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GUJARAT, INDIA AND WASHINGTON STATE, USA: A CONTRAST IN EARTHQUAKE PREPAREDNESS

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Abstract

On January 26, 2001, at 8:46 a.m. Indian Standard Time, a major earthquake occurred in the State of Gujarat, India. The Richter magnitude 7.7 earthquake was centered approximately 20 km north of the city of Bhuj, India, and occurred at a depth of 23.6 km. Authorities estimate that around 25,000 people lost their lives, 60,000 people were injured and some 200,000 were rendered homeless. Damage estimates from the temblor were estimated to be around $1.3 billion (US). Knowledgeable sources indicate that the Bhuj earthquake was so deadly because contractors did not use adequate construction practices or materials. Also, although building codes in India have provisions for construction in earthquake prone areas, they have been used as recommendations and not requirements. In contrast, on February 28, 2001, at 10:55 a.m. Pacific Standard Time, a major earthquake occurred in the State of Washington, USA. The Richter magnitude 6.8 earthquake was centered approximately 20 km northeast of the city of Olympia, Washington, at a depth of 52 km. This event, termed the Nisqually earthquake, killed one person (heart attack), injured more than 400 people and caused an estimated $2 billion (US) in damage to homes, businesses, roads, and government buildings. Although the geological setting of the Nisqually earthquake was thought to have played a role in buffering the resultant effects, it is believed that strict adherence to the earthquake building codes for new structures, a retrofitting program, and an earthquake hazard awareness campaign contributed to the low injury rate and no deaths. This paper compares and contrasts the two areas affected by the earthquakes and the local approach to protect structures and minimize the effects on the people living in the area.

Introduction

Earthquakes have been an integral component of our geologic evolution. Since the dawn of history, mankind has been continually reminded, usually without warning, of the ruinous power of earthquakes (Berlin, 1980). An earthquake is a series of shock waves that are generated following the brittle failure of rocks within the earth's crust or upper mantle as a result of a build-up of stress. Failure occurs at a point or in a fairly small subsurface zone known as the focus with the epicenter being the point on the earth's surface directly above. Once failure has occurred, movement may persist along a zone of weakness (known as a fault) for a considerable distance occasionally as much as 1000 Km. (The University of Edinburgh, 2002)

There are two important measures of the size and effect of an earthquake. The first is a quantitative measure of an earthquake's seismic wave and the second is a semi-qualitative assessment of the

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resultant damage caused by an earthquake. In 1935, Charles Richter developed the first earthquake magnitude scale based upon the logarithm of the maximum amplitude of the seismic wave. The Richter magnitude is known as the local magnitude (M_L). Because the scale is logarithmic, there is a ten-fold increase in wave amplitude, as measured with a seismogram (the record of the motion of the ground during an earthquake), with a unit increase of magnitude or about a 30-fold increase in the amount of energy released. In other words, a magnitude 6.7 earthquake releases over 900 times (30 times 30) the energy of a 4.7 earthquake. There is no beginning or end to this scale. However, rock mechanics seems to preclude earthquakes smaller than about -1 or larger than about 9.5. A magnitude -1.0 event release about 900 times less energy than a magnitude 1.0 quake. Except in special circumstances, earthquakes below magnitude 2.5 are not generally felt by humans. (NEIC, 2002)

Since the development of the Richter scale, several other methods have been derived to describe large earthquakes and distant earthquakes. These methods include the surface wave magnitude or M_S scale, the body-wave magnitude or M_b scale, the seismic moment or M_O, and the moment magnitude or M_W scale. The moment magnitude scale is being used more and more to describe moderate to large earthquakes (Yeats et al, 1977).

The intensity of an earthquake is the measure of the resultant effects of the event. The intensity of an earthquake is calculated by the damage to structures, the land, and the effects on humans. The intensity at a point depends not only upon the strength of the earthquake (magnitude), but also upon the distance from the earthquake to the point and the local geology at that point (NEIC, 2002). Typically, such information is collected by experts that canvass the area and from interviews of those living in the affected areas. Experts then construct maps showing the various levels of intensity. In 1902, Giuseppi Mercalli proposed an intensity scale that has since been revised several times and is known as the Modified Mercalli scale (MM) (Yeats et al, 1977). Table 1 shows approximate relationship between Richter magnitude and the maximum intensity from the Modified Mercalli scale.

