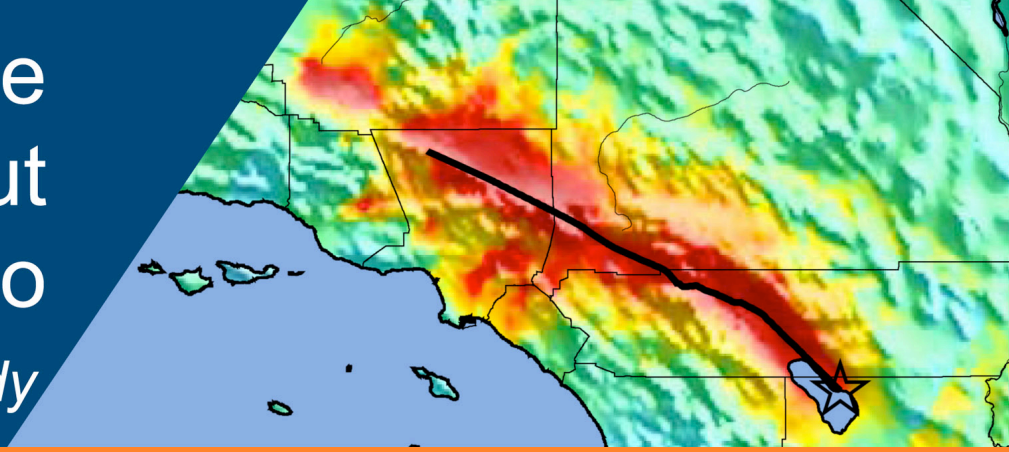
The ShakeOut Scenario

Supplemental Study



Hospitals

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Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario,* it refers to what is now named the ShakeOut Scenario.

Assessing the Impacts of a M7.8 Southern San Andreas Fault Earthquake on Hospitals

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4a. Previous Studies

In the 1994 Northridge earthquake, several hospitals lost functionality due to structural and/or nonstructural damage, [Pickett, 1995].

At the Olive View Medical Center, Sylmar, the earthquake caused a site free-field peak ground acceleration (PGA) of 0.91g and a PGA of 0.82 g at the base of the structure. The steel frame/steel shear plate wall structure performed well. Emergency power was intermittently lost due to equipment failures. However, there was significant water damage due to interior water lines rupturing after punching through nonstructural walls, shearing of fire sprinkler heads, and rupturing of chill water lines in HVAC ducts. Because of these problems, 300 patients were evacuated. Health care functions were performed in the parking lot for about 30 hours.

At the St. John's Hospital, Santa Monica, non-ductile reinforced concrete frame buildings built in 1942 and 1954 failed, Figure 1, and interior water lines ruptured due to failure of nonstructural walls. Electrical fires occurred as a result of electrical grounds. The hospital evacuated approximately 195 patients. The facility was completely closed for 3 months, and was not fully functional for 6 months.

At the Veterans Administration Medical Center, Sepulveda, the earthquake caused a site free-field PGA of 0.94g. Four buildings constructed in the period of 1952-1955 suffered major structural damage due to pounding at the intersections of wings of buildings, Figure 2, and at seismic joints, Figure 3. Interior water lines ruptured at these locations. Other interior water lines also ruptured due to failure of nonstructural walls. Emergency power was lost as a result of electrical grounds caused by these water line failures and due to emergency generator batteries toppling over. The 4 buildings were without electrical power for 48-60 hours. Approximately 330 patients were evacuated.

At the Holy Cross Medical Center (constructed 1976, never seismically retrofitted), water mains in the surrounding area ruptured. Interior water lines ruptured due to failure of nonstructural walls and rupture of heating water coils in HVAC ducts. All functions of the facility were interrupted, causing the evacuation of approximately 50 patients. The facility was not fully functional for 3 weeks. Emergency power was lost in portions of the facility due to circuit breakers opening automatically due to electrical grounds, caused by the water. As a result, one patient died due to loss of power to the respirator.

In the area surrounding the Granada Hills Community Hospital, water mains ruptured. The facility suffered interior damage when rooftop tanks moved in their saddles, and ruptured their piping, spilling their entire contents. This caused the loss of some functionality, resulting in over 1000 patients being treated in a parking lot. The facility could not accept trauma patients for 2 days.

