MESSAGE

I am pleased to note that Institute of Seismological Research (ISR) is bringing out its 2014-15 Annual Progress Report. Such reports are effective tool for dissemination of recent findings even before they are published in scientific journals for the benefit of the society. In case of ISR it is more important as the findings could be useful in saving lives and damage to property from earthquakes.

The scientific research at ISR started in mid 2006 and has proved to be a unique Institute in the world as research is undertaken in 16 different branches of earthquake science. Since then the institute has grown leaps and bounds under the able leadership of Prof. (Dr.) B.K. Rastogi, DG, ISR to the heights of national and international repute. The institute has very focused plans for the seismological studies in India with particular reference to the monitoring of seismicity in Gujarat. The institute has put three multi-parametric geophysical observatories in Kutch which add a new dimension to the earthquake prediction studies.

ISR is not only carrying out research in applied Seismology but also basic research of understanding Physics of earthquake process. It carries out research in assessment of earthquake hazard, helps education of earth science and works for various types of energy sector industries. NPCIL has acknowledged the technical knowhow which it received over the years for seismic resistant design of nuclear power plants from Institute of Seismological Research, Gujarat State Petroleum Corporation acknowledged its work on seismic safety factor for LNG Storage Terminal and Gujarat Intl. Finance Tec- City for suggesting seismic safety factor for cluster of skyscrapers. ISR is bridging the gap between academics and construction as well as other industries with the help of its research activities in the field of earthquake science and different fields of geosciences.

(G. R. Aloria)
Chief Secretary, Gujarat State
& Chairman Executive Committee of ISR

MESSAGE

Gujarat has been excelling in the field of Science & Technology since long. *Carrying forward this tradition, the State Department of Science and Technology* started Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Institute of Seismological Research (ISR), Gujarat Council of Science City, Gujarat State Biotechnology Mission and Gujarat Council of Science and Technology over a period of time.

It is worthwhile to mention that within a short span of a few years, ISR has become a Premier International Institute. Its data generated for Intraplate Earthquakes and Geotechnical Studies have formed basis for Frontier Research. ISR has been credited to have started disseminating information about Earthquakes within minutes of their occurence through VSAT-connected network of about 60 Broadband Seismographs which are rated one of the best in the Country. Round-the-clock watch is kept for safety from Earthquakes and Tsunami. ISR is helping in Seismic Safety of Nuclear and Hydropower projects. For Petroleum prospects it is assessing new source zones. ISR is promoting Earth Science Education and Popularization of Seismology. ISR has A to Z expertise in Seismic Microzonation as also equipments for different types of Geophysical Surveys. The network of Geodetic GPS and InSAR studies has also given precious insights into the cause of Kutch Earthquakes.

On this occasion when the ISR is bringing out 2014-15 Annual Report, I wish this premier organisation all success in its future endeavours.

SJ Haider

(S. J. Haider)

Secretary, Department of Science and Technology, Gujarat State

CHAPTER 1

EARTHQUAKE MONITORING AND SEISMICITY PATTERNS IN GUJARAT

(Santosh Kumar, A.P. Singh, Jyoti Sharma, P. Mahesh, Vandana Patel, Ketan Singharoy)

1.1 SEISMIC NETWORK

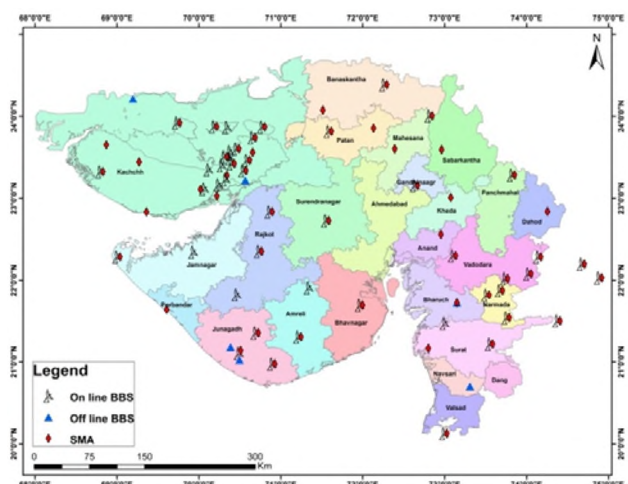


Fig. 1.1: Gujarat network consists of 60 Broadband Seismograph (BBS) stations (including 2 Very Broad Band Seismographs) out of which 49 are online. There are also 54 Strong Motion Accelerographs (SMA).

As Gujarat falls in seismic zones III to V seismic monitoring of Gujarat is done by ISR through a dense network of 60 broadband seismograph stations (49 connected by VSAT) and 54 Strong Motion Accelerographs (Fig.1.1). The network has detectibility of M2.0 in the Kachchh active area and M2.5 in the other areas of Gujarat. The mainshocks during 1668 to 2014 in Gujarat are depicted in Fig. 1.2. ISR also gets worldwide data online. The system is having advanced auto location, dissemination and archiving facility. Presently earthquake epicenter and magnitude is informed within minutes. It is planned to have information in seconds. By installing Earthquake Early Warning System if a large earthquake occurs at Kachchh, it will be informed within seconds to multistory buildings, high speed trains and nuclear power plants etc.

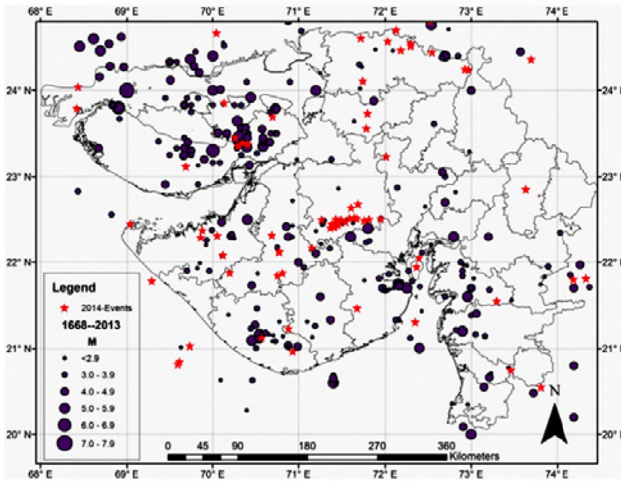


Fig. 1.2a: Epicenters of earthquakes of M≥2 from 1668 to 2014 in Gujarat excluding foreshocks and aftershocks (Stars are shocks in year 2014).

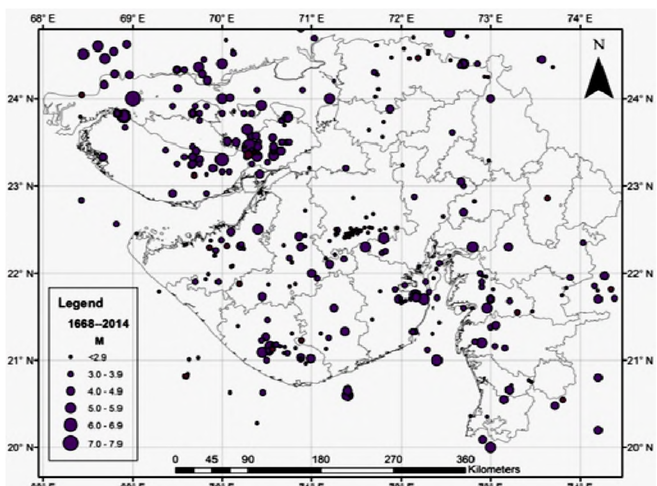


Fig. 1.2b: Epicenters of earthquakes of M≥2 from 1668 to 2014 in Gujarat excluding foreshocks and aftershocks.

1.2 DESCRIPTION OF RECORDED EARTHQUAKES

Strong Motion Accelerograph Data

In the year 2014, in Kachchh a tremor on 8th March 2014 of M4.1 which occurred 8 km NNW of Bhachcau (Table 1.1, Fig. 1.3) was recorded on 4 SMA stations. Some 25 shocks of M2.8-4.1 were recorded on strong motion accelerographs. Out of which 3 shocks (in Kachchh) were recorded on 2 or more stations. Remaining shocks were recorded on only 1 SMA station. In Kachchh 17 shocks were recorded in one of the accelerographs.

Table 1.1: List of earthquakes of M~4 or more and no. of SMA stations triggered

M	Date	Time (GMT)	Lat	Long	Dep	NST	Region
4.1	08-Mar-14	19:01	23.36	70.29	36.5	4	08 km NNW from Bhachau, Kachchh

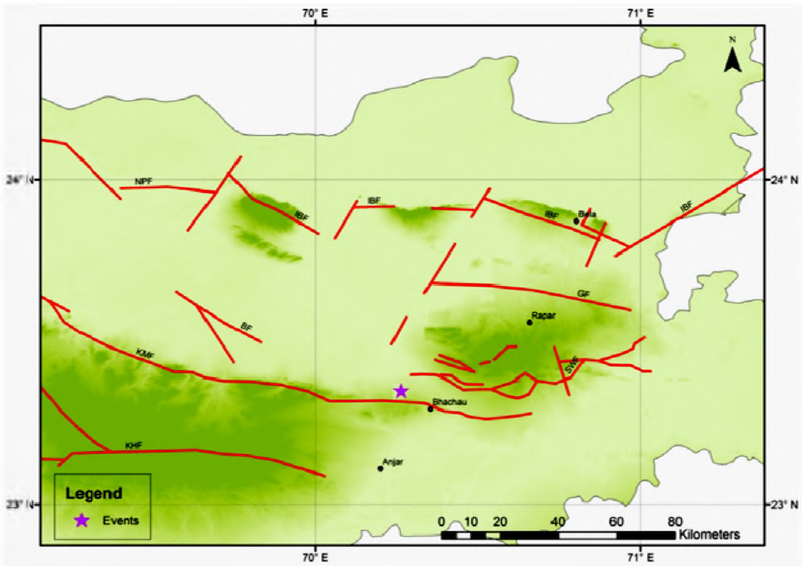


Fig. 1.3: Location of the earthquake of M4.1that occurred in Kachchh on 8.3.2014

Description of Earthquakes in Different Parts of Gujarat During 2014

Epicentres of earthquakes in magnitude range 0.4 to 4.1 in Gujarat during 2014 are shown in **Fig. 1.4.**

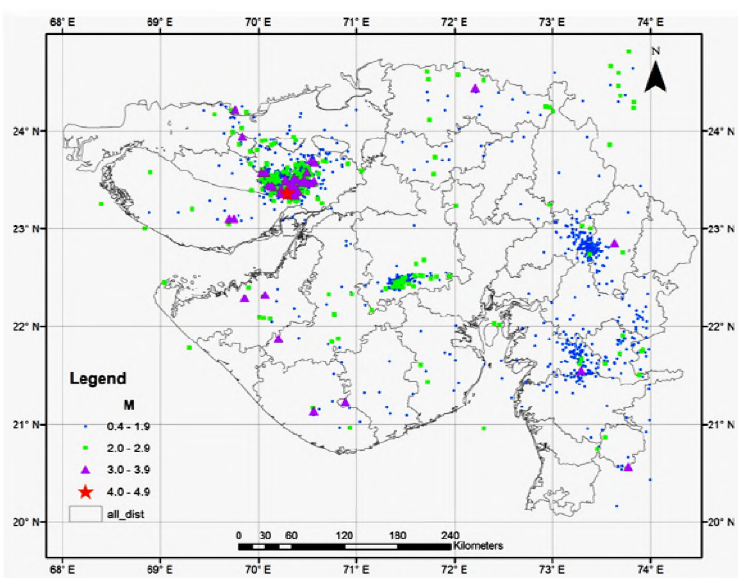


Fig. 1.4: Epicentres of earthquakes in magnitude range 0.4 to 4.1 in Gujarat during 2014

Magnitude-wise distribution of earthquakes in the three regions of Gujarat during 2014 is given in Table 1.2. In the Kachchh region 960 shocks were located of M0.7- 4.1 (59% of total in Gujarat). In the Saurashtra region 215 shocks were located of M0.7 -3.5 (13% of total in Gujarat). In the mainland 457 shocks were located of M0.4 – 3.7 (28% of total in Gujarat).

Table 1.2: Regional Distribution of Earthquakes Located in Gujarat during 2014

Region	<2.0	2-2.9	3-3.9	4-4.9	Total
Kachchh	687	227	45	1	960
Saurashtra	160	50	5	0	215
Mainland*	415	38	4	0	457
Total	1262	315	54	1	1632

***Includes shocks recorded on SSNNL network**

Monthwise seismicity in three regions, namely Kachchh, Saurashtra and Mainland of Gujarat in year 2014 are listed in Table 1.3 and shown inn Fig. 1.5.

Table 1.3: Monthwise seismicity in three regions, namely Kachchh, Saurashtra and Mainland of Gujarat in year 2014

Month / Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kachchh	68	67	75	96	97	61	84	71	109	91	53	88	960
Saurashtra	12	10	17	14	20	13	22	16	14	10	28	39	215
Mainland	91	47	47	48	43	25	38	16	28	28	25	21	457

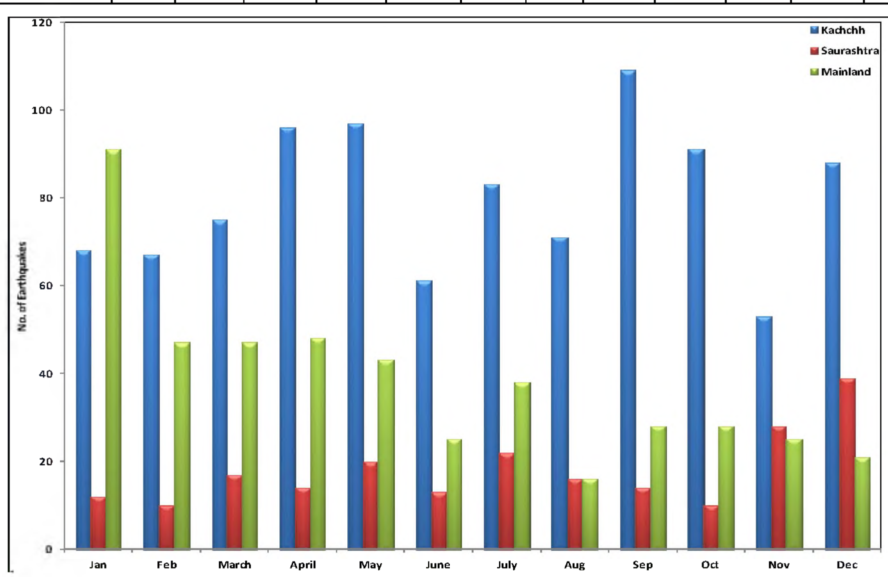


Fig. 1.5: Histogram showing the month wise seismicity in three regions namely Kachchh, Saurashtra and Mainland of Gujarat in year 2014.

During 2014, the network recorded nearly 1811 shocks of M0.4 to 4.1 out of which hypocentral parameters of 1632 shocks were located. Additional 34 regional earthquakes were also recorded from other states including M6.4, Nicobar earthquake on 21st March 2014. Some 187 distant earthquakes of M5.0 or greater were recorded including M8.2, Chile earthquake on 1st April 2014.

Seismicity in Kachchh

Seismicity in Kachchh has consistently been lower since 2008 (Fig. 1.6 and Table 1.3) with about 60 shocks of M≥3/y. During 2014 it is quite low. However, one M5 earthquake in 2012 has reminded its continuance to moderate level. Magnitude wise total No: M3-3.9= 2437, M4-4.9= 271, M≥5=21

Table 1.3: showing the no. of earthquakes of M≥3.0 which occurred in Kachchh since 2001

Year Magnitude	3-3.9	4-4.9	5-5.7	Total
2001	877	186	15	1078
2002	135	15	0	150
2003	98	3	1	102
2004	99	6	0	105
2005	267	16	0	283
2006	405	20	4	429
2007	143	6	0	149
2008	66	5	0	71
2009	73	4	0	77
2010	52	1	0	53
2011	62	3	0	65
2012	56	2	1	59
2013	59	3	0	62
2014	38	2	o	40
Total	**2187**	**252**	**21**	**2460**

These years in Kachchh there were 687 shocks of M0.7-1.9, 227 shocks of M2.0-2.9, 45 shocks of M3.0-3.9, and 1 shock of M4.1. The shock of M4.1 occurred on 8th March 2014 , 08 km NNW from Bhachau, Kachchh.

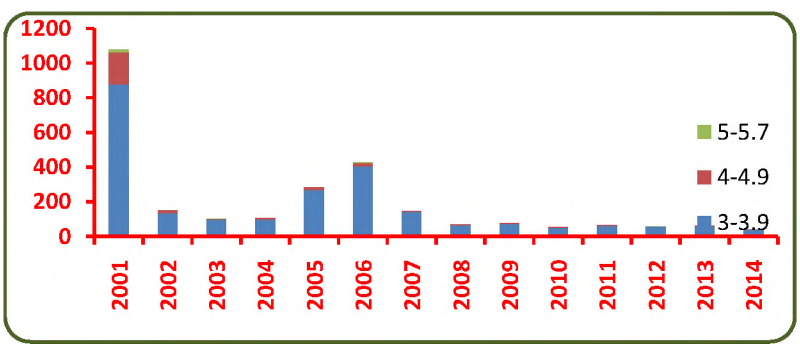


Fig. 1.6: Annual no. of shocks in Kachchh during 2001 to 2014.

Focal depths of Kachchh earthquakes for M≥3.0 which occurred in year 2014 are depicted in Fig. 1.7.

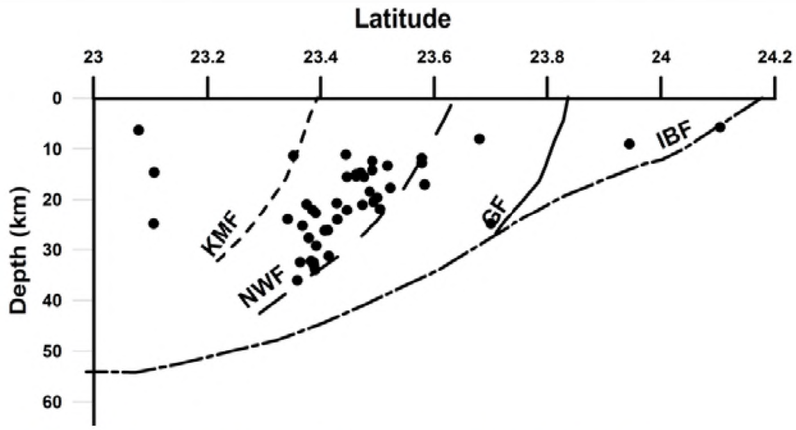


Fig. 1.7: Focal depths of the earthquakes of M≥3.0 in Kachchh during 2014.

Seismicity in Saurashtra

This year in Saurashtra there were 160 shocks of M<2.0, 50 shocks of 2.0-2.9, and 5 shocks of M3.0-3.9. Shock of Mmax.3.5 occurred on 05-01-2014, 17km NNW of Upleta. Epicentres of earthquakes of magnitude 0.7 to 3.5 in Saurashtra during 2014 are shown in Fig. 1.8.

During August 2006 to December 2014, 128 earthquakes have occurred of M3-3.9, 7 earthquakes of M4-4.9 and 2 earthquakes of M5.0 & M5.1 in Saurashtra (Tables 1.4 to 1.9 & Figures 1.9 & 1.10).

Tremors were recorded from previously active areas such as Talala (M≥5.0 on 6th November 2007 and on 20th Oct. 2011), near Surendranagar and Rajkot (M_{max}.3.4 on 19th Sept. 2012). 12 shocks of M1.-3.2 were recorded in Jamnagar. This year seismicity was nil in Bhanvad-Adwana area. Focal depths of shocks in Saurashtra are from near surface to about 10km. Surendranagar area showed a large no. of mcroearthquakes: M<2 are and M2-2.9 are .

Seismic activity in Talala of Junagadh District:

In the year 2014, some 34 shocks of M0.7- 3.2 were recorded from Talala area. Earthquake of Mmax.3.2 occurred on 13th June 2014, 10km NNE of Talala.

In year 2011, an earthquake of Mw5.1 occurred, 12 km WNW of Talala in Gir on 20th Oct. An aftershock of M4.1 that occurred about 9 hours after the mainshock on 21st Oct. and another of M4.0 on 12th November 2012 were also strongly felt.

Table 1.4: Seismicity of M≥ 3.0 from Aug. 2006 to December 2014 in the Saurashtra region

M	No. of earthquakes in Saurashtra
3.0-3.9	128
4.0-4.9	7
≥5.0	2

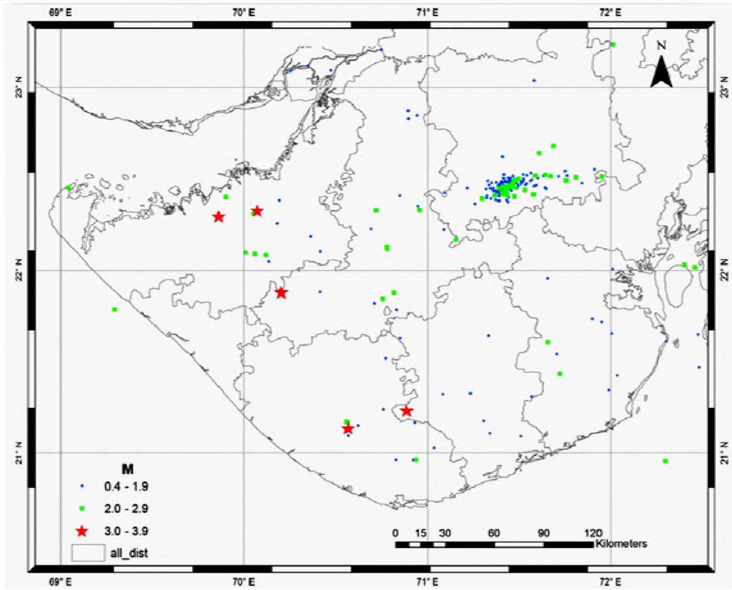


Fig. 1.8: Epicentres of earthquakes in magnitude range 0.7 to 3.5 in Saurashtra during 2014

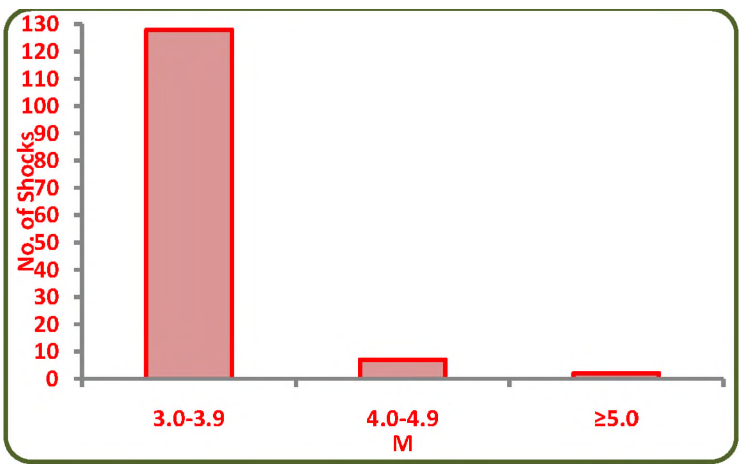


Fig. 1.9: Number of earthquakes in Saurashtra during Aug. 2006-Dec. 2014 in three magnitude categories.

Table 1.5: List of earthquakes with magnitude M≥ 3.0 in Saurashtra during 2014.

	Date	HR	Lat	Long	Depth	M	Region
1	05-01-14	0:50	21.877	70.205	3.1	3.5	17km NNW of Upleta
2	12-05-14	6:06	22.326	70.072	17.2	3.3	16 km NNE of Lalpur
3	13-06-14	18:17	21.136	70.568	12.1	3.2	9 km NNE of Talala
4	22-06-14	17:40	22.293	69.862	30.6	3.0	15 km NNW of Lalpur
5	27-08-14	18:34	21.231	70.887	4.5	3.0	42km ENE of Talala

Table 1.6: Annual number of earthquakes of M 0.5 to 5.1 in different areas of the Saurashtra region during 2007 to 2014.

Year	2007	2008	2009	2010	2011	2012	2013	2014
Rajkot	7	12	20	33	21	12	6	12
Surendranagar	39	174	325	314	311	537	139	103
Talala	361	375	67	113	465	83	34	14
Jamnagar	87	25	29	182	24	8	4	11
Total	**494**	**586**	**441**	**642**	**821**	**393**	**183**	**140**

Table 1.7: Annual number of earthquakes of M 0.5 to 5.1 in Saurashtra region during 2007 to 2014 magnitude wise.

Year	2007	2008	2009	2010	2011	2012	2013	2014
3.0 - 3.9	30	12	6	12	18	6	3	5
4.0 - 4.9	1	2	0	0	4	0	0	0
5.0 - 5.9	1	0	0	0	1	0	0	0
Total	**32**	**14**	**6**	**12**	**23**	**6**	**3**	**5**

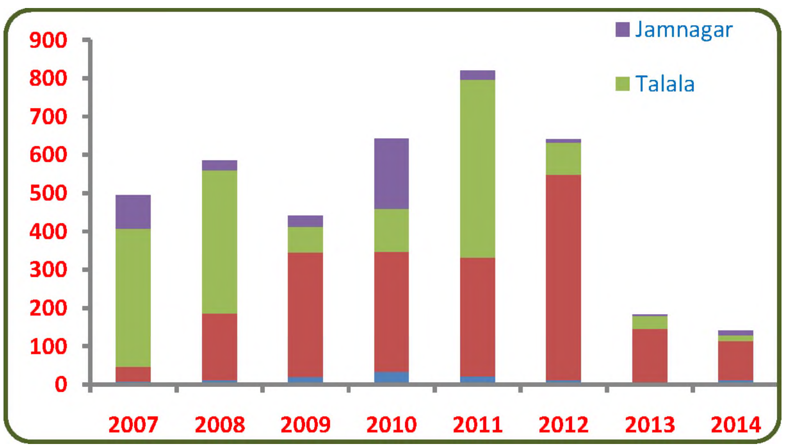


Fig 1.10: Histogram showing the year wise seismicity variation in Jamnagar, Talala (Junagarh), Surendranagar and Rajkot district of Saurashtra.

Table 1.8: List of earthquakes region wise with magnitude M0.9-3.6 in the Saurashtra region in 2014.

Region	< 2.0	2.0 - 2.9	3.0 - 3.9	Total
Lalpur	4	5	2	11
Porbandar	0	0	0	0
Talala	10	2	2	14
Bhavanagar	49	12	0	61
Rajkot	11	7	1	19
Surendranagar	81	22	0	103

Table 1.9: Monthwise list of earthquakes within the Saurashtra region during 2014.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Lalpur (Jamnagar)	0	1	0	3	1	1	0	0	1	0	1	3	11
Dwarkia	0	0	0	0	0	0	1	0	0	0	0	0	1
Talala (Junagadh)	2	3	0	3	0	1	2	1	0	0	1	1	14
Bhavanagar	4	4	9	4	8	3	3	5	4	3	4	10	61
Rajkot	2	1	1	0	2	2	1	1	1	1	6	1	19

Seismic activity around Rajkot:

In the year 2014, 19 shocks were recorded with M1.3-3.5. Shock of Mmax.3.5 occurred on 05-01-2014, 17km NNW of Upleta

Seismic activity around Surendranagar:

In the year 2014, 103 shocks of M1.1-2.5 were recorded. 2 Shocks of Mmax.2.5 were recorded on 14th March 2014, 21 km South of Surendranagar, and on 5th August 2014, 27 Km SW of Surendranagar respectively.

Earthquakes in Mainland Gujarat

In the mainland 457 shocks (includes shocks recorded on SSNNL network) were located of M0.4 – 3.7. Out of these 2 shocks are of M≥3.0. Shock of M3.6 occurred at IST 09:29 PM on 21st June 2014 at 38km ESE of Bharuch district in Valia Taluka (66km NE of Surat city). The Earthquake was felt in Bharuch, Surat and Narmada districts. The villages near the epicenter are Gundia, Petia, Rajpara, Sevad, Kamaliya, Jabugam, Itakla. Also most of the people living in high-rise buildings in nearby cities felt the earthquake, however no damage was reported. Shock of Mmax.3.7 occurred on 19th Nov 2014, 21 km NNE of Deesa in North Gujarat.

Seismicity around the epicenter of M3.6 Bharuch Earthquake of June 21, 2014

An earthquake of magnitude 3.6 occurred at 09:29 PM on 21st June 2014 at 38km ESE of Bharuch district in Valia Taluka (66km NE of Surat city). The Earthquake was felt in Bharuch, Surat and Narmada districts. The villages near the epicenter are Gundia, Petia, Rajpara, Sevad, Kamaliya, Jabugam, Itakla etc. (Figure 1.11). Also most of the people living in high-rise buildings in nearby cities felt the earthquake, however no damage was reported. There are some 20 Seismograph stations within about 200km radius of Bharuch which are used for location.

The Bharuch region has experienced 9 earthquakes of magnitude 3.1-5.4 in historical past (Table 1.10). The earthquake of Mmax.5.4 occurred on 23-03-1970 near Bharuch city. District Bharuch is in seismic zone III where earthquakes of magnitude up to 6 can be expected. It is considered to be moderately seismic. The region has a major fault along Narmada river and some other smaller faults. However, there is no known geological fault mapped in the area near the June 2014 epicenter. Geological faults in the region are shown in Figure 2. A small NW-SE trending Rajpardi fault of 20 km length is there north of the area and in East of Bharuch and Ankleshwar. The old faults are sometimes activated with small to moderate earthquakes. Moreover, Rajpardi fault is a small fault along which any major earthquake is not expected. Hence, no immediate action is warranted.

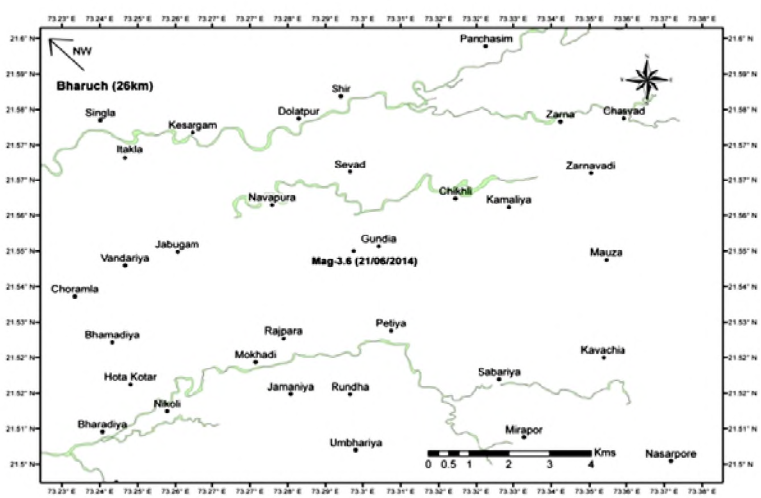


Fig. 1.11: Villages near the epicenter of the earthquake of M3.6 which occurred on 21-06-2014.

Table 1.10: Past earthquakes of M≥3.0 in Bharuch and nearby region

Year	MM	Date	Lat	Long	M	Region	Ref.
1970	3	23	21.7	73.0	5.4	Bharuch	NGRI
1970	8	9	21.7	73	3.5	Bharuch	USGS
1970	8	30	21.7	73	4.1	Bharuch	USGS
1970	9	10	21.6	72.7	3.4	Bharuch	USGS
1971	6	18	21.7	73	3.4	Bharuch	IMD
1979	8	24	22.11	72.43	3.1	Khambhat	GERI
1980	6	4	21.68	73.21	3.1	Nartrang	GERI
1980	7	21	22.87	72.14	3.1	Nartrang	GERI
1982	3	10	21.38	73	3.1	Bharuch	GERI

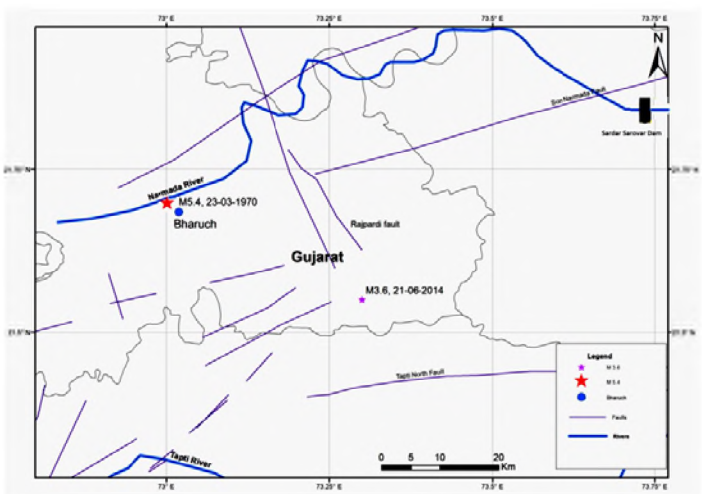


Fig 1.12: Geological faults of the area and epicenters of earthquakes of M3.0-4.5 which occurred during 1984-2014 and also of 1970 Bharuch earthquake of M5.4.

Intensity of Mw 3.9 tremor of March 19, 2015 in north Mahesana District

A tremor of magnitude Mw 3.9 of March 19, 2015 at 3:11 PM had epicenter 15 km NNW of Dharoi in north Mahesana district (24.027 N, 72.703 E, depth 5 km). The earthquake was felt in Sabarkantha, Banaskantha and Mahesana districts of north Gujarat on Thursday creating panic among people. At several places people from houses and shopping malls, cricket fans watching the India-Bangladesh World Cup tie and students taking exams rushed out in panic after experiencing the tremors. Many shop owners also downed their shutters for some time fearing larger tremors to follow.

The tremor caused maximum intensity which is assigned grade V on M M Scale as the tremor was strongly felt, vessels fell down and minor cracks were reported at places with distances up to 65 km: in Himmatnagar of Sabarkantha district at 65 km in SSE direction and at distances of 35 to 60 km up to Amirgadh, Vadgam, Danta, Ambaji etc. all in eastern Banaskantha district in NW to NE direction from the epicenter. The area within 30 km radius has thin population hence not many felt reports have been received from near distances. Also felt area is less in east-west direction and more in north-south direction (Fig. 1.13, Table 1.11).

The area is about 35 km east of Cambay basin and covered by soil. Precambrian hard rock's may be near surface. Felt area is large due to presence of rocks at shallow depth. There is no fault line near the epicenter. Hence, only some small fault may be there along which stresses due to normal tectonic processes when accumulated to critical stage are released in small tremors. In Cambay basin a transverse NE trending fault if extended will pass close to the epicenter.

The past earthquakes within about 100km radius of the epicenter are listed in Table 1.12. These tremors were around Mt. Abu, Patan and Palanpur. Mt Abu earthquakes are of magnitude up to 5.7. Others are of magnitude 3.1 to 4.6.

As Dharoi dam and reservoir are 15 km east and presently water depth is only 19 m (as against maximum 29 m), the tremor is not related to Dharoi dam.

DESCRIPTION OF FELT AND DAMAGE REPORTS

❖ **Reporting of Cracks**

Sabarkantha District: In Himmatnagar glass window panes cracked on the 3rd floor of a shopping complex. Some houses also reported minor cracks. Two benches in school of Mahor village of Vadali tahsil, near Himmatnagar damaged and two girls of 9th class fainted due to fear and were taken to hospital.

Banaskantha District: Cracks reported in school and some houses in Virampur and vessels fell down. In Danta's Punjpur, Balvantpura, Velwada and Ratanpur villages cracks were reported in some houses. Cracks in Walls of some houses were reported and utensils fell at Malan, Amirgadh, Ambaji, Hadai. A few cracks in houses of Palanpur, Vadgam. In Malan village near Palanpur cracks were reported in a school.

- **Strongly Felt: Tremor was felt for a few seconds. People ran out of houses and children from schools.**

Sabarkantha District: People came out from the multi-storey buildings and shopping malls at Tower road, Himmatnagar.

People of Prantij, Idar, Wadali, Khed Brahma, Poshina, Lamdia, Bhiloda, Vijaynagar as well as in villages of Deshotar, Umedgadh, Bolundra, Masal, Ratanpur near Idar were Panicked.

Banaskantha District: At Malan Primary School some 900 children ran out. At Isrol a person reported that his bed shook. At Rajpur village people ran out of houses. At Maheadeo, Umedpur, Medhasan, Sirdoi, Madhupur and Sampur there was first rumbling sound and then shaking. Shaking of utensils and disturbed decoration pieces were reported from many houses.

Mahesana District: Felt at Satlasana, Kheralu and Vadnagar.

Not Felt : Tremor was not felt at Dahod in Sabarkantha district. Tremor not felt in western part of Banaskantha district at places like Vaav, Tharad, Deesa, Bhabhar, Diyodar, Kankarej, Lakhani and Dantivada.

Table 1.11: Felt reports of M3.9 Dharoi tremor of March 19, 2015. Information about cracks in walls of houses, falling vessels and felt reports collected from News papers Divya Bhaskar, Sandesh, Gujarat Samachar, Rajasthan Patrika. The press clippings are attached.

District wise effect	Banaskantha District	Mahesana District	Sabarkantha District
Cracks	At Malan school & Amirgadh, At Virampur's School & Houses. At Danta and nearby places like Punjpur, Balvantpura, Velvada & Ratanpur At Ambaji & Hadai	Cracks in some houses	In Himmatnagar: Third Floor glass window panes of a shopping Mall had broken
Falling of objects	Vessels fell down from racks at several places.		
Strongly Felt	In Eastern Part at areas like: Danta, Amirgadh Vadgam and Palanpur	Satlasana, Kheralu, Vadnagar	Himmatnagar, Prantij, Idar, Vadali, KhedBrahma, Poshina, Lambadiya, Bhiloda, Vijaynagar
Not Felt	Western Part of Banaskantha district like: Vaav, Tharad, Disa, Bhabhar, Diyodar, Kankarej, Lakhani, Dantivada	No felt reports from south of Mahesana	Not felt at Dahod

Table 1.12: Shocks earlier experienced in about 70km radius of the epicenter

SN	Year	MM	DD	OT	Lat	Long	M	MMI	**Location**
1	1848	4	26		24.4	72.7	5.7	VII	Mount Abu
2	1906	8	15		24.4	72.7	4.3	V	MountAbu
3	1962	9	1	22 01	24	73	4.6		Palanpur
4	1969	10	24	11 45	24.8	72.5	5.5		MountAbu
5	2010	3	30	19:57	23.6	72.6	3.2		Mahesana
6	2010	9	2	8:39	23.9	71.9	4.4		Patan
7	2011	11	7	3:05	24.4	72.7	3.1		Palanpur
8	2013	8	3	1:17	24.4	72.9	3.3		44 km NNE from Dharoi
9	2014	11	19	15:26	24.4	72.2	3.1		23 km NNE from Deesa, Banaskantha
*10	2015	3	19	9:41	24.1	72.7	3.9	V	18 m WNW from Dharoi

*Present Tremor

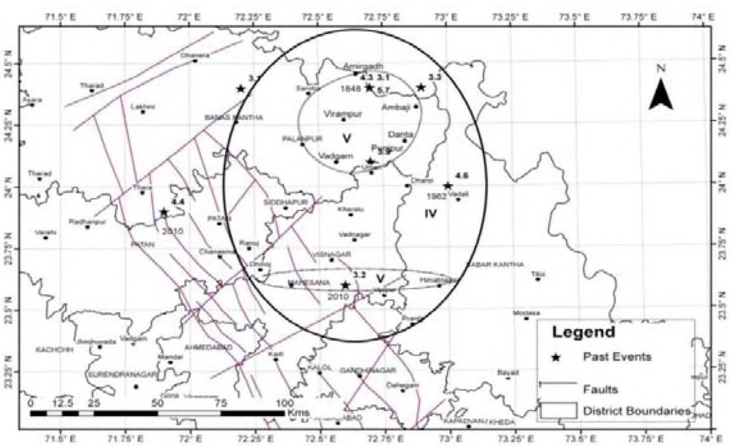


Fig. 1.13: Isoseismals for M3.9 Dharoi earthquake of March 19, 2015 and past nearby earthquakes

1.3 EMPIRICAL RELATIONSHIPS FOR THE EARTHQUAKE EARLY WARNING SYSTEMS

(Ketan Singha Roy, Sorabh Sharma, Pallabee Choudhury, Santosh Kumar and B. K. Rastogi)

An earthquake early warning (EEW) system forewarns an urban area of forthcoming strong shaking, normally with a few seconds to a few tens of seconds of warning time, i.e., before the arrival of the destructive S-wave part of the strong ground motion. The initial part of the P-waveform is very useful for determining magnitude, peak ground acceleration (PGA). Following Wu and Kanamori (2008), we have determined peak ground motion parameter Pa from the initial 3 sec of the P waveforms of high-pass filtered vertical seismogram and developed log-log empirical relationship Pa and PGA. Also, an attenuation equation among Pa, hypocentral distance and magnitude has been developed.

We selected 218 earthquakes occurred in the Kachchh region during 2006 to 2014 with magnitude range 1.7-5.2 listed in ISR catalog. All these earthquakes were recorded by 24 strong accelerograph (SMA) installed and operated by ISR. A total of 589 records are used in this study. Each accelerogram is integrated to velocity and displacement. We applied a 0.075 Hz high-pass recursive Butterworth filter to remove low frequency drift caused by integration process. From the first 3s of the P phase of vertical acceleration, velocity and displacement time series, we estimate the maximum acceleration (Pa), velocity (Pv) and displacement (Pd) respectively. Peak ground acceleration (PGA), velocity (PGV) and displacement (PGD) are estimated form the larger ground motion of the two horizontal components of the acceleration, velocity and displacement time series. Logarithmic – logarithmic empirical relationships between each of Pa, Pv, Pd with each of PGA, PGV, PGD are estimated.

According to our analysis, the Pa - PGA relationship (Fig. 1.14) shows minimum standard deviation $\delta = \pm\ 0.223$. Thus, in order to estimate PGA, the following linear equation is proposed as an optimal relationship for the Kachchh region by compiling all available data:

$$\log(PGA) = 0.692*\log(Pa) + 0.527, \qquad \delta = \pm\ 0.223$$

We attempt to find attenuation equation between Pa, hypocentral distance R and magnitude M as given below:

$$M = 0.442 *\log(Pa) + 1.433 *\log(R) + 1.341, \ \delta = \pm\ 0.495$$

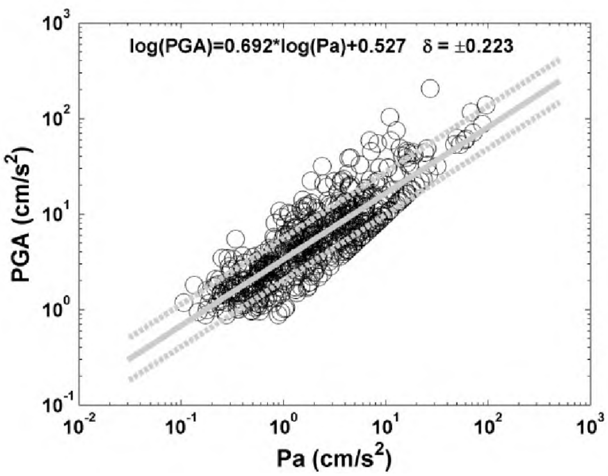


Fig.1.14: A log-log relationship between Pa and PGA. Solid grey line represents mean PGA and dotted grey lines are mean PGA ± 1std.

CHAPTER 2

PHYSICS OF EARTHQUAKE PROCESS

2.1 IMAGING SEISMOGENIC FAULT OF THE 2001 BHUJ EARTHQUAKE OF MW 7.7: DOUBLE DIFFERENCE SEISMIC TOMOGRAPHY

(A. P. Singh, Santosh Kumar and J. R. Kayal with collaboration Prof. Catherine Dorbath IRD, EOST, 5rue Rene Descartes, 67084 Strasbourg, cedex, France)

Some 834 Kachchh Rift Basin (KRB) aftershocks (Mw ≥2.4) of 2006-2014 recorded on 22 local broadband seismographs are relocated in this study by *double difference seismic tomography (TomoDD)* method. This method is combination of both hypoDD (double difference method; and ***Thurber's SIMULPS*** tomography algorithm. The relocated aftershocks and the velocity images shed new light in understanding seismogenic fault(s). A near vertical deeper fault is well imaged that correlates with the geologically mapped South Wagad fault (SWF) in the source area of the main shock and aftershocks. Among the other geologically known faults, the Kachchh Mainland fault (KMF) and the Gedi fault (GF) are also well reflected in the seismic sections. The geological and seismological models are critically examined to understand the deeper (10-35 km) intraplate earthquakes in the KRB.

2.2 STATION CORRECTION AND EARTHQUAKE HYPOCENTER RELOCATION USING THE JOINT HYPOCENTER DETERMINATION METHOD IN THE KACHCHH REGION OF WESTERN INDIA

(A.P. Singh, Mayank Dixit, P. Mahesh, Santosh. Kumar)

A set of 3650 shallow (of Mw ≥2.4 and depth 0-45 km) earthquakes recorded by some 32 broadband seismographs (BBS) during 2006-2013 in the Kachchh region of Gujarat state, western India are relocated by the Joint Hypocenter Determination (JHD) method. The region generated one of the largest intraplate earthquakes Mw 7.6 in 2001, and the aftershock activity is still continuing. The JHD method determines the station corrections, and relocates the hypocenters with higher precision. The hypocenter relocations show relatively large horizontal as well as vertical shifts from that located by the routine Hypo71 analysis. Further, the station correction map produced by the JHD method shows significant lateral variations of seismic velocity in the uppermost crust. The station corrections indicate larger variations from -0.37 to +0.48 s for P-wave and from -0.58 to +1.09 s for the S-wave. The positive station corrections (lower velocity sites) are obtained near the 2001 main shock epicenter area, whereas negative station corrections (higher velocity sites) are obtained in the surrounding areas. One negative correction zone is identified between KMF and KHF fault zones outside the main shock epicenter area where not many aftershocks occurred. The station corrections are comparable with the surface geology and crustal heterogeneities imaged by seismic tomography. The relocated events have brought out a precise seismicity pattern and the earthquake source structure much precisely. The earthquakes are mostly confined at a depth range 10-35 km, and a hidden near vertical structure is well identified.

2.3 SEISMIC MOMENT TENSOR ESTIMATION FOR KACHCHH RIFT BASIN EARTHQUAKES OF 2006-2013

(A. P. Singh, Santosh Kumar Collaboration with Prof. Li Zhao, Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan)

We have determined the focal mechanisms of 37 small and moderate earthquakes ($3.4 \leq Mw \leq 5.2$, Figs. 2.1 & 2.2) occurring from October 2006 to December 2013 in the Kachchh Rift Basin (KRB) by fitting the three-component waveforms of P and S waves using the cut-and-paste (CAP) method introduced in Zhao and Helmberger (1994) and improved by Zhu and Helmberger (1996). These earthquakes are recorded at broadband stations of the Gujarat seismic Network operated by the Institute of Seismological Research. Results show that the earthquakes have primarily strike-slip mechanisms and reverse-faulting mechanisms. Most earthquakes have depths between 15 and 35 km. We found that the nodal planes of the focal mechanisms correlate well with the local trends of the known tectonic faults. The P-axes for the obtained moment tensor solutions in the KRB region are oriented roughly NS and NNE, which is consistent with ambient stress field owing to the northward motion of the Indian Plate with respect to the Eurasian Plate. However, the orientations of P- and T-axes exhibit more complexity beneath the Bhuj mainshock, which could be attributed to the variable nature in the orientation of fractures.

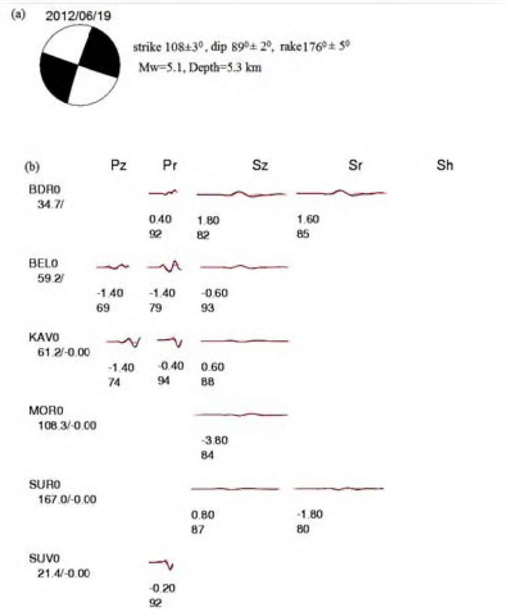


Fig. 2.1: Focal mechanism and waveform fit for the optimal solution for the 19 June 2012 earthquake. (a) Beach ball showing the focal mechanism. (b) Waveform fit for the optimal solution. Black and red traces are the observed and synthetic waveforms, respectively. The five columns of waveforms are, from left to right, the vertical- and radial- component P wave, and the vertical-, radial- and transverse-component S wave. The numbers below each trace are the time shift in seconds (positive means a delayed record) and the correlation coefficient. The station names are shown on the left and the number below each name is the epicentral distance in km.

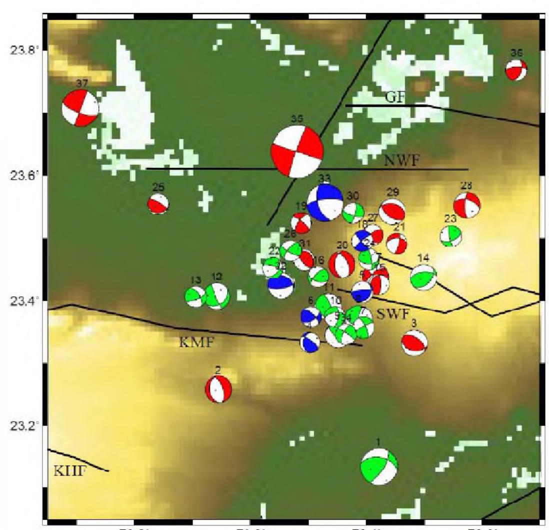


Fig. 2.2: The 37 fault plane solutions obtained in this study. Shown at the top of each beach ball is the event number. Black lines are major faults. The sizes of the beach balls are proportional to the magnitude, while the colors indicate source depths (red: 15 km or shallower; green: 15-25 km; blue: 25 km or deeper).

2.4 FOCAL MECHANISM BY MOMENT TENSOR SOLUTION

(Jyoti Sharma and B.K. Rastogi)

MTS for three earthquakes of M3.8 to 4.2 of 2014

The waveform inversion technique is popular for estimating source mechanism to study the nature of faulting processes. In the present study, attempt has been made with fair degree of precession, to estimate the MT solutions of three earthquakes of magnitude Mw ≥ 3.8 (Table 2.1, Fig. 2.3) using 3-components data recorded at multi-stations of ISR seismic stations in Gujarat region. Further, good signal to noise ratio velocity data has been used with epicentral distance ranging from 10 to 150 km and azimuth vary from 21^{o} to 320^{o}.

The present analysis is based on FORTRAN and MATLAB codes based ISOLA software (Sokos and Zahradnik, 2006), that is based on an extension of the Kikuchi and Kanamori method to regional and local distances. ISOLA allows a full wavefield inversion, based on the discrete wavenumber method of Bouchon (1981) and Coutant (1989), and provides a good stability. In this technique, initially a set of predefined point-source positions along a line or plane is considered. After obtaining a major point-source contribution or subevent, the corresponding synthetics are subtracted from data, and the residual waveform is inverted for another point source, and so on (Zahradnik et al., 2005). Because the optimum source position of each subevent is also to be retrieved, the technique is nonlinear. However, because the point sources are removed consecutively, one after another, each step has only two parameters (source position and onset time), thus contributing to the stability of the inversion (Zahradnik et al., 2005).The grid search provides the best position and time in terms of the absolute value of the correlation coefficient between the observed data and synthetics, which are calculated automatically during the least square.

In the present analysis, we have used band-passed (0.05-0.3 Hz) and instrumentally corrected velocity records as the input of ISOLA code. ISOLA integrates the input data to the band-passed displacement, which are used as input for moment tensor inversion. Here, simple triangular pulse is approximated for the source time function. Also, it is important to note that all solutions obtained using ISOLA are close to the first approximation (Zahradnik et al., 2005). Fig. 2.4 shows matching of waveform for the three earthquakes. Figs. 2.5 to 2.7 show MTS for these earthquakes.

Table 2.1: List of Mw ≥ 3.8 earthquakes occurred in kachchh in 2014

Event No.	Year	MN	Date	HR	MM	Sec	Lat.	Long.	Depth	M_L	M_w
1	2014	3	8	19	1	9.5	23.365	70.297	36.5	4.1	4.2
2	2014	4	29	5	55	0.6	23.490	70.280	12.5	3.7	3.8
3	2014	9	26	22	38	55.3	23.678	70.575	8.1	3.7	3.8

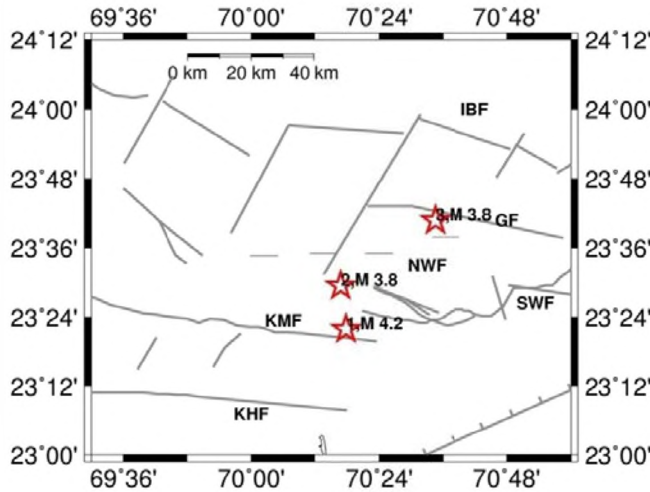
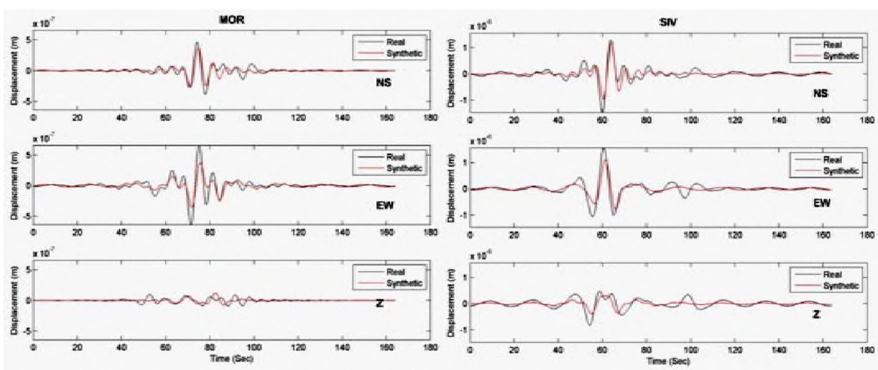


Fig.2.3: Epicenters of the earthquakes of 2014 for which MTS have been determined.

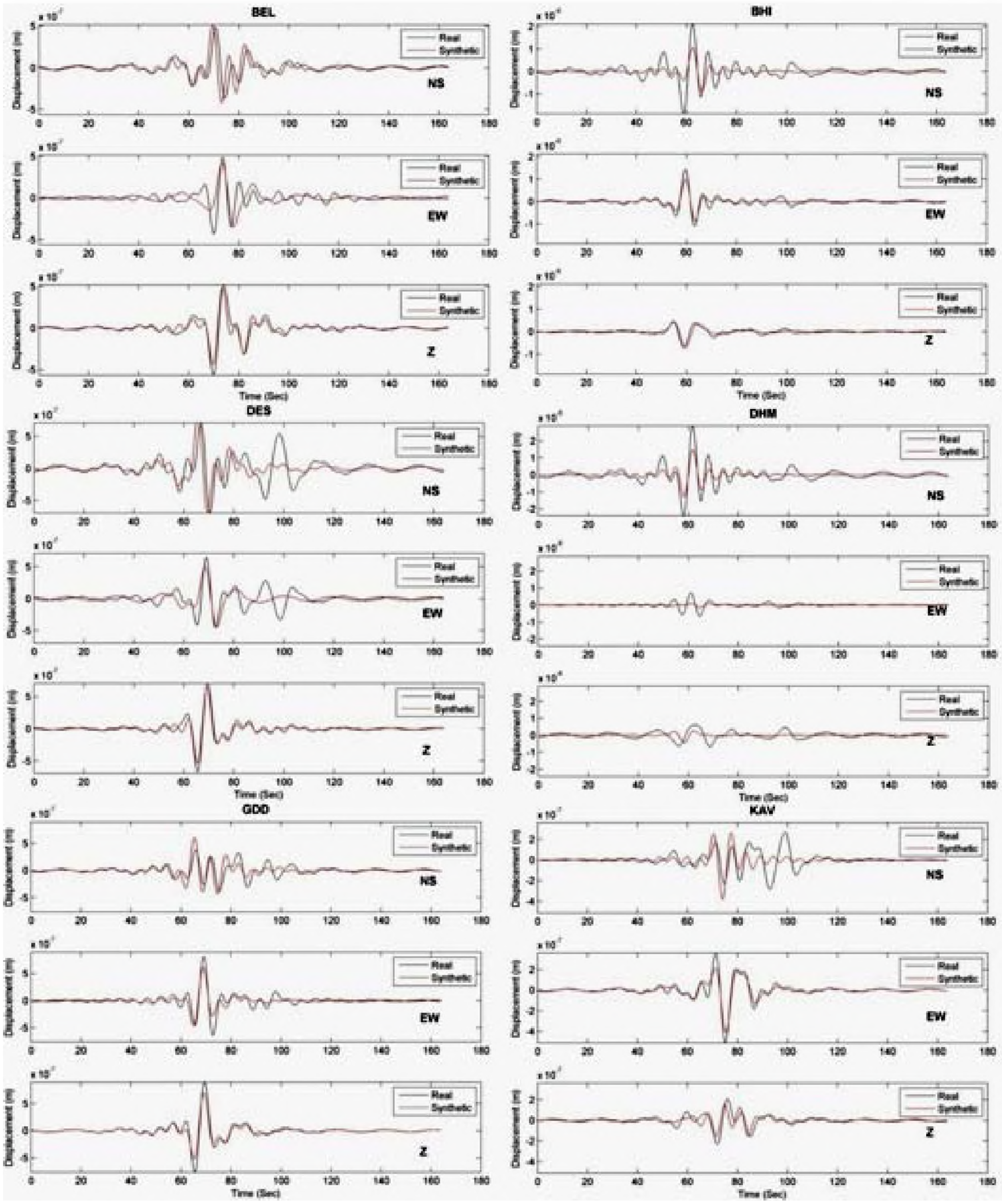
1: March 8, 2: Apr 29, 3: Sep 26

Results

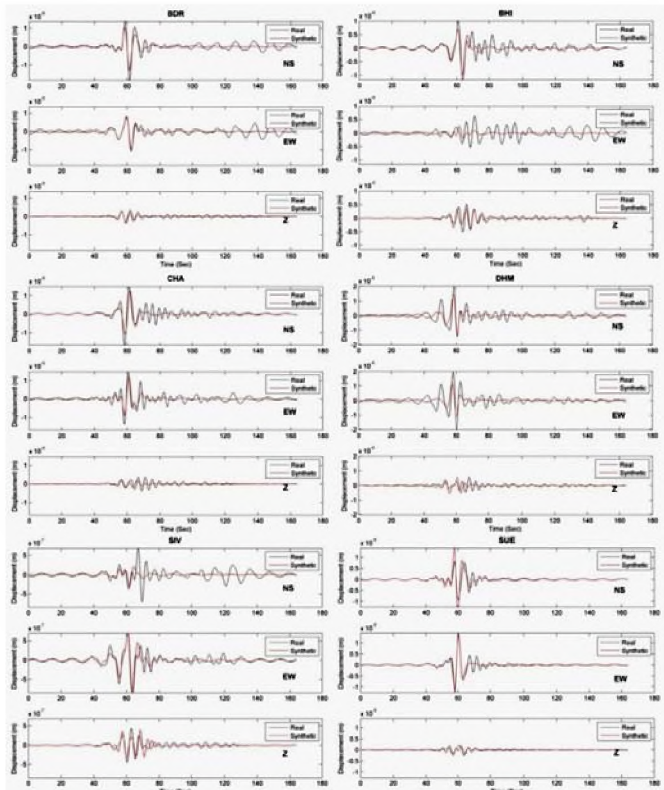
(1) Waveform Match using moment tensor inversion for the 08th March 2014 (event no. 1)



Waveform Match using moment tensor inversion for the 08th March 2014 (contd.)


BEL
BHI
DES
DHM
GDD
KAV
NS
EW
Z
Real
Synthetic
Displacement (m)
Time (Sec)

(2) Waveform Match using moment tensor inversion for the 29th April 2014 (event no. 2)



(3) Waveform Match using moment tensor inversion for the 26th Sept. 2014 (event no. 3)

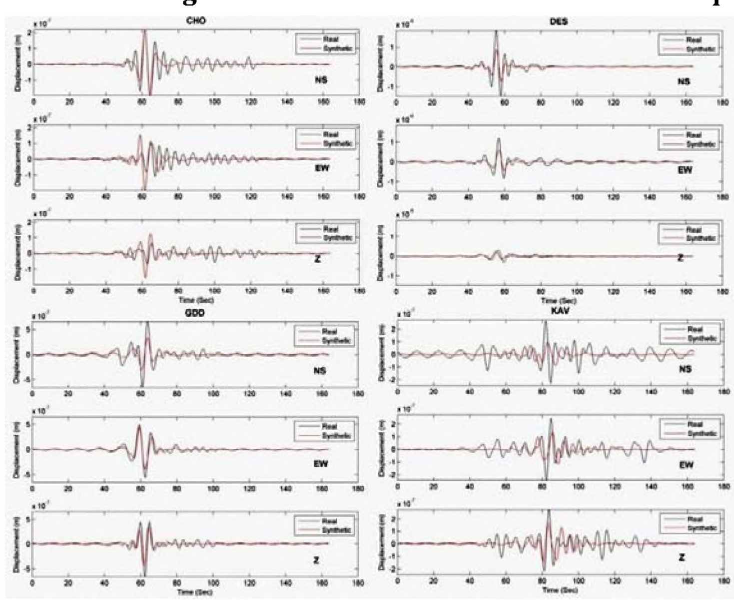


Fig. 2.4: Matching of observed and synthetic wave forms for estimated MTS of the three earthquakes of M~4 that occurred during 2014

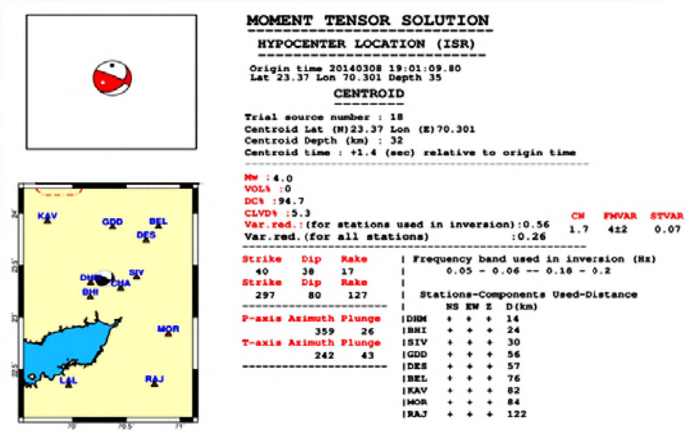


Fig. 2.5: Moment tensor Solution for the 8th March 2014 earthquake using ISOLA software

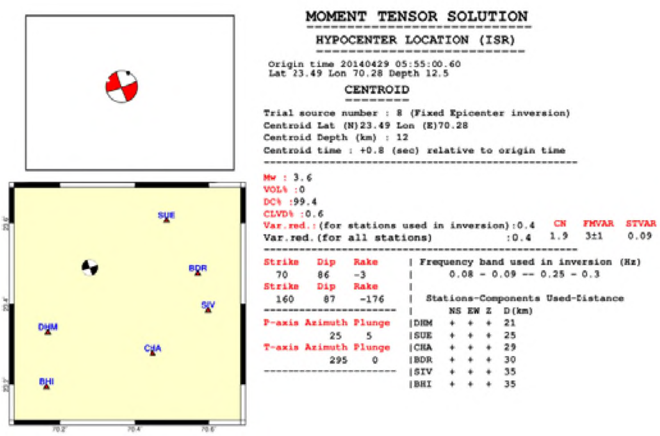


Fig. 2.6: Moment tensor Solution for the 29th April 2014 earthquake using ISOLA software

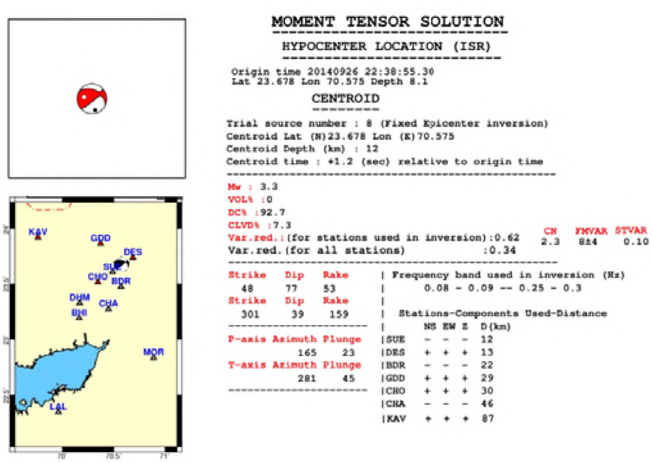


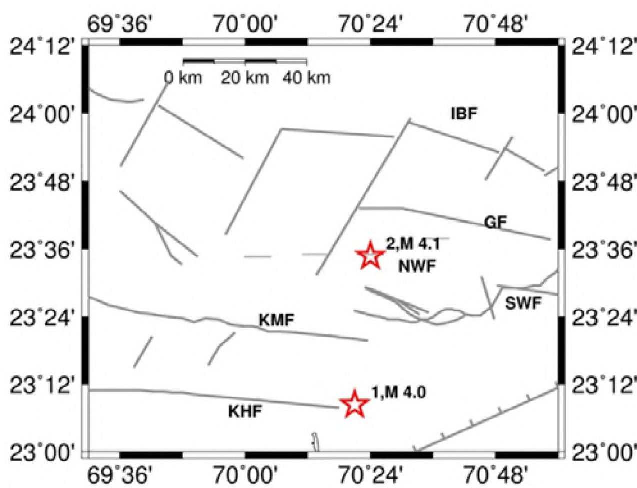
Fig. 2.7: Moment tensor Solution for the 26th Sept. 2014 earthquake using ISOLA software

MTS for an M4.0 earthquake of 2012 and M4.1 earthquake in 2013

MT solutions have been obtained for two earthquakes that occurred on 08th December 2012 and 30th March 2013 of magnitude $M_L \geq 4.0$ (Fig. 2.8) using 3-components data recorded at multi-stations of ISR seismic stations in Gujarat region. Further, good signal to noise ratio velocity data has been used with epicentral distance ranging from 10 to 250 km and azimuth varying from 23° to 324°.

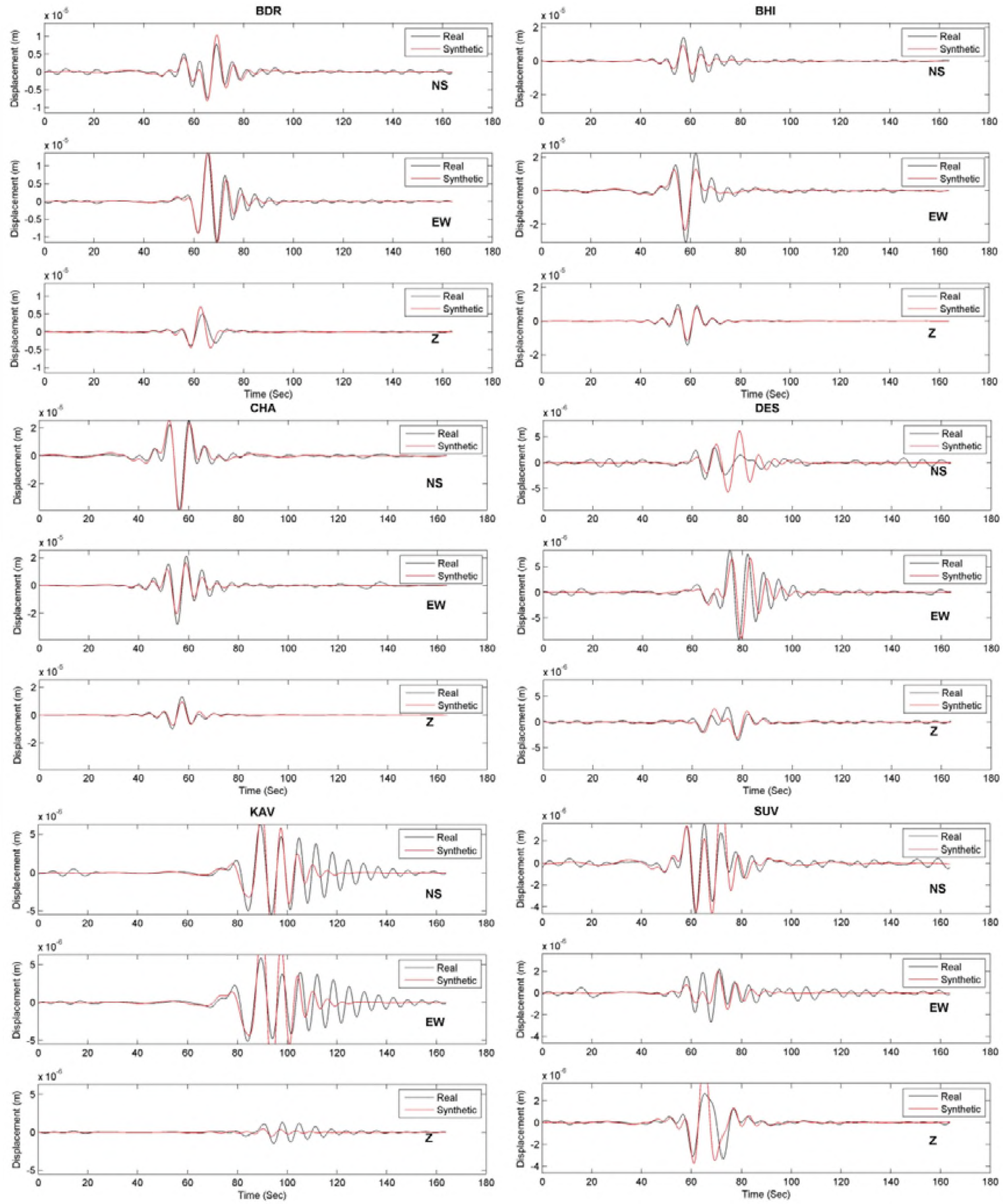
In the present analysis, we have used band-passed (0.05-0.2 Hz) and instrumentally corrected velocity records as the input of ISOLA code. ISOLA integrates the input data to the band-passed displacement, which are used as input for moment tensor inversion. Here, simple triangular pulse is approximated for the source time function. Also, it is important to note that all solutions obtained using ISOLA are close to the first approximation (Zahradnik et al., 2005). Fig. 2.9 shows the wave form matching and Fig. 2.10 & 2.11 show the Moment-Tensor Solutions.

Fig.2.8: Epicentral map of the earthquakes, 1) 08th December 2012 (M_L 4.0) and 30th March 2013 (M_L 4.1).



RESULTS

(1) Waveform Match using moment tensor inversion for the 08th December 2012 (M_L 4.0)



(2) Waveform Match using moment tensor inversion for the 30th March 2013 (M_L 4.1)

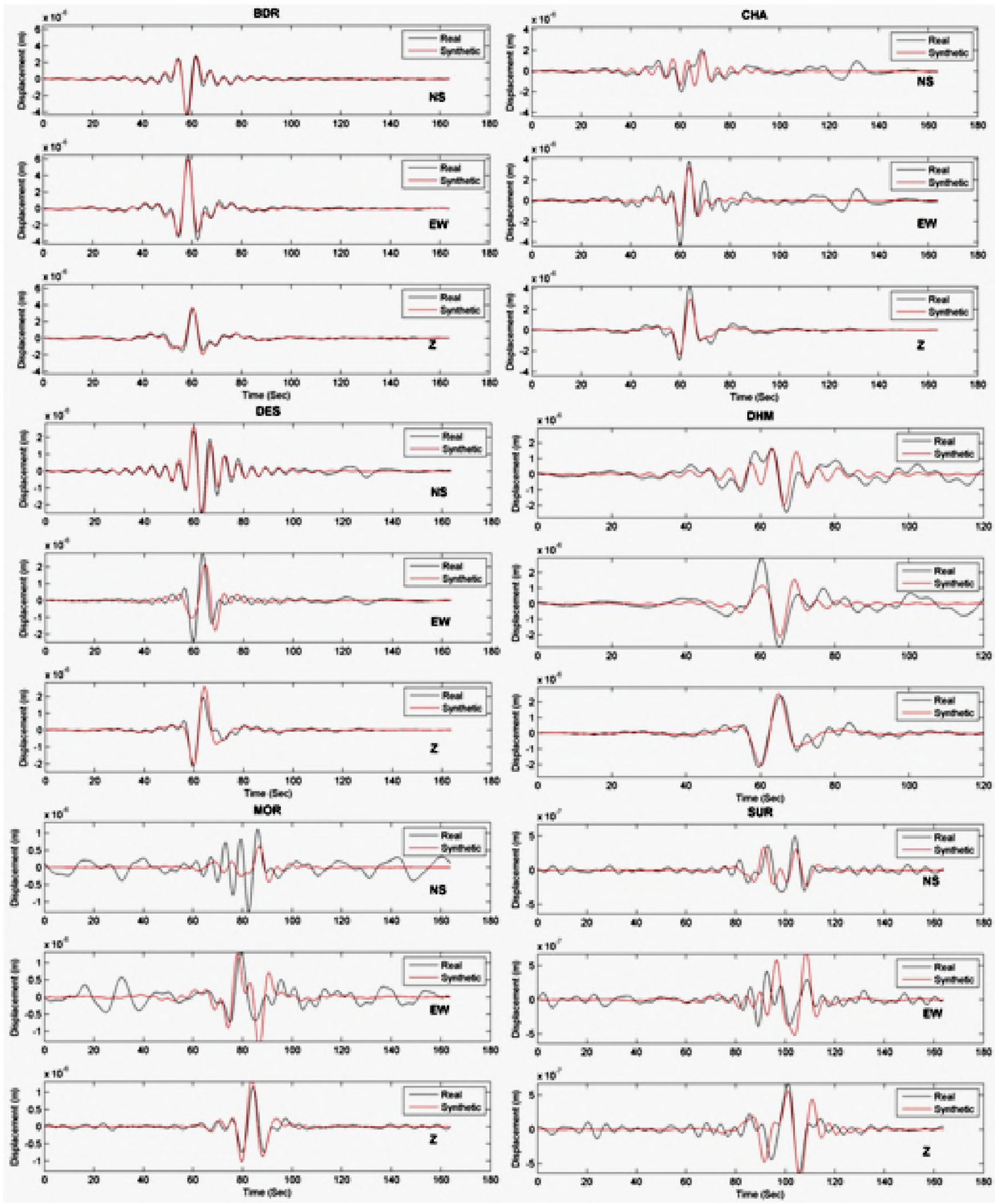


Fig. 2.9: The waveform match between the observed (red) and synthetic (blue) filtered displacement seismograms at different stations for the 30th March 2013 earthquake using ISOLA software.

