SOME ASPECTS OF AFTERSHOCK ACTIVITY OF BHUJ EARTHQUAKE OF 2001

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Abstract

A disastrous earthquake struck Bhuj and its surrounding area of Kachchh region of Gujarat state on January, 26 2001. The Bhachau town and its surrounding villages were razed to the ground. The main earthquake measuring Ml=7.2 on Richter scale was recorded by the seismological network of Sardar Sarovar Project. This network located about 400 km SE of epicentre has recorded 2299 shocks of magnitude M > 3.0 till the end of December 2001. The study indicates that the activity is concentrated around Bhachau in Kachchh in an area of 90 km x 70 km with a N45° E-N55° E trend. It seems that the concentration of the aftershock activity is also sympathetic to the Chambal - Jamnagar lineament in addition to the Kachchh Mainland Fault. The decay constant h and the b value of aftershock sequence are found to be 1.12 and 0.96 which are normal for large tectonic sequences.

Introduction

A disastrous earthquake struck the Kachchh region, Gujarat at 08:46 hrs on January 26, 2001. This earthquake was felt as far away as Delhi in North, Kolkata in the East and Chennai in the South. The Bhachau town located about 65 km east of Bhuj city and surrounding areas were razed to ground with heavy loss of life. The earthquake also produced wide spread liquefaction.

This earthquake was followed by several hundreds of aftershocks of varying magnitude up to 6.2. This paper briefly discusses, aftershock activity and its behaviour in space, the decay aspects and the frequency magnitude relation, etc.

Tectonics

The structural framework of Gujarat region is the resultant of the interplay of the three Precambrian tectonic grains, viz. (i) Delhi-Aravalli trend, (ii) Son-Narmada trend and (iii) Dharwar trends. Sequential reactivation along these Precambrian trends during different stages resulted in the formation of pericontinental rift basins in the western margin of the Indian shield. In Kachchh region, tectonic trend of Delhi belt is E-W, rifting along which resulted in the formation of the Kachchh Basin during the early Jurassic period. The SONATA rift enclosing the Satpura hills developed during late Cretaceous time and the Cambay graben formed in co-linearity with the Dharwar trend during early Cretaceous. The NE-SW Aravalli trend continues across Cambay Graben into Saurashtra, forming the south westerly plunging Saurashtra Arch (Biswas, 1987). The Mesozoic-Cenozoic sequence representing marginal overlap cover is well developed in the Kachchh area. Major part of Saurashtra is occupied by Deccan basalt. Quaternary pericratonic fill on attenuated continental crust covers a vast terrain in Kachchh, while this is restricted mainly along coastal fringes in Saurashtra. Alluvial fill along intracratonic linears is developed in and around Cambay graben. The structural configuration of

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Kachchh basin is characterised by high lands and plains, which are the areas of uplifts and half grabens, respectively. The uplifted blocks are bounded by east-west trending major faults prominent among them being Kathiawar, Kachchh Mainland and Island faults. Important lineaments of the region are the Lathi-Rajkot, Chambal-Jamnagar, West Coast, Kishangarh-Chipri and Luni - Sukri (Fig.1.)

Seismicity

The Kachchh region in the historical past was affected by a damaging earthquake near Samaji town on the Indus delta where 30000 houses sank into the ground due to the earthquake of Intensity X on MM scale in May 1668 (Chandra1977). The other damaging earthquake in Gujarat, in the past whose record available was the June 16, 1819 Kachchh earthquake. Though earthquake recurrence rate is low, the Kachchh rift basin is considered to be a major seismogenic domain due to occurrence of earthquakes of high intensity. Other major earthquakes of the twentieth century are Rann of Kachchh (January 14, 1903, M=6), Anjar (March 13, 1922 M=5.2,) and Anjar (July 21, 1956, M=6.0).