At the Los Angeles County Medical Center, the earthquake caused a site free-field PGA of 0.49g. Both the Psychiatric Hospital and the Pediatric Hospital suffered significant

damage to non-ductile reinforced concrete columns. Both facilities were constructed around 1952-1954 and had never undergone any seismic retrofit. The Psychiatric Hospital also suffered water damage when 3 rooftop tanks moved in their saddles, and ruptured their piping, spilling their entire contents. Both facilities were red tagged for over 15 months. The Pediatric Hospital evacuated 67 patients. The Psychiatric Hospital evacuated approximately 100 patients.

The University of Southern California "University Hospital" building was located across the street from the Los Angeles County Medical Center. This was a steel frame, base-isolated building, built in 1991. It remained functional and had less than $500 worth of damage.

In the 1999 Izmit, Turkey earthquake, several hospital buildings were located at sites subjected to PGA of 0.21g to 0.23g [Pickett, 2003]. Little damage and no disruption of function occurred at the newer buildings (built after 1973 with ductile reinforced concrete structural frames). But at 3 buildings (built around 1938-39, with non-ductile reinforced concrete frames or unreinforced masonry), there was significant wall and column damage that necessitated the evacuation of patients. Three hospital buildings were located at sites subjected to PGA of 0.4g. At these sites, wall and column damage occurred and patients were evacuated from 2 buildings constructed with non-ductile reinforced concrete frames, but there was little damage and no disruption of function at a ductile reinforced concrete frame hospital building.

In the 2007 Pisco, Peru earthquake [Pickett, 2007], the Felix Alva Hospital in Ica (PGA = 0.33g, Johansson) suffered damage to interior water and waste water lines. This caused a 75% loss of function and the evacuation of 60-80 patients. In Pisco (MM VII-VIII, Tavera, Johansson), two hospitals lost all functions in their unreinforced masonry buildings, Figure 4, while several ductile reinforced concrete buildings in these facilities remained undamaged but lost functionality due to loss of electrical power.

In a recent disaster, caused by a non-earthquake natural event, Hurricane Katrina (2005), water supply and waste water elimination were major problems. A hospital, with no structural or power problems, shutdown all functions, due to one problem, alone, loss of water. That hospital subsequently made plans to dig wells. Another hospital was unable to eliminate its waste water. The internally generated waste water eventually flooded the vault area that contained the main electrical panels. Consequently, emergency power had to be shutdown, and the facility was without power (except for a few hand-carried portable generators) for several days.

Fig. 1. Damage in non-ductile reinforced concrete frame building at St. John's Hospital, Santa Monica

Fig. 2. Damage due to pounding at the intersection of wings of a building at Veterans Administration Medical Center, Sepulveda

Fig. 3. Damage due to pounding at a seismic joint of a building at Veterans Administration Medical Center, Sepulveda

Fig. 4. Significant structural damage and loss of functionality in an unreinforced masonry hospital building, Pisco, Peru

4b. Assets Exposed to Loss

The Office of Statewide Health Planning and Development (OSPHD) lists 516 hospitals in the document entitled "California Hospitals Licensed as of 6/30/2007." The Structural Performance Category (SPC) and Nonstructural Performance Category (NPC) of 436 hospitals were reported to OSPHD in the "Summary of Hospital Seismic Performance Ratings," April 2001. In the 10 county region covered by this current study, there are 164 General and Acute Care (GAC) hospitals that provide licensed Emergency Medical Services (standby, basic or comprehensive). The 10 counties covered by this study include; Imperial, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, and Ventura.

For these 10 counties, Table 1 lists the total number of hospital buildings reported in the various SPC and NPC ratings, and their total licensed beds and GAC licensed beds. A rating of SPC = 1 means that the building poses "a significant risk of collapse and a danger to the public after a strong earthquake." A rating of SPC = 3 signifies that the building "may not be repairable or functional following strong ground motion." A rating of SPC = 5 means that the building "is reasonably capable of providing services to the public following strong ground motion." A rating of NPC = 2 signifies that the building "is expected to suffer significant nonstructural damage in a strong earthquake." A rating of NPC = 3 means that "nonstructural systems are adequately braced in critical areas of the hospital" and "the hospital should be able to provide basic emergency medical care following a strong earthquake." A rating of NPC = 5 means that "contents are braced" so that the "hospital building should be able to function" and that the building has "on-site fuel" and "water and waste water tanks, sufficient for 72 hours of emergency operations." A rating of zero means that no rating was reported for that building.