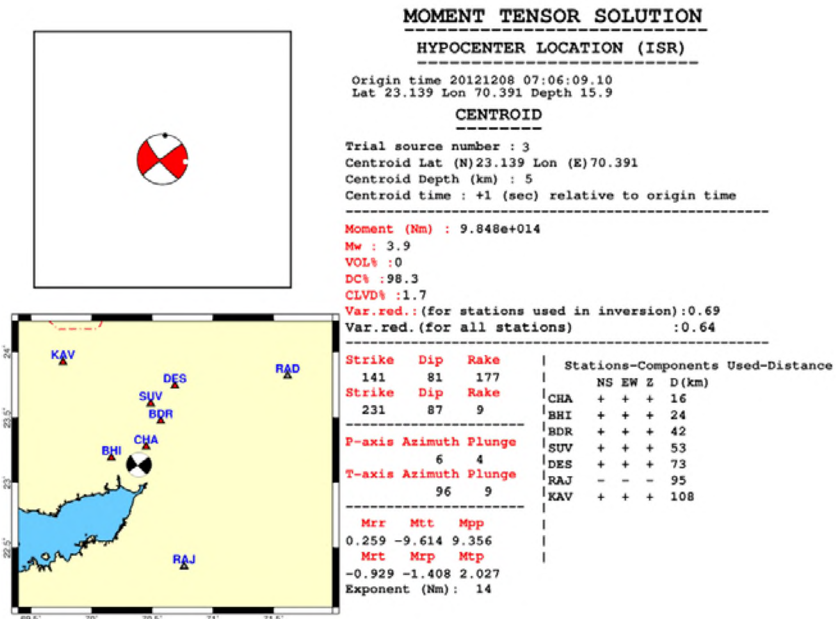


Fig. 2.10: Moment tensor Solution for the 08th December 2012 earthquake using ISOLA software.

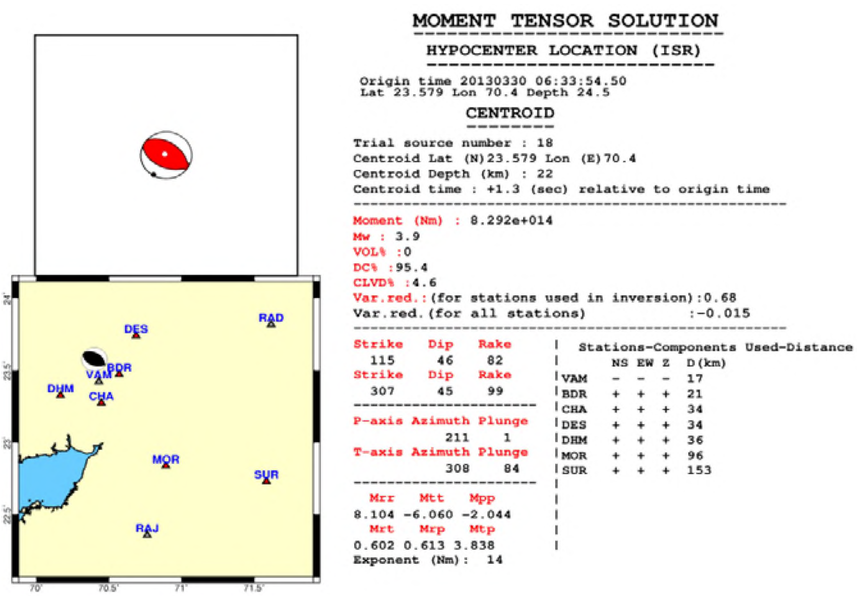


Fig. 2.11: Moment tensor Solution for the 30th March 2013 earthquake using ISOLA software.

2.5 ONE-DIMENSIONAL REFERENCE VELOCITY MODEL OF THE SAURASHTRA

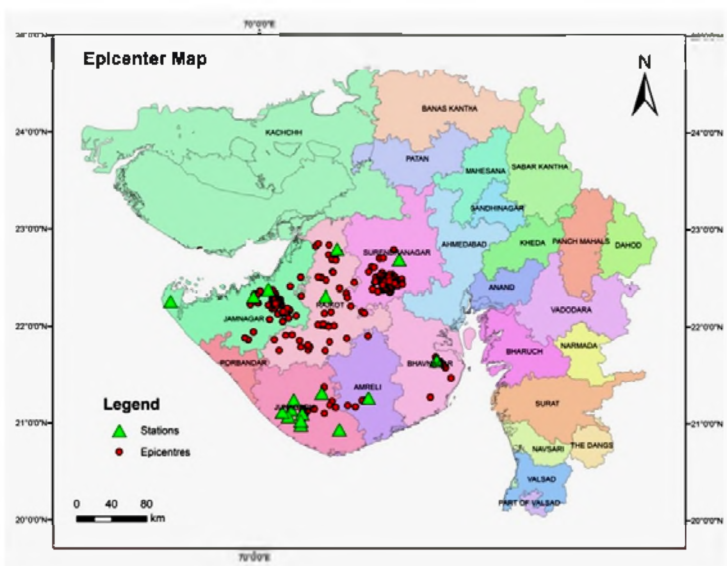
(P. Mahesh, Balwanth, B. K. Rastogi) * SRTM University, Nanded, Maharastra)*

We can estimate the seismic velocities beneath the area under investigation with the help of known hypocentral parameters. Results of local earthquake tomography highly depend on the initial reference model (Kissling *et al.*, 1994). Kissling et *al.* (1994) introduced the concept of the minimum 1-D model in local earthquake tomography that can be use as a initial reference model. The minimum 1-D model itself is a result of a series of simultaneous inversions of hypocentral parameters, 1-D velocity models (V_P & V_S), and station corrections. Besides serving as an initial reference model, the minimum 1-D model will provide high precision hypocenter locations for use in 3-D local earthquake tomography. One, therefore, tries to determine the hypocenters and the velocity structure simultaneously.

We used the program "**VELEST**" (Kissling, 1995) for simultaneous determination of hypocenters, 1-D *P*, *S* velocity structures and station corrections. The model geometry (layer thicknesses) is held fixed during inversion. The travel times are calculated by ray tracing using the shooting method (Thurber, 1981), and directly solves the normal equation with Cholesky decomposition (Press et *al.*, 1988). We derived an optimum 1D velocity model of the Saurashtra region, based on analysis of 4200 seismograms generated at 20 digital broadband seismic stations in the region during April 2006 and June 2012. These include data from 450 local earthquakes (Fig. 2.12) with azimuth gaps of <200°, each of which had a minimum of four P- and three S-phase readings. The 1-D velocity model (Fig. 2.13) obtained from seismic refraction/reflection studies (Rao, et.al, 2005) and an average Vp/Vs ratio of 1.72 abstracted from the *P*- and *S*- wave arrival time data from our network using the Wadati diagram is used as initial model.

The input velocity model was initially parameterized as stack of 2 km thick layers. The inverted velocity models were then iteratively simplified by fusing layers with similar velocities to form the next initial model (Kissling, 1994). The final *P* and *S* velocities obtained from combined inversion is shown in Figure 2.13. The final velocity model resulting from travel time inversion is well resolved only down to a depth of 13 km, because of very few hypocenters and rays below 13 km (Fig. 2.14).

Fig. 2.12: Epicentral distribution of the earthquakes (circles) used for 1-D inversion. The seismic stations used in this study are shown as triangles.



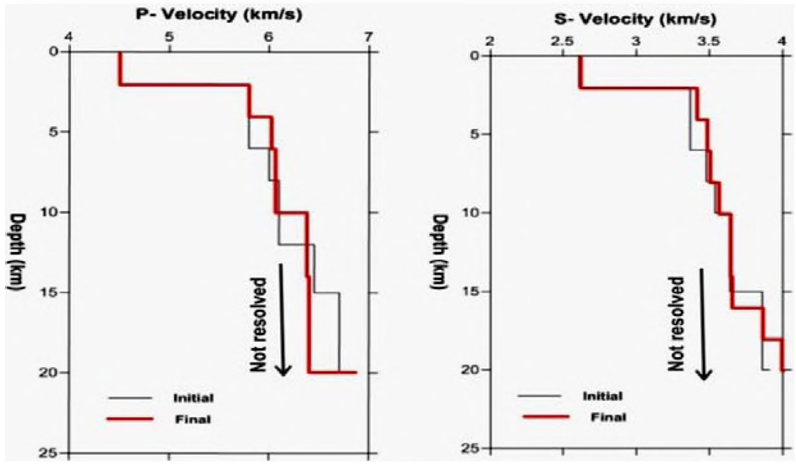


Fig. 2.13: Initial and final velocity models for P- and S- waves.

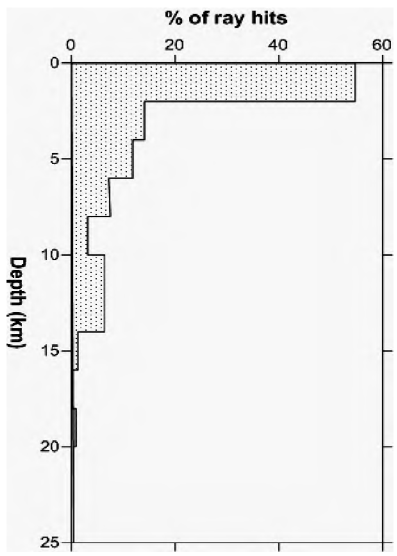


Figure 2.14: Ray distribution in depth.

REFRENCES

Kissling, E. (1995). Velest User's Guide, Internal report 26, Institute of Geophysics, ETH Zurich, Switzerland.

Kissling, E., W. Ellsworth, D. Eberhart-Phillips, and U. Kradofler (1994). Initial reference models in local earthquake tomography, J. Geophys. Res. 99, 635–646.

CHAPTER 3

LITHOSPHERIC STRUCTURE

3.1 ELECTROMAGNETIC, MAGNETO-TELLURIC AND RESISTIVITY IMAGING

Magnetotelluirc investigations in Kachchh region for identification of faults and crustal structure

(Kapil Mohan, B.K. Rastogi and Peush Chaudhary)

Detailed close station spacing (1–3 km) MT survey is conducted in the epicentral zone of 2001, Bhuj earthquake in two profiles (Western and Eastern) and having lengths of 15 and 25 km, respectively (Figure 3.1). The 2-D inversion of the acquired data gave the resistivity structure of the area up to a depth of 20 km for western profile and 10 km for eastern profile and suggested two conductors in each profile. Along the western profile, two conductors C3 and C4 (Fig. 3.2) are seen. The conductor (C3) dipping south (with a shallow dip) at a distance of 5 km in the north of Dudhai might be the signature of the Kachchh Mainland Fault. The conductor C4 that is at a distance of 10 km in the north of the first conductor (C3) with resistivity 0.1 to 4 ohm-m and that falls in the straight line of the western extension of South Wagad Fault, might represent the South Wagad Fault (Fig. 12 of Mohan et al., 2015). Along eastern profile, we have been able to see KMF dips south near Sikra village and the group of South Wagad Fault (dipping vertically up to 6 km and north dipping afterwards) near Vamka village. The area between conductors C1 and C2 has conductive sediments (Samkhiyali basin) of about 2 to 3 km thickness over the resistive block. Along the western profile KMF is seen 5 km North of Dudhai village and a possible extension of the South Wagad Fault is seen 10 km north of the KMF. The sedimentary thickness in this area between KMF and SWF is varying from 1.2 km to 2 km.

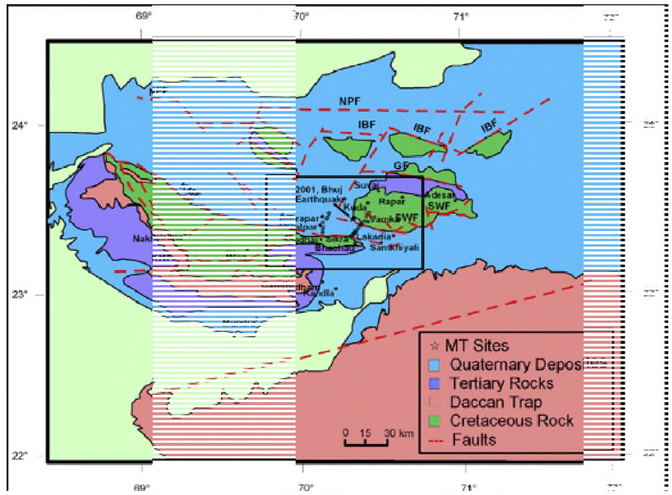


Fig. 3.1: Location map of the MT sites superimposed on geological map

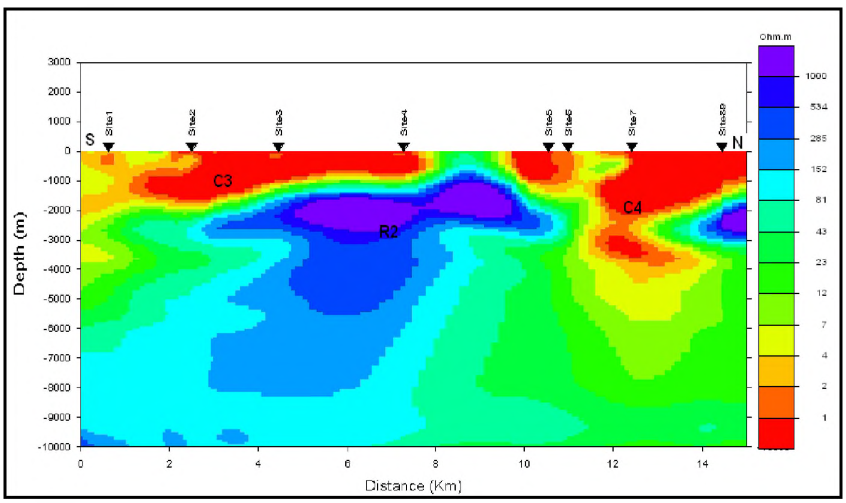


Fig. 3.2: 2-D geoelectric section of the western profile(Mohan et. el, 2015).

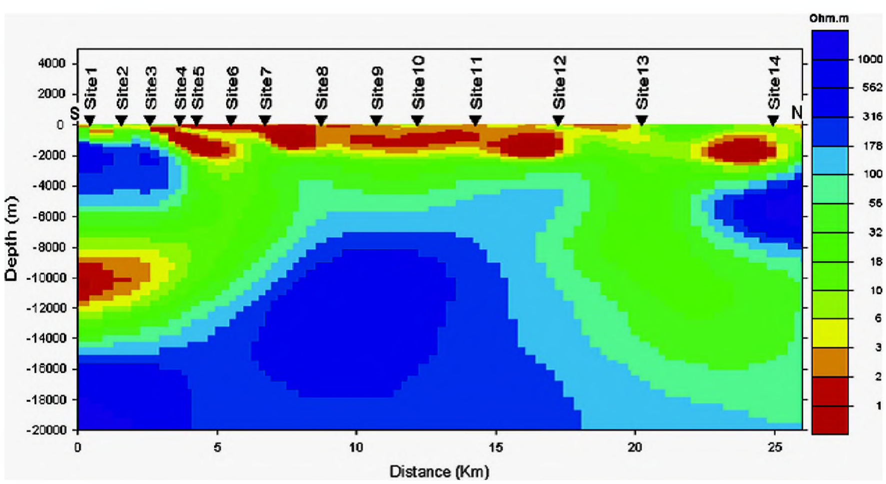


Fig. 3.3: 2D Magnetotelluric depth section (Eastern) (TE-TM mode) from Sikra village in the South to Kuda village in the North. C2: SWF and C1: KMF (Mohan et. el, 2015).

Data acquired for 3D Magnetotelluric studies (MT and LMT) by ISR and NGRI in Kachchh is shown in Fig. 34 and 3D interpretation in Fig. 5. There are total 37 MT stations with average spacing of 3km. LMT observations were made at 16 of these sites. MT observations were made for 3days and LMT for 2-3 weeks.

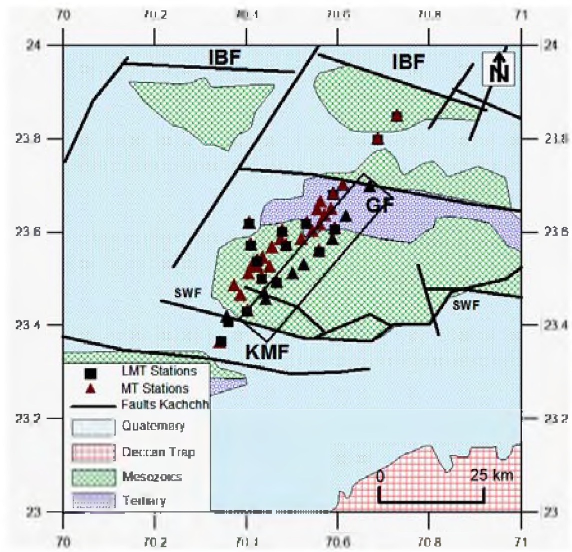


Fig. 3.4: Recently acquired MT sites are shown as black Triangles in rectangular block. The earlier acquired MT and LMT sites are also shown in the map.

MT study over Chabsar and Tuwa hot water spring region for identification of geothermal source zone

(Kapil Mohan, Peush Chaudhary, Pavan Gayatri, Virander Choudhary, Pruthul Patel, Mehul Nagar and B.K. Rastogi)

Magnetotelluric Survey is conducted at two sites Chabsar (Bavla) and Tuwa (Godhra) under the project sponsored by Gujarat Power Corporation Ltd. (GPCL).

(i) Chabsar: Broadband MT data at 31 sites have been acquired in the vicinity of Bavla region, Ahmadabad (Figure 3.5). The data processing and 1-D/ 2-D inversion of the acquired MT data has been carried out for detailed subsurface information of the region for possible presence of geothermal source. Apparent resistivity and phase curves of some sites are shown in figure 3.6.

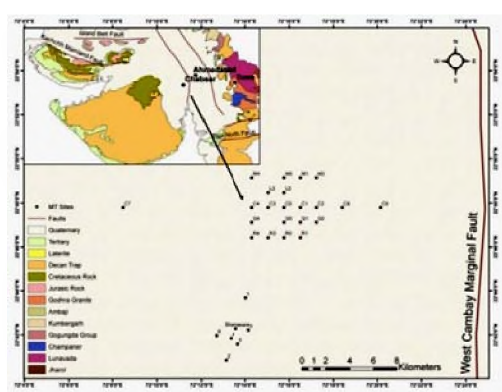


Fig. 3.5: Location map of acquired MT sites in Chabsar (Bavla) area.

Apparent resistivity and phase curves of some sites:

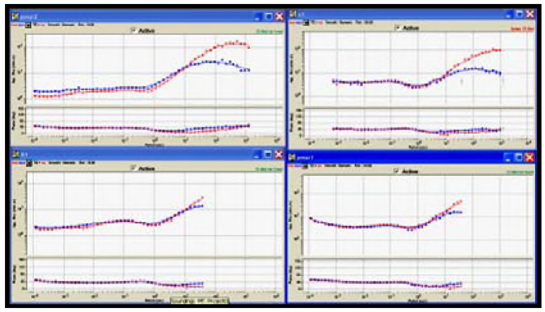


Fig 3.6: Apparent resistivity and phase curves at some sites along the profile

(ii)Tuwa: Broadband MT data at 41 sites have been acquired in the vicinity of Tuwa region, Godhra (Figure 3.7). The processing and 1-D/ 2-D inversion of the acquired MT data has been carried out for detailed subsurface information of the region for possible presence of geothermal source. Apparent resistivity and phase curves of some acquired sites are shown in figure 6.

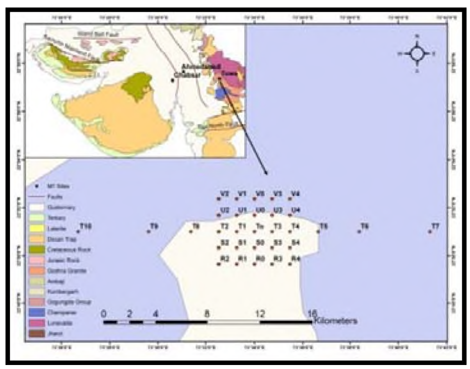


Fig. 3.7: Location map of MT sites near TUWA hot water spring.

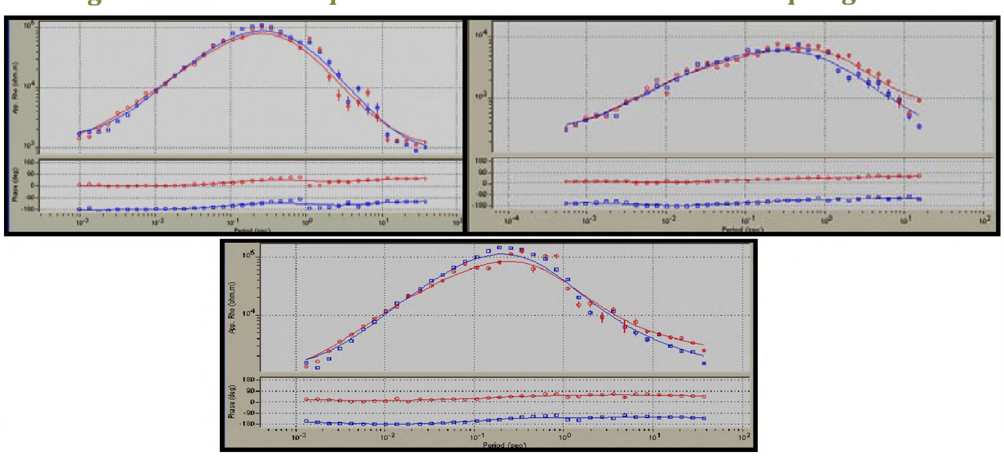


Fig. 3.8: Apparent resistivity and phase curves for some sites at Tuwa

SURVEY PLAN:

Magnetotelluric survey has been started at Chabsar and Tuwa (Fig. 3.9) to identify geothermal energy source if any in these areas. The project is entrusted by Gujarat Power Corp. Ltd. Chabsar is just west of the West Cambay fault in soil area. Tuwa is 100 km east of Cambay basin and in Proterozoic granite area. At Tuwa the survey has been suggested east of the hot spring. At Chabsar there is no hot spring. Some bore wells were dug in which hot water is coming out. One bore well is at Bhamasar and a few more are around it. Hot water is still coming out from Bhamasar well. Chabsar (2248'N 7216'E) is in Ahmadabad district and 40 km SSW of Ahmadabad city. Tuwa (2251'N 7334'E) is about 130 km SSE of Ahmadabad and is in Panchmahal district (20km short of Godhra).

Station deployment is such that in 5kmx5km area is surveyed in more details and surrounding area with sparse stations. The area covered (5X5=25 sq. km) is divided into grid of 1.25km X 1.25km (approx.). The central line having 11 stations has longer length of 10km. It extends both sides of the grid with three stations at each side (at 2,3 &5km distance from the inner grid). Total 31 stations are covered at each site.

OBJECTIVE

To image the subsurface in a grid pattern with the main objective of locating subsurface structures related to geothermal resources in the area with a good resolution.

PRELIMINARY RESULTS

A conducting body of about 10km width is observed at a depth of 2.5km (Fig. 3.10).

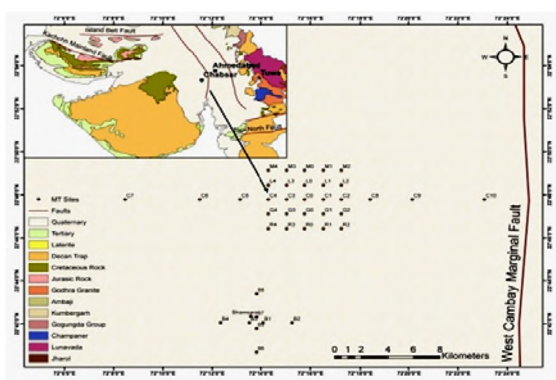


Fig. 3.9: Locations of Chabsar and Tuwa on geological map. Stations deployment at Chabsar is also shown

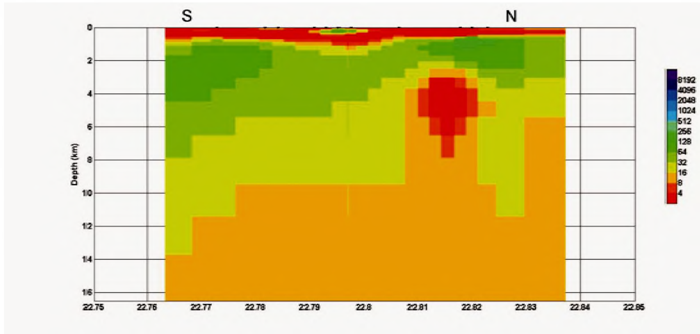


Fig. 3.10: 2D view of a 3D structure at Chabsar

Transient electromagnetic investigations in the Ahmadabad region, central Cambay basin, Gujarat

(G. Pavan Kumar, Virender Choudhary, E. Mahender, Yashavant Kumar Singh, K. Damoder, Kapil Mohan and B.K.Rastogi)*

Time domain electromagnetic (TDEM) survey has been carried out at Chabsar in the Bhavla region of the Ahmadabad district located just west of the Cambay basin (Fig. 3.11) to delineate shallow subsurface resistivity image of the region. Fixed in-loop TDEM soundings were made at 20 selected locations with 100 m sided transmitter loop.

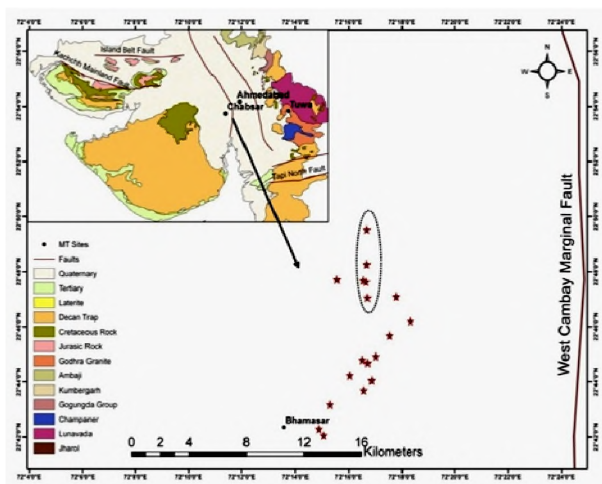


Fig. 3.11: Location map of TDEM sites (stars) superimposed on geological map of Gujarat

For each loop, the transmitter is operated for a sequence of data repetition frequencies ranging from 32 Hz to 1 Hz. Rate of change of secondary magnetic field produced due to the induced eddy current in the subsurface has been measured at every TDEM sounding site using a receiver coil. The data were processed to get apparent resistivity as a function of decay time. Decay curve and apparent resistivity curves for a site is shown in Fig. 3.12.

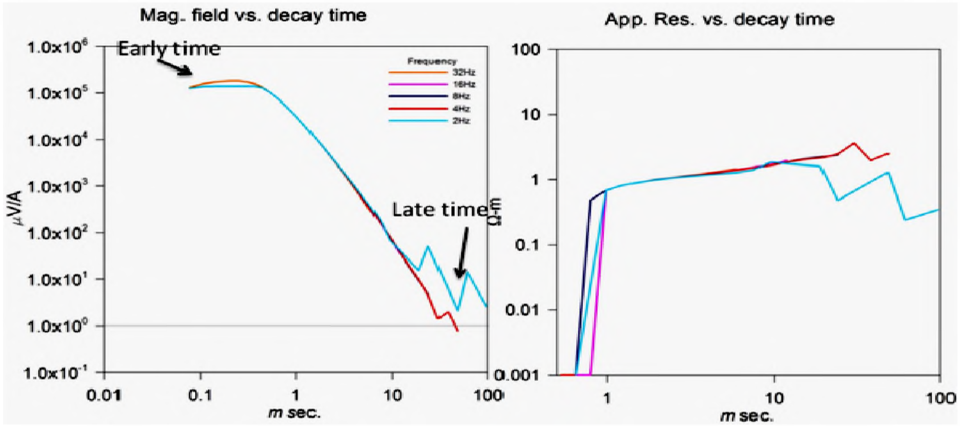


Fig. 3.12: Decay and apparent resistivity curves for a site

One dimensional inversion of the data is carried out to obtained the true resistivity distribution as a function of depth. The 1-D layer structure for a site is shown in figure 3.13.

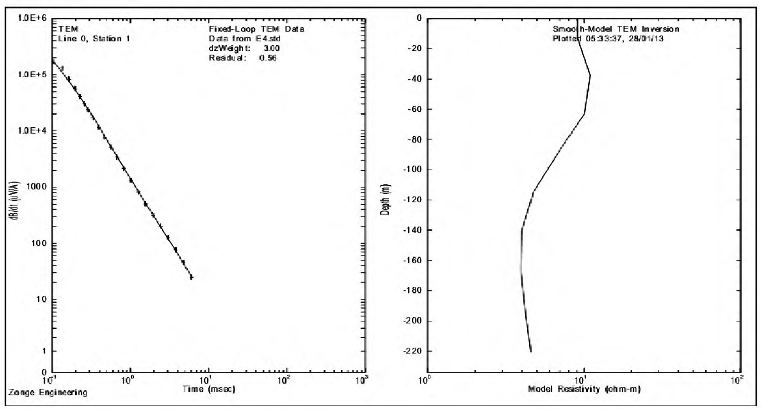


Fig. 3.13: 1-D resistivity structure for a site along with the data fit.

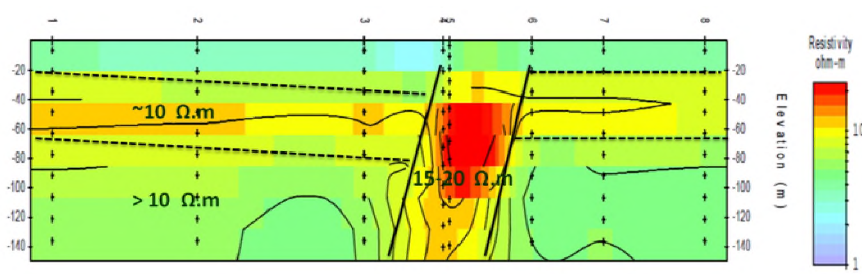


Fig. 3.14: One dimensional resistivity structure for a N-S profile for the site shown in figure 3.11

The subsurface electrical resistivity image obtained by combining the results of 1-D smooth inversion for 10 locations along a 10 km long N-S line indicates in general at three-layered structure upto 160m (Figure 3.14). A 20-30m thick conductive channel of resistivity ~10 Ω.mat a depth of 20-25m, interpreted as saturated/unconsolidated rock, is overlain on another saturated rock (with possible content of sulfides, clay etc.) of comparably low resistivity. A fractured resistivity zone (20-25Ω.m) at a depth of 20m extending to entire depth section is observed at the north central part of the line. The results could be integrated with hydro geophysical information for further characterization of the aquifer and the fractured zones observed in region.

Magnetotellurics data analysis over anisotropic and inhomogeneous medium- Results from a synthetic study

(Mahender, E., Yashavant Kumar Singh, Damodar, K. and G. Pavan Kumar)

Anisotropy in upper mantle and lower crust of the earth subsurface has been inferred from various geophysical investigations mainly through seismological and magnetotellurics (MT) studies. Thus anisotropic modelling of subsurface could give better resolved image of the earth interior as well as preliminary information on the fault zones, which indeed have anisotropic in nature due to stress and strain variations. Analysis of MT data in presence of anisotropy over a 2-dimensional medium is complex as the impedance tensor may not decouple into two polarization modes. Here we present the results from analysis of synthetic response of two models comprising electrical anisotropy and inhomogeneity each. We have designed two block models based on a published MT results, one incorporating anisotropy block (5/50/50 Ω.m) underlying on an isotropic block and another block model indeed having inhomogeneity (Fig. 3.15). Forward responses of the two models are generated using an algorithm for 2-D modelling of anisotropic media.

The analysis of the apparent resistivity and phase curves suggests that apparent resistivity and phase curves splits in both anisotropic and inhomogeneous medium (Fig. 3.16). However, the splitting occurs at the interface between overlying isotropic and top of the anisotropic block, where as for the inhomogeneous medium the splitting observed at top and bottom of the inhomogeneous block. The magnitude of splitting is depends on anisotropic ratio and underlying resistivity contrast in anisotropic and inhomogeneous medium respectively. We have also analysed the impedance tensors using phase tensor (PT) approach and method on ellipticities of telluric vectors (ETV). The analysis suggests the non-zero skew angles for the anisotropic block along with deviation of the major axes from the regional strike of the body. The response from inhomogeneous medium show zero skew angles with major axes oriented in regional strike. Non-zero ellipticities of the telluric vectors within the period band of the anisotropic block have been obtained after ETV method and splitting in the telluric distortion angle curve is observed similar to impedance phase. In case of inhomogeneous medium, the ellipticities and distortion angles are equal to zero. Thus the analysis the distortion indices, like PT- skew angle, distortion angle, and ellipticities of the telluric vectors might be good indicators for presence of anisotropic body compared to apparent resistivity, phase curve splits.

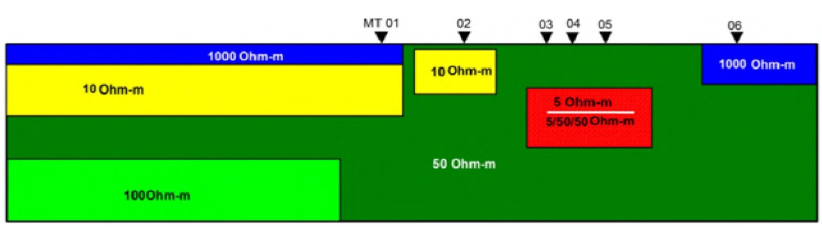


Fig 3.15: Forward model considered for the present study

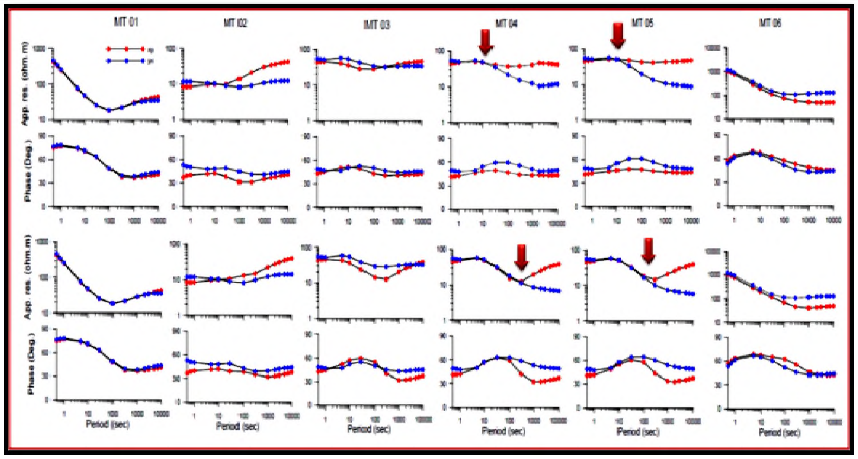


Fig. 3.16: App. Res & Phase curves for anisotropic (top) & inhomogeneous (bottom) media

3.2 GRAVITY AND MAGNETIC STUDIES

(R.K Singh, S.Venkateswara Rao, B.K Rastogi, Rakesh Dumka, Amit Mishra & Avinash Chouhan)

1. Gravity and Magnetic Observations in Cambay basin

Total 160 gravity and 404 magnetic (including 244 locations where gravity observations were earlier taken) observations were taken in Cambay basin along the sections Viramgam-Sanand-Sarkhej-Odhav-Kathlal and Sardar Patel ring road of Ahmedabad (Fig. 3.17). Some 60 gravity observations and magnetic observations in Ahmedabad city area were done in early morning between 2 A.M & 6.30A.M to avoid traffic. Observations were conducted at an interval of 1 km along the different sections covering 5 blocks of Cambay basin. The gravity surveys were carried out with CG-5 Autograv gravimeter whose sensitivity is 0.001 mgals and Magnetic surveys with Proton Precession Magnetometer.Precise location and elevation of the gravity stations are taken by Real time kinematic (RTK) GPS survey. The Gravity and magnetic data is processed using Geosoft software. Bouguer gravity map is prepared at an interval of 1 mgal interval for better resolution of different features of the basin. Different sections of gravity and magnetic observations in Cambay basin are:

1) Dholka-Kheda-Mahmedabad
2) Vijapur-Visnagar
3) Vijapur-Rampur (Mehsana)
4) Gandhinagar-Vijapur
5) Bechraji-Sitapur-Dalod-Mandal
6) Detroji-Kadi
7) Kadi-Kalyanpur-Viramgam
8) Mehsana-Chanasma-Radhanpur
9) Viramgam-Sanand-Sarkhej-Odhav-Kathlal

Bouguer gravity map (Fig. 3.18) and magnetic map (total field, Fig. 3.19) show the following features:

1 Becharaji basin (around 23°35'N) is reflected by low gravity and magnetic signature.

2 Regional fault trending NNW passing through Kheda-Odhav-Ahmedabad-Balol and

terminated at Jotana and dipping towards NE is well reflected by sharp contrast of low on east side and high on west side in Bouguer gravity map. Since this signature is not present in magnetic map, the fault may be deep seated.

3 Two isolated magnetic highs near Kadi & Kalol may be mafic intrusions which are also present in Bouguer gravity map, west side of a NNW trending regional fault.

4 Dholka & Bavla region occupied by gravity high west of the NNW trending regional fault passing between Kheda & Mehamadabad, may be due to basement uplift. The region is occupied by low magnetic field which suggests that the Deccan traps may be absent or thin and lying at deeper depth.

5 Gravity high within the higher gravity region between Dholka & Kheda may be source of local upliftment of basement which may be possibly source of geothermal energy. But detailed gravity and Magnetic surveys are required to decipher the sub-surface/basement configuration.

6 Gravity high along Sami-Harij-Patan-Sidhpur trending NE-SW supported by magnetic high may be the reflection of Aravali formation for a width of 50 km at some depth within the basin at around Patan (23°49' 48.77" N).

7 A portion of Radhanpur Arch covered in the survey shows gravity high.

8 Radhanpur-Deesa section shows the presence of Deccan traps which is reflected in the form of magnetic high. The gravity low may be either due to lesser thickness of traps along that section or larger thickness of meta-sediments.

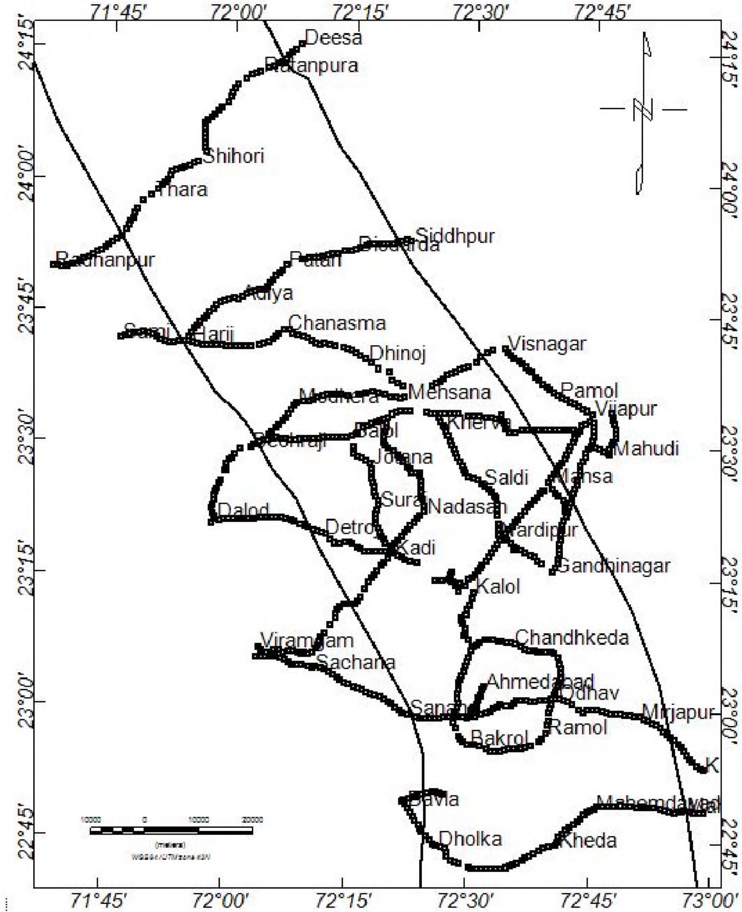


Fig. 3.17: Location map of gravity and magnetic observations in Cambay basin

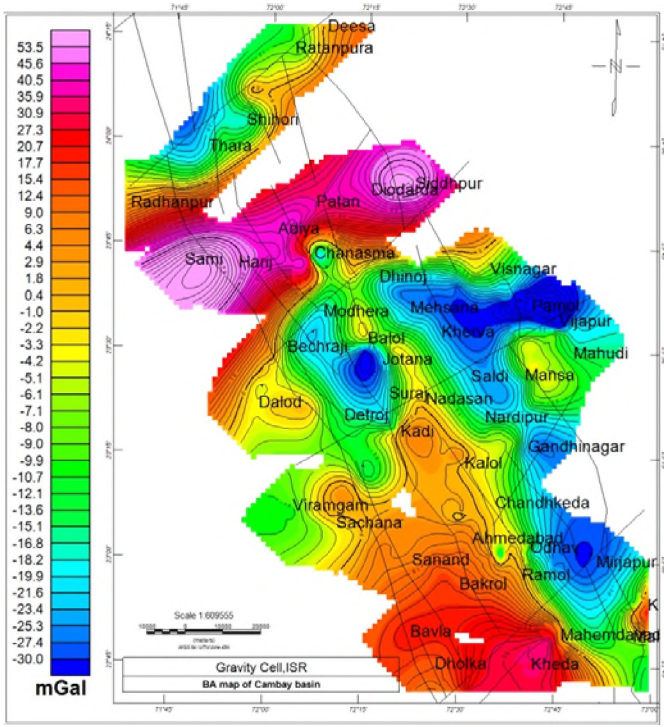


Fig. 3.18: Bouguer anomaly map of Cambay basin

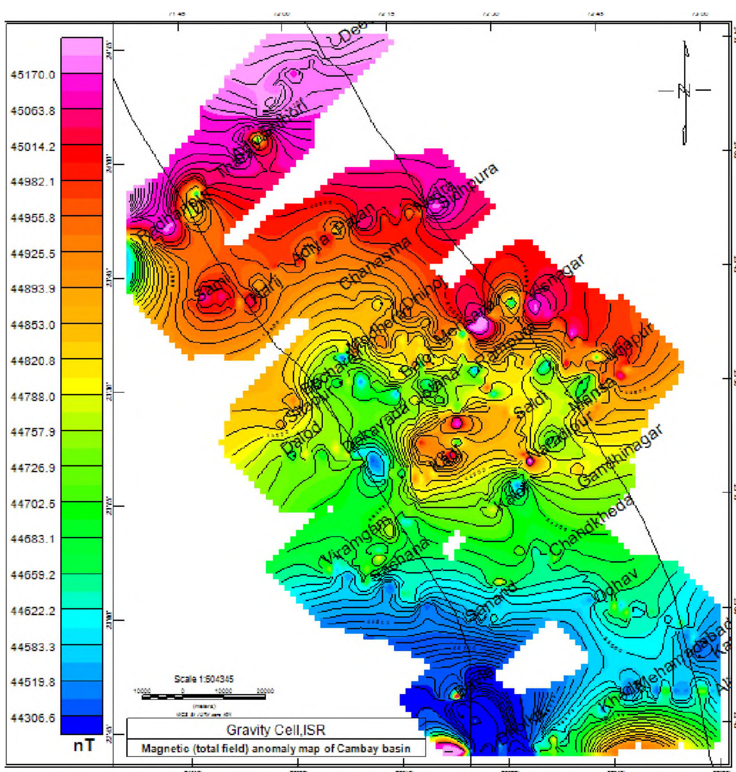


Fig. 3.19: Magnetic (Total field intensity) map of Cambay basin.

Establishment of permamnent Gravity Bases at useful locations like MOGO, seismic stations and areas of active defomation:

Total 36 gravity stations were fixed in Kachchh basin adjacent to all the GPS locations (Permanent & Campaign mode) for temporal variations of gravity field over these stations (Fig. 3.20). To understand the vertical crustal deformation few stations were made along North and South of KMF to observe the Crustal deformation along KMF. We have planned to observe gravity values over these stations periodically every 3 to 6 months of interval.

Fig. 3.20: Location map of GTV (Gravity temporal variation) stations near GPS stations

3.3 SURFACE WAVE TOMOGRAPHY FOR THE GUJARAT REGION

(Jyoti Sharma[1], Enrico Brandmayr[2], B. K. Rastogi[1], Franco Vaccari[2], and G. F. Panza[2])

1. *Institute of Seismological Research, Gandhinagar, Gujarat.*

2. *Department of Mathematics and Geosciences (DMG), Trieste University, Italy*

Seismic tomography is a technique to image the Earth interior with waves generated by earthquakes. Seismic tomography as defined by Clayton (1984) is not limited to imaging the Earth or part of the Earth using body-wave arrival time data; it has been extended to include surface waves and waveforms as well. Hence, in the present study of surface wave tomography, following methods are applied in sequence to get the 3-dimensional S-wave velocity (Vs) models for the Gujarat region; (a) frequency - time analysis, FTAN (Levshin et al., 1989 and references therein), to measure group-velocity dispersion curves of the fundamental mode of Rayleigh waves; (b) two dimensional tomography (Yanovskaya, 2001 and references therein) to map the distribution of group velocities of Rayleigh waves, discretised on a grid 2^{o} x 2^{o} to compile the cellular dispersion curves; (c) non-linear inversion (Panza, 1981 and references therein) of the assembled cellular dispersion curves to calculate the set of accepted V_S models for each cell.

Data

Thirteen regional/teleseismic earthquakes recorded by 32 Broadband Seismographs (BBS), operated by Institute of Seismological Research (ISR), Gujarat, India has been used in the present study. The length of most of the epicentre-to-station paths considered does not exceeded 3,000 km in order to have, as much as possible, reliable measurements of group velocity at short and intermediate periods. The distribution of the ISR stations used in the present study and ray path coverage are presented in Figure 1 and list of earthquakes are provided in Table 1.

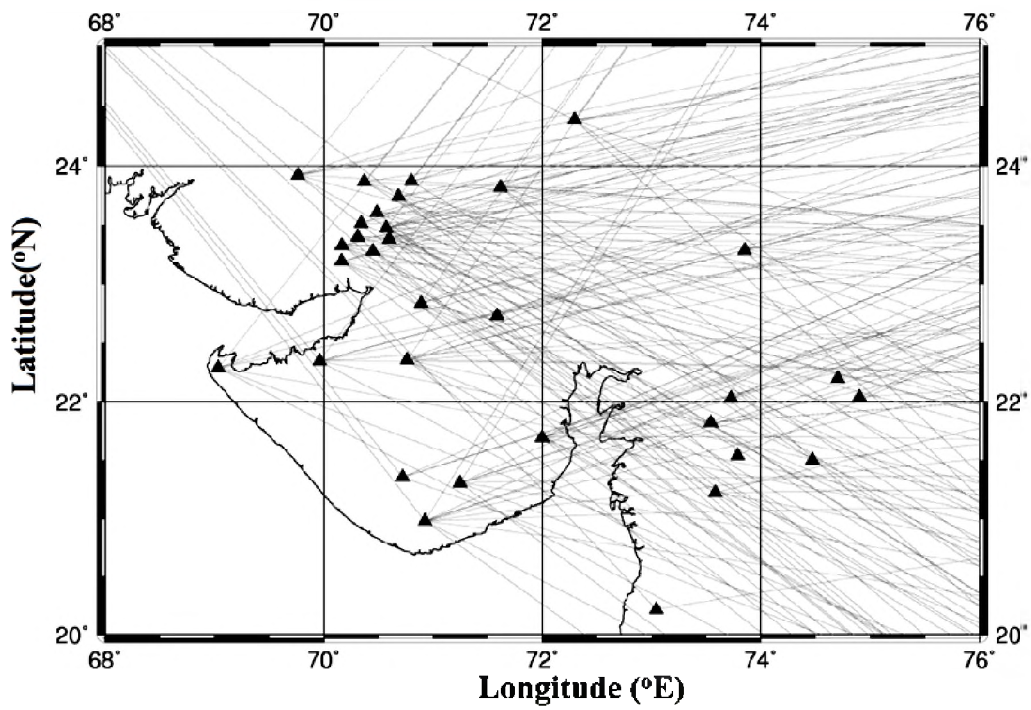


Fig.3.21: Distribution of ISR stations (black triangle) and seismic paths used in the present study.

Table 3.1: List of earthquakes used in the present study with epicentral parameters.

Event No.	Date (yyyy/MM/DD)	Origin Time (Hr:Mn:Sc)	Lat. (°N)	Long. (°E)	Depth	Mag.	Place
1	2013-04-20	00:02:47	30.308	102.888	6.6	6.6	56 Km WSW of Linqiog, China
2	2013-09-28	07:34:06	27.183	65.505	12.0	6.8	85 Km NNE of Awaran, Pakistan
3	2013-10-03	06:12:39	27.290	88.402	9.9	5.2	11 km WNW of Singtam, India
4	2013-11-06	04:16:16	26.412	93.645	34.3	5.4	24 Km S of Bokakat,India
5	2014-02-12	09:19:49	35.905	82.586	10.0	6.9	272 ESE of Hotan, CHINA
6	2014-03-21	13:41:09	7.745	94.334	21.5	6.4	111 Km ESE of mohean, India
7	2014-05-05	11:08:43	19.656	99.670	6.0	6.1	13 Km NNW from Phan, Thailand
8	2014-05-18	01:02:32	4.248	92.757	35.0	6.0	Northern Sumatra
9	2014-05-21	16:21:54	18.201	88.038	47.2	6.0	276 Km SE of Konak, India
10	2014-05-30	01:20:15	25.000	97.845	10.0	5.9	29 km NWW of Pingyam, China
11	2014-07-31	13:41:00	12.435	92.200	5.8	5.8	280 km ENE of Port Blair, India
12	2014-08-03	08:30:13	27.189	103.409	12.0	6.2	11 Km W of Wenping, China
13	2014-09-09	09:28:23	22.160	93.141	10.0	5.4	40 Km SSE of Saiha, India

Methodology

The 2D seismic tomography

The group and/or phase surface wave velocities, observed along different paths, are widely used to map local values of the velocities for a set of periods, monitoring the horizontal and vertical variations in the Earth's structure. The group velocity is most efficiently obtained performing a moving window analysis to the signal (Dziewonski and Hales, 1972; Levshin et al., 1972 and 1992). These measurements lead to a change δt, in the arrival time of a narrow-band wave packet with centre frequency ω, that can be related to the average group velocity perturbation along the reference ray in the laterally homogeneous background model:

$$\delta t = \int \delta\left(\frac{1}{U}\right) ds = -\frac{1}{U^2}\int \delta U ds \qquad (1)$$

The obtained dispersion measurements are linear integrals of the local perturbations in the group velocity (Eq 1). The local velocity perturbation can be obtained by a tomographic inversion of the integral (1). The 2D seismic tomography technique used in the present study is based on time residuals, which can be directly used to estimate lateral variations of surface wave velocities (Yanovskaya, 2001).

For regional studies it is possible to use the method for the general inverse problem for the travel times with Cartesian coordinates (x, y) because a small part of a spherical surface is easily reduced to the case of a plane by the Mercator transformation of the coordinates and velocity (Yanovskaya, 1982; Yanovskaya et al., 1990; Yanovskaya and Ditmar, 1990). If the given data are the phase and/or group velocities at different periods and along some paths, crossing the region under investigation, and if we want to determine a function which fits the data, the general two-dimensional tomography problem can be formulated in the framework of ray theory (Yanovskaya and Ditmar, 1990), i.e., to assume surface waves to travel along paths that are lines. It is generally supposed that the source-station travel time is given by an integral over the ray. Accordingly, the time residual relative to some initial approximation is determined, in a linearized formulation, from the functional:

$$\delta t_i = \int_{L_{0i}} \frac{\delta V(r)}{V_0^2(r)} ds \qquad (2)$$

where $V_0(r)$ is the velocity in the initial approximation; $\delta V(r)=V(r) - V_0(r)$; L_{0i} is the path corresponding to the initial approximation.

Further, the Backus–Gilbert method is used to get the unique solution of the problem. The Backus–Gilbert method imposes a restriction on the behaviour of the desired functions: the solution must have the minimum norm (to minimize the integral of the squared derivative). Moreover, Ditmar and Yanovskaya (1987) and Yanovskaya and Ditmar (1990) have provided the method for constructing the solution for a flat Earth approximation that is valid when the region is smaller than 4000 km. The resolution is estimated at any point by the size of the averaging area, similarly to the Backus–Gilbert method, where the resolution is given by the length of the averaging interval.

The "Hedgehog" non-linear inversion method

The Hedgehog method (Valyus, 1972; Valyus et al., 1969; Knopoff, 1972), is an optimized Monte Carlo search. In this technique, the unknown structural Earth model is replaced by a set of parameters; therefore the retrieval of the model is reduced to the determination of the numerical values of the parameters. For each cross-section, the theoretical values are computed by comparison with real data and the discrepancy between the computed data and the observed ones is calculated. The set of cross-sections for which the discrepancy is sufficiently small is the solution of the problem. Therefore the problem is reduced to find the zone of minimum of a multidimensional function in the space of the unknown parameters of the cross-section (Panza, 1981) and it is independent from the starting solution.

In this technique, multidimensional region is divided into a M-dimensional grid, in the investigated model space (M equals the number of independent parameters). The function of parameters is calculated in every knot of the grid and finally the points in which the function is sufficiently small are chosen. The criteria to choose one cross-section as solution of the inversion problem is the following: for each structural model selected in the model space, surface wave dispersion curves are calculated and the differences between the theoretical and the experimental dispersion curves are computed. If, at each period, this difference is less than the measurement errors and if the r.m.s. (root mean square) of the differences, at all periods considered, is less than a chosen quantity (usually 60–70% of the average of the measurement errors), the model is accepted (Panza,1981).

Output

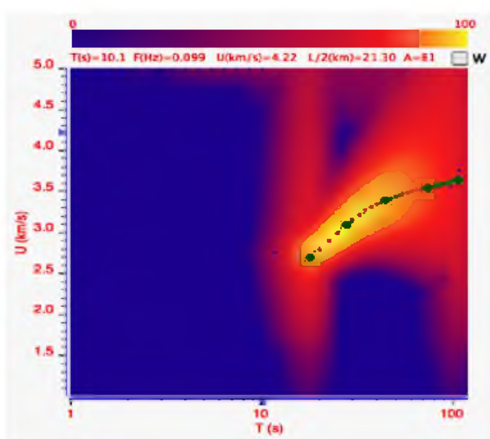


Fig. 3.22: FTAN diagram obtained after multiple filter analysis for group velocity of Rayleigh waves.

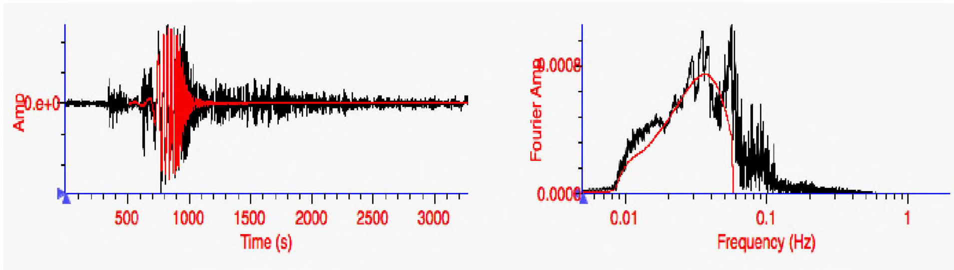


Fig. 3.23: Comparison between raw waveform (in black) and extracted waveform of fundamental Rayleigh wave (in red), which corresponds to the dispersion curve that will be used in the 2D tomography.

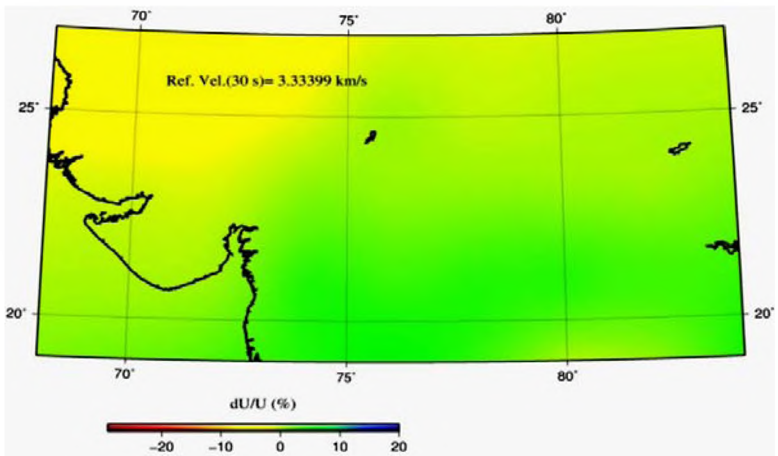


Fig. 3.24: Distribution of group velocity at 30 s period using Rayleigh wave tomography.

CHAPTER 4

LONG-TERM EARTHQUAKE PROGNOSIS

4.1. PALEOSEISMOLOGY AND ACTIVE FAULT INVESTIGATION IN KACHCHH BASIN

4.1.1 Tectonic Activity along a newly identified South Katrol Hill Fault, Kachchh, Western India

Archana Das*, Tarun Solanki, S. P. Prizomwala and B. K. Rastogi

Katrol Hill Fault (KHF) is one of the active faults of Kachchh (Fig. 4.1). The Southern Kachchh Mainland is delimited by KHF in north and Gulf of Kachchh in south. Some 15 – 20 km south of scarp of north KHF ~ is a younger and relatively smaller scarp which runs in the same direction (i.e. E-W). Spatial and temporal variations in tectonic activity lead to the formation of characteristic slopes and valley shapes. Steep and straight mountain fronts with cross-cutting "V" shaped valleys characterize areas where tectonic processes prevail, whereas gentle and sinuous mountain fronts with cross-cutting "U" shaped valleys characterize areas where erosional processes prevail. In semi-arid climates, the sinuosity of the mountain fronts, the cross-sectional shapes of the valleys ("V" or "U" shaped), and steepness of the stream channels have been found useful geomorphic markers to help quantify tectonic activity of fault segments in both high- or low-strain regions. Several studies have shown use of topography, drainage pattern analysis and geomorphic features in evaluating recent and present-day tectonic features and activity along them.

Here we employ geomorphic indices to study the geomorphic evidences of South Katrol Hill Fault and evaluate relative tectonic activity along its various segments. We studied seven drainages cutting the SKHF for longitudinal river profile, stream length gradient index, hypsometric integral, valley floor width to height ratio and mountain front sinuosity. These parameters provided useful insights into variation in valley shape, gradient and relief as rivers cut through SKHF.

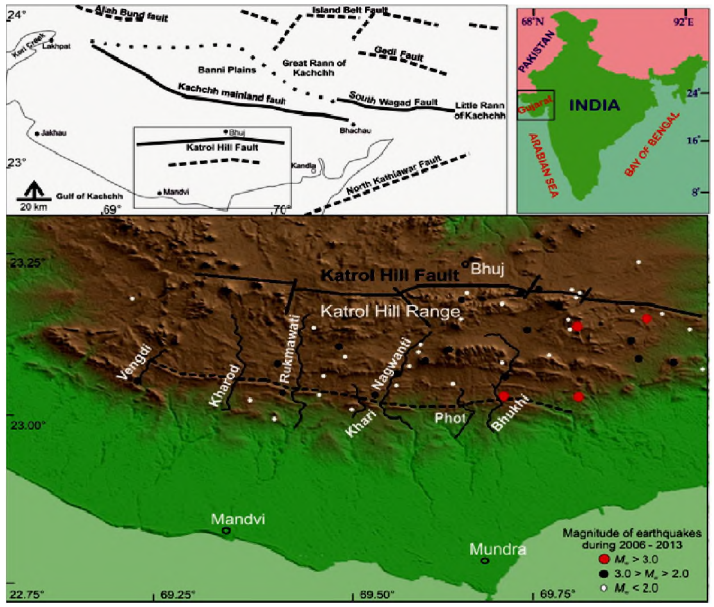


Fig. 4.1: a) Inset map of India, b) major faults in Kachchh and c) Seismicity and drainages across South Katrol Hill Fault (SKHF)

It is believed that the Katrol Hill Fault (NKHF) is a tilt block structure in Kachchh mainland which is dipping towards south. Based on anomalous increase in river incision in the middle reaches, it was suggested that the southern Kachchh Mainland is divided into two blocks by an E-W running fault, which most likely is a splay structure of the main KHF (NKHF). The position of increase in incision in the south flowing drainages coincides with a young escarpment. We employed longitudinal river profile and SL index, which responds to gradient changes. Interestingly the position of SKHF is associated with SL peak and convex nature of longitudinal river profile in all the drainages except Vengdi. Although the variations in SL values and longitudinal river profile are governed by rock strength, in our case the SKHF lies in segment with same lithology, hence we attribute this SL peaks and changes in longitudinal river profile to be manifestation of tectonic activity along SKHF. The lack of variation observed in Vengdi River could be due to lack of tectonic activity in west compared to eastern and central segments of Kachchh mainland. The lower values of mountain front sinuosity estimated by studying the E-W escarpment, hints at an uplifting structure ~ the SKHF. Similarly the lower values of V_f just downstream of the SKHF also suggest a younger valley, mostly produced by an uplifting structure. Interestingly the presence of deeply incised ravines exactly south of SKHF (i.e. on the uplifted block of SKHF) is a manifestation of uplift in the form of tectonic phase experienced by the SKHF during Late Quaternary period. Figure 4.2 shows the tilt tectonic configuration of southern Kachchh mainland and major tectonogeomorphic signatures.

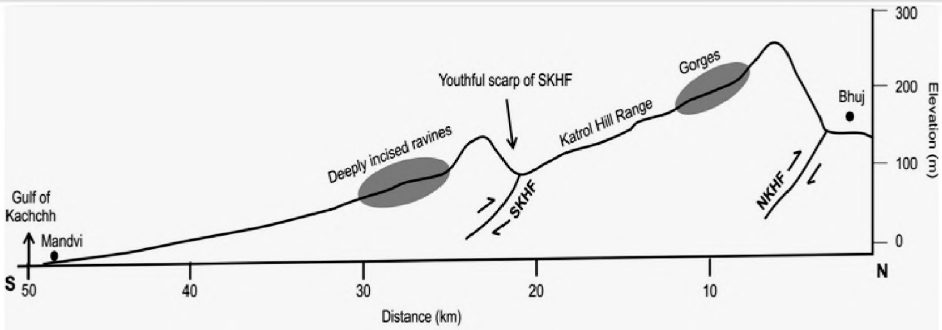


Fig. 4.2: Schematic diagram of tectonic configuration of tilt block structure of Southern Kachchh Mainland along with Tectono-geomorphic features.

Table 4.1: Spatial variation in Relative Index of Tectonic Activity along SKHF

River	SMF class	HI class	VF class	SL class	RIAT	RIAT class	
Vengdi	2	4	3	3	3	3	Lesser Active
Kharod	2	1	3	1	1.75	2	
Rukmawati	4	1	2	1	2	2	
Khari	3	3	4	2	3	3	Moderately Active
Nagwanti	1	2	3	1	1.75	2	
Phot	2	1	3	2	2	2	Very Active
Bhukhi	1	2	2	1	1.5	1	

In order to ascertain relative tectonic activity undergone by various segments of SKHF, we classified all geomorphic indices into four arbitrary classes with decreasing activity from class 1 to class 4. All the indices were combined and averaged to form a new parameter called the 'Relative Index of Tectonic Activity'. The values of this parameter were then sub divided as, class 1 < 2.0; very active, 2.0 < class 2 < 2.5; active, 2.5 < class 3 < 3.0; moderately active and class 4 > 3.0; least active (Table 4.1). The eastern KHF shows highest tectonically active class i.e. class 1 followed by central segment with class 2 and then western segment with class 3. The presence lowest HI value (0.38; class 4) and concave nature compared to other rivers with convex to concave-convex shapes hints, at lesser active western segment of southern Kachchh mainland. The presence of lower V_f and S_{mf} values in eastern KHF also corroborated the claim that eastern SKHF is more active segment. Our RIAT suggests eastern and central segments of SKHF (corresponding to eastern NKHF) belong to 'very active to active' tectonic classes.

The parameters studied corroborates the earlier claim that southern Kachchh mainland is a south dipping tilt block structure with a E-W trending fault, south of main Katrol Hill Fault, ~ known as a South Katrol Hill Fault which shows neotectonic activity. The study of spatial variation in tectonic activity along SKHF shows that the eastern KHF is an 'Active' segment of SKHF corresponding to class 1 of RITA followed by central and western segments.

4.1.2 Uplift/Incision rate along the Eastern Kachchh Mainland Fault during the Late Pleistocene-Holocene period, Kachchh, Western India

(S. P. Prizomwala, Archana Das, Tarun Solanki and B. K. Rastogi)

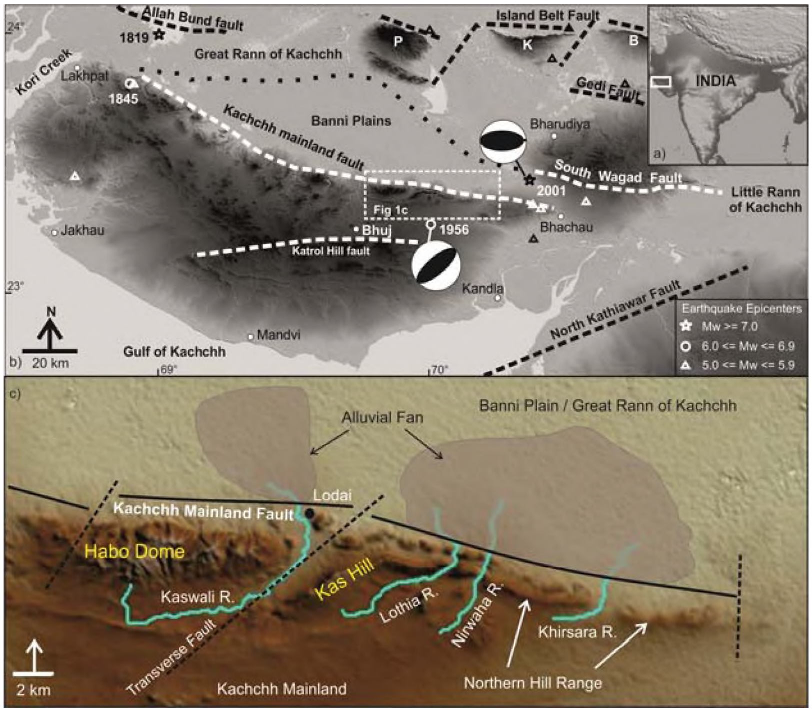


Fig. 4.3: a) Inset map of India showing Kachchh, b) major seismicity and study area in Kachchh and c) geomorphic setting of eastern Northern Hill Range (NHR)

Kachchh Mainland Fault (KMF) is a 170 km long major fault (4.3) responsible for generation of several earthquakes during the historical past. The KMF is dissected by several NE-SW oriented transverse strike-slip faults along its length. It is well known that the KMF is an active fault but this present study attempts to identify which segment of the KMF is more active relative to the other segments. In order to estimate the spatial variation in activity along the KMF, we attempt to estimate the uplift/incision rate of various segments which is of vital importance for understanding longterm earthquake history and tectonic activity of KMF.

In present study we selected Lothia River in the eastern Northern Hill Range (NHR) for detailed sedimentological, geomorphic and chronological study. We explored the geomorphology and Quaternary sediments in Lothia River and identified a site for detailed study. The site selection was based on presence of a strath terrace where Lothia River had incised a bedrock upto 11m and had a thin valley fill Quaternary sequence of 4m on top (Fig. 4.4). Before entering the Banni sediments the Lothia River abruptly incises the bedrock and then merges in to the Quaternary sediments of Banni Plains. We attribute this anomalous incision in bedrock dominantly to uplift along the KMF. This is based on understanding that the fluvial systems in Kachchh region which typically experiences annual precipitation less than 30 cm cannot incise the bedrock solely controlled by climatic phenomenon. Figure 4.4 shows the lithostratigraphy of Lothia section with OSL chronology.

Fig. 4.4: Strath terrace section in Lothia River with OSL chronology.

Based on regional studies the Late Pleistocene period has been known for arid climate in western India. We attribute the bedrock incision as dominantly uplift driven along the KMF and hence based on OSL chronology of three samples we suggest a minimum uplift rate of 1.12 mm/a for eastern KMF during the Late Pleistocene-Early Holocene period.

4.1.3 Geoenvironmental and Geotechnical studies in the parts of Central Gujarat alluvial plain, Sabarmati basin

(Thokchom Sarda, Falguni Bhattacharya with Dr. Navin Juyal of PRL, Ahmedabad)

The present study is focused on the middle alluvial segment of ephemeral Sabarmati River in western India. The Sabarmati River originates in the southwestern spurs of the Aravalli hills in Mewar region and flows through a semi-arid region with a mean annual rain-fall 650 mm. The river finally debouches into the Gulf of Cambay (Fig. 4.5). The river traverses through three geomorphic zones, viz. the rocky upland, the middle alluvial plains and the lower estuarine zone (Tandon et al., 1997). Regional stratigraphy based on subsurface data shows that nearly 300-m thick Quaternary sediments overlie the Tertiary basement Biswas, 1987; Maurya et al., 1995; Tandon et al., 1997). In the foregoing, it is amply clear that the Late Quaternary alluvium in the Sabarmati basin is a potential geological archives to discern the pattern of climate (monsoon) variability as also to understand the recent (late Quaternary) tectonic history. During the recent times, Sabarmati basin is witnessing proliferation of constructional activities. These structures are built on the Sabarmati alluvium. As a contribution towards the societal implication of the present study, attempt has also been made to evaluate the granulometric properties of the alluvial succession. This study indicates that the alluvial sequences are silty-sand in characteristic. Therefore, constructional activities need to address mechanical properties of the sediment.

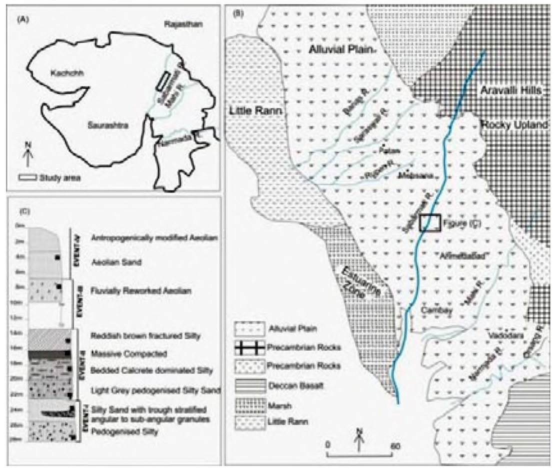


Fig. 4.5: Stratigraphy of Alluvial Sequence along Sabarmati River

Broadly four major palaeo-hydrological/palaeo-environmental events have been identified during the deposition of fluvial sequences. These are the event-I dominated by braided-meandering fluvial system, suggesting high sediment water ratio. Event-II constitutes laterally avulsive channel deposit, implying deposition under consistent flow regime. The event-III is identified as a mixed fluvio-aeolian sedimentation suggesting fluctuating hydrological condition. Finally the event-IV which marks the termination of sediment succession at the study area represents dwindling hydrological condition and onset of desert condition. Further investigation is undergoing in order to meet the above mentioned objectives.

4.1.4 Study of Neotectonics near proposed Pancheshwar dam site on Kali River, Kumaun Lesser Himalaya, Uttarakhand

(Girish Ch. Kothyari)

Geomorphological investigations have been done around the proposed Pancheshwar dam (height 315 m) site on two rivers Kali (N-S flowing) and Saryu (SE flowing) in Kumaun Lesser Himalaya on Nepal border (Fig. 4.6). The proposed dam height is 315 m and the area likely to be submerged by the reservoir will be ~120 km^2 in India and ~14 km^2 in Nepal. Study has been done for a stretch of 20 km in NW direction starting from the proposed dam site up to Naichun along the Saryu river that follows the North Almora Thrust (NAT). Morphotectonic evidences have been observed along the imbricated zone of southwest dipping high angle North Almora Thrust (NAT). These features include tilting of terraces towards the hanging wall of NAT, development of three levels of strath terraces, incision of river forming deep gorge at Ghat and southward shifting of river channel.

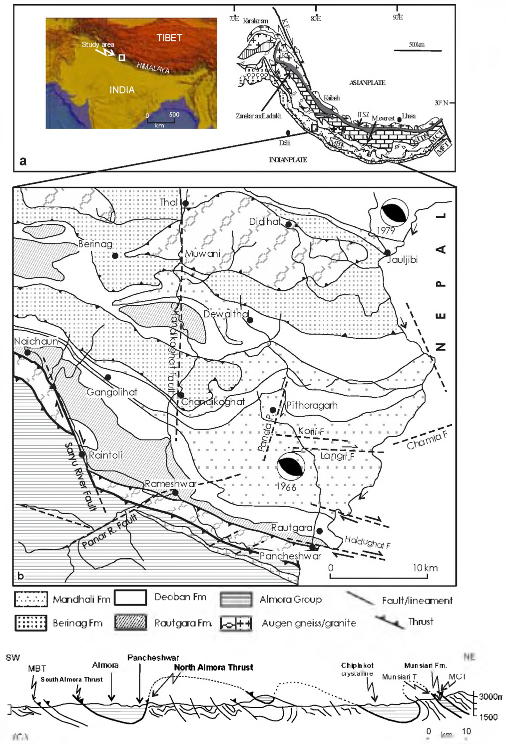


Fig. 4.6: (a) Location of the study area showing major thrusts and faults (Godin, 2003), (b) geological map of the study area (modified after, Valdiya and Kotlia, 2001), (c) simplified geological cross section across the Lesser Himalaya (Valdiya, 1980).

During 1966 and 1979, the region experienced earthquake swarm with the strong magnitude of 6.7 and 7.5, respectively. Seismicity of M≥3.5 is being continuously recorded till date.

4.1.5 Active Faulting and OSL Chronology of Quaternary Landforms around Gedi Fault, Eastern Kachchh, India

(Girish Ch Kothyari, B. K. Rastogi, P. Morthekai and Rakesh K Dumka)

North of Wagad region of Kachchh rift basin (western India) experienced an earthquake of magnitude 5.7 in 2006 along the E-W trending Gedi Fault (GF). Enhanced seismicity has been seen in the area, since then. The area is 60 km NE of the epicenter of 2001 **Mw** 7.7 earthquake (~80 km NE of Bhachau) at the northern end of the Wagad upland. Active fault mapping in the area (around Desalpar-Gedi-Fatehgadh) was carried out including. Development of an active fault scarp, shifting of a river channel, offsetting of streams along left-lateral E-W trending GF and SE tilting of the ground indicate that the terrain is undergoing active deformation. Based on detail field investigations three major fault controlled uplifts have been identified in the GF zone. These uplifts were developed in a step-over zone of GF and formed due to compressive force generated by left-lateral motion within the segmented blocks. Optically Stimulated Luminescence (OSL) age of the sediments from the footwall of GF yielded an age of 8020 ± 860 years for oldest sediment and 1050 ± 90 years for youngest sediments. These ages suggest that the average rate of uplift is of 0.29-1.12mm/yr during the last 9 ka.

