SEISMIC ASSESSMENT OF THE SAN DIEGO WATER SYSTEM

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ABSTRACT

The City of San Diego water system serves 1,200,000 people. We examine how this water system behaves under scenario earthquakes on the Rose Canyon, Silver Strand, La Nacion and Elsinore faults. The system is exposed to ground shaking, liquefaction, landslide and surface faulting hazards. The city is microzoned using regional and local geologic information into areas with high or low liquefaction potential. Geotechnical models relate the probability of PGA, PGV, and PGD (settlement, lateral spread, downslope movement, fault offset) versus the localized hazard. The water system is modeled with 3,100 miles of buried pipelines, and all tanks, pumping plants, outlet towers and water treatment plants. The performance of the water system is analyzed on a pressure zone basis, with a total of 99 zones. Analyses are done using ARCVIEW and a specialized GIS software package (SERA) using Monte Carlo simulation techniques. The performance of the system is measured using performance goals (life safety, fire loss, hospital and customer service).

The Water System

The San Diego Water Distribution System is composed of about 3,100 miles of distribution pipe, 3 water treatment plants, 51 pump stations, 31 treated water reservoirs, 14 pressure tanks, serving 99 pressure zones. The 3 water treatment plants get raw water either from the City's own raw water reservoirs, or directly from the San Diego County Water Authority aqueducts, which deliver water from the Colorado River and the State Water project to the San Diego region. These aqueducts are also used to fill some of the City's raw water storage reservoirs.

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Seismic Environment

Fig. 1. Faults Near San Diego Service Area

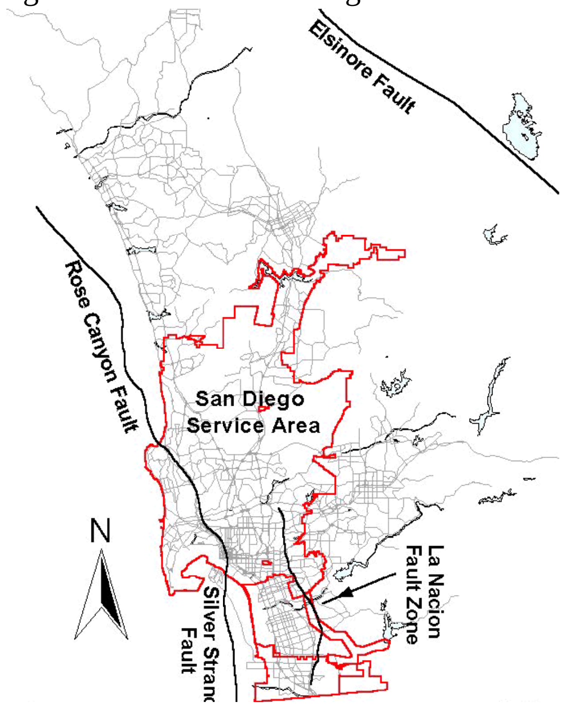
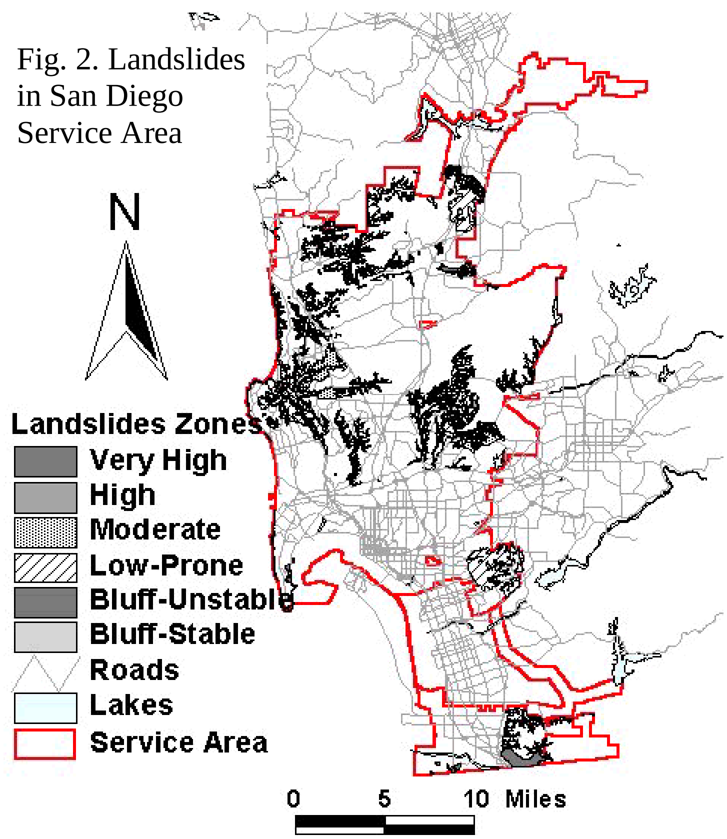