	Total													Total	GAC
	Reported		SPC	Ratings					NPC	Ratings				Licensed	Licensed
Counties	Buildings	0	1	2	3	4	5	0	1	2	3	4	5	Beds	Beds
Imperial	22	0	9	2	0	7	4	0	16	0	0	6	0	221	221
Kern	63	1	19	8	0	28	7	1	33	13	2	13	1	1636	1253
Los Angeles - North	451	1	241	22	62	84	41	7	363	64	7	8	2	20665	17748
Los Angeles - South	214	0	95	18	29	41	31	0	161	41	6	6	0	8927	7310
Orange	181	14	61	9	15	63	19	14	139	23	0	4	1	6843	5699
Riverside	80	0	29	3	15	24	9	1	59	15	2	1	2	3203	2764
San Bernardino	135	1	56	9	19	26	24	1	104	18	2	10	0	4015	3446
San Diego	158	15	55	15	18	44	11	15	134	8	0	1	0	6790	5289
San Luis Obispo	25	0	5	1	4	10	5	0	12	10	1	2	0	554	498
Santa Barbara	45	0	16	6	2	13	8	0	28	10	0	7	0	1211	743
Ventura	48	0	18	2	9	13	6	0	32	8	3	4	1	1510	1120
10 County Total =	**1422**	**32**	**604**	**95**	**173**	**353**	**165**	**39**	**1081**	**210**	**23**	**62**	**7**	**55575**	**46091**
Statewide Total =	**2507**	**35**	**975**	**211**	**291**	**672**	**323**	**49**	**1807**	**430**	**63**	**143**	**15**	**90136**	**73684**
%of Statewide Total =	**57%**	**91%**	**62%**	**45%**	**59%**	**53%**	**51%**	**80%**	**60%**	**49%**	**37%**	**43%**	**47%**	**62%**	**63%**

Table 1. Hospital building ratings and licensed beds in the region of study

Comparing the 10 county totals to the statewide totals, there are significant percentages of California hospital buildings in the lower ratings (SPC $\leq$ 3, NPC $\leq$ 2) that are exposed to loss in the event of strong ground motion (SPC = 1, 62%; SPC = 2, 45%; SPC = 3, 59%: NPC = 1, 60%; NPC = 2, 49%). Also, the percentages of total licensed California beds exposed to loss in the 10 county region are significant (62-63%).

4c. Vulnerability of Assets

Based on ground shaking maps developed for the postulated M7.8 southern San Andreas Fault earthquake [Porter], the peak ground accelerations (PGA) at the locations of the 164 GAC hospitals exposed to loss in the 10 county region are presented in Table 2.

Counties	Number of GAC Hospitals PGA<0.1	Number of GAC Hospitals 0.1≤PGA<0.2	Number of GAC Hospitals 0.2≤PGA<0.3	Number of GAC Hospitals 0.3≤PGA<0.4	Number of GAC Hospitals 0.4≤PGA<0.5	Number of GAC Hospitals 0.5≤PGA<0.6	Number of GAC Hospitals 0.6≤PGA<0.7
Imperial	2	0	0	0	0	0	0
Kern	9	1	0	0	0	0	0
Los Angeles	17	32	10	3	2	0	0
Orange	5	23	2	0	0	0	0
Riverside	3	4	3	1	0	0	0
San Bernardino	0	3	6	2	1	2	1
San Diego	17	1	0	0	0	0	0
San Luis Obispo	3	0	0	0	0	0	0
Santa Barbara	4	0	0	0	0	0	0
Ventura	6	1	0	0	0	0	0
Total =	66	65	21	6	3	2	1
% of Total	40%	40%	13%	4%	2%	1%	0.6%

Table 2. Peak ground acceleration (PGA) at the sites of 164 GAC hospitals in the region of study