4.1.6 Secondary Surface deformation Along North Wagad Fault/Bharudia Fault (BhF) Zone in Kachchh rift basin, western India

(Girish Ch. Kothyari and Rakesh K. Dumka)

We mapped secondary surface deformation from the 2001 Mw7.7 Bhuj earthquake near the surface trace of the North Wagad Fault (NWF) just north of Bharudia and about 20 km NE from the 2001 main shock epicenter (or 30km N of Bhachau) with the help of ASTER satellite data followed by ground checks. A 10km long and 350m wide stretch has been covered. Important active deformational geomorphic features present in the NWF zone are fault scarps, block tilting, co-seismic uplift, and drainage offsets.Northward movement of the hanging wall caused fault bend folding of Wagad sandstone, whereas horizontal strain caused surface deformation on the hanging wall and forelimb of the fault. It also results in development of numerous north dipping tensional fractures. We used Ground Penetrating Radar (GPR) to identify several north-dipping surface breaking subsidiary faults within a 324 m wide zone across the BhF/NWF. These tensional features have been mapped along ~10 km strike length of the NWF. Real Time Kinematic (RTK) geodetic survey along eastern part of the BhF/NWF indicates ground uplift of 1.5 m and lateral spreading of tensional fractures in 500m × 900m area (ISR Annual Report, 2010-11 and 2011-12). Based on these observations, we propose a model to understand brittle and ductile behavior of the BhF/NWF that may be useful for evaluation of seismic hazards in the region.

Deformation during the 2001 earthquake resulted into secondary uplift in the Bharudia area. At one site, thrusting of Jurassic Wagad sandstone over Quaternary deposits created a 2m high scarp (Fig. 4.7). Coseismic deformation resulted in southward tilting of the Wagad Mesozoic sandstone units by 8°. The secondary surface rupture might be due to thrust movement along the E-W faults BhF/NWF. Numerous north dipping surface breaking subsidiary faults were also identified. The co-seismic movement has resulted into the development of tensional fractures all along the strike length of the BhF/NWF. Northward movement of the hanging wall caused fault bend folding within the BhF/NWF zone.

The seismological aftershock data show that the upper part of the crust (down to 8 km) is not seismogenic, and the earthquakes being mostly confined between 8 and 35 km depth. Brittle and ductile behavior of the BhF/NWF zone has been modeled on the basis of geological and seismological observations. The observed structures like tensional fractures and fault scarp are illustrated in the model as observed in the field. It is however interesting to note that the seismogenic zone is south dipping at depth (8-40 km), while the surface fault/fractureson the other hand are shallow and dipping towards north. The hanging wall movement along the south dipping fault has generated tangential longitudinal strain on the upthrown block resulting into bending of the Wagad sandstone in brittle regime.Bending of the rock units generates extensional strain in the convex side of the anticline fold resulting into development of tensional cracks all along the fault zone.

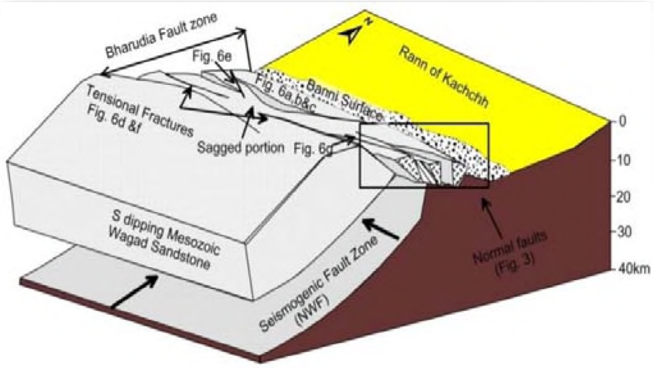


Fig. 4.7: Three dimensional block model of the fault rupture zone showing development of secondary surface deformational features during the 2001 Bhuj earthquake in Bharudia area

4.1.7. Optical dating of fluvial terraces along the Pachcham and Wagad island, Kachchch, Gujarat. (Falguni Bhattacharya)

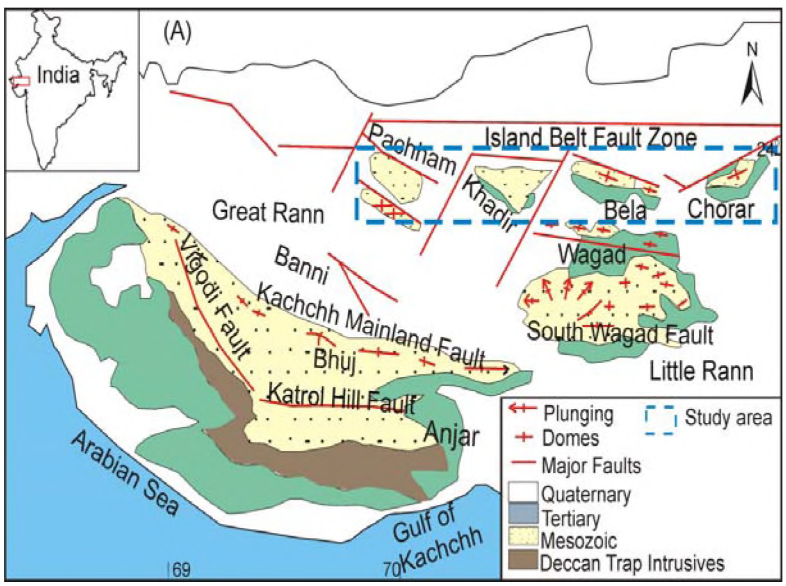


Fig. 4.8: Map showing geology and major structures of Kachchh Mainland, Wagad highland and Island Belt Fault zone.

The tectonically active Kachchh rift basin is characterized into discrete blocks which behave differently (Biswas, 1974). Six major uplifts describing the structural evolution of the Kachchh basin are: Pachcham, Bela, Khadir island, Chorar Hill, Wagad Highland and the Kachchh Mainland (Fig. 4.8). The 'Mainland' uplift is the largest which is followed by the 'Wagad-uplift' occurring in en-echelon fashion with 'Island-Belt' in the north and 'Mainland' in the south (Biswas, 1974).

Four terraces have been identified along the island belt fault zone. The samples from these terraces are optically dated for determination of the age of the terraces. The four fluvial terraces along the Island belt fault zone are dated to be: ~60 ka, 45 ka, 30 ka and 2 ka (Table 4.2). Considering that the Island belt is traversed by the geologically youngest NE-SW and NW-

SE trending strike-slip faults (Biswas, 1995), we ascribe the landform deformation as observed in the present study to the activity along these faults.

Table 4.2: Details of OSL dating along island belt (Gy=Grays, ED=Equivalent Dose, OD=over dispersion, CAM=Centralized Age Model, MAM=Minimum Age Model)

Sample No.	CAM De (Gy)	MAM De (Gy)	Age (ka)	OD%
BN-1A	51 ± 3	45 ± 2	45 ± 3 (MAM)	40
BN-2A	67 ± 2	66 ± 2	31 ± 1 (CAM)	25
BN-3	119 ± 5	60 ± 4	30 ± 2 (MAM)	44
BN-4	6.5 ± 0.3	3 ± 0.3	2 ± 0.2 (MAM)	43
JP-2	187 ± 7	101 ± 8	62 ± 5 (MAM)	31
JP-3	120 ± 3	110 ± 2	60 ± 3 (CAM)	20
KR-1	4 ± 0.2	2 ± 0.2	2.6 ± 0.2 (CAM)	44
PPR-1A	144 ± 5	78 ± 6	38 ± 3 (MAM)	34
PPR-2	67 ± 1	39 ± 2	32 ± 1 (CAM)	23

4.1.8. Optical dating of fluvial terraces along the Wagad upland, Kachchch, Gujarat.

(Falguni Bhattacharya)

It has been suggested that the eastern part of Kachchh is a highly strained zone for potential earthquakes (Biswas and Khattri, 2002; Mathew et al. 2006) and is capable of generating large magnitude earthquakes in near future (Rastogi, 2001; Mandal et al. 2004). Wagad upland is the second largest upland area in Kachchh (Biswas and Deshpande, 1970; Biswas, 1987) which extends from latitude 23°20′ and 23°45′ and longitude 70°15′ and 71°10′. The area is surrounded by Rav basin to the north and the Little Rann of Kachchh to the south-east. Lithologically, the terrain is dominated by Jurassic and Cretaceous sand stone, shale and lime stone with some out crop of Tertiary lime stone and sand stone in the north and southeast of Wagad (Biswas and Deshpande, 1970). The E-W trending faults in the eastern Kachchh are identified as the SWF, NWF and the GF (Biswas and Khattri, 2002; Rastogi, 2001; Mandal et al. 2004) (Fig. 4.9).

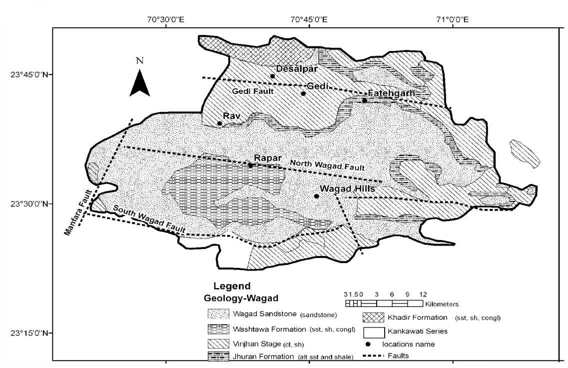


Fig. 4.9: Geology and major structures of Wagad upland

In addition to this, Manfara Fault (MF) which trends NE-SW (transverse fault) has displaced the E-W trending faults suggesting its young age. The 2001 Bhuj earthquake was associated with the activity along the MF (Rastogi, 2001; McCalpin and Thakkar, 2003). Additionally, moderate earthquake of M_w 5.0 during 2006 was associated with the GF implying the active nature of this fault (Rastogi, 2008).

The present study is focused on the basin morphology and drainage network of Wagad highland in order to understand understand the role of seismicity (structure) in the evolution of drainage basins. Two generations of terrace formation have been identified in Wagad highland. River terraces are considered as geomorphic and sedimentologic manifestations of unsteady vertical channel incision (Schumm et al., 1987; Bridgland, 2000). Optical dating of the samples from the river terraces have been done. Details of the optical dating can be found in the previous section. The tectonic phases developing the river terraces along the Wagad highland have been dated prior to ~29 ka and ~15 ka (Table 4.3).

Table 4.3: showing details of OSL dating along Wagad upland

Sample No.	CAM De (Gy)	MAM De (Gy)	Age (ka)	OD%
BGD Loc2_1	10 ± 0.8	4.5 ± 0.5	2 ± 0.2 (MAM)	71
BGD-1	40 ± 1.4	22 ± 1.4	44 ± 2 (CAM)	30
BGD-2	44 ± 2	44 ±2	29 ± 2 (CAM)	30
BGD2-Loc2	1.5 ± 0.08	1.4 ± 0.09	1 ± 0.04 (CAM)	48
BGSB-1	1.2 ± 0.07	1.2 ± 0.07	0.2 ±0.02 (MAM)	62
KRD-1B	3 ± 0.15	3 ± 0.14	1 ± 0.1 (MAM)	40
KRD-2	5 ± 0.4	2 ± 0.2	1 ± 0.1 (MAM)	66
KRS-Loc2	37 ± 1.5	19 ± 1.4	8 ± 1 (MAM)	37
KRS Ch-bottom	6 ± 0.18	5 ± 0.19	3 ± 0.1 (CAM)	24
KRS Ch-top	3.2 ± 0.18	3 ± 0.15	2 ± 0.1 (MAM)	40

(Gy=Grays, ED=Equivalent Dose, OD= Over dispersion, CAM=Centralized Age Model, MAM=Minimum Age Model)

4.1.9. Optical Dating of fluvial sediments along the Gujarat alluvial plain

(Falguni Bhattacharya)

Optical Dating of fluvial sediments have been carried out along the Gujarat alluvial plain. Banas and Saraswati are the two rivers along the Gujarat Alluvial Plain (Fig. 4.10). Gujarat Alluvial Plain extends from the Narmada river basin in the south to the Luni river basin in the north. Major part of the Mainland is included within the Cambay and the Narmada grabens (Merh and Chamyal, 1997). Precambrian rocks of Delhi and Aravalli super group marks the tectonic boundary along the East and the North-east. The Eastern Cambay Basin Bounding Fault extending almost N-S broadly delineates the Quaternary alluvium deposits of the Gujarat alluvial plain from the Precambrian rocks of Delhi and Aravalli super group. Rivers in the region have deeply incised the Quaternary alluvium. Older rivers traversed southwest to west from the rocky upland and were guided by E-W to NE—SW trending fractures and step faults (Maurya et al., 1995). According to Merh and Chamyal (1997) the region experienced major tectonic activity after the aeolian sedimentation that not only shifted the rivers to their present course but also caused them to incise the sediments (Juyal et al., 2006).

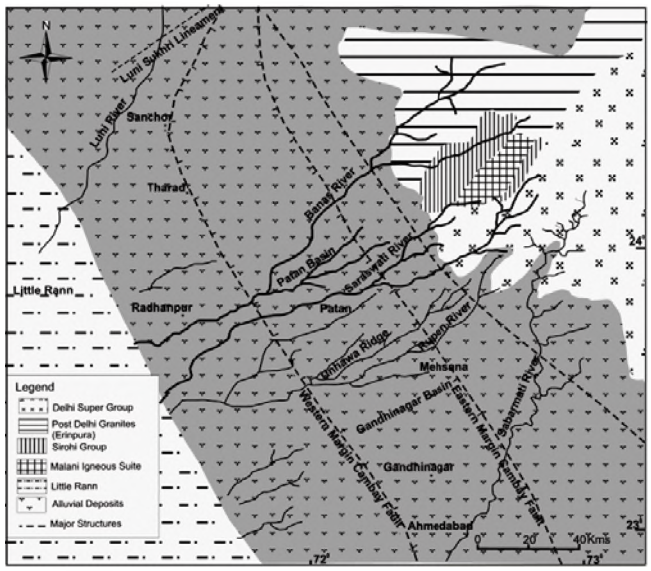


Fig. 4.10: Map showing drainages and geology of Gujarat alluvial plain

Chronology suggests that fluvial sedimentation commenced along the Banas basin at ~37 ka which continued till ~6 ka. Aeolian sedimentation initiated at 6 ka and blanketed the fluvial sediments till 1 ka. Optical dating suggests that the sediment sequence along the Saraswati river basin initiated at ~32 ka. Aeolian activity depositing fine sand to silt is dated to 2 ka.

Table 4.4: showing details of OSL dating along Gujarat alluvial plain

Sample	ED (CAM)	ED (MAM)	Age (ka)	OD%
SDS-1A	103±3	57±4	32±1.5 (CAM)	29
SDS-OSL-3A	136±6	71±6	27±2 (MAM)	38
SDS-OSL-3B	119±5	62±3	20±1 (MAM)	39
SDS-OSL-4B	9±0.3	9±0.3	3±0.1(CAM)	28
SDS-OSL-5	4±0.1	4±0.1	2±0.1 (CAM)	10
SDS-OSL-6	0.18±0.01	0.18±0.01	0.1±0.08 (MAM)	54
SDS-OSL-7	0.49±0.02		0.2±0.01(CAM)	20
JD-1	111±4	109±6	37±2(CAM)	35
JD-2	92±4	48±4	22±2 (MAM)	47
JD-3A	93±6	47±5	18±2 (MAM)	47
JD-3B	78±3	37±5	11 ± 1.6 (MAM)	80
JD-5	80±4	41±3	12±1 (MAM)	39
JD-6	84±2	47±4	10.5±1 (CAM)	14
JD-7	27±2	13±1	5.6±0.5 (MAM)	52
JD-8	17±0.3	17±0.3	3±0.1 (CAM)	10

JD-PB	7±0.7	3±0.4	1.0±0.1 (MAM)	76
JD-MFP	3±0.4	3±1	0.7±0.1 (CAM)	10
DW-1	98±4	56±4	26±1.6 (CAM)	25
DW-2	25±1	25±1	5.5±0.3 (CAM)	33
GN-1	80±3	42±3	20±2 (MAM)	39
GN-2	2.2±0.1	2±0.1	1±0.1 (MAM)	56
OG-1	98±2	97±2	37±2(MAM)	25
OG-2	82±4	43±4	31±3 (MAM)	35
IQB	37±1	20±1	5.0±0.3(MAM)	37
MA	62±2	33±2	25±2 (MAM)	29

(Gy=Grays, ED=Equivalent Dose, OD= Over dispersion, CAM=Centralized Age Model, MAM=Minimum Age Model)

4.1.10. Luminescence dating of fluvio-lacustrine sediments of Kashmir basin

(Falguni Bhattacharya, Javid Ahmad Dar, Jagdish Vadher)

The Kashmir valley, located in the northwestern Himalayas, provides an intermontane valley fill comprising unconsolidated fluvio-lacustrine sediments of more than a km thickness. The intermontane basin-fill of Kashmir is basically a result of the orogenic processes associated with the Himalayan uplift. The upthrusting of the Pir Panjal range (Burbank and Reynolds, 1984), southwest of the main Himalayan Zanskar Range, resulted in the formation of a vast lake. Subsequent uplift and downcutting by rivers have exposed the fluvio-lacustrine deposits, known as Karewas. The present study has been carried out in the fluvio-lacustrine sediments of Kashmir basin (Fig. 4.11). Both Upper and Middle Karewa successions have been studied for both vertical and lateral variations. The Upper Karewa successions have been studied in districts of Baramulla (site-1) and Pulwama (site-2), while as Middle Karewa succession is studied in district Budgam (site-3). Following are the tentative dates obtained along the Upper and Middle Karewas.

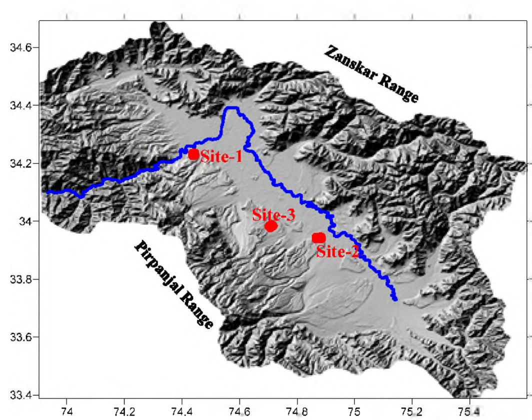


Fig. 4.11: Sampling locations along the Kashmir basin situated between Zanskar and Pirpanjal Ranges.

Table 4.5: Showing details of OSL dating along Kashmir basin

Sample	ED (CAM)	ED (MAM)	Tentative age (in ka)	OD%
C-1	164 ± 4	96 ± 5	36 ± 0.03 (CAM)	23
C-7	5 ±0.4	2 ± 0.5	1 ± 0.01 (MAM)	54
C-10	86 ± 4	44 ± 3	4 ± 0.04 (MAM)	45
C-11	117 ± 4	63 ± 4	4 ± 0.04 (CAM)	32
C-13	76 ± 4	75 ± 4	16 ± 0.02 (CAM)	35
C-15	69 ± 3	36 ± 3	16 ± 0.02 (CAM)	35
GL-1	28 ± 1	14 ± 1	1 ± 0.01 (MAM)	52
GL-2	37 ± 2	33 ± 2	8 ± 0.01 (CAM)	33
GL-3	24 ± 2	24 ± 2	5 ± 0.05 (MAM)	52

(Gy=Grays, ED=Equivalent Dose, OD= Over dispersion, CAM=Centralized Age Model, MAM=Minimum Age Model)

4.1.11 Chronology of late Quaternary climatic and tectonic changes in the Rukmawati river basin, Kachchh, Western India

(Archana Das, Falguni Bhattacharya and B.K.Rastogi in collaboration with Dr. Navin Juyal (PRL, Ahmedabad), M.G. Thakkar (K.S.K.V. Kachchh University, Bhuj)

Dryland Rivers by virtue of their preservation potential, serve as suitable archives towards understanding climate-tectonic coupling. Dryland fluvial systems are not sediment limited instead there is a transport deficit. Even though the sensitivity of the dryland compared to its humid counterpart is high, however, study pertaining to its response to climate and tectonic perturbations are very limited (Candy et al., 2004; Waclawik et al., 2008). The arid and semiarid western India was the focus of research on river response to monsoon variability (Pant and Chamyal, 1990; Tandon et al., 1997; Juyal et al., 2000; 2006; Jain and Tandon, 2003; Prasad et al., 2014). Attempt has also been made to deconvulate the climate tectonic signal (Srivastava et al., 2001). These studies have been limited to the northern and central Gujarat alluvial plain, and only limited data base exists from the tectonically active Kachchh region (Mathew et al., 2006; Bhattacharya et al., 2013; 2014).

Kachchh peninsula as whole and the southern Kachchh in particular are considered to be one of the most seismically active regions in India (Biswas, 2005; Rastogi et al., 2012). In the present study we investigated the fluvial records of southerly-draining rivers in the semi arid southern Kachchh, western India (Fig. 4.12). The present study investigates the southern flowing Rukmawati River which originates from the southern slopes of the Katrol Hill Range (KHR). The geomorphic setups shows that Rukmawati River can be divided into four major zones 1) rocky uplands consisting of domes and hills, 2) pedimont zone fringing the domes and hills, 3) deeply incised ravines in the pedimont/alluvial cover and 4) alluvial zone consisting of alluvial plains in the south (Fig. 4.13).

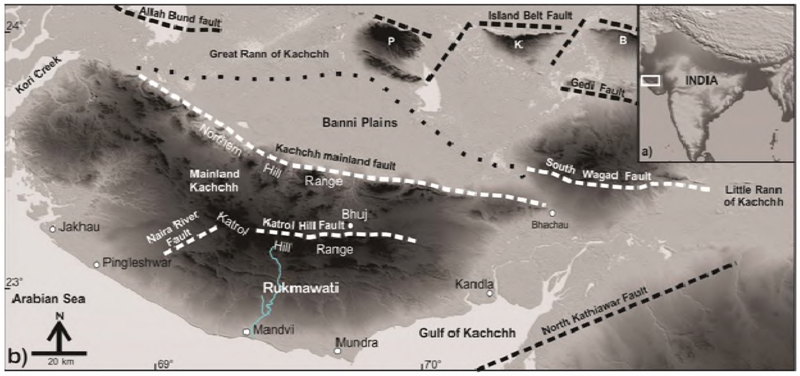


Fig. 4.12: a) Key map of India showing Gujarat. b) Tectonic map of Kachchh showing major faults along with study area

Valley fill sequences in the Rukmawati River can be traced from its rocky uplands to the coastal alluvial plains. We studied three sites 1) Rampar south of the NKHF (i.e. hang wall block), 2) Asambia Gangaji south of the SKHF (i.e. hang wall block) and 3) Kodai in the alluvial zone, for detailed sedimentological investigation. Here only upland site is precisely explained with stratigraphy and depositional environment along with chronology.

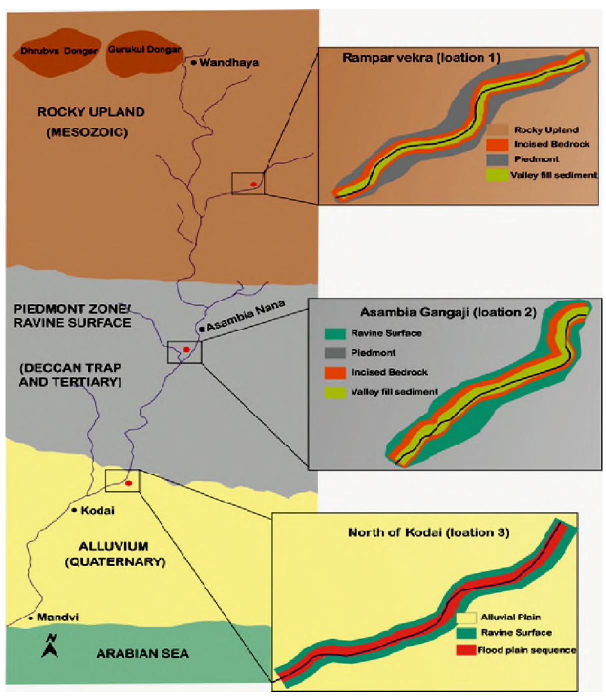


Fig. 4.13: Geomorphic map shows rocky upland, piedmont zone and alluvial surface

RAMPAR - The 9.2 m thick sedimentary sequence investigated in the present study overlies the beveled Mesozoic (Fig. 4.14). Based on the sediment characteristics, the succession can be divided into 9 units following the sedimentary facies classification of Miall (1996). The Gcm facies lying above the beveled planar bedrock represents erosional contact. The beveling of the bedrock occurs due to change in the ratio of vertical to lateral erosion which is a characteristic of the down-cutting river in an active terrain (Hancock and Anderson, 2002; Bhattacharya et al., 2014). The beveling takes place during conditions of low sediment supply (Lave and

Avouac 2001); which provide accommodation space for the valley fill aggradation. Deposition of angular to sub-angular clasts dominated gravel (unit-1) indicates deposited under high sediment water ratio similar to debris flows. In dry land fluvial system such flows are generated by episodic rainout events which mobilize the sediments from poorly vegetated catchment during stressed climatic condition. Deposition of 120 cm thick coarse to medium planar cross-stratified sand (unit-2) indicates improved hydrological condition having well regulated sediment flux from the catchment. Planar cross stratified sand can be interpreted as channel bar facies deposited under lower flow regime. Presence of the platy lithoclast indicates occasional contribution from the proximal slopes. The overlying crudely laminated fine sand (unit 3) suggests gradual improvement in the hydrological condition. Mottled in the sand suggests sediment were exposed to atmosphere (oxidation) before the deposition of the overlying horizon (unit-4). Deposition of poorly organized angular and platy lithoclast in unit 4 suggest weakening of the hydrological condition with occasional mobilization of sediments from poorly vegetated proximal areas during episodic storm surge events as sediment gravity flow (Miall, 1996). The overlying crudely laminated mottled coarse sand suggests reestablishment of improved hydrological condition with seasonality. Presence of endurated clay suggests flood plain environment implying lateral avulsive channel. Occurrence of rhizolith in the upper part is indicative of vegetative cohesive banks (Juyal et al., 2000). Presence of diffused carbonate in association with rhizolith can be ascribed to weakly soil forming event on the laterally avulsive flood plain (Kraus, 1997). From unit-6 to unit-9, sediments are dominated by miliolite sand. Considering that the miliolite in Kachchh are primarily deposited by aeolian process (Bhaskaran et al., 1989; Mathur, 2005) they have been fluvial reworked and transported under varying hydrological conditions (Bhatacharya et al., 2013). For example, the massive miliolite sand with rhizoliths (unit-6) and nodular calcrets (unit-8) can be interpreted as deposition moderately flow condition (transitional braided-meandering system). The intervening trough cross-stratified miliolite (unit-7) indicate short-lived flashy events (braided channel). The upper most crudely laminated platy lithoclast dominated unit-9 indicates their deposition under sediment gravity flow implying weakening in the hydrological condition.

The sedimentary succession preserved at Rampar Vekra allows us to draw the following inferences:

Absence of sediment prior to 12 ka indicate that prior to 12 ka, due to the weak ISM (Sirocko, et al., 1993) the hydrological condition were subdued. In dry land fluvial environment, weak monsoon conditions are represented by flashy condition, which might mobilize large volume of sediment from poorly vegetated catchment, but this sediment rarely get preserved in the fluvial record due to infrequent storm surge events. Therefore absence of appreciable sediment pile on the beveled Mesozoic sands stone basement except for the thin angular ferruginous sand stone litho- clasts, suggests that fluvial energy was utilized for the frequent mobilization and lateral planation of the bed rock. Following this except for the deposition of angular Mesozoic lithoclast dominated unit-3, dominance of laminated coarse to medium sand with occasional rhizolith and mottling dated between 12 ka and 9 ka suggests prevalence of improved hydrological condition with minor fluctuations implying overall strengthened ISM in Kachchh. Continental record of strengthened monsoon during the early Holocene is also obtained from the northern Gujarat alluvial plain (Srivastava et al., 2001; Juyal et al., 2006), Ganga plain Srivastava et al., (2003) and from the central Himalaya (Ray and Srivastava 2010; Juyal et al., 2010). Similarly, the marine record from the Arabian Sea show enhanced productivity during the early Holocene which is interpreted as intensified monsoon activity in the western and northwestern Arabian Sea (Van Campo, 1986; Overpeck et al., 1996; Sirocko et al., 2000).

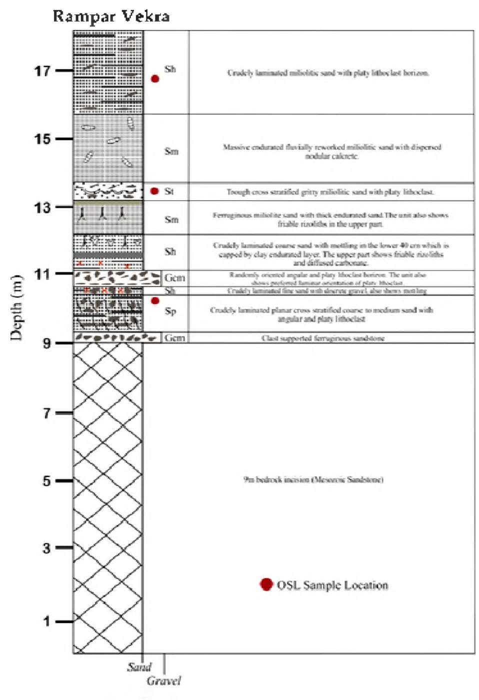


Fig. 4.14: Lithofacies and stratigraphy of Rampar Vekra section, Kachchh

After 9 ka the sedimentary record at Rukmawati indicate a short-lived decrease in the river hydrological as indicated by the deposition of locally derived gritty sand admixed with the platy lithoclast from the surround catchment slopes. However, a persistent decrease (compared to a period between 12 ka and 9 ka) can be suggested during the deposition of the uppermost fluvially reworked massive miliolite horizon dated to 8 ka. In the adjoining Gunawari river valley, Bhattacharya et al., (2014) suggested that the due to the decline in the monsoon strength after around 7 ka the river becomes avulsive in nature. Within the dating uncertainty, this observation accords well with the temporal changes in the hydrological condition inferred from the Rukmawati River. Considering that in the Kari and Gunawari river preserved sediment till around 3 ka, absence of sediment younger than 8 ka in Rukmawati river could be due to lack of preservation which can be assigned to episodic high intensity rainfall events and or terrain instability caused due to the tectonic activity.

From the middle reach (Gangaji mandir) the lowermost sample dated from unit 2 is 30±1.5 ka and unit 4 is dated to 28±1.4 ka. Similarly from the lower reach (Kodai) the lowermost sample dated from unit 4 is 33±2 ka and unit 6 is dated to 16±1 ka. At this stage, either of this interpretation would remain conjectural till more sequences are studied from the southern Katrol hill range.

4.2. CRUSTAL DEFORMATION STUDIES BY GPS MEASUREMENTS

(Rakesh K. Dumka, B.K. Rastogi, Pallabee Chodhury, Prakash Kumar and Sandip Prajapati)

GPS derived deformation estimates of Gujarat region

Crustal deformation rate in Gujarat is measured starting 2006 with 22 permanent and 10 campaign mode GPS stations. To measure the deformation rate near Anjar and Dudhai area, where vertical deformation was identified by our previous studies using InSAR, two new GPS permanent and 10 campaign mode sites were established in May 2014 by ISR. Data of 22 stations were processed using GAMIT-GLOBK 10.50 software. Campaign mode survey has been conducted twice a year in Kachchh region during April and November every year. GPS data at first were converted into the RINEX (Receiver Independent Exchange) format using the program TEQC (translation, editing and quality control). This program is used for general data pre-processing and provides a summary that contains L1/L2 tracking status for each SV session's start and end time, data logging interval, list of satellite observed and missing observations, clock drift rate/gaps, numbers of cycle slip and session length. This information is useful to decide or select the file for post – processing. The data were post-processed using GAMIT-GLOBK software, developed by MIT, USA (King and Bock, 1998, Herring et al., 2010) to create constrained solution (H-) files of parameter estimates and covariances (Herring et al., 2006). The basic input for GAMIT are the observation files of permanent/IGS stations in the RINEX format, orbit file or g-files (sp3 /g-files) and the Global Navigation files. The orbit and IGS-RINEX files are available at Scripps Orbit and Permanent Array Centre (SOPAC) and brdc files are available at Continuously Operating Reference Stations. The IGS Stations used for present study are IISC (Bangalore, India), HYDE (Hyderabad-India), KIT3 (Kitab-Uzbekistan), LHAZ (Lhasa-China), DGAR (Diego Garcia Island- U.K.), TEHN (Tehran-Iran), KUNM (Kunming-China), URUM (Urumqi-China), POL2 (Bishkek - Kyrghyzstan), COCO (Cocos Island - Australia), DARW (Darwin- Australia), KARR (Karratha-Australia), SELE (Almaty-Kazakstan), and MALI (Malindi-Kenya). After processing the data in GAMIT time series of the sites (Fig..), after removing outliers, were generated. By stabilizing core IGS stations using GLOBK site velocities were calculated in ITRF2008 reference frame (Table 4.6 and Fig. 4.15). Estimated time series of 22 permanent sites of ISR are shown in Fig. 4.16

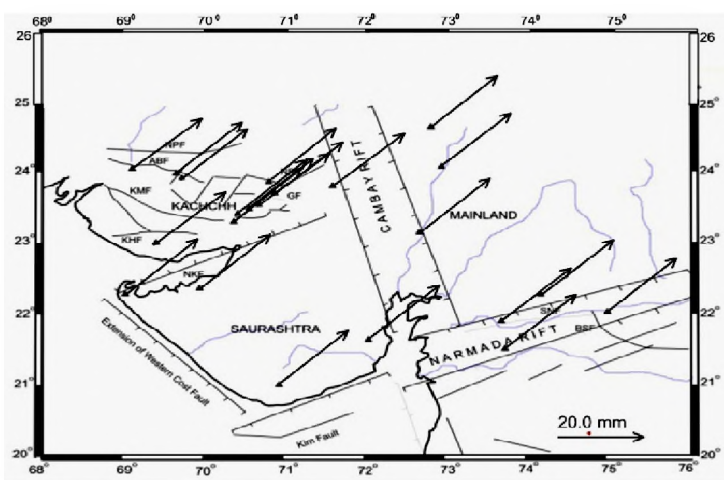


Fig. 4.15: Estimated velocities of GPS sites of ISR in ITRF08 reference frame

Table 4.6: ITRF08 velocity of sites of Gujarat region, monitored by ISR

SN	SITE	Long	Lat	Velocity ITRF08	Velocity w.r.t. Indian plate	Sigma	Region
1	BARW	74.9017	22.04442	51.599	3.2	0.062	South Gujarat
2	ALRP	74.35227	22.28713	50.207	1.6	0.062	South_Gujarat
3	SAGB	73.79038	21.54723	51.836	3.1	0.079	South_Gujarat
4	KEVA	73.67406	21.89908	49.846	1.3	0.049	South_Gujarat
5	DHAR	72.84671	24.007	49.156	0.8	0.04	North Gujarat
6	MABU	72.77982	24.65318	48.295	0.7	0.051	North Gujarat
7	ISRR	72.6685	23.1597	48.097	0.9	0.037	Central Guj.
9	DEVG	72.01238	21.6304	49.575	0.9	0.05	Saurashtra
10	LALP	69.96315	22.34688	49.29	0.4	0.034	Saurashtra
11	DWAR	69.03661	22.2887	49.437	0.5	0.049	Saurashtra
12	UNAG	70.9264	20.97739	50.05	1.1	0.147	Saurashtra
13	FATH	70.86448	23.68293	48.699	1.7	0.049	Kachchh
14	BELP	70.80122	23.87382	47.053	3.8	0.139	Kachchh
15	GADH	70.69398	23.89794	47.387	1.6	0.033	Kachchh
16	DESA	70.68661	23.742	48.12	1.0	0.046	Kachchh
17	RAPR	70.6585	23.55939	47.843	2.1	0.118	Kachchh
18	LLPR	70.63573	23.52631	49.65	2.2	0.061	Kachchh
19	BADR	70.57085	23.47477	48.58	1.8	0.136	Kachchh
20	SUAI	70.49246	23.6138	48.196	1.9	0.034	Kachchh
21	VAMK	70.43061	23.42506	48.245	1.8	0.118	Kachchh
22	EKAL	70.40765	23.60946	46.912	2.5	0.124	Kachchh
23	GIBF	70.37312	23.8665	47.975	1.8	0.045	Kachchh
24	BACH	70.3489	23.30048	48.469	1.6	0.125	Kachchh
25	DUDH	70.14488	23.32784	49.527	1.6	0.267	Kachchh
26	CHAD	70.14176	23.28485	49.2	1.3	0.045	Kachchh
27	HUBA	69.85214	23.3538	49.253	1.9	0.282	Kachchh
28	KHAV	69.76609	23.922	46.027	3.9	0.032	Kachchh
29	KBET	69.71321	23.9909	45.885	3.1	0.078	Kachchh
30	VAND	69.39497	23.02491	48.926	0.9	0.046	Kachchh
31	VKOT	69.19615	24.21525	46.833	2.3	0.053	Kachchh
32	RADP	71.61723	23.81996	48.401	1.1	0.043	Kachchh

Local deformations of all the sites were estimated in Indian reference frame using the Euler pole given by Mahesh et al. (2012). Kachchh region shows deformation rate of 1-4 mm/yr. GPS sites south of Narmada rift at Barwani (MP) and Sagbara (Maha) indicate deformation rate of >3 mm/yr. Two sites north of Narmada Alirajpur (MP) and Kevadia (Guj) show deformation of 1.6 and 1.3 mm/yr, respectively. Most part of mainland Gujarat and Saurashtra region indicate less than 1 mm/yr of deformation

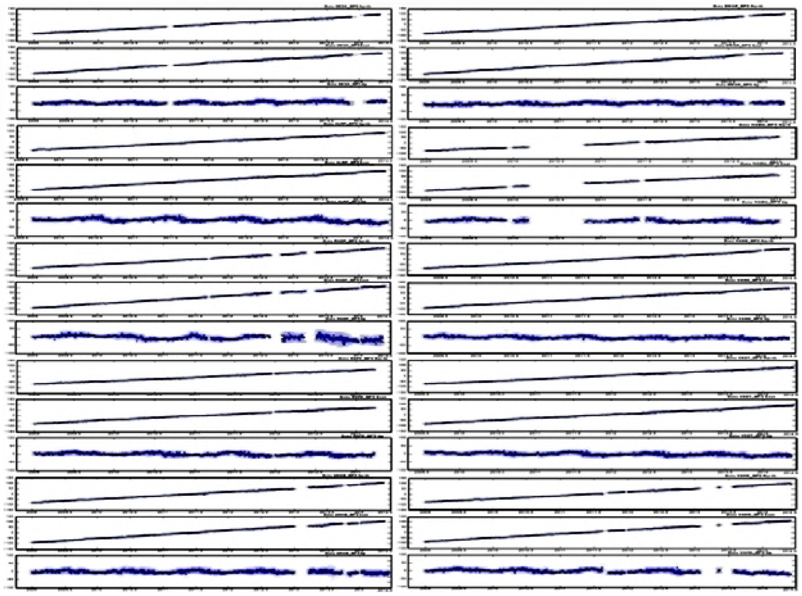


Fig. 4.16: Estimated time series of 22 permanent sites of ISR

GPS study of Kumaun Himalaya, Uttarakhand

(Rakesh K Dumka)

We present the geodetically estimated crustal strain rates in Kumaun Himalaya which has been considered as a part of seismic gap region. The GPS data in campaign mode, obtained from the sites covering all the litho-tectonic units of Kumaun Himalaya (Table 4.7), were processed using GAMIT-GLOBK software. Interpretation of site velocities (Figure 4.17.) of our study area reveals that at present HFF and MBT are locked with the Indian plate, showing almost negligible amount of deformation. Maximum deformation of about 15 mm/yr is estimated towards the northern part between NAT and Higher Himalaya w.r.t. GBPK while sites in Lower Lesser and Shivalik Himalaya indicate 1-2m//yr deformation. Analysis of strain reveals that most of the strain is being accommodated in the vicinity of seismically active MCT and Higher Himalaya (Fig. 4.18.) being in the range of 6 – 8 x 10^{-07} strain/year. Strain tensor results confirm that maximum compressional strain is also functional in the zone of MCT as well as hanging wall of MCT in the higher Himalaya. A correlation of observed strain pattern with present day seismic activity in the study area indicates that the rupture may have been generated at down dip edge of fault system due to the southward motion of the Higher Himalaya. Neotectonic activities in the zone of MCT are also recognised in the form of geomorphic rejuvenation of terrain (Fig. 4.18) (Dumka et al., 2014). Almost negligible amount of strain is estimated in the Sub and Lesser Himalayan parts.

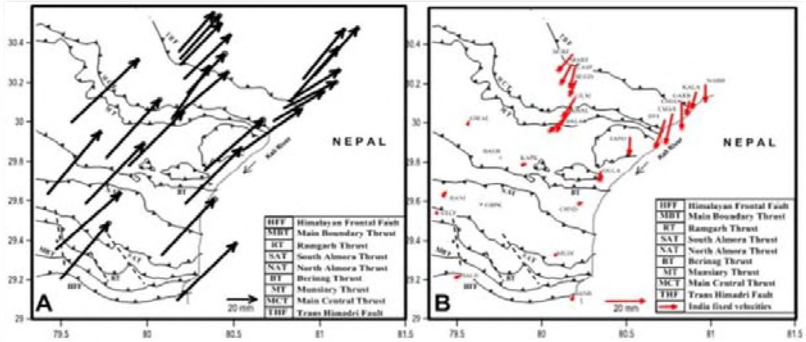


Fig. 4.17: Velocities of GPS sites in Kumaun Himalaya in (A) ITRF08 and (B) in Indian reference frame (Dumka et al., 2014).

Table 4.7: GPS stations on campaign mode in Kumaun, Himalaya

SN	Site code	Site Locality	Latitude (Degree)	Longitude (Degree)	Velocity (mm/yr)	S.D. (mm/yr)	Tectonic unit
1	HALD	Haldwani	29.21	79.51	49.85	1.97	Sub-Himalaya
2	BANB	Banbasa	29.10	80.18	49.63	1.61	Sub-Himalaya
3	CHND	Chandak	29.69	80.23	46.72	1.84	Lesser Himalaya
4	MUDI	Mudiyani	29.33	80.09	45.44	2.13	Lesser Himalaya
5	OGLA	Ogla	29.76	80.34	41.02	1.00	Lesser Himalaya
6	TAPO	Tapovan	29.86	80.56	38.85	1.03	Lesser Himalaya
7	BAGR	Bageshwar	29.82	79.77	46.59	1.08	Lesser Himalaya
8	KAPK	Kapkot	29.78	79.90	45.19	1.06	Lesser Himalaya
9	NTLP	Nainital	30.35	79.25	46.10	1.98	Lesser Himalaya
10	RANI	Raniket	29.64	79.43	48.55	1.09	Lesser Himalaya
11	GWAL	Gwaldom	30.00	79.57	47.35	1.12	Lesser Himalaya
12	GBPK	Almora	29.64	79.62	47.10	1.07	Lesser Himalaya
13	LASP	Laspa	30.29	80.20	34.84	1.79	Higher Himalaya
14	BUGD	Bugdiyar	30.22	80.22	38.34	1.09	Higher Himalaya
15	LILM	Lilam	30.15	80.24	32.55	1.77	Higher Himalaya
16	KHAL	Khalia	30.06	80.19	33.23	1.03	Higher Himalaya
17	BALA	Bala	30.02	80.15	37.93	2.97	Higher Himalaya
18	JIPT	Jipti	30.01	80.74	37.90	1.25	Higher Himalaya
19	LMAR	Lamari	30.07	80.80	38.2	1.11	Higher Himalaya
20	CHIA	Chialekh	30.11	80.83	39.38	2.10	Higher Himalaya
21	GARB	Garbyang	30.13	80.86	36.32	2.06	Tethys Himalaya
22	KALA	Kalapani	30.22	80.91	36.25	2.17	Tethys Himalaya
23	NABH	Nabhidhang	30.24	80.98	35.91	1.79	Tethys Himalaya
24	BURF	Burfu	30.36	80.19	30.69	2.61	Tethys Himalaya
25	MART	Martoli	30.32	80.20	35.07	2.84	Tethys Himalaya

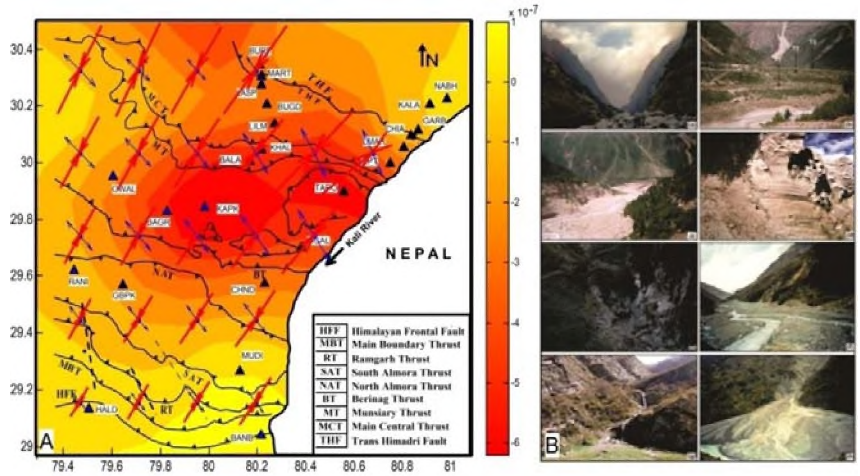


Fig. 4.18: Estimated strain tensors in Kumaun Himalaya along with distributed strain rate (B) presence of various Geomorphic features representing the imprints of neotectonic activity in the zones of Main Central Thrust (MCT) (Dumka et al., 2014)

Joint Crustal Deformation Studies of ISRO and ISR in parts of KMF in Kachchh

Two new permanent sites in Dharampur (N of KMF) and Jhikdi (S of KMF) (both being 35km west of Bhachau) are established under a collaborative program between ISR-NRSC and ISRO.

CHAPTER 5

EARTHQUAKE HAZARD ASSESSMENT

5.1 NEW RESULTS FROM GEOTECHNICAL INVESTIGATIONS, SEISMIC HAZARD ASSESSMENT AND MICROZONATION IN GUJARAT

(B.K. Rastogi, Kapil Mohan, Pallabee Choudhury, Vasu Pancholi, B. Sairam, A.P. Singh and Ketan Singharoy)

Earthquake hazard assessment for India is done at ISR from macro to micro level ie. for the whole country, states, regions, areas and individual sites. The scheme of investigations is different for different levels. *At macro level* the Institute has prepared Probabilistic Seismic hazard Assessment map of India for the Bureau of Indian Standards. Earthquake hazard is also estimated at state level. Vulnerability of coastal installations from earthquakes and tsunami is being studied in coasts of Gujarat. Site characteristic map of Gujarat has been prepared based on Vs30, shear-wave velocity to 30m depth measured by MASW shallow seismic and PS logging. Various geological units have been assigned ranges of values. GIS based intelligent shake map of Gujarat is being prepared. At *micro level* seismic microzontation has been done for several cities and areas while earthquake hazard assessments are made for critical structures like Nuclear Power Plants, LNG Terminals and clusters of Skyscrapers. The Institute has unique expertise of carrying out all aspects of seismic microzonation.

These studies in a nutshell are as listed below:

At international level participation in global efforts of seismic hazard assessment:

(i) Global Earthquake Model (With Italy and Germany)
(ii) Seismic & Tsunami hazard using EU – India e-Infrastructure (with Italy) using Grid & cloud computing.

National level: Probabilistic Seismic Hazard (PSH) Map of India for BIS.

Regional Scale (Seismic Hazard Maps):

(iii) Probabilistic Seismic Hazard map of Gujarat.
(iv) Characteristic frequency and amplification map of Gujarat.
(v) Vs30 Map of Gujarat.
(vi) Deterministic PGA Map and Response Spectra for important selected areas of Gujarat
(vii) Vulnerability Assessment of Ports and installations in Coastal Gujarat.

ISR has done seismic microzonation studies at:

i. At Gandhidham-Kandla -Anjar area, Ahmedabad and Gandhinagar.
ii. Dholera Special Investment Region between Ahmedabad and Bhavnagar along the Delhi-Mumbai Corridor where a no. of cities with high-rise buildings, industrial hubs, an airport, a railway station are planned.
iii. The cities of Surat & Bharuch have been taken up in collaboration with Geological Survey of India. Now every year one new area will be taken up for seismic microzonation.
iv. Review has been done of Seismic Microzonation work of Guwahati City and suggestions have been made for its improvement and for incorporation of seismic hazard in Town Planning.

Seismotectonic and geotechnical studies at Local scale:

i. ISR has done seismotectonic study for cluster of skyscrapers coming up in Gujarat International Finance Tec (GIFT) city at Gandhinagr which will have numerous buildings of 30 to 100 storeys. Two buildings of 28 floors are constructed which are designed based on our suggestion of seismic safety factor and foundation depth as well as design.
v. Sardar Patel Statue of Unity near Sardar Sarovar dam on Narmada river which is planned to be the tallest statue of height 182 m ie. double than Statue of Liberty
vi. LNG storage terminals at Mundra and Dahej,
vii. Nuclear Power Plants at Kakrapar and Kota,
viii. Proposed 16-storey V S Hospital, Ahmedabad
ix. Proposed multi-storey commercial complex, 'The Capital' on Science City road, Ahmedabad.
x. About 30m high pavilions of exhibition site of Vibrant Gujarat at Gandhinagar.

The details of some aspects are given as follows:

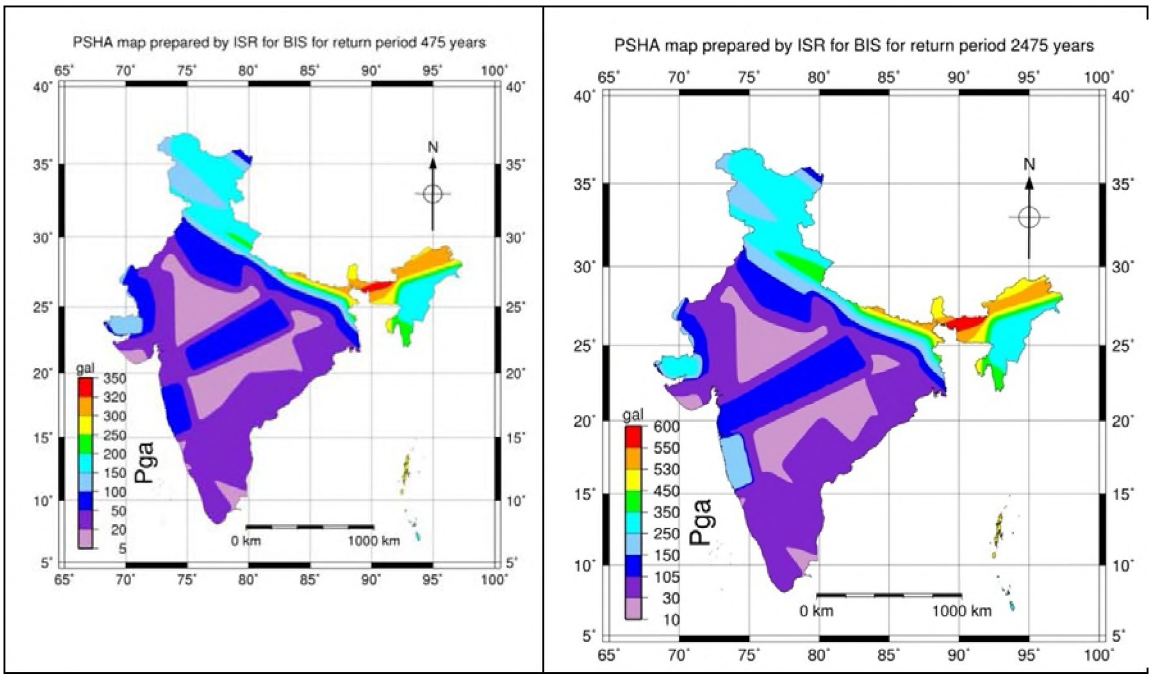
SEISMIC ZONING MAP OF INDIA

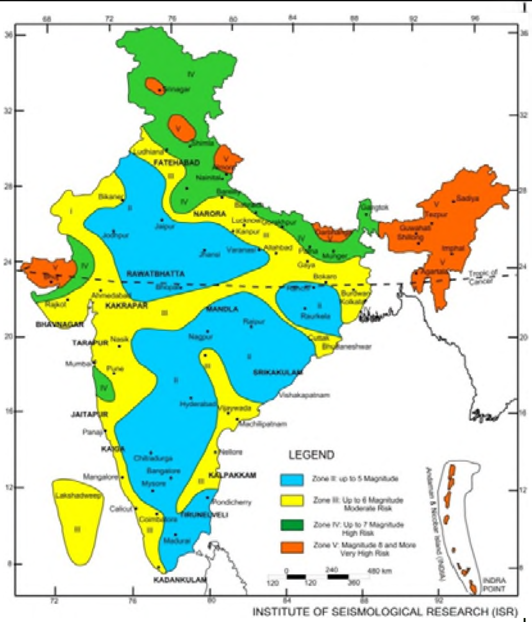
Seismic Zoning Map of India (Fig. 1, Bureau of Indian Standards, 2000) divides India in zones II, III, IV and V having potential of earthquake intensities VI (M5), VII (M6), VIII (M7) and ≥IX (M≥8), respectively. This map is prepared on the basis of intensities experienced at places and their tectonic belts. Himalayan belt is assigned zone V and IV. Kachchh is the only area outside Himalaya-Andaman belt which is assigned zone V. Koyna and Latur area is assigned zone IV. The Indo-Gangetic plains, Saurashtra peninsula, the west coast region and the Narmada belt is zone III. Most other parts of peninsular India are in zone II.

Geographically Gujarat is divided into three parts: The Kachchhh Peninsula which is westernmost, the Saurashtra Peninsula south of it and the Mainland which is east of both these regions. The Kachchh region is seismically one of the most active intraplate regions of the World. It falls in zone V of the seismic zoning map of India with potential of M8. The other two regions mostly fall in zone III with M≤6 potential.

PROBABILISTIC SEISMIC HAZARD ASSESSMENT MAP OF INDIA

ISR has prepared Probabilistic Seismic Hazard Assessment (PSHA) map of India for Bureau of Indian Standards which will help all the citizens of India in adopting optimum seismic coefficients for earthquake resistant designing of buildings based on the probability of occurrence. Maps for Possible Peak Ground Acceleration at 10% probability in 50y (or return period of 475y) and 2% probability in 50y (or return period of 2475y) are shown in Fig. 5.1 (top). The maps are prepared based on the homogenized catalog of moment magnitudes considered for India and adjoining regions for AD180 to 2008. Initially 35,000 were considered out of which around 50% dependent events (foreshocks and aftershocks) were removed.





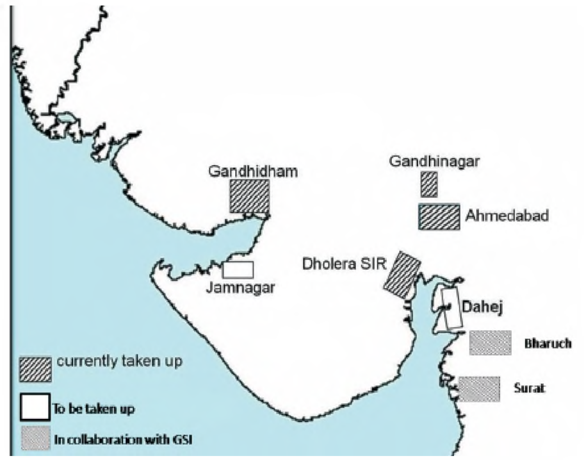


Fig. 5.1: (top left) Possible Peak Ground Acceleration at 2% probability in 50y (or return period of 2475y) (top right) Possible Peak Ground Acceleration at 2% probability in 50y (or return period of 2475y). (left) Seismic Zoning map of In. (above) Areas of Seismic Microzonation in Gujarat

Cut off magnitude is 4.5 for interpolate region while 4.0 for intraplate (peninsular India). The estimates were made for 32 source zones assigned based on geology.

Based on the estimated earthquake hazard parameters (maximum magnitude, earthquake activity rate, beta, b-value and return periods estimated using Kijko approach) probabilistic seismic hazard map was prepared. The analysis was carried out by using CRISIS 2003-CL, version 3.0.2 and all ground motions are computed for hard rock ($V_s \geq 610$ m/s).

The attenuation relations used here are Youngs et al. (1997), Abrahamson and Silva (1997) and SEA99 (1997). In Youngs et al (1997), attenuation relation for peak ground acceleration for subduction zone earthquake is determined. The attenuation relation is given as,

$$\log (PGA)_{ij} = C_1^* + C_2M_i + C_3^*\ln[\,(R)_{ij} + \exp\{ C_4^* - (C_2/C_3^*)M_i\}] + C_5Z_{ss} + C_8Z_t + C_9H_i + \eta_i + \varepsilon_{ij}$$

$$C_1^*= C_1+ C_3C_4- C_3^*C_4^* \,;\; C_3^*= C_3 + C_6\,Z_s \,;\; C_4^*= C_4 + C_7\,Z_s$$

where i is earthquake index, j is the recording station index for the ith event, M is moment magnitude, R is the closest distance to the rupture plane in km, H is focal depth, C_k, k=1 to k=10 are coefficients determined by regression analysis, Z_{ss} indicates shallow stiff , η_i (inter-event component representing earthquake to earthquake variability of ground motions)and ε_{ij} (intra-event component representing earthquake variability of ground motions) are error terms, Z_t indicates source type (0 for interface events and 1 for intraslab)

In Abrahamson & Silva (1997), attenuation relation is derived for the average horizontal and vertical component for shallow earthquakes in active tectonic regions. The attenuation relation is given below:

$$\log(PGA)= a_1 + a_2(M-6.4) - a_3(8.5-M)^2 + \{ a_4 + a_5(M-6.4)\}LN(R)$$

where a_1, a_2, a_3, a_4, and a_5 are constants, M stands for given magnitude and R is the closest distance to the rupture plane in km.

SEA99 (1997) developed ground-motion prediction equations for geometric mean horizontal PGA and 5% damped PSV from the extensional region strong-motion data set. This relation may be used in the 5.0-7.7 range of moment magnitude and the 0-100 km distance range for extensional regime ground motions. The general form of the regression relation is

$$\log_{10}(Z) = b_1 + b_2 (M-6)+b_3 (M-6)^2 +b_5 \log_{10}D+b_6 \Gamma$$

where Z is peak horizontal acceleration (g) or pseudovelocity response (cm/sec) at 5% damping for the geometrical mean horizontal component of motion, M is moment magnitude (Hanks and Kanamori, 1979).

$$D=(r_{jb}^2+h^2)^{1/2}$$

rR_{jb} is the distance, Γ is 0 for a rock site and is 1 for a soil site, and b_1, b_2 . . . . b_6, and h are regression coefficients that depend on period.

In present study Youngs et al. (1997) is used for the plate margin regions, Abrahamson and Silva (1997) for active regions near the plate margins.SEA99 (1997) has been used for Peinisular region as most earthquakes have occurred in its extensional regions.

The Seismic Zoning Map (SZ Map) of India (bottom left) currently recommended by BIS for designing earthquake resistant buildings is based on the intensity (magnitude) of the past earthquakes experienced in different tectonic (geological) zones. The logic used is what has happened can happen again. However, the seismic gap theory suggests that the areas which have not experienced earthquakes in the past in any tectonic belt may be more prone than the areas which have already experienced the earthquakes. Hence, the areas in Himalaya which are shown as zone 4 may have potential of zone 5. Moreover, the present SZ Map tells the potential of different zones without assigning any probability of occurrence. The assigned earthquake for a zone may occur tomorrow or after 10,000 yr without giving any probability of occurrence. The Probabilistic Seismic Assessment (PSHA) Map gives the probability of occurrence in different time periods. Hence, the PSHA map is more practical. Also different types of structures need assessment for different return periods for assigning maximum possible earthquake in a tectonic zone. For example the ordinary buildings need only 475 years return period (10% probability in 50 yr, while an LNG terminal will need 2475 year return period (2% probability in 50 yr) and a Nuclear Power Plant will be designed for 10, 000 years return period (0.5% probability in 50 years). The PSHA map provides information towards this need. The PSHA map also provides fine gradation of hazard in a particular tectonic zone. Presently some zones like entire Kachchh are given zone 5. As the southern portion of Kachchh has not experienced large earthquakes and there are no major faults, in PSHA map the southern part of Kachchh is assigned lesser hazard.

SITE CHARACTERISTIC AND AMPLIFICATION MAPS OF GUJARAT

Site characteristic maps of Gujarat have been prepared amplification, characteristic frequencies, PGA, spectral accelerations at certain periods. These maps have been prepared with both Probabilistic and Deterministic assessments. Various geological units have been assigned ranges of values based on seismotectonic conditions as well as Vs30, shear-wave velocity to 30m depth. Amplification of acceleration at different sites is estimated based on actual earthquake seismograms, microtremor survey and the Vs distribution. Hundreds of measurements are being done in different types of geological conditions for preparation of such maps for Gujarat.

In addition, ISR will soon display GIS based intelligent hazard maps based on amplification values and distance of causative fault on its website giving out details of extent of damage that can happen in a given area for different magnitudes in different regions. The site would also impart information on safety measures to be adapted in particular areas.

SEISMIC MICROZONATION

Gujarat is the only state outside Himalayan region which has high seismic hazard of magnitude 6 to 8. Even then, earthquake resistant high-rise buildings can be constructed with only 5-7% extra cost. Hence, the areas of rapid growth in Gujarat need to have prior information about earthquake safety factor to be considered. Moreover due to different ground conditions or soil distribution with depth seismic waves amplify differently for different heights of buildings which is to be assessed. For this purpose, ISR is carrying out **Seismic Microzonation** of different cities (Fig. 1) and provide knowledge for seismic safety factor to be considered for each region of Gujarat for different heights of buildings. From this study, structural response curves are determined which give acceleration for different natural periods in 250-500m grid. This analysis involves geotechnical investigations through numerous boreholes and geophysical measurements of seismic wave velocities by seismic survey and PS logging. The liquefaction potential is also assessed. ISR has well-equipped geotechnical and geophysical labs for different lab and on-site tests.

Seismic microzonation is a rigorous process involving several types of studies including seismic, geophysical, geological and geotechnical investigations for estimating peak ground acceleration and spectral acceleration in a grid pattern of any area, amplification due to soil for different heights of buildings and ground conditioning methods to safeguard against liquefaction. ISR has developed A to Z facilities and expertise to carry out these investigations. The seismicity studies include preparation of seismotectonic maps in 80 km and 300 km radius. Seismotectonic map is first prepared based on published literature and then ground checking. Locations of faults are ground checked and in some cases by Geophysical Surveys. The Geophysical Surveys which are carried out include Magnetotelluric, Transient EM, Resistivity Imaging, Gravity, Magnetic and Ground Penetrating Radar for determining sedimentary thickness, nature of basement and hidden faults as well as layers of the shallow and deep crust. The location and elevation of geophysical measurement points are measured by Land Survey with Total Station & RTK-GPS.

Seismograph stations are deployed for assessing local seismicity and site response from local / regional earthquakes. Geomorphological map is prepared of the area by remote sensing, ground check and land survey for elevations and locations of drilling points. Geological studies include identification of possible layers of rocks to several km depths from past geological and geophysical studies.

Geotechnical investigations include drilling of boreholes to 50m or greater depth in a grid of 1-2 km, measurement of soil strength by Standard Penetration Tests and lab measurements of soil properties of samples collected at 1.5m interval. Various conventional physical and mechanical properties of the soil samples are determined. SPT values are corrected for overburden and other factors and correlated with Vs at that depth derived from geophysical methods. Undisturbed and disturbed samples are alternately collected. The laboratory soil tests are carried out in accordance with the relevant IS Codes at Institute of Seismological Research (ISR). For undisturbed soil samples (UDS) shear parameters (Cohesion and Angle of Friction) are determined by Dynamic Triaxial and Direct Shear tests to determine. Physical tests such as Grain Size Analysis, Atterberg's Limit, Specific Gravity, Free Swell Index tests are conducted for all the samples. Field dry Density and Water Content tests are done for the undisturbed soil samples.

Engineering geophysical measurements include shallow seismic surveys, microtremor surveys and PS logging for P and S-wave velocities of individual layers. The high-Resolution shallow seismic survey (Multichannel Analysis of Surface Waves, MASW method) is used for defining shallow soil layer depths and shear-wave velocity to 30-60m depth. Array Microtremor measurements and broadband seismographs are deployed for shallow as well as deeper layers. The microtremor array surveys yield details of layer velocity and depth to 200 m depth.

Based on geotechnical data as well as from geophysical surveys the depth to Engineering Bed Layer (EBL) is assessed in the whole area which is having a Vs 500m/s or more. The 2D and 3D soil profiles are prepared for the area using geotechnical data from which soil modeling is done. Soil modeling is done for each borehole. The strong-motion time history is estimated at the EBL for near and far field scenario earthquakes from stochastic finite source method incorporating dynamic corner frequency. The scenario earthquakes are assigned based on seismicity knowledge. The earthquake model includes information about maximum credible earthquake, fault length, strike, dip, focal depth, high frequency attenuation rate, i.e. kappa value, slip distribution, shear-wave velocity, density, anelastic attenuation, geometric spreading and pulsing percent (50%). Rupture propagation starts from element no. one. Focal depth is assigned. Stress drop is typically assumed to be 40 bars for M6 and 160 bars for Kachchh earthquake M7.7. Based on geotechnical data, soil profiles, 3D soil maps and Vs above the EBL the soil models are prepared for each borehole and extrapolated to different grid points. Taking soil model as input, the time history at the EBL is migrated to the surface using SHAKE Program which estimates amplification due to each layer. The time history is converted into the PGA, Response Spectra (spectral acceleration for different natural periods of buildings) and Design Basis Ground Motion required by structural engineers. Liquefaction potential is estimated using soil properties, depth to water table and ground acceleration as well as by cyclic –triaxial test. Safe Bearing Capacity of the soil is also estimated.

An important finding of seismic microzonation is that the low-rise buildings of 3-5 stories need to have 50-100% higher seismic factor than that recommended in the National Code in most of Kachchh and up to20 km distance from Cambay and Narmada faults. For highrise buildings soil-structure interaction and dynamic analysis needs to be done for realistic estimation of seismic force to be considered for different floors.

5.2 FREQUENCY DEPENDENT *LG* WAVE AVERAGE ATTENUATION AND SOURCE, SITE CHARACTERIZATION IN GUJARAT, WESTERN INDIA

(Sandeep Kumar Aggarwal with PK Khan of ISM)

The Lg wave average displacement spectral amplitude decay was studied through generalized inversion at frequencies ranges 0.5 to 10 Hz for Gujarat region. The Lg wave propagation efficiency measured from Lg to Pn spectral ratio found excellent of the order of greater than 5 for 400 paths exploited in this study. The inversion at 0.5 to 10 Hz frequency results three outputs, first frequency dependent average attenuation, second site term and third magnitude of earthquakes used. The input data set consist of 39 Kachchh, 18 Saurashtra, 2 Cambay and 2 Mainland crustal earthquakes at 60 sites in Gujarat. The 61 earthquakes have 400 travel paths recordings in geographical region 20-25 Deg Latitude and 69-75 Deg Longitude at a distance ranges about 200 to 600 km. The magnitude size M 3.6 to 5.1 and quality of the data used were sufficient to estimate average Q_{Lg} of Gujarat region. We found two best fitted relationships for average frequency dependent attenuation, as Q_{Lg} (f) = $357f^{0.17}$ valid in frequency range 0.5-2.0 Hz and Q_{Lg} (f) = $250f^{0.65}$ valid in frequency range 2.0 to 10 Hz for Gujarat region. For complete frequency band 0.5-10 Hz, the relationship found is $Q_{Lg}(f) = 333f^{0.45}$. The site response for different frequency is evaluated by site term estimated, which is comparable with local geological condition and agree with estimates of site amplification by other researchers. The magnitudes estimated are little underestimated. This study is the first attempt to determine Q_{Lg} for Gujarat region using Gujarat earthquakes and provide knowledge on attenuation of Lg waves needed for the prediction of ground motion during future earthquakes.

5.3 SIMULATION OF MW5.1 EARTHQUAKE NORTH OF BHACHAU USING NGA RELATIONS

(Monika Khanna and Pallabee Choudhury)

The Mw 5.1 earthquake of 19 June 2012 occurred about 30 km North of Bhachau and 20 km south of Dholavira along the NE trending Khadir (Ekal-Amrapar) transverse fault (strike=18°, dip=77°). The location of main shock (70.288°N 23.654°E, focal depth 11.1km) is about 15km north of the aftershock zone of 2001 earthquake. The earthquake was recorded by 17 SMA stations of varied geological units like Deccan trap, Mesozoic, Tertiary, Quaternary and Holocene (Vs30 ranging from 800 to 170 m/s).

In the present study, we have compared the observed PGA for the Mw 5.1 earthquake that occurred north of Bhachau with the calculated ones using the ground motion prediction equations called Next Generation Attenuation (NGA) relations developed for shallow crustal earthquakes in the western United States and similar active tectonic regions to simulate. The four NGA relationships used are Abrahamson and Silva (2008), Boore and Atkinson (2008), Campbell and Bozorgnia (2008) and Chiu and Youngs (2008). The earthquake recorded on 17 SMA stations made it possible to validate the result estimated by the NGA relations. The difference between the two sets is +/- 30%. The observed and calculated residuals (Fig. 5.2) fall within plus / minus one sigma values. This shows that the results obtained from simulation are reasonable within statistical limits.

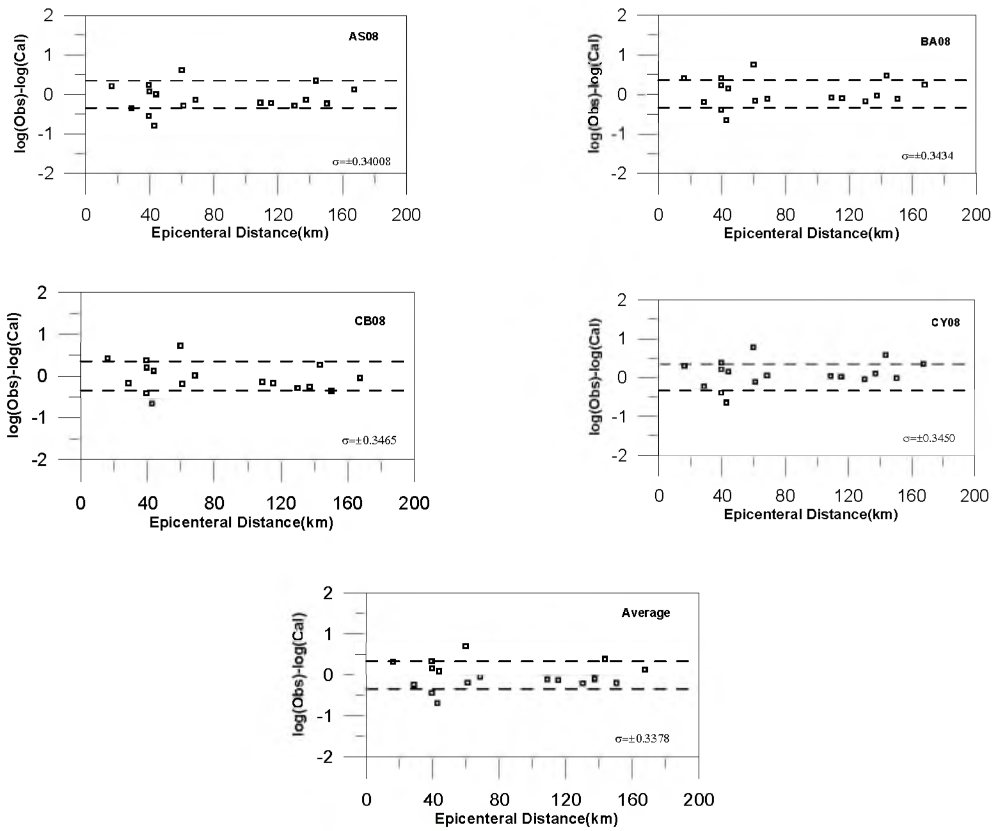
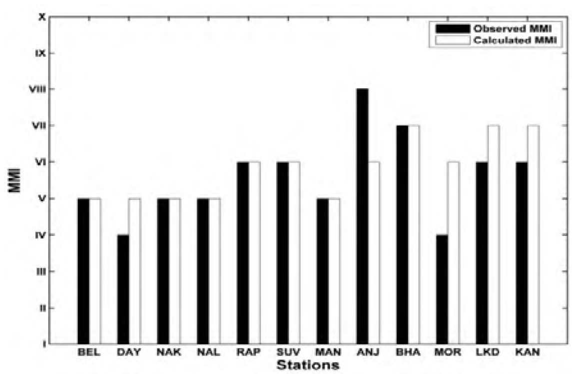


Fig. 5.2: Residuals between observed and calculated accelerations against epicentral distance estimated by four sets of relations. The plus and minus standard deviation (s) are marked with dotted lines. AS08: Abrahamson and Silva (2008), BA08: Boore and Atkinson (2008), CB08: Campbell and Bozorgnia (2008), CY08: Chiu and Youngs (2008) and Average: Average of all four sets of relationships.



5.4 SIMULATION OF 1956 ANJAR EARTHQUAKE USING EMPIRICAL GREEN'S FUNCTION APPROACH

(Pallabee Choudhury, Ketan Singha Roy, Jyoti Sharma and B K Rastogi)

We estimated ground motions at some selected 12 sites in the Kachchh rift basin of Gujarat, western peninsular shield area of India where the damaging 1956 Anjar earthquake (Mw 6.0) was experienced. The ground motions are estimated using the Empirical Green's Function (EGF) approach taking an earthquake of Mw 4.5 as an element, which occurred on the inferred rupture plane of the Anjar earthquake with nearly a similar fault mechanism. The estimated peak ground acceleration (PGA) varies between 23 cm/s^2 and 128 cm/s^2 at these sites, located at distances of 21 to 127 km from the epicenter. The maximum accelerations are correlated with the MM intensity reported for the Anjar earthquake using the empirical relationship between the PGA and intensity. At most of the sites, the level of accelerations could explain the reported damages (Fig. 5.3). At few sites, the reported damages are more compared to the accelerations obtained from the synthesis.