Fig. 1 shows a map of the City of San Diego. Also shown in this map is the service area boundary for the City's water system, as well as the locations of the faults considered in the current analysis. These faults are the Rose Canyon, Sliver Strand, Elsinore and the La Nacion fault zone. Five scenario earthquakes were considered for the seismic vulnerability assessment: Rose Canyon – Silver Strand M 7.2, rupturing from La Jolla to Mexico; Rose Canyon M 6.5, rupturing from La Jolla to Mission Bay; Silver Strand M 6.5, rupturing from downtown to Mexico (matches the CDMG SP-100 1990 scenario); Elsinore M7.4; and La Nacion M 6.6. The La Nacion fault zone is mapped in the southeast portion of San Diego, and is not considered active; however, we consider it on a scenario basis, recognizing that retrofits to accommodate this event may not be cost effective on a risk basis.

The water system is exposed to ground shaking, liquefaction, landslide and surface faulting hazards. Figs. 2 and 3 show the mapped liquefaction and landslide zones. The liquefaction zones were characterized as being in "high" or "low" susceptibilities. The landslide zones were characterized as being in one of nine susceptibilities; Fig. 2 shows six of these zones. Each landslide or liquefaction zone is digitized as a polygon; typical boundary accuracy is ± 20 feet. There are over 240,000