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Table 2 indicates that 40% of the GAC hospitals in the 10 county region are located at sites that would have a PGA < 0.1g. And 80% of the GAC hospitals in this region are at sites that would have PGA < 0.2g. However, 13% of the hospitals would be subjected to 0.2g ≤ PGA <0.3g, and 7% would be subjected to 0.3g ≤ PGA <0.7g. The locations of

those hospitals subjected to PGA ≥ 0.2g are limited to 4 counties; Los Angeles, Orange, Riverside, and San Bernardino. And only 2 counties, Los Angeles and San Bernardino, have hospitals located at sites with postulated PGA ≥ 0.4g.

Based on observed and reported data from previous earthquakes, and utilizing the postulated PGA, Table 2, and reported SPC and NPC ratings of Tables 3, 4, and 5, an estimate can be made the vulnerability of hospital facilities to damage and loss of functionality.

Examination of Table 3 reveals that for those hospital buildings in the 4 county region (Los Angeles, Orange, Riverside, San Bernardino) exposed to a postulated ground motion of 0.2g ≤ PGA < 0.3g, approximately 65% have a rating of SPC ≤ 3, and approximately 87% have a rating of NPC ≤ 2.

Examination of Table 4 reveals that for those hospital buildings in the 3 county region (Los Angeles, Riverside, San Bernardino) exposed to a postulated ground motion of 0.3g ≤ PGA < 0.4g, approximately 69% have a rating of SPC ≤ 3, and approximately 98% have a rating of NPC ≤ 2.

Examination of Table 5 reveals that for those hospital buildings in the 2 county region (Los Angeles, San Bernardino) exposed to a postulated ground motion of 0.4g ≤ PGA < 0.7g, approximately 63% have a rating of SPC ≤ 3, and approximately 85% have a rating of NPC ≤ 2.

Recalling the definitions of the SPC and NPC ratings [OSPHD 2001], this data indicates that for those hospital buildings in the 4 county region (Los Angeles, Orange, Riverside, San Bernardino) subjected to the strongest postulated ground motion (0.2g ≤ PGA < 0.7g), over 63% of the buildings "may not be repairable or functional following strong ground motion," and that the over 85% of the buildings are "expected to suffer significant nonstructural damage in a strong earthquake."