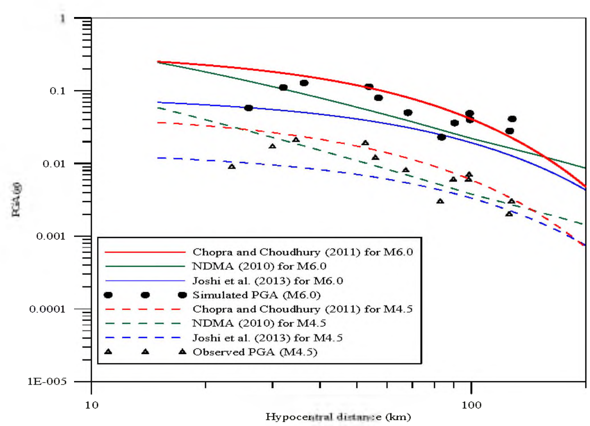


Fig. 5.3: Comparison of observed and estimated intensities. Black bars represent intensity in MMI as reported by Tandon (1959) and white bars are the intensities estimated in the present study.

The maximum PGA near the epicenter area are estimated to be in the range 250-300cm/s^2 as inferred by the ground motion prediction equation (GMPE) developed for the region by Chopra and Choudhury (2011) which is closer to the results obtained by the present analysis (Fig. 5.4).

The GMPE is

$$\log(SA) = -3.8017 + 0.5568M - 0.00928R - 0.1125S$$

where SA is spectral acceleration (at 0.05s), M is the magnitude, R is the hypocentral distance and S =0 for rock and 1 for soil. The analysis shows that if strong motion recordings of the present day smaller earthquakes are available from the rupture plane of large/great historical earthquakes then it is possible to estimate PGAs of the target historical earthquake by the EGF method.

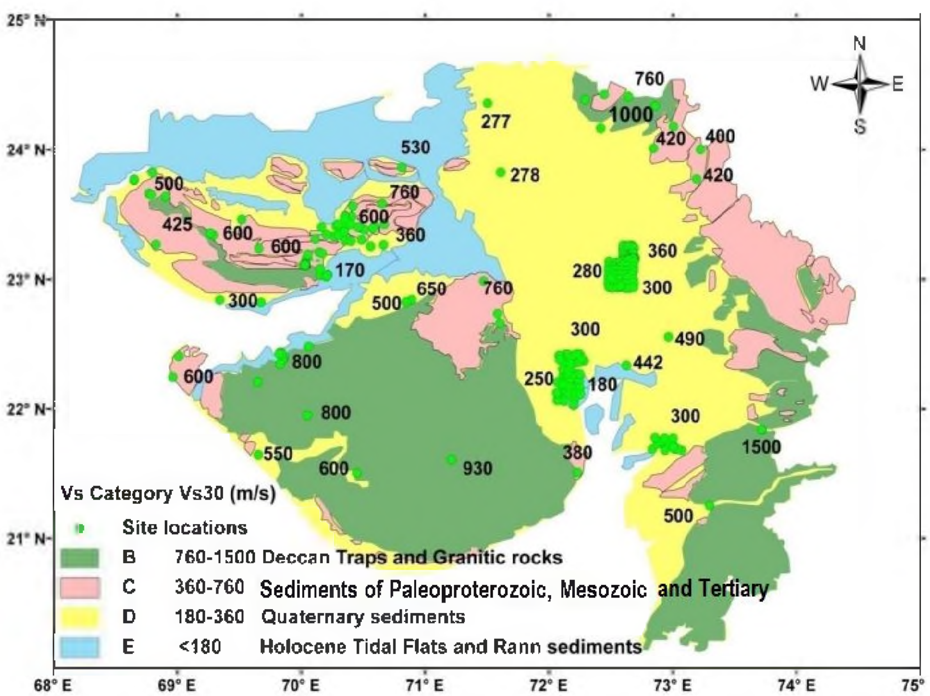


Fig. 5.4: Comparison of PGA estimated in present study with the attenuation relation obtained by Chopra and Choudhury (2011), Joshi *et al.* (2013) and NDMA (2010)

5.5 ESTIMATION OF SHEAR-WAVE VELOCITIES IN DIFFERENT PARTS OF GUJARAT

(B. Saram and Vandana Patel)

Shear wave velocity, Vs30 has been measured at about 400 locations in different geological formations of Gujarat (Fig. 5.5). The valueas are around: Quaternary 250-300m/s, Mesozoic in Kachchh 600m/s, Deccan Traps 800-1000m/s, Proterozoic in SE and NE 1000-1500 m/s (but in NE it is as low as 400m/s).

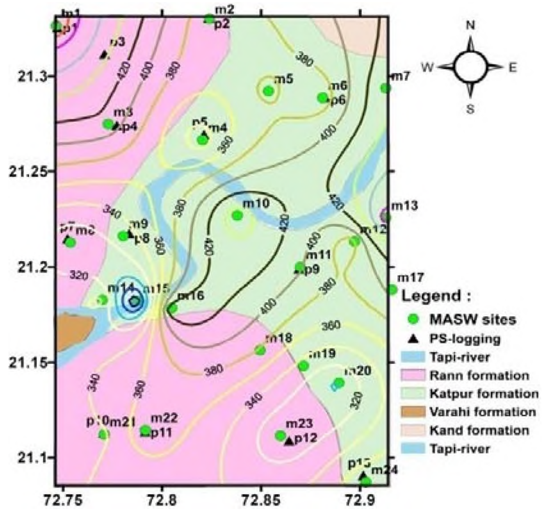


Fig. 5.5: Vs30 for different geological formations in Gujarat

Estimation of Shear wave velocity from MASW and PS-logging in Surat

(B. Sairam, B. K. Rastogi and Vandana Patel)

S-wave velocities were measured by Multichannel Analysis of Surface waves (MASW) at 24 sites and by Suspension PS-logger at 13 sites in Surat. These sites are well distributed in Surat area. We have compared shear wave velocity estimates by both the methods. The comparison is showing good correlation. We computed Vs30 for all the sites and classified according to NEHRP classification. The estimated Vs30 is in the range of 320 to 500 m/s.

Fig. 5.6: Vs30 Contours of Surat area

Some patches in the southern and southwestern portion of study area show Vs30 in the range <360 m/s, but most of the area shows C class soil (Vs30=360-760 m/s) (Fig. 5.4.1).

Shear-Wave Velocity Estimations and Site Characterization of the Dholera Area, Gujarat, India,

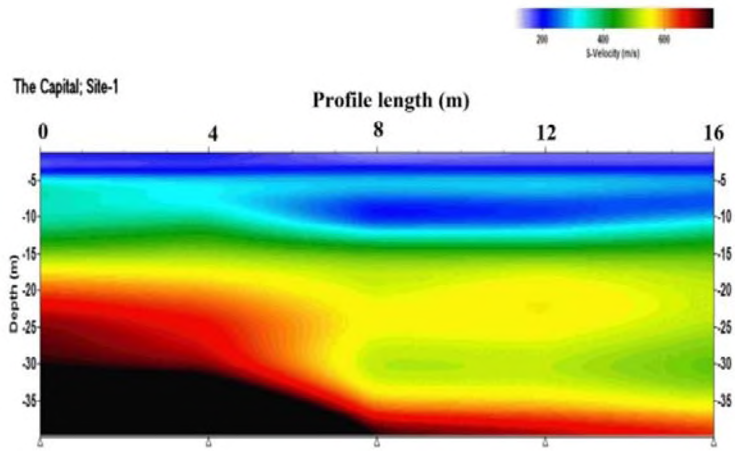
(B. Sairam, B. K. Rastogi and Vandana Patel)

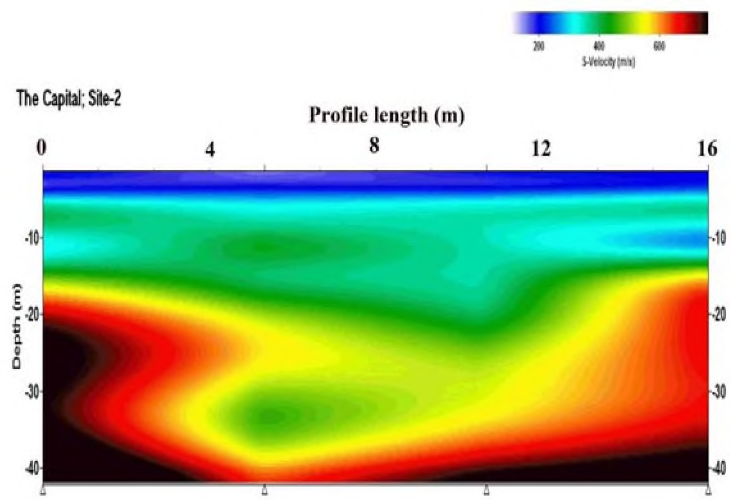
The Dholera area is prone to earthquake hazard as it falls in Seismic zone III and area is covered with loose soils as it is along the coastal area. The area experienced intensity up to VII during the 2001 Bhuj earthquake. The area is to be developed as Special Investigation region with smart cities and precision industries. Thus, there is urgent need to do site characterization and site response study to understand seismic hazard of the area. Therefore, we have studied site characterization of the area using Shear-wave velocity estimates (Vs) of 57 sites that are acquired by MASW and PS-logging techniques. The average Vs of top 30 m soil, Vs30 of study area is in the range of 190 - 341 m/s. In view of this, the study region is classified as D-class following the NEHRP classifications. We have correlated Geomorphology with VS30 of the study area. New Mud Flat (NMF) areas have lowest VS30 of 200 m/s. The VS30 of Salt Flat (SF) areas is in between 220 and 290 m/s. Old Mud Flats (OMF) are showing highest VS30 among all the geomorphological units of the area in the range of 300 – 340 m/s.

The Vs30 shows good correlation with geomorphology of the region. From these observations, it is inferred that higher site effects may be possible in the NMF and SF areas than OMF areas.

Shear wave velocity estimation at the Capital project in Ahmedabad, Gujarat

(B. Sairam, B. K. Rastogi, Sarvesh Kumar, Utsav Mishra and Vandana Patel)





Two shear-wave velocity (Vs) profiles are obtained by MASW method within the Capital project area to get better and high resolution clarity on the sub-stratification of the site. The MASW test was carried out at 7 m below from the surface, as the project area was excavated up to 7 m. Therefore, Vs profile represents velocities of soil from 7m to downward depth from subsurface. The two-dimension Vs models were obtained up to 40 m depth. Top layer down to 14m has Vs in the range of 200-450 m/s. Second layer, at the 10 - 40 m depth has Vs in the range of 450 – 900 m/s.

5.6 SITE CHARACTERIZATION OF THE BHUJ CITY

(B. Sairam, B. K. Rastogi, Vandana Patel, Sarvesh Kumar, Utsav Mishra, Pritesh Chauhan and Bharat Mevada)

S-wave velocities are estimated by MASW at 19 sites in and around the Bhuj city. Sites are well distributed in different parts of the city. Most of the shear wave velocity profiles show that the shear wave velocity increases steadily with depth. In the study area, Vs at the surface in the range 260 - 620 m/s. Shear-wave velocity at 30 m depth is varying in between 500 m/s and 1300 m/s depending on the site geology. We computed Vs30 for all the sites and classified according to NEHRP classification. The study area's Vs30 in the range of 400 - 915 m/s. therefore, study area is classified as C-class and B-type soil following NEHRP classes based Vs30. Most of the area has C-type soil. Only three sites: 9, 11 and 14 have V_{S30} in the range of 815-915 m/s, which are classified as B-type.

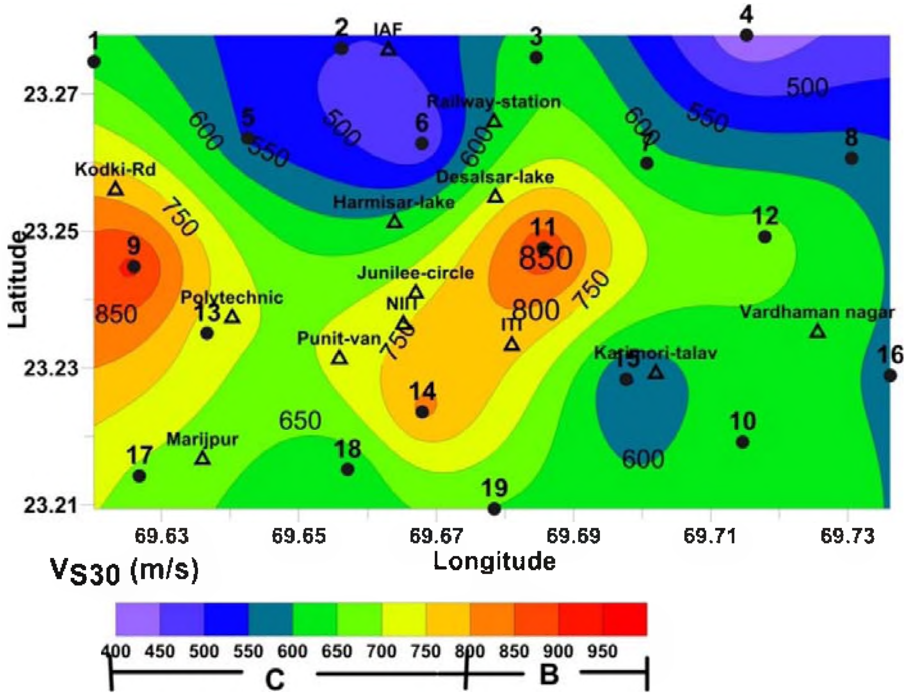


Fig. 5.7: Vs30 in Bhuj city

5.7 POSSIBLE SITE EFFECTS IN AHMEDABAD CITY

(B. Sairam, B. K. Rastogi, Sandeep Aggarwal and Vandana Patel)

The Ahmedabad city has seismic hazard of intensity of VII-VIII as the city falls in seismic zone III of Indian. There is probability to occur Earthquakes of Mw ~ 6 in the Cambay basin, which is near to the city. Moreover, there are chances to occur great earthquake of Mw ~8 in the Kutch seismic zone, which is at about 250 km away from the city. Additionally, there is possibility for site effects in the city because the city is on the thick soft soils, which can amplify ground motion and intensity of in case of earthquake. It is well know that during the 2001 Bhuj earthquake, several mid-to-high-rise buildings such as 5-10 floors damaged or collapsed along the old path of the

Sabarmati river (western-side of the present position of the river) and the lakes and ponds on east side of the river. Generally, 5-10 floor buildings natural frequency lies in the range of 1-2 Hz. We have carried out site response (SR) study at some selected damaged and undamaged sites using broadband records of earthquakes. The SRs ware estimated at 12 selected sites damaged and undamaged sites using the broadband records of some 24 earthquakes ($M_w \geq$ 3.5). The Vs of 65 sites were estimated using MASW and PS-logging. The average Vs of the top 30 m (V_{S30}) is in the range of 265-360 m/s. The western and southern areas with V_{S30} (265-305 m/s) experienced more damages compared to the higher V_{S30} (320 -360 m/s) areas in the east and northeast part (Fig. 5.8). The SR estimates show that maximum peak amplifications are up to 6.0 and 3.0 in the frequency of 0.5 – 2.0 Hz and 2.1-4.9 Hz, respectively. These frequencies match up with resonance frequencies of mid-to-high-rise buildings. The maximum peak amplifications in the range of 1.0-2.0 are observed in the frequency range of 5.0-10 Hz, which corresponds to 1-2 floor structures. These results imply that multistory buildings of more than three floors require careful seismic design. The site characterization map of the Ahmedabad city shows higher site effects along the western bank of the Sabarmati river and also along the lakes and ponds, where maximum damages occurred.

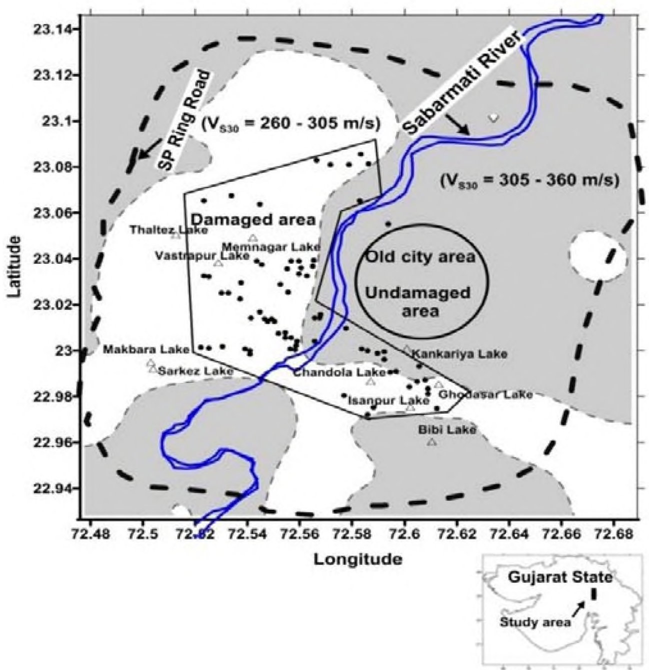


Fig.5.8: Damaged buildings in Ahmedabad in 2001 were all confined to areas having Vs30 <305m/s

5.8 SHEAR WAVE VELOCITIES OF SHALLOW SOIL LAYERS AND AVERAGE OVER 30M IN GANDHINAGAR

Vs Estimation by PS Logging Method

For estimation of Vp and Vs, the Suspension PS Logging test was carried out in 5 boreholes drilled by ISR up to depths of 50m. Suspension PS Logger probe is about 8.0 m long, containing a wave-genration source, lower and upper geophones. Borehole is filled with water for measurements.

Measurement of Shear Wave Velocity By MASW

2D MASW (Multichannel Analysis of Surface Waves) seismic profiles each of 50m length were done at 63 locations (Fig. 5.9) for determining depth of different layers and their seismic velocities.

Measurement of phase velocity of Rayleigh waves of different frequencies is done and converted to shear-wave velocity. Waves are generated by a few hammer strokes on a metal plate and recorded on a set of cable connected 24nos. 4.5Hz geophones spread at 1m interval for a 50m profile and at 2m interval for a 100m profile. After every recording the first geophone is disconnected and put at the end of the line. The arrival times of different phases corresponding to different layers are plotted to give dispersion curves which give 2D velocity and depth distribution of different layers for a length of 50 /100 m and to a depth of 30-50m. The 1.D velocity distribution can be estimated for a location and Vs30, average to entire depth of 30m or so may be estimated

Conclusion of MASW

As per Vs30, shear wave velocity to 30m depth and according to US Nat. Earthq. Reduction Program (NEHRP) classification the northern part of the city around sector 28, Pethapur and GEB colony (5% area) the soil is dense (soft rock C-type) having Vs in the range of 360 -420 m/s. In most of Gandhinagar the soils are classified as stiff soil (D-type) (260-360m/s)(Fig. %.10). The D type stiff soil is considered to be strong. However, the depth distribution of N-value indicates start of dense soil (N-value >50) at shallow depth of 7-10m. The N-value >100 for rock is reached at 18-20m though rock in the area is at 300m depth.

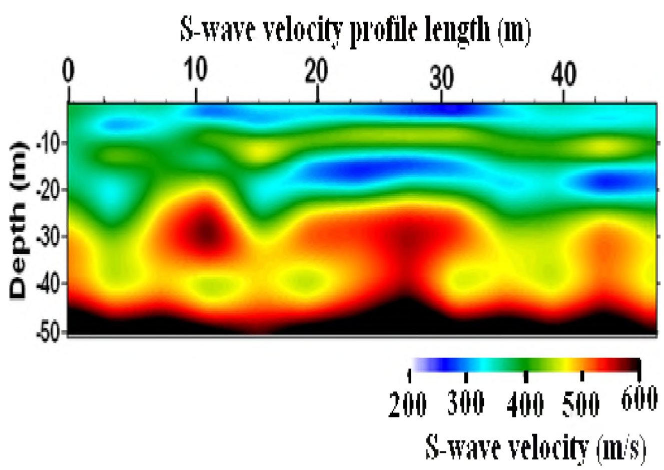


Fig. 5.9: Typical 2-D velocity profile in Gandhinagar

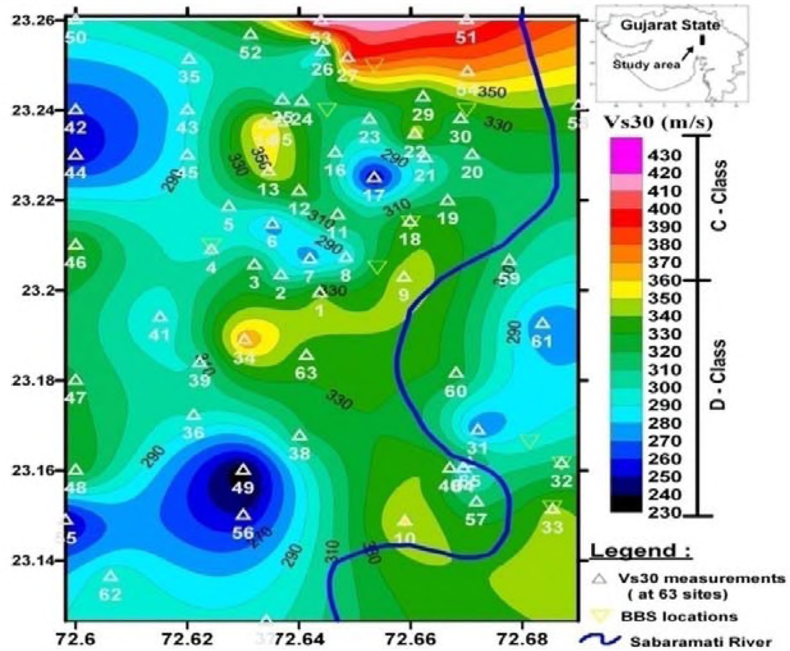


Fig. 5.10: Contour map of Vs30 and site characterization in the study area Gandhinagar

5.9 SITE AMPLIFICATION AND DEPTH TO SOME LAYERS FROM SEISMOGRAMS AS WELL AS AMBIENT VIBRATIONS RECORDED ON BROADBAND SEISMOGRAPHS AND MICROTREMOR RECORDERS AT GANDHINAGAR

(A.P. Singh and B.K. Rastogi)

ARRAY MICROTREMOR SURVEYS AT GANDHINAGAR

Recording of Microtremors (natural vibrations generated due to ocean waves and swaying of trees) on array of seven number 5sec seismometers (Fig. 5.11) allows obtaining shear-wave velocity of different layers and their depths by dispersion analysis (Fig.5.12). We carried out array microtremor measurements in Gandhinagar at eight sites to determine shear wave velocity profiles. The recording duration at each site was for 60 minutes at 100 samples/sec. for time matching recording is triggered. For interpretation an initial model is constructed inverted for the layered velocity structure under the observation site.

We have determined site amplification and characteristic frequency analysis using earthquake records (at nine locations) as well as microtremor records on broadband seismographs (at 28 locations) and microtremor records on microtremor recorders (at 10 sites as central seismometer of the array deployment as given in the previous section). The resonance frequencies give the rough estimates of the layer boundaries whose impedance contrast causes amplification. The seismogrpaphs were operated until a few earthquakes were recorded at each of 9 locations. Microtremors were recorded for 1 hour at each site. Sampling rate was 100 samples/ sec for all the data.

In H/V method assumption is that vertical component is not amplified. Amplification is of horizontal component. Hence H/V spectral ratio gives site amplification. The FFT is applied to the signal of the three components to obtain three spectral amplitudes. The two horizontal components are resolved to get a resultant. For microtremors a time window of 70 sec was used for each estimate. For earthquakes 10.5 sec time window starting from 0.5 sec before S-wave phase arrival was used.

Each site may cause amplification of ground shaking at one or more resonance frequencies. The buildings having fundamental frequency matching with the resonance frequencies will experience amplified ground motion. Depth to different layers, H is estimated from resonance frequency, f and average shear-wave velocity, Vsav up to the depth of the layer contrast.

Natural period, T of a building can be estimated from the formula of niform building code of USA (1985) $T=0.09H/\sqrt{D}$, where H is the total height of building in meters and D is the total width of the building in meters in the direction of earthquake. Roughly, T can be taken as 1/N sec where N is no of storeys.

The H/V spectra of microtremors recorded on microtremor recorders and broadband seismographs are shown in Figs. 5.13 to 5.15.The resonace frequencies, the depth from where this resonance is caused and amplification corresponding to this resonance are given in Table 5.1.

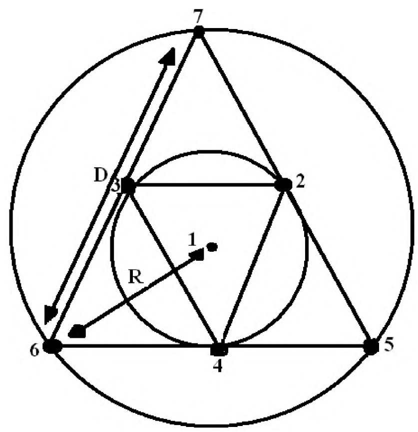
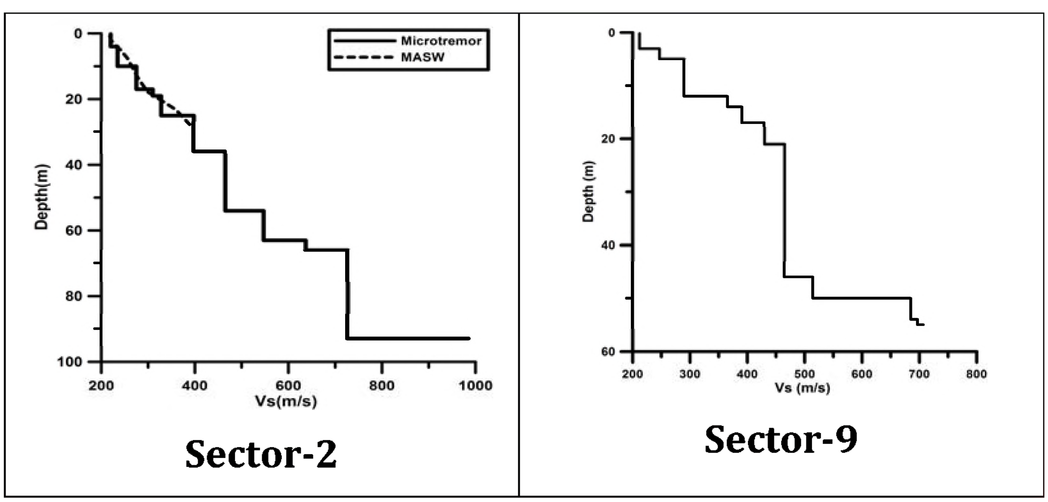


Fig. 5.11: Geometry of the station deployment in microtremor array observations. D was chosen to be 50m.



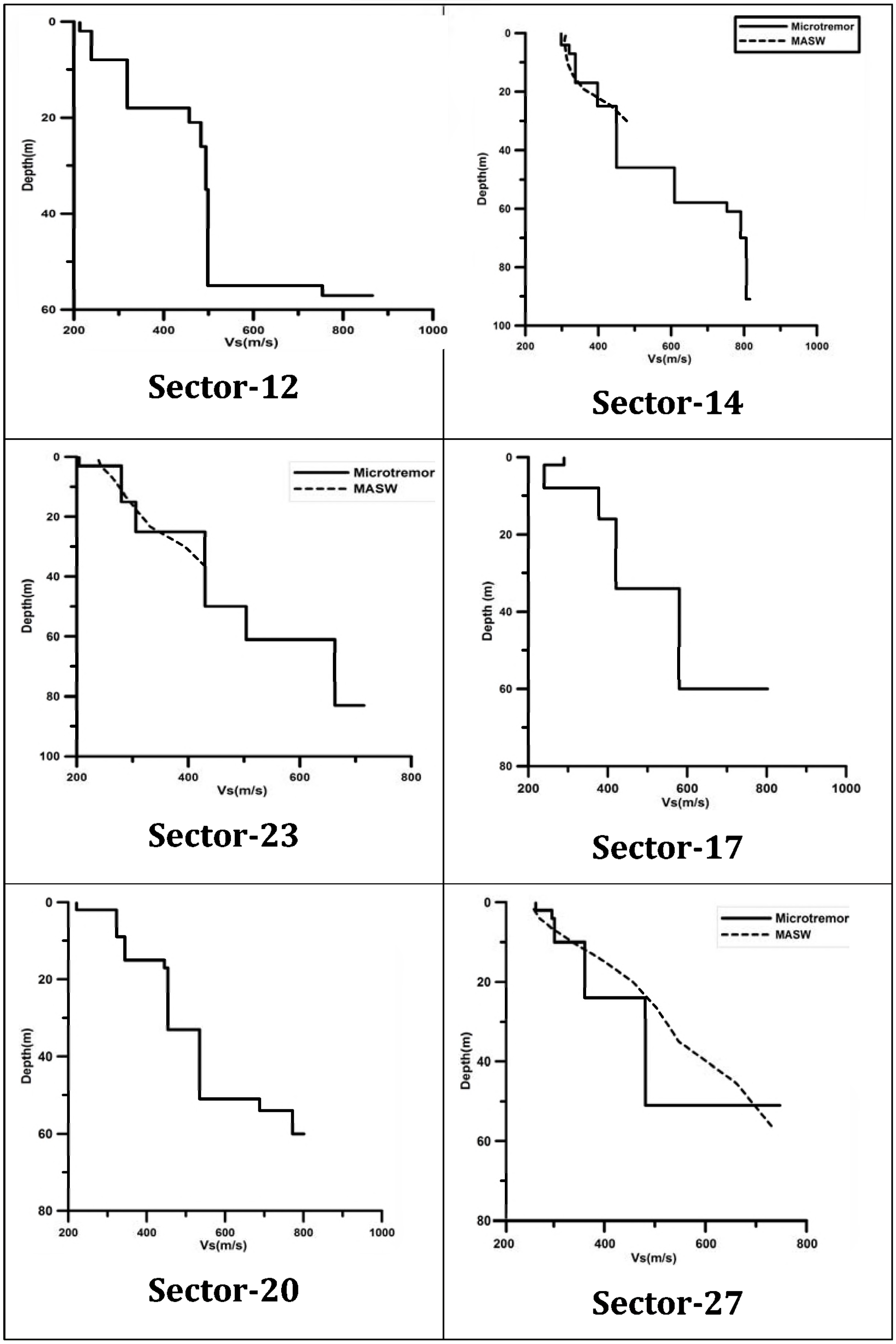


Fig. 5.12: Comparison of Shear wave velocity obtained with array microtremor measurement and MASW method Sector-2, 14, 23 & 27. Shear wave velocity (V_S) profile at sector-9, 12, 17 & 20 are also presented

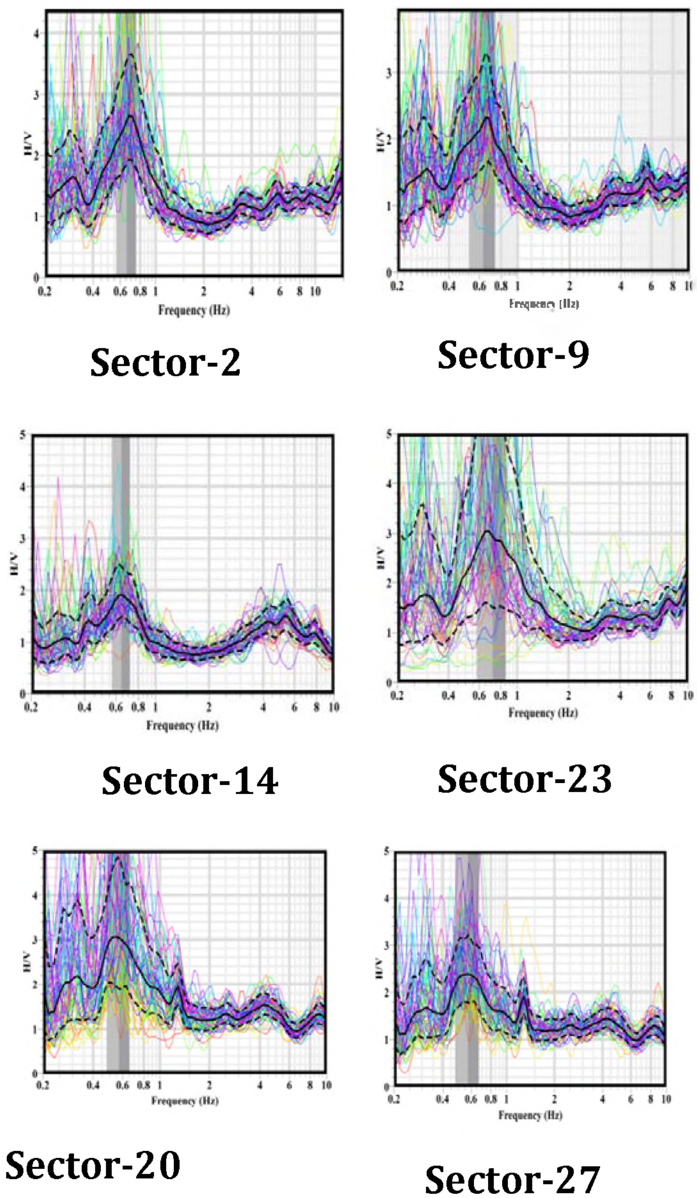
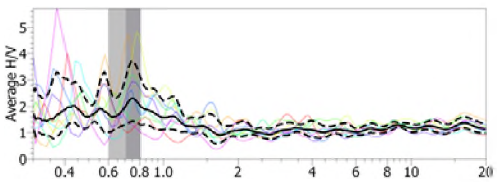
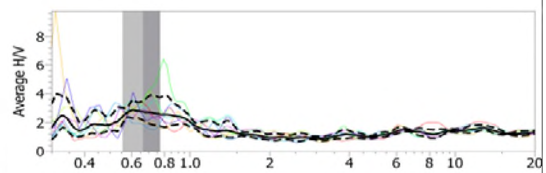


Fig. 5.13: Estimated H/V of the central seismometer of the array microtremor measurments in Gandhinagar. The continuous solid line shows average and dashed lines ±1 standard deviation.



Sector-1C



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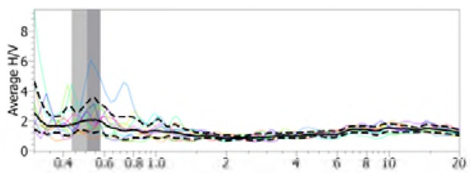
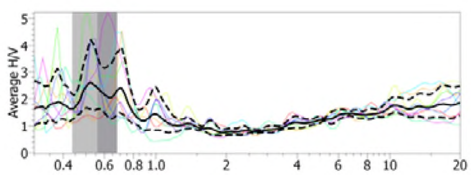


Sector-3A

Sector-4A



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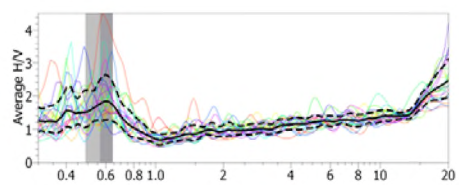
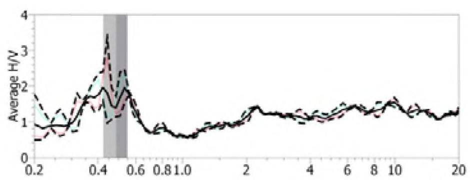


Sector 6



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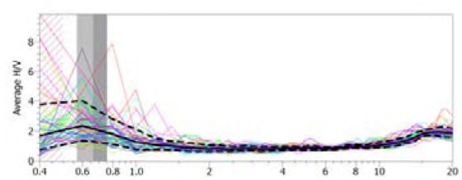

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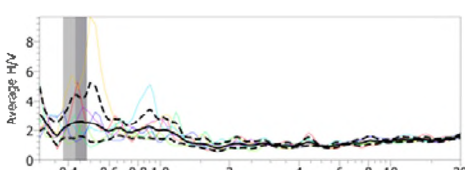

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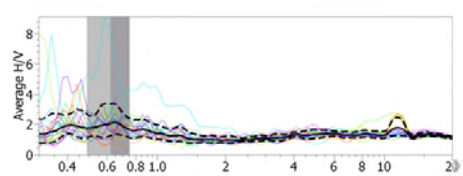
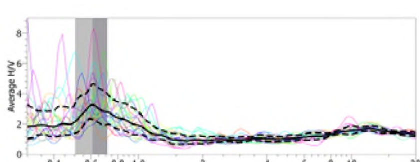


Sector 13b



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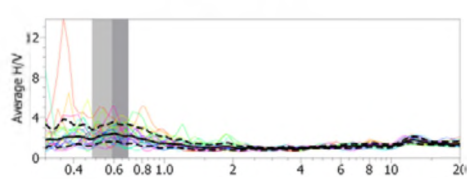
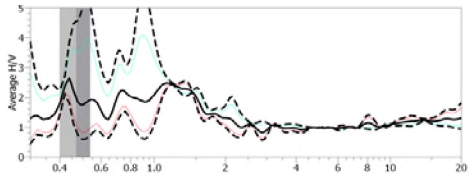


Sector 15



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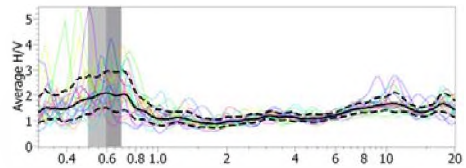

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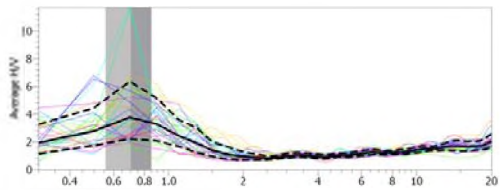

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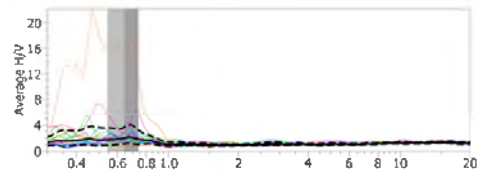

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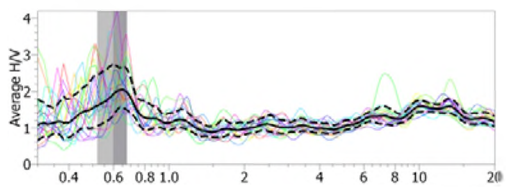

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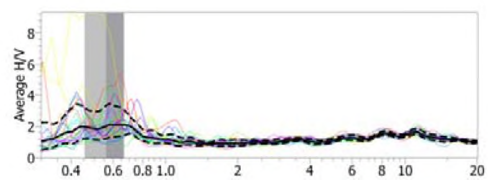

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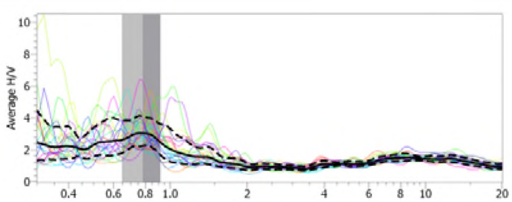
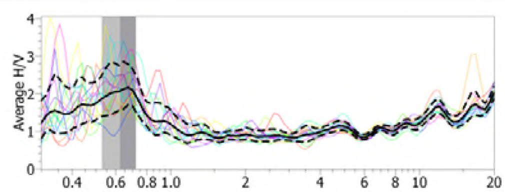
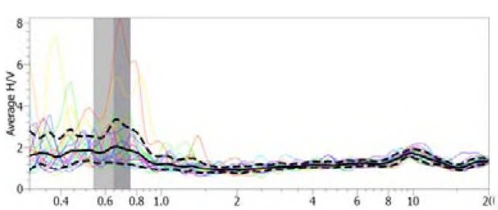


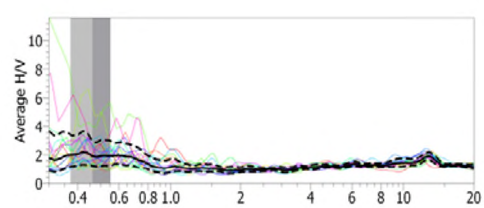
Sector 26



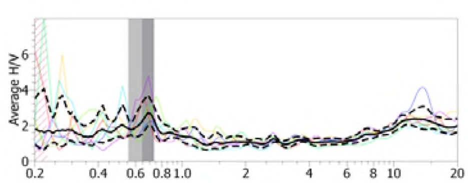
Infocity



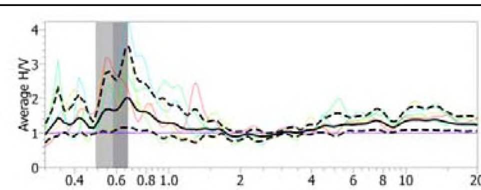
Sector 28



Sector 29



ISR Campus



BISAG

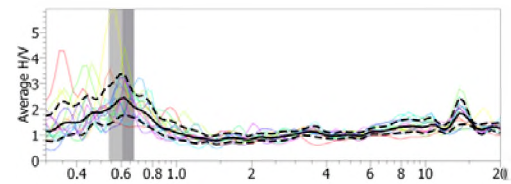
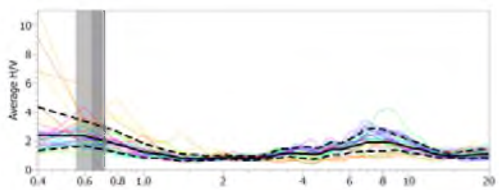
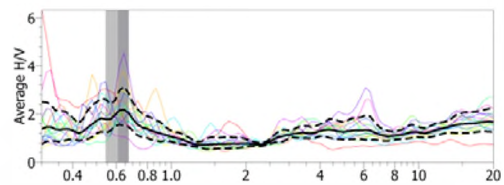
Raisan	 Daskosi (Nr.Raisan)
 Sardargram (Nr. Raisan)	 Heritage Farm

Fig. 5.14: Spectral analysis of microtremors recorded on single microtremor recorder at different sites in Gandhinagar

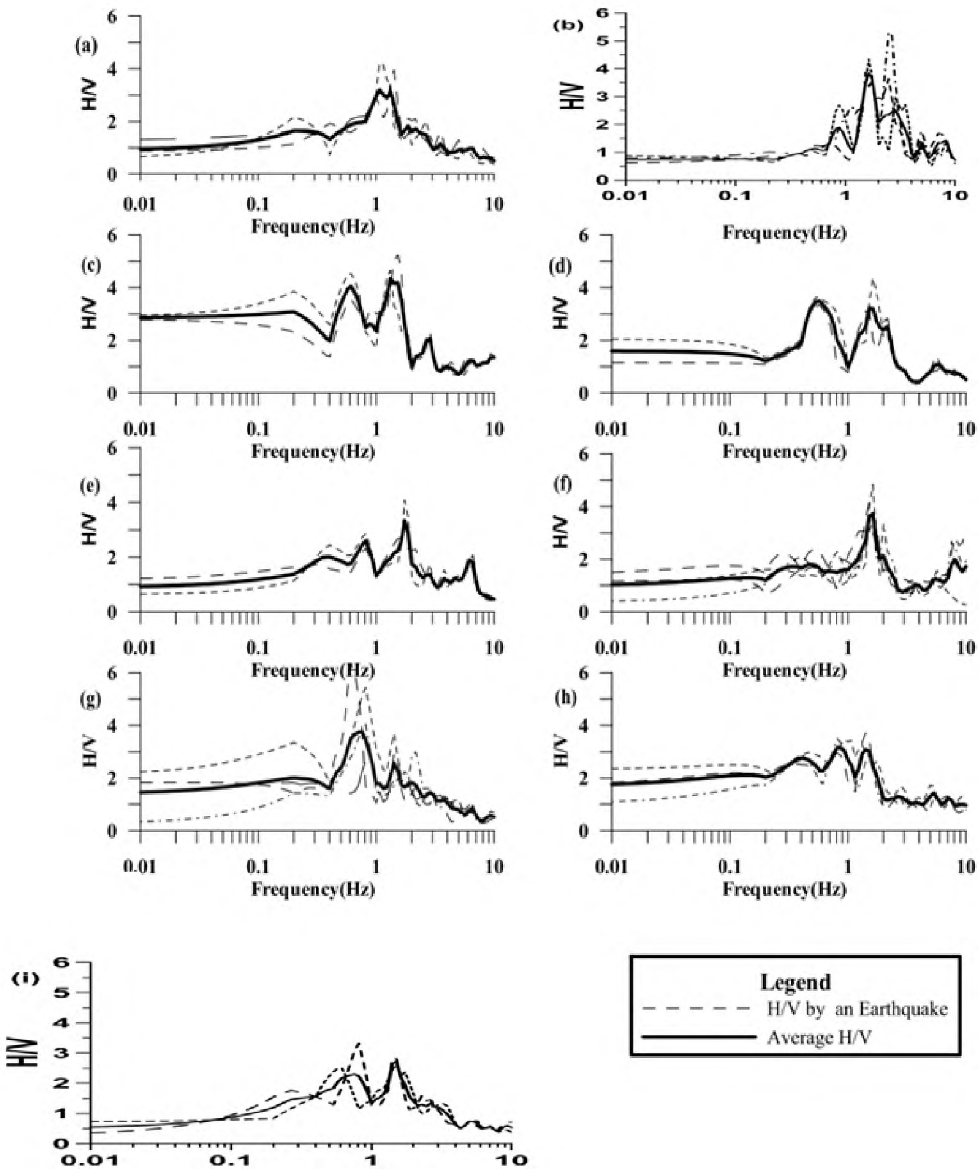


Fig. 5.14: Site amplification (H/V) by Nakamura method using earthquake records at nine sites viz a) Setor-4, b) Sector-8. c) Sector-17, d) Sector-18, e) Sector-24, f) Sector-30 in Gandhinagar while g)Firozpur, h) Jethipura and i) Ratanpur at GIFT City adjacent to Gandhinagar (ISR Annual Report 2010-11)

Table 5.1.: Estimated Frequencies and Depths in Gandhinagar city using single microtremor recorder and broadband seismographs (earthquake and microtremors)

Site name	Frequencies (f), amplifications (Af) and Depths									Source
	<1 Hz	Af	Q-T (AVs=720 m/s)	1-2 Hz	Af	H-P (AVs= 600 m/s)	≥2.1 Hz	Af	H1/11 (AVs=300 m/s)	
Sector-1C	0.6	1.7	300	-		-	4.5	1.2	17	MT
Sector-2A	0.6	2.6	300	-		-	5	1.0	15	MT MTc
Sector-3A	0.5	2.1	360	-		-	5	1.0	15	MT
Sector-4A	0.5	1.6	360	1.6 1.2	1.2 3.4	93 125	4.0	1.2	19	MT Eq
Sector-5A	0.6	2.2	300	1.0	1.4	150	5.0	1.2	15	MT
Sector-6	0.6	1.8	300	-	-		4.5	1.2	17	MT
Sector-7A	0.5	1.4	360	-		-	4.0	1.2	19	MT
Sector 8	0.8	1.9	225							Eq
Sector-9	0.5 0.6	1.6 2.3	360 300	-		-	6.0 4.0	1.21.2	13 19	MT MTc
Sector-11	0.5	2.2	360	-		-	-		-	MT
Sector 12	0.6	4.0	300							MTc
Sector-13 B	0.6	1.8	300	1.5	1.6	100	-		-	MT
Sector-14	0.6 0.6	2.6 1.8	300	-		-	4.0 5.0	1.0 1.5	19 15	MT, MTc
Sector-15	0.6	2.4	300	-		-	4.2	1.0	12	MT
Sector-16	0.6	1.4	300	1.5	2.4	100	4.0	1.2	19	MT
Sector-17	0.6 0.6	2.1 4.0	300	1.5 1.5	1.8 4.4	100	4.0 4.2	1.2 1.6	19 12	MT Eq
Sector-18	0.6	3.3	300	1.7	3.3	90				Eq
Sector-19	0.6	1.8	300	1.8	1.2	83	4.5	1.4	17	MT
Sector-20	0.6	2.0 3.0	300	1.5	1.8	100	4.0 4.0	1.0 1.5	19	MT MTc
Sector-21	0.6	2.0	300	-		-	4.5	1.0	17	MT
Sector-23	0.6	1.8	300	-		-	3	1.2	25	MT Eq.
Sector-24	0.8	2.6	225				7	1.9	10	Eq
Sector-25	0.6	2.1	300	1.8	1.0	83	5	0.8	15	MT
Sector-26	0.6	2.2	300	-		-	5.0	1.0	15	MT
Sector-27	0.5 0.6	2.0 2.4	360 300	1.5 1.5	1.8 1.8	100	4.0 4.0	1.21.4	19	MT MTc
Sector-28	0.6	1.8	300	1.5	1.5	100	3.5	1.6	21	MT
Sector-29	0.5	2.0	360	1.5	1.6	100	4.0	1.5	19	MT
Sector-30	0.5	1.8	360	1.7	3.6	90	8	2	10	Eq
GIFT CITY										
g.Firozpur	0.7Hz	3.5	280	1.3	2.6	115				Eq
h.Jethipura	0.7Hz	3.0	280	1.4	2.9	100				Eq
i.Ratanpur	0.7Hz	1.9	280	1.6	2.7	93				Eq

Note:- Amplification values and other data in this table are from microtremor recorders. Eq: earthquake indicates that similar resonance freq. observed on seismogram also; MT: Microtremor, MTc: Microtremor on central seismometer of array deployment, Q: Quaternary;

T: Tertiary; P: Pleistocene; HI: Holocene-I; H-II: Holocene-II; A_f: Amplification; AVs: average shear wave velocity. The amplification at 0.5- 0.8 Hz (layer at 300m depth) using earthquake records is 1.4-3 and 3-4 at 1.5-1.7Hz (layer at 80-100m depth).

Summary Site Response Gandhinagar

Gandhinagar city is lying on Quaternary sediments. Site amplification has been computed using earthquake records at nine sites and microtremor records at 30 sites. Depth of the impedance contrast (H) is related to the S-wave velocity (Vs) and frequency of amplification f by the relation, $H = Vs/(4f)$.

Inferences from Array and Single Microtremor Recorders

Possible geological boundaries of the shallow to deeper depths are detected by both i.e. single (H/V spectrum ratios) and array microtremor measurement at the site. The layer boundaries are as given below-

Uppermost Layer	AVs 300m/s	depth~10m	f7-8Hz A<2	
Holocene-I/II	AVs 400m/s	depth ~20m	f ~4Hz	A<1.5
Holocene-Pleistocene	AVs 600m/s	depth ~100m	f~1.5-1.7Hz	A3-4
Quaternary-Tertiary	AVs 720m/s	depth ~300m	f~0.6Hz	A2-4

Tertiary/Deccan Trap boundary (AVs2500m/s) depth more than 4km (ONGC Seismic data)

There are predominant amplifications at impedance contrasts at two depth zones. One is A2-4 at ~0.6-0.8Hz that corresponds to Quaternary-Tertiary boundary at ~300m depth assuming average shear velocity of 720m/s to that depth. It may affect high-rise buildings of 20-30 storeys. This resonance is observed at all the sites. However, it is in a broad frequency range indicating 25-50km transition zone. The other is A3-4 around 1.2 – 1.7Hz. It corresponds to the impedance contrast at about 100-125m (assuming AVs 600m/s) that may affect 5-7 storied buildings. Also there is amplification of ~2 in frequency range of 7-8Hz at some sites due to impedance contrast of shallow layer at 10m depth (AVs300m) which will correspond to single or double storey buildings.

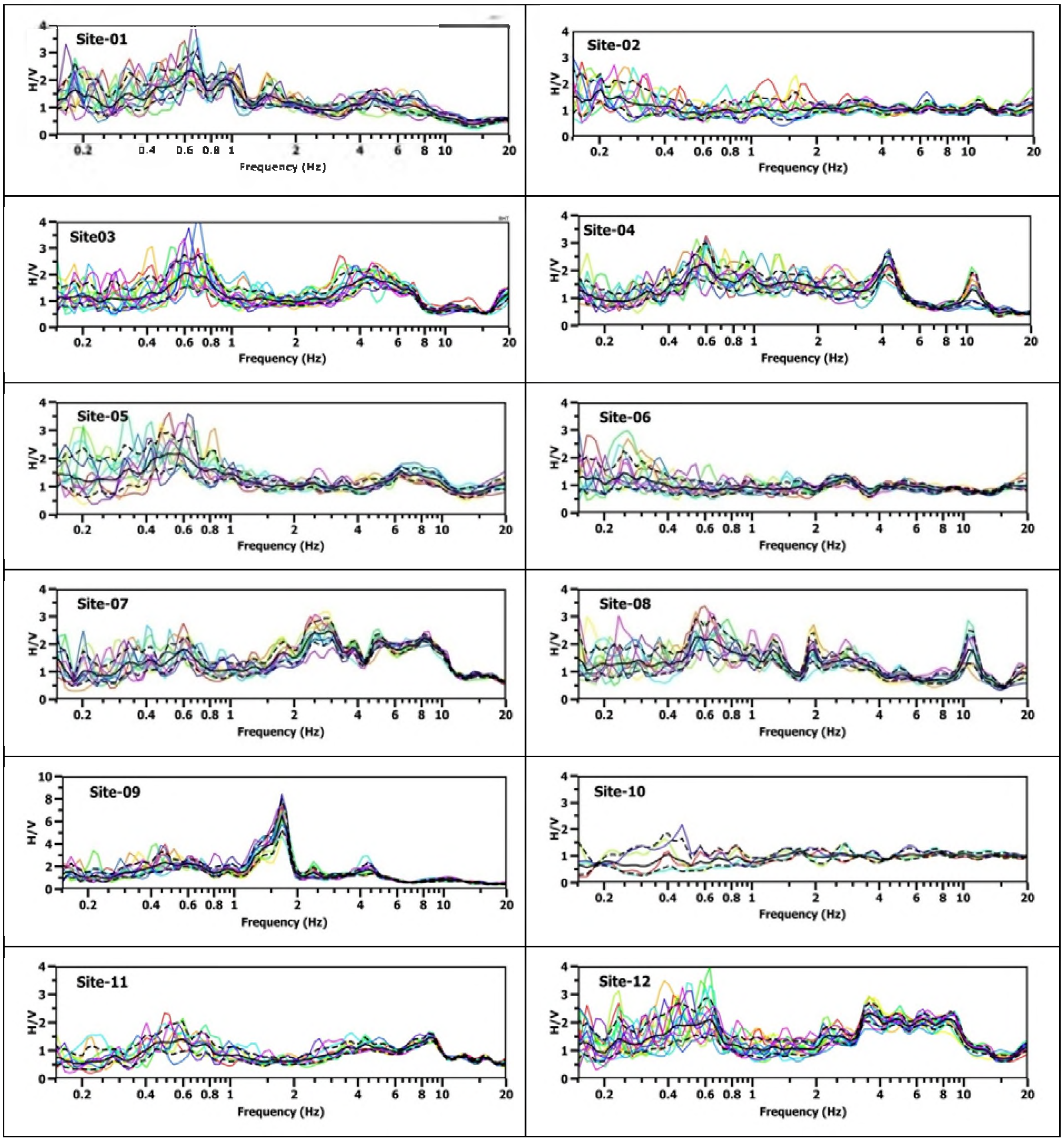
5.10 SITE RESPONSE ANALYSIS AT AHMEDABAD

(B.K. Rastogi and A.P. Singh)

Site Response Analysis at Ahmedabad by Ambient Vibration Records on Broadband Seismographs

In regions with low seismicity but high seismic risk, such as Ahmadabad city, it is of high importance to derive the predominant frequency and amplification factor from the microtremor observation. The results estimate the resonance and dynamic behavior of multi-storey buildings or structure for assessment of damage due to local and regional earthquakes. In order to obtain the variations of these characteristics in the Ahmadabad city area, the systematic Broadband microtremor measurements, at 17 sites were carried out. Maps of predominant frequencies and amplification factors were obtained. In the studied area the ground motion amplification factor is usually 1.3- 2.5 over a frequency range of 0.6 to 10 Hz.

The lower predominant frequency of resonance is 0.6 Hz which will correspond to Quaternary/Tertiary boundary at 300 m depth if Av Vs is taken as 720m/s. The higher frequency of resonance of 4 Hz may correspond to Holocene1/Holocene 2 boundary at 20 m depth for Average Vs 320 m/s (Fig. 5.15, Table 5.2) and the top layer at 5-6 m for 200 m/s at 9-10Hz.



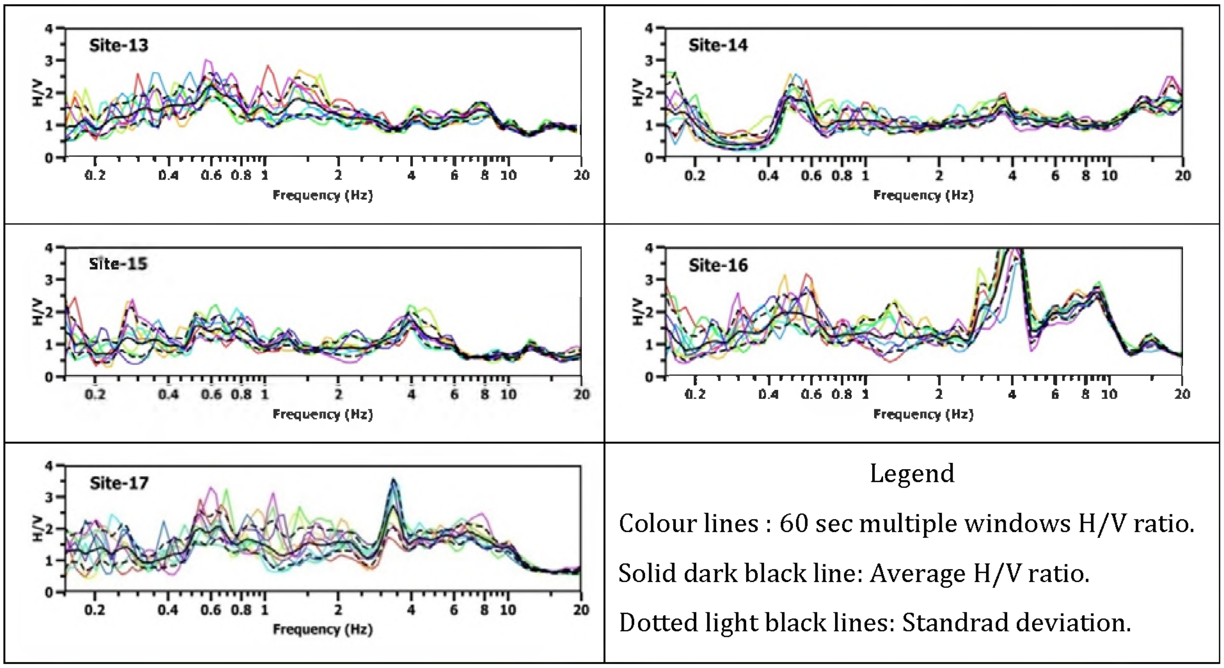


Fig. 5.15: H/V at different stations of seismograph operation using ambient vibrations (ISR Annual Report 2012-13)

Peak frequency of Microtremor H/V spectral ratio of BBS sites depicts three main layers in Ahmadabad city (Table 5.2). Uppermost soil layer is highly heterogeneous as compared to middle and bottom geological layer, because the high frequency amplification is varying drastically.

Site Amplification Using Earthquake Records of Broadband Seismographs at Ahmedabad *(Sandeep Kumar Aggarwal, B.K. Rastogi)*

Twenty-four small to moderate earthquakes (mostly from Kachchh and four regional) were recorded at 12 sites. H/V spectral ratios are shown in Fig. 5.16. For each seismogram spectra were determined for three portions of S-wave recording as shown on top of the figure.

In general, since the whole Fourier spectra show sudden decrease of amplitude at 10-20 Hz, this may be due to both the low magnitudes and site characteristics. And mostly all records have components of frequency between around 0.1 to 10 Hz. There is amplification of about 4 for frequency around 0.6 Hz. This will correspond to buildings of about 15 storeys. However, energy at this frequency is much reduced even for distant earthquake and may be no energy for local earthquakes. Important is amplification of around 4 for frequencies 0.8 to 1.7 Hz (12 to 6 storey buildings) which are observed to have been amplified for the Bhuj earthquake of 2001 and may be present in strong local earthquakes. This may not be modeled by SHAKE program as the amplification is due to impedance contrast of Holocene-Pleistocene boundary at 60-125m depth. Such areas show low Vs30 where multistory buildings were damaged in 2001.

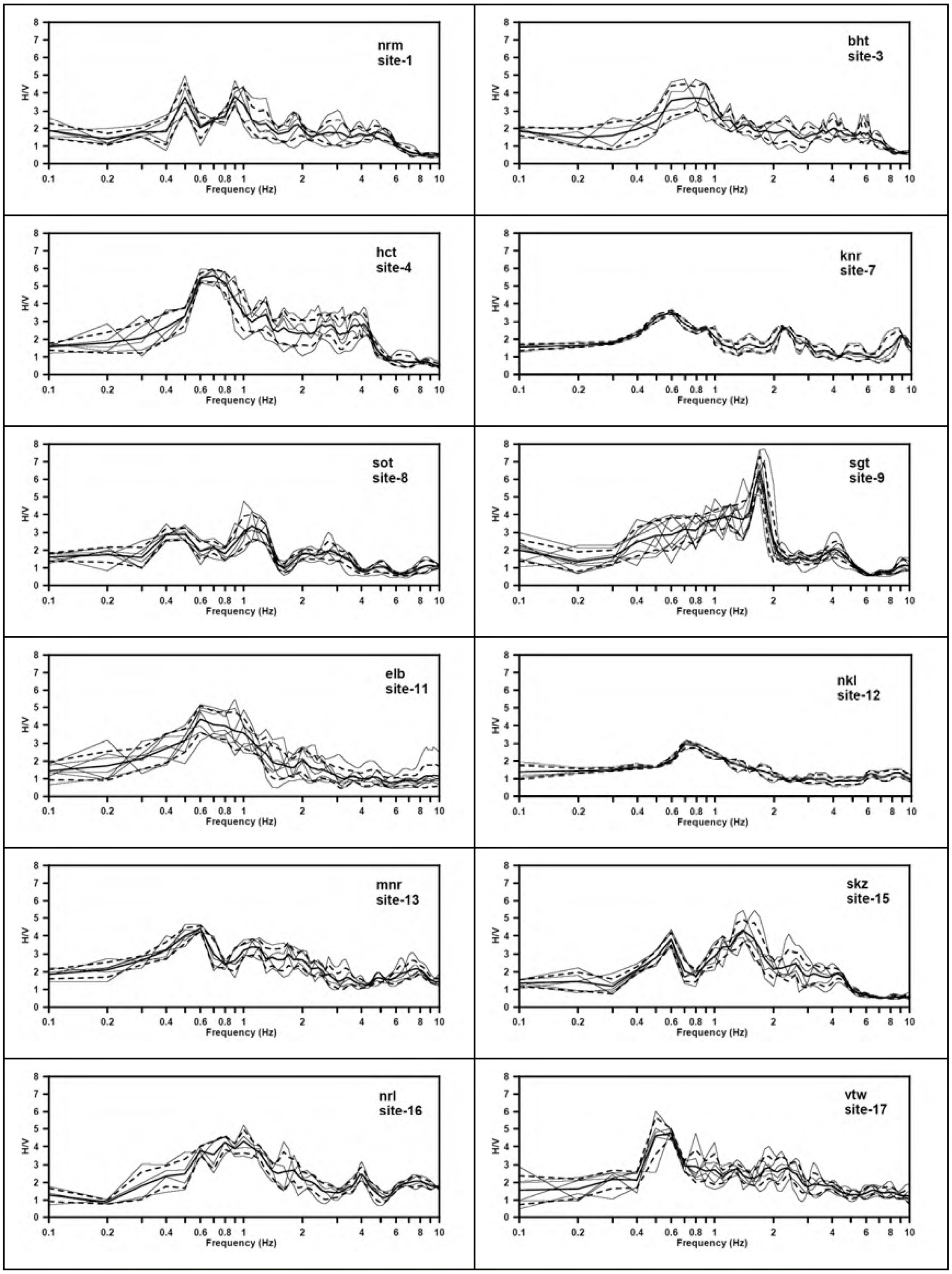


Fig. 5.16: H/V for earthquakes at 12 locations in Ahmedabad

Estimation of Engineering Bed Layer, Depths to Layers of Resonance and Resonance Frequencies by Micro-Tremor Method at Ahmedabad

(A.P. Singh and Annam Navneeth)

Microtremor array recordings were made at 11 locations (Fig. 5.17). The phase velocity dispersion of recorded ambient vibrations for 1-hr duration was interpreted in terms of depths to different layers and their shear-wave velocities. From the records of the central seismometer at 13 locations the H/V spectral ratios were measured which also yielded depths to different layers of impedance contrast, amplifications at these contrasts and corresponding frequencies.

The ambient vibration (micro-tremor) measurement is very inexpensive, non-destructive, non-invasive method and it can be applied in regions with low seismicity rates, a short time of acquisition is required in the field and low computational time and minimal computing resources are needed to analyze data. This technique uses low frequency ambient vibration generated due to ocean tides, winds and small and large scale meteorological phenomena, while local cultural noise is avoided. The analysis of micro-tremor recording for site effect estimation has gained more interest in recent years and it is commonly thought that both single station horizontal-to-vertical spectral ratio's technique and multi-station (array) measurements may allow obtaining dynamic characteristics of the subsoil from ambient vibration measurements (Bard, 1999; Okada, 2003; Rastogi et al., 2011). Furthermore, in the earthquake engineering field, the shear wave velocity of the subsurface structure is considered a key parameter for its major influence on local ground motion behavior. In this study, we measure resonance frequencies of soil layers, the relevant shear wave velocity profile and depth of the engineering bed layer. Amplification is noted but not used in the hazard estimation as it is not considered reliable by some researchers.

Single and Array Micro-Tremor Measurement & Methodology:

Small aperture (60m) array measurement has been done at 11 sites to determine 1D velocity structure to 60-100m depth. The observations were carried out for an hour at each site. Central station recordings at these eleven sites and two additional sites were subjected to H/V spectral analysis. For reliable experimental conditions we followed the guidelines proposed by Koller et al. (2004).

The array measurements were taken using circular array which consists of three recording stations on the circumference of the inner circle, three on the outer circle and one in the center of the circle. Seven sets of Lennartz LE-3D-5sec seismometers with City Shark-II digital recorders were deployed. It also has a master remote control which is used to trigger all the seven stations at a time in order to avoid any phase shift. In this campaign, maximum arm length was chosen as 30 m for the array.

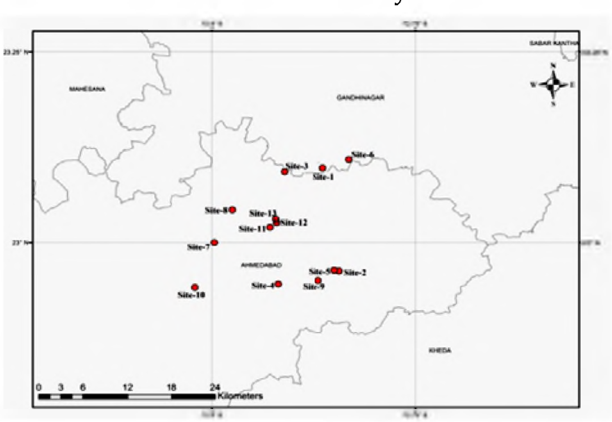
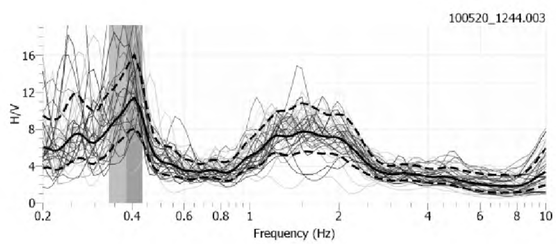


Fig.5.17: Locations of array and single microtremor measurements in Ahmedabad city

Results of Single Micro-Tremor Measurements:

The H/V spectral ratios at 13 sites (Fig. 18) show site amplifications corresponding to different frequencies in the area. These are similar to those obtained by Parvez and Madhukar (2007) and Mathur et al. (2009). Maximum amplification is around 0.6 Hz corresponding to an impedance contrast at about 300 m, by using the formula $f = Vs/4H$ for a shear wave velocity 720 m/s. It corresponds to Quaternary-Tertiary boundary. The peaks observed at about 0.6 Hz are broad which indicates that the impedance contrast is not high and the Tertiary sediments are semi-consolidated with gradual increase of density and velocity.

Site 1



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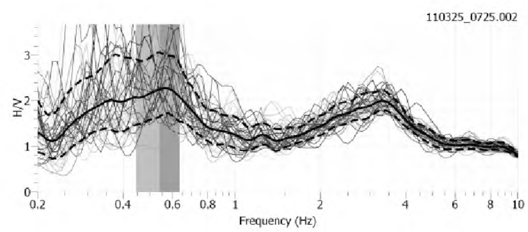

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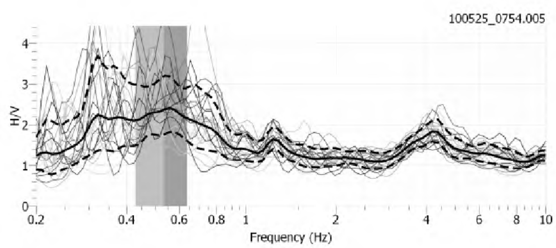

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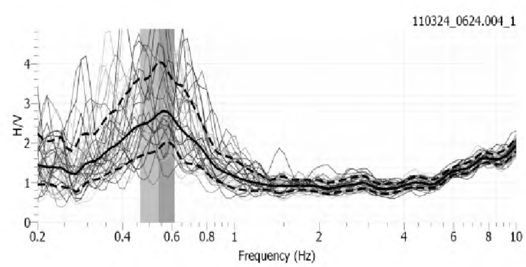

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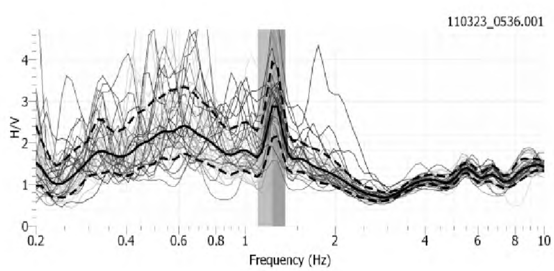
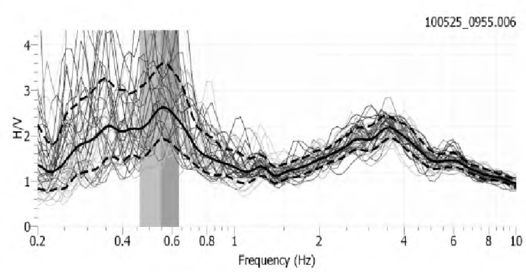
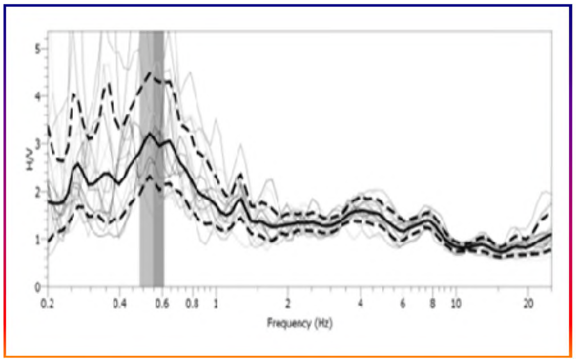


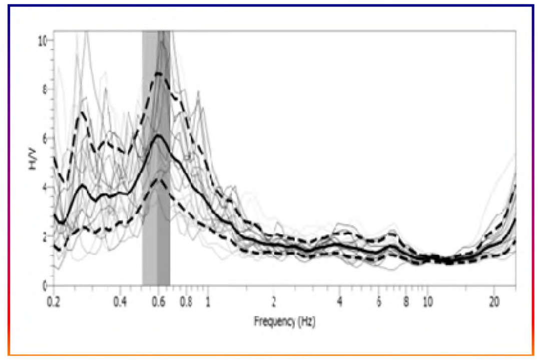
Site 6



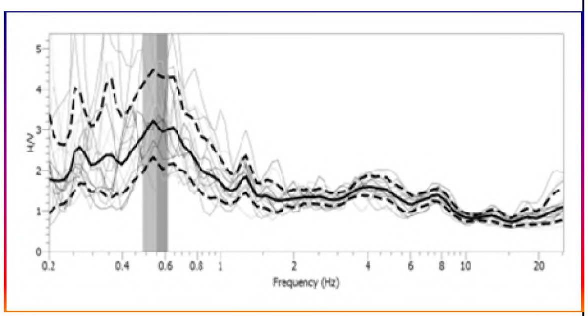
Site7



Site 8



Site 9



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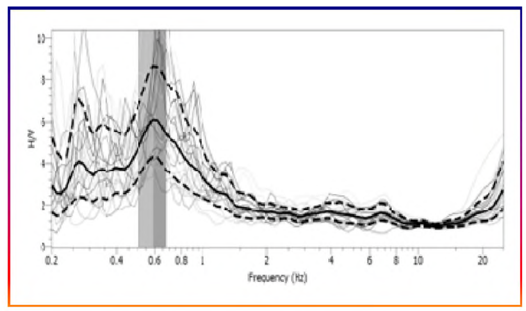

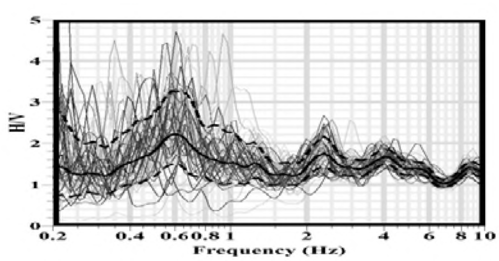

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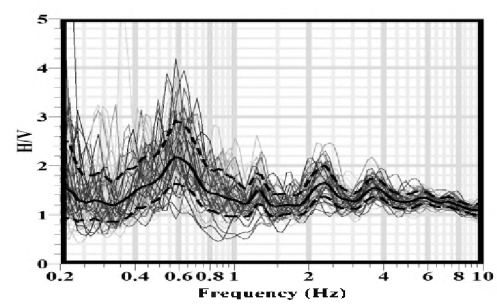

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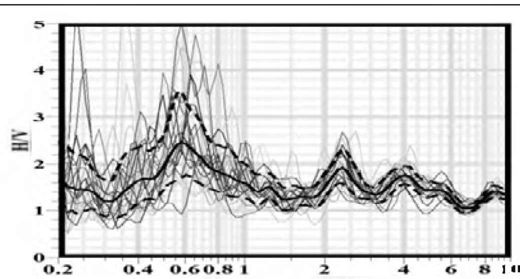


Site-13

Fig. 5.18: H/V spectral ratio plots using earthquakes records showing amplifications due to impedance contrasts at different frequencies in Ahmedabad

Summary of Microtremor Observations

1 It is found that the frequency of maximum amplification (fundamental frequency) of 0.6Hz indicates that the Quaternary thickness of about 300 m is reasonably uniform without much lateral variation at 11 sites in Ahmadabad city and is responsible for producing peak amplification of 2-2.5. As the peak is not sharp but broad there is no high impedance contrast. This amplification corresponds to Q-T boundary and may affect buildings of about 16 stories which should be constructed with care.

2 Secondary peaks in the H/V spectral ratio observed at about 1.5 Hz, which is not much clear as impedance contrast is less. Another clear peak is observed at about 2.1 Hz, which corresponds to 4-5 stories building. The response of this peak may be from the depth of 120 m. Micro-tremor survey also indicates layers at 38 m and 70 m. Holocene-Pleistocene boundary at 60 and 100 m

3 The array analysis of micro-tremor shows Engineering Bed Layer at around 20 m depth marking Holocene I and II boundary. The boundary causes amplification of about 2 for about 4 Hz and 2-3 storey buildings.