Fig. 2. Landslides in San Diego Service Area



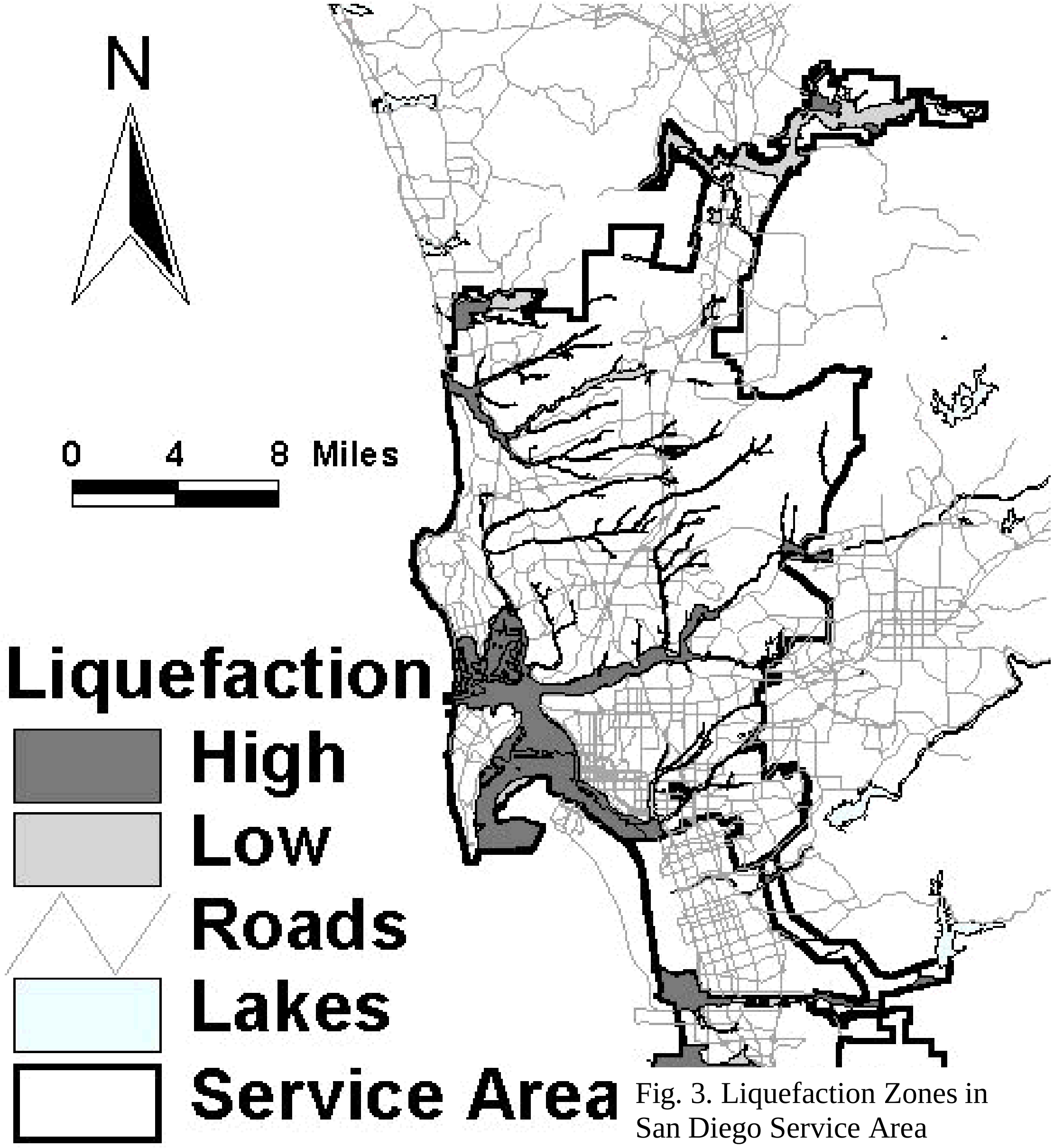


Fig. 3. Liquefaction Zones in San Diego Service Area

digitized points used to characterize these hazard zones.

GIS Analysis

A GIS analysis was performed for the pipeline inventory. A polygon-based method was used to consider the hazards. Arbitrary assumptions inherent when using "cell" type GIS analyses are avoided, albeit at a CPU time processing penalty. For example, the model uses over 240,000 points to digitize the 2,000± hazard polygons, and 1,100,000 points to digitize the 3,100 miles of pipe. This averages to about any digitization point for every 15 feet of pipeline. The results of the GIS analysis are in Table 1.

