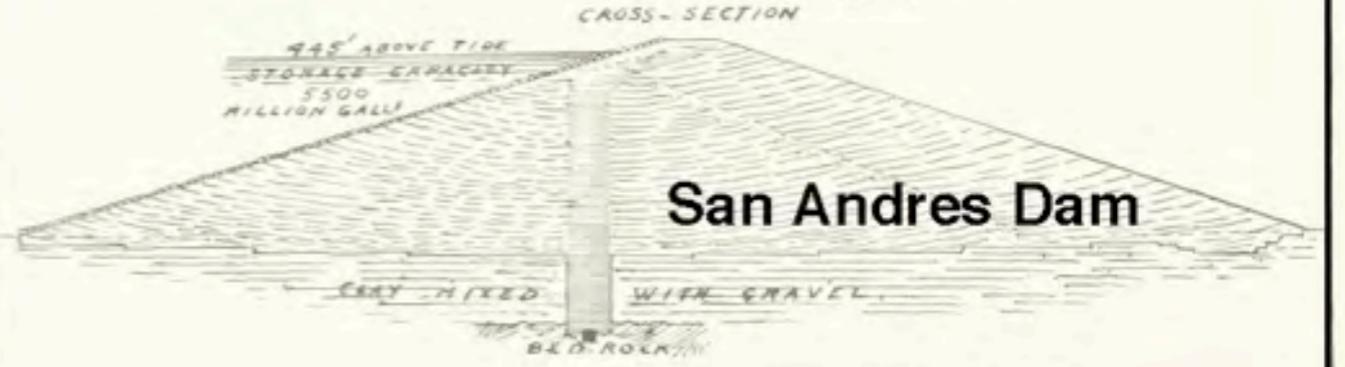
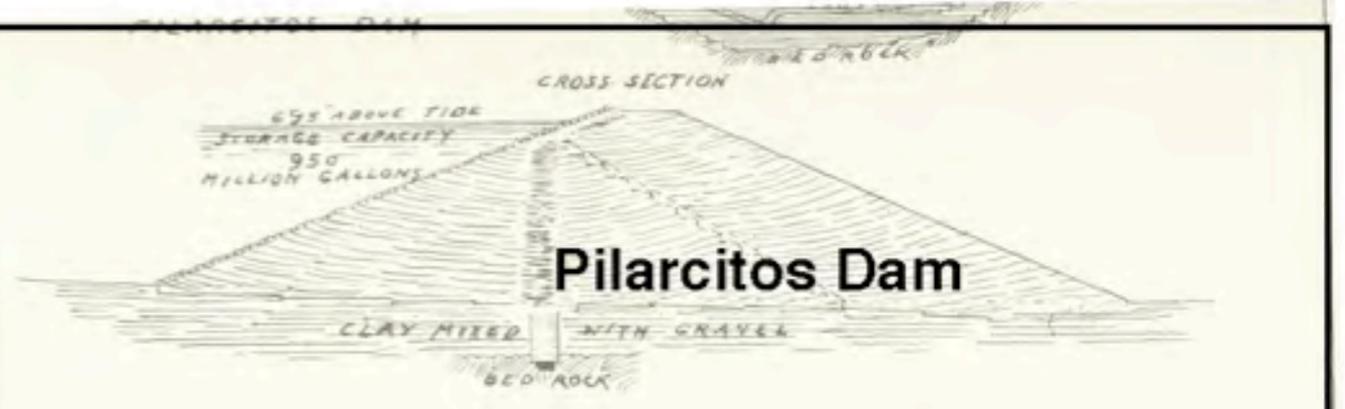
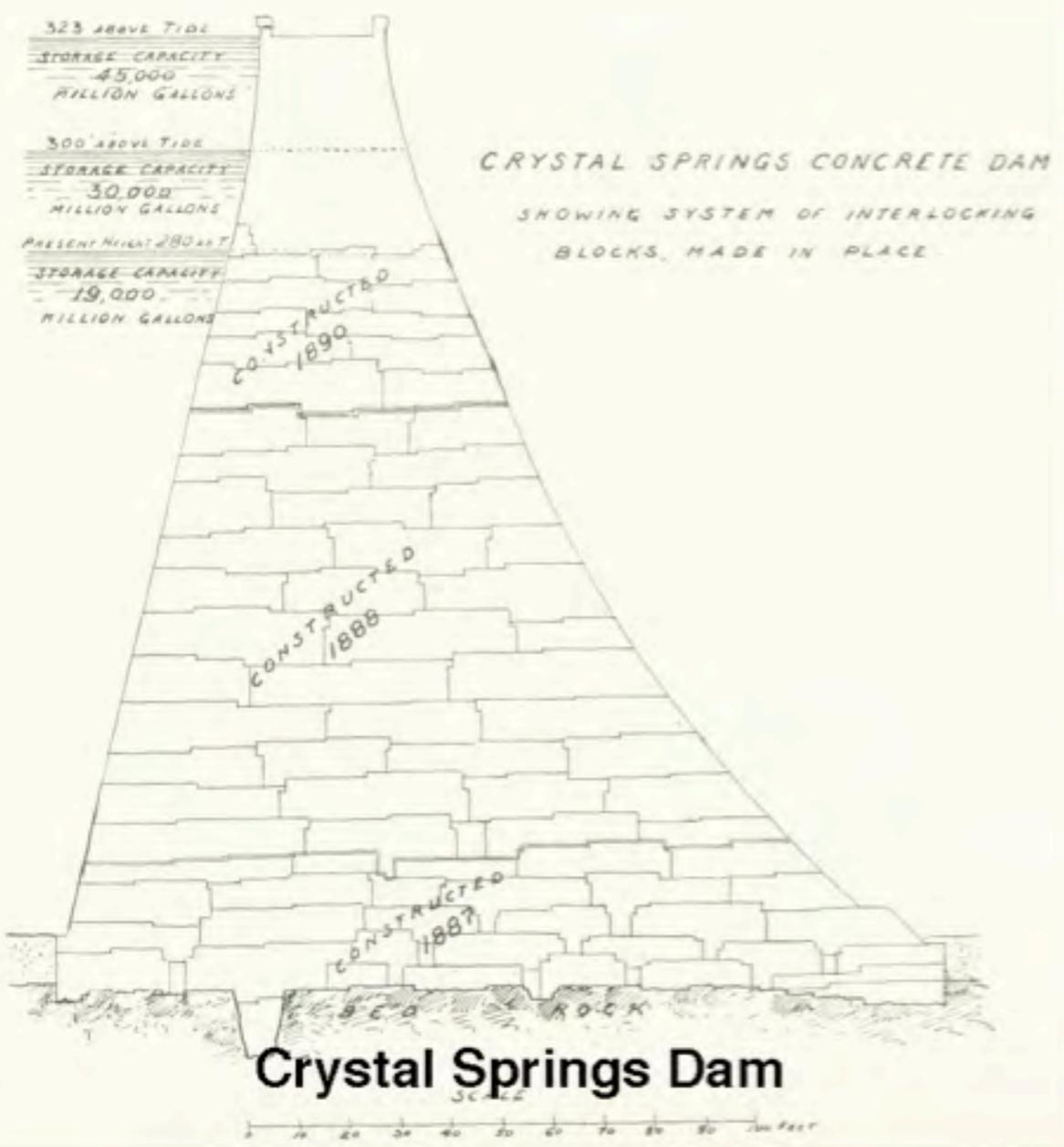
71. Street at waterfront with stuck "1 hp SUV"