Table 5.2: Estimated Frequencies and Depths in Ahmedabad area using single microtremor (MT) recorder and Earthquake records (Eq). NOTE: 1.The earthquake records show amplification of 2 or less for resonance frequency 8-9 Hz (but not listed here). NOTE 2. Q: Quaternary; T-Tertiary; H-I: P: Pleistocence; Holocene-I; H-II-Holocene-II; A_f: Amplification; MT: Microtremor; average shear wave velocity given in each geological

Site Name		Frequencies, amplifications and Depths											Source
	<1 Hz	A_f	Q/T 720 m/s	1-3 Hz	A_f	H/P 600 m/s	>3 Hz	A_f	H-I/ H-II400m/s	>7 Hz	A_f	Top layer 300 m/s	
Bhatt village	0.45	6.0	400	1.5	4.0	100	4.0	2.5	22				MT & Eq
Lal Gebi Ashram	0.62	2.2	291	1.5	1.4	100	3.2	2.0	33				MT
BRTS, Motera	0.60	2.2	300	1.5	1.8	100	4	1.5	22				MT
Vatwa	0.60	2.2	300	2.5	1.0	60				6.0	1.1	12	MT & Eq
GIDC	0.65	2.2	277	1.5	2.5	100				7.8	1.2	10	MT
Chiloda	0.62	2.8	291	1.5	1.8	100				7.8	2.5	10	MT
Vastrapur	0.55	3.0	328	1.2	2.1	125				7.5	1.5	10	MT
Sunrise park	0.65	6.1	277	-		-				7.5	1.5	10	MT
Asopala Society	0.55	3.1	328	1.5	2.1	100				7.8	1.8	10	MT
Dolia	0.62	6.1	291	2.5	2.1	60				6.5	1.8	11	MT
Ellisbridge	0.6	2.1	300	2.4	1.8	62	4.0	1.5	25				MT & Eq
Ellisbridge	0.6	2.2	300	2.4	1.6	62	3.8	1.8	26				MT & Eq

Site Name		Frequencies, amplifications and Depths											Source
	<1 Hz	A_f	Q/T 720 m/s	1-3 Hz	A_f	H/P 600 m/s	>3 Hz	A_f	H-I/ H-II400m/s	>7 Hz	A_f	Top layer 300 m/s	
Ellisbridge	0.6	2.3	300	2.4	1.8		4.0	1.3	25				MT & Eq
Adinathnagar	0.49	1.9	367	-	-		4.0	1.7	25				Eq
Sarkhez	0.54	1.6	333	-	-		4.0	1.7	25				Eq
Narol	0.47	2.0	382	-	-		4.1	4.2	24				Eq
Nicol	0.63	2.1	285	-	-					8.6	2.1	12	Eq
Maninagar	0.60	2.2	300	1.4	1.8	107				7.8	1.5	11	Eq
Krishannagar	0.60	1.8	300	2.9	2.5	51				8.5	2.2	12	Eq
High court	0.60	2.2	300	-	-		4.3	2.2	23				Eq
Nirma University	0.66	2.2	272	-	-	-	-	-	-				Eq
D-mart near ONGC	0.20	2.0	900	-	-	-	-	-	-				Eq
Hanspura	0.52	2.2	346				4.3	1.5	23				Eq
Gandhiashram	0.25	1.5	720	2.8	1.3	53	-	-	-				Eq
Sonam Tower	0.57	2.3	315	2.0	1.8	75							Eq
Sagar tower	0.47	2.4	382	1.7	6.5	88	4.3	1.7	23				Eq

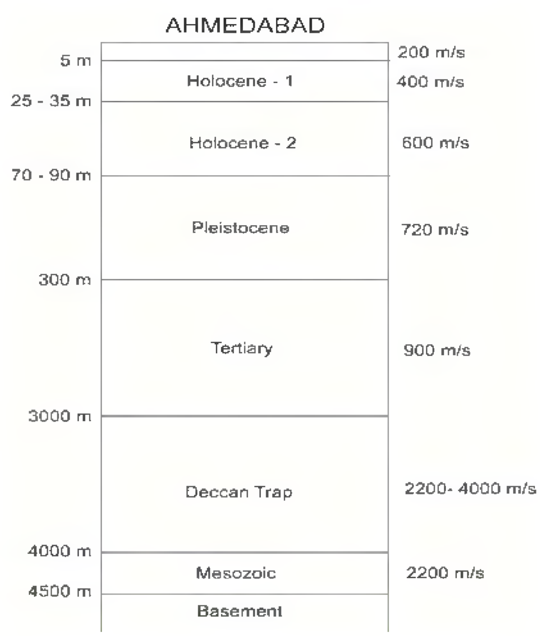


Fig. 5.19: The derived stratigraphy model for Gandhinagar and Ahmedabad areas using geotechnical data for Holocene I & II layers while deeper layer boundaries with Seismograpph and Microtremor data

CHAPTER 6

GEOTECHNICAL INVESTIGATIONS

(Vasu Pancholi, Rahul Ranjan, Suraj Kumar, Vinay Kumar Dwivedi, Sarda Maibam, Jaina Patel, Darshit Modi)

6.1 GEOTECHNICAL INVESTIGATIONS FOR SEISMIC MICROZONATION OF AHMEDABAD CITY

18 boreholes were drilled with Standard Penetration Test (SPT) and soil samples at every 1.5m depth. SPT values are corrected for overburden and other factors. Undisturbed and disturbed samples are alternately collected. The laboratory soil tests were carried out in accordance with the relevant IS Codes and approved testing procedures for laboratory testing at Institute of Seismological Research (ISR). For undisturbed soil samples (UDS) shear parameters (Cohesion and Angle of Friction) are determined by Dynamic Triaxial and Direct Shear tests to determine. Physical tests such as Grain Size Analysis, Atterberg's Limit, Specific Gravity, Free Swell Index tests are conducted for all the samples. Field dry Density and Water Content tests are done for the undisturbed soil samples.

6.2 GEOTECHNICAL INVESTIGATIONS OF THE MULTI STOREY COMMERCIAL COMPLEX AT SCIENCE CITY ROAD, SOLA, AHMEDABAD

One Borehole of 45m is drilled by rotary drilling at proposed site as shown in **Fig: 1**. As the construction site was excavated upto 5m depth, all the tests start from 5m depth.

During drilling borehole sampling was done at the interval of 1.5m. Some 20 Disturbed/SPT and 12 undisturbed were collected and subjected to laboratory soil test. Results are as follows:

1. Standard Penetration Test (SPT) was conducted at an interval of 3.0 m depth. The test gives N-value; the blow counts of last 30 cm of penetration of the split spoon sampler with 65 kg hammer falling freely from 75 cm height. Disturbed samples of soil are obtained from the split spoon sampler after completion of the tests.

Table 6.1: N_{SPT} Obtained at different depths

Depth, m	N-Value	Depth	N-Value
5.0	24	29	Refusal
8.0	51	32	Refusal
11.0	Refusal	35	Refusal
14.0	Refusal	38	Refusal
17.0	79	41	120
20.0	107	44	Refusal
23.0	62	47	Refusal
26.0	76	50	Refusal

Fig. 6.1: Site location at Sola

2. Ground water table was found at 5m depth from the surface level.

3. Soil index properties were determined through lab tests like Grain Size Analysis (Sieve & Hydrometer), Atterberg's Limit, Specific Gravity, Moisture Content, Dry Density etc. The laboratory soil tests were carried out in accordance with the relevant IS Codes and approved testing procedures for laboratory testing

4. Evaluation of Liquefaction Potential was done and factor of safety against liquefaction was calculated.

Conclusion: It may be concluded that the study area mostly comprises of Sand with the mixture of Silt and Clay. After 38m of depth, clayey soil persists upto termination depth. Also, the density of the soil at the site ranges from 1.95 to 2.34 which come under the Stiff condition. As per the results obtained by the calculation of Liquefaction Potential of soil in the study area, it is found that the factor of safety against liquefaction is well above the criteria of 4 and hence the area is Safe and Liquefaction susceptibility is negligible below 5m. It must be noted that the soil upto 5m depth was already been excavated from the site.

6.3 LIQUEFACTION HAZARD STUDY OF DAHEJ AND KAMBOI PORT AREA, GUJARAT

Over the past decade we have observed increase in seismic activity all over the world. Seismically active regions cause losses of many lives and properties due to earthquake. So it is a prime requirement of evaluating seismic hazard possibilities. One of the major effects caused by earthquake is Liquefaction phenomenon. Liquefaction leads to large failure of structures and devastating collapse in the form of sudden settlements, landslides, lateral spreading etc. Evaluation of Liquefaction began to evolve after Great Alaskan earthquake (M=9.2) and 1964 Nigata earthquake (M=7.5), which produced significant liquefaction related damages.

Looking at the recent development and industrial growth on the coastal belt of Gujarat there is a requirement of soil liquefaction study to save losses of so many lives and damages of properties from future earthquakes.

This poster shows liquefaction study of Dahej and Kamboi port area, Gujarat by Seed and Idriss simplified procedure. There are two boreholes drilled upto depth of 40m. Soil samples were collected at every 1.5m depth for which we performed lab tests like Grain size Analysis, Atterberg Test, Density, Specific Gravity and Moisture Content are performed for evaluation of Liquefaction potential. Standard Penetration Test is also carried out at the depth interval of 3m in both boreholes. The N value obtained from SPT test is corrected to get $(N_1)_{60}$ for evaluation of Liquefaction. The overburden correction (C_N) was done using the equation suggested by Kayen et al. (1992), which yields a maximum value of 1.7 for C_N. The other corrections for N values were applied based on NCEER (1997). The area at Dahej site comprises of alternate layers of silt and clay with having some patches of sand at lower depth the soil is dense silty sand with some percentage of gravels whereas Kamboi area under study comprises of layers of clay, silt and sand alternatively. At both sites, the surface soils are found to be loose and susceptible to Liquefaction hazard. Hence, Liquefaction potential is determined and factor of safety against it is calculated for each depth.

6.4 LIQUEFACTION POTENTIAL EVALUATION OF SABARMATI SAND SOIL WITH DIFFERENT SILT CONTENTS BY CYCLIC TRIAXIAL TESTING

In past as well as during recent earthquakes, large scale liquefaction in silty-sand is reported and many investigations are presented in literature of recent years. But there is no consent in the literature regarding the manner in which the presence of fines influences the pore water pressure generation characteristics, thus the liquefaction behavior of sandy soils. Some of the studies have concluded that silty sand is more liquefiable than the clean sand. Thus, to study the susceptibility of liquefaction of such soil and to know whether it is true or not about the higher susceptibility of liquefaction, an attempt was made in the form of laboratory investigation program through stress controlled cyclic triaxial tests. To study, soil of Sabarmati River (Ahmedabad) was used, as large area of river bank has silty sand. Additionally, near Sabarmati River, water level may become high due to river front construction, thus, this study can also give some conclusion about the liquefaction susceptibility of this soil.

In this study, results are derived in terms of cyclic stress ratio required for failure of the sample in effective cycles, for different fine contents (silt) in pure sand. Both the failure criteria i.e. 100% pore pressure ratio (R_u=1) and 5 % double amplitude strain, are studied to evaluate liquefaction potential. The findings of the present study help to justify some of the existing conclusion and disregard some others on liquefaction and pore pressure generation characteristics of sand-silt mixture.

The results indicate that silt in pure sand increases the susceptibility of liquefaction up to some limiting percentage (30%), after that decrement is noted. At 45% silt content, it becomes very less. Thus, limiting silt content is the most important finding for any silt-sand mixture, which gives brief idea about effect of fine content on liquefaction properties of sand.

6.5 GEOTECHNICAL CHARACTERIZATION OF PROBLEMATIC SOILS: SWELL, DISPERSION AND COLLAPSE PREDICTION

Soils are unconsolidated materials that are result of weathering and erosion process of rocks. When water content of some soils change, it creates problems for civil activities. These problems include swelling, dispersing and collapse. Problematic soil is found in different shapes such as swelling, high water absorption, quick, collapsible and loose soils. Problematic soils are formed in especial geological conditions. Field observation and laboratory test can be useful to identify problematic soils. From geotechnical and engineering geology points of view, collapsible soils are classified as problematic soils. The existence of collapsible soils has been reported in all of the world continents. One of the most important problems concerning collapsible soils is instability and considerable settlement due to minor changes in the water content which can cause remarkable damages to overlying structures. Therefore, evaluation of collapsibility potential through defining many empirical criteria is especially important. In this study some of empirical criteria were classified and implemented to evaluate the collapsibility of soil of coastal region of Gujarat along Gulf of Kachchh. As a case study, port areas in the regions were considered because of considerable risk of failure due to collapsibility phenomena. After site investigation and performing many laboratory tests, the soil collapsibility potential was confirmed through comparison of selected criteria.

CHAPTER 7

SEISMIC MICROZONATION AND HAZARD AT INDIVIDUAL SITES

7.1 SEISMIC MICROZONATION OF GANDHINAGAR

(BK Rastogi, Kapil Mohan, B. Sairam, Sandeep Aggarwal, AP Singh,Vasu Pancholi, Vandana Patel, Sarda Maibam, Jaina Patel, Vinay Kumar Dwivedi, Mr. Suraj K. Singh, Mr. Rahul Ranjan Mandal)

Introduction

Gandhinagar City (the Capital of Gujarat) falls under Zone III of seismic zoning map of India where an earthquake of magnitude 6 can be expected that can damage buildings within 20km distance. Multistoey buildings can be damaged due to large earthquakes in Kachchh. It is also a well established fact that the site amplification/ shaking and damage is large in soil covered areas. As large scale development including scy scrapers are planned, Seismic Microzonation was carried out.

Details of Investigations

Field investigations like drilling, PS logging, seismic survey, microtremor survey, operation of seismographs are listed in Table 7.1. Seismic microzonation of Gandhinagar city (45km^2) has been carried out in 1:50,000 scale with the following investigations:

- Geological maps of GSI and ONGC (1:50,000) have been used (Fig. 7.1).
- Geomorphological (Fig. 7.2) and seismotectonic (Fig. 7.3) maps have been prepared (1:50,000). Catalog of past earthquakes within 50 km has been prepared (Table 7.2).
- Total 14 boreholes, 50m deep were got drilled by ISR (Fig. 7.4). PS Logging was done for 8 boreholes. All these boreholes had SPT tests for N-value every 3m. Disturbed / undisturbed soil samples were collected alternately every 1.5 m and their soil properties measured (Table 7.3). Lithologs (Fig. 7.5) and N-value with depth plots (Fig. 7.6) have been prepared. The 2D and 3D soil profiles (Figs. 7.7-7.9) have been prepared and generalized soil types with depth to 50m (Table 7.4) has been assessed which helped in soil modeling needed as input for SHAKE program.
- Vs 30, Shear wave velocity were measured at 63 sites by MASW and Vs30 map on 1:50,000 scalehas been prepared.
- Site response (the amplified frequencies, amplifications at these frequencies and depths to layers corresponding to these frequencies) has been worked out using array microtremor measurements at 8 sites, single microtremor at 17 sites, natural earthquakes and microtremors recorded on BBS at 9 sites (with recordings of 3-4 earthquakes at each location by operation of 6 broadband seismographs). Amplifications noted from these measurements are for a general idea of the area. The resonance frequencies yield depths of different layers having good impedance contrast.
- Depth to Engineering Bed layer has been estimated (Fig. 7.10).
- Response spectra were estimated at different sites in Ahmadabad using geotechnical properties and velocities of different layers as inputs.
- Liquefaction potential has been worked out.
- Attenuation relation has been worked out for Gujarat region.

Deliverables:

Following hazard maps are attached to the Final Report in scale of 1/50,000

a) Geomorphic Map
b) Earthquake Ground Motion Ma
c) Liquefaction Potential Map
   Integrated Hazard Map
d) Integrated Vulnerability Map
e) Specific Recommendations on foundation and structural design aspects for the area based on the output of the study.
f) The GIS database is in shape format as a vector file with duly attached attributes (if any) and .tiff format for raster files.

Table 7.1: Quantities of Geotechnical drilling and Geophysical Investigations

Description		Total Depth (m)
Bore hole Drilling by ISR	14 Boreholes	502
PS Logging	8 surveys	250
MASW	63 profiles	-
Microtremor Array	10 surveys	
Single Microtremor	29 locations	-
Earthquake records on BBS	9 locations	
Microtremor on BBS	9 locations	

Geological Setup

The city of Gandhinagar is part of north Gujarat alluvial tract and situated in tectonically controlled, about 50-75 km wide Cambay Basin, which is characterized by two northwest trending boundary faults named as East Cambay Fault (lying close to Gandhinagar) and West Cambay Fault. The area falls in seismic zone III with zone factor (PGA) of 0.16 and spectral acceleration Sa max of having possibility of M<6 along the Cambay fault. Other smaller faults are not likely to cause significant earthquakes. The basin is filled up with 300-400 m thickness of Quaternary and about 3 km or more Tertiary sediments lying over 1-2km thick Deccan Trap. The Quaternary sediments are of fluvial and Aeolian origin.

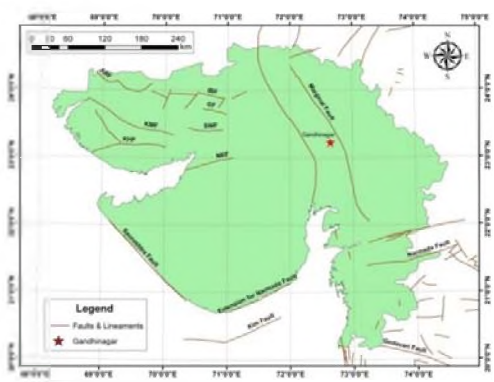


Fig. 71: Seismo tectonic setup around Gandhinagar City

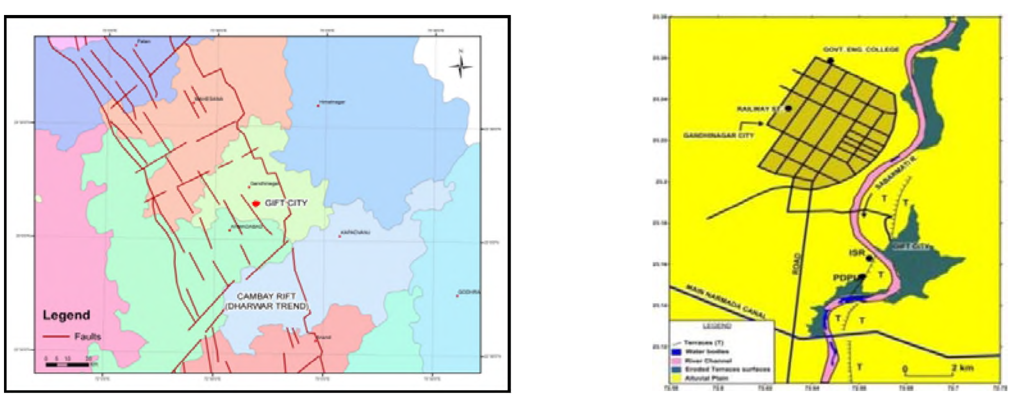


Fig. 7.2: Geomorphic map prepared by ISR for Gandhinagar area.

2. Geomorphologic Setup:

Geomorphic Map has been prepared by ISR, after identification of geomorphic attributes through topographical sheets, Google imageries, satellite images and the geo-morphological map for Gandhinagar city by GSI and checking them on ground.

The geomorphic units covering the area are shown in Fig. 7.2. Major part of Gandhinagar city consists of flood plain deposits of Sabarmati River consisting a flat topography with an altitude of about 100 m above MSL.

Flood plains cover the entire Gandhinagar region where the silty / clayey sand is exposed on the surface. Lower litho units are sand, clay or silt. Relatively younger soil is deposited on the eastern bank. Thickness of loose sand varies from 3 - 10 m whereas calcrete lenses are 1 - 2 m thick. The sediments are mainly of fluvial and Aeolian origin. Though, terrain is significantly flat, slight undulations observed in the area away from Sabarmati River are result of Aeolian activity whereas ravines in proximity to river bank are result of distinctive river dynamics. Abandoned channels have been left due to lateral shifting of river courses.

Geomorphologically two types of landforms occur in the area, viz. fluvial and Aeolian landforms. There are two fluvial terraces in the area. The oldest terrace is very prominently developed. The younger one, developed in limited extent, is at some distance from the river bank.

Detailed Description of Lithounits at Surface:

The upper Quaternary sequence has been divided into two types of formations viz. Varahi and Akhaj (excerpts from GSI Report). The Varahi Formation is fluvial in origin. It comprises of highly oxidized fine to coarse grained sand and clay. The litho units of Varahi formation are highly dissected and eroded to form gullies and badlands along the river banks. Maximum thickness of this unit reaches 10 m north of Indroda. Geomorphic units of this formation are represented at places by detached buried channels, possibly remnants of old river course of Sabarmati aggraded with sand. A paleo-channel is also delineated near Raisan and Koba villages from satellite data. The Akhaj formation is represented by Aeolian deposits as cover over the Varahi Formation (Tandon et al., 1997) occurring as parabolic dunes and sandy flats. The formation consists of grey, yellowish grey, fine to medium grained sand (medium sand dominating) with dull white discoidal grains of calcareous material.

Seismicity around Gandhinagar City

Gandhinagar falls in seismic zone III where there is not much seismicity around Gandhinagar city. Eight shocks of magnitude 2.7 to 5.0 have been registered within 80 km of the Gandhinagar City (Table 7.2). In the historical past, Ahmedabad located 15 km SW experienced 3 earthquakes in 1840, 1843 and 1864 of magnitudes 4.6, 3.7 and 5.0, respectively. Five other small shocks are cataloged. A large earthquake in Kachchh region (M > 7) can also affect high rise buildings in Gandhinagar city.

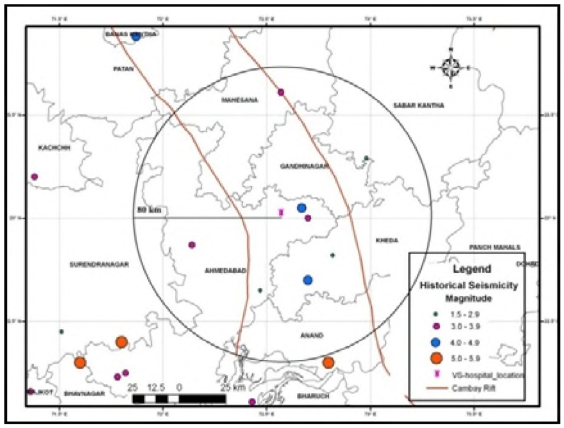


Fig. 7.3: Epicenters of earthquakes M ≥ 1.5 occuring in the Gandhinagar-Ahmadabad and surrounding region during the period 1668 to 2013

Table 7.2: Catalog of earthquakes within 80 km radius of Gandhinagar City (23.4 N 72.5 E) during 1668 to 2010

Year	Month	Date	Origin	Lat	Long	Depth	Magnitude	Intensity	Location	Ref.
1821	8	13		22.70	72.70		4.6		Kaira	USGS
1840	11	10		23.05	72.67		4.6		Ahmedabad	USGS
1843	2	8		23.00	72.70		3.7	IV	Ahmedabad	OLD
1864	4	29		22.30	72.80		5.7	VII	Ahmedabad	CHAN
1897	10	0		23.00	72.70		3.7		Ahmedabad	USGS
1898	10			23.05	72.67		4.3		Kheda	USGS
1962	9	1	22:01:30	24.00	73.00		4.6		Palanpur	IMD
1980	8	27	6:20:00	22.82	72.82		2.7		Chandraga	GERI

3. Geotechnical investigations for seismic microzonation of gandhinagar city

There are 14 boreholes drilled for soil investigation of the study area of about (8kmx4.km) 32 km2. Locations of these boreholes are shown in Fig. 7.4.

Summary of the Geotechnical work done in Gandhinagar is as given below:

1. A total of 152 UDS, 200 SPT and 50 DS were collected during drilling for which soil properties were estimated in geotechnical lab of ISR.
2. Soil index physical properties were measured including Grain Size Analysis (Sieve & Hydrometer), Atterberg's Limit, Specific Gravity, Moisture Content, Dry Density etc. Shear parameters (Cohesion and Angle of Friction) were measured by Dynamic Triaxial and Direct Shear Tests.
3. The 2D and 3D soil models were genraed using software applications like Rockworks, Surfer, ArcGIS, Global Mapper, etc.

4 Thr lithologs in Gandhinagar indicate - layer 1(0-18m): silty/ clayey sand, layer 2 (18-28m): clay, layer 3 (28-45m): silty/ clayey sand, layer 4: clay or silty/clayey sand.

5 Based on the geotechnical investigations, it may be concluded that the soil of study area has good shear strength. The higher value of penetration resistance (SPT – N value) also shows the stiff nature of soil. Liquefaction study was done for the study area. As per the results, whole study area is almost safe against liquefaction barring small areas of very low susceptibility.

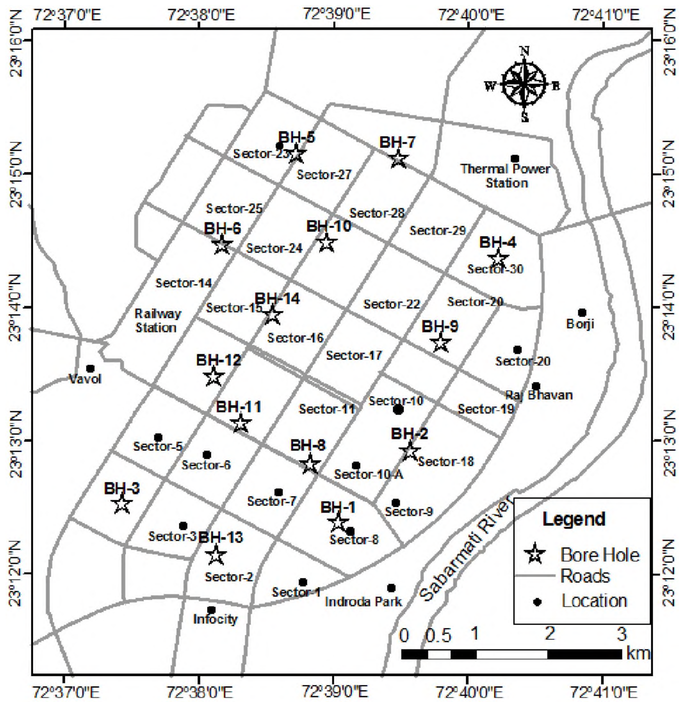


Fig. 7.4: Location map of boreholes-sites in Gandhinagar

Table 7.3: No. of geotechnical tests performed

Borehole No.	Samples		Sieve Analysis	Hydrometer Analysis	Specific gravity	Density	Moisture content	Atterberg test	Shear test
	UDS	SPT/DS							
01	14	20	34	34	14	14	34	34	6
02	14	20	34	34	14	14	34	34	10
03	14	22	36	36	14	14	36	36	11
04	13	22	35	35	13	13	35	35	12
05	21	23	44	44	21	21	44	44	19
06	21	25	46	46	21	21	46	46	12
07	7	27	34	10	7	7	34	34	-
08	14	19	33	7	33	14	33	33	-
09	11	13	24	20	24	11	24	24	3
10	12	13	25	20	25	12	25	25	3
11	9	13	22	14	22	9	22	22	2
12	8	12	20	15	20	8	20	20	4
13	8	11	19	10	19	8	19	19	3
14	12	11	23	20	23	12	23	23	3
Total	**178**	**251**	**429**	**345**	**270**	**178**	**429**	**429**	**88**

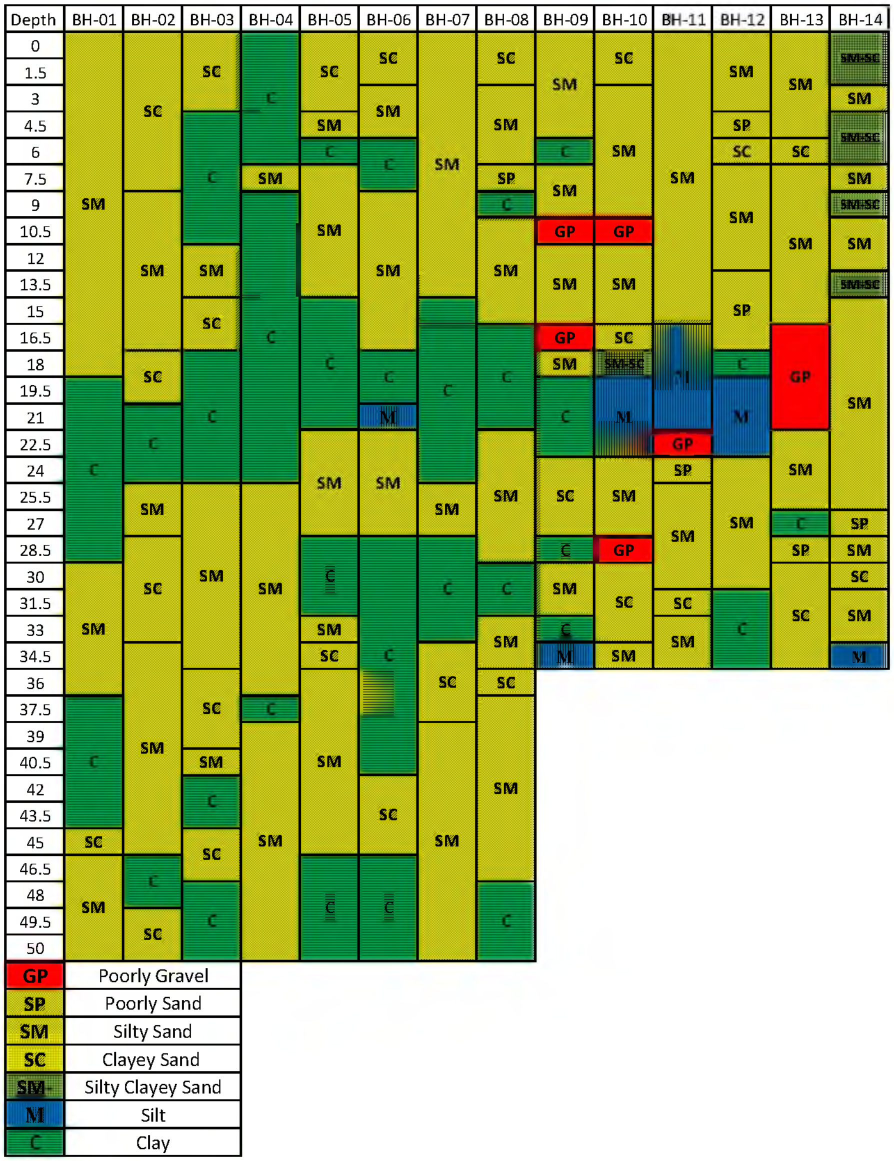
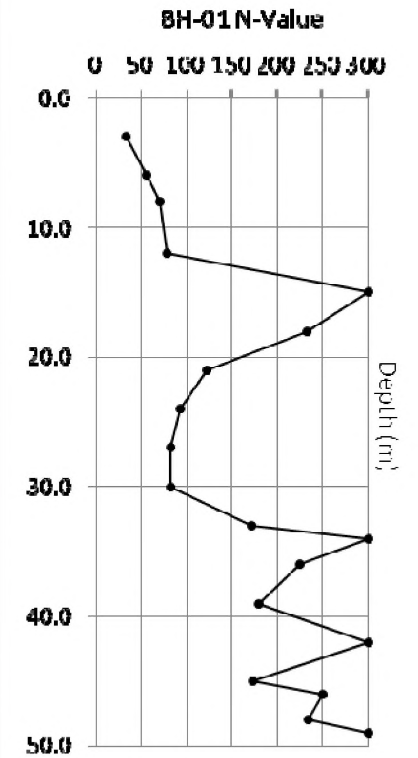
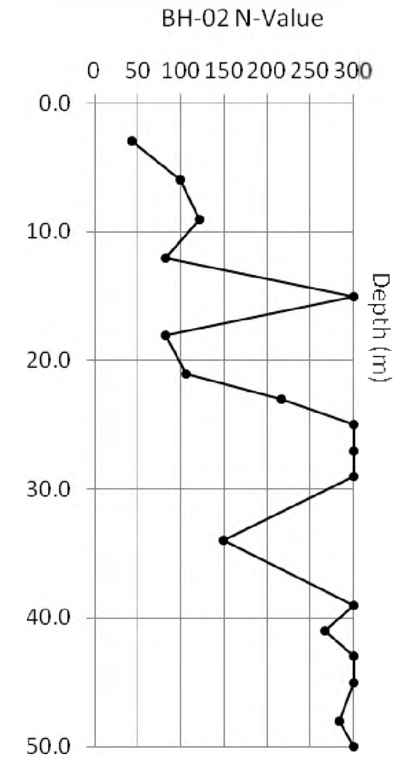


Fig. 7.5: Lithologs of Gandhinagar. Top layer is silty / clayey sand. Yellow: Sand, Green: Clay, Blue: Silt. SC: Sandy Clay, SM: Silty sand, CL: Clay with low plasticity, CI: Clay with intermediate plasticity, ML: Silt with low plasticity, MI: Silt with intermediate plasticity

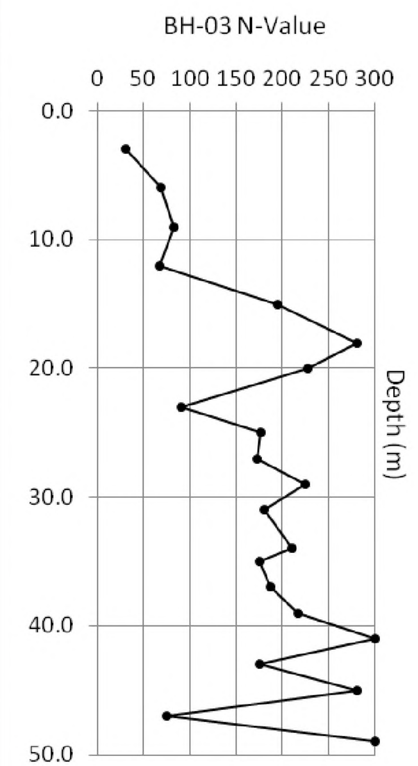
Depth	Log	N-SPT
0		-
1.5		-
3		33
4.5		-
6		56
7.5		-
9	SM	71
10.5		-
12		79
13.5		-
15		975
16.5		-
18		233
19.5		-
21		122
22.5		-
24	C	93
25.5		-
27		83
28.5		-
30		82
31.5		-
33	SM	171
34.5		-
36		225
37.5		-
39		180
40.5	C	-
42		300
43.5		-
45	SC	173
46.5		-
48		234
49.5	SM	375
50		-



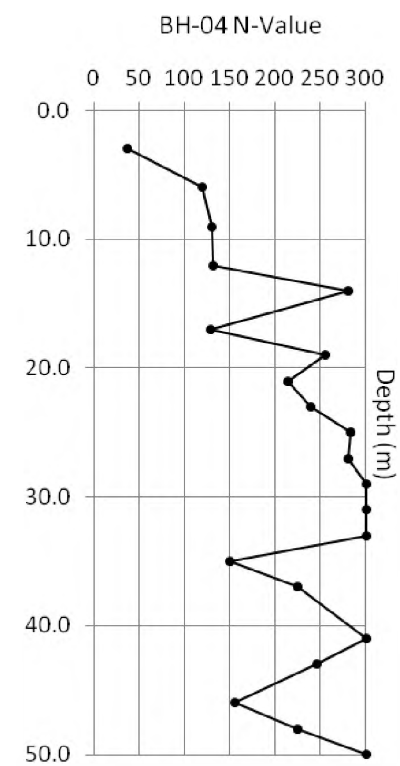
Depth	Log	N-SPT
0		-
1.5		-
3	SC	43
4.5		-
6		99
7.5		-
9		122
10.5		-
12	SM	83
13.5		-
15		468
16.5		-
18	SC	83
19.5		-
21		106
22.5	C	-
24		217
25.5		-
27	SM	650
28.5		-
30	SC	375
31.5		-
33		150
34.5		-
36		325
37.5		-
39	SM	325
40.5		-
42		267
43.5		-
45		338
46.5	C	-
48		283
49.5		-
50	SC	450



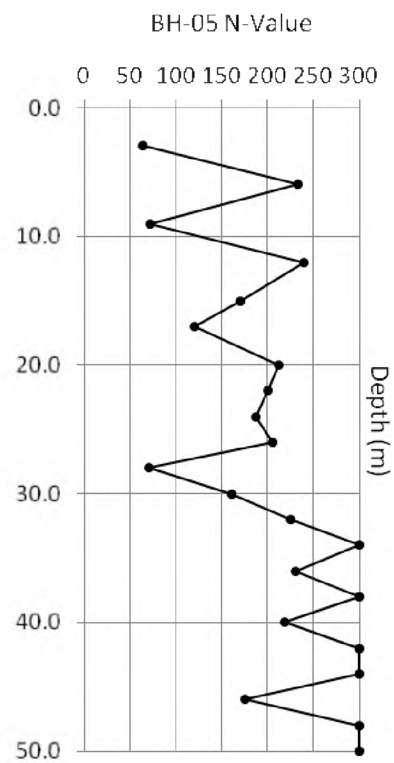
Depth	Log	N-SPT
0		-
1.5	SC	-
3		30
4.5		-
6		69
7.5	C	-
9		83
10.5		-
12	SM	67
13.5		-
15		195
16.5	SC	-
18		281
19.5		-
21	C	228
22.5		-
24		91
25.5		-
27		173
28.5		-
30	SM	225
31.5		-
33		210
34.5		-
36		188
37.5	SC	-
39		217
40.5	SM	-
42	C	175
43.5		-
45	SC	281
46.5		-
48		525
49.5	C	-
50		-



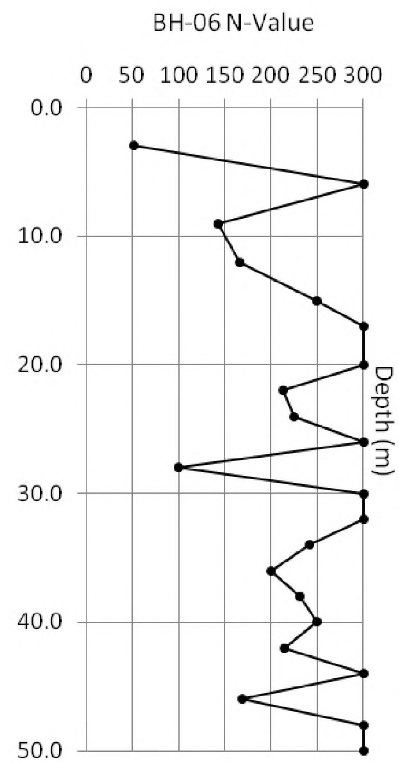
Depth	Log	N-SPT
0		-
1.5		-
3	C	37
4.5		-
6		120
7.5	SM	-
9		131
10.5		-
12		131
13.5		-
15		281
16.5	C	-
18		214
19.5		-
21		214
22.5		-
24		240
25.5		-
27		281
28.5		-
30	SM	400
31.5		-
33		300
34.5		-
36		225
37.5	C	-
39		300
40.5		-
42		245
43.5		-
45	SM	155
46.5		-
48		225
49.5		-
50		1000



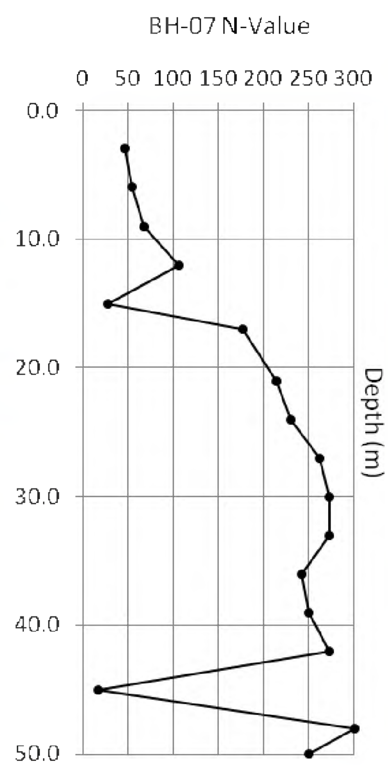
Depth	Log	N-SPT
0		-
1.5	SC	-
3		64
4.5	SM	-
6	C	233
7.5		-
9		72
10.5	SM	-
12		240
13.5		-
15		170
16.5		-
18	C	120
19.5		-
21		200
22.5		-
24	SM	188
25.5		-
27		205
28.5		-
30	C	161
31.5		-
33	SM	425
34.5	SC	-
36		231
37.5		-
39		218
40.5	SM	-
42		375
43.5		-
45		175
46.5		-
48		375
49.5	C	-
50		333



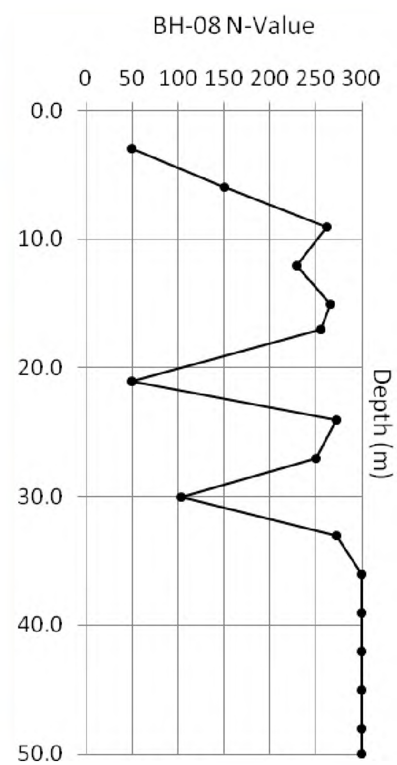
Depth	Log	N-SPT
0	SC	-
1.5		-
3	SM	52
4.5		-
6		300
7.5	C	-
9		143
10.5		-
12		167
13.5	SM	-
15		250
16.5		-
18		600
19.5	C	-
21	M	213
22.5		-
24		225
25.5	SM	-
27		100
28.5		-
30		500
31.5		-
33		242
34.5	C	-
36		200
37.5		-
39		250
40.5		-
42		214
43.5	SC	-
45		169
46.5		-
48		375
49.5	C	-
50		429



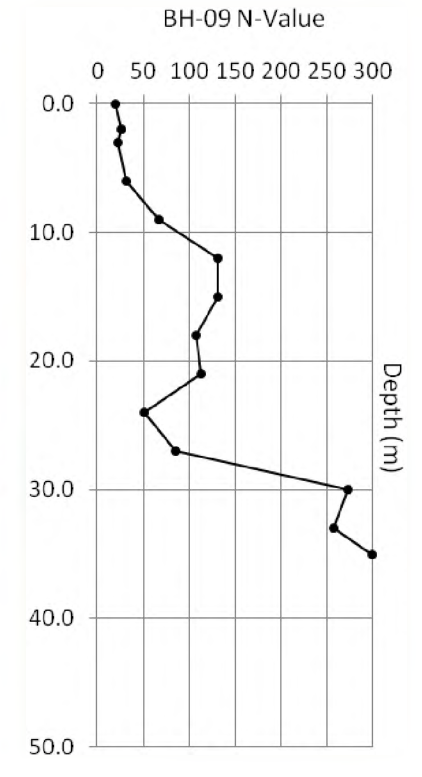
Depth	Log	N-SPT
0		-
1.5		-
3		46
4.5		-
6		54
7.5	SM	-
9		68
10.5		-
12		106
13.5		-
15		28
16.5		-
18		177
19.5	C	-
21		214
22.5		-
24		231
25.5	SM	-
27		263
28.5		-
30		273
31.5	C	-
33		273
34.5		-
36	SC	242
37.5		-
39		250
40.5		-
42		273
43.5		-
45	SM	17
46.5		-
48		375
49.5		-
50		250



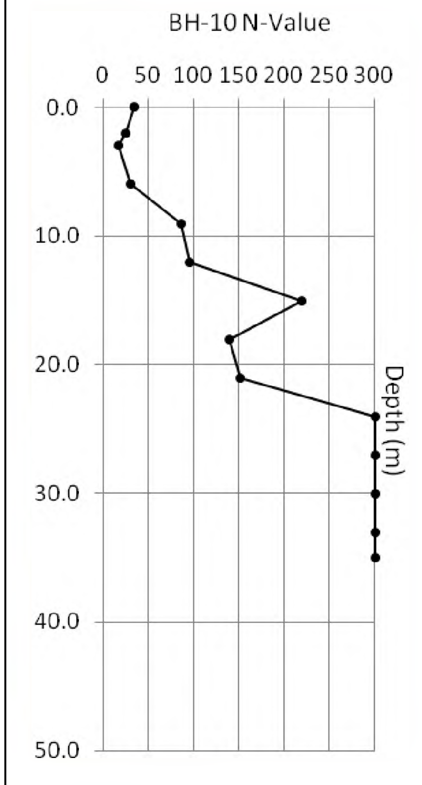
Depth	Log	N-SPT
0	SC	-
1.5		-
3		50
4.5	SM	-
6		151
7.5	SP	-
9	C	263
10.5		-
12	SM	229
13.5		-
15		265
16.5		-
18	C	255
19.5		-
21		49
22.5		-
24		273
25.5	SM	-
27		250
28.5		-
30		104
31.5	C	-
33	SM	273
34.5		-
36	SC	600
37.5		-
39		300
40.5		-
42	SM	300
43.5		-
45		333
46.5		-
48		375
49.5	C	-
50		600



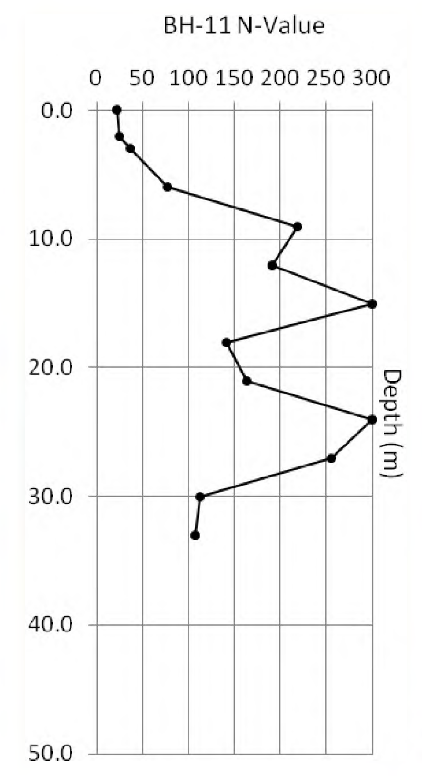
Depth	Log	N-SPT
0		20
1.5	SM	-
3		22
4.5		-
6	C	31
7.5	SM	-
9		67
10.5	GP	-
12		131
13.5	SM	-
15		132
16.5	GP	-
18	SM	108
19.5		-
21	C	113
22.5		-
24		51
25.5	SC	-
27		85
28.5	C	-
30	SM	273
31.5		-
33	C	257
34.5	M	-



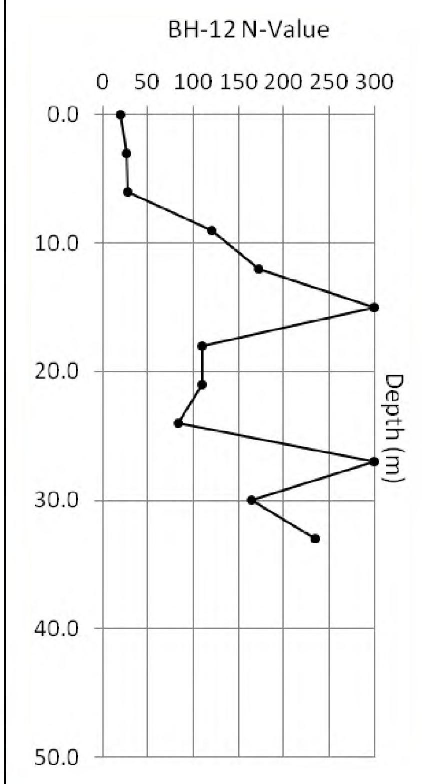
Depth	Log	N-SPT
0	SC	34
1.5		-
3		17
4.5		-
6	SM	30
7.5		-
9		86
10.5	GP	-
12		96
13.5	SM	-
15		219
16.5	SC	-
18	SM-SC	140
19.5		-
21	M	151
22.5		-
24		300
25.5	SM	-
27		350
28.5	GP	-
30		437
31.5	SC	-
33		600
34.5	SM	-



Depth	Log	N-SPT
0		22
1.5		-
3		37
4.5		-
6		77
7.5	SM	-
9		218
10.5		-
12		191
13.5		-
15		347
16.5		-
18	M	141
19.5		-
21		164
22.5	GP	-
24	SP	300
25.5		-
27	SM	255
28.5		-
30		113
31.5	SC	-
33	SM	107
34.5		-



Depth	Log	N-SPT
0		20
1.5	SM	-
3		26
4.5	SP	-
6	SC	27
7.5		-
9	SM	120
10.5		-
12		172
13.5		-
15	SP	383
16.5		-
18	C	110
19.5		-
21	M	110
22.5		-
24		84
25.5		-
27	SM	300
28.5		-
30		164
31.5		-
33	C	235
34.5		-



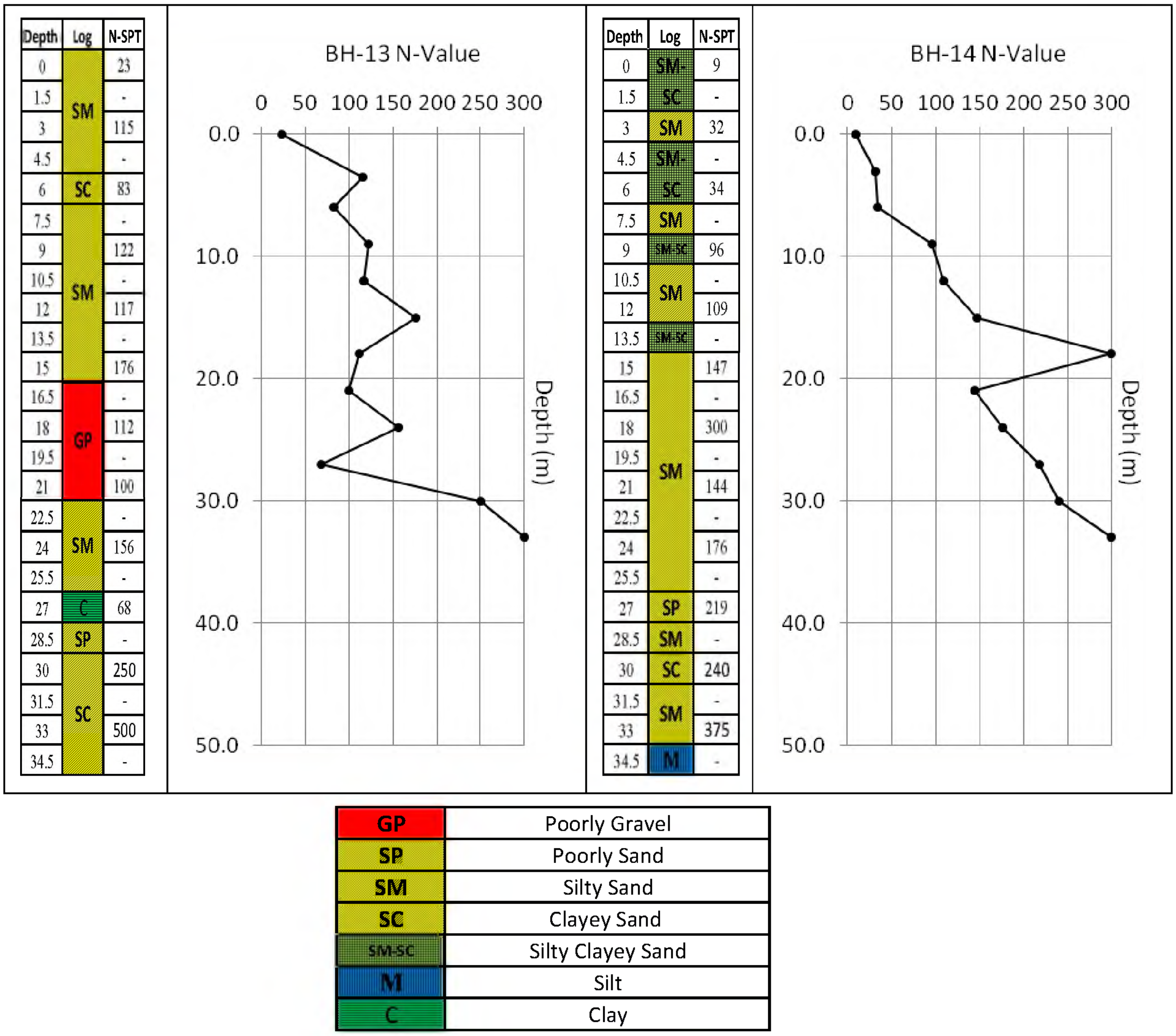


Fig. 7.6: N value Curves

3D and 2D Soil Model of Gandhinagar City:

A 3D model has been made using soil data of all 14 boreholes data as per Indian standard soil classification criterion (Figs. 7.7 to 7.9). It clearly shows that most of the area is covered by silty & clayey sand while clay and silt is found as small patches. Majority of the area is covered by Silty sand. The eastern region has Clayey sand strata at surface while some Clay patches are found in western region at lower depth but negligible at the surface.

Two 2D subsurface profiles (North to South & West to East) are plotted to get the more precise subsurface lithological assemblage. These subsurface profiles are developed considering the drilling and I.S. classification results.

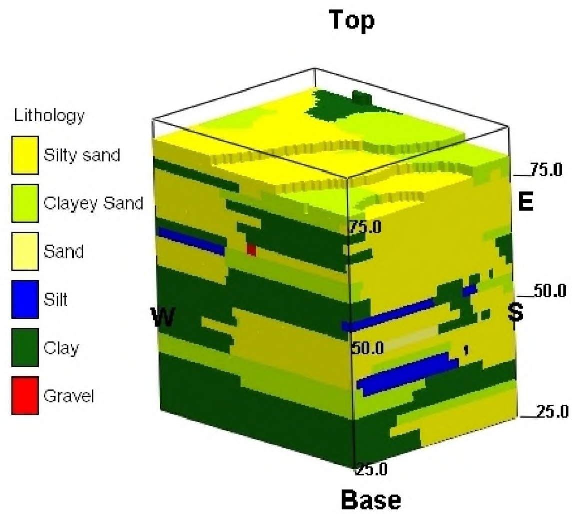


Fig. 7.7: Generalized 3D-Soil Model of Gandhinagar City. Elevations AMSL are marked

Profile I:

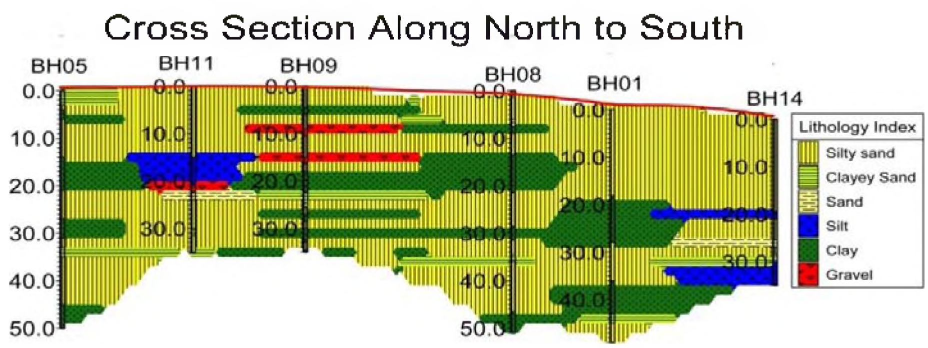


Fig. 7.8: The 2D profile in N-S direction

The direction of the above subsurface profile is from North to South. A total of six boreholes are taken in consideration for the subsurface stratum with maximum depth of borehole around 50m. Majorly, the subsurface stratum comprises of Silty Sand with significant patches of Clay and Clayey sand. Presence of gravel is also visible in very small patches.

Profile II:

For subsurface profile in West to East direction four boreholes are taken for the subsurface stratum with maximum depth of borehole around 50m. Majorly, the subsurface stratum comprises of Silty Sand. The Eastern region shows a thick layer of clayey soil. Presence of gravel is also visible in small patches at certain depths.

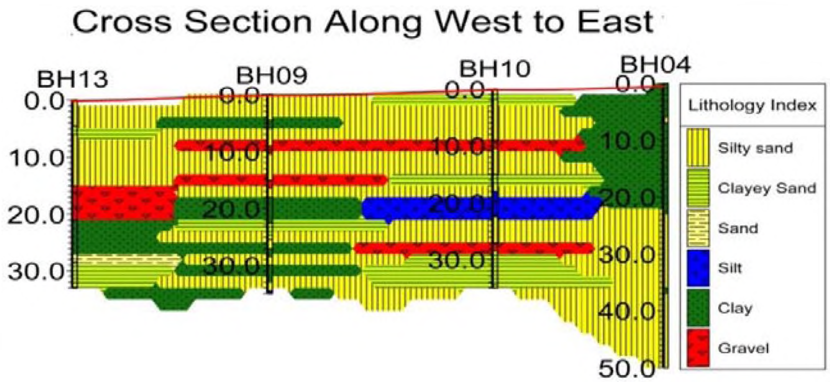


Fig. 7.9: The 2D profile in W-E direction

Table 7.4: Generalized Sub-Surface Litho-assemblage of Gandhinagar City

Layers	Soil Description with depth
1st layer	Thin layer (< 1m)of Humus and Land fill
	Comprises of Sandy soil with silt (0-18m)
2nd layer	Comprises of Clayey soil with silt (18-28m)
3rd layer	Comprises of Sandy soil with silt (28-45m)
4th layer	Comprises of Clayey soil with silt (45-50m)

Layer I: There are 14 boreholes covering whole city of Gandhinagar. Apart from a thin layer (< 1m) of humus and land fill, arenaceous and argillaceous soils are alternatively deposited with varying thickness in almost whole city. BH - 4, 10, 2, 1 and 14 lie along the river Sabarmati. It is found that the amount of coarse grained soil particle increases moving from North to South downstream along the river bank. In Southern region (around BH-14), clay is present in traces which gives boarder line classification of SM-SC to the soil. There is high clay content with some sand patches in NE region whereas in Eastern and SE region it decreases and further increases to some extent towards SW region. The central part of the study area covering BH – 8, 12, 9 and 11 comprises of silty sand layer up to approx depth of 18m. Like the central part, the western part of the study area also comprises of silty sand layer. But moving towards the NW region, small patches of clayey sand persist.

Layer II: There is a thin layer with varying depth of clayey soil stretched all over the study area except the western side which has sandy texture with little patch of clay at terminating depth. The NE and SW region has comparatively thick layer of clay content.

Layer III: Further, alternating thin layer of silty sand is observed throughout the study area. Apart from this SW as well as the western part has small patch of clayey sand at the lower end of this layer. NE region has comparatively thicker layer of silty sand till examined depth.

Layer IV: Again, thin argillaceous layer with some silt content exists in the study area all around. Especially the western region has mixed texture of clayey as well as sandy soil at lower depth.

Liquefaction Analysis

The results give nil potential for liquefaction hazard. Water table in Gandhinagar is around 25-30m. For liquefaction the water table has to be shallower than 20m. The soils with N-values greater than 100 do not liquefy. In Gandhinagr this value is generally at 1shallow depth of 10m or less. Soils having free swell index values greater than 100% are considered to be liquefiable and of of below 50% not. Swell indexes are measured to be < 50%.

Estimation of Engineering Bed Layer (EBL) at Gandhinagar

Depth to EBL is assessed from depth to a layer which is present in the entire area with Vs > 400 m/s and high N-value. Based on these considerations the EBL is found varying from 21 to 33m, being shallow in the central city area (Fig. 7.10).

ESTIMATE OF STRONG GROUND MOTION AT SURFACE

To estimate the effect of soil on ground motion and to estimate the strong ground motion parameters at surface, the soil modeling and the ground response analysis are conducted along uniformly distributed 14 boreholes drilled upto a depth of 50m. From the site response analysis it is seen that three layer boundaries are causing amplifications: Tertiary (900m/s)/Quaternary(760m/s) at depth of 300-400m, Pleistocene (760m/s) /Holocene (500m/s) at depth of 60-90m and the EBL at Holocene-I(500m/s)/Holocene-II(400m/s) at depth of 21 to 33m. The methodology is divided into three parts (i) Estimation of depth of Engineering Bed layer (EBL) (a layer with a shear wave velocity ≥ 400m/sec, N value >80 and minimum soil variation below it through soil modeling, (ii) Estimation of Ground Motion at EBL due to scenario earthquakes from Motadezian and Atkinson (2005) method of dynamic corner frequency stochastic finite source model (iii) Estimation of surface strong ground motion using 1D ground response analysis through SHAKE 2000 program. The amplification factors worked out by Boore for T/Q and P/H are applied. The EBL (at depth of 21 to 33m, Fig. 7.10) is shallower in central part and deeper in northern and southern parts. Due to this and / or shallower hard clay beds The Near Field scenario earthquake (Eq.) of magnitude Mw6.0 is considered along East Cambay Fault (normal fault, 60^{o} dip towards Gandhinagar) located at about ~ 20km east (Table 7.5) and Far Field scenario Eq. of Mw 7.6 is considered along Kachchh Mainland Fault located ~270km west (Table 7.6). The Peak Ground acceleration (PGA) of 0.172 to 0.237g (Fig. 7.11) and Peak Spectral Acceleration (PSA) of 0.522 to 0.851g (Fig. 7.12) with predominant periods of ~0.1sec and 0.25sec (10 Hz and 4 Hz corresponding to 1 to 3 storey buildings) are estimated in the city due to Near Field scenario Eq. Acceleration is found more in the central part probably due to the presence of silty sand in the central part as compared to clayey sand and higher N-value (a measure of soil strength) in the northern and southern parts. The shallower EBL in the central city area may not be the reason for higher acceleration.The PGA is found increased by 5 to 38% in the first subsurface soil layer in Gandhinagar city (being 11 to 38 % increase in silty sand and 5 to 28% increase in clayey sand layer) having thickness of 1 to 6m (Fig. 7.13). Hence, 5-38% lower PGA may be considered if foundation is deeper than 6 m. PGA of the order of 0.059g to 0.072g and peak Spectral acceleration of the order of 0.187g to 0.272g are computed due to Far Field scenario Eq. and are found less than Indian code. The PGA and Spectral acceleration (Sa) values (Fig. 7.14) are found higher than the Indian code in the period range of 0.1 to 0.4sec (one to four storey buildings) for Near Field Eq. PGA is up to 50% high while Sa is up to up to 100% at locations up to 20km from the East Cambay fault.

Earthquake Scenarios and Modeling parameters:

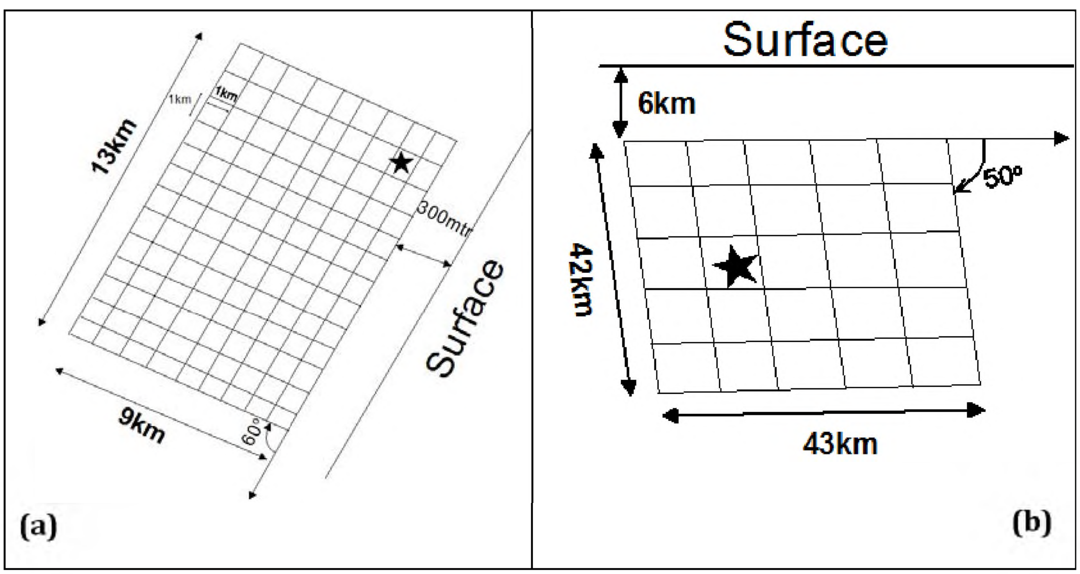
The two scenario earthquakes are: local magnitude 6.0 on East Cambay fault, distant magnitude 7.6 in Kachchh. Input parameters considered for strong motion simulation are given in Tables 7.5 and 7.6.

Table 7.5: Model Parameters for simulation of ground motion at EBL for Near Field Eq

Magnitude	6.0 (Mw)	
Fault Length and Width	13 km and 9 km	
Strike and Dip	N330° and 60°E	
Slip Distribution	Random	
Shear Wave Velocity	3.6 km/sec	
Density	2.8 gm/cm^3	
Stress Drop	40 bars	
Kappa	0.03	
Anelastic Attenuation Q(f)	$149f^{1.43}$	Chopra et al. (2010)
Geometric Spreading	$1/R$ ($R \leq 40$ km)	Bodin et al. (2004)
	$1/R^{0.5}$ ($40 \leq R \leq 80$ km)	
	$1/R^{0.55}$ ($R \geq 80$ km)	
Duration Properties	f_c^{-1} ($R < 10$ km)	Eastern North America
	$f_c^{-1} + 0.16R$ ($10 \leq R \leq 70$km)	Atkinson & Boore, (1995)
	$f_c^{-1} - 0.03$ ($70 < R \leq 130$ km)	
	$f_c^{-1} + 0.04R$ ($130 < R < 1000$ km)	
Pulsing Percent **Pulsing Percent**	50%	

Table 7.6: Model Parameters for simulation of ground motion at EBL for far field Eq

Magnitude	7.6 (Mw)	
Fault Length and Width	45 km and 40 km	
Strike and Dip	N100° and 50°S	
Slip Distribution	Random	
Shear Wave Velocity	4.1 km/sec	
Density	3.0 gm/cm^3	
Stress Drop	160 bars	
Kappa	0.03	Mandal & Johnston (2006)
Anelastic attenuation Q(f)	$800f^{0.42}$	Singh et al (2004)
Geometric Spreading	1/R (R ≤ 40 km)	Bodin et al. (2004)
	$1/R^{0.5}$ (40 ≤ R ≤ 80 km)	
	$1/R^{0.55}$ (R ≥ 80 km)	
Duration Properties	f_c^{-1} (R < 10 km)	Eastern North America
	f_c^{-1} + 0.16R (10 ≤ R ≤ 70 km)	Atkinson & Boore (1995)
	f_c^{-1} - 0.03 (70 < R ≤ 130 km)	
	f_c^{-1} + 0.04R (130 < R < 1000 km)	
Pulsing Percent	50%	



The rupture considered for (a) Near Field Eq. and (b) Far Field Eq. scenarios in the present study. The star shows the nucleation point of the rupture.

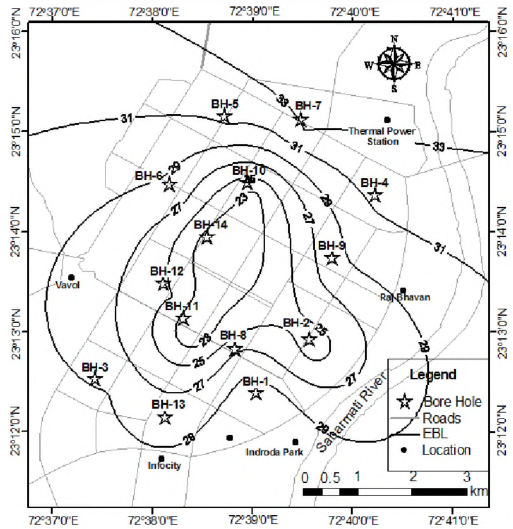


Fig. 7.10: EBL depth in Gandhinagar is 21 to 33m, being shallow in the central city area

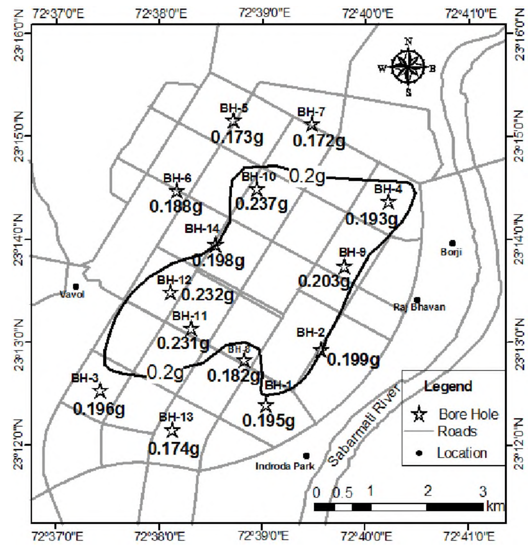


Fig. 7.11: Peak Ground Acceleration due to near field eq

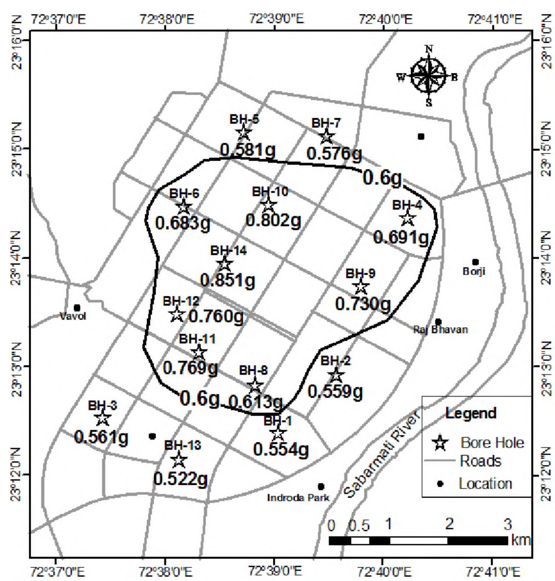


Fig. 7.12: Maximum Spectral Acceleration (coming for the period ranging 0.1-0.4s) due to near field earthquake in Gandhinagar

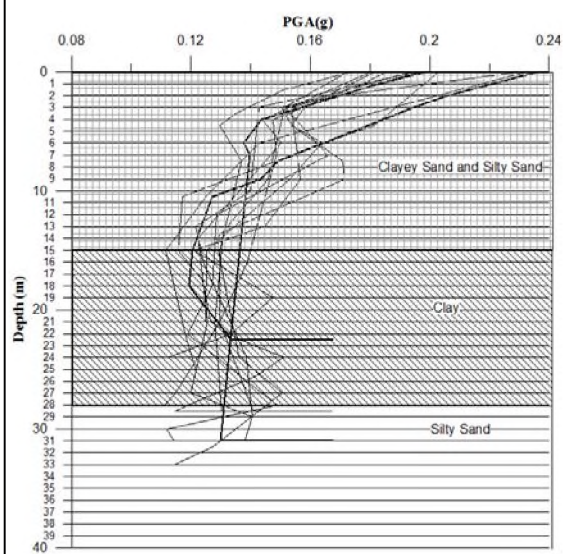


Fig. 7.13: PGA Vs. Depth along all boreholes

Ground Response Analysis:

The 1D Ground-response analysis is carried out using SHAKE2000 for both Near Field and Far Field earthquakes scenarios. The following four inputs are required in ground response analysis:

i. Simplified soil model based on Soil Type, density, thickness and shear wave velocity/ N value as discussed earlier
ii. Depth of base rock/EBL.
iii. Strong ground motion at EBL
iv. Shear Modulus and critical damping curves

The estimated outcrop ground motion using Stochastic Finite Fault Modeling Technique (Motazedian and Atkinson, 2005) which is taken as outcrop motion is to be converted to base rock motion. The SHAKE 2000 converts the outcrop motion to base rock motion. Amplification for soils of Vs30 (average shear wave velocity for upper 30 m) at 520 cm/sec is considered to estimate EBL (Outcrop motion) as proposed by Boore and Joyner (1997).

The soil behavior under irregular cyclic loading due to an earthquake is modeled using modulus reduction (G/G max) and damping ratio (β) vs. strain curves. The non-linearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer. The degradation curves for sand, clay and rock used for the present work are those proposed by Seed and Idriss (1970), Sun et al. (1980) and Schnabel (1973), respectively. These curves are shown in Fig. 7 and 8. These curves are built-in within the SHAKE within database and used during calculations by selecting the options.

Results of Strong Motion Analysis for Gandhinagar

PGA and Sa Estimates for Near Earthquake:

The PGA at surface varies from 0.172g to 0.237g (Fig. 7.11). Higher PGA (≥0.21g) is observed in the central Gandhinagar area (Sectors-5, 6, 11, 15, 16, 17, 22 and 24) due to presence of silty sand with low N-Value upto 18m of depth (Fig. 7.6). Lower PGA is observed in the northern area of Sectors 23, 27, 28, 29, 30 and Thermal Power station as well as in the southern part (Sec- 1 and 2) due to presence of Clayey Sand with high N-value in shallow layers as compared to Silty Sand in the central area).

Depthwise variation of PGA (Fig. 7.13) indicates significant increase in the top loose layer from 1 to 6m and a Clayey / Silty Sand layer at 10 to 14m depth. PGA is reduced in between 6 to 10m due to Clay patches with intermediate plasticity. The response spectra at surface for 5% damping indicate the peak Spectral Acceleration of 0.522g to 0.851g.

PGA and Sa Estimates for Kachchh Earthquake:

Strong motion at Gandhinagar is estimated for magnitude Mw 7.6 earthquake along the eastern part of Kachchh Mainland Fault. The strong ground motion is estimated at the surface by passing the input motion estimated from strong motion corresponding to Quaternary-Tertiary boundary (Base rock), Holocene-Pleistocene boundary and EBL which is Holocene I/II boundary through prepared soil models. The accelerogram thus generated at the suface of each borehole are having PGA at surface varying from 0.059g to 0.072g. The response spectra are computed at the surface of each borehole at 5% damping (Fig. 7.14). The peak Spectral acceleration is varying from 0.187g to 0.272g in the Gandhinagar City which is found less than BIS suggested values for Zone III.