Table 1. Length of Pipes in Various Hazard Zones

Hazard	Cast Iron	Cast Iron Cement Lined	Steel Cement Lined	Steel	Steel Cement Lined and Coated, Welded Joints	Asbestos Cement	PVC	Rein. Concrete Steel Cylinder	Prestress Concrete Steel Cylinder	Steel Cylinder Rod Wrap	Ductile Iron	Unknown	Total
Fault Crossings													
Rose Canyon	28	2	0	3	0	62	1	2	0	1	0	11	110
Silver Strand	0	0	0	0	0	2	2	0	0	0	0	1	5
La Nacion	12	0	0	1	2	55	11	4	0	3	1	12	101
Soil Conditions													
Rock / Rock Like	156.07	24.45	10.52	37.37	14.38	1774.45	257.45	68.10	10.23	83.88	22.37	128.79	2588.06
Firm Soil	76.27	11.28	0.32	5.20	1.64	306.50	43.00	13.51	2.46	8.09	3.49	53.51	525.27
Liquefaction Conditions													0.00
High Liquefaction	16.84	5.15	0.14	5.06	0.89	62.17	20.02	4.84	0.01	4.14	3.67	18.59	141.52
Low Liquefaction	4.88	0.13	0.00	0.25	1.14	42.70	12.69	2.69	0.29	3.22	1.20	2.05	71.24
Landslide Conditions													
Very High	0.03	0.00	0.00	0.00	0.22	10.84	1.41	0.43	0.00	0.14	0.00	0.21	13.28
High	0.00	0.00	0.00	0.00	0.00	6.11	1.13	0.20	0.00	0.09	0.14	0.02	7.69
Moderate	1.21	0.21	0.00	0.00	0.00	47.94	4.32	0.39	0.00	0.00	0.54	1.06	55.67
Low - Prone	7.83	0.15	1.60	2.40	0.92	229.59	26.12	3.62	1.98	9.62	2.13	6.71	292.67
Bluff - Unstable	0.06	0.00	0.00	0.00	0.00	0.80	0.02	0.00	0.00	0.00	0.00	0.09	0.97
Bluff-neutral	0.05	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Bluff - stable	0.00	0.00	0.00	0.01	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.02	0.70
Very Low	171.40	28.52	4.71	15.81	10.46	1558.43	207.91	51.04	7.30	59.65	15.58	114.45	2245.26
Very Very Low	30.09	1.30	4.27	0.17	0.56	120.65	27.41	6.49	2.42	5.88	2.61	14.80	216.65
Liquefaction Distances													
< 100 feet	1.92	0.28	0.03	0.35	0.69	7.69	3.05	0.93	0.01	0.48	1.20	1.84	18.47
100 to 200 feet	2.53	0.49	0.00	0.53	0.23	9.58	2.41	0.74	0.00	1.05	0.87	2.23	20.66
200 to 500 feet	4.13	1.54	0.12	1.13	0.19	22.59	9.53	1.59	0.00	1.58	1.57	4.17	48.14
> 500 feet	13.14	2.96	0.00	3.30	0.91	65.02	17.73	4.27	0.29	4.25	1.23	12.41	125.51
Hazard by Pipe Diameter													
10" or Smaller, Rock	95.91	3.23	0.14	0.51	0.22	1328.59	171.18	0.04	0.00	0.01	3.21	120.49	1723.53
12" to 16" Rock	54.14	11.75	0.14	1.43	0.59	432.56	85.53	0.04	0.00	0.06	7.13	5.00	598.37
20" or Larger Rock	6.03	9.47	10.24	35.43	13.58	12.86	0.73	68.03	10.23	83.82	12.03	3.30	265.75
10" or Smaller, Firm	38.33	1.67	0.00	0.22	0.02	215.87	21.21	0.00	0.00	0.00	0.89	49.57	327.78
12" to 16" Firm	33.87	7.85	0.02	0.61	0.49	87.42	20.63	0.00	0.00	0.04	0.93	3.54	155.40
20" or Larger Firm	4.07	1.76	0.30	4.37	1.14	3.20	1.16	13.51	2.46	8.05	1.66	0.40	42.08
10" or Smaller, High Liq	4.08	0.20	0.00	0.17	0.00	31.75	8.72	0.00	0.00	0.00	0.70	17.86	63.48
12" to 16" High Liq	11.26	4.95	0.00	0.61	0.47	28.68	10.35	0.00	0.00	0.04	1.25	0.68	58.29
20" or Larger High Liq	1.50	0.00	0.00	4.28	0.42	1.75	0.95	4.84	0.01	4.10	1.72	0.04	19.61
10" or Smaller, Low Liq	2.54	0.00	0.00	0.00	0.00	23.17	7.96	0.00	0.00	0.00	0.06	2.05	35.78
12" to 16" Low Liq	2.32	0.13	0.00	0.09	0.00	18.83	4.48	0.00	0.00	0.00	0.93	0.01	26.79
20" or Larger Low Liq	0.02	0.00	0.14	0.16	1.14	0.70	0.26	2.69	0.29	3.22	0.01	0.00	8.63
Length in Any Slide Zone	210.67	30.18	10.58	18.39	12.16	1975.06	268.32	62.17	11.70	75.38	21.00	137.36	2832.97
Length in Any Liq Zone	21.72	5.28	0.14	5.31	2.03	104.87	32.71	7.53	0.30	7.36	4.87	20.64	212.76
Total Length (miles)	232.34	35.73	10.84	42.57	16.02	2080.95	300.45	81.61	12.69	91.97	25.86	182.30	3113.33
Pct Large Diameter (20"+)	4.3%	31.4%	97.2%	93.5%	91.9%	0.8%	0.6%	99.9%	100.0%	99.9%	52.9%	2.0%	9.9%
Pct Med Diam (12-16")	37.9%	54.9%	1.5%	4.8%	6.7%	25.0%	0.6%	0.0%	0.0%	0.1%	31.2%	4.7%	24.2%