77. Mission Street at 7th St at Post Office. 12" pipe ruptured



CROSS-SECTION



Upper Crystal Springs Dam (Highway 92)

Alameda 36" Pipeline
Brings Water to SF from Sunol
Crosses Bay Mud at Dumbarton
Minor damage - 2 minor leaks at 8" blowoffs,
1 slip joint pulled apart a few inches



1906 36" Alameda Pipeline



1906 1934 1923

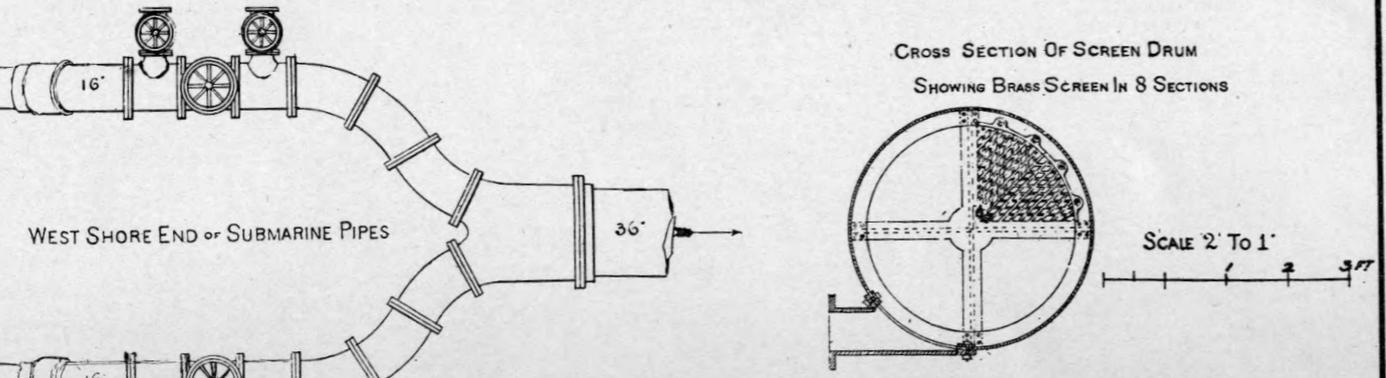
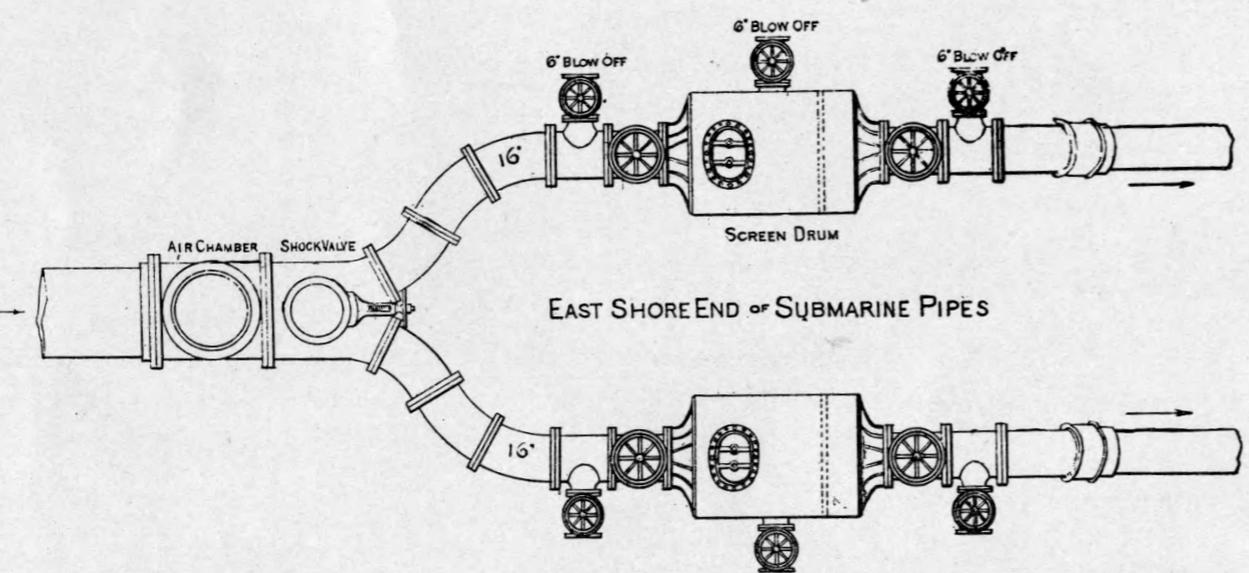
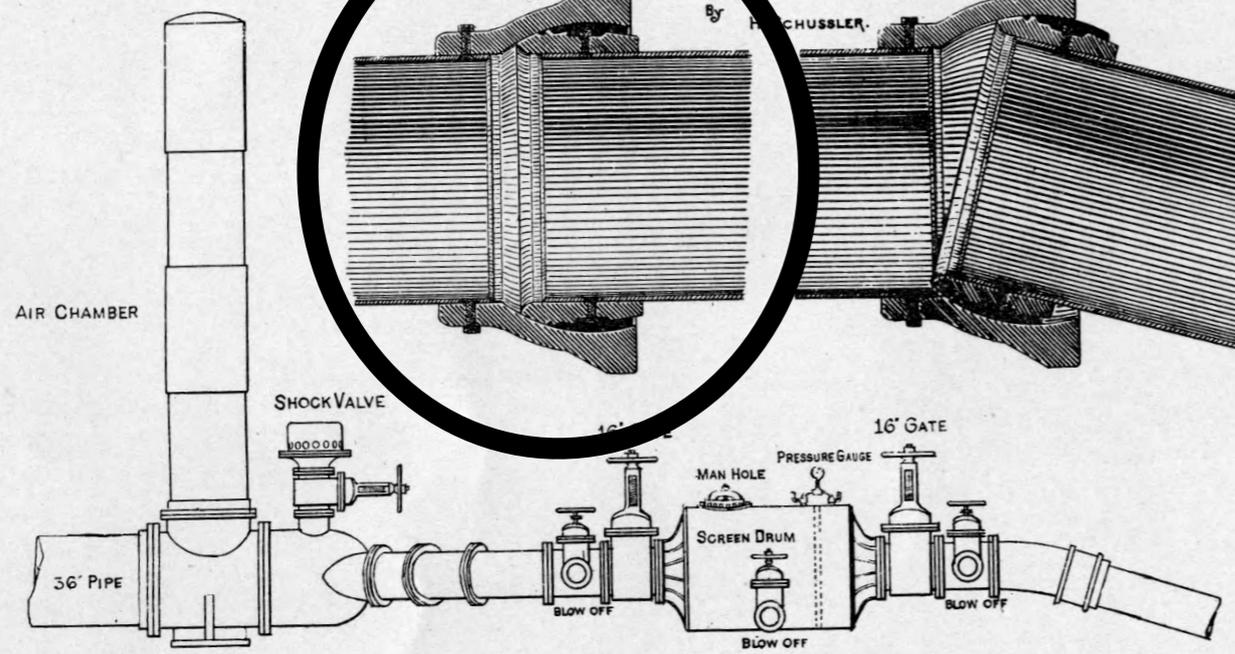
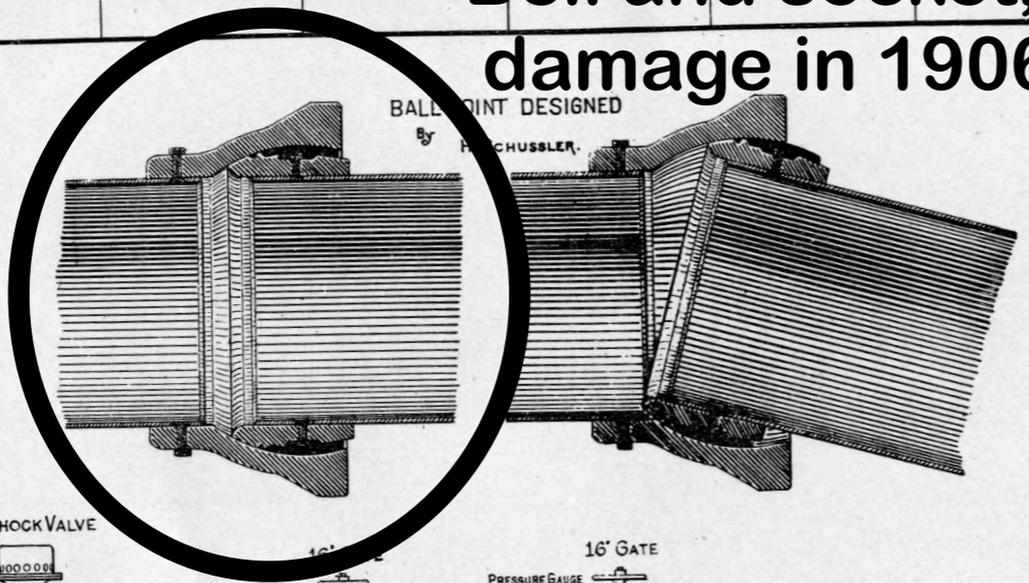