Among the major earthquakes of stable continental region world wide, intensity wise, the Kachchh Earthquake of June 16, 1819, ranks the fourth. The shock was felt over a radius of 1600 km and caused heavy damage to the property. Around 1500 people died in the town of Bhuj. A 6-9 m high scarp appeared on the ground trending roughly E-W for at least 90 km and is known as Allah Bund (wall of God) (Seisat18, Seismotectonic Atlas of India, GSI.). The Anjar Earthquake of July, 21, 1956 had caused 115 fatalities and hundreds of injuries. About 1350 houses were destroyed in Anjar town alone and about 200 houses were partially damaged.

The Earthquake Engineering Research Institute (EERI) in their Preliminary report regarding the origin of the present earthquake sequence opined that "The Indian sub-continent is moving northward at a rate of approximately 53 to 63 mm/yr colliding with Asian plate which is also moving northward but at about half the rate of the Indian plate. This difference in the velocities produces an intracontinental collision forming the Himalayan Mountains and also causing the eastward and westward movement of large Crustal blocks away from the Himalayan orogen". The said report further states the location of the earthquake within 400 km of the active plate margin near the prominent bend in the plate boundary and in a region surrounded by Quaternary active structures and large magnitude earthquakes, indicates that western Gujarat may be a transitional zone between the stable continental interior and the plate margin. Analysis of historical seismicity in the region shows a recurrence period of approximately 200 years for large magnitude earthquakes. Further, the presence of folds and faults, involving Tertiary and younger sediments stands in contrast to the marked stability of the Peninsular India east of the Khambat graben and indicates long term tectonic activity."

Discussion

The Sardar Sarovar Narmada Nigam Ltd (SSNNL) is operating a network of nine seismological stations around Sardar Sarovar Project mainly designed for monitoring micro earthquake activity within and around the large reservoir. The locations are shown in figure-1.The network is located about 400 km south-east of Bhachau, the source region of the 2001 Bhuj earthquake.. The types of instruments installed are given in Annexure.1. A total of