The Fragility Models

The inventory of water system infrastructure is exposed to simulated earthquakes using a Monte Carlo simulation model (SERA). The model incorporates the location of faults, attenuation models to account for spectral variations with distance from the fault and local soil type; landslide models which account for the proportion of each slide zone that can actually slide, a Newmark-type analysis of each slide to assess the chance of slide given local accelerations and soil profile type, the displacement of the slide given that motion occurs, with variations for saturation or unsaturated conditions; liquefaction models which assess the chance of liquefaction given local accelerations and soil profile type, the vertical and horizontal displacement of the zone given that motion occurs, with allowance for the distance of the zone to the nearest open cut face to a creek, river or bay location; and the amount of surface fault offset at locations where pipes cross faults. For each site location, the peak ground acceleration, response spectral ordinate, peak ground velocity and permanent ground deformation is calculated.

Given the local site conditions, the inventory at that site is evaluated used fragility models. Every facility was site inspected. For buried pipelines, we use a series of models that are under development for the American Lifelines Alliance. The pipe models incorporate available empirical evidence, considering the pipe material, pipe joinery, pipe diameter, age (proxy for corrosion susceptibility), local system historical performance of the pipes, orientation of the pipe versus direction of lateral spread. For example, see Fig. 5. The steel and concrete tank fragility models are based on tank-specific engineering attributes such as anchorage type, diameter and height, etc. The building fragility models are based on building specific information, such as type construction and code-based design. The outlet towers are based on reservoir-structure interaction models. SCADA equipment is modeled based on field-inspected installations. Emergency generator evaluations consider type of vibration isolators and condition of batteries. Detailed models of supporting lifelines (SDCWA, SDG&E) are performed. The SDG&E model includes 27 substations from 138 kV to 500 kV.