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OSHPD ID	Latitude (degrees)	Longitude (degrees)	PGA g	Total Reported Buildings	SPC Rating 0	SPC Rating 1	SPC Rating 2	SPC Rating 3	SPC Rating 4	SPC Rating 5	NPC Rating 0	NPC Rating 1	NPC Rating 2	NPC Rating 3	NPC Rating 4	NPC Rating 5	Total Licensed Beds	GAC Licensed Beds
106190137	34.10	-117.75	0.24	4	0	0	4	0	0	0	0	0	0	4	0	0	64	38
106190413	34.09	-117.89	0.26	10	0	6	0	0	2	2	0	0	10	0	0	0	235	180
106190410	34.07	-118.11	0.23	2	0	2	0	0	0	0	0	2	0	0	0	0	152	124
106190538	33.97	-118.21	0.22	1	0	1	0	0	0	0	0	1	0	0	0	0	81	81
106190197	33.99	-118.22	0.22	2	0	2	0	0	0	0	0	2	0	0	0	0	114	114
106190315	34.07	-118.12	0.20	6	0	3	0	0	3	0	0	6	0	0	0	0	211	211
106190176	34.13	-117.99	0.27	5	0	0	3	0	2	0	0	0	5	0	0	0	165	165
106190198	34.02	-118.19	0.22	4	0	4	0	0	0	0	0	0	4	0	0	0	130	100
106190673	34.10	-117.83	0.25	3	0	1	0	0	1	1	0	3	0	0	0	0	93	64
106190200	34.10	-118.11	0.22	7	0	2	0	4	1	0	0	4	3	0	0	0	274	191
Los	**Angeles**	**County**	**Total=**	**44**	**0**	**21**	**7**	**4**	**9**	**3**	**0**	**18**	**22**	**4**	**0**	**0**	**1519**	**1268**
106301127	33.93	-117.89	0.20	5	0	2	0	0	2	1	0	4	0	0	0	1	162	116
106301297	33.89	-117.84	0.26	4	0	2	0	0	0	2	0	4	0	0	0	0	114	114
	Orange	**County**	**Total=**	**9**	**0**	**4**	**0**	**0**	**2**	**3**	**0**	**8**	**0**	**0**	**0**	**1**	**276**	**230**
106334048	33.90	-117.18	0.25	1	0	0	0	0	0	1	0	0	0	0	0	1	101	101
106334487	33.91	-117.20	0.24	1	0	0	0	0	0	1	0	0	1	0	0	0	439	362
106331312	33.98	-117.38	0.26	5	0	4	0	1	0	0	0	5	0	0	0	0	364	330
	Riverside	**County**	**Total=**	**7**	**0**	**4**	**0**	**1**	**0**	**2**	**0**	**5**	**1**	**0**	**0**	**1**	**904**	**793**
106361110	34.25	-116.89	0.24	2	0	2	0	0	0	0	0	2	0	0	0	0	30	9
106361144	34.03	-117.69	0.29	5	0	1	4	0	0	0	0	5	0	0	0	0	126	112
106364144	34.47	-117.30	0.21	3	0	0	0	0	0	3	0	0	0	3	0	0	83	83
106361166	34.08	-117.70	0.28															
106361266	34.27	-117.17	0.24	5	0	3	0	0	0	2	0	1	2	0	2	0	35	17
106361318	34.10	-117.64	0.23	13	1	4	0	1	4	3	1	12	0	0	0	0	330	284
San	**Bernardino**	**County**	**Total=**	**28**	**1**	**10**	**4**	**1**	**4**	**8**	**1**	**20**	**2**	**3**	**2**	**0**	**604**	**505**
		4 County	**Total=**	**88**	**1**	**39**	**11**	**6**	**15**	**16**	**1**	**51**	**25**	**7**	**2**	**2**	**3303**	**2796**
	Percent of	**4 County**	**Total=**		**1%**	**44%**	**13%**	**7%**	**17%**	**18%**	**1%**	**58%**	**28%**	**8%**	**2%**	**2%**		

Table 3. Hospital building ratings and licensed beds in facilities subjected to a postulated ground motion of 0.2g ≤ PGA < 0.3g

OSHPD ID	Latitude (degrees)	Longitude (degrees)	PGA G	Total Reported Buildings	SPC Rating 0	SPC Rating 1	SPC Rating 2	SPC Rating 3	SPC Rating 4	SPC Rating 5	NPC Rating 0	NPC Rating 1	NPC Rating 2	NPC Rating 3	NPC Rating 4	NPC Rating 5	Total Licensed Beds	GAC Licensed Beds
106190298	34.13	-117.87	0.38	2	0	1	0	1	0	0	0	0	2	0	0	0	106	106
106196035	34.06	-117.99	0.39	4	0	0	0	3	0	1	0	0	3	1	0	0	269	269
106190455	34.68	-118.15	0.39	10	0	4	0	0	0	6	0	10	0	0	0	0	117	117
Los	**Angeles**	**County**	**Total=**	**16**	**0**	**5**	**0**	**4**	**0**	**7**	**0**	**10**	**5**	**1**	**0**	**0**	**492**	**492**
106331326	33.93	-116.95	0.33	4	0	1	1	0	1	1	0	4	0	0	0	0	68	52
	Riverside	**County**	**Total=**	**4**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**4**	**0**	**0**	**0**	**0**	**68**	**52**
106361223	34.07	-117.44	0.36	15	0	9	0	2	4	0	0	15	0	0	0	0	424	424
106361308	34.04	-117.20	0.39	13	0	8	1	2	0	2	0	13	0	0	0	0	172	123
San	**Bernardino**	**County**	**Total=**	**28**	**0**	**17**	**1**	**4**	**4**	**2**	**0**	**28**	**0**	**0**	**0**	**0**	**596**	**547**
		3 County	**Total=**	**48**	**0**	**23**	**2**	**8**	**5**	**10**	**0**	**42**	**5**	**1**	**0**	**0**	**1156**	**1091**
	Percent of	**3 County**	**Total=**		**0%**	**48%**	**4%**	**17%**	**10%**	**21%**	**0%**	**88%**	**10%**	**2%**	**0%**	**0%**		