SAN FRANCISCO

WHERE SUBMARINE PIPES CROSS

2 16-inch and 2 22-inch pipes Bell and socket, No damage in 1906



PROFILE AND DETAILS OF DOUBLE LINE OF 16" SUBMARINE PIPES, LAID BY S.V.W.W. ACROSS BAY OF SAN FRANCISCO, NOV. 1887. HERMANN SCHUSSLER, CHIEF ENGINEER

PLAN AND SIDE VIEW OF SUBMARINE PIPE AND BARGE

SCALE 20 TO 1
60 FEET

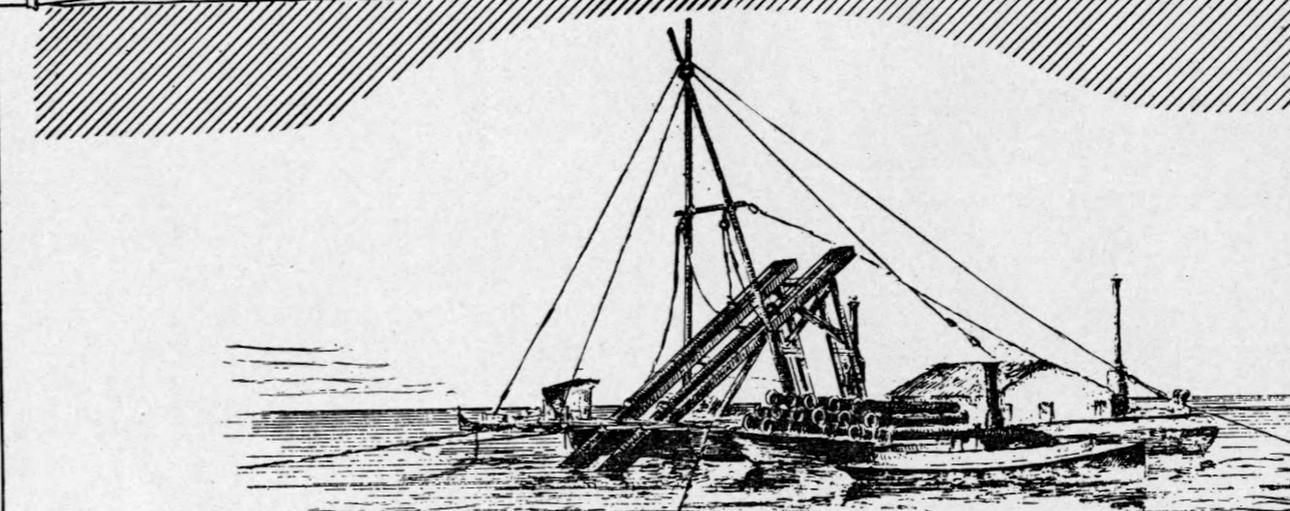
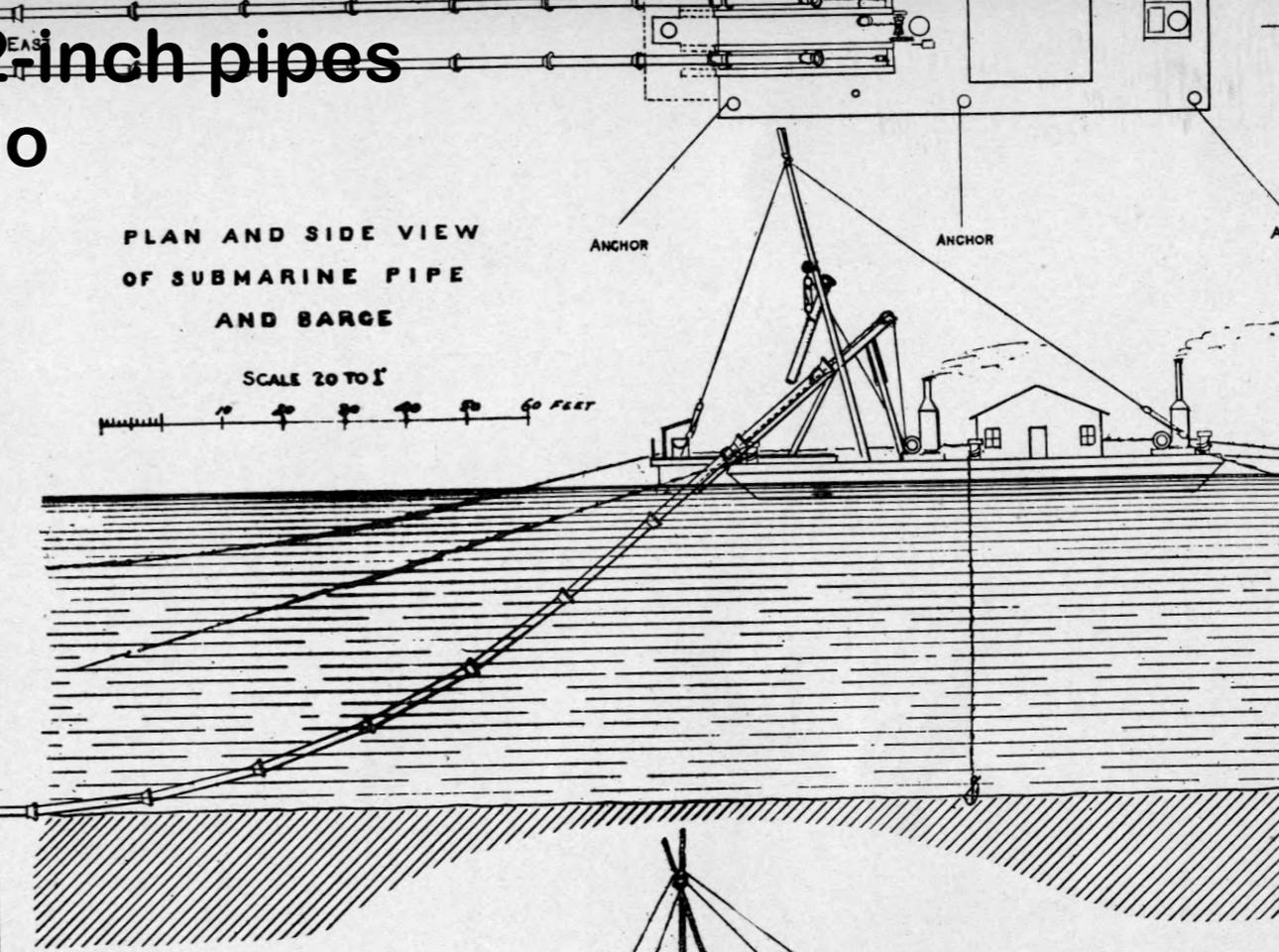
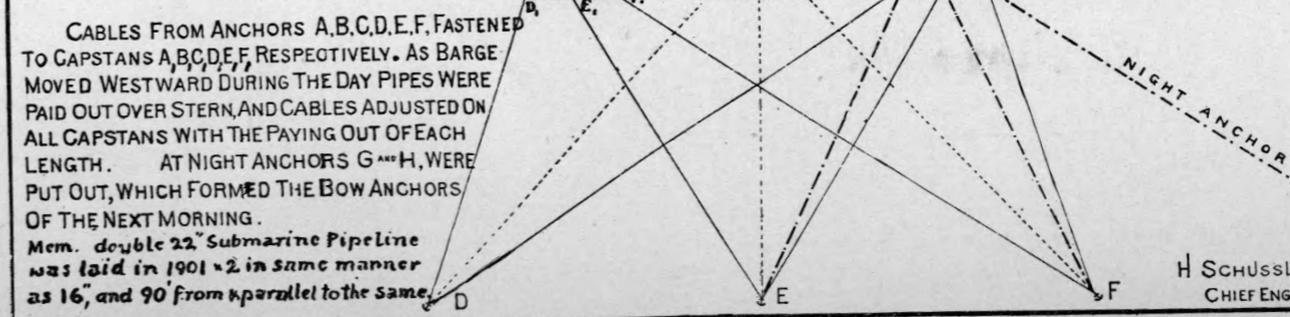


DIAGRAM SHOWING HANDLING OF ANCHORS

SCALE: 100' TO 1'
EAST
200 FEET
MORNING NOON EVENING
POSITION OF BARGE
CABLE
NIGHT ANCHOR



CABLES FROM ANCHORS A, B, C, D, E, F, FASTENED TO CAPSTANS A, B, C, D, E, F, RESPECTIVELY. AS BARGE MOVED WESTWARD DURING THE DAY PIPES WERE PAID OUT OVER STERN, AND CABLES ADJUSTED ON ALL CAPSTANS WITH THE PAYING OUT OF EACH LENGTH. AT NIGHT ANCHORS G AND H, WERE PUT OUT, WHICH FORMED THE BOW ANCHORS OF THE NEXT MORNING.
Mem. double 22" Submarine Pipeline was laid in 1901 & 2 in same manner as 16", and 90' from parallel to the same.