Table 1: Approximate Relationship Between Richter Magnitude and Maximum Intensity from the Modified Mercalli Scale (Gere and Shah, 1984).

Richter Magnitude	**Maximum MM Intensity**	**Typical Effects**
2.0 and Under	I-II	Not generally felt by people.
3.0	III	Felt indoors by some people; no damage.
4.0	IV-V	Felt by most people; objects disturbed; no structural damage.
5.0	VI-VII	Some structural damage, such as cracks in walls and chimneys.
6.0	VII-VIII	Moderate damage, such as fractures of weak walls and toppled chimneys.
7.0	IX-X	Major damage, such as collapse of weak buildings and cracking of strong buildings.
8.0 and Over	XI-XII	Damage total or nearly total.

A great earthquake, with a magnitude of greater than 8.0, can be expected to occur every 8 to 10 years, but a significant number of smaller earthquakes, which are still capable of destruction, occur each year. Table 2 shows data from the United States National Earthquake Information Center (NEIC) and describes the worldwide frequency of earthquakes based on observations made since 1990. According to the NEIC, it is estimated that several million earthquakes occur in the world each year. However, many go undetected because they strike remote areas or have very small magnitudes. The NEIC now locates about 50 earthquakes each day, or about 20,000 a year.
(NEIC, 2002)

The largest recorded earthquake in the United States was a magnitude 9.2 (Mw) event that struck Prince William Sound, Alaska, on Good Friday, March 28, 1964. The largest recorded earthquake in the world was a magnitude 9.5 (Mw) event in Chile on May 22, 1960. Table 3 shows the number of recordable earthquakes that have occurred since 1997 and the estimated death toll. As can be observed in the table, earthquakes have the potential for catastrophic consequences.

Table 2: Frequency of the Occurrence of Earthquakes (NEIC, 2002).

Descriptor	Magnitude	Annual Average
Great	8.0 and Higher	1
Major	7.0 - 7.9	18
Strong	6.0 - 6.9	120
Moderate	5.0 - 5.9	800
Light	4.0 - 4.9	6200 (estimate)
Minor	3.0 - 3.9	49000 (estimate)
Very Minor	< 2.9	Magnitude 2 -3: About 1000 Per Day Magnitude 1- 2: About 8000 Per Day

Table 3: Worldwide Earthquakes 1997 - 2001 (NEIC, 2002).

Descriptor	Magnitude	1997	1998	1999	2000	2001
Great	8.0 and Higher	0	2	0	4	1
Major	7.0 - 7.9	20	14	23	16	14
Strong	6.0 - 6.9	125	113	123	153	130
Moderate	5.0 - 5.9	1118	979	1106	1345	1152
Light	4.0 - 4.9	7938	7303	7042	8045	8214
Minor	3.0 - 3.9	4467	5945	5521	4782	6137
Very Minor	< 2.9	6204	7332	7017	7911	7977
Total Number of Earthquakes		19872	21688	20832	22258	23625
Estimated Death Toll		2907	8928	22711	231	21358

Bhuj Earthquake

The subcontinent of India is a union of 25 states and 7 centrally administered territories. The State of Gujarat was created in 1960 and lies in the western part of India (Figure 1). Gujarat has a total population of about 50.6 million people or about 5% of the population of India and occupies about 196,000 km^2 (about 6% of India's total surface area). Gujarat is one of India's wealthiest states, with industrial complexes as well as thriving village handicrafts.

Figure 1. Map of India (The University of Texas, 2002).

On January 26, 2001, at 8:46 a.m. Indian Standard Time, a major earthquake occurred in the State of Gujarat, India. The Richter magnitude 7.7 earthquake was centered in the Kutch region approximately 20 km north of the city of Bhuj and occurred at a depth of 23.6 km. This event was termed the Bhuj or Kachchh earthquake. Authorities estimate that around 25,000 people lost their lives, 60,000 people were injured, and some 200,000 were rendered homeless. In Kutch, major towns such as Bhuj, Anjar, Bhachau, and Rapar were almost totally destroyed. Damages from the temblor were estimated to be around $1.3 billion (US) (USGS 2002). Table 4 shows a summary of the damage to villages and towns in Gujarat.