Table 4. Hospital building ratings and licensed beds in facilities subjected to a postulated ground motion of 0.3g ≤ PGA < 0.4g

OSHPD ID	Latitude (degrees)	Longitude (degrees)	PGA G	Total Reported Buildings	SPC Rating 0	SPC Rating 1	SPC Rating 2	SPC Rating 3	SPC Rating 4	SPC Rating 5	NPC Rating 0	NPC Rating 1	NPC Rating 2	NPC Rating 3	NPC Rating 4	NPC Rating 5	Total Licensed Beds	GAC Licensed Beds
106190034	36.39	-118.16	0.40	14	0	6	0	2	6	0	0	14	0	0	0	0	331	266
106190352	34.05	-118.04	0.40	2	0	0	1	0	1	0	0	2	0	0	0	0	117	104
Los	**Angeles**	**County**	**Total=**	**16**	**0**	**6**	**1**	**2**	**7**	**0**	**0**	**16**	**0**	**0**	**0**	**0**	**448**	**370**
106361323	34.13	-117.32	0.54	9	0	4	0	2	3	0	0	9	0	0	0	0	305	210
106361245	34.05	-117.25	0.63	8	0	2	0	2	4	0	0	2	0	0	6	0	671	671
106361339	34.13	-117.28	0.43	7	0	4	0	2	1	0	0	7	0	0	0	0	443	363
106364121	34.13	-117.33	0.53	1	0	0	0	1	0	0	0	0	1	0	0	0	60	60
San	**Bernardino**	**County**	**Total=**	**25**	**0**	**10**	**0**	**7**	**8**	**0**	**0**	**18**	**1**	**0**	**6**	**0**	**1479**	**1304**
		2 County	**Total=**	**41**	**0**	**16**	**1**	**9**	**15**	**0**	**0**	**34**	**1**	**0**	**6**	**0**	**1927**	**1674**
	Percent of	**2 County**	**Total=**		**0%**	**39%**	**2%**	**22%**	**37%**	**0%**	**0%**	**83%**	**2%**	**0%**	**15%**	**0%**		

Table 5. Hospital building ratings and licensed beds in facilities subjected to a postulated ground motion of 0.4g ≤ PGA < 0.7g

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4d. Damage Scenario

A M7.8 earthquake would cause an immediate interruption of commercial electrical power. Hospitals in the affected region would be expected to have emergency generators that would start-up, automatically, upon the loss of commercial power. Also these facilities would be expected to have Automatic Transfer Switches (ATS), which would transfer the connections of the hospital's electrical system from the commercial source to the emergency source. Consequently, there would be little interruption of electrical power to critical systems and equipment, initially.

However, some buildings would suffer major structural damage. Hospital buildings, subjected to a postulated ground motion of $0.4g \leq PGA < 0.7g$, and having a rating of $SPC \leq 3$ would suffer damage (failures of non-ductile beam-column joints, pounding at wings and seismic joints and wall failures) that would cause leaks or ruptures of interior water and waste water piping systems.

Table 5 shows that there are 2 hospitals in Los Angeles County and 4 hospitals in San Bernardino County that would be subjected to a postulated ground motion of $0.4g \leq PGA < 0.7g$. And in these facilities, 63% of the buildings have a rating of $SPC \leq 3$ and 85% of the buildings have a rating of $NPC \leq 2$.

For example, the Loma Linda University Hospital (OSHPD ID = 106361245, located in San Bernardino County at 34.05˚ N 117.25˚ W) would experience a postulated PGA = 0.63g. In this facility, 4 out of 8 buildings have a rating of $SPC \leq 3$, and 2 out of 8 buildings have a rating of $NPC \leq 2$. This hospital has 671 total licensed beds, all of which are GAC licensed. Thus this hospital contains approximately 17% of the total licensed beds (4015) and 19% of the GAC licensed beds (3446) in San Bernardino County.