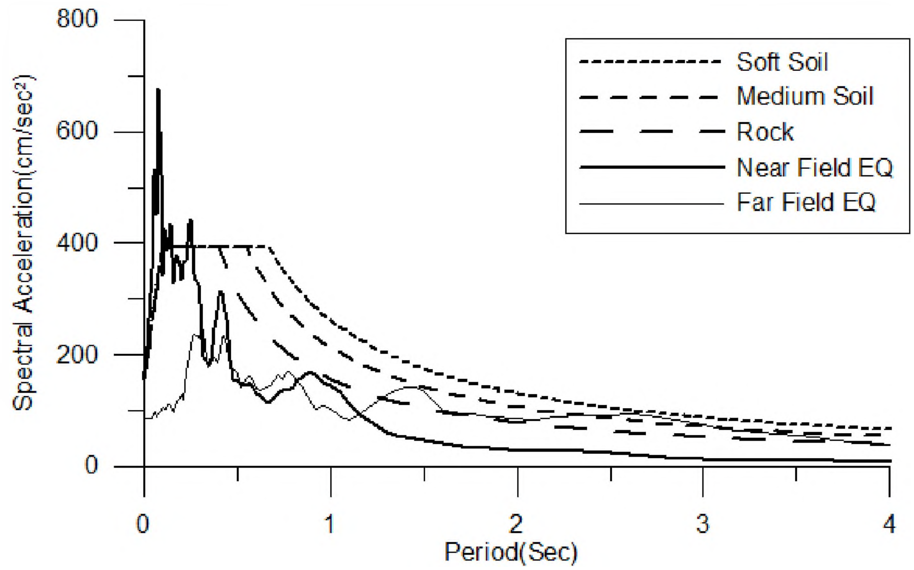


Fig. 7.14: Spectral acceleration for Gandhinagar considering amplifications from T/Q (1.5s, 0.6Hz), P/H (0.7s, 1.4Hz) and H-I/II (0.25s, 4Hz) boundaries

7.2 SEISMIC MICROZONATION STUDIES IN AHMADABAD

(B.K. Rastogi, Kapil Mohan, Sandeep Aggarwal, B. Sairam, Vandana Patel, A.P. Singh, Vasu Pancholi, Vinay Dwivedi, Rahul Ranjan and Suraj Singh)

Ahmadabad city has earthquake hazard of damaging MM intensity of VII-VIII as the city falls in seismic zone III of Indian classification. Earthquakes of M~6 could be along nearby Cambay faults or M~8 in Kutch at 250km distance. Moreover, there is possibility for site effects in the area as the city is on the riverbed of soft soils, which can amplify seismic waves and intensity of damage. During the 2001 Bhuj earthquake, several mid-to-high-rise buildings (of 5-10 floors and natural period 0.5 -1sec or 1-2 Hz) damaged or collapsed along the old path of the Sabarmati river (western-side of the river) and the lakes and ponds on east side of the river. We have carried out site response (SR) study at some selected damaged and undamaged sites using records of earthquakes (broadband) and microtremors (on broadband as well as 5sec seismometers). The SR was estimated at 12 selected sites using broadband seismograms of some 24 far field earthquakes ($M_w \geq 3.5$) and at 12 other sites by microtremor recordings. The Vs was measured using MASW and PS-logging at 65 selected sites. The Vs estimates show that average Vs of the top 30 m (V_{S30}) is in the range of 265-360 m/s. The western and southern areas with V_{S30} (265-280 m/s) experienced more damages compared to the higher V_{S30} (320 - 360 m/s) areas in the east and northeast part. The SR estimates show that maximum peak amplifications are up to 6, 4 and 2 in the frequency range of mostly 0.4 – 0.6 Hz sometimes extending up to 1 or 1.2 Hz (2.2-0.8s or 8-20 floor buildings), 1.5-2.0 Hz (0.6-0.5s or around 5 floors buildings) and 2.1-4.9 Hz (0.2-0.5s for 2-5 floors buildings), respectively. These frequencies correspond to resonance frequencies of 1-20 floors buildings. The maximum peak amplification of 1.5-2 is observed at 8-9Hz, which corresponds to one floor buildings. Some 18 boreholes were drilled (17of them to 80m depth and 1 to 50m depth) (Fig. 7.15) for geotechnical investigations. SPT-N value was estimated at every 3 m and soil samples collected every 1.5m. Different physical and mechanical soil properties were measured. The area mainly comprises of silty sand soil layer on surface followed by thin clayey layer beneath. Also, penetration resistance (field N-value) obtained shows that the soil upto shallow depth of 3m to 6m has loose texture becoming stiffer at lower depths.The soil profiles were prepared for the city and soil models were prepared for each borehole for ground response analysis using the SHAKE program. The SHAKE program indicates 50-100% higher PGA and Sa for periods of 0.1-0.4s than the national code up to 20km distance from a nearby fault. Beyond this period the acceleration is estimated within the national code. For a Kutch earthquake in Ahmadabad, even if the SR amplification is considered acceleration is expected to be within the national code. However, the higher mode vibrations due to 0.1-0.5s waves may cause damage to high-rise buildings (of natural period 1-2s) which has to be worked out by dynamic analysis. As there may be different characteristic frequencies at different locations the dynamic analysis needs to be done for each location. The site characterization map of the Ahmadabad city shows higher site effects along the western bank of the Sabarmati River and also along the lakes and ponds, where maximum damages occurred. However, it is found that the weak soil layer is to about 6m depth, below that is dense soil. This layer amplifies about two times the lower period (0.1-0.4s) waves. Hence, foundations deeper than 6m will be on firm ground and may experience less seismic force. These results imply that 1-20 floor buildings in the city area require careful seismic design.

Cambay basin around Ahmedabad and Gandhinagar comprises of ~300-350m Quaternary sediments over the Tertiary rock. The basin effect as observed from site response studies is as given in Table 7.7

Table 7.7: Depth to various Quaternary soil layers in Ahmedabad and Gandhinagar

Layer	DEPTH, m	Vs, m/s	F, Hz	A_{obs}	A_{cal}	Method
Quaternary-Tertiary	300-400	720	~0.6	2-4 (6)		Boore
Holocene-Pleistocene	60-100	600	~2	2-4 (6)		Boore
Holocene I-II (EBL)	25-35	400	~4	1.5-2		Boore
Holocene II- Nr. Surface	6-10	300	~8	1-2	1.5	SHAKE

The velocity-depth model of the crust proposed by Kaila et al. (1990) with Quaternary layers as assessed by us (Table 7.7) has been used for wave path effect from source to EBL in the stochastic finite source simulation EXSIM program of assessing input motion at EBL by Motadezian and Atkinson (2005). The strong ground motion at the surface is estimated by considering deep basin effect. The amplifications are computed for three layers up to a velocity of 550 cm/sec (EBL) corresponding to different shear wave velocity layers present in the Quaternary soil column. The amplification estimated w.r.t. frequencies from Boore (1996) methodology were supplied as input parameter to estimate strong ground motion at EBL. The Surface strong ground motion is estimated using ground response analysis through SHAKE 2000 program by passing strong ground motion estimated at EBL through prepared soil model from Geotechnical and Geophysical dataset (Fig. 7.16).

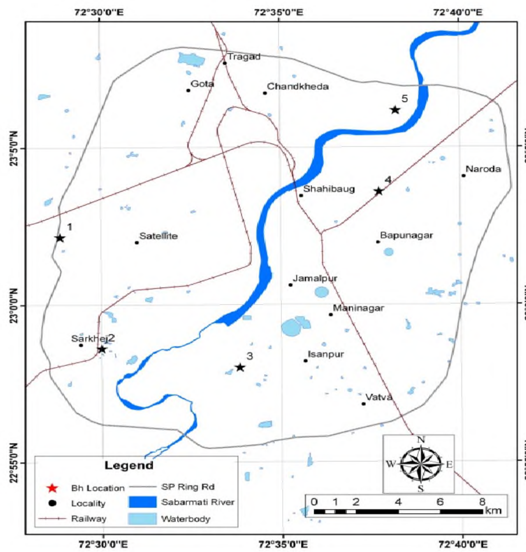


Fig. 7.15: Location map of boreholes in Ahmedabad

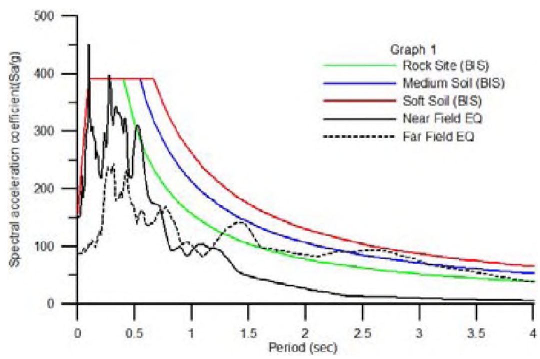


Fig. 7.16: The spectral acceleration (Sa) curves at 5% damping for near field (dotted line) and far field (with dark black line) scenario earthquakes at ground surface. The Sa curves are compared with BIS SA curves for Zone III

7.3 SEISMIC HAZARD ASSESSMENT OF MULTI-STOREY COMMERCIAL COMPLEX AT SCIENCE CITY ROAD, SOLA, AHMEDABAD.

(Kapil Mohan, B.K. Rastogi, Vasu Pancholi, B.Sairam, Suraj Kumar, Drasti Gandhi, and Rahul Ranjan)

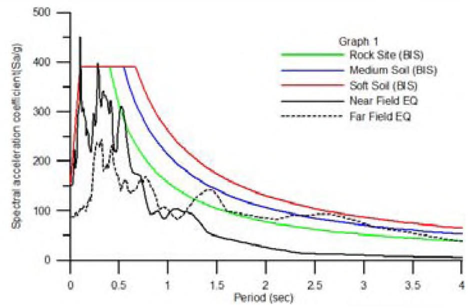
'The Capital' site is planned on Science city road at Sola area in Ahmedabad City. The structure is planned for 17 storey + 3 (basement). The Capital site can be affected by the following two earthquakes: One is "Far Field Earthquake" with larger magnitude such as Mw7.6 in Kutch where seismicity is high and the epicenter is more than 200 km away. The other one is "near field earthquake". The seismicity near The Capital site is low and maximum magnitude will be Mw = 6.0 along the West Cambay Margin Fault. According to the estimation in the project, near field earthquake and far field earthquake both can affect the site. Detailed calculations are made at 50 m deep borehole drilled at the site. Estimates have been made on PGA at engineering bed layer and ground surface, and also response acceleration spectra. These data can be referred for anti seismic design of structures in the area. The following assessments were made:

PGA of 150.8 gals (cm/sec2) and 94.8 gals (cm/sec2) are estimated due to near field and far field earthquake consideration. Also these values are within Zone factor Z=0.16g for Zone III of BIS (Bureau of Indian Standard) to which 'The Capital' site belongs. Geology, Soil and Geomorphology: In this project, existing literature on geology, soil and geomorphology are studied and deep soil investigation was conducted through drilling of 50 m deep borehole by ISR. Soil modeling for the ground response analysis was done at this borehole. Vs was determined by geophysical prospecting like shallow seismic (MASW). The necessary corrections to N-Values are also applied. Together with drilling and onsite tests, geophysical prospecting, the Engineering Bed Layer (EBL) was identified at the layer boundary of Vs around 550 m/s. The depth of EBL is fixed at 33.0 m from surface based on N-Value, Vs and Wet Density.

AVs30 (Average Shear Wave velocity between 0 - 30 m depth) is one of the critical index of dynamic ground characteristics. AVs30 is 300 m/sec. At surface ~ 200 m/s Vs is computed, which means relatively less amplification of seismic motion between EBL and surface. The soils in the study area is showing top Sandy layers which are very stiff in nature above the Clay layers which are hard in nature. Below clay, the hard sandy layers are present. At a depth of around 17.0 m, the corrected N-values reach > 50, while at deeper depths the values reach > 100. A total of 6 Direct Shear Tests were conducted on UDS for estimation of shearing values, which shows that the soils are of the order of Silty Sand and Clayey Sand (Shape: Round and Angular).

The area is falling in the "Not Liquified" category of liquefaction hazard. Hence it can be said that the area is safe from liquefaction.

The spectral acceleration (Sa) values computed from both near field earthquake scenario and far field earthquake scenario in ground response analysis using SHAKE program shows 452.1 cm/sec2 and 244.66 cm/sec2 at 5% damping, respectively (Fig. 7.17). The spectral acceleration is found higher than BIS suggested values at 0.1sec and 0.28sec corresponding to 1 to 3 storey building (approx.) in case of near field earthquake consideration. These values are lower than the BIS recommendation for ZONE III in case of far field consideration. In view of this, the Sa of 452.1cm/sec2 is recommended for 0.1 to 0.28sec and BIS Sa values of Zone III for period higher than 0.28sec to be on conservative side.



(a) **(b)**

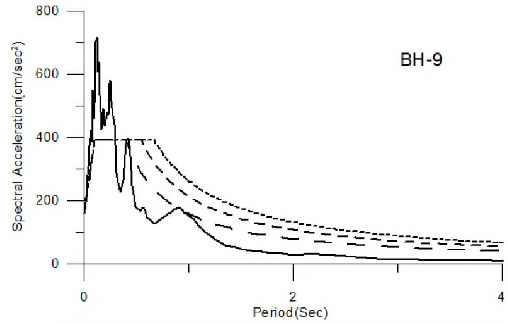
Fig. 7.17: (a) The planned multi storey building for which seismic Hazard assessment is conducted Fig : (b) The spectral acceleration (Sa) curves at 5% damping for near field (dotted line) and far field (with dark black line) scenario earthquakes at ground surface. The Sa curves are compared with BIS SA curves for Zone III

7.4 SEISMIC HAZARD ASSESSMENT OF VIBRANT SUMMIT EXHIBITION SITE IN GANDHINAGAR

(Kapil Mohan, Vasu Pancholi, Drasti Gandhi, Vinay Divedi, Santosh Kumar and B.K. Rastogi)

Seismic hazard was studied for the Exhibition Centre, Helipad ground, Sector 17, Gandhinagar. The constructions are up to 30m height. The area is 125000 sq. mtrs. Peak Ground Acceleration of 20% of Acceleration due to gravity 'g' and maximum spectral acceleration of 80% of 'g' was suggested.

The maximum earthquake of M5.7 occurred in the past in the vicinity of Gandhinagar city and possibility of magnitude M6.0 cannot be ignored. Therefore, Scenario earthquake of Magnitude Mw 6.0 is considered along East Cambay Fault (ECF). The strong ground motion is estimated at the surface by passing strong motion corresponding to EBL (Base rock) through prepared soil models. The accelerograms thus generated at the surface passing motion estimated EBL through soil models generated from Borehole data. The response spectra at 5% damping at the surface of both of the boreholes are computed. The maximum PGA of 0.2g and PSA of 0.85g is estimated from ground response analysis with a predominant period of 0.1sec (Fig. 7.18). The comparison of response spectra with Bureau of Indian Standards (BIS) codes show that the Spectral acceleration values are exceeding the BIS values in the period range of 0.1 to 0.4 sec and therefore 1 to 4 storey structures are to be constructed with site specific strong motion parameters.



(a) **(b)**

Fig. 7.18: (a) A model of Exibition Hall and (b) response spectra at one of the borehole computed through ground response analysis.

7.5 SEISMIC HAZARD ASSESSMENT OF CRYOGENIC ETHANE RECEIPT AND STORAGE FACILITY AT DAHEJ

(Kapil Mohan and B.K. Rastogi)

Soil Modeling, ground response analysis and Seismic Hazard is estimated at five boreholes drilled up to a depth of 50m. The earthquake of magnitude Mw6.0 is considered as Operating Basis Earthquake (OBE) for return period of 475yrs., Mw6.5 is considered as Safe Shutdown Earthquake (SSE-I) for return period of 2475 yrs. and Mw7.1 is considered as Safe Shutdown Earthquake (SSE-II) for return period of 10000 yrs. The South Narmada Fault is the nearest active fault in the region and therefore the scenario earthquakes are considered along this fault (extended portion closet to Dahej). The PGA and response spectra at 2% and 5% damping are generated for all three earthquake considerations. The design spectra is provided for seismic resistant design of cryogenic ethane receipt and storage facility.

CHAPTER 8

EARTHQUAKE PREDICTION RESEARCH

8.1 OPERATION OF MULTI-PARAMETRIC GEOPHYSICAL OBSERVATORIES

(K. M. Rao, M.S.B.S. Prasad and Prasanna Simha)

An earthquake research center at Bhachau and three Multiparametric Geophysical Observatories are operational since March 2009 in Kachchh region at Badargadh, Vamka and Desalpar for Earthquake Precursory Research. MPGO sites are east and northeast of the aftershock zone of 2001 Bhuj earthquake (Mw 7.6) where the activity has migrated from 2006 onwards. Magnitude 5 earthquakes are still occurring in Kachchh occasionally and 70 shocks of magnitude ≥1 are recorded on an average per month. Very Broadband Seismometer, Strong Motion Accelerograph, GPS and Radon recorders are installed at all the three sites. The radon sensors were only functional since June, 2013 after the recalibration/repair at Sarad Systems, Germany. Both Fluxgate magnetometers have worked well at Desalpar and Vamka. The DFM at Vamka is showing higher values of Z-component and other two components are normal. The Super Conducting Gravimeter which has been installed at Badargadh has worked smoothly. Two water level recorders at Desalpar and Badargadh are worked well. Three Overhauser Magnetometers, three Declination/Inclination Magnetometers, three ULF Magnetometers are installed at MPGO's in December-2012. All these Magnetometers are working well. ISR in collaboration with ISRO has established the CALVAL site at Desalpar. This site is useful for Calibration of optical and microwave sensors and validation of Geo-physical data products which form an integral and vital component of any satellite programme. There are no considerable earthquakes with magnitude more than 5.0 occurred in this region during 2014. However, we observed some anomalies in the magnetic, radon and gravity measurements which can be correlated with micro earthquakes in the region.

8.2 AEROSOL RADIATIVE FORCING FLUCTUATIONS AT RAN OF KACHCHH AND VALIDATION OF MODIS SENSORS- CAL-VAL ANALYSIS

The role of aerosol particles in atmospheric processes is extremely important in climate research, rain formation, weather forecasting, bio-geochemical cycling as well as remote sensing of the reflectance and texture of ground and other surfaces. The aerosol forcing affects the atmosphere in two ways: (1) direct effect - in which aerosols reflect and absorb solar radiation; (2) indirect effect – when aerosols affect clouds by (a) increasing drop concentration and optical depth and (b) by reducing drop size making the clouds more stable with lower potential to produce rain. The last effect extends the lifetime of the clouds and modifies ground wetness. For this reason, systematic studies are undertaken now in order to retrieve global as well as regional distributions of aerosols. As part of CAL_VAL ISRO programme, the CIMEL Sun photometer has been deployed at MPGO, Deslapur site in order to study the spatial and temporal variation of aerosol radiative forcing on the atmosphere and to validate the satellite sensors. The main purpose of CIMEL CE 318 automatic sun tracking photometer is to measure sun and sky radiance in order to derive aerosol properties, total column water vapour, ozone using a combination of spectral filters and azimuth/zenith viewing controlled by a microprocessor. It has been operating since 19th March 2014, and its diurnal variation of Aerosol Optical Thickness (AOT) at 550nm over different seasons in the desert environment has been shown in figure 8.1.

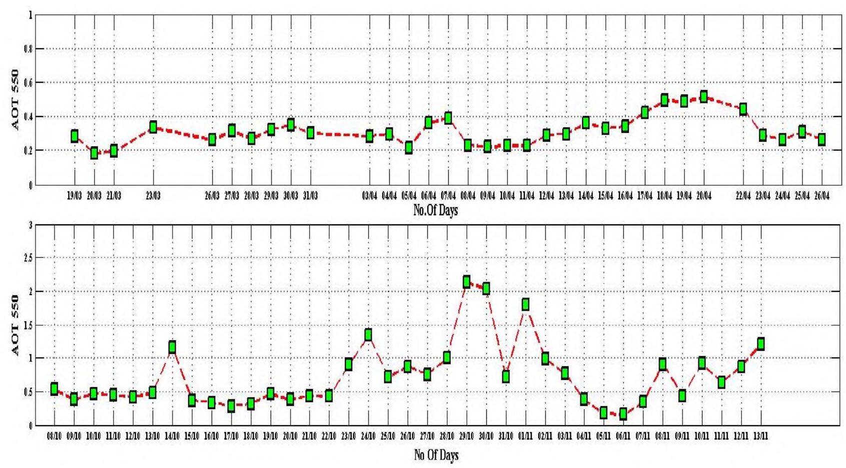


Fig 8.1: Diurnal Variation of AOT 550 at the MPGO, Desalpaur.

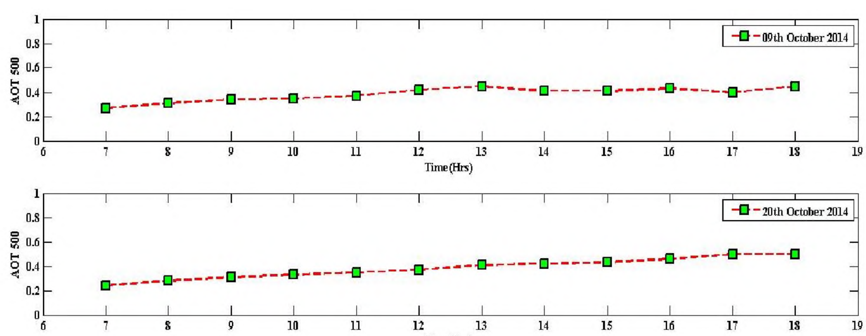


Fig 8.2: Temporal variation of AOT 550 over the MPGO Desalpaur.

The entire observation period has been divided in to two periods, i.e., Pre monsoon (March-Apr) and Post monsoon (Oct-Nov-Dec). Low AOT values have been noticed during the pre monsoon compared to post monsoon, and it's because of bringing of marine air mass to the desert environment. The AOT values have varied from 0.2 to 0.6, 0.2 to 3.0 during pre monsoon, post monsoons respectively. With the above discussion, its came to clear that aerosol radiative forcing is higher during pre monsoon period than post monsoon (i.e., higher AOT values will absorb more solar radiation cause lower aerosol radiative forcing and vice versa)and hence low pressure are created to the desert environment because of heavy aerosol radiative forcing, the desert are having quite stable boundary layer (fig. 8.2),on behalf of quite homogeneity and keeps continues heating of environment because of high radiative forcing the atmosphere to enhance the convection cycles to precipitate rains.

Validation of MODIS Sensor

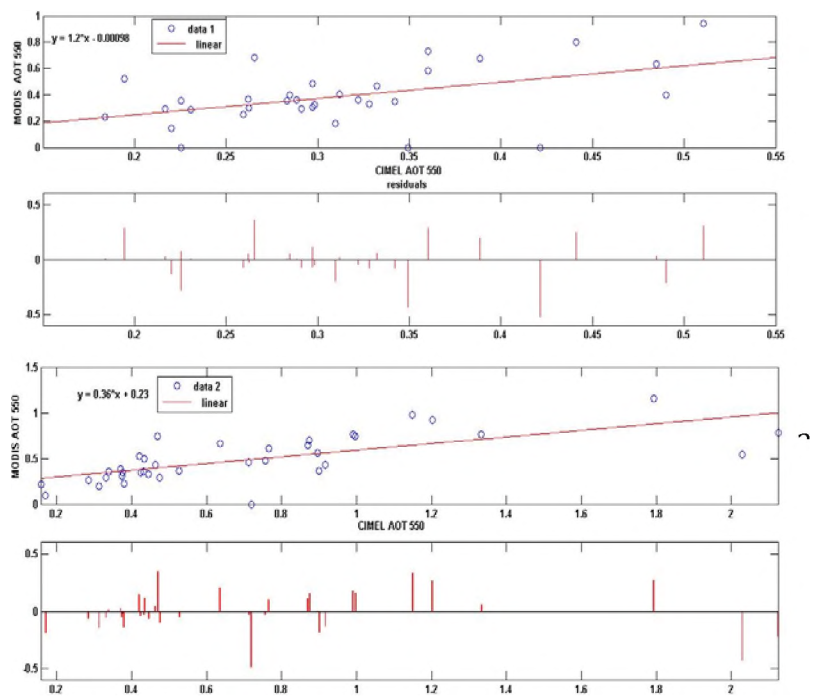


Fig 8.3: Validation of Vs MODIS, 1: Pre monsoon, 2: Post monsoon.

Figure 8.3(1&2) shows the validation of MODIS sensor data of AOT 550nm with our fully established CIMEL Sun Photometer AOT 550nm over two different periods. CIMEL data has nicely correlated with the MODIS satellite sensor and its correlation coefficient (R2 value) observed to be 1.028 for pre monsoon period and 1.054 during post monsoon period. In both the cases, first order linear fit has shown that MODIS satellite data and CIMEL AOT is varying linearly (Fig.3, y= mx+c, c≈0). In order to further validate MODIS data with CIMEL AOT, residual analysis have carried out over the two different seasons, that is variation of archived CIMEL and MODIS data from reference zero line, in that analysis pre monsoon values have shown more positively than post monsoon values. With the effect of haze and heavy fog with one to one relation between MODIS and CIMEL has disrupted compared to pre monsoon period.

8.3 PASSIVE REMOTE SENSING TECHNIQUES TO STUDY THE ANNUAL AND SEASONAL VARIATION OF THE AEROSOLS, PRECIPITABLE WATER CONTENT, AND TOTAL COLUMNAR OZONE IN LITTLE RANN OF KACHCHH AND RANN OF KACHCHH, GUJARAT, INDIA.

The seasonal and annual variations of Aerosol Optical Thickness (AOT), Preceptible Water Content (PWC) and Total Columnar Ozone (TCO) in the Little Rann of Kachchh and Rann of Kachchh near the MPGO site, Desalpaur are observed in this study. The main objective is to study the AOT, TCO and PWC changes in Rann of Kachchh over winter and summer seasons and its influence on the monsoon cycle. We have followed standard protocol for field measurements such as 32 campaigns in little Rann of Kachchh (2012-13) and 32 campaigns in Rann of Kachchh (2013-14) in synchronization with some of the Indian satellites such as IRS-P6, IRS-RS2, OCM-2 of ISRO and Land SAT 7+ of NASA satellite. For the above mentioned periods of satellite radiance, estimated radiance have been computed by compiling the 6S radiative transfer code (input as: Zenith Angle (θ), Azimuth Angle, AOT, PWC, TCO and ground reflectance) in Fortran-77 within the limits of different band radiance of the satellites sensors (Green, Red, Nir and Swir bands). Passive remote sensing technique have been applied for our study and it works on the principle of beer-lamberts law and differential optical absorption techniques, portion of light which is coming from the sun after attenuating by scattering and absorption of water molecule, aerosols and gasses has taken at a certain zenith angle. Spectral analysis of the acquired data over two years in different seasons reveals the different species concentration such as AOT at 550nm, Preceptible water content(PWC), and Total columnar ozone(TCO) over the desert site. Influence of the desert aerosols radiative forcing over the study period has been done by computing the fraction of sunlight attenuated by aerosols and its influence for active and break monsoon over the study period. 10 to 20% high AOTs at lower wavelength have been observed at Rann Of Kachchh (2014) than Little Rann of Kachchh (2013), which tells the more abundance of absorbing type aerosols due to accumulation of finer particle in the year of 2014 than 2013, IMD observatories also recorded rainfall of 777.33mm in 2013(excessive rainfall) and 463.9mm in 2014(normal rainfall) over Gujarat in monsoons.

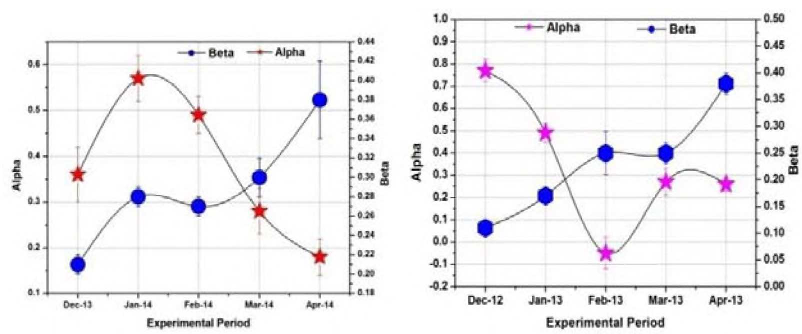


Fig 8.4: Aerosol loading over the two sites during 2013, and 2014.

The loading of aerosols in 2013 and 2014 in the Little Rann of Kachchh and Ran of Kachchh is shown in figure 8.1. Alpha and beta are the second order logarithmic derivatives between spectrum AOTs and wavelengths. Alpha is the ratio of larger particle to smaller particle, higher alpha represents domination of larger particle compared to the smaller particle, larger particle are mainly generated by the natural activity (such as originated by Ocean, Desert, Volcanos).

During the study period, higher alpha has observed during 2013 than 2014 (Figure. 4), which means accumulation of more marine air mass which has evidenced by NOAA hysplit back trajectory model at different altitudes (500m,1500m,2000m, Figure 8.5 & 8.6). With the higher aerosol radiative forcing and the increased convections, excessive rainfall has register during 2013 compared to 2014(IMD)

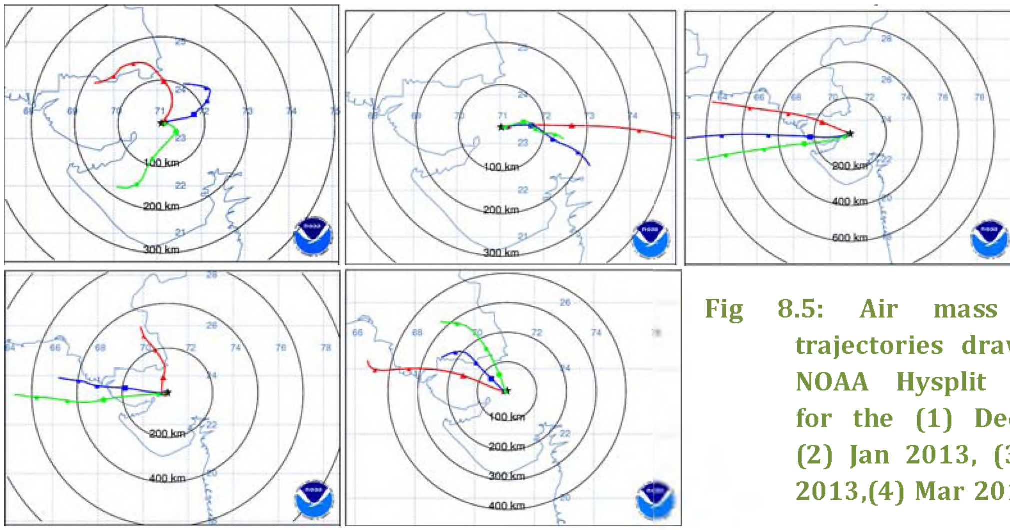


Fig 8.5: Air mass back trajectories drawn by NOAA Hysplit Model for the (1) Dec2012, (2) Jan 2013, (3) Feb 2013,(4) Mar 2013, (5)

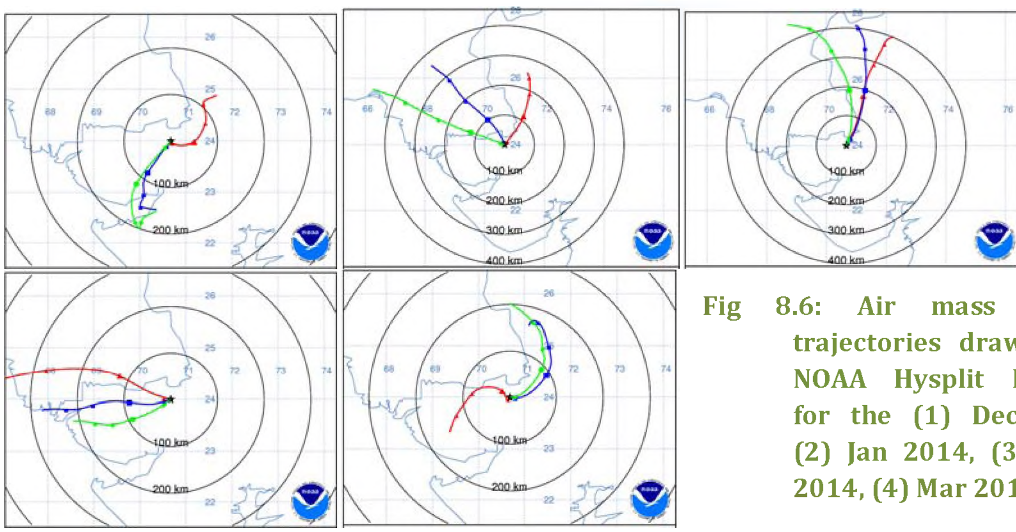


Fig 8.6: Air mass back trajectories drawn by NOAA Hysplit Model for the (1) Dec2013, (2) Jan 2014, (3) Feb 2014, (4) Mar 2014, (5)

8.4 VALIDATION OF TEC DERIVED FROM PERMANENT GPS STATION AND IRI MODEL

The validation of the TEC derived from permanent GPS station(bela) and with IRI-2012 (FORTRAN-77) has done during 30th May to 09th June 2013 (10 days). The approach to derive TEC from GPS station data is to estimate the 'satellite plus receiver' biases from the nighttime portion of the data, when the ionospheric TEC is negligibly small. Then the estimated biases are applied to the slant TEC measurements, from which the vertical TEC is computed, and this data, along with the estimated biases, are then used to fit a simple model ionosphere at the points of a 2-d grid at the ionospheric height using a weighted least squares estimator. The first step is preprocessing of the raw data. The Matlab code has developed to get RINEX format for data files, including an extension of the standard RINEX specification that allows intermediate results, as well as the raw data, to be stored within the RINEX format. It takes dual frequency range data in the input RINEX file (obtained from the permanet GPS site(Bela)) and computes the slant ionospheric delay, the latitude and longitude of the 'pierce point', and the elevation and azimuth of the satellite, storing the results in an 'extended' RINEX format file. The output file includes, in the file header, a unique label for the receiver as well as the precise receiver position.

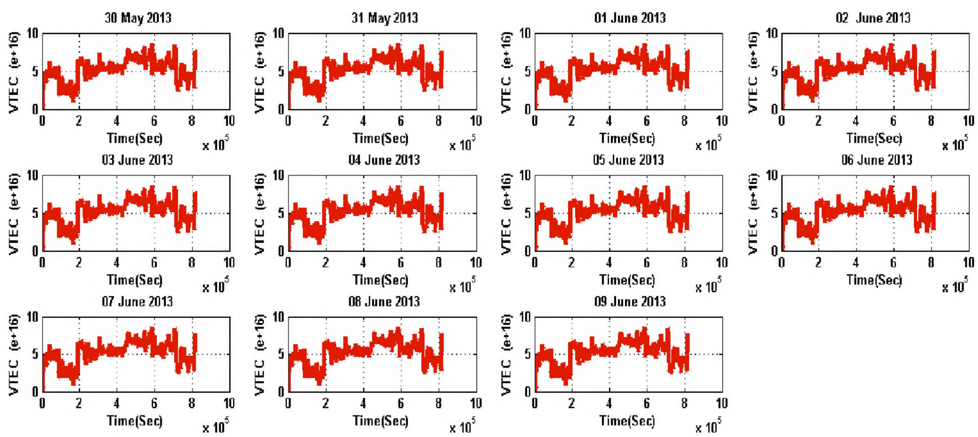


Fig 8.7: Temporal Variation of VTEC values from the GPS station data.

Temporal variation of VTEC (vertical TEC values) has been shown in figure 8.7. It has followed very low at morning and evening time and maximum in the after noon period because of accumulation of more electron because of high solar activity in after noon, it has varied from 0.1 to 7.2TECU with 0.01 sigma during 10 days of period. This type of behaviour is in association with the sun spot activity. In order to validate our results GPS, IRI modeled TEC is also derived during the above study period.

The Modelled STEC values have varied from the 0.1 to 4TECU and observed minimum in morning and evening and peak at after noon period because of accumulation of more electron because of high solar activity in after noon (Figure 8.8). Derived and modelled TEC values are in the range the little difference of 2TECU has observed because of modelled output is STEC where mapping function(f(zenith angle)) has not done. But whereas derived VTEC, multiplication of mapping function has done, hence little bit very minimum difference has observed.

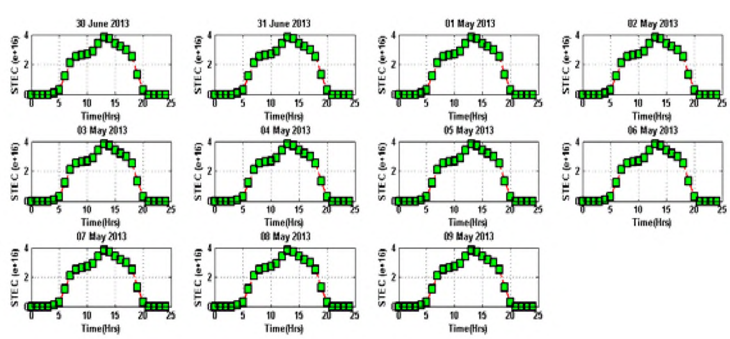


Fig 8.8: Temporal Variation of STEC values from the IRI-2012 model from igs station data.

8.5 TEC, SST, OLR AND ATMOSPHERIC PRESSURE ANOMALIES DURING THE GREATER EARTHQUAKES IN THE KACHCHH

Atmospheric-ionosphere variations in association with greater earth quakes (Magnitudes 4.1) in the Kachchh have been studied by using IRI 2007 Fortran Model, and NCEP NCAR reanalysis data. The STEC have been derived by using IGS data set using IRI 2007 FORTRAN model and sea surface temperature (SST), Outgoing long wave radiation (OLR) and atmospheric pressure (mB) for the greater earthquakes of magnitudes 4.1 in the Kachchh, Gujarat. Figure 8.9 shows the STEC variations with in the vicinity of 4.1 earthquake (9th March 2014), the values have varied from 0.1 to 5.6TECU with sigma (2.16) and it's having range of 5.5 TECU, because of modelled gridded outputs, sigma (error bar) has increased.

Sea surface Temperature (SST) anomalies have been plotted for the above earthquake regime (figure 10), the positive and negative anomalies have been computed for the study area, and in association variations nearer to the event site (Kachchh) have analysed. The anomalies have been computed by considering difference of two days (8days), 4 figures have obtained, third one is the event time anomalies, rest are pre and post variations. The SST anomalies with in the vicinity of preparatory zone is from -1 to 0.5, little bit of enhancement of SST (0.5) have been clearly noticed in the third one of figure 8.10.

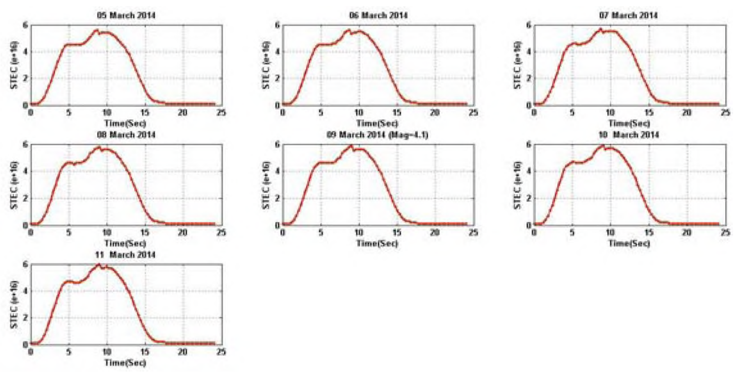


Fig 8.9: Temporal variation of STEC from IRI model during the earthquake.

Outgoing Long wave radiation (OLR) anomalies have been plotted for the above earthquake regime (figure 8.11), the positive and negative anomalies have been computed for the study area, and in association variations nearer to the event site (Kachchh) have analysed. The positive and negative anomalies have been computed for the study area, and in association variations nearer to the event site (Kachchh) have analysed. The anomalies have been computed by considering difference of two days (8days), 4 figures have obtained, third one is the event time anomalies, rest are pre and post variations.

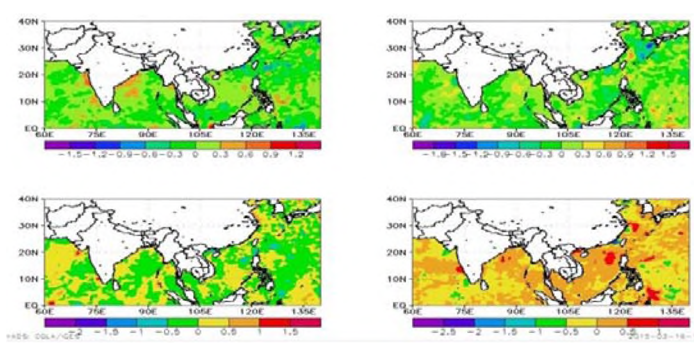


Fig 8.10: SST anomalies for the greater earthquake.

The SST anomalies with in the vicinity of preparatory zone is from -20 to 60, the OLR has increased up to 60 above in the event time sustained after that also figure 8.11.

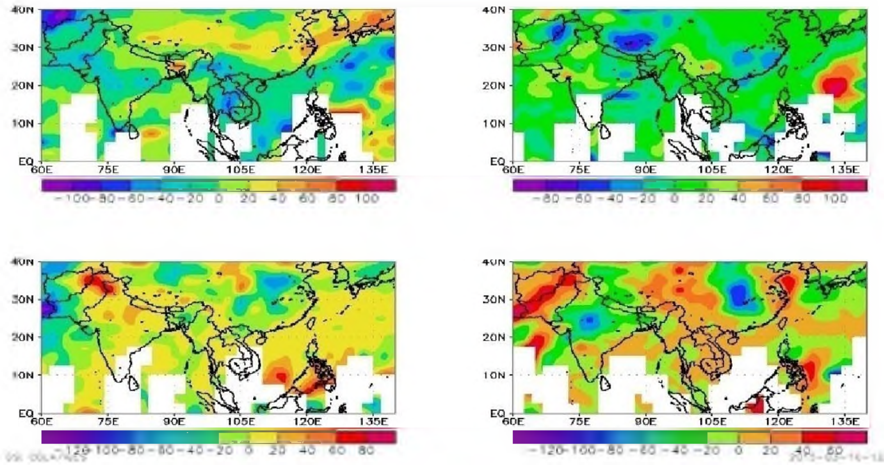


Fig 8.11: OLR anomalies for the greater earthquake.

Atmospheric Pressure (mB) anomalies have been plotted for the above earthquake regime (figure 8.12), the positive and negative anomalies have been computed for the study area, and in association variations nearer to the event site (Kachchh) have analysed. The positive and negative anomalies have been computed for the study area, and in association variations nearer to the event site (Kachchh) have analysed. The anomalies have been computed by considering difference of two days (8 days), 4 figures have obtained, third one is the event time anomalies, rest are pre and post variations. The Pressure anomalies with in the vicinity of preparatory zone is from -200 to 200, the atmospheric pressure have shown only during the event time and raised up to 200 and suddenly drops after the event(as shown in figure 8.12).

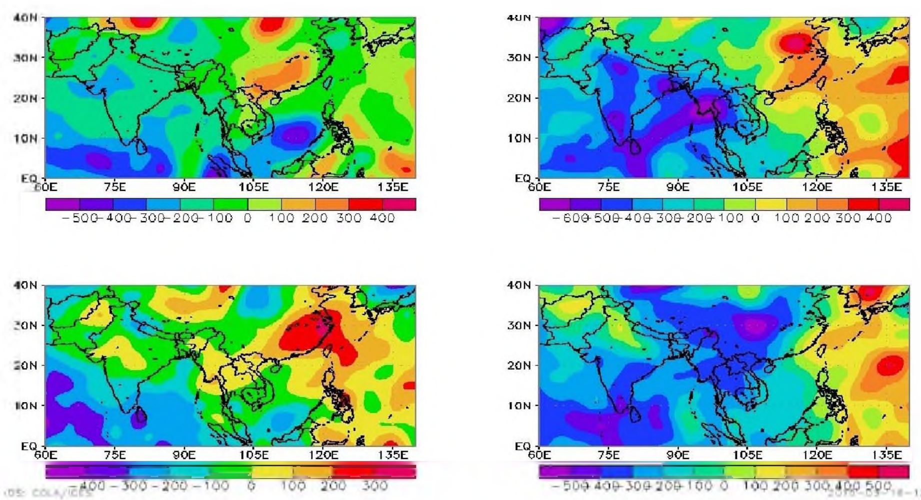


Fig 8.12: Atmospheric Pressure anomalies for the greater earthquake.

8.6 DETECTION AND EXTRACTION OF DIURNAL AND SEMI- DIURNAL COMPONENTS FROM SUB-SOIL RADON-222 TIME SERIES IN SEARCH OF POSSIBLE EARTHQUAKE PRECURSOR

Sub-soil radon concentration has been continuously monitored at a subsurface depth of 1 meter at ISR premises (23.1600N; 72.6680E), Gandhinagar with an aim to find out possible earthquake precursor. The entire time series has been analyzed by means of various mathematical tools such as FFT analysis to detect various oscillations involved in the data set. Empirical Mode Decomposition (EMD) method has been applied to extract various oscillatory modes indicated by FFT analysis. The diurnal and semi-diurnal oscillations are observed in the sub-soil radon-222 time series data during January 01, 2014 to May 10, 2014 shown in Fig. 8.13.

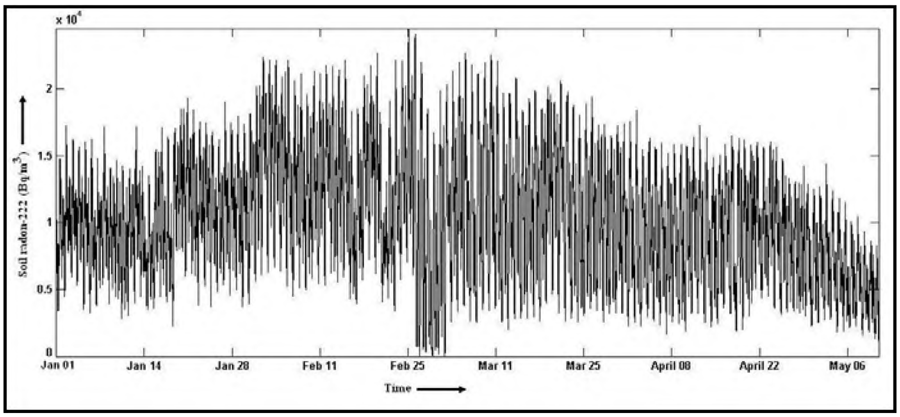


Fig 8.13: Soil radon time series recorded during January 01, 2014 to May 10, 2014 at ISR, Gandhinagar campus.

Primarily, we have selected a day long concentration profiles of soil radon recorded during 6-7 arbitrary days of the months of the observation period. Figs. 8.14 and 8.15 exhibit clearly that the concentration oscillates twice a day very prominently. This feature is supported by the FFT periodograms generated from the time series in Fig 8.16. Two sharp oscillations have been clearly observed in Fig 8.16. Now, in order to find out the seismic contribution we have extracted these oscillations by means of Empirical Mode Decomposition method. The essence of the method is to identify the intrinsic oscillatory modes by their characteristic time scales in the data empirically, and then decompose the data accordingly.

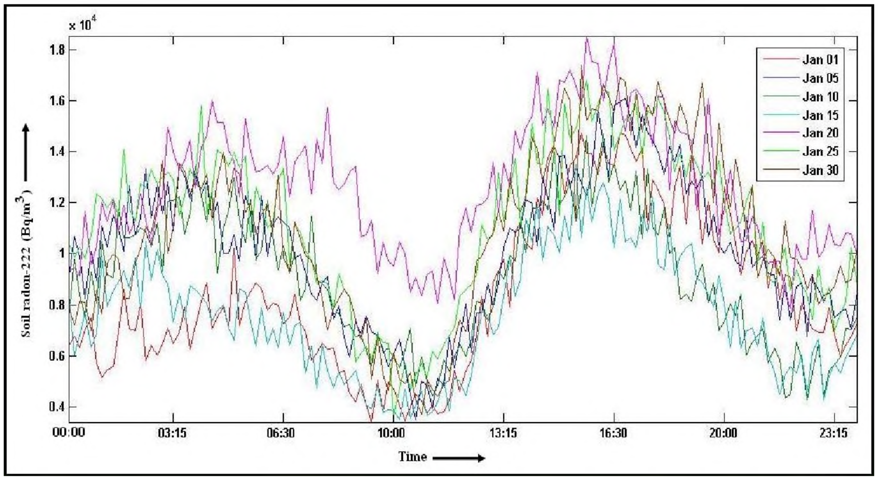


Fig 8.14: Soil radon concentration of 7 days (1st, 5th, 10th, 15th, 20th, 25th, 30th days of the month) during January, 2014.

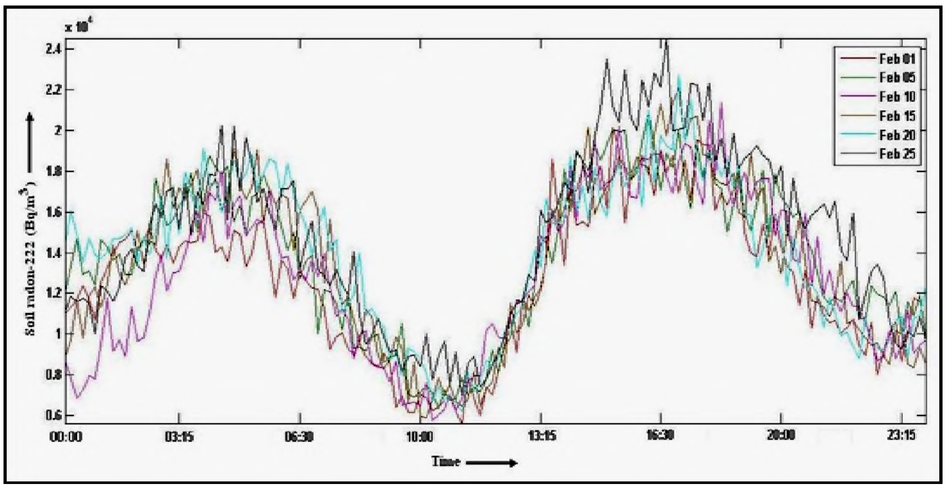


Fig 8.15: Soil radon concentration of 7 days (1st, 5th, 10th, 15th, 20th, 25th days of the month) during February, 2014.

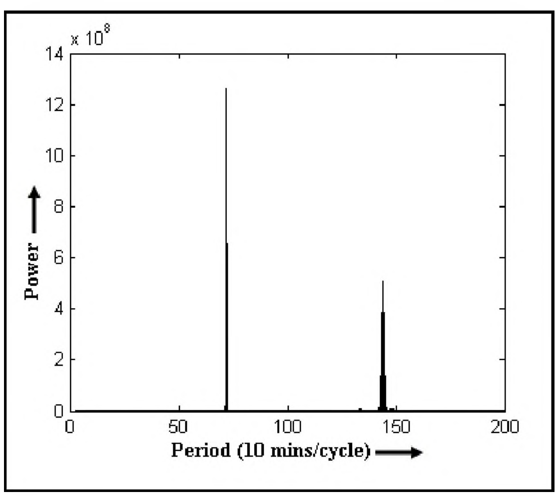


Fig 8.16: FFT periodogram of the radon time series shown in Figure 8.13.

The method is described below.

The decomposition is based on the assumptions: (1) the signal has at least two extrema (1) one maximum and one minimum; (2) the characteristic time scale is defined by the time lapse between the extrema; and (3) if the data were totally devoid of extrema but contained only inflection points, then it can be differentiated once or more times to reveal the extrema. Final results can be obtained by integration(s) of the components. The iterative method of EMD consists of the following steps:

i. Find a sequence of local maxima and fit a spline through it, Xip.

ii. Find a sequence of local minima and fit a spline through it, Xin.

iii. Find the mean, Xm= (Xip+Xin)/2

iv. Calculate the residual, Xr=X−Xm.

v. Iterate steps (i)−(iv) on Xr until a stopping criterion is satisfied yielding the first intrinsic mode function (IMF), C1=Xm.

vi. Calculate the residual, R1=X−C1 and iterate procedures (i)−(v) replacing X with R1 to obtain the second IMF, C2.

vii. Repeat steps (i)−(vi) for successive mode functions, Ci+1=Ci−Ri+1 until only a trend is left as the residue.

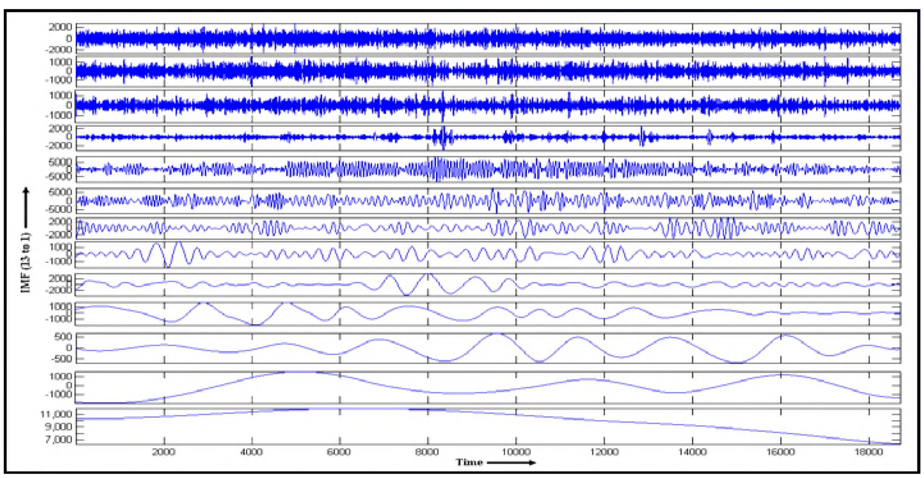


Fig 8.17: IMFs generated by applying Empirical Mode Decomposition method to the soil radon time series data shown in figure 8.13.

The IMFs generated by applying the above iterative process are shown in Fig. 8.17. The frequency or period of all these IMFs are determined by means of FFT analysis same as in Fig. 8.16. The first 4 (four) IMFs (from top in Fig. 8.17) evaluates with high frequency or small period. Primarily, these are mainly introduced by instrumental setup and may be treated as noise part in the signal. These may not be considered to be very significant modes in analyzing soil radon-222 signal for seismic purpose. The 5th, 6th and 7th IMFs from the top in Fig 8.17 evaluates with period 12 hours and 24 hours. These two periodic oscillations are primarily observed in all the one day data segments in Figs. 8.14-8.15. These two periodic modes are basically the influence of Earth tides, present in the soil radon data. These daily periodic components are removed from the signal. Rests of the IMFs are of low frequency- high period. These components are integrated and depicted in Figure 8.18 (lower panel). The high frequency components along with the daily oscillations are summed up separately and shown in Fig 8.18 (upper panel). The last IMF is nothing but the trend of the data set which clearly indicates higher radon emanation during dry- winter season.

This EMD-based algorithm is utilized in appropriate way to remove daily-periodic oscillations from soil radon data time series in order to better relate seismic activities to changes in soil radon concentration. Despite all the limitations and unfavorable conditions, geochemical monitoring works as reported widely in the literature have yielded encouraging results and have contributed to the multi- disciplinary efforts in the direction of comprehension of earthquake mechanism.

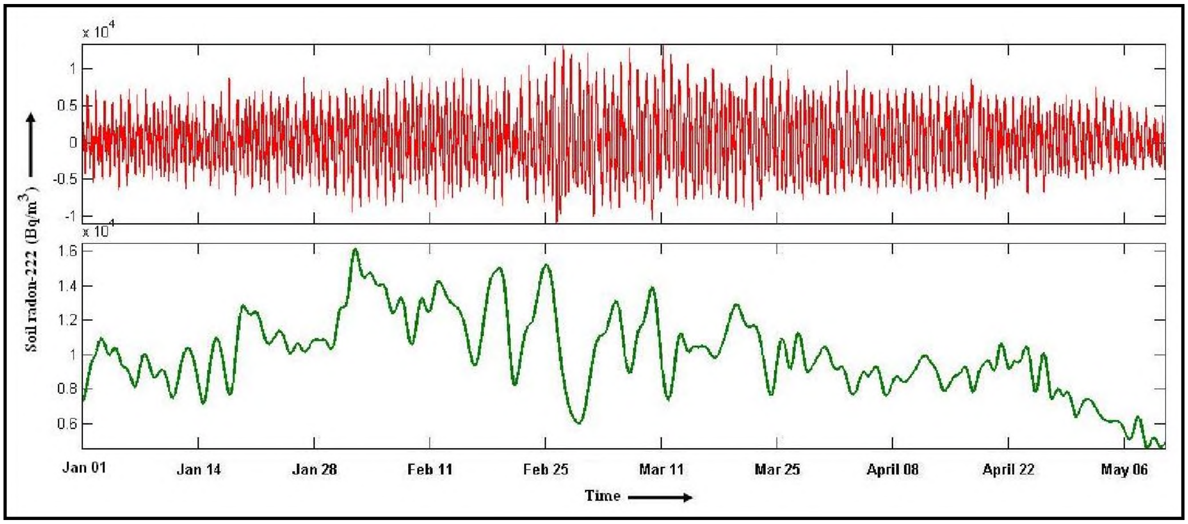


Fig 18: High frequency components including diurnal & semi-diurnal components (upper panel); Low frequency components after removing diurnal & semidiurnal components from the radon time series (lower panel).

8.6 CORRELATION OF RADON ANOMALIES WITH SEISMIC EVENTS IN KACHCHH REGION

Radon emanation from the soil gas was studied using Sarad rad at two locations in Kachchh and one location in Gandhinagar. The study was carried out during 2014. Changes in radon concentrations have been observed before moderate earthquakes in Kachchh. Effects of meteorological parameters on radon emission were also studied. The measured radon data shows a moderate positive correlation with relative humidity but no specific relation with air temperature and rainfall. Data obtained have been correlated to the earthquakes that occurred around the measuring sites.

Radon (Rn-222) is a radioactive noble gas which is a by-product of the natural radioactive decay of radium that is derived from the decay series of U-238, formed in the earth crust. Along the active fault region the radon emanation is high which makes an indication that radon gas has the major path to diffuse out. The essential information for predicting earthquake can be sorted out by investigating the relationship between radon emanation and seismic activity (Asumadu-Sakyi et al., 2011). The studies of radon concentration (underground and well water) and its correlation to seismic events and/or meteorological parameters have been studied in different regions of the India (Arora et al., 2012; Ramola, 2010; Walia et al., 2005; Ghosh et al., 2009, 2011). The radon content (i.e. concentration) along the surface of the earth crust differs from place to place. Because of its variation or rapid changes in soil or ground water, it has been used for predication of earthquake.

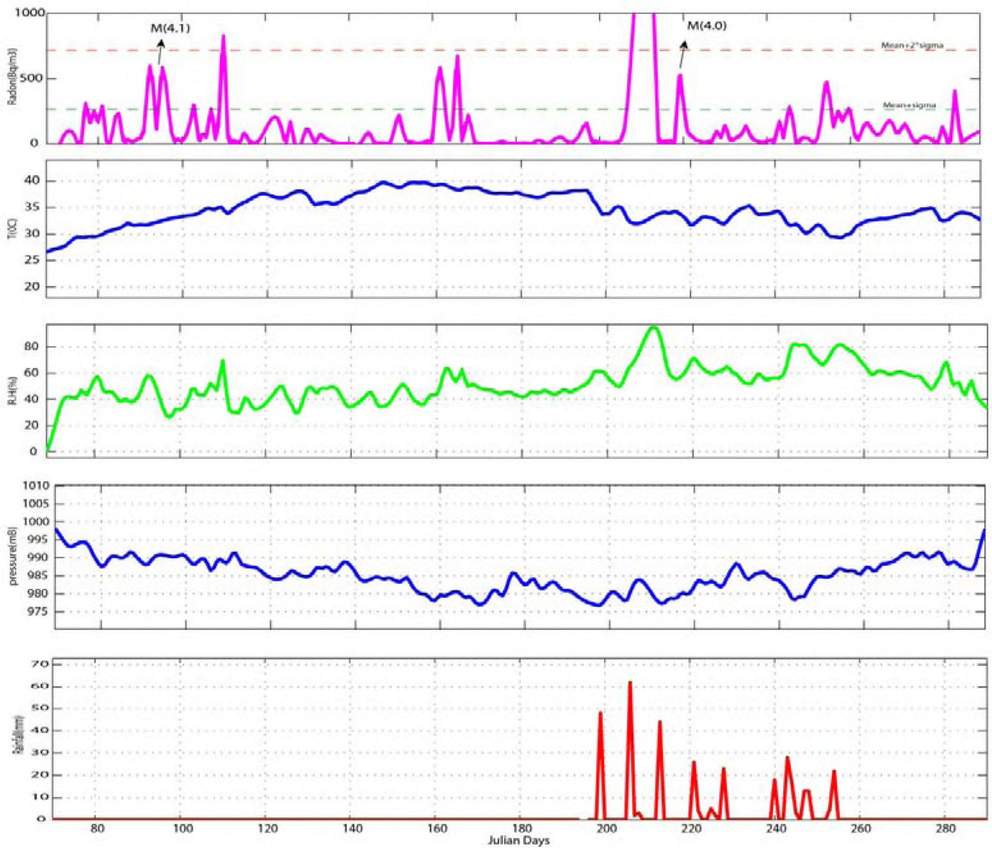


Fig 19: Radon time series along with other meteorological parameters

The meteorological parameters were plotted with the radon concentration values (Fig. 8.19) in order to evaluate the effect of these parameters on radon emission. The dailly average of air temperature, pressure and relative humidity for whole data set during 2014 has been correlated to the measured radon data whereas the rainfall during the monsoon period has been correlated to the radon data and the same is listed in table 1. The air temperature and rainfall shows a moderate inverse relation with radon emission. The correlation coefficient between radon and air temperature was found to be -0.55 for Gandhinagar and -0.16 for Badargadh (Fig. 8.20) whereas between radon and rainfall have been found to be -0.14 and 0.16 respectively (Fig. 20). This shows that the air temperature and rainfall have a little influence on the measured soil radon data. However, the relative humidity shows a moderate positive relation with radon emission at Badargadh. The correlation coefficient was found to be 0.42 (Fig. 20) indicating that the relative humidity has a significant influence on radon emission. The positive correlation obtained between the measured radon concentration and the relative humidity shows that radon concentration increases with increase in soil moisture

(Damkjaer, Korsbech 1985; Lindmark and Rosen, 1985). The average value (X) of radon concentration at Gandhinagar (table 8.1) was recorded to be 10784 Bq/m^3 with a standard deviation (SD) of 518 Bq/m^3. Whereas the average value at Badargadh are 298.2 Bq/m^3 with a standard deviation (SD) of 83.7 Bq/m^3.

Table 8.1: Correlation of Radon with other meteorological parameters

ISR Campus, Gandhinagar

Parameter	Average	Standard Deviation	Correlation Coefficient
Radon(Bq/m^3)	10784.79	518.88	
Temperature(^{0}C)	25.84	5.86	-0.55
RH (%)	75.93	22.71	0.00
Pressure(mb)	997.82	47.65	-0.01
Rainfall(mm)	16.58	21.84	-0.14

Badargadh

Paarameter	average	Standard Deviation	Correlation Coefficient
Radon(Bq/m^3)	298.2	83.7	
Temperature(^{0}C)	20.62	16.26	-0.16
RH (%)	32.28	26.71	0.42
Pressure(mb)	992.06	0.00	0.07
Rainfall(mm)	22.00	0.00	0.16

The first increase in radon concentration (about 200 Bq/m^3) was observed between 83th–95th day of the observation period which was followed by an earthquake of M4.1 which occurred on 91st day at a distance of 47 km from Badargadh site. This may be considered as an anomaly before the M4.1 quake. The second anomalous increase in radon concentration (about 750 Bq/m^3) was recorded between 200th–218th day. This anomalous increase may be correlated to an earthquake of M4.0 which occurred on 220th day at a distance of 43 km from the measuring site. Anomalous increase in radon concentrations may be correlated with moderate earthquakes occurred around the measuring sites during the observation period.

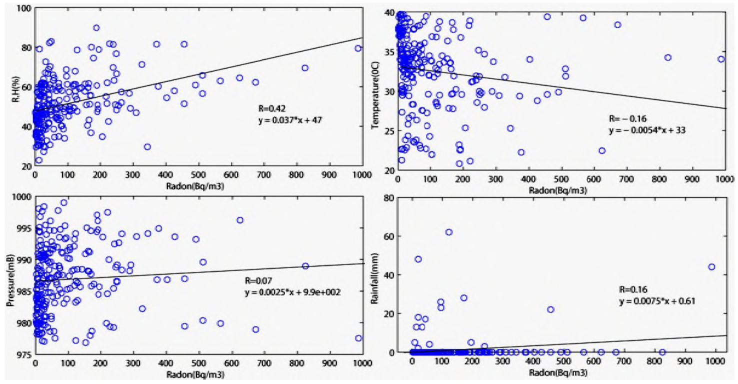


Fig 8.20: Correlation of Radon with other meteorological parameters

8.6 DIGITAL FLUXGATE MAGNETOMETER DATA ANALYSIS

A digital fluxgate magnetometer is in operation at Desalpar and the data is being recorded at 1 sample per second. Different scientists have used different analysis techniques like polarisation ratio analysis, transfer functions, induction vectors for earthquake prediction studies. Here we have employed the polarisation ratio method. The terrestrial geomagnetic field data collected at 1sample per second using Digital Flux gate Magnetometer of GMBH, Germany is taken for the period from 3-4-2014 to 31-12-2014. The time series of DFM data along with histogram of earthquakes, seismic index, Dst and Kp are shown in fig. 8.21.

There has been reported that it is useful to use the ratio of magnetic vertical to horizontal component Z/G or Z/H where Z is vertical component, H and D are horizontal components and G is $\sqrt{H^2+D^2}$ to distinguish the seismogenic ULF emissions from other noises (Hayakawa, M, 1996). While we expect that this ratio (Z/G) (polarization) is relatively small for the plasma waves coming from the ionosphere/magnetosphere, we expect that this ratio is considerably enhanced, Z/G ~ 1 or even more for seismogenic emissions. We apply this method to find any anomalies before moderate earthquakes occurred in Kachchh during 2014.

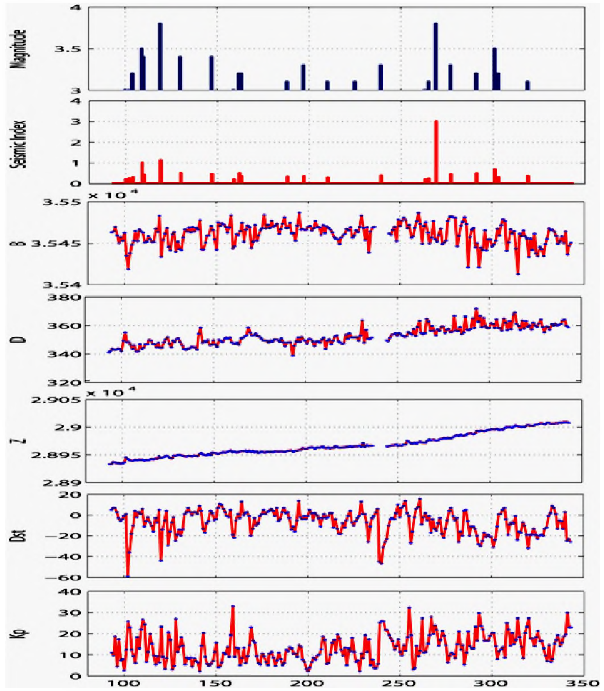


Fig 8.21: DFM time series data of Desalpar observatory B, D, Z along with histogram of Kachchh earthquakes and seismic index, Dst and Kp values.

In order to avoid diurnal variations and other day time cultural noise the night time data i.e. 18-21UT data is used for determining the polarization ratios in five frequency bands i.e. f1 (0.001-0.005), f2 (0.005-0.01Hz), f3 (0.01-0.05Hz), f4 (0.05-0.1Hz) and f5 (0.1-0.5Hz). The polarization ratios Z/G and Z/H are calculated and correlated with moderate earthquakes of magnitude greater than 3M and within 100 km hypo central distance from Desalpar to know how the polarization ratios vary with Kachchh seismicity and found significant rises prior to large events. We compare these with the corresponding data from remote stations in order to distinguish between the local and global effects (expressed by Kp and Dst). The global Kp sum& Dst values are shown in the figure 8.21 in the bottom panels.

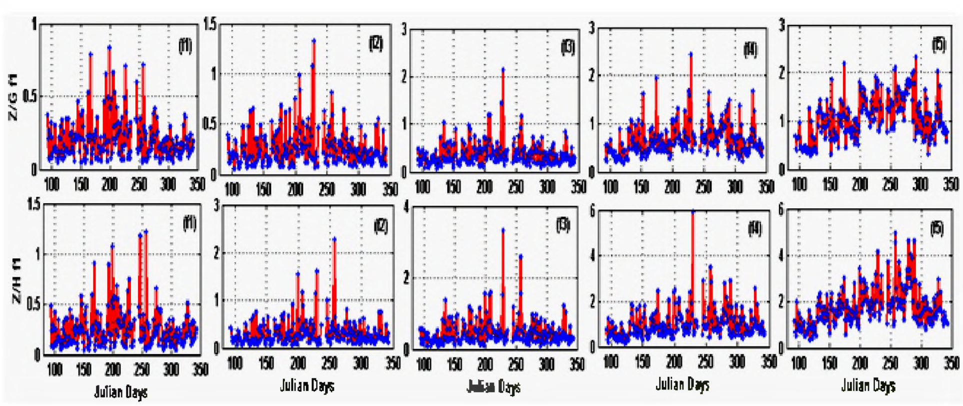


Fig 8.22: Desalpar DFM night time(18-21UT) data Polarization analysis; panel (a) &(b) polarization ratio variations in five frequency bands f1,f2,f3,f4 and f5 using Z/G&Z/H.

During our period of observation i.e. from 3-4-2014 to 09-12-2014 even though large events have not occurred but only two events of magnitude 3.8Mw taken place within 100km of hypo central distance from Desalpar, one on 29-4-2014 and the other on 26-9-2014 and both are preceded by small rise in polarization ratios. The polarization is seen to be increased from the background value of ~ 1.0 to more than double prior to the 1st earthquake. We see a decrease in polarization and, when this decrease is stabilized, we had the 1st earthquake. Clear rise in PR prior to the later event for which the seismic index is also high can be noticed. And the anomalous rise in five day moving averages of polarization ratio plot (fig. 8.22) in all five frequency bands i.e.f1 (0.001-0.005Hz), f2 (0.005-0.01Hz), f3 (0.001-0.05Hz), f4 (0.05-0.1Hz) and f5 (0.1-0.5Hz) can be seen 13 days before the occurrence of the event. Based on our results, we can conclude that the polarization at Desalpar is found to be enhanced prior to the earthquake. This means that the polarization of the magnetic field variation is a good parameter to monitor the local seismic activity, and the important point is that the polarization increase is taking place before the earthquake.

P.S.D analysis:

Desalpar DFM night time (18-21UT) data has been taken and the psds in five frequency bands f1(0.001-0.005Hz,f2(0.005-0.01Hz),f3(0.01-0.05Hz),f4(0.05-0.1Hz) and f5(0.1-0.5Hz) in all three components H, D and Z are plotted for the period from 03-04-2014 to 09-12-2014 (Fig. 8.23). We observed anomalous variations shown under shaded portion in all three components prior to the two large events of magnitude 3.8Mw one on 29-4-2014 and the other on 26-9-2014 (Fig. 8.24).

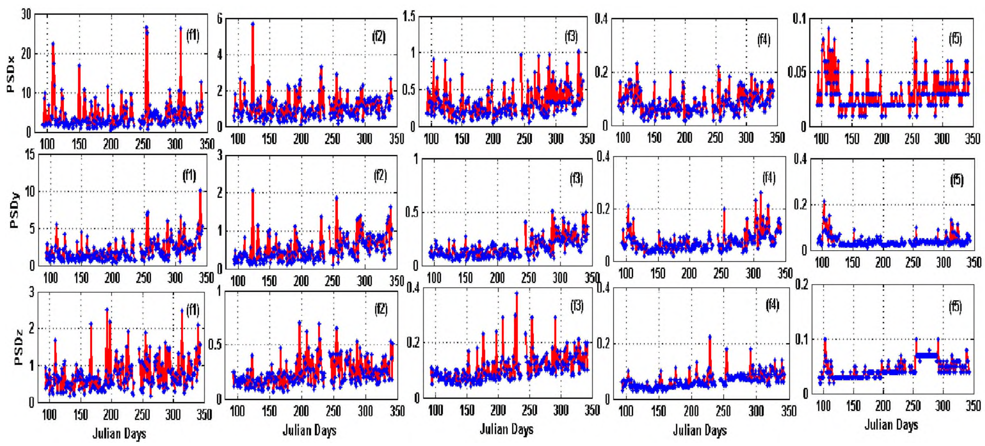


Fig 8.23: Power spectral amplitude analysis of H, D, Z Components of DFM data on five frequency bands as indicated in the above text.

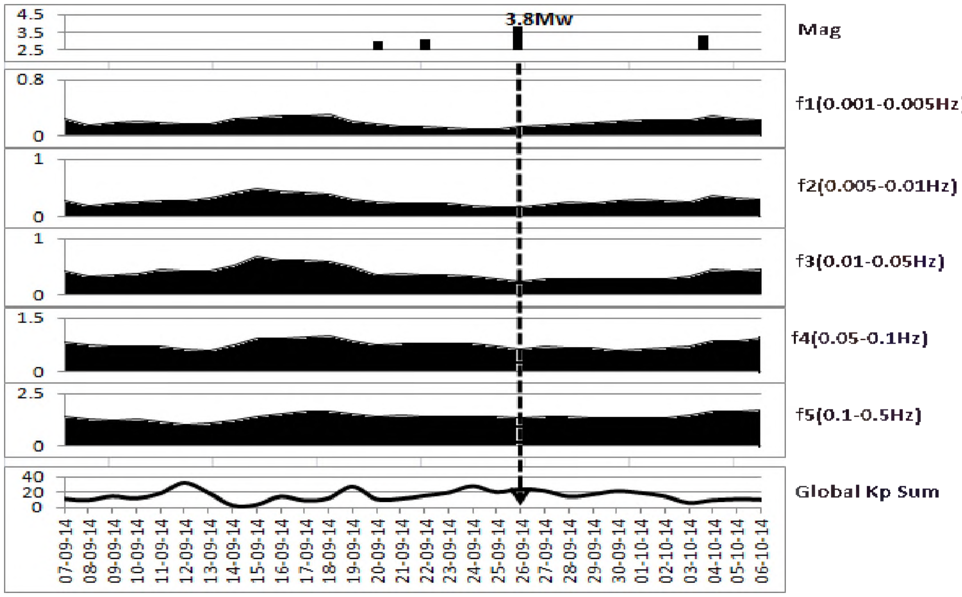


Fig 8.24: Anomalous rise in five day moving average of polarization ratio variations in five frequency bands prior to the significant event of mag 3.8Mw occurred on 26-9-2014;Panel(a) Kachchh seismicity(≥3M,≤100Km from Desalpar);panels (b),(c),(d),(e)&(f) are five day moving averages of polarization ratio in five frequency bands; Panel(g) Global kp sum.

The PSD variations of the total horizontal (G) and vertical (Z) components in five frequency bands at Desalpar along with Kachch seismicity & global Kp sum is plotted in figure. We observed dominancy of psd in vertical component than horizontal component prior to the significant event of 3.8Mw occurred on 26-9-2014 and is shown under shaded portion in fig 25 band. We can attribute this rise to PSD rise in vertical component (Z) than the total horizontal component (G) (Fig. 8.25).