Table 4: Settlement Profile and Number of Building Affected by Earthquake in Gujarat, India (TARU, 2001 and Census of India, 1991).

Settlement Profile				**Buildings Affected by Earthquake (000's)**			
District	Area, 10^2 km	Villages	Towns	Residential Houses	Commercial & Industrial	Public & Institutional	Total
Kachchh	457	884	10	350	30	11	391
Rajkot	112	841	13	561	71	8	630
Jamnagar	141	694	18	371	36	6	413
Mahesana	90	1093	15	758	81	11	851
Surendranagar	105	648	11	291	33	8	331
Ahmadabad	87	646	25	1186	146	10	1342
Gandhinagar	6	73	3	95	5	1	101
Banas Kanatha	127	1368	7	450	34	5	490
Sabar Kanatha	74	1363	8	380	48	3	431
Kheda	72	965	21	758	97	7	862
Bharuch	90	1116	10	367	32	5	403
Surat	77	1185	14	723	128	5	856
Vadodara	78	1639	21	593	84	5	708
Bhavnagar	112	865	17	460	58	7	525
Junagadh	106	1034	23	567	53	8	633
Amreli	68	595	12	253	27	4	284
Panch Mahals	89	1889	9	448	93	2	543
Valsad	52	821	25	423	57	3	483
The Dangs	18	309	2	24	8	0	32
Total	**1960**	**18028**	**264**	**9075**	**1127**	**109**	**10311**

In addition to the devastation to villages and towns, it was reported that damage occurred to the railway system; 100 km of the National Highway had been damaged with moderate to severe damage to major and minor bridges; there was severe destruction to the telecommunications infrastructure with 82,000 lines and 147 telephone exchanges damaged; there was reportedly severe damage to the power transmission and distribution system in Kachcch; and major structural damage was reported at Kandla Port (TARU, 2002).

According to the Gujarat Relief Engineering Advice Team that investigated the earthquake areas, most people were killed or badly injured because of the following (Patel et al, 2001).

- Poorly constructed buildings either totally or partially collapsing.
- Walls collapsing within narrow streets, burying escaping people.
- Untied roofs and cantilevers falling onto people.
- Free-standing high boundary walls, and balconies falling due to severe shaking.
- Gable walls falling over.
- The failure of modern reinforced structures with large open spaces at ground to first floor level. For example garage or shop spaces, collapsing and burying occupants (soft story collapse).
- Inhabitants not knowing how to respond to the shaking and collapse of walls around them.

Earthquakes and their devastating effects are not new to India as 16 significant events (magnitude 6.0 or greater) have occurred in the 1900's; four of these events occurred in the 1990's and are summarized in Table 5. Following the earthquake, there was a myriad of discussions in the engineering community in India as to the reasons for the large-scale damage in some of the communities.

Table 5: Major earthquakes in India during
the 1990's (India Meteorological Department, 2002).

Date	Earthquake Name	Magnitude	Death Toll
October 20, 1991	Uttarkashi	6.6	769
September 30, 1993	Latur	6.3	7610
May 22, 1997	Jabalpur	6.0	39
March 29,1999	Chamoli	6.8	103

The development of formalized Indian seismic building codes date back to the 1960's and modifications have since been made several times. Furthermore, seismic zone maps that delineate risk areas within the subcontinent have also been developed and have been modified after significant earthquake events. Unfortunately, the Indian seismic codes are not mandatory and considered only as construction guidelines. According to educators in India, construction is governed by the municipal by-laws and the seismic provisions have yet to be incorporated into the by-laws. Since a majority of the building construction activity in the country is carried out in an informal manner, with no involvement of engineers, most of it is done without regard to seismic safety. On the other hand, the governmental departments and public sector organizations manage a large fraction of the formal sector constructions (large dams and nuclear power plants) and are formally committed to follow the seismic codes. (Jain and Nigam, 2000).