As another example, the Community Hospital of San Bernardino (OSHPD ID = 106361323, located in San Bernardino County at 34.13˚ N 117.32˚ W) would experience a postulated PGA = 0.54g. In this facility, 6 out of 9 buildings have a rating of $SPC \leq 3$, and all 9 buildings have a rating of $NPC \leq 2$. This hospital has 305 total licensed beds, 210 of which are GAC licensed. Thus this hospital contains approximately 8% of the total licensed beds (4015) and 6% of the GAC licensed beds (3446) in San Bernardino County.

Thus these two facilities contain 25% of the total licensed beds and 25% of the GAC licensed beds in San Bernardino County,

In these two facilities, the rating of NPC ≤ 2 would mean that some roof mounted HVAC cooling towers would topple over due to insufficient anchorage. Also, some roof mounted saddle tanks would move in their saddles, rupturing their inlet/outlet piping, and losing their contents. Water from these sources would cause grounds in the buildings' electrical distribution systems. In order to avoid fires caused by these grounds, circuit breakers would be tripped open, either manually or automatically. Consequently, the facilities would be without any source of electrical power. And thus critical systems and equipment would be inoperable. The hospitals may have a few portable, hand-carried, generators, but probably not in sufficient quantity to power enough systems and equipment to regain normal functionality. Thus electrical grounds caused by water line ruptures would cause near total loss of functionality for these facilities.

For these facilities, the external supply of potable water could be lost in a M7.8 earthquake, and the external waste water system could become fractured and unusable, and the length of time of these conditions could be several days.

The postulated M7.8 earthquake would cause an immediate interruption of commercial telecommunication systems for these hospitals. Landlines would be severed and the telephone company would perform line-load-dumping. Cellular systems would fail either due to saturation or due to tower failure, Figure 5. Facility PBX systems (Private Business Exchange) could be functional, only if the UPS switch (uninterruptible power supply) had a viable power source to switch to. Due to the water and electrical grounding problems mentioned above, there would be no power source. Wall mounted INTERCOM systems would be grounded by the water sources, mentioned above. Consequently, interior and exterior communications could only be maintained by radio-telephones.

Since 11 of the 17 buildings at these two facilities have rating of NPC ≤ 2;

- Rupture of medical gas piping would occur due to interior nonstructural wall failure.
- Patient care functions would be interrupted by the toppling over of unrestrained patient record shelves, Figure 6, and unanchored nurses' stations, Figure 7.
- Unrestrained equipment, such as, cylinders (medical gas, water filtration) would topple over, Figure 8.
- Unanchored shelf-equipment, desktop and counter top equipment would fall off the shelf, desk or counter, Figure 9.

Transportation (roads, bridges) failures would make it difficult for EMS crews to bring patients with earthquake related injuries to the hospitals. Off-duty hospital staff relief personnel would have difficulty reaching the hospital, causing exhaustion problems for the hospital staff that was on-board at the time of the event. The transportation of fuel, food, medical gas, and clinical supplies would be disrupted.

Fig. 5. Wireless phone tower collapsed.

Fig. 6. Unrestrained patient records shelves toppled over.

Fig. 7. Unanchored nurses' station toppled over.

Fig. 8. Unrestrained cylinder toppled over.

Fig. 9. Unrestrained shelf equipment fell off shelf.

4e. Mitigation

Mitigation efforts can be categorized as "structural" or "non-structural."

Structural:

The reduction of potential structural damage would be the most effective means of mitigating the effects on a hospital of a M7.8 Southern San Andreas Fault earthquake. In the design and construction of a new facility, seismic detailing is already required in the structural building codes for this 10 county region. However, structural building codes primarily address occupant life safety. Therefore, to ensure continuation of a building's function, additional seismic detailing, for strength and ductility, would be required, such as, ductile beam-column joints, shear walls, and possibly, base isolation. The effectiveness of these efforts has been demonstrated in previous events. For example, in the 1994 Northridge earthquake, the University of Southern California "University Hospital" building (steel frame, base-isolated, built in 1991) remained functional and had less than $500 worth of damage.

In retrofit construction, base isolators can also be installed in existing buildings to mitigate structural damage due to ground shaking, Figure 10.