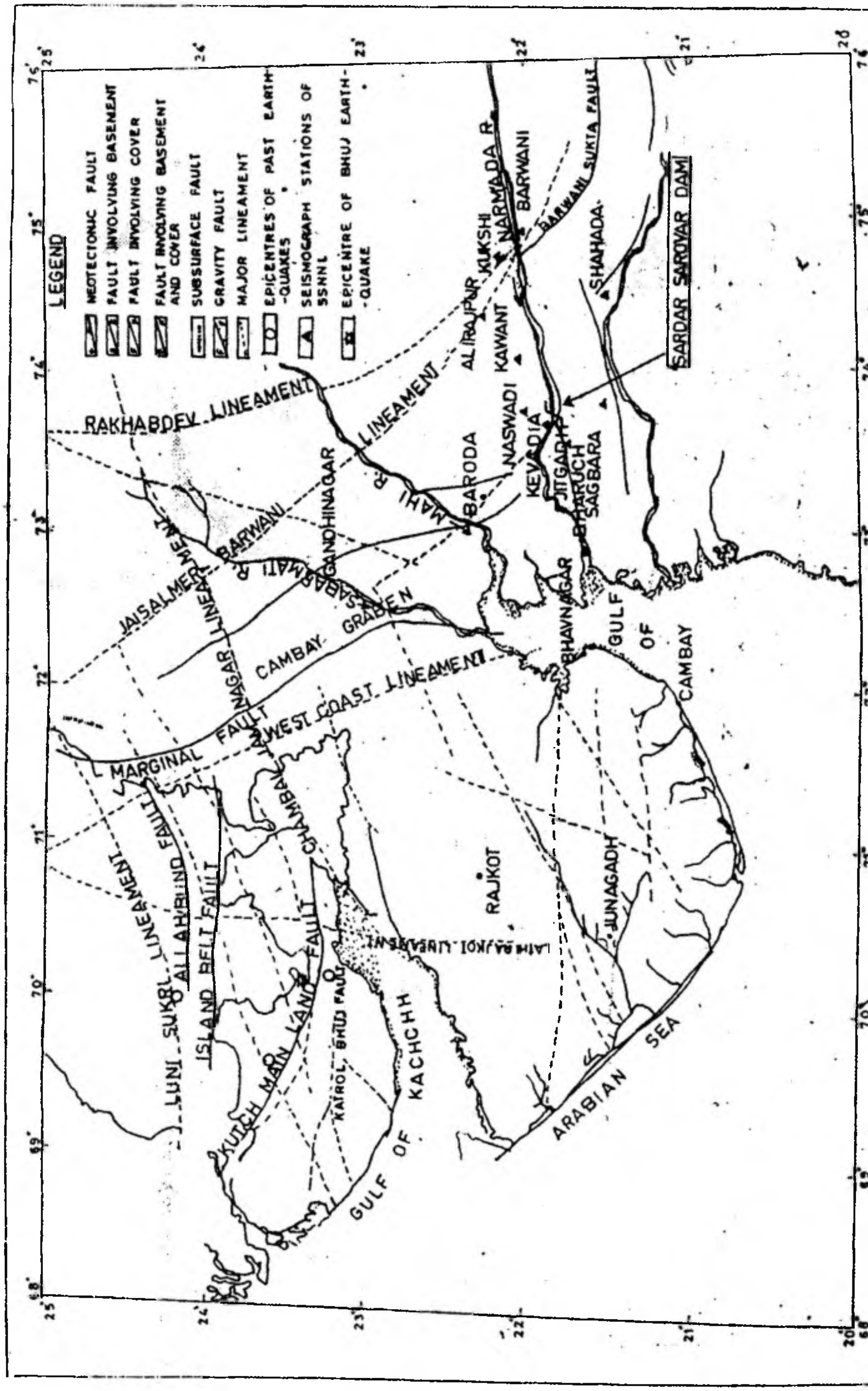

FIG. 1:- EPICENTRE OF BHUJ EARTHQUAKE, MAJOR TECTONIC FEATURES AND SEISMOGRAPH STATIONS OF SSNNL.

2299 shocks with M=3.0 were recorded by the network till end of December 2001. Of these, the locations of 520 aftershocks could be located accurately. The month wise distribution of shocks is shown as histogram in figure 2.

The magnitude of main shock and some well recorded aftershocks of $M \geq 5.0$ have been calculated from the data of Wood Anderson-Seismographs.

i) Main Shock

Date	:	January 26, 2001
Origin Time	:	08:46:39 (IST)
Epicentre	:	Lat. 23.40° (N),
		Long. 70.09° (E)
Focal Depth	:	22.6 km
Magnitude Ml	:	7.2
Location	:	Near village Jharan about 30 Km N W of Bhachau.

ii) Aftershock Sequence

During the 6 days immediately after the main shock the frequency of occurrence of $M \geq 5.0$ after shock was high with 36 shocks per week. This decreased to 2 shocks in a week during February and further decreased to 1 in a fortnight during March 2001.

The migration of activity could be seen between 69.8° and 70.8° along E-W to NE-SW trends. The shock of M=6.2 on January, 28, 2001 has been largest aftershock till date. The aftershock sequence for the period January-December 2001 is shown as epicentral plots in figure 3.

The activity is spread in an area of roughly 1°x1°(110 km x110 km) with much of the activity between Lat.23.00°-24.00°N and Long.69.80°-70.80°E extending roughly along NE-SW direction. Most of the well located aftershocks were concentrated in the region NW of Bhachau with a cluster located within 1 - 30 km of main shock. Not much activity could be noticed towards west of Rajkot-Lathi lineament during this period. It seems that Rajkot-Lathi lineament might have played some role in the energy release and controlling the migration. During the activity was within Lat. 23.2°-24.0° and Long 70.0°-70.6° with another preferential N-S direction of in addition to the earlier NE trend March 2001. After March 2001 most of the activity concentrated in the NE part of the main event with some diffused pattern in 40 km x 40 km area.