Figures 2 and 3 are photos showing damage from the Bhuj earthquake.

Figures 2 and 3: Photos of damage from the Bhuj Earthquake.

According to the Gujarat Relief Engineering Advice Team, the building damage was caused by a combination of effects (Patel et al, 2001).

- Old decaying buildings predating modern construction practices.
- New buildings not being designed to Indian seismic building codes.
- Lack of knowledge, understanding, or training in the use of Indian seismic building codes by local engineers.
- Unawareness that Gujarat is a highly seismic region.
- Buildings erected without owners seeking proper engineering advice.
- Improper detailing of masonry and reinforced structures.
- Poor materials, construction, and workmanship used, particularly in commercial buildings.
- Alterations and extensions being carried out without proper regard for effects on structure during and earthquake.
- Buildings having poor quality foundations or foundations built on poor soils.
- Little or no regulatory authority administering or policing the seismic building codes.

Nisqually Earthquake

The Unites States is a democratic union of 50 states. Washington achieved statehood in 1889 and is situated in the far western part of the United States (figure 4). Washington State has a total population of 5.9 million people or about 2.1% of the population of the United States and occupies about 172,000 km^2 (about 1.9% of the United States' total surface area). Washington state ranks 15^{th} in gross state product in the United States. (USBC, 2000)

Figure 4: Map of Washington State (The University of Texas, 2002).

More than 1,000 earthquakes occur in Washington annually. Washington has a record of at least 20 damaging earthquakes during the past 125 years. Large earthquakes in 1946, 1949, and 1965 killed

15 people and caused more than $200 million (1984 dollars) in property damage. Most of these earthquakes were in western Washington, but several, including the largest historic earthquake in Washington (1872), occurred east of the Cascade Crest. (Walsh et al, 2001) Therefore, earthquake events are not uncommon to this area.

On February 28, 2001 at 10:55 a.m. Pacific Standard Time, a major earthquake occurred in Washington. The Richter magnitude 6.8 earthquake was centered approximately 20 km northeast of the city of Olympia, Washington, at a depth of 52 km. This event, termed the Nisqually earthquake, killed one person (heart attack), injured more than 400 people and caused an estimated $2 billion (US) in damage to homes, businesses, roads, and government buildings. (USGS 2002)

The effects of the earthquake were as follows (EMD, 2002 and EQE, 2002).

- The effects of the earthquake were observed in homes over a 25 county area and impacted 25 Native American tribes.
- Many businesses were disrupted and widespread damage occurred, but most businesses were able to work around the damage and continue to operate.
- Schools fared well, with most students getting an unexpected holiday. No student injuries were reported in large part due to extensive training on ' duck, cover, and hold' training.
- The Washington State Ferries Coleman Dock reported minor damage.
- Railroad traffic was interrupted, 700 miles of railroad lines had to be inspected before passenger and freight traffic was allowed to resume.
- The Capital Campus, which housed most of the State buildings, was heavily damaged. The Legislative Building, (the State Capital building), was considered unsafe for occupancy.
- Due to the relatively moderate ground motions, damage to modern structures was very light, consisting of damage to nonstructural components. Where structural damage did occur, it was generally at sites with soft soils or outdated construction with known seismic vulnerabilities.
- Puget Sound, which is a hub for many industries, experienced light damage and resumed operations rapidly.
- The water utilities in the epicenter reported little or no damage. Wastewater treatment facilities were able to maintain full operation.
- Approximately, 217,000 customers lost electrical power. Within 6-hrs of the earthquake only 6,000 customers remained without power.
- Wire and wireless communications were overloaded for about two days. In the first few hours after the event, cable Internet access provided the only means of communication. AT&T rejected about 7 million calls within 24-hrs of the event.
- Only one gas leak was detected in the regional natural gas transmission system.
- The SeaTac International Airport, located 40 km from the earthquake epicenter, experienced extensive damage to the control tower. The airport was partially reopened within a day of the earthquake.
- The Interstate Highway System in the area experienced minor damage overall, however, two modern bridges on the Interstate Highway System failed. Local bridge damage was limited to aging structures approaching the end of their service life.