H. SCHUSSLER, CHIEF ENGINEER

Transmission Pipes On the Peninsula

- Pilarcitos (98 Year Outage)
- Crystal Springs No. 1 (30 Day Outage)
- San Andreas No. 1 (62 Hour Outage)

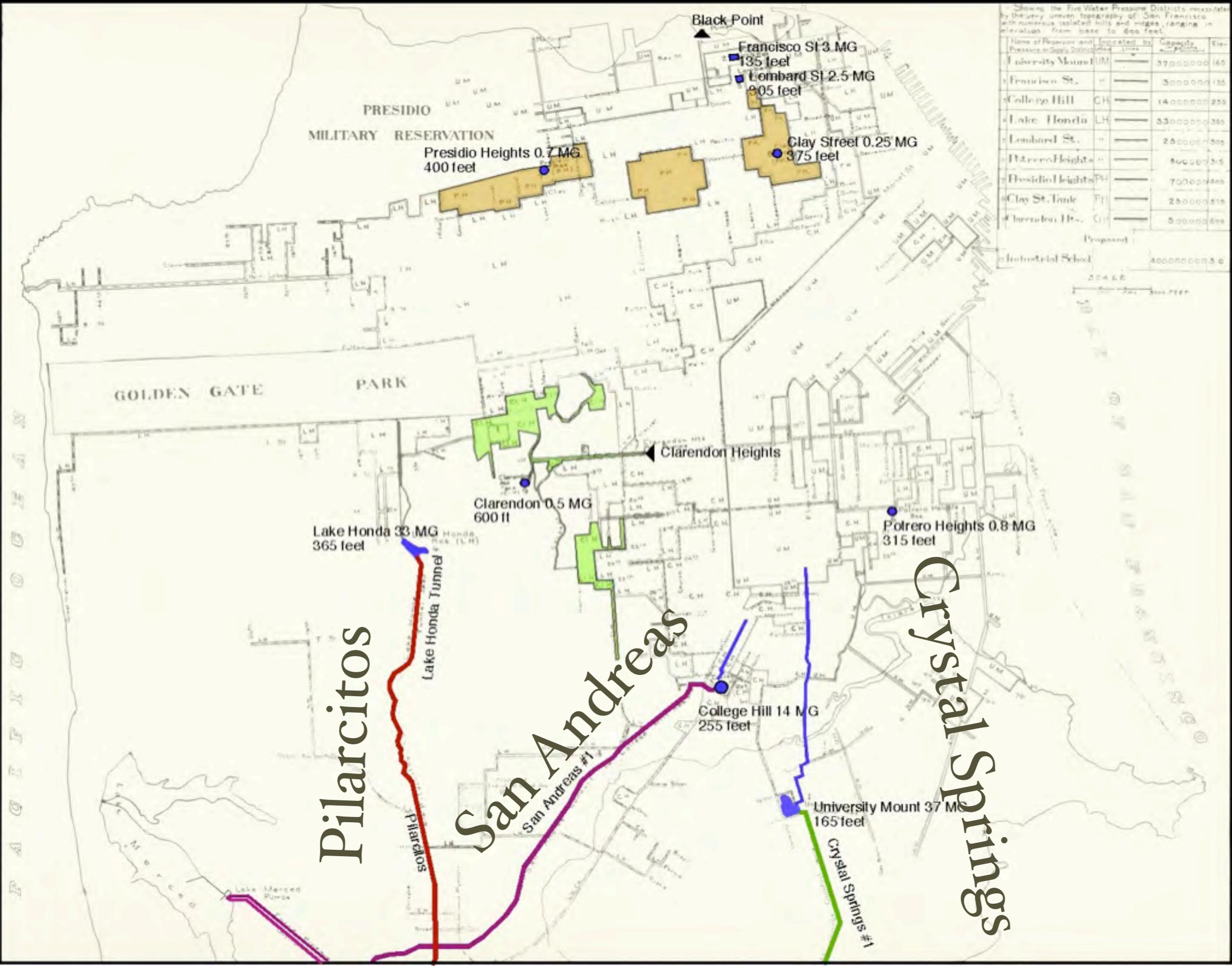
P A C I F I C O C E A N

Show the Fire Water Pressure Districts necessitate by the irregular topography of San Francisco with numerous isolated hills and ridges, ranging in elevation from base to 600 feet.

Name of Reservoir and Position in Supply District	Capacity in Millions of Gallons	Elevation in Feet
University Mount	37,000,000	165
Francisco St.	3,000,000	135
College Hill	14,000,000	255
Lake Honda	33,000,000	365
Lombard St.	2,500,000	305
Potrero Heights	8,000,000	315
Presidio Heights	7,000,000	400
Clay St. Tank	2,500,000	375
Clarendon Hts.	5,000,000	600

Proposed	Capacity in Millions of Gallons	Elevation in Feet
Industrial School	4,000,000	300

SCALE
1" = 1000'