During January 2001, out of 588 events recorded in the first six days of the main shock, 101 events with magnitude range 3.5 - 6.2 could be properly located. It seems that on 26th most of the aftershocks after 13.00 hrs, clustered in an area of 30km x 50 km around the location of main earthquake. The general trend was NE-SW. The area of concentration of these aftershocks is considered as immediate aftershock area associated with the main shock. During later period also, the aftershock area remained spread over an area of 40km x 40 km. The general trend was also almost the same except in the month of March 2001, during which the general trend of the activity became N-S, the trend of Rajkot-Lathi lineament. The distribution of higher magnitude events has similar trend as that of lower magnitude ones. The migratory/ oscillatory trend is also almost the same.

iii) Depth distribution

The focal depths of the events were plotted and between Latitude 22.0^0-24.5^0 and Longitude 69.5^0-71.5^0 for studying the extent and attitude of the aftershock in the present earthquake sequence. The depth of the activity for the period January-December 2001 was down to 40 km. Much of the activity is lying between 10 to 30 km. Out of 520 shocks located, 42% were within 20 km, 23% between 21 and 30 km while 29% occurred between 30 and 40km .This indicate shallow nature of the entire aftershock sequence. The cross section along East-West direction showed that the dip of the plane for events was 20°-30° due West.

iv) Decay of aftershock activity

The regularity in the distribution of foreshocks and aftershocks is a very interesting and important characteristic. Utsu (1961) found that the time distribution of aftershocks is given by the inverse power law.

$$N(t) = ct^{-h}$$

Where **N(t)** is the frequency of aftershocks per unit time and **c** and **h** are constants and **t** is the time elapsed after the main shock. The value of h indicates the rate of decay of aftershock frequency. The decay trend of aftershocks was studied for a period of twelve months by taking t as one day.

Accordingly

$$N(t) = 589.4\, t^{-1.13}$$

The decay constant **h** is found to be **1.13** which can be considered as slow decay.

v) Frequency-Magnitude Distribution

Gutenberg and Richter (1944, 1954) frequency and magnitude relationship for earthquakes is given by

$$\log N = a - bM$$

where a and b are constants and M is the magnitude of shocks and N is number of M +ΔM

The data recorded at Kevadia and Naswadi stations were used to make a plott of cumulative frequency against magnitude interval of 1.0 unit. The standard regression through least-square method yielded the equation with **b** value is **0.96**,

$$\log N = 6.46 - 0.96M$$

when the main shock is included in the sampling. The typical plot of the same is shown in figure 5.

Conclusions

- The concentration of the aftershock activity shows a general NE-SW trend.
- The activity appears to be more sympathetic to the Kachchh Mainland Fault, Lathi Rajkot Lineament and other parallel / sub parallel features in the region.
- The focal depth distribution is found to be confined down to 40 km including the main shock. Mort of focal depths are around 10-30 km.
- The decay constant **h** for the sequence is found to be **1.13** which is normal for large tectonic sequences.
- The "**b**" value of this sequence is found to be **0.96** which is also in agreement with normal global tectonic sequences.

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DETAILS OF NETWORK OF SEISMOGRAPH STATIONS AROUND RESERVOIR OF SARDAR SAROVAR (NARMADA) PROJECT