Figures 5 and 6 are photos showing damage from the Nisqually earthquake.

Figures 5 and 6: Photos of damage from the Nisqually Earthquake.

The reasons for the very small loss of life from the Nisqually earthquake can be attributed to several factors. First, from a geological perspective, the hypocentral depth of the Nisqually earthquake was 52 km below the surface and was more than twice as deep as the Bhuj earthquake. In the Nisqually earthquake, there was a large expanse of "very strong" shaking, but no reports of "severe or violent shaking" even in those places nearest to the epicenter. Within the first week of the Nisqually earthquake, only a few aftershocks had been recorded, and the largest was a magnitude 3.4 event. It is common in earthquake devastated areas for moderately sized aftershocks to damage already weakened structures, so the lack of aftershocks must have been a mitigating factor in minimizing the total loss. (SCEC 2002)

Second, in 1985, The U.S. Geological Survey, the Federal Emergency Management Agency, the Washington Department of Natural Resources, and the Washington Department of Community Development, Division of Emergency Management, began a multi-year cooperative earthquake hazards reduction program to investigate earthquake potential, hazards mitigation, and preparedness efforts in the Puget Sound area. In 1987, the program was enlarged to include the Portland Oregon area. (Noson et al, 1988)

Third, the local government in the Washington State area has taken proactive steps to control the magnitude of earthquake damage by regulating land use through building permits, zoning provisions, and ordinances. The Seattle Greenbelt Ordinance is an example of local regulations that can be used to control and limit land use to reduce earthquake hazards. Another example is the King County Sensitive Areas Ordinance 4365. This ordinance can limit land use in areas that are landslide prone or contain significant earthquake hazard. (Noson et al, 1988)

The Uniform Building Code, is in common use in the Western United States and focuses on protection of the occupants. In the area of the Nisqually earthquake, there were 14 structures with control systems that were affected by the earthquake. Although not all of the control systems were activated by the quake, in those that were activated, all of the structures remained fully functional after the quake.

Summary and Discussion

It is impossible to directly compare the resultant effects of the earthquakes that occurred in Gujarat, India, and Washington, USA because of the dramatically different geological settings, the differences in earthquake magnitude (the Bhuj earthquake released more than 32 times the energy of the Nisqually earthquake), and the depths of the two events (Bhuj earthquake- 23.6 km versus Nisqually earthquake - 52 km). One can however observe the dramatic differences in earthquake preparedness. In Washington State, the federal, state, and local governments are making earnest attempts to retrofit old structures, effectively legislate and enforce seismic building codes for new construction, and educate the public. To meet this need, several group have been formed to address earthquake issues. For example, one group, Contingency Planning and Recovery Management (CPARM), was originally a public/private collaboration and is now part of Seattle's larger disaster program, Project Impact, which is sponsored by the Federal Emergency Management Agency. Seattle's Project Impact is a public-private partnership whose overall goal is to make communities more resistant to the damaging effects of disasters. Project Impact encourages people to take action before a disaster occurs through initiatives promoting safer homes, schools, businesses, and better earthquake and landslide hazard mapping. Perhaps, the people living in Washington State have learned much from the experience of its nearby neighbors in California State, where earthquake events and mitigation are a common way of life.

The conditions in India, on the other hand, are much more challenging because of the less formal approach of integrating the engineering profession into the construction industry, the lack of seismic building code enforcement options, and the myriad of buildings that exist, which are already structurally deficient. The key to improving conditions in India is to develop and implement a long-range plan that effectively utilizes the knowledgeable engineering professions (which already exist in the country), develop comprehensive up-to-date hazard maps and enforceable seismic building codes and diligent construction inspections, and educate the public about earthquake hazards, and sensible methods of mitigation. An Indian educator summarized the nature of the problem in India succinctly. "Earthquakes don't kill people; it is the structures built by man that kill people. With frequent reminders of moderate earthquakes staring into our eyes, India is at the crossroads of earthquake preparedness. It has only two options to choose from - prepare now or pay later." (Murty 1998).

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