Pilarcitos

San Andreas

Crystal Springs

Presidio Heights 0.7 MG
400 feet

Francisco St 3 MG
135 feet
Lombard St 2.5 MG
305 feet

Clay Street 0.25 MG
375 feet

Clarendon 0.5 MG
600 ft

Lake Honda 33 MG
365 feet

Potrero Heights 0.8 MG
315 feet

College Hill 14 MG
255 feet

University Mount 37 MG
165 feet

Lake Honda Tunnel

Crystal Springs #1

Pilarcitos

San Andreas #1

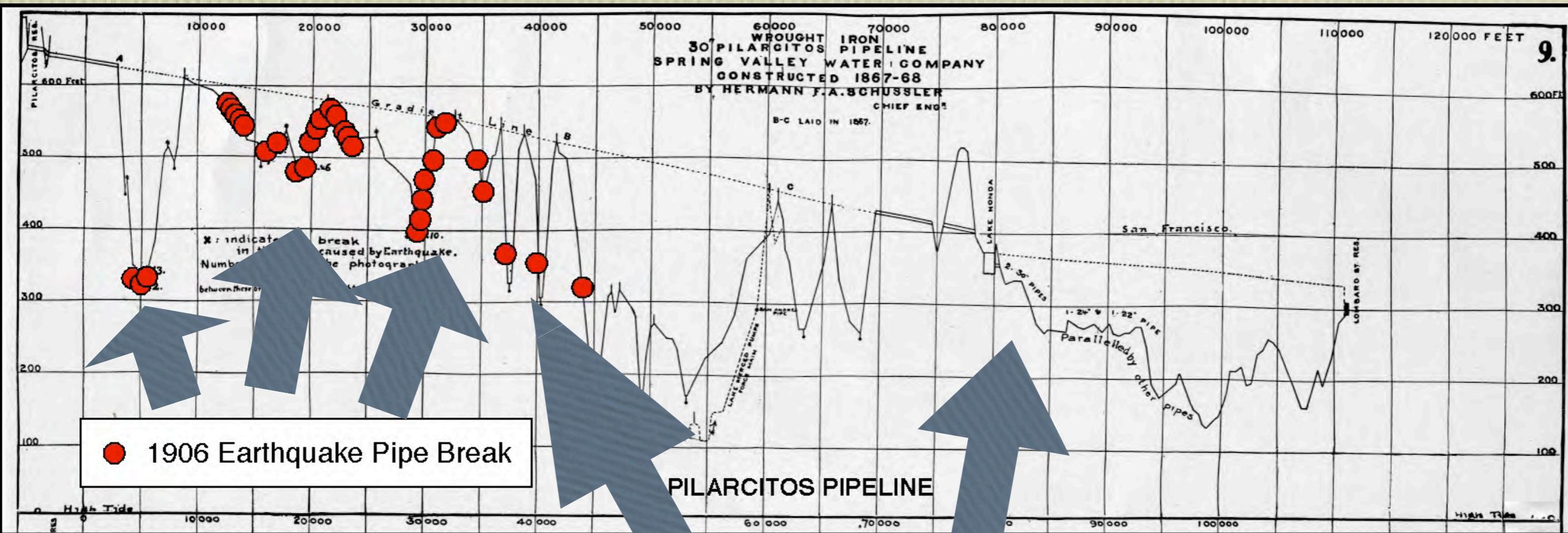
GOLDEN GATE PARK

PRESIDIO
MILITARY RESERVATION

Black Point

Lake Merced Pump

Pilarcitos Pipeline



Many fault crossings

Good Geology

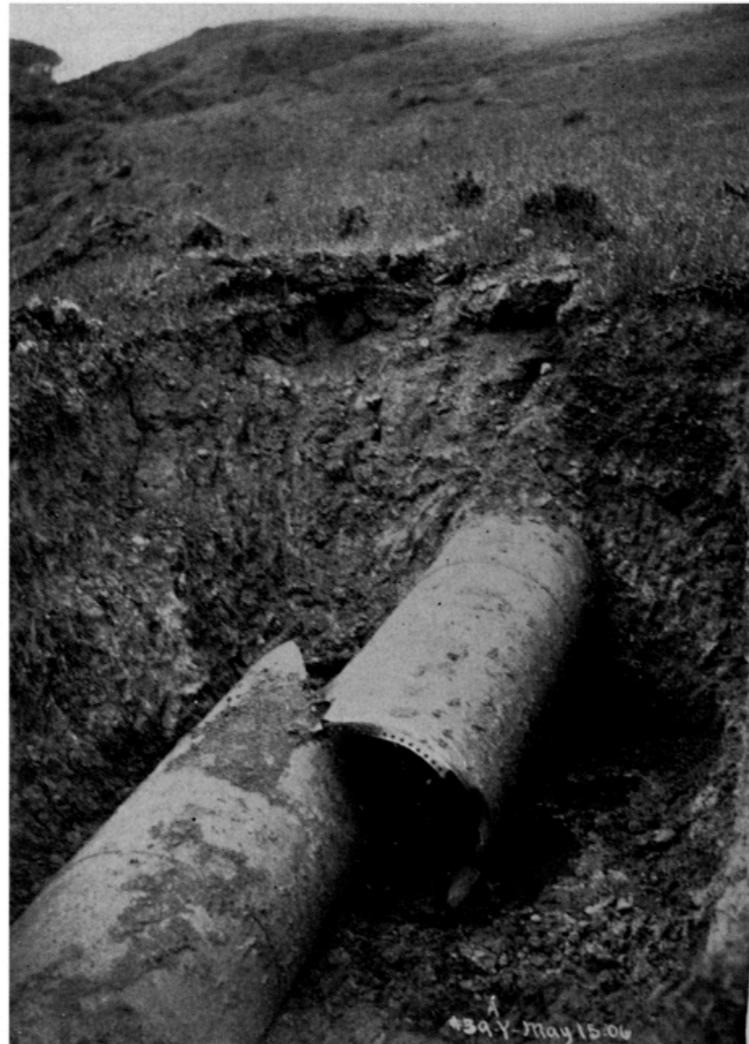