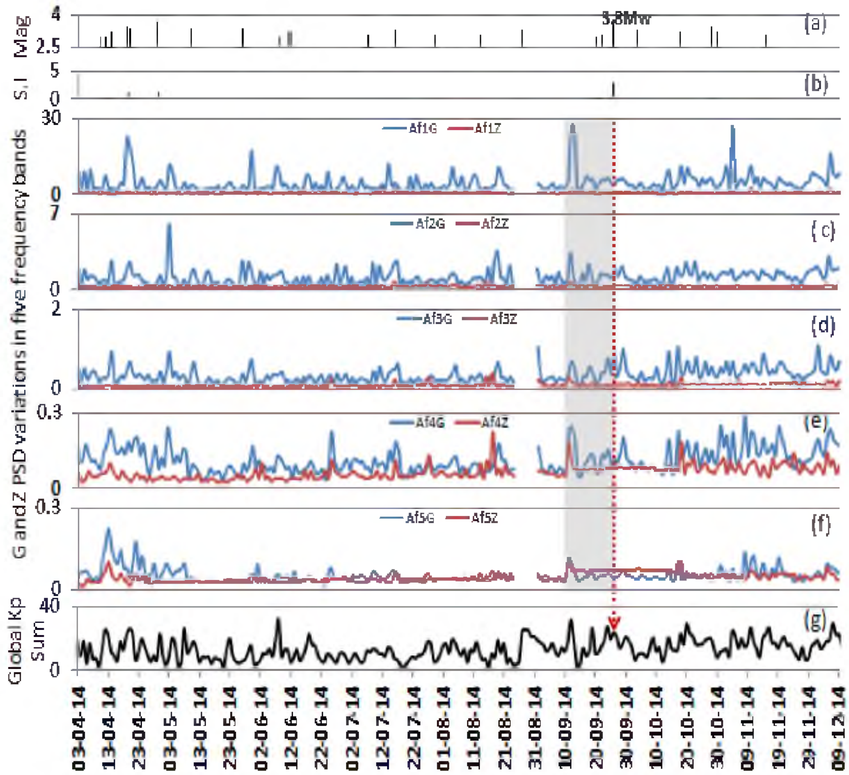


Fig 8.25: Power spectral amplitude analysis of G and Z Components in five frequency bands; Panel (a) Kachchh seismicity(≥3M,≤100Km from Desalpar);panel(b) Seismic indices; panels (c),(d),(e),(f)&(g) are psds in five frequency bands; panel(h) Global Kp sum.

8.7 OVERHAUSER MAGNETIC DATA ANALYSIS

Some earthquake precursory changes have also been observed by several scientists in total magnetic field data acquired by using overhauser magnetometer. The overhauser magnetometer is in operation at Badargad to record the terrestrial total geomagnetic field (F) variations at one sample per second. The raw data plot of the total geomagnetic field F (nT) is shown for the period from 1-1-2014 to 31-5-2014.The diurnal variations due to ionospheric currents can be observed. The noise like large spikes in the fig may be due to electrical and other day time cultural noise can be seen during. The large magnetic field fluctuations during magnetic storms can be observed in the total field raw data plot (fig. 8. 26).

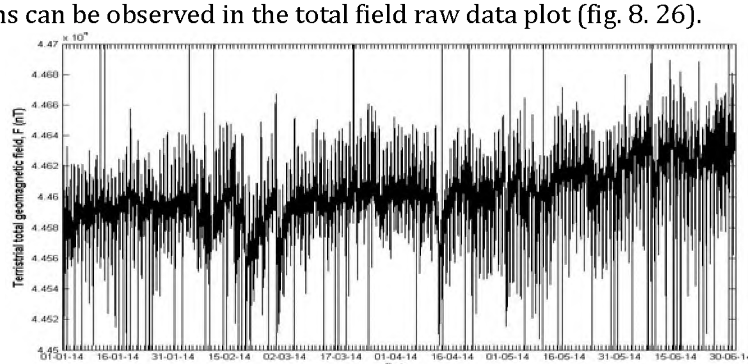


Fig 8.26: Raw data of total geomagnetic field variations at MPGO Badargad station using OHM (Jan-May2014).

P.S.D analysis: In order to avoid day time noise and other cultural noise the night time (18-21UT) data is taken for PSD analysis. The PSD analysis has been carried out by taking 8192 points using MATLAB program in five frequency bands f1(0.001-0.005Hz), f2(0.005-0.01Hz), f3(0.01-0.05Hz), f4(0.01-0.1Hz) and f5(0.1-0.5Hz) for the period from 01-01-2014 to 31-12-2014.

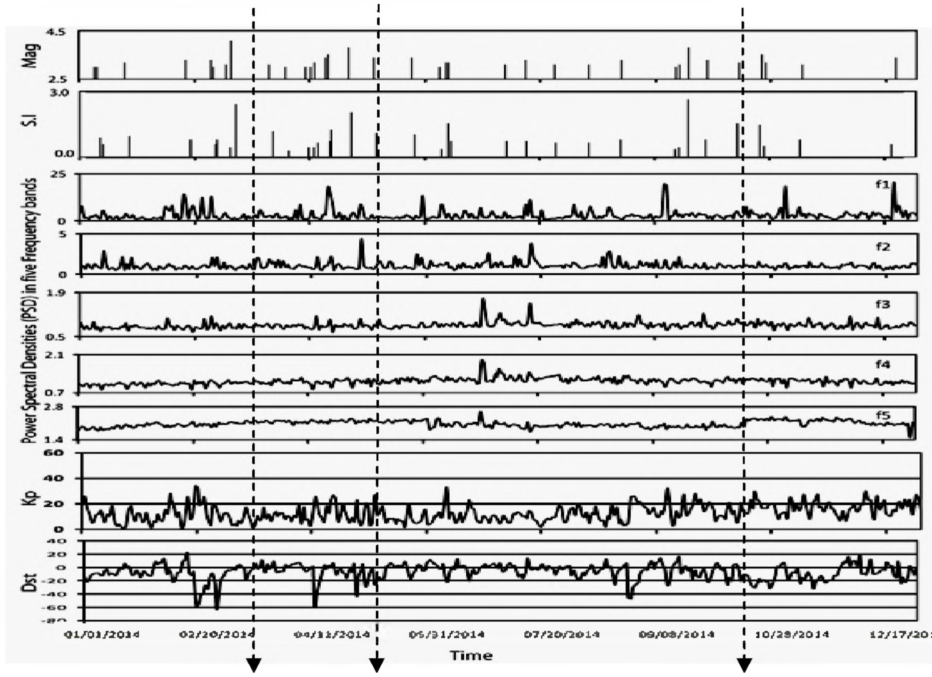


Fig 8.27: Panel (a) Kachchh Seismicity, panel (b) seismic indices, Panel (c) night time (18-21UT) average value variations of total field(F) at Badargadh, Panels(c),(d),(e),(f),(g)&(h) are psd variations in five frequency bands f1(0.001-0.005Hz),f2(0.005-0.01Hz),f3(0.01-0.05Hz),f4(0.05-0.1Hz)&f5(0.1-0.5Hz), panels (i) &(j) global kp sum & dst values.

The Kachchh seismicity of magnitude greater than 3M and hypocentral distances within 100 km from Badargadh and its seismic indices in panel (a) and (b).The night time average total field variations in panel(c).The psd variations in all five frequency bands have been plotted in panels (d), (e), (f), (g) and (h) in the figure. The global Kp sum and Dst value variations are also plotted in panel (i) and (j) at the bottom (Fig. 8.27). Even though there are no large near events during the period of observation, three large events have occurred within 100km from Badargadh. A gradual rise in psd in higher frequencies i.e f4, f5 followed by fall and simultaneous rise in low frequencies i.e. f1, f2 and f3 can be seen prior to those events.

The PSD variations during the three significant events can be seen in figure 8.28.

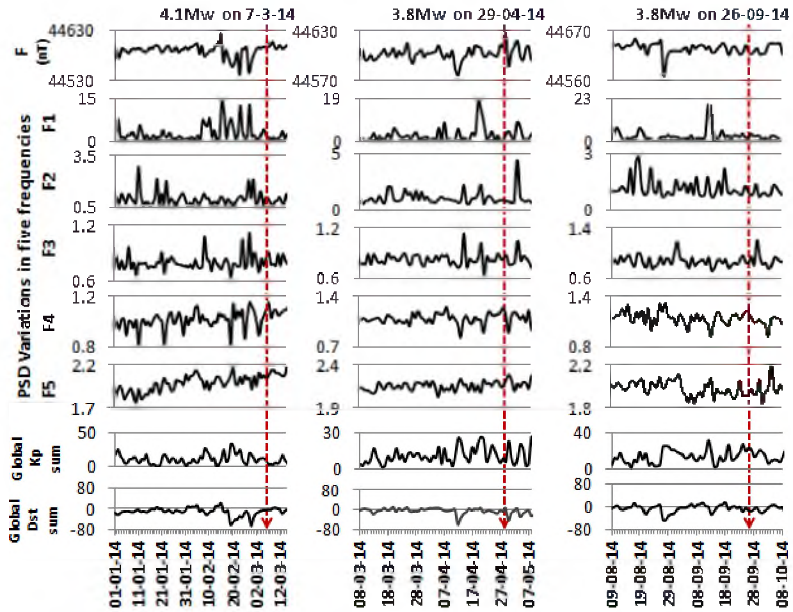


Fig 8.28: The PSD variations in five frequency bands before three earthquakes in Kachchh

8.8 PRINCIPLE COMPONENT ANALYSIS ON OVERHAUSER MAGNETOMETER DATA

We adopted the principal component analysis (PCA) for the ULF data observed at two stations at Badargadh and Desalpar. By using the ULF data observed at close stations, we can have 2 sets of data, which enables us to separate three possible sources. Generally speaking, the ULF signal observed at a station is a combination of a few effects; (1) geomagnetic variation of the magnetosphere (e.g., geomagnetic storms) due to the solar activity, (2) man-made noise, (3) any other effect (including seismogenic emissions). We have traced the eigen-value λn (n = 1, 2, 3) of three principal components in the frequency range from T = 10 s to T = 100 s by using the time-series data with duration of 30 m. As the result of analysis, the first principal component (λ1) is found to be highly correlated with the geomagneric activity (Ap). The second eigen-value (λ2) is found to have a period of 24 hours, with daytime maximum and nighttime minimum. This suggests that this noise is due to the human activity (Fig. 8.29). Fig. 8.30 illustrates the temporal variation of the 3rd principal component (λ3). We notice an enhancement in λ3 from the middle Fibraury to the first week of June (about a few weeks), followed by a quiet period (about 1-2 days before the 1st earthquake of M4.1 on Mar 9 2014) and by a sharp PCA is a standard tool used in modern data analysis in diverse fields from neuroscience to computer graphics, because it is a simple, non-parametric method for extracting relevant information from confusing datasets. With minimal effort, PCA provides a roadmap for how to reduce a complex dataset to lower-dimension datasets to reveal the sometimes hidden and simple structures that often underlie a dataset. To extract any existing geomagnetic signature of the earthquake, PCA was performed to investigate long-term variations due to different sources (e.g., geomagnetic variations, man-made noise and seismic variations).The procedure of PCA is as follows: Step 1: Subtract the mean. For PCA to work properly we need to subtract the mean from each of the data dimensions; the mean is the average across each dimension(y). The data matrix Y = [y] T is obtained, where T denotes the transpose. Step 2: Calculate the covariance matrix R = YYT. Step 3: Calculate the eigenvectors of the covariance matrix. Since the covariance matrix is square, we can calculate the eigenvectors and eigenvalues for this matrix. The eigenvalues decomposition of R is R = VKVT, where K is the eigenvalue matrix with values λ1, λ2, and λ3, and V is the eigenvector matrix with columns v1, v2, and v3. Here the subscripts 1, 2, and 3 indicate the order of magnitude (i.e., λ1> λ2> λ3).

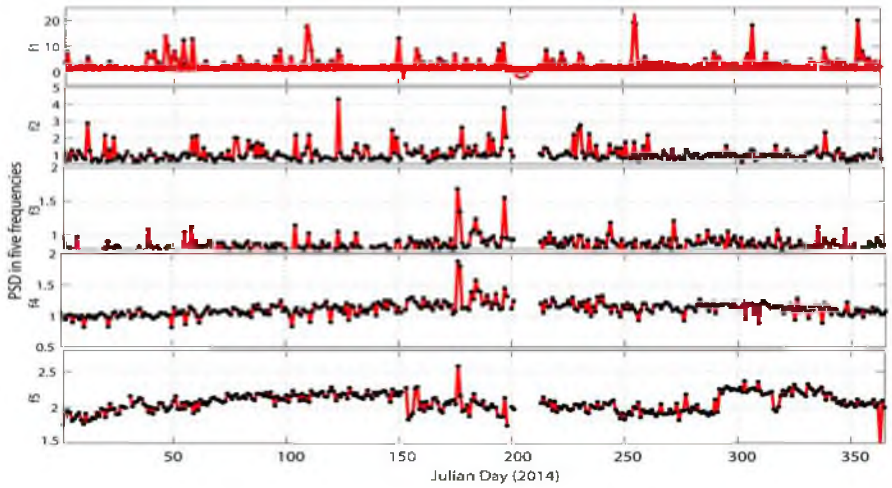


Fig 8.29: Power spectral densities at five frequency bands

Power spectral densities of five different frequency bands are shown as fig 29. The mathematical process of PCA is eigenvalue analysis of the covariance matrix of the observed signal matrix. Figure 30 shows the lowest Eigen values analysis of the OverHausser data it has varied from 1.739 to 16.03 with the mode of 1.739. 10days before the earthquake the 3rd PCA values have varied from 10 to 16.03; in 4days before earthquake, they have varied with the factor of 3.2. even though, such variations has observed after the earthquake, this maximum of 3rd PCA values have incurred only just 10 days before the 4.1 earthquake.

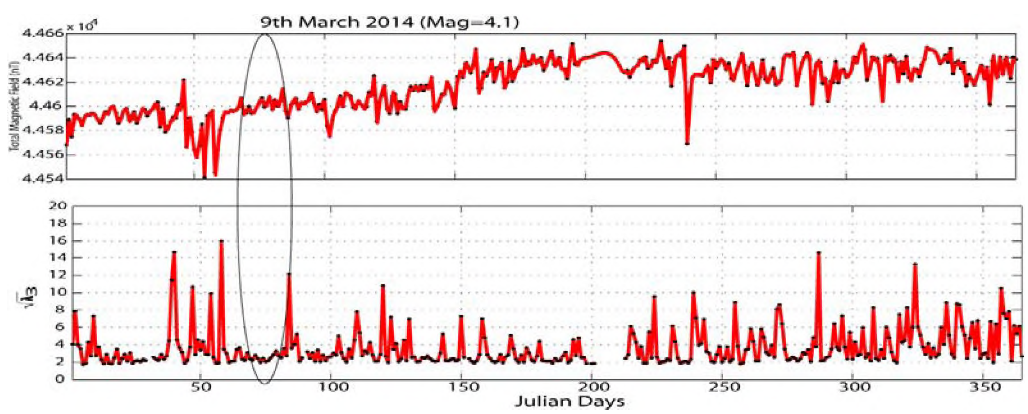


Fig 8.30: 3rd Principle component analysis values

8.9 MONITORING OF ULF (ULTRA-LOW-FREQUENCY) GEOMAGNETIC VARIATIONS ASSOCIATED WITH EARTHQUAKES

The Schematic diagram of induction coil magnetometer has been shown in Figure 8.31. It consists of three induction coil magentometers (LEMI 30) in orthogonal directions (east-wet,north-south and vertical) having lenght 1m each. It is used to measure the variation in magnetic field in the range 0.01-30Hz. These magnetometers measure magnetic field components namely Bx, By and Bz. GPS antena provides information about lattitude, longitudes, altitudes and universal time (UTC). LEMI 30 logger is used for recording data from induction coil magnetometers, acquired by CAM unit, and to handle the commands to the CAM Unit through its graphical user interface. The data from each magnetometer are digitized at the sampling rate of 64Hz and recorded on the hard disc.

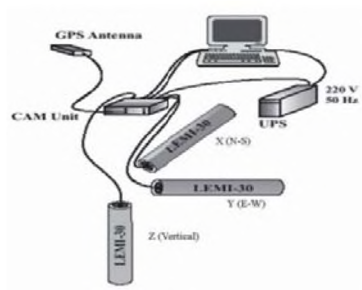


Fig 8.31: Schematic Experimental set up of Lemi 30 instrument at MPGO sites.

The daily variations of Bx, By, Bz components are shown in figure 8.32, 'Bx' values have varied from -0.021 to -0.038, (mean=-0.027, standard deviation=0.003), Coefficient of variation of Bx values came around 11% . 'By' values have varied from 0.001 to 0.010 (mean= 0.003, standard deviation= 0.001), Coefficient of variation of By values came around 35%. Bz values have varied from -0.032 to -0.003 (mean= -0.015, standard deviation= 0.005), Coefficient of variation of By values came around 32%.

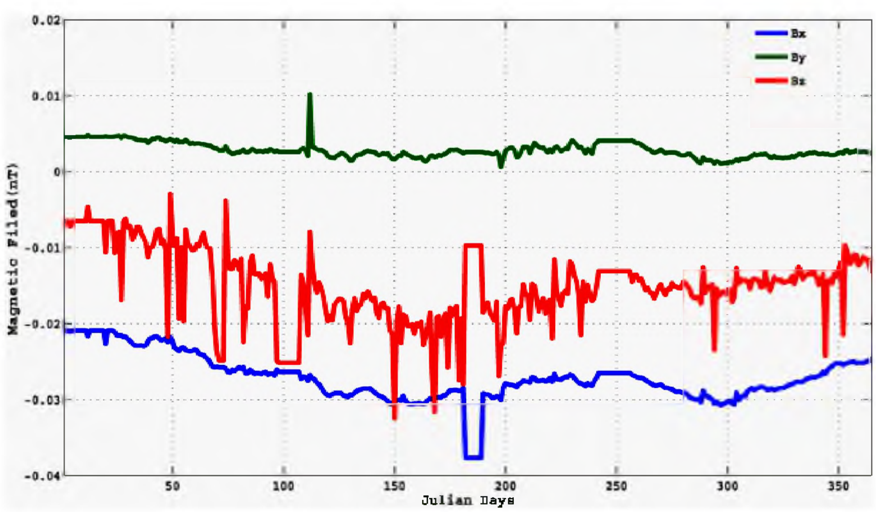


Fig 8.32: Day-to-day variation of Bx, By, Bz components during 2014.

The Polarization ratios (Z/G and Z/H) have been computed for 5 bands of frequencies ranging from 0.001- 1Hz for this data during 2014 and shown in Figures 8.33 & 8.34.

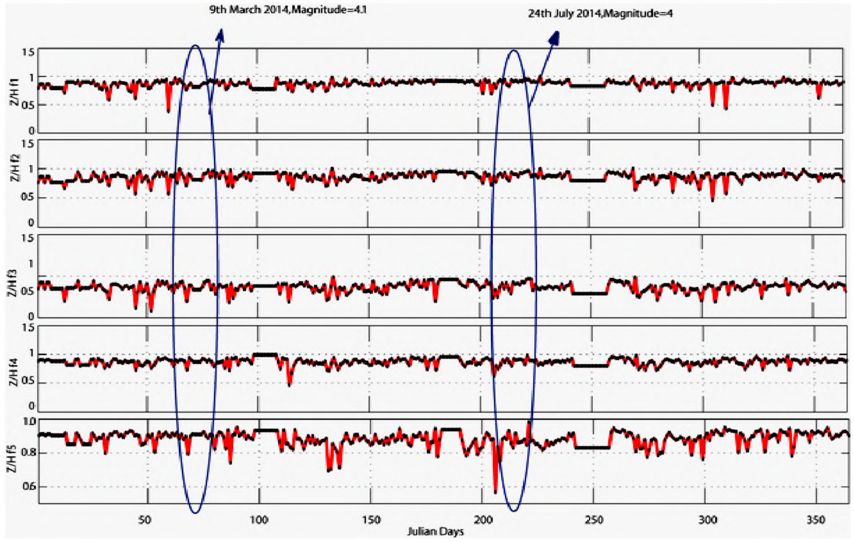


Fig 8.33: Polarization ratios (Z/H) for five frequency bands ranging from 0.001-1Hz.

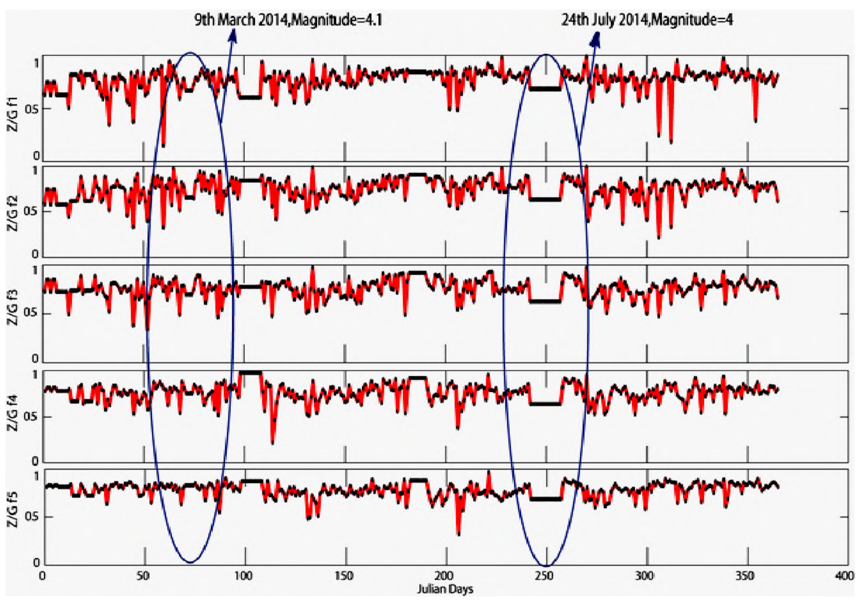


Fig 8.34: Polarization ratios (Z/G) for five frequency bands ranging from 0.001-1Hz.

The Z/G variations are more predominant than Z/H at five frequency bands. They have varied from 0.5 to 1. In order to synthesis anomalies pre and post earthquakes, two earth quakes of magnitude 4 and 4.1 has considered , 70 to 80% sudden drop of Z/G values for pre and during the event time has been observed, and 81 to 89% enhancement of Z/H values for the post earth quake have seen in the polarization ratios. In order to further investigate, spectrograms and power spectral densities analysis have been done for 5days before and 2days after with reference to event day (Magnitude~4.1). The Power Spectral Densities have varied from 40 to 60, they have followed exponential decayed sinusoidal behaviour has been observed over the study period, there is 5-10% of sudden rise of the Bx, By, Bz component compared to the pre and post earthquake regime has observed in the study period.

Spectral variation of three components over the study period is shown in figure 8.35. Schumann (1952) has predicted an extremely low frequency (ELF) resonance in the earth-ionospheric waveguide. The resonance occurs between the electromagnetic wave, generated by lightning and thunderstorm, travelling along ground surface and returning to the starting point, with a phase difference of $2\pi n$ (n = integer number).

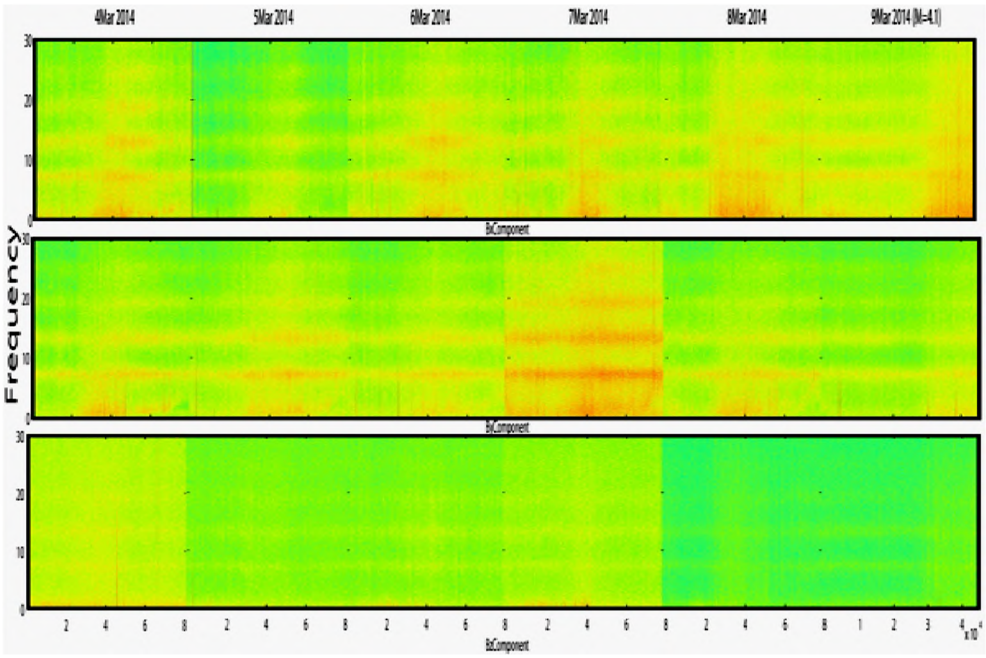


Fig 8.35: Spectrogram of Bx, By, Bz components during 6days regime with reference to the event

Assuming the perfectly conducting earth and ionospheric boundaries, different modes of resonance frequencies can be derived from the following relation (Schumann, 1952),

$$fn = \frac{\omega n}{2\pi} = \frac{c}{2\pi RE}\sqrt{n(n+1)}$$

Where n is an integer, c is the velocity of light and RE is the radius of earth. In reality, the ionosphere is not a perfectly conducting medium and energy losses due to its finite conductivity reduce the resonance frequencies to 7.8, 14.1, 20.3, 26.3 and 32.5 Hz (Madden and Thomson, 1965, chand et al., 2009). We can clearly see the distinct bands of these Schumann resonances at 7.8, 14.1, 20.3 and 25 Hz in figure 35. We have not observed much change in the spectral amplitudes before the earthquake of M4.1 on 09-03-2014.

8.10 STUDY OF GROUND WATER LEVEL VARIATIONS AT DESALPAR USING MEDOFILL-11 SENSOR

Several scientists observed changes in ground water levels before earthquakes. We are monitoring and studying ground water fluctuations at Desalpar and Badargadh. The ground water level changes have been measured using medofil pressure sensor placed in a borehole at a depth of about 17mt. This also measures temperature and pressure in a borehole. The data is collected at the rate of one sample per one/two min. During the period of observation i.e. from 3-4-2014 to 22-6-2014 the fall in the Ground Water Level can be seen. The ground water level fluctuations along with Kachchh seismicity of magnitude greater than 3M and within 100Km hypocentral distance from Desalpar is shown in the figure to see any precursory phenomenon. The daily fluctuations caused by sun and moon positions along with the changes due to earthquakes can be seen in the raw data plot. Some anomalous rise and falls as shown under shaded portion before some events can be seen in the figure. We can observe water level rises before some large events (07-03-2014, M4.1; 29-04-2014) as indicated in the fig. 8.36.

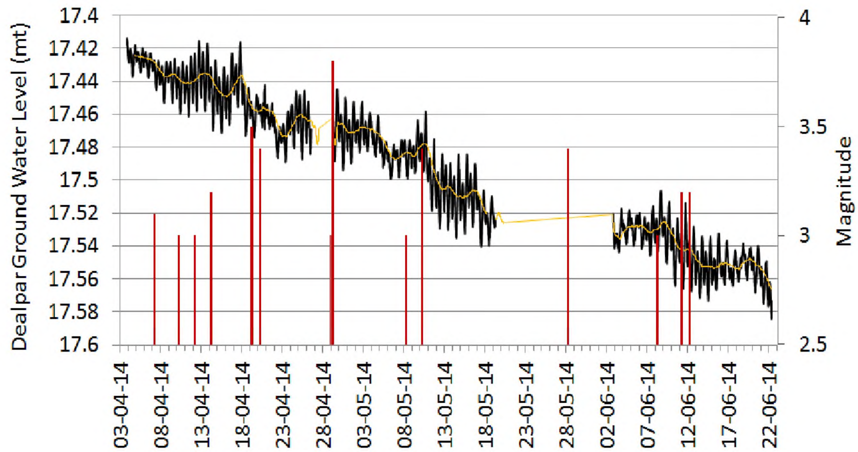


Fig 8.36: Ground water level Variations (mt) at Desalpar for the period from 03-04-2014 to 22-06-2014.

8.11 PASSIVE REMOTE SENSING TECHNIQUES TO STUDY THE ANNUAL AND SEASONAL VARIATION OF THE AEROSOLS, PRECIPITABLE WATER CONTENT, AND TOTAL COLUMNAR OZONE IN LITTLE RANN OF KACHCHH AND RANN OF KACHCHH

(C. P. Simha, K. M. Rao, B. K. Rastogi with V. N. Sridhar, R. Prajapati, A. K. Shukla of Space Application Centre (SAC), ISRO, Ahmadabad, Gujarat-382009.)

This study deals with winter and summer variation of Aerosol Optical Thickness (AOT), Perceptible Water Content (PWC) and Total Columnar Ozone (TCO) in the Little Rann of Kachchh and Rann of Kachchh near the MPGO site, Desalpaur and its influence on the monsoon cycle. We have followed standard protocol for field measurements such as 32 campaigns in little Rann of Kachchh (2012-13) and 32 campaigns in Rann of Kachchh (2013-14) in synchronization with some of the Indian satellites such as IRS-P6, IRS-RS2, OCM-2 of ISRO and Land SAT 7+ of NASA satellite. For the above mentioned periods of satellite radiance, estimated radiance have been computed by compiling the 6S radiative transfer code (input as: Zenith Angle (θ), Azimuth Angle (), AOT, PWC, TCO and ground reflectance) in Fortran-77 within the limits of different band radiance of the satellites sensors (Green, Red, Nir and Swir bands). Passive remote sensing technique have been applied for our study and it works on the principle of beer-lamberts law and differential optical absorption techniques, portion of light which is coming from the sun after attenuating by scattering and absorption of water molecule, aerosols and gasses has taken at a certain zenith angle. Spectral analysis of the acquired data over two years in different seasons reveals the different species concentration such as AOT at 550nm, Perceptible water content(PWC), and Total columnar ozone(TCO) over the desert site. Influence of the desert aerosols radiative forcing over the study period has been done by computing the fraction of sunlight attenuated by aerosols and its influence for active and break monsoon over the study period. 10 to 20% high AOTs at lower wavelength have been observed at Rann of Kachchh (2014) than Little Rann of Kachchh (2013), which tells the more abundance of absorbing type aerosols due to accumulation of finer particle in the year of 2014 than 2013, IMD observatories also recorded rainfall of 777.33mm in 2013 (excessive rainfall) and 463.9 mm in 2014(normal rainfall) over Gujarat in monsoons.

8.12 ANALYSIS OF SPECTRAL CHARACTERISTICS OF PRE-EARTHQUAKE AMBIENT SEISMIC NOISE FOR ADVANCE WARNING

(Indra N. Gupta1, David P. Schaff2, Paul G. Richards2, Bal K. Rastogi3, P Mahesh3, Prateek Mondal3 and Robert A. Wagner1

(1) Array Information Technology, Greenbelt, Maryland, USA, (2) Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA, (3) ISR)

A significant fraction of the ambient short-period seismic noise at a given site may be attributed to P, S, Rayleigh and Love waves with spectral characteristics strongly dependent on the geological structure underlying the recording station. An earthquake may have intense pre-event activity within the hypocentral region. This pre-earthquake activity may occur at one or more places at various depths mostly within the hypocentral region and over short and/or long periods of time, leading to significant temporal variations in the geological environment. It may also generate new sources of seismic waves. All these disturbances will have significant influence on the spectral characteristics of noise and among the vertical, radial and transverse component ratios observed at nearby three-component recording stations.

The focal mechanism of an earthquake indicates specific directions of compression (C) and tension (T) axes orthogonal to each other. This implies pre-seismic compression of rocks within the hypocentral region along the C direction and tension or dilation along the T direction. In other words, any pre-seismic activity can introduce strongly anisotropic characteristics to the ambient noise wave field as observed at a recording station. The spectral ratios such as Transverse (T)/Radial(R) components can be strongly influenced by the characteristics of pre-earthquake activity. For example, if the creation of new cracks dominates, then their directions and size can strongly influence the observed H and V components. Pre-earthquake activity, such as generation of long cracks or slippage on pre-existing faults, can strongly influence the low-frequency radiation of energy as observed on Z, R and T components.

We analyzed pre-earthquake ambient seismic noise from four earthquakes located in four different regions: Nevada (one recording station), California (4 stations), Alaska (one station) and Kachchh, India (4 stations). The spectra of several hours' long segments of noise for three different periods of time: (1) one year before, to reduce the influence of seasonal variation, (2) one month before and (3) just before, ending a few sec before the first P from the earthquake, were compared. It seems that large earthquakes are associated with intense and extremely complicated pre-event activity mostly within the hypocentral region. Our analysis shows that this pre-earthquake activity significantly impacts the prevailing ambient seismic noise and leads to several measurable changes in the spectral characteristics of low frequency noise as observed on the three orthogonal components of ground motion. The most important parameters indicating premonitory changes have been observed to be temporal variations in (1) spectral peak frequencies and their associated amplitudes on each component of ground motion and (2) inter-component amplitude ratios. Moreover, the above two relationships generally show significantly larger variability during a segment of time just before the earthquake. Our results indicate that observation of significant changes in one or more of these parameters simultaneously at several recording stations can provide advance warning of several hours or better before a large earthquake occurs.

The Kachchh, India M_w 5.0 Earthquake of 19 June 2012 is well recorded at several broadband stations at various epicentral distances. Analysis of limited data from four stations has indicated two distinct premonitory variations in the low-frequency (less than 0.5 Hz) spectral characteristics of noise, initiating several days (10 days) before the earthquake: (1) systematic shift of peak frequencies to lower values and (2) significant changes among the three components (vertical V, radial, R and transverse, T) of ground motion, evidenced by spectral ratios such as T/R.

These results for pre-event variations are similar to those observed for several earthquakes in the United States. Results from the two stations also show rapid variations among the component ratios during the last half-hour, suggesting intensified pre-event activity. Although these preliminary results need to be confirmed by analyzing considerably more data from several additional recording stations, they appear to suggest an entirely new methodology for obtaining advance warning of a few days or more before a large earthquake.

Details of Analysis of Spectral Characteristics of Seismic Noise Preceding Kachchh, Earthquake of (M 5.1) 19 June 2012

We analyzed spectral characteristics of pre-earthquake seismic noise for an earthquake recorded by three-component instruments at epicentral distances mostly within 50 km. Several minute long samples of noise are used so that isotropic contributions to noise tend to cancel out.

We have taken data from 4 seismographs of Kachchh earthquake of (M 5.1) 19 June 2012 (Fig. 8.37). The spectral characteristics of pre-earthquake seismic noise at the four seismic stations Suvai(SUV), Gadada(GDD), Badargadh(BDR) and Khavda(KAV) at epicentral distances of 21, 26, 39 and 61 km are shown in Figures 8.38 to 8.42. Spectra of Vertical (V) component of seismic noise at three different times, as indicated by different colors, are shown in Figure 8.38 (a) at SUV station. The three sets of spectra appear similar, with nearly the same spectral peak values, averaging at about 0.35 HZ, for the component V. For each component, the spectral peak values tend to decrease as the earthquake origin time approaches. The temporal variation of spectral peak frequencies, for V, R and T components within 0.1 - 0.5 Hz from 80 consecutive windows, each 256 sec long, comprising slightly over four hours of noise for three different segments of time preceding the earthquake is shown in Figure 8.38 (b, c, d). The average and mean slope are shown by continuous and dashed lines, respectively. The average values are the lowest for the just-before segment. Moreover, during the last four hours ending just-before the earthquake, the spectral peak frequency values (red) indicate a shift to lower values, probably due to a decrease in medium velocity and an increase in attenuation.

Continuous variations in peak frequencies based on 40 point moving average of 256 sec windows for V, R and T components, starting 17 days before the earthquake at SUV is shown in Figure 8.39. The three components, indicating significant drop in peak frequency about 15 days before the earthquake. Similarly continuous variations in peak frequencies based on 40 point moving average of 256 sec windows for V, R and T components, starting 7, 12, 12 days before the earthquake at GDD, BDR & KAV are shown in Figures 8.40 to 8.42.

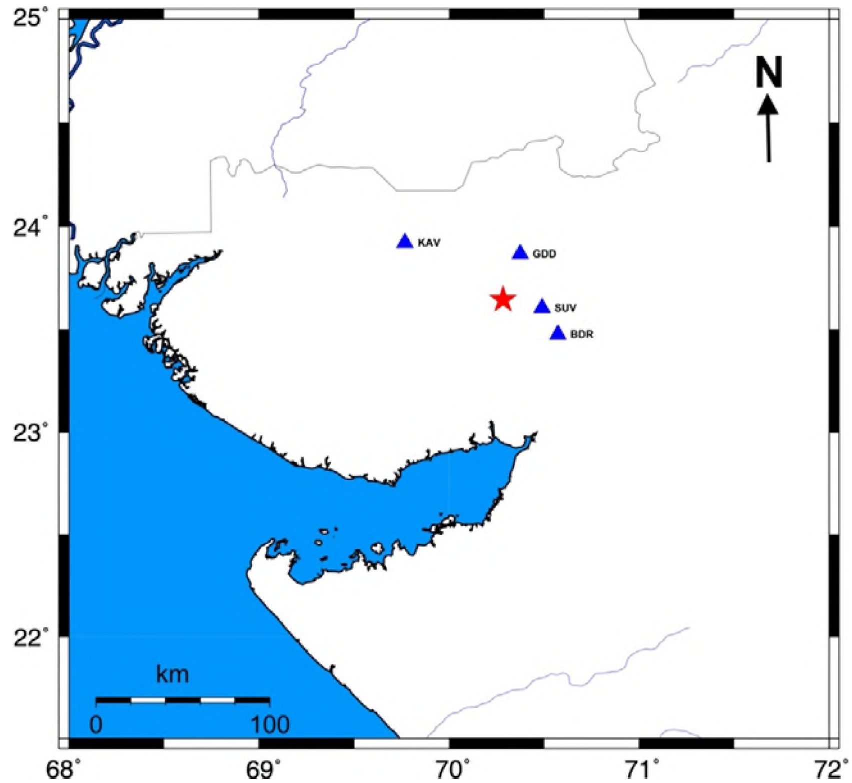


Fig 8.37: Epicentral location of the Kachchh, Mw 5.1 Earthquake of 19 June 2012 and the four recording stations SUV, GDD, BDR and KAV at epicentral distances of 21, 26, 39 and 61 km, respectively.

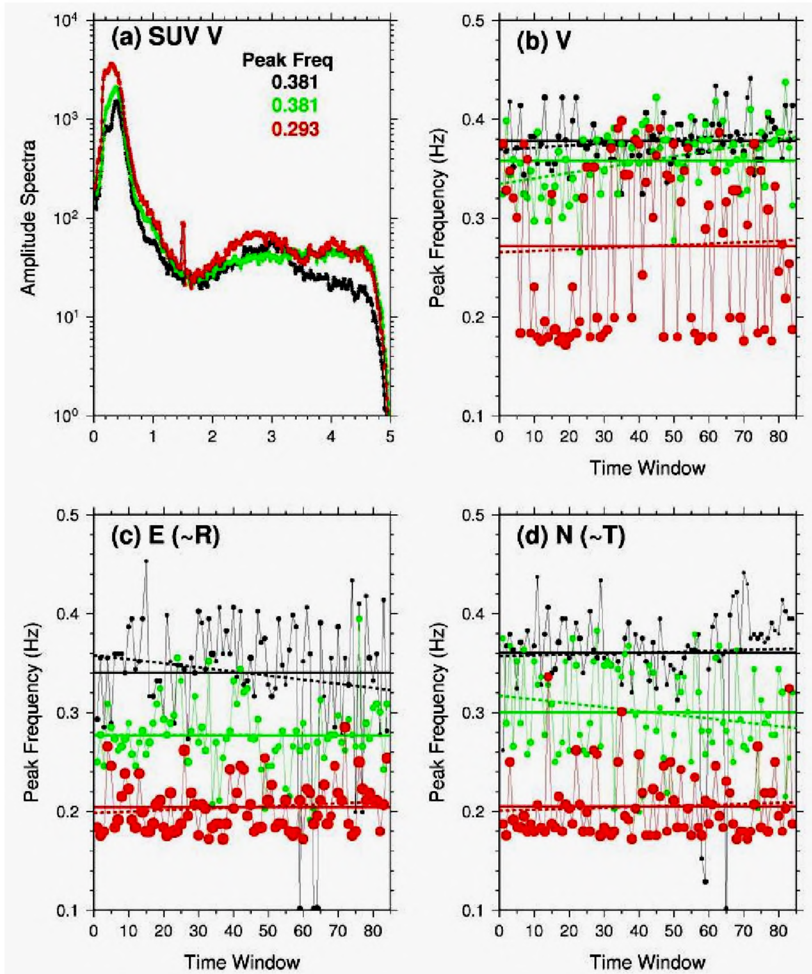


Fig 8.38: (a) V component average spectra;(b), (c) and (d) temporal variation of spectral peak frequencies(average and mean slope shown by continuous and dashed lines, respectively) and associated peak amplitudes (filled circles of varying size) for V, R and T within 0.1 - 0.2 Hz for 4 hours of noise at three different times preceding the earthquake: one-year before (black), one-month-before (green) and just-before (red) For the just-before segment of time on all three components, lower peak frequencies and amplitudes with significantly larger fluctuations and a temporal decrease in slope (red dashed lines) may be regarded as useful premonitory indicators.

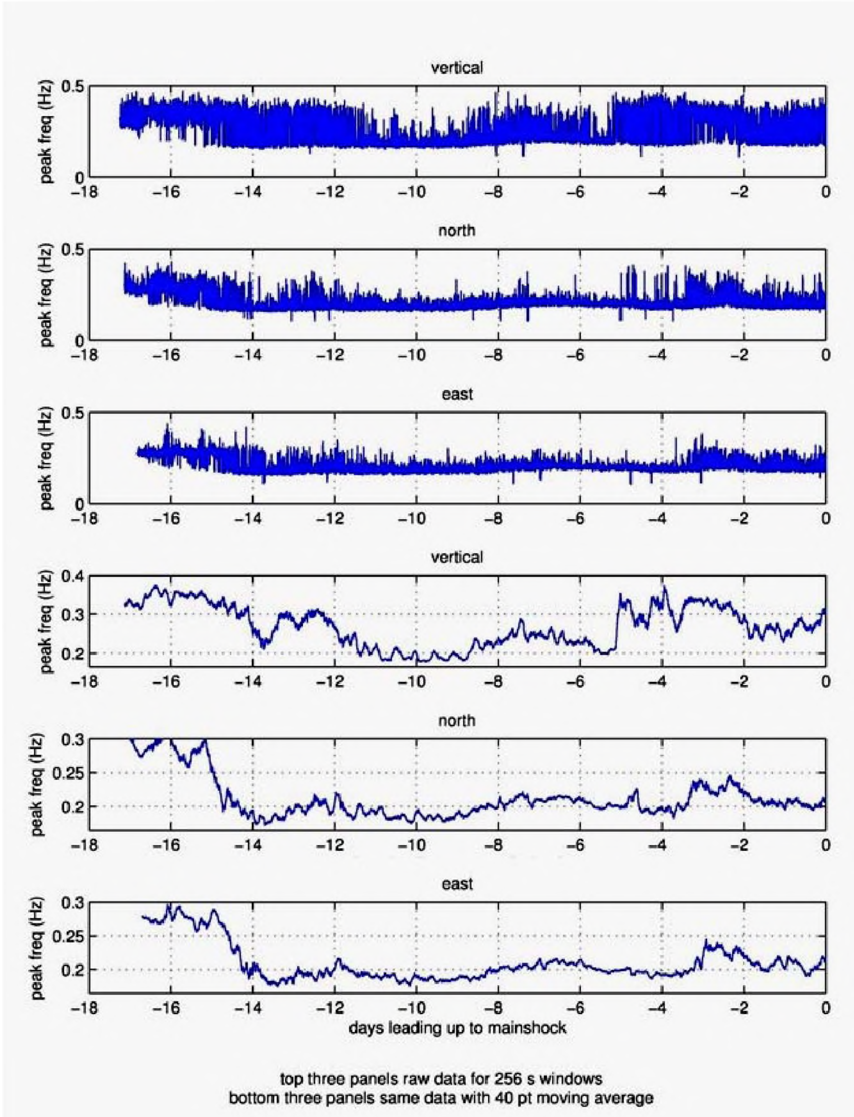


Fig 8.39: Continuous variations in peak frequencies based on 40 point moving average of 256 sec windows for V, R and T components, starting 17 days before the earthquake at SUV. The three components, indicating significant drop in peak frequency about 15 days before the earthquake.

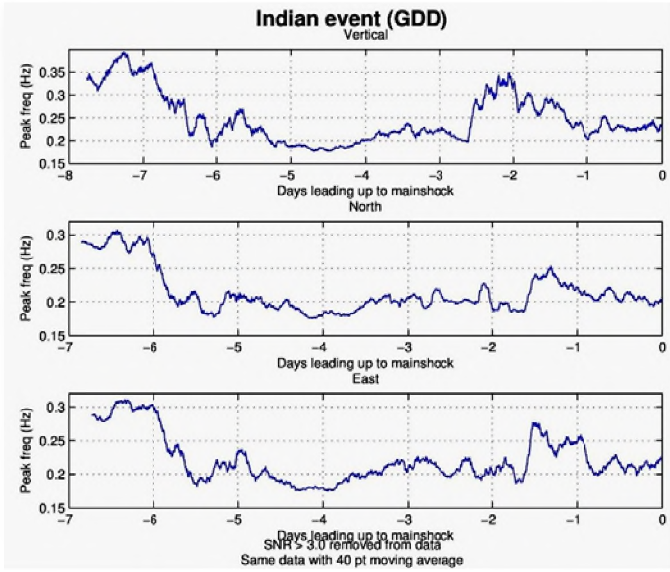


Fig 8.40: Similar to Figure 8.39 for the Kachchh, earthquake recorded at GDD, starting about 7 days before the earthquake. The three components, indicating significant drop in peak frequency about 6 days before the earthquake.

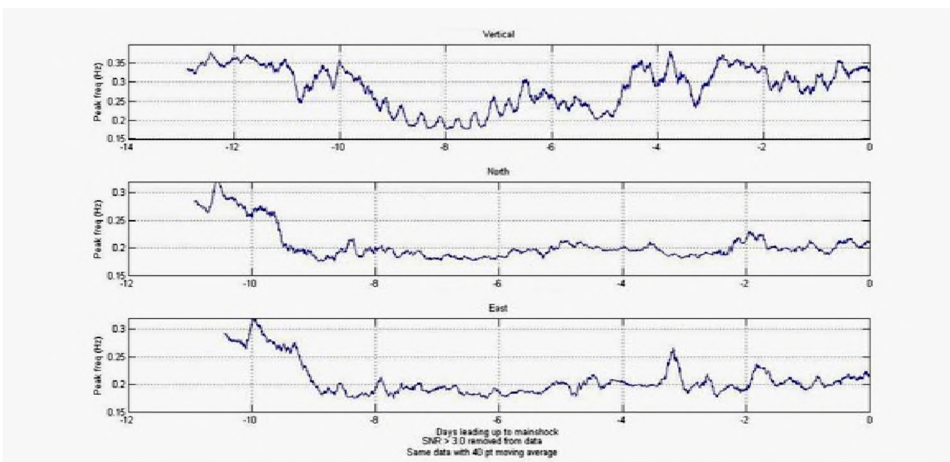


Fig 8.41: Similar to Figure 3 for the Kachchh, earthquake recorded at Badargadh(BDR), starting about 12 days before the earthquake. The three components, indicating significant drop in peak frequency about 9 days before the earthquake.

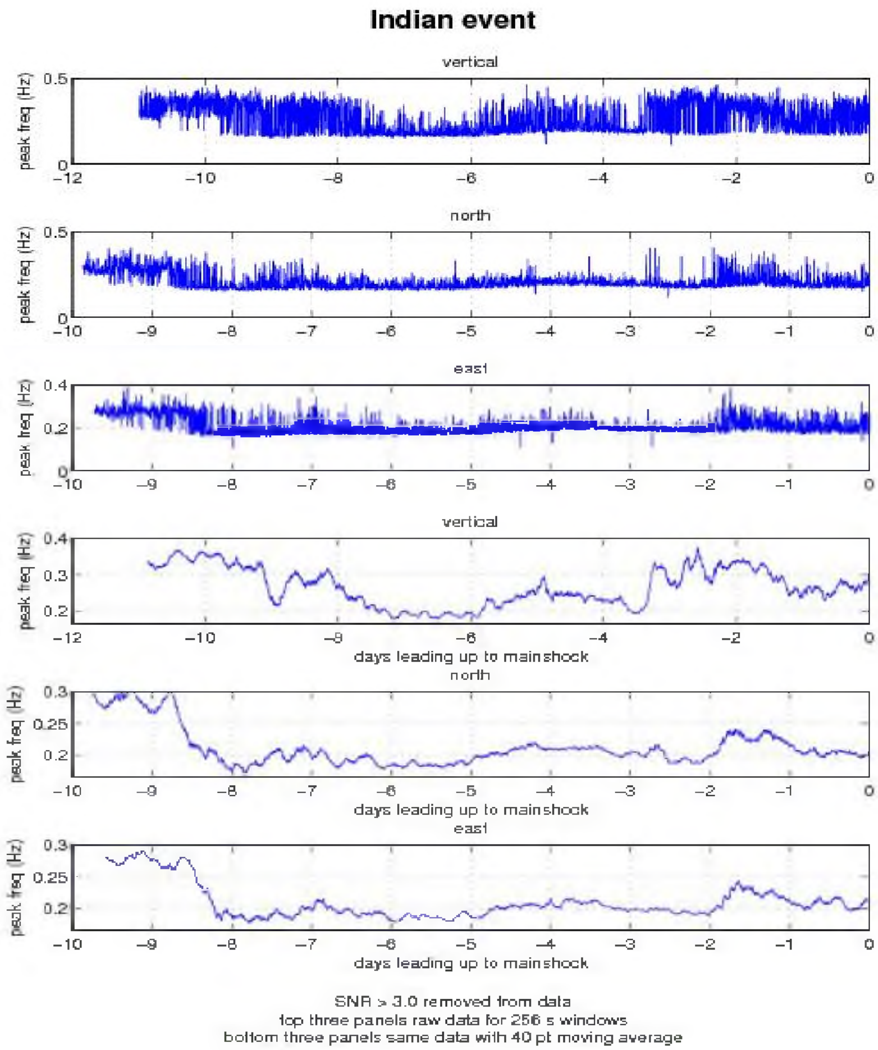


Fig 8.42: Similar to Figure 3 for the Kachchh, earthquake recorded at Khavda (KAV), starting about 12 days before the earthquake. The three components, indicating significant drop in peak frequency about 10 days before the earthquake.

The most important parameters indicating premonitory changes derived from three-component data appear to be temporal variations in (1) spectral peak frequencies and their associated amplitudes on each component of ground motion, (2) inter-component amplitude ratios. Moreover, the above two relationships generally show significantly larger variability as the origin time of the earthquake approaches. Our results suggest that observation of significant changes in one or more of these parameters simultaneously at several recording stations can provide a clear indication of an impending large earthquake.

CHAPTER 9

NATIONAL AND INTERNATIONAL SCIENTIFIC COLLABORATION, PROJECTS OF SOCIETAL IMPORTANCE AND ADVICE TO IMPORTANT DEVELOPMENT ACTIVITIES

9.1 MOU SIGNED

Memorandum of Understanding (MOU) signed between Institute of Seismological Research (ISR) and Politecnico Di Torino, Torino, Italy

MOU was signed by Prof. Claudio Scavia (Head of the Department of Structural, Geotechnical and Building Engineering) & Prof. Gian Paolo Cimellaro (Professor) of Politecnico Di Torino, Torino from Italian side and Dr. B.K. Rastogi (Director General) of Institute of Seismological Research (ISR) from Indian side.

9.2 ISR GEOPHYSICAL EXPLORATION FOR GROUND WATER IN RAJASTHAN

Time-Domain Electro-Magnetic surveys carried out by ISR in collaboration with NGRI in the Ramgarh area, Dist. Jaisalmer, Rajasthan could detect potable water bearing layer at 250m depth below the saline-water layer. The work was given to NGRI by World Bank as a pilot project. NGRI does not have this equipment. Finding of potable water in perched Rajasthan is like finding gold mine. Hence, this survey is of special importance.

9.3 SEISMICITY STUDY AROUND SUBANSIRI LOWER H.E. PROJECT, NHPC LTD. ASSAM/ ARUNACHAL PRADESH

(P. Mahesh, Santosh Kunar and B. K. Rastogi)

NHPC Limited is carrying out microearthquake (MEQ) studies in Subansiri Lower HE Project, Assam / Arunachal Pradesh since May 2006. The earthquake data has been acquired by NHPC by operating a network of 5 seismograph observatories. The work of analysis and interpretation of the data acquired from 2010 to 2012 is entrusted to Institute of Seismological Research (ISR) since April 2014. The detailed processing and analysis of the acquired data was carried out by ISR with the broad objectives as follows:

- To map the seismogenic sources and to establish possible relationship of the observed seismicity with the prevailing geological and tectonic environment on the basis of the located earthquake events.
- To study the present seismic status of major tectonic features close to Subansiri Lower H.E. project site mapped earlier from geological and geophysical investigations.

During 2010-2012, a total of 487 earthquakes have been located of M1.0-4.6 up to 250 km from the dam site. Out of these 383 earthquakes were recorded and located with the data on single observatory (using a single station 3-component methodology). Two observatories data was available for 76 earthquakes. There are only 28 earthquakes for which the data was available at three observatories. Majority of the micro seismicity seems to be associated with Thrusts trending NNE-SSW and dipping northwesterly. In addition, few earthquakes are found to be located along Main Boundary Thrust (MBT), Main Frontal Thrust (MFT) and some local Faults. Some events are also observed to occur between MFT and Dauki Thrust (DT). We observed that the seismicity around 50 km radius of the dam site during 2010 to 2012 is of no concern for the construction of the dam (ISR.Tech.Rep.78, 2014; ISR.Tech.Rep.82, 2014).

Collaborative Studies

1. Collaborative work with Dr. Harsh Bhu of Department of Geology, ML Sukhadia University, Udaipur in the field of active tectonics in Rajasthan. OSL dating from Kanoi fault in Jaisalmer region.
2. Collaborative project on "Finding natural period of buildings by ambient vibrations". Dr. A.P. Singh, ISR coordinator, Prof. VM Patel, Pricipal Shankersinh Vaghela Bapu Inst. Tech. (SVBIT).

CHAPTER 10

PUBLICATIONS

TABLE 1: NUMBER OF PUBLICATIONS

1	Books (authored/edited)	-
2	Chapters in Books	2
2	SCI Research Papers (2014)	20
3	Non-SCI , Referred journals Res. Papers	2
3	Symp. Proceedings	-
4	Articles/Lecture Notes	2
4	Tech. Reports	9
5	Abstracts/Papers Presented in Sem.	40
6	Invited Lectures	7
7	Keynote Addresses	2
	Total	**84**

10.1 CHAPTERS OF BOOKS

Rastogi, B.K. P. Mandal, S. K. Biswas (2014) Seismogenesis of earthquakes occurring in the ancient rift basin of Kachchh, Western India, in: *Intraplate Earthquakes* (Ed. P. Talwani), Cambridge University Press, pp. 126-161.

Peresan, A., I.A. Parvez, F. Vaccari, B.K. Rastogi, S. Cozzini, A. Magrin, D. Bisignano, F. Romanelli, P. Choudury, K.S. Roy, Ashish, R.R. Mir, G.F. Panza, "Neo-deterministic definition of seismic and tsunami hazard scenarios for the territory of Gujarat (India)", In: "Earthquakes and their impact on Society", Ed.: Sebastiano D'Amico, Springer

10.2 RESEARCH PAPERS PUBLISHED

Published in standard refereed 'Scientific Citation Index(SCI)' Journals (*also listed in 2013 report)

1. ***Bhattacharya, Falguni, BK Rastogi**, M G Thakkar, R C Patel, Navin Juyal (2014) Fluvial landforms and their implication towards understanding the past climate and seismicity in the northern Katrol Hill range, Western India" *Quaternary International,* **333**, 49-61, doi: http://dx.doi.org/10.1016/j.quaint.2014.03.002 **[Impact Factor 1.96]**

2. ***Choudhury, Pallabee** Sumer Chopra , Ketan Singha Roy & **B. K. Rastogi (2014)** A review of strong motion studies in Gujarat State of western India*, J. Natural Hazards*, **71 (3),** 1241-1257 **[Impact Factor 1.638]**

3. **Gandhi, D.**, Prajapati, P., **Prizomwala, S.P.,** Bhatt, N., and **Rastogi, B.K.** (2014) Delineating the spatial variability in Neotectonic Activity along the Southwestern Saurashtra using Remote Sensing Approach. *Zeitschrift für Geomorphologie* **DOI:** http://dx.doi.org/10.1127/0372-8854/2014/0122 (Impact factor 0.821).

4. Jade, S; Mukul, M; Gaur VK; Kumar, K; **Dumka, R.;** Satyal, G; Saigetth, J; Ananda, M. B., Dilip Kumar (2014) Contemporary deformation in the Kashmir-Himachal, Garhwal-Kumaun Himalaya: insights from 1995-2008 GPS time series, Journal *of Geodesy*, vol **1** (1-9) (Impact factor 3.92).

5. **Dumka R.K.**, Kotlia, B.S., Kireet Kumar, Satyal, G., and L. Joshi, 2014: Crustal deformation revealed by GPS in Kumaun Himalaya, Journal of Mountain Science, Vol. **1**(Impact factor 0.67).

6. **Dumka, Rakesh K**, B S Kotlia, K Kumar and G S Satyal, Quantification of crustal strain rate in Kumaun Himalaya (India) using GPS measurements of crustal deformation. Himalayan Geology, 2014, 35(2) 146-155.

7. **Kayal, J.R.** (2014). Seismotectonics of the great and large earthquakes in Himalaya, *Curr. Sc.* **106** (2), 188-197 **[Impact Factor 0.897]**

8. **Kothyari, G. C.** (2014) Morphometric analysis of Tectonically active Pindar and Saryu River Basins, Central Kumaun Himalaya, India Z. F. Geomorphology **DOI:** http://dx.doi.org/10.1127/zfg/2014/0162 (Impact factor 0.821)..

9. ***Kumar, Santosh,** Dinesh Kumar, **B.K. Rastogi** (2014) Source Parameters and Scaling Relations for Small earthquakes in the Kachchh Region of Gujarat, India", *Journal Natural Hazards* DOI 10.1007/s11069-014-1133-4 **[Impact Factor 1.638]**

10. Mishra, O.P., **A.P. Singh**, Dinesh Kumar, **B.K. Rastogi** (2014). An insight into crack density, saturation rate, and porosity model of the 2001 Bhuj earthquake in the stable continental region of western India*, J. Asian Earth Sc.*, **83**, 48-59

11. **Mohan, Kapil** (2014) Seismic hazard assessment in the Kachchh region of Gujarat (India) through deterministic modeling using a semi-empirical approach, *Seim. Res. Lett,* doi: 10.1785/0220120123, **85** (1), 117-125

12. **Pavankumar, G,** Manglik, A. Thiagrajan, S. (2014) Crustal geoelectric structure of the Sikkim Himalaya and adjoining Gangetic basin, Tectonophys.,

13. ***Prizomwala, S. P.**, N. P. Bhatt and N. Basavaiah (2014) Sediment fluxes from a dry land fluvial regime: An example from Rukmawati river basin, Kachchh, western India. Intl J Sediment Research, 29, (109-119). [Impact factor: 1.82]

14. ***Prizomwala, S.P.,** Nilesh Bhatt and N. Basavaiah (2014). Understanding the sediment routing system along the Gulf of Kachchh coast, Western India: Significance of small ephemeral rivers. Journal of Earth System Science 123 (1), 121-133. [Impact factor: 0.89]

15. Sharma, Babita and **B. K. Rastogi** (2014) Spatial distribution of scatterers in the crust of Kachchh region, Western India by inversion analysis of coda envelopes, *Disaster Advanves*, **7** (5), 84-93**[Impact Factor 2.27]**

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18. ***Singh, A.P., N. Annam and S. Kumar** (2014) Assessment of predominant frequencies using ambient vibration in the Kachchh region of western India: implications for earthquake hazards. Nat. Hazards, DOI 10.1007/s11069-014-1135-2 4 **[Impact Factor 1.638]**

19. Sati, S.P., Ali, S.N., Rana Naresh, **Bhattacharya Falguni**, Bhushan Ravi, Shukla, A.D., Sundriyal, Y.P., Juyal Navin (2014) Timing and extent of Holocene glaciations in the monsoon dominated Dunagiri valley (Bangni glacier), Central Himalaya, India, *Journal of Asian Earth Sciences, 91, 125-136* [Impact factor: 2.215]

20. Patel, Vijendra Muftlal, Dholakia, M. B. , **Singh, A.P.** (2014), Emergency prepradness in the cast of Makran tsunami: a case study on tsunami risk visualization for the western parts of Gujarat, India, Geomatics, Natural Hazards and Risk, dx.doi.org./10.1080/19475705.2014.983188

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22. Basavaiah, N., Mahesh Babu, J.L.V., Gawali, P.B., Nagakumar K. Ch. V., Demudu, G., **Prizomwala, S. P.,** Hanamgond, P.T., Rao, K.N. (2015) Late Quaternary environmental

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23. Luirei, K., Bhakuni S. S. and **Kothyari G. C.** (2015). Drainage response to active tectonics and evolution of tectonic geomorphology across the Himalayan Frontal Thrust, Kumaun Himalaya. Geomorphology (Accepted)
24. Luirei, K., Bhakuni S. S. and **Kothyari G. C.** (2015). Quaternary extensional and compressional tectonics revealed from Quaternary landforms along Kosi River valley. Outer Kumaun Lesser Himalaya, Utterakhand India International Journal of Earth Science (Accepted)
25. **Mohan, Kapil, B. K. Rastogi, Peush Chaudhary** (2015) Magnetotelluric studies in the epicenter zone of 2001, Bhuj earthquake, J Asian Earth Sc., 98, 75-84[**Impact factor: 2.215**]
26. Phartiyal, Binita, Randheer Singh Kaira and **Girish Ch. Kothyari** (2015). Late-Quaternary geomorphic scenario due to changing depositional regimes in the Tangtse valley, Trans-Himalaya, NW India, (Palaeogeography, Palaeoclimatology, Palaeoecology 422, (11-24) (**Impact Factor. 2.75**)
27. **Prizomwala, S.P., Drasti Gandhi,** Vishal M. Ukey, Nilesh Bhatt and **B.K. rastogi** (2015) Coastal Boulders as evidences of high-energy marine events from Diu Island, west coast of India: storm or palaeotsunami, Nat. Hazards, DOI 10.1007/s11069-014-1371-5, 75:1187-1203 [**Impact Factor 1.638**]
28. **Singh, AP** (2015) Seismic Hazard Evaluation in Anjar City Area of Western India: Microtremor Array Measurement, Soil Dynamics and Earthquake Engineering, 10.1016/j.soildyn.2015.01.009
29. **K.Madhusudhanarao,** M. Ravikumar and **B.K.Rastogi** (2015) "Seismic evidences for Underplating and Uplifted Crust beneath the Northwestern Deccan Volcanic Province, India", Journal of Geophysical Research: Solid Earth, April 2015, 120, 1-21, doi: 10.1002/2014JB011819 (**Impact Factor 3.44**)

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2. Choudhury, Pallabee, Sumer Chopra, Ketan Singha Roy and Jyoti Sharma, Ground motion modeling in the Gujarat region of Western India using Empirical Green's function approach, submitted to SRL.
3. Choudhury, Pallabee, Sumer Chopra, Ketan Singha Roy, Jyoti Sharma and B K Rastogi, Revisiting the 1956 Anjar earthquake in Western India: Empirical Green's function approach, communicated to PAGEOPH
4. Das, Archana, Gaurav Chauhan, S.P. Prizomwala, M.G.Thakkar and B.K.Rastogi (2014): Assessment of Realtive Tectonic Activity from the Southern Mainland Kachchh, Western India: Insights from Geomorphic Indices and Drainage Pattern Analysis. Journal of Asian Earth Science (communicated).

5. Gupta, Sandeep, P. Mahesh, S. S. Rai and Ajay Paul (2014), 3-D Seismic velocity structure of Kumaon-Garhwal (Central) Himalaya: Insight into quartz rich felsic rocks and earthquake occurrence, BSSA.
6. Joshi, Vishwa, V Patel and S Aggarwal, "Crustal Velocity Models Retrieved From Suaface Wave Dispersion Data For Gujarat Region, India", BSSA.
7. Kothyari, G.C., Response of monsoon fed rivers to unusual rainfall during June 2013: Evidence from Saryu River, submitted to Natural Hazard.
8. Kothyari, G.C., B. K. Rastogi, P. Morthekai and Rakesh K Dumka (2014) Active Faulting and OSL Chronology of Quaternary Landforms around Gedi Fault, Eastern Kachchh, India, Tectonophys.
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10. Mohan, Kapil, B.K. Rastogi, B. Sairam, Rajesh Mishra and Vandana Patel, "Seismic Hazard Assessment at Industrial Sites in Kachchh (Western India) based on shear wave velocities" submitted to Journal of Soil Dynamics and Earthquake Engineering.
11. Mohan, Kapil, B.K. Rastogi, Vasu Pancholi and Drasti Gandhi (2015). Seismic hazard assessment at micro level in Gandhinagar (the capital of Gujarat) considering soil effects, J. Soil Dynamics

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13. Phartiyal, Binita, Girish Ch. Kothyari and Randheer S Kaira (2014) Climate paramount over tectonics during Late Quaternary-Ladakh Himalaya, Western Tibet" submitted to Nature -Geoscience
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15. Prizomwala, S.P., Nilesh Bhatt and W. Winkler. How important is multiproxy approach in source to sink studies: an example form gulf of Kachchh, western India. Earth Science Review
16. Rao, K.M, M. Ravi Kumar and B.K.Rastogi, "Seismic evidences of volcanism beneath Gujarat, Western India",
17. Rao, K.M, M. Ravi Kumar and B.K.Rastogi "Radial Anisotropy beneath Gujarat, Western India using direct S wave splitting",
18. Rao, K.M, M. Ravi Kumar and B.K. Rastogi, Complex D" layer anisotropy beneath Gujarat, Western India using differences of SKS and SKKS splitting ", "Excitation of free oscillations of recent large earthquakes using superconducting gravimeter data"
19. Rao, KM et al. Mantle deformation beneath the Northwestern Deccan Volcanic Province from shear wave splitting analysis, communicated to Journal of Geophysical Research - Solid Earth. Manuscript 2013JB010261
20. Rastogi, B.K. and Jyoti Sharma (2014) Global Seismic Cyclicity and Enhanced Seismicity since 2000, Natural Hazards

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22. Simha,C.P., Annam Navaneeth, K.M.Rao, B.K.Rastogi, G.PavanKumar, P.Mahesh, V.N.Sridhar and A. K. Shukla, Spatial and Temporal Variations of Total Electron Content (TEC) and Outgoing Long Wave Radiation (OLR) during greater earthquake period near the Indian Subcontinent
23. Singh, A.P., I, G. Roy and J.R. Kayal (2013) Seismic source characteristics in Kachchh and Saurashtra regions of western India: b-value and Fractal dimension mapping of aftershock sequences, Natural Hazards.
24. Telesca, L. Aggarwal, S. K., Khan, P. K., Rastogi, B. K., Visibility graph analysis of 2003 - 2012 earthquake sequence in Kachchh region Gujarat Western, India. Pageoph (date of communication August 2014)
25. Kapil Mohan, Peush Chaudhary, Pavan Gayatri and B.K. Rastogi, Magnetotelluric investigations in southern end of the Cambay Basin-Gujarat, India communicated to Journal of Asian Earth Sciences.

Non-SCI (but referred journals) Research papers:

1. B. K. Rastogi (2014). Seismicity and Earthquake Hazard Studies in Gujarat, J.of Earthquake Sc. (JoES) vol. 1 (1)
2. B. K. Rastogi and A. G. Chhatre (2014). Seismotectonic Investigations for Siting of Nuclear Power Plants, Assessment of Design Basis Ground Motion and Tsunami Hazard, J.of Earthquake Sc. (JoES) vol. 1 (1)

Articles Published

Rastogi, B. K. (2014) Geological and Geophysical Applications in Hydrocarbon Exploration, PDPU Lecture Series, pp.5

Gandhi, Drasti, S.P.Prizomwala, N.Y.Bhatt, Kapil Mohan and B.K.Rastogi (2014) Exploring the proxy toolkit for palaeotsunami deposits: An example from Diu, Western India, Bhukampan, ISES Newsletter.

10.3 TECHNICAL REPORTS

1. Kapil Mohan and B.K. Rastogi, Peush chaudhary, Pavan Gayatri, Virender chaudhary, Mohit Arora and Drashti Gandhi, Magnetotelluric survey to Identify Geothermal source zones at Chabsar Thermal spring site, ISR Tech Rep No. 80, pp. 8.
2. B. K. Rastogi and Santosh Kumar (2014). A short report on Bharuch Earthquake of June 21, 2014, ISR Tech. Report No. 81-2014
3. Mhesh, P., Santosh Kumar and B. K. Rastogi (2014). Microearthquake data processing, interpretation and report preparation for 2011 data for seismogenic sourcesaround Subansiri Lower Project, Tech. Report No. 82-2014.
4. Kapil Mohan, Vasu Pancholi, Drashti Gandhi, Vinay Divedi, Santosh Kumar and B.K. Rastogi (2014). Report on Seismic Hazard Assessment of Vibrant Summit site in Gandhinagar. Report No. 83-2014

5. Kapil Mohan and B.K. Rastogi (2014). Report on Seismic Hazard Assessment of Cryogenic Ethane Receipt and Storage Facility at Dahej. Report No. 84-2014.
6. Rastogi B. K., Kothyari, G. C. and Sukumaran, P. (2015). Geomorphological and Geological Investigation of Giyre lineament, Sindudurg District of Maharashtra. Report No. 85-2015.
7. Kapil Mohan, B. K. Rastogi, Vasu Pancholi, B. Sairam, Suraj Kumar, Vandana Patel, Drasti Gandhi, Rahul Ranjan and Vinay Dwivedi (2015). Report on Seismic Hazard Assessment of Multi-Storey Commercial Complex at Science City Road, Sola. Report No. 86-2015.
8. Kapil Mohan, B. K. Rastogi,Peush Chaudhary, Pavan Gayatri, Virender Chaudhary, Mehul Nagar, Pruthul Patel, Dilip Singh and Drasti Gandhi (2015). Magnetotelluric survey to Identify Geothermal source zones at Tuwa Thermal spring site, ISR Tech. Report No. 87-2015.
9. Prasanta. K. Patro and **Kapil Mohan** "3D modeling of MT data and interpretation for geothermal source zone near Chabsar, Gujarat" NGRI Report No: NGRI-2015- Exp-875, ISR Tech. Report No. 88-2015
10. B.K. Rastogi and Santosh Kumar (2015) Intensity of Mw 3.9 tremor of March 19, 2015 in north Mahesana District, Institute of Seismological Research, Technical Report No. 89-2015

10.4 ABSTRACTS

International Union of Quaternary Association (INQUA), 27 July - 2 August, 2015, in Nagoya, Japan

1. Girish Ch. Kothyari, Anil Shukla and Navin Juyal (2014), Late Quaternary climate variability and landform evolution of Pindar river valley, Central Himalaya, Utarakhand, India. International Conference on LateQuaternary Perspectives on Climate Change, Natural Hazards and Civilization.

2. Bhattacharya Falguni, Patel R.C. and Rastogi, B.K. (2014), Towards understanding the evolution of fluvial landforms in seismically active Katrol Hill Range, Kachhch, Western India

Conf. Luminescence Emission Dosimetry (LED, 2014), Canada, July 7-11, 2014

3. Shukla, Anil D. Falguni Bhattacharya, B.K. Rastogi (2014) Chronology and geochemistry of dry land fluvial system, western India

19th international association of sedimentologists conference held on Geneva (18th – 20th August 2014)

4. Das, Archana, Gaurav Chauhan, Falguni Bhattacharya, M.G.Thakkar and B.K.Rastogi (2014): Climate – tectonic signatures in sedimentary packages of Rukmawati River, Kachchh, Western India.
5. Prizomwala S. P., Solanki T., Chauhan G., Bhatt N., Basavaiah N., Thakkar M. G., Rastogi B. K. (2014) Climate-Tectonic Interactions in the Fluvial Sequences of the Eastern

Northern Hill Range, Kachchh, Western India: Luminescence Chronometry and Geomorphic Evidences

Am. Geophysical Un. Fall Meeting, San Fransisco, Sep 2014

6. Indra N. Gupta (of Maryland), David P. Schaff*(Columbia Univ., NY), Bal K. Rastogi, P. Mahesh, and Robert A. Wagner (Columbia University, New York), "Analysis of Spectral Characteristics of Seismic Noise Preceding Kachchh, India Earthquake of 19 June 2012 for Advance Warning"

36th Annual Convention, Seminar on Exploration Geophysics with Special Theme on "Advanced Geophysical Techniques in Exploration of Deep-Seated Resources, NGIR, Hyderabad, October 16-18, 2014

7. B.K. Rastogi (2014) Shallow and deep geophysical investigations for imaging faults, basement and crustal configuration in Gujarat (Abstract No. 58), Symp. Souvenir

Engineers Conclave, Ind Inst. Sc., Bangalore, Organised by ISRO, October 30-Nov1, 2014

8. B.K. Rastogi (2014) Early Warning Systems for Geohazards, Engineers' Conclave 2014, pp 16-17

National Conference on Himalayan Glaciology (NCHG-2014) Shimla, 30-31 October 2014

9. S.P. Sati, Sheikh Nawaz Ali, Naresh Rana and Falguni Bhattacharya "Towards improving our understanding of Holocene glaciations in monsoon dominated regions of Himalaya: evidence from Dunagiri valley, Garhwal Hialaya, Uttarakhand, India".

NASA-ISRO (NISAR) two day Workshop on "SAR Applications", SAC, Ahmadabad 17-18 Nov. 2014

10. B.K. Rastogi, Pallabee Choudhury and Rakesh Kumar Dumka (2014) "SAR Measurement for Earthquake Studies in India"

Symposium, Indian Geophysical Union, Nov. 19-21, 2014, Kurukshetra.

11. Aggarwal, S.K. and P.K. Khan (2014) "The Lg seismic wave attenuation for Gujarat region "Western Indian", IGU-2014.
12. Joshi, Vishwa and Sandeep Aggarwal (2014). Crustal Shear Wave Velocity Model Retrieved from Love and Rayleigh Wave Dispersion Data in Saurashtra Peninsula,
13. Mahesh, P., Sandeep Gupta, S. S. Rai and Ajay Paul (2014). 3-D seismic velocity structure of Kumaon-Garhwal Himalaya: Insight in to quartz rich rocks and earthquake occurrence. IGU-2014.
14. Manglik, A., G. Pavan Kumar and S. Thiagarajan (2014). Integrated magnetotelluric and seismic mdel of the deep crustal and lithospheric structure of the Sikkim Himalaya
15. Mayank Dixit (2014). Effect on the Geomagnetic Field due to variation in the axial speed of earth.IGU-2014
16. Mohan Kapil, B.K.Rastogi, Vasu Pancholi and Drasti Gandhi (2014). Seismic Hazard Assessment at Micro Level in Gandhinagar, Gujarat considering Geotechnical Parameters. IGU-2014.