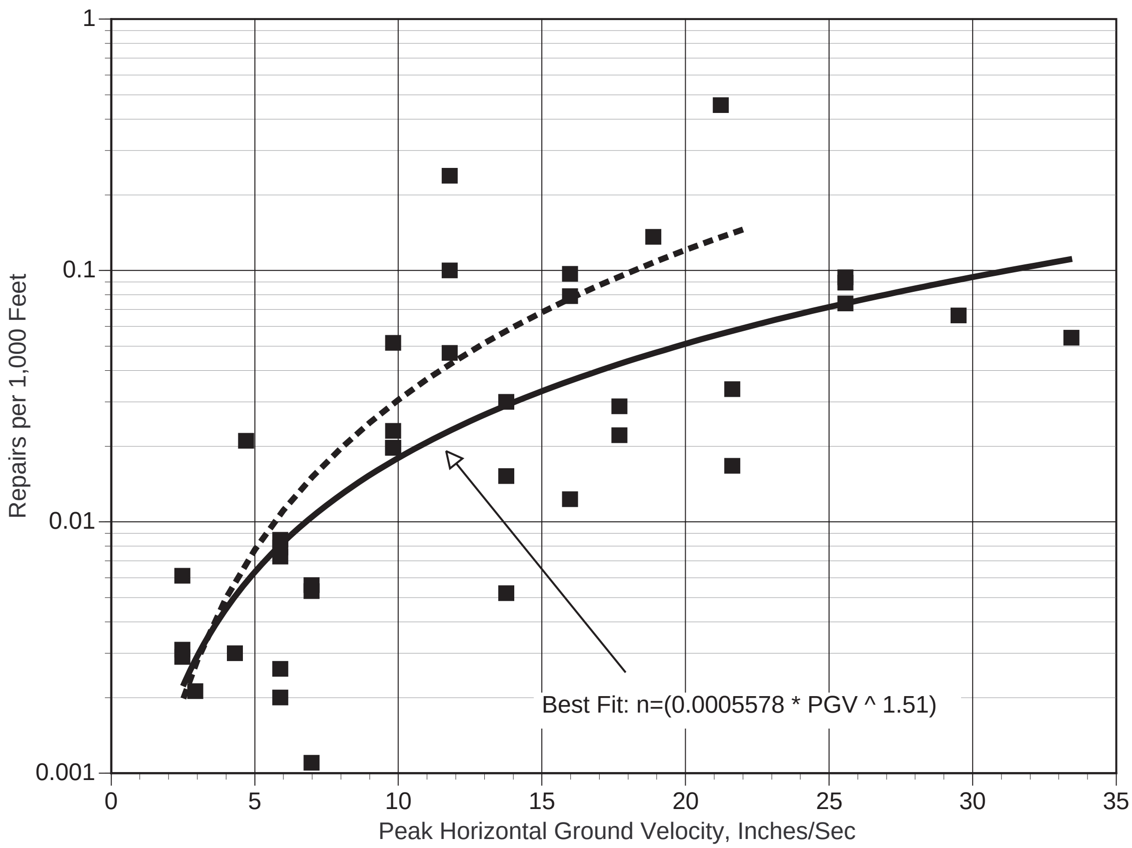


Fig. 5. Pipe Fragility Curve – Dashed Line Pre-Northridge, Solid Line Post-Northridge

Key Findings

Table 2 shows pipeline damage due to the five scenario earthquakes. The bulk of the damage is due to liquefaction. Table 3 lists the number of pumping plants expected to lose SDG&E power soon after the earthquake. Portable power is needed where fire threat is high, and Table 4 lists expected fire ignitions. Given the City's available work force crews, Table 5 presents the likely time needed to restore water service. Major weaknesses are related to long duration water outages in the Mission Bay and Point Loma areas, due to liquefaction and fault offset. Improvements in the system will focus on restoring fire service to all high risk areas within hours after any earthquake.

Table 2. Pipe Repairs Following Scenario Earthquakes

Scenario Earthquake	Total Repairs	Repairs due to Ground Shaking	Repairs due to Liquefaction	Repairs due to Landslide	Repairs due to Fault Offset
Rose Canyon M 6.5	2,010	209	1,111	600	61
Silver Strand M 6.5	1,086	126	712	242	5
RC – SS M 7.2	2,514	349	1,268	783	99
Elsinore M 7.4	72	26	0	45	0
La Nacion M 6.6	1,521	228	712	508	59

Table 3. Power Outages Following Scenario Earthquakes

Scenario Earthquake	Pumping Plants losing SDG&E Power 1 Hour After the Earthquake	Pumping Plants losing SDG&E Power 24 Hrs After the Earthquake
Rose Canyon M 6.5	17	8
Silver Strand M 6.5	10	4
RC – SS M 7.2	23	12
La Nacion M 6.6	21	10
Elsinore M 7.4	1	0-1

Table 4. Fire Ignitions Following Scenario Earthquakes

Scenario Earthquake	Total Number of Ignitions	Fire Ignitions in Gravity Zones	Fire Ignitions in Pumped Zones
Rose Canyon M 6.5	99	83	16
Silver Strand M 6.5	71	58	13
RC – SS M 7.2	115	94	21
Elsinore M7.4	15	10	5
La Nacion M 6.6	101	76	25

Table 5. Restoration of Water Service Following Scenario Earthquakes

Scenario Earthquake	Stabilize System	Restore Backbone Pipes	Restore Distribution Pipes	Complete All Pipe Repairs
Rose Canyon M 6.5	1.7 Days	20 Days	35 Days	74 Days
Silver Strand M 6.5	1.0	13	20	43
RC – SS M 7.2	2.0	24	43	91
La Nacion M 6.6	1.4	18	29	62