Timber trestles over canyons

Pilarcitos Pipeline

Normal supply from Pilarcitos Res to Lake Honda



3. 30" Pilarcitos Pipe pulled apart 2 feet

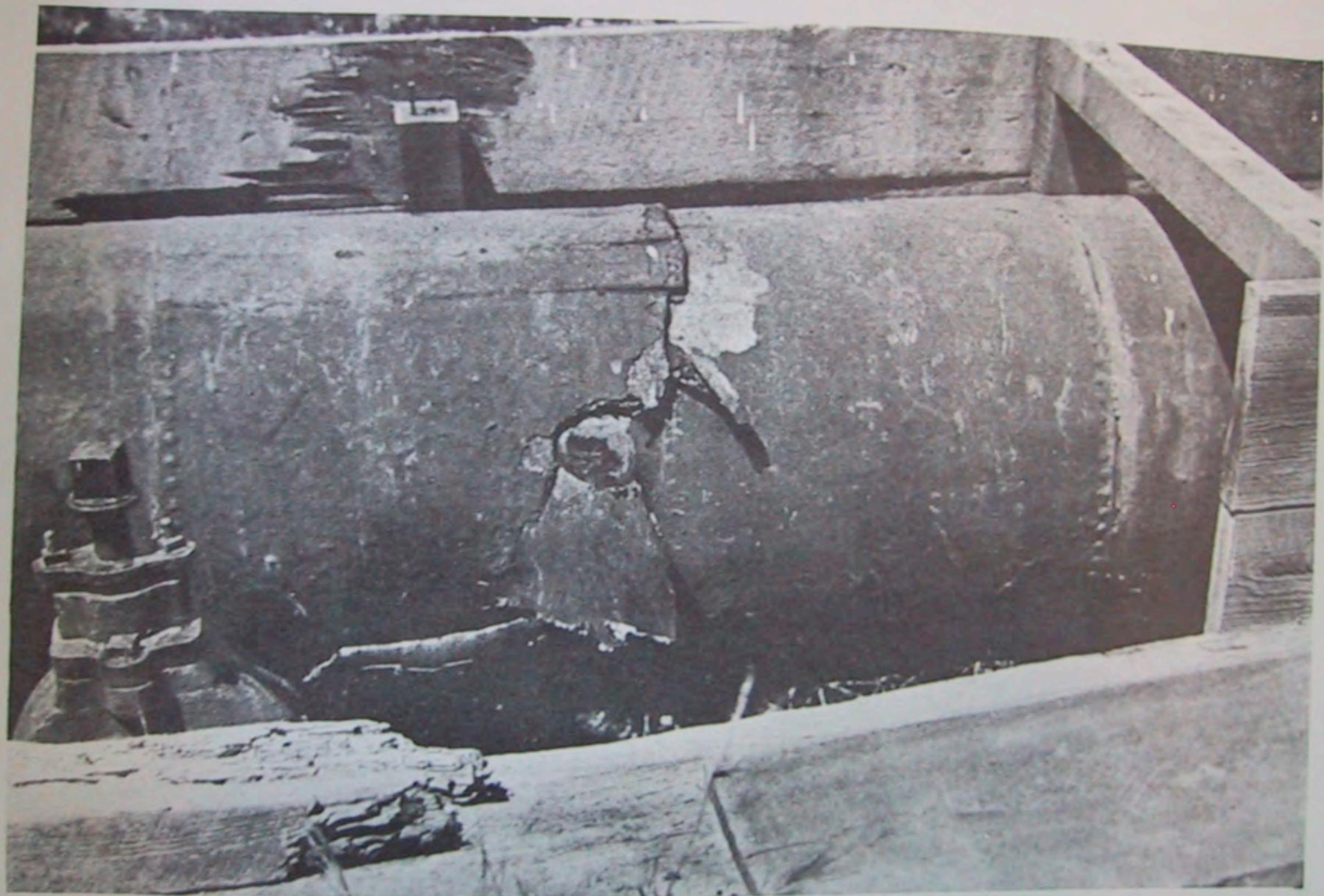


6. 30" Pilarcitos Pipe telescoped



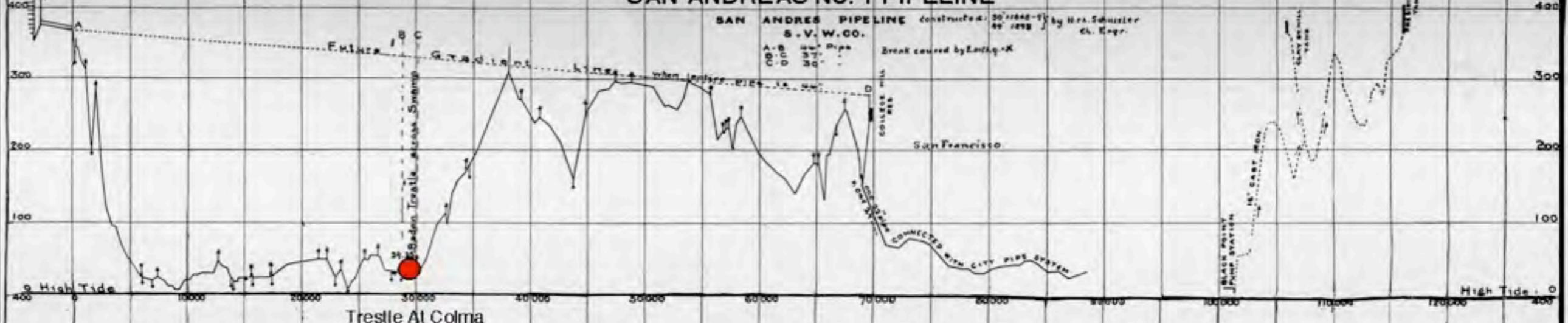
7. 30" Pilarcitos Pipe pulled apart 3 feet

This pipeline criss-crossed the San Andreas fault at many locations. It was also supported on wooden trestles across a few canyons, and suffered complete collapse. There was so much damage, the pipeline was abandoned south of Daly City. Today, Pilarcitos Reservoir dumps its water to San Andreas Reservoir.