Non-Structural:

Water has been the single cause of most major non-structural problems in past natural disasters. Damage to non-structural walls has caused rupture of interior water, waste water, and HVAC water lines, resulting in electrical grounds that have caused the loss of all electrical power and interior communications. Hospitals need to conduct inexpensive walk-downs to identify vulnerable lines. Then the installation of flexible, and/or telescoping connections in the vulnerable lines (Figure 11), and the creation of relative motion gaps in wall penetrations, would be successful mitigation procedures. This mitigation of electrical grounds caused by water would eliminate the loss of hospital emergency power and interior communications. This would enable the hospital to continue functioning after the event.

If emergency power could not be regained due to electrical grounds, hospitals would need a sufficient number of portable hand-carried generators. This would enable critical equipment and systems to remain functional.

If electrical grounds caused the loss of communications, hospitals would need a sufficient number of radio-telephones, and chargeable batteries with chargers connected to some reliable power supply, either a portable or a functioning stationary emergency generator. This would enable the facility to maintain interior and exterior communications. In order for a building to qualify for a rating of NPC = 5, there would have to be enough spare batteries on-hand for 72 hours of communications [OSPHD 2001].

For the needs of patients and staff, hospitals must "have water and waste water holding tanks – sufficient for 72 hours of emergency operations – integrated into the plumbing systems" in order to qualify for a rating of NPC-5 [OSPHD 2001]. This will enable the hospital to continue to provide care for current patients and to treat the earthquake related injuries of incoming patients.

In order to mitigate the potential inability of fuel suppliers to bring fuel to the facility, hospitals must have "an onsite fuel supply for 72 hours of acute care operation" [OSPHD 2001].

Hospitals can also conduct inexpensive walk-downs to identify other nonstructural systems and pieces of equipment that are vulnerable to sliding, toppling over, or colliding with other items or systems. Inexpensive mitigation efforts would include:

- installation of anchor bolts and restraining straps on heavy pieces of equipment, electrical panels, and on tanks, Figure 12;
- wall restraints on shelf mounted equipment, Figure 9;
- restraints on desktop equipment, Figures 13 and 14.

The continued operation of desktop and shelf mounted equipment will help to maintain the functionality of the hospital.

Fig. 10. Base isolator installed as a retrofit.

Fig. 11. Telescoping water pipe across a structural joint

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Fig. 12. Restraining anchor bolts and straps on a tank

Fig. 13. Restraints on computer screens

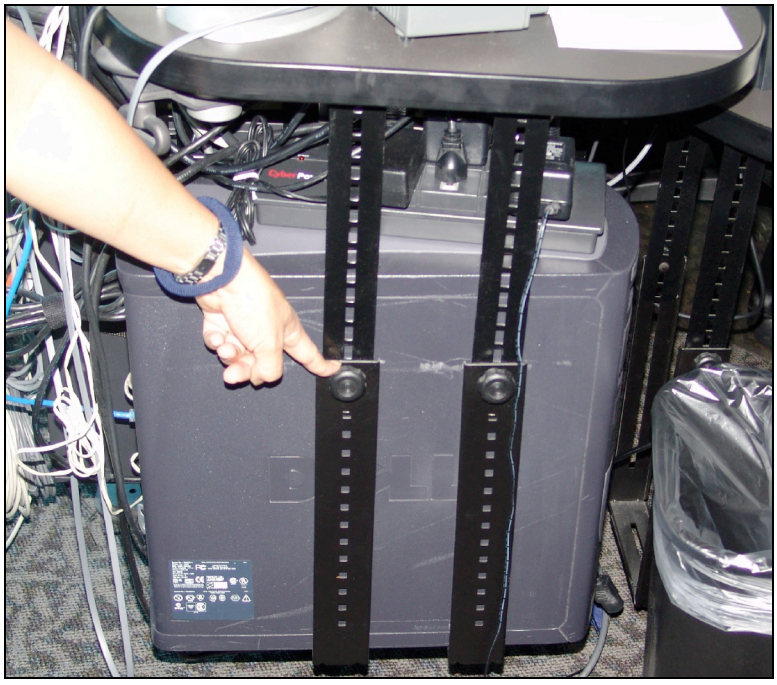

Fig. 14. Restraints on computer CPU

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