Sr. No	STATION LOCATION	FOUNDATION	INSTRUMENT	COMPONENT	PERIOD SEC	GAIN dB	FILTERS LOW HIGH
1	Kevadia Colony	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	72	out 5 Hz
	Lat. 21°52'34"		anolog recorder(VR_60) (Visual Type)	N	1.0	60	out 5 Hz
	Long 73°42'0"			E	1.0	60	out 5 Hz
			(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
				N	1.0	20	anti-alias
				E	1.0	20	25 Hz
			(iii)Long period seismometer(S-5100) with analog recorder (VR-60) (Visual type)	Z	30.0	60	out 5 Hz
			(iv)Digital event recorder(DR-200)	Z	30.0	20	low cut out anti-alias
			(v)Digital strong motion Accelerograph (DR-210	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
			(vi)Wood-Anderson seismograph	N	0.8	1 K	-
				E	0.8	1 K	-
2	Naswadi	Sandstone	(i) Short period seismometer(S-7000) with	Z	1.0	72	out 5 Hz
	Lat 22°1'42"		anolog recorder(VR_60) (Visual Type)	N	1.0	60	out 5 Hz
	Long 73°46'7"			E	1.0	60	out 5 Hz
			(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
				N	1.0	20	anti-alias
				E	1.0	20	25 Hz
			(iii)Digital strong motion Accelerograph (DR-210	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
			(iv) Wood-Anderson seismograph	N	0.8	1 K	-
				E	0.8	1 K	-
3	Jitgadh	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	66	out 5 Hz
	(Karjan dam site)		anolog recorder(VR-60) (Visual Type)	N	1.0	60	out 5 Hz
	Lat. 21°49'32"			E	1.0	60	out 5 Hz
	Long 73°33'0"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
				N	1.0	20	anti-alias
				E	1.0	20	25 Hz
			(iii)Digital strong motion Accelerograph (DR-210	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
4	Kawant	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	66	out 5 Hz
	Lat. 22°5'0"		anolog recorder(VR_60) (Visual Type)				
	Long 74°3'20"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
			(iii) Digital strong motion Accelerograph (DR-21	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz

Sr. No.	STATION LOCATION	FOUNDATION	INSTRUMENT	COMPONENT	PERIOD SEC	GAIN dB	FILTERS LOW HIGH
5	Alirajpur	Granite	(i) Short period seismometer(S-7000) with	Z	1.0	72	out 5 Hz
	Lat. 22°17'30"		anolog recorder(VR_60) (Visual Type)				
	Long 74°10'40"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
			(iii)Digital strong motion Accelerograph (DR-21(	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
6	Barwani	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	66	out 5 Hz
	Lat. 22°02 0"		anolog recorder(VR_60) (Visual Type)				
	Long 74°55'0"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
			(iii)Long period seismometer(S-5100) with	Z	30.0	60	out 5 Hz
			analog recorder (VR-60) (Visual type)				
			(iv)Digital event recorder(DR-200)	Z	30.0	20	low cut out
							anti-alias
			(v)Digital strong motion Accelerograph (DR-210	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
			(vi)Wood-Anderson seismograph	N	0.8	1 K	-
				E	0.8	1 K	-
7	Kukshi	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	66	out 5 Hz
	Lat. 22°12'0"		anolog recorder(VR_60) (Visual Type)				
	Long 74°42'30"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
			(iii)Digital strong motion Accelerograph (DR-21(	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
8	Shahada	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	72	out 5 Hz
	Lat. 21°30'12"		anolog recorder(VR_60) (Visual Type)				
	Long 74°24'48"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
			(iii)Long period seismometer(S-5100) with	Z	30.0	60	out 5 Hz
			analog recorder (VR-60) (Visual type)				
			(iv)Digital event recorder(DR-200)	Z	30.0	20	low cut out
							anti-alias
			(v)Digital strong motion Accelerograph (DR-210	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz
			(vi)Wood-Anderson seismograph	N	0.8	1 K	-
				E	0.8	1 K	-
9	Sagbara	Deccan trap	(i) Short period seismometer(S-7000) with	Z	1.0	66	out 5 Hz
	Lat. 21°30'24"		anolog recorder(VR_60) (Visual Type)				
	Long 73°42'54"		(ii)Digital event recorder(DR-200)	Z	1.0	40	low cut in
			(iii)Digital strong motion Accelerograph (DR-21(	Z	-	-	low cut in
				N	-	-	anti-alias
				E	-	-	25 Hz