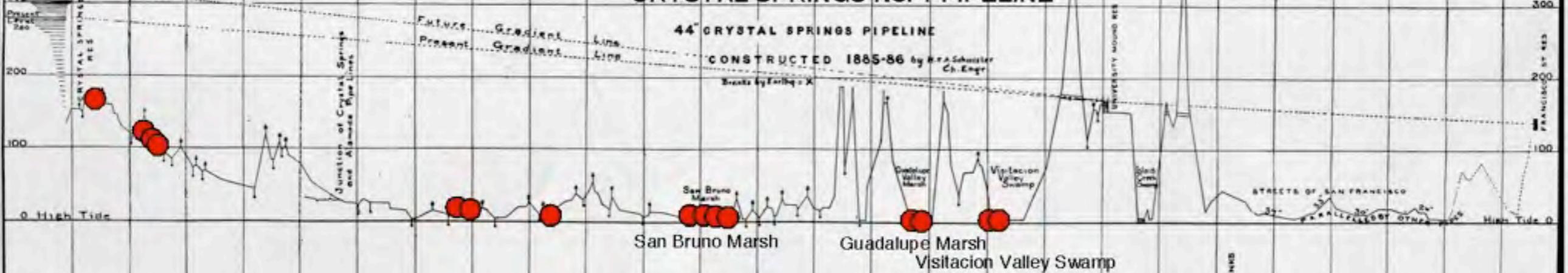


B. Thrust of 30-inch water-pipe by fault, northwest of San Andreas Lake. Amount of telescoping is 58 inches. A. C. L.

SAN ANDREAS No. 1 PIPELINE



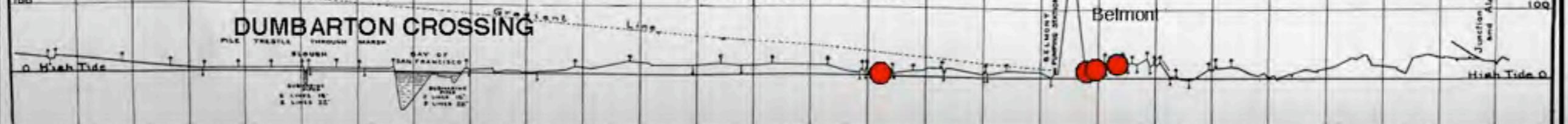
CRYSTAL SPRINGS No. 1 PIPELINE



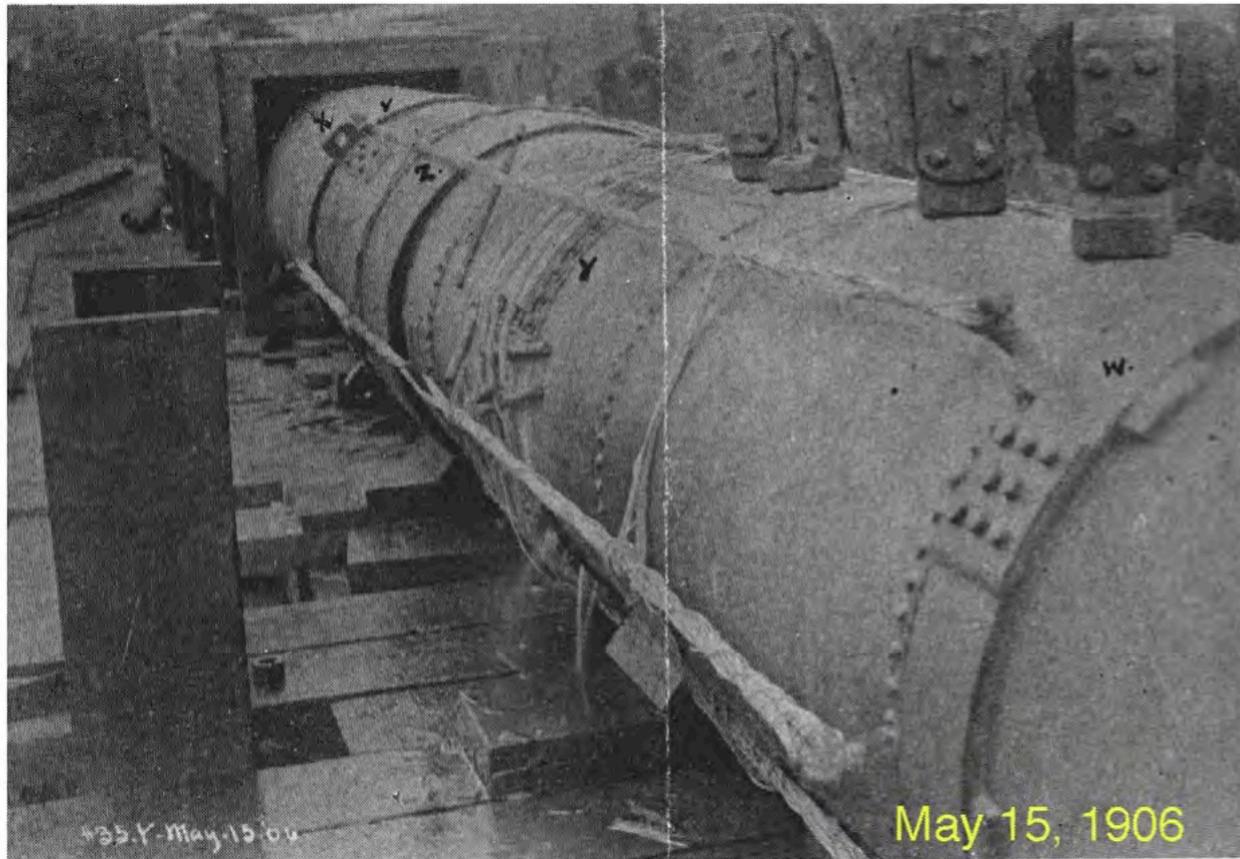
● 1906 Earthquake Pipe Break

ALAMEDA 36" PIPE LINE constructed 1887-9 }
SUNOL AQUEDUCT constructed 1889-1900 }
AND }
NILES AQUEDUCT constructed 1887-8 }
S. V. W. CO. doublets substituted 1902-1 }
Breaks caused by Earthq. - X

ALAMEDA PIPELINE



San Andreas Pipeline



24. 37" San Andreas Pipe Repair at Colma Creek



25. 37" San Andreas Pipe Repair

Badly fractured at 1 location, on a trestle crossing modern Colma Creek. It took 62 hours to fix it

Crystal Springs 44" Pipe

500 feet of 44" pipe
thrown from trestle
onto the mud flats

It took 30 days to
fix this.



22. 44" Crystal Springs Pipe at
San Bruno Marsh on reconstructed trestle



23. 44" Crystal Springs Pipe at
San Bruno Marsh on reconstructed trestle

Emergency Repairs and
Bypass Pipes
(One month later)



58. View south on Valencia Street showing new 24" and 16" pipes on top of pavement of sunken street



57. Repair of 37" wrought iron pipe on Harrison Street



59. Valencia Street showing above ground emergency pipe. The street that settled 5 feet at the point A

Other Areas

Santa Clara
1906





Water Tank

Inverness



1906 Lessons Learned

- SFFD built and maintains a redundant high pressure pipeline system for fire fighting
- SFPUC built San Andreas #2, #3 and Crystal Springs #2, #3 pipelines are routed around (or under) the liquefaction zones of 1906
- Not a single SFPUC pipeline crosses the San Andreas fault

Questions and Answers