17. Pancholi, Vasu, Rahul Ranjan, Suraj Kumar, Vinay Kumar Dwivedi and B.K. Rastogi(2014). Liquefaction hazard study of Dahej and Kamboi port area, Gujarat
18. Pavan Kumar, G. and Manglik, A. (2014). Distortions and geoelectric strike analyses of magnetotelluric impedance tensors from the Sikkim Himalaya.

    Asian Seismological Commission, Makati City, Philippines (17-20th Nov-2014)
19. Pavan Kumar, G., Virender, Kapil Mohan and B.K.Rastogi (2014). Time domain electromagnetic investigations in the Ahmedabad region, cenral Cambay basin, Gujarat. IGU-2014.
20. Radhe Shyam, Mayank Dixit and Sandeep Aggarwal (2014). Hydrographic survey for Archaeological and Geological evidences. IGU-2014.
21. Singh, R.K., Venkateswara Rao, B.K. Rastogi, Rahul Singh, Monica and Komal(2014).

    "Delineation of geological structures in and around Cambay basin using Gravity and Magnetic surveys". IGU-2014

    IOT2014: "A Decade of Palaeotsunami Research", Pondicherry, December 10-13, 2014.
22. S. P. Prizomwala, Tarun Solanki, Archana Das, Nilesh Bhatt and B. K. Rastogi Palaeotsunami deposits from the southwestern Kachchh coast, western India

    National Conference on Quaternary Climatic Changes: New Approaches and Emerging Challenges to be held at Lucknow during 15th to 16th December 2014
23. Drasti Gandhi, S.P.Prizomwala, N.y.Bhatt, Kapil Mohan and B.K.Rastogi (2014) Exploring the proxy toolkit for palaeotsunami deposits: An example from Diu, Western India.
24. Kothyari G. C., Rastogi, B. K., Morthekai, P and Dumka Rakesh " Active Faulting and OSl chronology of Quaternary Landforms around Gedi Fault, Eastern Kachchh India

    ISR International Symposium at ISR on "Reducing Earthquake Losses" and 5th International Convention on Earthquake Science during Jan 5-7, 2015
25. Gupta, Indra N, David P. Schaff, Bal K Rastogi, P Mahesh and Robert A Wagner "Analysis of Seismic Noise Preceding Kachchh, India Earthquake of 19 June 2012 for Advance Warning – Encouraging Results"
26. Mahender, E., Damodar, K., Yashavant Kumar Singh and G. Pavan Kumar

    "Magnetotellurics data analysis over anisotropic and inhomogeneous medium- Results from a synthetic study"
27. Pancholi, Rahul Ranjan, Suraj Kumar and Vinay Kumar Dwivedi, Geotechnical Characterization of Problematic Soils: Swell, Dispersion and Collapse prediction,
28. Pancholi, Vasu, Suraj Kumar, Rahul Ranjan and Harshal B. Chauhan, Liquefaction Potential Evaluation of Sabarmati Sand Soil with Different Silt Contents by Cyclic Triaxial Testing
29. Rastogi, BK "New results from geotechnical investigations, seismic hazard assessment and microzonation in Gujarat"

30. Rastogi, B.K., Kapil Mohan, B. Sairam, Sandeep Aggarwal, Vandana Patel, A.P. Singh, Vasu Pancholi, Vinay Dwivedi, Rahul Ranjan and Suraj Singh Microzonation Studies In Ahmedabad

31. Sairam, B., B. K. Rastogi and Vandana Patel "Shear-Wave Velocity Estimations and Site Characterization of the Dholera Area, Gujarat, India"

32. Singh, R.K., Venkateswara Rao. S., Rastogi. B.K., Amit Mishra and Avinash Chouhan: "Mapping of basement configuration and sedimentary thickness of Cambay basin using Gravity and Magnetic surveys"

Three days National Seminar on Science and Technology for Human Development organised by Indian Science Congress National Seminar Chapter-II, 21st -23rd January, 2015 Imphal, Manipur

33. Th. Sarda, N.N. Dogra, Falguni. B and B. K. Rastogi, Geoenvironment studies in the middle reaches of Sabarmati River, Gujarat: Implication towards past monsoon variability.

6th International conference on innovative trends in Civil Engineering architecture and environment engineering for sustainable infrastructure development" during 24-25th Jan. 2015 at JNU New Delhi.

34. Viraj Parekh, Kapil Mohan and Tejas Thaker "Comparative analysis of PGA-MMI relationships for January 26th 2001 M7.6 Bhuj earthquake"

29th Gujarat Science Congress, Sc. City, Ahmedabad, Feb 28 and March 1, 2015

35. Vasu Pancholi*, Vinay Kumar Dwivedi, Sarda Maibam, Suraj Kumar, Rahul Ranjan, B.K. Rastogi (2015) Geotechnical Investigations of Soil of Gandhinagar, Capital City of Gujarat, Abstract No. F1

36. B.K. Rastogi, Santosh Kumar, A.P. Singh (2015) "New Initiatives on Earthquake Studies in Gujarat", Abstract No. F22

4th national conference of Ocean Society of India OSICON 2015 at NIO, Goa during 22-24march 2015.

37. S. P. Prizomwala, Drasti Gandhi, N.P. Bhatt and B. K. Rastogi Evidences of high energy marine events from Gujarat coast, Storm or tsunami deposits?

38. Drasti Gandhi, S. P. Prizomwala, N.Y. Bhatt, Kapil Mohan, B.K. Rastogi Evaluation of numerical models for paleotsunami and palaeostorms deposits from Saurashtra coast, western India

39. Nisarg Makwana, S. P. Prizomwala, N.P. Bhatt and B. K. Rastogi A review of Late Holocene climate dynamics form western India: hunting sites for reconstructing high resolution climate dynamics

International Union of Quaternary Association (INQUA), 27 July - 2 August, 2015, in Nagoya, Japan

40. Girish Ch. Kothyari, Anil Shukla and Navin Juyal (2014), Late Quaternary climate variability and landform evolution of Pindar river valley, Central Himalaya,

Utarakhand, India. International Conference on Late Quaternary Perspectives on Climate Change, Natural Hazards and Civilization.

41. Bhattacharya Falguni, Patel R.C. and Rastogi, B.K. (2014), Towards understanding the evolution of fluvial landforms in seismically active Katrol Hill Range, Kachhch, Western India

10.5 SEMINARS / WORKSHOPS ATTENDED WITHOUT ABSTRACTS

1. B.K. Rastogi, K.M. Rao, Santosh Kumar and Jignesh Patel, Seminar on M-Governance, Mahatma Mandir, Gandhinagar.
2. Komal, Monica and Parul, Geophysicists attended Workshop on"Acqifer Mapping and Management", Ahmedabad Management Association, March 7, 2014.
3. Kapil Mohan and Vasu Pancholi "Brainstorming workshop on Geotechnical Engineering", Paper presented "Geotechnical investigations for Seismic Microzonation", the seminar Sponsored by DST, New Delhi, IIT, Mumbai, 26.3. 2014
4. B.K. Rastogi, Pallabee Choudhury and Rakesh Kumar Dumka attended NASA-ISRO (NISAR) two day Workshop on "SAR Applications" B.K. Rastogi acted as chairman of a session on Geological aspects and presented a paper on "SAR Measurements for Earthquake Studies in India", 17-18 Nov. 2014
5. K.M. Rao, Santosh Kumar and Sidhartha Prizomwala attended half day workshop on 'Post-Disaster Reconstruction after Tsunami in Tamil Nadu' at GIDM, 19.11.2014 (Main Presentation by Dr. Vareethiah Konstatine, Prof. of Zoology, TN).
6. BK Rastogi, Seminar on Economic Growth andNational Integration, organised by In. Intl. Friendship Soc., at India International, Delhi 24.11.2014
7. Dr. A.P.Singh attended a workshop on Challenges in seismic site characterization and solutions through recent developments on 10th December, 2014 at Indian Institute of Technology (IIT), Roorkee
8. Shri Santosh Kumar attended an International Conference at Earthquake Engineering Department at Indian Institute of Technology (IIT), Roorkee during the period 11th - 13th December, 2014

Mr. Santosh Kumar, Dr. Rakesh Dumka, Dr. Girish Kothyari, Dr. K.M. Rao and Dr. B.K. Rastogi attended Workshop on "National Consultation on Training Modules Developed for Disaster Risk Reduction in India and Incident Response System, GIDM, 12-13 February 2015

B.K. Rastogi, Dr. Kapil Mohan, Dr. Pavan Gayatri and Mr. Peush Chaudhury attended one day Workshop on Geothermal Energy, PDPU, Dr. Kapil Mohan presented report on ISR investigations of 3D MT at Chabsar and Tuwa Geothermal energy source areas, 3.3.2015

Dr. B.K. Rastogi, Dr. Kapil Mohan, Mr. Vasu Pancholi, Mr. Vinay Dwivedi, Mr. Suraj Kumar and Mr. Rahul Ranjan attended "Recent Trends in Sustainable Geotechniques", organized by Dept. of Civil Engg., School of Technolgy, PDPU, 20.03.2015.

Dr. Sidhartha Prizomwala and Nisarg Makwana attended symposium **4th national conference of Ocean Society of India OSICON 2015 at** Nat Inst. Oceanography, **Goa** and presented paper **during 22-24 March 2015.**

10.6 INVITED LECTURES

1. Santosh Kumar "Understanding Earthquakes" in the "Vacation Training Program on Bioresources for School Children", Science City, 8-29 April, 2014", 16.4.2014
2. B.K. Rastogi invited Seminar Talk at Karlsruhe Inst. of Tech. entitled "Geological, geophysical, geotechnical and seismotectonic investigations in Gujarat (India) for seismic hazard assessment at macro to micro levels" on 15.5.2014.
3. B.K. Rastogi, invited Seminar Talk at Trieste Univ., Italy entitled "Geological, geophysical, geotechnical and seismotectonic investigations in Gujarat (India) for seismic hazard assessment at macro to micro levels" on 20.5.2014.
4. Rakesh K Dumka, invited to deliver a lecture on "Advance surveying: DGPS and its application" on one day workshop organized by CISPT, Changa, Anand, 8 August 2014
5. B.K. Rastogi (2014) Shallow and deep geophysical investigations for imaging faults, basement and crustal configuration in Gujarat (Abstract No. 58), Symp. Souvenir, 36th Annual Convention, Seminar on Exploration Geophysics with Special Theme on "Advanced Geophysical Techniques in Exploration of Deep-Seated Resources, NGIR, Hyderabad, October 16-18, 2014
6. Rakesh K Dumka (9th August, 2014): Invited lecture "Introduction to Differential Global Positioning System (DGPS) Theory and Application" at Charotar University of Science and Technology, Changa, Anand, Gujarat.
7. Rakesh K Dumka (15th October 2014): Expert Talk on "Application of Remote Sensing and GPS for disaster assessment" at A D Patel Institute of Technology, New Vallabh VidyaNagar, Gujarat.

KEYNOTE ADDRESSES

1. B.K. Rastogi (2014) Early Warning Systems for Geohazards, Engineers' Conclave 2014, pp 16-17, Engineers Conclave, Ind Inst.Sc., Bangalore, Organised by ISRO, October 30-Nov1, 2014.
2. B.K. Rastogi (2015) "Earthquake Studies in Gujarat: Significant contributions" 29th Gujarat Science Congress, Sc. City, Ahmedabad, March 1, 2015

CHAPTER 11

SOCIETAL OUTREACH

11.1 HELP TO THE UNIVERSITIES

Help to PhD students from different Universities

1. With ISR Scientist Dr. AP Singh: .Prof. Vikram M. Patel, Structural Engineer and Head of Civil Department, B S Patel Polytechnic was awarded PhD degree from Ganpat Univ. by way of working Title of his thesis is "Analysis & Design of Structures in Tsunami Prone Area", 2013
2. With ISR Scientist Dr. AP Singh: Mr. Vijendra M. Patel, Asst. Prof. Dept. Civil Engg. KD Polytechnic, Patan is working on Tsunami studies since 2013.
3. With ISR Scientist Dr. AP Singh: Abhijitsinh Parmar, Asst. Prof. SVBIT, Gandhinagar on "Natural Period of Buildings" since 2014
4. Mr. Javid Dar from BHU has stayed cumulative for over a year for age determination of sediments in our OSL lab and geotechnical measurements of soil samples 2013 to 2014. In 2014 he visited during May-July 2014.
5. Ms. Parul C. Trvedi of India Meteorological Department, Ahmedabad has taken our earthquake data and taking help in analysis for her PhD thesis. Dr. Kapil Mohan has reviewed her thesis entitled "Study of Seismicity over Kutch Region Using Multiparametric Observations: 2001 to 2011" submitted to Saurashtra University, Rajkot (Dur. Aug-Nov.2014).
6. Mr. Sanjay Singh Negi, Senior Research Fellow of Wadia Institute of Himalayan Geology taking help in doing seismic tomography of Kumaon-Garhwal Himalaya for his PhD form Sri P. Mahesh Scientist of ISR.
7. Ms. Madhvi Dabhi, KSKV Kachchh University during 23rd January to 31st January 2015 (OSL dating of Nirona river section)

11.2 VISITORS

1. Ms Aditi Chaturvedi, Director All India Society of Electronics and Computer Tech. (AISECT), Ahmadabad Center (9099006302) and Dr. Suryanshu Choudhary, Asstt. Prof. (phys), village Mendia, Bhojpur, Raisen, MP (09977676759) for discussion on electromagnetic earthquake precursors, 21.4.2014
2. Dr. Sanjib K. Biswas, Visiting Professor, for joint geological work, Apr 29 – May 1, 2014
3. Shri K.N. Shrivastava, IAS (Retd), Member NDMA (Drought), June 26, 2014
4. Prof. J.R. Kayal, Visiting Scientist, July 2-10, 2014
5. Dr. T.J. Majumdar, Emeritus Sc., SAC, ISRO, July 5, 2014
6. Dr. T. Seshunarayana, NGRI, July 5-6, 2014
7. Dr. Neha Ranjan Patra, IITk, Geotechnical expert, July 5-6, 2014
8. Ms. Shweta Sharma, Collaborator on earthquake loss modeling, SAC-ISRO, July 9, 2014
9. A team of GWSSB (Guj. Water & Sewage S. Board) consisting of: R.N. Shukla, Consultant, DK Pandya , Suptd. Geologist, and D.N. Rao, Geophysicist was sent by Principal Secy. Dr. Rajiv Kumar Gupta for ISR help in hydrological modeling of Kachchh basin, July 2014
10. Prakash Suthar, Director, Owner and researcher, Windsor Wood (India) Private Limited

    Cell no. 09820788430 for demo of processed wood which is very strong and flexible and may be used for earthquake-resistant construction, 23.7.2014
11. A team of ONGC geophysicists: 1.C. Markendeyulu, DGM, OU 1980, 2. Patnaik, DGM, AU 1982, 3. Chauhan, Geophysisit, IITkh 2010, visited to give us a sponsored project for monitoring shaking due to blasting, 24.7.2014
12. Prof. J.R. Kayal, Visiting Professor, Aug 21-30, 2014
13. Prof. Tina M. Niami, Universityof Missouri at Kansas, USA, Fullbright Fellow, Sep.4 – 12, 2014
14. Prof. Anirbid Sircar with Ms.Shreya Sahipal, Asst. Prof. , Gaurav Negi, Res. Associate and Vijayan Vaidya, Res. Asstt. for discussions on investigations for Geothermal energy sources, Nov. 3, 2014.
15. Prof. Vikram Patel, Principal, SVBIT for discussions on estimating natural periods of high rise buildings, Nov. 3, 2014
16. Osmania Univ. team of the following for review of research facilities at ISR for recognition as external center for PhD:-Prof. Madhusudan Rao, Associate Prof. Viraiah (Electrical resistivity), Both from Center Exploration Geophysics, Dean: Prof. Nageswar Rao (Chemistry), Registrar: Prof. Pratap Reddy (Zoology), Dy. Registrar: Poddar and Asstt. Registrar: Sudendra, Nov. 3-4, 2014.
17. Mr.CH Rao, JVSS Narayan Murty and Santosh Dubia of GERMI for discussions on formulating a collaborative project on Passive Seismicity Investigations for Oil Prospecting, 12.11.2014

18. Mr. Rajendra Mistry of Guj.Power Cor.Ltd and Prof. Anirbid Sircar and team of SOPT-PDPU for review of Geothermal work and future plan, Nov.19, 2014,
19. Prof. Frans Coenen, Prof. Stephen Holloway, Ms. Lynn E Evans, Ms. Christine Bateman faculties of Liverpool University visited ISR on 20/11/2014 for 2015-16 University of Liverpool India Fellowships Program.
20. Dr. R. Rangarajan and Muralidharan, sr. scientists of NGRI for discussions on geophysical surveys for ground water and potash in Kachchh, 8.12.2014
21. Prof. RK Verma formerly Head Dept. Geophysics, ISM, Dhanbad to deliver lectures on "Geodynamics of India", on three days Dec 17-19, 2014
22. Shri Kunjilal Mina, IAS, Secretary, Disaster Management Dept. and Shri Vijendra Singh, OSD Disaster Management, Jaipur, Rajasthan, 18/12/2014
23. Vaishali Patil, Swapnil Jadhan and Sunil Prasad Shetti, Bharti Vidyapeeth's Inst. of Management & Information Tech., Navi Mumbai-400614, 18/12/2014
24. From Disaster Management Cell, New Delhi: 1. Head, Dr. Anil Agarwal, Addl. Secreatry (Revenue), Mr. Praveen Jha, ADM, Southwest Delhi, Mr. Pradep Kumar, Grade 2 Officer, DDMA
25. From Disaster Management Department of Rajasthan, Jaipur: Sri Kunji Lal Mina, Secretary and Sri Bijendra Singh, OSD, 18.12.2014
26. Prof. K.S. Valdiya, Distinguished Visiting Fellow, Jan 2-15, 2015
27. Prof. J.R. Kayal, Visiting Professor, Jan 3-17, 2015
28. Mr. Samir Kumar, IAS, Secretary (Revenue-Director, Disaster Management),Punjab with 3 associates, 21/1/2015
29. A team of 10 persons including Bangladesh Disaster Management and Govt. representatives visited ISR accompanied by Dr. Dilip Kumar Singh, Assistant Director and Mr. Darwin Samuel, Senior Research Fellow from Disaster Management Institute (DMI) Bhopal, 19.02.2015

List of Bangladesh Delegation

Sn.	Name	Designation
1	Mr. M. Khalid Mahmood	Director (Joint Secretary), Dept. of Disaster Management
2	Mr. Md. Akhtaruzzaman	Deputy Project Director (Director Secretary), Dept. of Disaster Management
3	Mr. Mohammad Manirul Islam	Sr. Asst. Secretary, Min. of Disaster Management & Relief
4	Mr. Mohammad Mahbubul Alam Majumder	Sr. Asst. Secretary, Min. of Disaster Management & Relief

Sn.	Name	Designation
5	Mr. Md. Hasanuzzaman	Sr. Asst. Chief, Min. of Disaster Management & Relief
6	Mr. Mohammad Abul Kashem	DRDO, Brahmanbaria
7	Mr. Md. Abdul Alim	PIO, Bagaichari, Rangamati
8	Mr. Mohmmad Razaul Karim	PIO, Gafargaon, Mymensingh
9	Mr. Md. Jalal Uddin	PIO, Symnagor, Satkhira
10	Mr. Mohammad Tariqul Islam	PIO, Fhatikchari, Chittagang

30. Sohanlal of Sanghi Cement, want to Construct multi story hotel in Bhuj and Tiwari, Kachchh, 11.02.2015
31. Sri R.K. Jain, Scretary NDMA, Dhannanjay Reddy, IAS Revenue and Director Disaster Mnagement and Anil Sinha, Vice-Chairman, BSDMA, 12.2.2015
32. Dr. N.R. Ramesh, former Dy. Director General, GSI and Dr. S.G.S. Swami, KSCOST, Govt. of Karnataka, 05/02/2015
33. Umesh Dayal -Technical Director -Geotechnical, Rizzo Associates, Pittsburgh, U.S.A, Feb 5, 2015 [a geotechnical engineer, specializing in design of foundations of dams and power plants, He will be involved for Mithi Virdi NPP through Westinghouse] <umesh.dayal@Rizzoassoc.com> umesh_dayal@yahoo.com My contact no. in India is 09560587288
34. Sri Anil Sood, Executive Director, and Head of Instititute, GEOPIC, Keshav Deo Malviya Inst. of Petroleum Exploration, ONGC, 4.3.2015 [offered to give two projects on passive seismicity for oil industry]
35. Dr. S.K. Biswas, March 23-25, 2015

11.3 VISIT OF FOREIGN SCIENTISTS

From Institute of Earth Sciences, Academia Sinica, Taipei: Prof. Li Zhao; Prof. Wen-Tzong Liang; Prof. Bor-Shouh Huang; and Dr. Cedric Legendre, **March 15-19, 2015**

From Department of Geosciences, National Taiwan University, Taipei: Prof. Yih-Min Wu, **March 15-19, 2015**

11.4 VISIT OF STUDENT GROUPS

2014-2015

1. Some 85 students of Venus International College of Technology, Bhoyan Rathod, Opp IFFCO, (ONGC WSS), Adalaj-Kalol highway, Dist. Gandhinagar- 382 420, venusict@gmail.com along with 3 faculty members including Prof. Megha Shah, Prof. Pranav Mehta, Prof. Ram Gareja visited ISR on 3.4.2014.
2. Some 37 students of Government Engineering College, Palanpur, Jagana, Palanpur-Ahmedabad Highway, Palanpur, Dist: Banaskantha, Gujarat, gec_palanpur@live.in

along with 3 faculty members including Prof. Kamini A. Parmar (Asst. Prof.) GEC, Palanpur, Prof. S.G. Chauhan, Shri Girishbhai Mevada visited ISR on 19.4.2014.

3. Some 28 students of B.Tech Petrolium Engineering visited along with their faculty coordinator Dr. Uttam Bhui, On 24th June 2014,
4. Some 28 students of B.Tech Petrolium Engineering visited along with their coordinator Ms. Rincy Anto & Ms. Rajshree Saini. On 26th June, 2014
5. A group of 50 students (Diploma in C.E. and I.T. Engg.) from Dalia Institute of Diploma Studies, Kanera, Kheda along with their faculty Prof. Shailesh Patel, Prof. Prashant Patel, Prof. Rocky Patel, Prof. Bijal Patel and Prof. Kinjal Patel on 07/08/2014.
6. Some 20 students of fifth semester (EC) from Dalia Institute of Diploma Studies, Kanera, Kheda, visited ISR along with Prof. Vipul Patel and Prof. Haresh Patel on 5/9/2014.
7. Some 32 trainees of RCTI College training course of Civil Engineering, arranged by Dr Subrato Roy of NITTTR, Bhopal, Mobile No. 07869529500, Nov 20, 2014
8. Some 25 students MSc Geol., MG Sc. Inst, Guj Univ. along with faculty, 20.1.2015
9. Visit of 30 students of B.Tech Civil of G.K. Bharad Inst. of Engg. – Tramba, Rajkot Faculty Pradip R. Gosai, Mr. A.M. Malhakiya and Mr. P.M. Dholiya 6.2.2015
10. A visit of 55 students of 3rd and 4th year Civil Engineering students of AD Patel Inst. of Tech., New Vidyanagar along with HoD Prof. Bhatt and their three faculties including Prof. Kumar Trivedi, Yagnik and Bhaven Patel, 7.2.2015.
11. Study Tour of 30 MCA Sem-II students accompanied by two faculty members Prof. Minal V. Shah and Prof. Sagar P. Patel Of Dharmsinh Desai University, Nadiad Prof. DP Ahalpara (hod.mca@ddu.ac.in) on (Friday) 13-2-2015
12. Visit of 120 students of 6th Sem of Dept. of Civil Engg., L.D. Engg. College, Ahmedabad with their faculty Dr. Chirag N. Patel, Asst. Prof., 21.02.2015
13. Visit of 60 students of 6th semester of B.E. Civil of Govt. Engg. College, Palanpur with 2 faculty, Prof. V.R. Sharma, 20.03.2015
14. Visit of 28 students of M.Tech Civil of Nirma Univ. with 3 faculty, Prof. (Dr.) Sharadkumar P. Purohit, Prof. Jhanvi Suthar,Prof. Paresh Patel 4.3.2015
15. A visit of 60 students of 4th Semester IT/CE students of Dalia Institute of Diploma Studies, Kanera, Kheda along with their 4 faculties on 3.3.2015.
16. Dr. Poornima, Sr. Lecturer, GCERT, Education Department, Gandhinagar has brought about 70 school teachers at Higher Secondary level working in Govt. of Gujarat, 19.3.2015.
17. Vist of 60 final year M. Tech students and 4 faculty of Government Engineering College, Palanpur, 20.3.2015

11.5 DISSERTATIONS OF STUDENTS

TABLE: No. of Dissertations University wise during 2014-15

State	University/College	No. of Students
Guj.	Ganpat Univ., Kherva	7 of 2014 Batch 12of 2015 Batch
Guj.	MG Sc. College	
Guj.	Vishwakarma Govt. Engg. College, Gandhinagar	4
Guj.	LE College Morbi	**1**
Guj.	LD College of Engg	**2**
Guj.	**PDPU**	**2**
Haryana	Kurukshetra University	5
MP	Bundelkhand University	5
Maha	NMIMS University, Mumbai	1
Maha	Marathwada Univ., Nanded	2
Maha	Design Education and Architectural Studies (IDEAS), Nagpur	1
TN	Manomaniam Sundernar Univ., Tirunelveli	18
TN	Bharathidasan University, Tiruchirapalli	3
TN	Veltech University	3
AP	Adikavi Nannya Univ., Rajhamundri	6
Kerala	Marine Geoph., Cochin Uni.	6
Karnataka	Mysore Uni.	5
	Total	**82**

TABLE: Dissertations of 2014 M. Sc. Geophysics batch of GANPAT UNIVERSITY, KHERVA

Sr no.	Name	Topic	Mentor
1	Shital Patel	Analysis of Strong motion and geotechnical data in Gandhinagar	Dr. Kapil Mohan
2	Bhavesh Patel	Magnetotelluric observations in Tuwa	Dr. Kapil Mohan
3	Pruthul Patel	Ground Response Analysis of Ahmedabad	Dr. Kapil Mohan
4	Dilip Singh Kushwaha	TDEM in Jaiselmer	Dr. Kapil Mohan
5	Mehul Nagar	Magnetotelluric in Bavla	Dr. Kapil Mohan
6	Priyanka	Structure of northern Cambay basin by gravity data	Sri R.K. Singh
7	Jignasa Modi	Shear wave in Ahmedabad using MASW	Dr. B. Sairam

TABLE: Dissertations of 2015 M. Sc. Geophysics batch of GANPAT UNIVERSITY, KHERVA

Sr no.	Name	Topic	Mentor
1	Chavda Bhoomi	Fault mechenism of Talala region	Dr. A.P.Singh
2	Dave Devarsh	Broadband seismology	Ms. Jyoti sharma
3	Gupta nishant	Strong ground motion	Dr. Pallabee chaudhry
5	Pancha Harsh	Broadband seismology	Ms. Jyoti sharma
6	Patel Ankita	Seismology	Mr. Santosh kumar
8	Patel Jaywheel	Strong ground motion	Dr. Pallabee chaudhry
10	Patel Tejas	Microzonations & hazards	Dr. A.P.Singh
11	Prajapati Upasana	Seismology	Mr. Santosh kumar
12	Trivedi Yogesh	Gravity	RK Singh
13	Joshi Shivam	Well-logging	ONGC
14	Patel Dhaval	Well-logging	ONGC
15	Patel Jitendra	Well-logging	ONGC

List of B. Tech., M. Sc./M. Tech. Dissertations and Training of Students from various colleges and universities in Gujarat and other parts of the country during 2014-15.

Mr. Ganpat Parmar, T.O., Doing MBA, Thesis entitled "Establishment of Real Time Seismic network to save Lives and Property", Guide Mr. Santosh Kumar

Geology, Active Fault Study and Paleoseismology

Mr. K. Durga Surendra from M. Sc. Geology (Petroleum Exploration), 2009-2014., Adikavi Nannaya University, Rajahmundry, Dissertation title: **Tectonic controls on drainage evolution of Shetrunji River, Western India** Guide: SIDHARTHA PRIZOMWALA dissertation period5 months, Jan to May 2014

Mr. S. Srikanth Kumar, student of M. Sc. Geology (Petroleum Exploration), 2009-2014., Adikavi Nannaya University, Rajahmundry, Dissertation title: **GEOMORPHIC EVIDENCE OF TECTONIC ACTIVITIES IN PACHCHAM ISLAND AROUND ISLAND BELT FAULT, KACHCHH, GUJARAT**, Guide: G.C. Kothyari, dissertation period5 months, Jan to May 2014

Mr. A. Durga Prasad, student of M. Sc. Geology (Petroleum Exploration), 2009-2014., Adikavi Nannaya University, Rajahmundry Dissertation title: **TECTONIC AND MORPHOMETRIC EVIDENCE OF BELA ISLAND AROUND ISLAND BELT FAULT, KACHCHH, GUJARAT.** , Guide: Ms. Falguni Bhattacharya, dissertation period 5 months- Jan to May 2014.

Mr. Raj Sunil Kandregula Final year M.Sc Geology (Petroleum Exploration), Department of Geology, Adikavi Nannaya University, Rajahmundry "**Quantitative Morphometric analysis and assessment of active tectonics of seismically active South Wagad**

Fault in Kachchh area of Western Peninsular India" , Guide: G.C. Kothyari (20-01-2014 to 20-05-2014).

Priyanka Upadhyay, M.Sc. (Geology) Bundelkhand University Jhansi **Geophysical and Remote Sensing Approaches for Mineral Exploration**, Guide G.C. Kothyari (28-01-14 to 11-04-14).

Maruprajapati Naran P., M.E. CIVIL (Water Resources Management) L.E. College, MORBI. Dissertation topic - Ground Water Modeling & Management of Kutch Basin. Guide:- Girish Kothyari, Duration - 1 year. Starting date:- 17/9/2014 to 1/6/2015

Two students MR. Thondepu Pradeep and Mr. Mohammed Sabirali of 4th sem M.Sc geology (specialization in petroleum exploration in Adikavi Nannaya University, Rajahmundry, Andhra Pradesh, Dissertationin geology, guide Dr. Siddarth Prizomwala. for one month (period from 24-12-2014 to 24-01-2015)

Zikrullah Ansari, M.Sc. Final year Geology in Bundelkhand University Jhansi work in OSL lab under the super vision Dr. Girish Chand Khothari, Dissertation Title "Techniques of Optically Stimulated Luminescence **(OSL)** dating", During- 22 January 2015 to 22 April 2015

Geotechnical Investigations

Four students Khokhar Zeeshan Ali I, Chaudhary Krunal R, Sathwara Himanshu B and Sarany Manan B (B. tech. Civil, 8th Semester) from Vishwakarma Govt. Engineering college, Gandhinagar on the topic **"Role of Geotechnical engineering in seismic microzonation"** Eight months during 27/7/2013 to 10/04/2014, under guidance of Mr. Vasu Pancholi.

One student Mr. Muzahid Ahmed, M.Sc- Geology, final year student of Bundelkhand University, Jhansi completed Dissertation on "Determination of soil properties through field and lab tests" from 28-01-2014 to 11-04-2014

Mr. Harshil Vikmani B. Tech. (civil) from Mukesh Patel School of Technology Management & Engineering, NMIMS University, Mumbai in Geotchnical Lab, During 3rd Sep 2014 to 18th Oct 2014.

Mr. R. Karthikeyan, Mr. M. Syed Mustafa and Mr. M. Mahendran (M.Tech – Geotechnology and Geo-Informatics) students of Bharathidasan University, Tiruchirappalli have done their summer training on the topic "Physical Attributes of Soil" from 09/06/2014 to 27/06/2014 under guidance of Shri Vasu Pancholi.

Mr. Sandeep Kumar, Miss. Amandeep Kaur and Miss. Parul Mishra, M.Sc – Applied Geology (Final Year) students of Kurukshetra University, Kurukshetra have done their dissertation on the topic "Geotechnical Investigation of Soil" from 23/06/2014 to 22/08/2014 under guidance of Shri Vasu Pancholi.

Mr. Zeeshan Mustafa Quadri and Mr. Nikhil Chawla, M.Sc – Geology (Final Year) students of Bundelkhand University, Jhansi are doing their dissertation on the topic "Geotechnical properties of problematic soil: Collapse, Swell and Dispersion" from 23/01/2015 to 24/04/2015 under guidance of Shri Vasu Pancholi.

Mr. Rupak Banik, Md. Shakir Alam and Mr. Vikram Kumar, B.Tech – Civil Engineering (Final Year) students of Veltech University, Chennai are doing their project on the topic "Geotechnical Investigation for earthquake resistant buildings" from 09/01/2015 to 09/04/2015 under guidance of Shri Vasu Pancholi.

Gravity Surveys

One student Priyanka, Final year M. Sc. Geoph, Ganpat University Mehsana, Topic :- "Mapping of basement configuration and overburden thickness of northern part of Cambay basin using gravity survey", Guide: Mr. R. K. Singh, duration 6 months, Jan-June 2014

Engineering Geophysics

Three students 1- Vysakh E S, 2-S .Siva Kumar, 3-Mohamed Niyas M of M. Sc. Applied Geophysics (final yr), Centre for Geotechnology, Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu , "**Estimation of P-Wave Velocity and Thickness of Subsurface Layer Using Seismic Refraction Method"**, Guide: Dr. B. Sairam, Jan-March 2014:

Three students: 1. K. Anantha Raj, 2. S. Raj Kumar, 3. P. Arumuga SivaSankar of MSc Applied Geophysics (final yr), Centre for Geotechnology, Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu , "**Estimation of shear wave velocity using Multichannel Analysis of Surface Wave (MASW) Method",** Guide: Dr. B. Sairam, Jan-March 2014:

One student, Deepak. T.K from Cochin University of Science and Technology, 4th Sem Marine Geophysics Topic: "Estimation of P-Wave velocity and thickness of subsurface layer using Seismic refraction method" under Dr B. Sairam during 4 months January to June 2014

One student, Abdul Samadani from Cochin University of Science and Technology, 4th Sem Marine Geophysics Topic: "Estimation of Shear Wave velocity using Multi-channel Analysis of Surface Wave (MASW) method in Ahmedabad", under Dr B. Sairam during 4 months January to June 2014

One student, Jignasa Modi, Final year M. Sc. Geoph, Ganpat University Mehsana, Topic :- "Estimation of shear-wave velocity using multi-channel analysis of surface waves (MASW) in the Ahmedabad area", Guide: Dr. B. Sairam, Duration 6 months, Jan-June 2014

One student, Ms.Dharmesh Dhola,2nd year M.Tech Student of PDPU ,"Estimation of P-wave Velocity and Thickness of Subsurface layer using Seismic Refraction Method". Guides: Dr. B. Sairam (ISR) and Dr. Bhawanisingh Desai (PDPU), Duration: 1 month, July-Aug 2014

Three students namely *Arunbose.S, Karthikeyan.E, Stalin Raju* were doing final year in M.Sc Applied Geophysics in *Manonmaniam Sundaranar University*, Tirunelveli, Tamilnadu-627011. Dissertation on **"Estimation of 2- D shear wave velocity profiles by the surface wave technique in the Ahmedabad city, Gujarat, India"** is carried under the guidance of *Dr.B.Sairam* under the topic of seismic survey for the period of three months from Jan 8-March 25, 2015.

Three students namely *Aswin Martin, Ramprasanth.M, Sudheep.C.J* were doing final year in M.Sc Applied Geophysics in *Manonmaniam Sundaranar University*, Tirunelveli, Tamilnadu-627011. Dissertation on **"Determining P-wave velocity of subsurface layers of a site near to the bank of Sabarmati River, Gandhinagar, Gujarat"** is carried under the guidance of

Dr.B.Sairam under the topic of seismic survey for the period of three months from Jan 8-March 25, 2015.

Electromagnetic and Microzonation Lab

Binil Baby, M.Sc. Marine Geophysics student from Department of Marine Geology& Marine Geophysics Cochin University of Science and Technology Cochin , Kerala, **"Geoelectric strike comparison of Dholera and Tuwa region of Gujarat using Magnetotellurics"** during 02.12.2014 to 26.02.2015.

Binu B, M.Sc. Marine Geophysics student from Department of Marine Geology& Marine Geophysics Cochin University of Science and Technology Cochin , Kerala, **"Delineation of Geoelectric Structure in Seismically Active Wagad Region of Kachchh (Gujarat)"** during 02.12.2014 to 26.02.2015.

Vivek G Babu, M.Sc. Marine Geophysics student from Department of Marine Geology& Marine Geophysics Cochin University of Science and Technology Cochin , Kerala, **"Estimation of Geoelectric structure of the Godhra (Gujarat) region using magnetotelluric studies"** during 02.12.2014 to 26.02.2015.

One student, Sharath K.M. Final year Applied Geology, Department of Earth Science, University of Mysore, Karnataka, Topic: "Subsurface electrical resistivity imaging of Bavla region, Central Cambay Basin using Magnetotelluric", Guide: Dr. Kapil Mohan, 2 months, 12/01/2014 to 10/03/2014

One student, Sarath Kumar K., Final year Applied Geology, Department of Earth Science, University of Mysore, Karnataka, Topic: "Comparison of geoelectrical strike in eastern Kachchh and Central Cambay Basin through Magnetotelluric study", Guide: Dr. Kapil Mohan, duration 2 months, 12/01/2014 to 10/03/2014

One student, Akhil Kumar K., Final year Applied Geology, Department of Earth Science, University of Mysore, Karnataka, Topic: "Detailed analysis of geoelectric strike in the epicenter zone of 2001 Bhuj earthquake (Mw7.6) region using Magnetotelluric investigations, Guide: Dr. Kapil Mohan, duration 2 months, 12/01/2014 to 10/03/2014

One student, SHITAL PATEL , Final year M. Sc. Geoph, Ganpat University Mehsana,Topic:- "Estimation of Surface Strong Motion Parameters Using Geotechnical Data in the Gandhinagar City, Gujarat, India", Guide: Dr. Kapil Mohan, Duration 6 months, Jan-June 2014

One student, Pruthul N. Patel, Final year M. Sc. Geoph, Ganpat University Mehsana,Topic:- "Ground Response Analysis of Central Ahmedabad region", Guide: Dr. Kapil Mohan, Duration 6 months, Jan-June 2014

One student, Kushwaha Dilip Singh, Final year M. Sc. Geoph, Ganpat University Mehsana,:-Time Domain Electromagnetic (TDEM) Investigations in Jaisalmer Basin, Rajasthan", Guide: Mr. Pavan Gayatri, Duration 6 months, Jan-June 2014

One student, Mehul Nagar, Final year M. Sc. Geoph, Ganpat University Mehsana, Topic:- "Subsurface Electrical Mapping of Bavla Region Ahmedabad, Gujarat using Magnetotellurics, Guide: Dr. Kapil Mohan, Duration 6 months, Jan-June 2014

One student, Bhavesh Patel, Final year M. Sc. Geoph, Ganpat University Mehsana, Topic :- "Subsurface Electrical Mapping of Tuwa Region , Gujarat using Magnetotellurics", Guide: Dr. Kapil Mohan, Duration 6 months, Jan-June 2014

Dissertation of 2 students Gaurav Kumar and Shankey Bansal final yr MTech (Appld Geophysics), Kurukshetra Univ with Dr. Kapil Mohan on EM Methods from Feb-May 2015.

Seismic Hazard

One student, Ms. Viraj Parekh, 2nd year M. Tech Student of Infrastructure Engineering and Management, Department of Civil Engineering, School of Technology, "Earthquake intensity based risk assessment" Guides: Dr. Kapil Mohan (ISR) and Dr. Tejas Thaker (PDPU) Duration: Approx 1 year (1st of July – 30th April 2014)

Shallow sub-surface Geophysics

Two students, Mr. Habeeb Thanveer. K, & Mr. Maibam Debaroy Singh, 4th semester Applied Geology, Department of Studies in Earth Science, University of Mysore "Microtremors' HVSR and its correlation with the surface geology at Kachchh region, Gujarat, **Guide: Dr. A. P. Singh 1.5 months (12-01-2014 to 25-02-2014).**

Six students namely *Arunbose.S, Aswin Martin, Karthikeyan.E, Ramprasanth.M, Stalin Raju, Sudheep.C.J* were doing final year in M.Sc Applied Geophysics in *Manonmaniam Sundaranar University*, Tirunelveli, Tamilnadu-627011. Dissertation work is carried under the guidance of *Dr.B.Sairam* under the topic of seismic survey for the period of three months from Jan 8 to April 8, 2015.

Seismology

Mr. Balwanth Oandurang Laxmikant, Ms.c Final year student of Geophysics in Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra worked in Seismology Division under the super vision of Mr. P. Mahesh Title of Disertation: Determination of 1-Dimensional Velocity Model of Saurashtra Region, May 2014- March 2015.

Tsunami Modeling

One student Mr. Bhupesh K. Katariya 4th semester ME from Department of Water Resources Management, L. D. College of Engineering "**Tsunamigenic earthquake in the Makran Subduction zone and its effects along the Gulf of Kachchh, Gujarat** (11-10-2013 to 13-05-2014)

Mr. Vijendrakumar M. Patel (PhD Registration No: 10D0257), L.D.College Of Engineering, Ahmedabad, **"Emergency Preparedness in the Case of Makran Tsunami-Evacuation Analysis for the Western Parts of Gujarat, India"** (2009-2014)

Miscellaneous Subjects

Srushti Tiwari, student of Institute of Design Education and Architectural Studies (IDEAS), Nagpur for Architectural case study of ISR, March 2015

11.6 TRAINING TO M.SC./M. TECH. STUDENTS

ISR student Training Program has become very popular all over India. ISR trains about 100 students annually from different Universities from all over India for Summer-Winter Training, M.Sc. / M. Tech. Dissertation and PhD. These Universities are not only from Gujarat but are from all corners of India from Delhi, UP, Haryana, Jharkhand, West Bengal, Manipur, Andhra Pradesh, Tamil Nadu, Karnataka etc. including prestigious Institutes like IITkh, BHU and In. Sch. of Mines.

Comments from one of the trainees are given below:

"Respected Sir,

We have safely reached our respective homes after completing the training at ISR. The training turned out to be a fruitful one and has inspired us deeper into the field of geophysics. We developed a strong liking for the subject during the training and are keen on learning more of it too. We thank you for the scientific environment conducive to learning that ISR provided us with. Also the staff was helpful and supportive and made our stay a memorable one.

Thanks, Regards. Aditi Sharma, Indian School of Mines, Dhanbad, 22.6.2011"

Another student K. Sarath of Mysore University after dissertation in 2014 wrote:

"I would like to thank you again for all your support. We got there a good exposure to MT. We wish we could spend a few more months there. I hope in the future our juniors can also carry out their dissertation at ISR. We will remain grateful to you & your team throughout our life for providing us such a great opportunity. Thank you once again sir. Wish you & your team all the success."

SUMMER / WINTER TRAINING TO STUDENTS

2014-2015

One student Bhavesh Sharma, 2nd yr M. Sc. Geol., MSU, One month training on OSL dating from 12.5.2014 to 11.6.2014.

One student Balwant Pandurang Laxmikant, M.Sc. Geophy, First Year student of S.R.T.M.U. Nanded Maharashtra, Subject of training: Seismology, 22/05/2014 to 7/6/2014

Four M. Sc. Applied Geology students 1. Mr. M. N. Naveen Kumar (email: nawintucker@gmail.com) 2. Mr. S. Ranjith (georanjith1993@gmail.com), 3. Mr. M. Johnson (gelogistsamson@gmail.com), 4. Mr. G. Shaik Fareeth (fareethshaik3@gmail.com) of Anna University- Chennai, One month training on time domain electromagnetic survey, June 1- 30, 2014

Three students (Manojdivakaran V., Sabarinathan N. and Kumaresan PR.) of Bhartidasan Univ., Tiruchirapalli, TN, One month training on geological field work and shallow seismic survey, June 1- 30, 2014

Three students Mr. R. Karthikeyan, Mr. M. Mahendran, and Mr. M. Syed Mustafa of M.Tech, Geotechnology and Geo-Informatics, Department of Centre for Remote Sensing, 3rd year student of Bharathidasan University , Tiruchirappalli has been imparted Summer Training on "Physical Significance of Soil" during 09-06-2014 to 27-06-2014 (2 weeks)

3 Students, Sandeep Jaglan, Parul Mishra and Amandeep of Kurushetra University (M.Sc. Applied Geology 2nd year) trained for two months in Geotechnical Lab on "**Geotechnical Investigation of soil**", July-Aug, 2014.

One student Mr. Harshil Vikmani B. Tech. (civil) from Mukesh Patel School Of Technology Management & Engineering, NMIMS University, Mumbai in Geotchnical Lab, During 3rd Sep 2014 to 18th Oct 2014.

11.7 LECTURES IN TRAINING COURSES (2014-15)

Kapil Mohan (2014) delivered expert lecture on “**Earthquake Measurements & Hazard Assessment** at Department of Civil Engineering, Nirma University, Ahmedabad. under short term training programme on “Earthquake Resistant Design & Retrofitting of structures” ” on 04/07/2014

A.P.Singh “Earthquake Resistant Construction Practice” For GSDMA-LDCE training Programme at Bhuj, Kachchh, on 31/07/2014.

AP Singh, **"Introduction to earthquake hazard of the country and the state" in the** training program for professional engineers & architects of Bhavnagar District at Bhavnagar are coordinated by L D College of Engineering & GSDMA, 4 September 2014.

Pallabee Choudhury on “Introduction to earthquake hazard of the country and the state” in training program on “Earthquake resistant construction practices” organized by L D College of Engineering and GSDMA held at Vadodara, 13 Nov 2014

Pallabee Choudhury on “Introduction to earthquake hazard of the country and the state” in training program on “Earthquake resistant construction practices” organized by L D College of Engineering and GSDMA held at Surat on 27 Nov 2014

RK Singh “Ground water exploration using geophysical methods”, Training course of Guj. Jalseva Training Inst., 16.12.2014

Om Prakash Goswami “Introduction to earthquake hazard of the country and the state” in training program on “Earthquake resistant construction practices” organized by L D College of Engineering and GSDMA held at Rajkot, Dec 2014

Lecture in Training Program on "Earthquake Engineering & Building Codes-II" from 21-23 January, 2015 at the Gujarat Institute of Disaster Management, Gandhinagar by Dr. A. P. Singh

CHAPTER 12

HUMAN RESOURCE AND DEVELOPMENT

12.1 HONORS/ RECOGNITIONS/AWARDS

To ISR 'Skoch order of Merit Award 2014' on the topic "Seismological Studies in Gujarat to Save lives and Damage due to Earthquakes & Tsunami" September 2014.

Prof. B. K. Rastogi nominated as Member of steering committee for Centre of Excellence for Geothermal Energy (CEGE) 20th June 2014, PDPU

Prof. B.K. Rastogi received 'Bharat Jyoti Award' conferred by In. Intl. Friendship Soc., Delhi 24.11.2014

Ms. Archana Das, Geologist, has been selected from India (out of 10 worldwide) for current year for **IAS Grant Award of 1000 Euros** by the International Association of Sedimentologist (IAS), Belgium for sedimentological Investigations in Kachchh.

Prof. B.K. Rastogi nominated as Member Advisory Committee on Earthquake of Bihar State Disaster Management Authority (October 2014-).

B.K. Rastogi nominated as Member Core Organisational Committee for the World Innovation Symposium to be held during Vibrant Gujarat Summit 2015 (12-13 Jan)

Prof. B.K. Rastogi nominated Member Steering Committee "Kachchh Jalmani Yojna", Gujarat Water Supply and Sewerage Board (July 2014 -)

Prof. BK Rastogi nominated as a member Earth Science Section Committee of Guj. Sc. Academy (2014-15) to elect Fellows of the Academy.

Dr.KM Rao and Mr. Santosh Kumar acted as jury for Children Sc. Congress, Sc. City, 29.11.2014

12.2 PHD DEGREE AWARDED TO

Total no. of PhDs including the following three is 12.

K. Madhusudan Rao **"Lithospheric Structure and Mantle Deformation beneath Gujarat, Western India"** from Osmania University, guides: M.Ravi Kumar and B.K. Rastogi, 16.7.2014.

G. Pavan Kumar 'Crustal electrical resistivity structure of the Sikkim Himalaya" from the University of Hyderabad, Guide: Ajay Manglik of NGRI on 2.8.2014.

P. Mahesh 'Seismotectonics and 3-Dimensional crustal velocity structure of the Kumaon-Garhwal Himalaya", Osmania University, Hyderabad. Guide: Dr. S. S. Rai, of NGRI, 27.4.2015

M. Tech. Awarded

Mr. Bhupesh Katariya (M.Tech student of LD Engg. College now Prof. Civil Engg., Shankarsinh Vaghela Bapu Inst. of Tech.) Awarded Master of Engineering on the thesis **"Tsunamigenic Earthquake in the Makran Subduction zone and its Effects along the Gulf of Kachchh, Gujarat"**, from Gujarat Technological Unniversity, Guides: Prof. A.T. Motiani and Dr. A. P. Singh (of ISR). The candidate was awarded first prize in presentation.

12.3 DEPUTATIONS ABROAD

Prof. B.K. Rastogi deputed to Karlsruhe Germany under DST, GoI project for collaborative study, 15 days (May 15-30, 2014)

Dr. Kapil Mohan deputed to Karlsruhe Germany under DST, GoI project for collaborative study, 25 days (May 11-June 5, 2014)

Dr. Pallabee Choudhury, Ms. Jyoti Sharma and Ketan Singha Roy deputed to Univ. Trieste, Italy for strong motion modeling, Neodeterministic hazard assessment and regional tomography using surface waves Sep15 to October 17, 2014.

Dr. A. P. Singh deputed to Inst Earth Sc (Academia Sinica), Taipei, Taiwan for full waveform modeling, Nov 1-30, 2014.

12.4 TRAINING OF ISR STAFF AT ISR

Training of Gravity interpretation

12.5 TRAINING OF ISR STAFF OUTSIDE

1. Vasu Pancholi, one week short-term course on "Geotechnical Earthquake Engineering" during June 2-6, 2014 at IIT Roorkee which is sponsored by AICTE.

2. Mr. Rahul Ranjan (Geotechnical Engineer) and Mr. Vinay Kumar Dwivedi (JRF) 15 days Training on Cyclic Triaxial Instrument and determination of cyclic strength of soil and Liquefaction potential using cyclic triaxial test from 22/09/2014 onwards at Indian Institute of Science (IISc) Bangalore under guidance of Prof. T.G. Sitharam.

12.6 ISES-ISR DISTINGUISHED LECTURES / SPECIAL LECTURES

Prof. Tina Niemi, of University of Missouri at Kansas "Paleoseismology and Earthquake Hazard Assessment Studies", Distinguished Lecture, Sep 5, 2014

Seminar Talks by Visitors

1. Prof. RK Verma formerly Head Dept. Geophysics, ISM, Dhanbad delivered lectures on "Geodynamics of India": 1. Himalaya- Major Tectonics, 2.Seismotectonics of NW Himalaya, 3.Seismicity of NE India, Dec 18-20, 2014
2. Prof. Li Zhao, **From Institute of Earth Sciences, Academia Sinica, Taipei** "Full-wave Seismology: Imaging Anisotropic Structure under Southern California", 18.3.2015
3. Prof. Yih-Min Wu **From Department of Geosciences, National Taiwan University, Taipei** "Development of Earthquake Early Warning and Shake Map Systems using Low Cost Sensors in Taiwan", 18.3.2015

12.7 ISR SEMINAR TALKS

J. R. Kayal "Various methods of earthquake locations, 27th Aug 2014

J. R. Kayal "Focal mechanism solutions and seismotectonics of India, 28th Aug. 2014.

Mr. R.K. Singh "Recent gravity and Magnetic Surveys in Mehsana block Cambay basin" December 9, 2014

12.8 LISTS OF STAFF

Scientific staff

Sn	Name	Post	PG	PG yr	Joining
1	Dr. K. Madhusudan Rao	Sc. D, GoG Plan	M.Sc. Tech. Geophys & PhD, OU	1995 2014	01.02.2006
2	Santosh Kumar	Sc. D, GoG Plan	M. Tech. Applied Geophysics., KU	1996	01.04.2006
3	Dr. (Miss) Pallabee Choudhury	Sc. C, GoG Plan	M.Sc. Phys. Tezpur PhD Geophy. Tezpur	2001 2006	19.07.2007
4	Dr. Kapil Mohan	Sc. C, GoG Plan	M.Tech Geophys., KU Ph.D Geophys., KU	2001 2009	11.07.2007
5	Dr. B. Sairam	Sc. B, GoG Plan	M.Sc. Tech. Geophys. OU; Ph.D Geophys. OU	2003 2012	17.08.2006
6	Dr. A. P. Singh	Sc. B, GoG Plan	M.Sc. Tech. Geophy., BHU; Ph.D Geophys., KU	2002 2013	14.08.2006
7	Ms. Jyoti Sharma	Sc. B, GoG Plan	M.Sc. Phys., DU M.Tech, IITkh	2005 2008	01.12.2011
8	Mr. P. Mahesh	Sc. B, GoG Plan	M.Sc. Phys, AU	2005	29.12.2011
9	Dr. G. Pavankumar	Sc. B, GoG Plan	M.Sc. Phys. AU PhD, Hyd Univ	2004 2014	05.01.2012
10	Dr. Girish Chandra Kothyari	Sc. B, GoG Plan	M.Sc. Geol, Kumaun PhD, KU Nainital	2001 2009	13.04.2009
11	Dr. Rakesh Kumar Dumka	Sc. B, GoG Plan	M.Sc. Geol Kumaun PhD Kumaun	2003 2011	01.08.2007

Sn	Name	Post	PG	PG yr	Joining
12	Ms. Falguni Bhattacharjee	Sc. B, GoG Plan	M.Sc. Geol, Jadavpur Uni	2004	13.02.2008
13	Mr. Sandeep Aggrawal	Sr. Geophys.	M.Tech Geophys., KU	2004	20.07.2007 to Jan 2013 Apr 2013 to 6.2.2015
14	Mr. M.S.B.S.Prasad	Sr. Geophys.	M.Sc. Tech. Geophys. AU	1989	11.06.2007
15	Mr. Vasu Pancholi	Sr. Geophys.	M.Sc. Geol., GU	2005	08.09.2011
16	Mr. Ketan Singha Roy	Sc. B, SSNNL	M.Tech. Computational Seismology, Tezpur Uni.	2009	30.07.2009
17	Mr. Vandana Patel	Geophysicist, EEWS	M.Sc., Phys. Bhavnagar	2006	06.09.2008
18	Mr. Peush Chaudhary	Geophysicist, EEWS	M.Tech. Appl. Geophy Kurukshetra	2011	02.01.2012
19	Dr. Siddharth P Prizomwala	Geologist Fast Track	M.Sc. Geology, MS Uni PhD, Geology, MS Uni..	2008 2013	08.10.2012
20	Mr. Sorabh Sharma	Geophysicist, EEWS	M.Tech. App. Geophy., K.U.K	2009	07.10.2013
21	Mr. C. Prasanna Simha	Project Sc., CAL-VAL	M.SC. Physics, Sri Venkteswara Uni.	2005	06.11.2012
22	Mr. S. Venkateswar Rao	Sr. Geophysicist, GoG Plan	M.Sc. Tech. Geophys. AU	2007	04.06.2012
23	Mr. Tarun Solanki	Sr. Geologist, GoG Plan	M.Sc. Geology, MS Uni.	2008	15.06.2013
24	Annam Navaneeth	Geophysicist	M.Sc. Geophys. OU	2009	19.04.2010
25	Ms. Archana Das	Geologist	M.Sc. Geology, MS Uni.	2010	22.03.2012
26	Ms. Vishwa R. Joshi	Geophysicist GoG Plan	M.Sc. Physics, Bhavnagar University	2007	20.05.2009
27	Ms. Sarda Maibam	Geophysicist GoG Plan	M.Sc. Earth Sc. Manipur	2009	05.11.2009
28	Ms. Monika Arora	Geophysicist GoG Plan	M.Tech. App. Geophy., K.U.K	2013	10.09.2013
29	Mr. Mayank Dixit	Geophysicist, ISRO 3	M.Tech. App. Geophy., K.U.K	2013	03.09.2012
30	Mr. Suraj Kumar Singh	Geotech. Eng.	B.Tech. Civil Engg. Veltech Univ., Chennai	2013	10.06.2013
31	Mr. Rahul Ranjan Mandal	Geotech. Eng.	B.Tech. Civil Engg. Veltech Uni., Chennai	2013	10.06.2013

List of JRFs

Sn	Name	Post	Qualifications	PG yr	Joined on
1	Ms. Jaina P. Patel	JRF, GoG Plan	M.Sc. Env. Sc & Tech	2009	01.06.2009
2	Mr. Vinay Kumar Dwivedi	JRF, GoG Plan	M.Sc. Geol. Bundelkhand Uni.	2012	21.07.2012
3	Ms. Drasti Gandhi	JRF, GoG Plan	M.Sc. Geol, MG Sci. A'bad	2012	18.09.2012
4	Ms. Parul Mittal	JRF, ISRO 1	M.Tech App. Geophy., K.U.K	2013	19.09.2013
5	Mr. Virender Kumar Singh	JRF, ISRO 3	M.Tech App. Geophy., K.U.K	2013	03.09.2013

Geophysicists Joined:

1.Dheerendra Mani Tripathi, M. Sc. Tech App. Geophy., BHU (2013), joined as Geophysicist, Date: 24.06.2014 Hydrology/ MASW (with Sairam),

2. Ajay Kumar Pandey, M .Sc. Tech App. Geophy., ISM, Dhanbad (2013), joined as Geophysicist, Date: 24.06.2010 Hydrology/ Seismology (with Santosh),

3.Mr. Om Prakash Goswami, M.Sc. Tech. App. Geophy., ISM, Dhanbad (2013), DoJ: 08.07.2014 GPS/ Hydrology (with Pallabee/Dumka),

4.Avinash Kumar Chauhan, M.Sc. Tech. Geoph, IITkh, (2013), DoJ 30.8.2014, (Gravity)

5. Mr. Nikhil Srivastava, Geophysicist, MSc Tech, ISM, 2013. 1 y service in ESSAR Oil Co., INSPIRE FELLOW, 4.3.2015

6.Mr. Laxmi Srinivas, Geophysicist, MSc Tech, AU, 2011, Mtech IITb 2013. 1 y service in an Oil Co., 4.3.2015

JRFs joined

ISM

1. Mr. Ali Asger, on 9.7.2014 Seismology and GPS

3. Mr. Prakash Kumar, on 9.7.2014 Seismology and GPS

4. Mr. Sarvesh Kumar, on 9.7.2014 (MASW with Sairam)

5. Mr. Amit Kumar Mishra, Gravity (with R.K. Singh) on 27.06.2014

6. Mr. Utsav Mishra, on 27.06.2014 (MASW with Sairam)

7.Mr. Prateek Mondal, on 7.7.2014, Taiwan – 1, EEWS (with Santosh Kumar)

Ganpat Univ. Mehsana

1. Sri Dilip Singh Kushwaha, M.T. (with Kapil), M.Sc. Geophysics, Ganpat University (2014), joined as JRF, DoJ: 2.2.2015.

2. Shri Pruthul Patel, M.T. (with Kapil), M.Sc. Geophysics, Ganpat University (2014), joined as JRF, Date: 01.07.2014

3.Mehul Nagar, M.T. (with Kapil), M.Sc. Geophysics, Ganpat University (2014), joined as JRF, Date: 11.8.2014

KuK:

Amita, M.Sc. Tech Gephys, KuK,, JRF, DoJ: 29.9.2014

Arpan Shastry, M.Sc. Tech Gephys, KuK,, JRF, DoJ: 29.9.2014

Jitendra Prasad, M.Sc. Tech Gephys, KuK,, JRF, DoJ: 29.9.2014

BHU

Yashwant Kumar Singh M. Sc. Tech App. Geophy., BHU (2014), JRF, 26.8. 2014 (with Satosh)

Satyaveer Singh, M. Sc. Tech App. Geophy., BHU (2013), JRF, 9.9.2014 Hydrology/ MASW (with Santosh)

MSU, Baroda: Nisarg Makwana, Geol MSU, 2014, (with Sidhartha Prizomwala)

Osmania Univ (OU):

E. Mahender, M.Sc Geophysics, OU (2014) joined as JRF, 01.10.2014 (with G. Pavan Kumar)

K. Damodhar , M.Sc Geophysics, OU (2014) joined as JRF, 01.10.2014 (with G. Pavan Kumar)

M.G. Science Institute, Ahmedabad (GU):

Jagdish Vadher, M.Sc. Geology, GU (2013) joined as JRF, 04.11.2014, OSL Lab

JRFs joined & Resigned

1.Radhe Shyam, M. Sc. Tech. Geophy. (2013), JRF, DoJ: 22.7.2014, DoR:

2.Ms. Rashmi Singh, Taiwan-2 Project, Full Wave form modeling (with A.P. Singh), DoJ: 7.7.2014, DoR: 28.1.2015.

3. Mr. Vipin Kumar Pathak, JRF, ISM M.Sc. Tech Geoph, micro tremor study with A.P. Singh DoJ: 9.7.2014, DoR: 28.1.2015.

4. Mr. Anshuman Baxi, Gravity (with R.K. Singh) 27.6.2014 to Apr 2015

Technical Officer

Sn	Name	Qualification	Joined on
1	Mr. Ganpat Parmar	BE (EC)	17.11.2007
2	Mr. Jignesh Patel	BE (CE)	12.04. 2006

Technical Assistant

Sn	Name	Qualification	Joined on
1	Mr. Jay Pandit	B.Com.	16.06.2007
2	Mr. Nirav Patel	DEE	18.10.2007
3	Mr. Sandip Prajapati	DEC	24.12.2007
4	Mr. Bharat Mevada	DEC	18.01.2008
5	Mr. Tejendra Vaghela	DEE	03.10.2008
6	Mr. Mahesh Valekar	DEE	03.03.2009
7	Mr. Ankit Pandya	Dipl. Civil Engg.	01.04.2009
8	Mr. Bihari Darji	ITI Electronics	20.04.2009
9	Mr. Pritesh Chauhan	DCE	01.05.2009
10	Mr. Jayesh Parmar	DEC	01.05.2009

11	Mr. Darshit Modi	DEC	04.05.2009
12	Mr. Suresh Thadani	BE (EC)	13.07.2012
13	Mr. Paresh Paradia	DEE	16.10.2012
14	Mr. Thokchom Romio	B.Tech. EC	05.04.2013

Administrative Staff:

SN	NAME	Qualification	DoB	Post	DoJ
1	Purushottam H. Charan	M. Com.		Accounts Officer	28/08/2010
2	Mr. Giriraj Chavda	B. Com.	30/03/81	Accountanat	06/11/2009
3	Mr. Mitesh Lakhwara	H. Sc.	15/04/92	Clerk	01/08/2012
4	Mr. Ashok Thakur	H. Sc.	20/08/82	clerk	20/04/2009
5	Mr. Sunil Patni	VIII	04/12/80	Peon	15/05/2007
6	Mr. Mithun Salat	VII	10/02/93	Peon	19/07/2013
7	Mr. Kunal Parekh	X	28/12/93	Peon	28/5/2014
8	Mr. Ramnik Lal Suchak			Office Suptd, ISES	

Distinguished Visiting Professor:

1. Padmasri K.S. Valdiya, Hon. Prof., Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore

Visiting Professor:

1. Dr. JR Kayal, Former Addl. Director General Geological Survey of India

2. Prof. V.C. Thakur, Former Director Wadia Institute of Himalayan Geology, Dehradun

3. Dr. S.K. Biswas, Ex-Director KDMIPE, ONGC

Visiting Scientist:

- Shri R.K. Singh

Consultant:

- Shri NK Das, formerly Director Geological Survey of India

Staff Posted in Kachchh

Sr. No.	Name	Date of Birth	Educational Qualification	Date of Joining	Designation
1	Mr. Shivrajsinh Jadeja, Bhachau	10.06.1975	8^{th} Pass	01.08.2007	LA
2	Mr. Jayendra V. Jadeja, Vamka	14.01.1985	12^{th} passed, Computer Knowledge	12.02.2009	LA
3	Mr. Harpal Singh, Vamka	03.08.1981	B.A., LLB	2010	LA
4	Mr. Vimal A.Parmar, Badargadh	26.05.1984	Diploma in Electrical, 2005	12.02.2009	TA
5	Mr. Imran Ghanchi Desalpar	02.09.1986	B.Sc.(IT), 2008	12.02.2009	TA
6	Mr. Rajesh Gusai, Desalpar	17.01.1992	SSC, ITI(Computers)	01.07.2011	LA
7	Shri Bagirath,	18/07/1985	ITI (Electrical)	01/10/2013	LA

	Badargadh				
8	Ganubha Tapubha Jadeja, Desalpar	01/05/1994	ITI Diploma, Computer	06/02/2014	LA

13.10 LIST OF STAFF THAT RESIGNED FROM ISR DURING 2014

Scientific Staff who resigned

Dhaval Patel, JRF, to join as JRF at BIT, Jaipur @Rs. 16,000 p/m as against Rs. 8,000 p/m we paid, DoJ: 12.7.2013, DoR: 7.5.2014.

Mohit Arora, Geophysist, MScTech Geophys., KU, Joining Tojo Vikas, Geophysical Survey Co., @Rs. 24,000 p/m as against Rs. 12,000 at ISR. Doj: 10.9.2013 DoR 12.5.2014

Aurobindo Kumar Basantray, JRF, M.Sc. Geoph, Berhampur (2012), joined SAC-ISRO, DoJ: 20.4.2013 DoR:1.1.2014

Pankaj Das, JRF, Indian School of Mines Dhanbad, M.Sc.Tech Applied Geophysics Date of Joining: July 18th, 2014, Date of Resign: August 13th, 2014, Got JRF ship at IIG Mumbai @ Rs. 16,000/month.

Santu Ghoshal, JRF, Indian School of Mines Dhanbad, M.Sc.Tech Applied Geophysics Date of Joining: July 18th, 2014, Date of Resign: August 13th, 2014, Got JRF ship at IIG Mumbai @ Rs. 16,000/month.

Komal Pasricha, JRF, Kurukshetra Univ., MSc Geoph Date of Joining : September 10th, 2013, Date of Resign : September 25th, 2014, Got JRF ship at NRSA @ Rs. 18,000/month + HRA.

Mr. Sushant Kumar Sahoo, JRF, CAL-VAL, M.Sc. Geophy, Berhampur (2009), joined Odisha Govt. DoJ ISR: 2.4.2012 DoR: 22.9.2014

Rahul Kumar Singh, JRF, Appl. Geop, ISM (2013) DoJ 17.6.2013 DoR:31.10.2014

Sidhartha Dimri, Sr. Geologist, M.Sc. Geol., HNB Garhwal University (2002) Joined IIG, Mumbai DoJ ISR:, 15.1.2008, DoR: 27.11.2014

Ms. Dipika Ahirao, MSc. Geol, Guj Univ., JRF, DoJ: 5.8.2013, DoR: 20.1.2015

Ms. Jayshri Solanki, MSc Geomatics, JRF, CEPT, DoJ: 4.9.2012, DoR: 31.1.2015

Technical Staff who resigned:

Mr. Dilip Chaudhari (JTO), DEE, BE (EE), Joined Guj. Govt. Service, DoJ ISR: 30.10.2007 DoR: 30.10.2014

CHAPTER 13

BUDGET, PROJECTS AND FUNDS

13.1 COLLABORATIVE STUDIES

1. Collaborative work with Dr. Harsh Bhu of Department of Geology, ML Sukhadia University, Udaipur in the field of active tectonics in Rajasthan. OSL dating from Kanoi fault in Jaisalmer region.
2. Collaborative project on "Finding natural period of buildings by ambient vibrations". Dr. A.P. Singh, ISR coordinator, Prof. VM Patel, Pricipal Shankersinh Vaghela Bapu Inst. Tech. (SVBIT).
3. **ISR got a New collaborative project** "Monitoring broadband EM (electro-magnetic) atmospheric noise (RFD system)" in Kachchh for 18 months which has been approved by MoES to Mr. Vinayak Kolvankar, Dr Vaishali Patil and Prof Sonali Kulkarni of Bharati Vidyapeeth, Navi Mumbai

13.2 INTERNATIONAL PROJECTS

1. Italian Project, "Definition of seismic and tsunami hazard scenarios by means of Indo-European e-infrastrucres", Department of Geoscience, University of Trieste, Italy, Participants Indian: Prof. B.K. Rastogi, Dr. Pallabee Choudhury, Ketan Singharoy, Italian Participants:

2. DAAD-DST Project entitled "Probabilistic Analysis of Seismic Losses for Urban Areas and Lifeline Networks In Kachchh (Gujarat), India" , Participants and PI from ISR :-Dr. B.K. Rastogi, Director General, **Dr. Kapil Mohan**, Sci-C, Peush Chaudhary, JRF. Participants from Karlsruhe Institute of Technology, Germany: **Prof. Friedemann Wenzel**, Director and James Daniell, for two years starting February 2014

3. Development of earthquake early warning system for Kachchh Region of Gujarat. India-Taiwan project with National Taiwan University (NTU) approved by Government of India, Department of Science and Technology, PI: - Santosh Kumar (Rs. 22, 41,300)

4. Full 3-D waveform tomography and Lg attenuation for Kachchh, Gujarat, India, India-Taiwan project with Institute of Earth Sciences, Academia Sinica, Taipei approved by Government of India, Department of Science and Technology, PI:- Dr. A.P. Singh (Rs. 22, 41, 300)

13.3 NATIONAL PROJECTS

1. Fast Track DST, New Delhi Project, Morphotectonic and Geological Investigation of Inner Kumaun Lesser Himalaya, Uttarakhand: Constraints on Neotectonic Evolutions, PI: Dr. Girish Chandra Kothyari, Rs. 19,67,000, 3yr Sep 2011- Sep 2014.

2. Fast Track DST, New Delhi Project "Identification of progressively growing crustal strain zones along MCT in Uttarakhand Himalaya, Using GPS geodesy" PI: **Dr. Rakesh K. Dumka** Total approved fund: Rs.21,50,000, 3 years, November 2013 to October 2016.

3. Fast Track Project from Department of Science and Techonology, Government of India "3-D surface wave group velocity distribution and Attenuation structures for Gujarat" To PI: - **Dr. Ajay Pratap Singh.** (Sanctioned amount: Rs. 16,80,000,), 3 years June 2014 – June 2017

4. Fast Track Project from Department of Science and Technology, Government of India entitled "Aggradational – incisional phases in the Fluvial sequences of southern Saurashtra: Implication of Sea level/Tectonic forcings during the Late Quaternary" **PI: - Dr. Siddharth Pravinbhai Prizomwala.** (Sanctioned amount: Rs. 24,20,000), 3 years June 2014 – June 2017

5. NHPC Project entitled "Microearthquake data processing interpretation and report preparation for seismogenic sources around Subansiri Lower Project", PI: Santosh Kumar, 1yr, July 2013- July 2014 (Rs. 22.50 lakhs).

6. ISRO-SAC-NRSC Project on "GPS & GAGAN/IRNSS data analysis for Intra-Plate Geodynamic Profiling in Active Seismic Zone", with National Remote Sensing Centre and Space Applications Centre **Dr. Rakesh K. Dumka** and B.K. Rastogi (ISR Team and PI), **Dr. Sreejith, K.M.,** Shri Ritesh Agarwal, Shri Hrishikesh Kumar and Dr. A.S. Rajawat (SAC Team and PI), **Dr. S. Muralikrishnan**, P. Krishnaiah, J. Narendran and Dr. K. Vinod Kumar, Dr. John Mathew and Mr. Ritwik Majumdar **(**NRSC team & **PI),** Duration 3 yr, Starting April 2014 (Total sanctioned amount Rs. 30, 00, 000, with an amount of Rs 5,00,000 for current year).

7. ISRO-SAC Project “Earthquake Precursory studies in Kachchh” ISR-PI: Dr. B.K. Rastogi, Dr. Rakesh K. Dumka and Dr. Pallabee Choudhury, SAC-ISRO Team: Dr. A.S. Rajawat and **Dr. Sreejith, K.M.,** RS. 25.47 Lakh, February 2013 to January 2016

8. ISRO-SAC Project on “Development of a Cal-Val site at Desalpar in Rann of Kutch for Land and Atmosphere”, ISR Team: B.K. Rastogi, K.M. Rao, Prasanna Simha, SAC Team: Shukla, Sridhar

Rs. 261.50 Lakh, May 2012 to April 2017

9. ISRO-SAC Project on “Development of a Multi-criteria Model to Assessing the impact of Earthquake on Human settlement

10. MoES Project entitled “ Reconstructing the catalogue for high energy marine events from Gujarat coast using geological signatures during the last 6000 years. PI: Dr. B. K. Rastogi, co-PI: Dr. A. P. Singh, co-**PI: Dr. Siddharth Prizomwala.**

11. ISR will be participant in the MoES project “A system to acquire genuine earthquake precursors by “monitoring broadband EM (electro-magnetic) atmospheric noise (RFD system)”, approved to Bharati Vidyapeeth Institute of Management and Information Technology, and Bharati Vidyapeeth College of Engineering, Sector 8, CBD Belapur, Navi Mumbai - 400 614, Project PI and Co PI: Mr. Vinayak Kolvankar, Dr Vaishali Patil and Prof Sonali Kulkarni, Duration: 18 Months

Total External Cash Flow during 2014 (barring GoG): about Rs. 3 crore

13.4 GOG PROJECTS

1. GoG NON Plan Rs. : 135.00 Lakh

2. GoG Plan Approved Amount Rs. 747.00 Lakh

- (i) Paleoseismology and Active fault Investigations in Gujarat
- (ii) Site amplification study of Gandhinagar
- (iii) Salary of Geophysicist & Scientist
- (iv) Earthquake Early Warning System
- (v) Multi Parametric Geophysical & geochemical Monitoring for Earthquake Precursor Study in the Kachchh region, Gujarat
- (vi) 3D Magnetotelluric study in the Kachchh region of Gujarat

NEW GoG Projects: 1. Deep Seismic Sounding Studies in Kachchh: Rs. 265.72 lakhs

Details of Funds received during Financial Year 2014-2015

Sr. No.	Funding Agency	Project Name	Amount Rs.
Government of Gujarat			
1	Science & Technology Department (GoG)	Govt. of Gujarat - Non Plan Sanctioned: Rs.1,35,00,000	1,35,00,000
2	Science & Technology Department (GoG)	Govt. of Gujarat - Plan (Continuing 727.00 Lakh + New Items 283.72 lakh) :Rs. 10,10,72,000	10,10,72,000
3	Gujarat State Disaster	Corpus Fund (Interest)	1,48,96,000

Sr. No.	Funding Agency	Project Name	Amount Rs.
	Management Authority	Total	
4	Gujarat State Disaster Management Authority	Financial Support for AES 2015	10,00,000
		Sub Total	
Gujarat State Projects			
5	Sardar Sarovar Narmada Nigam Ltd	Seismic Monitoring around Sardar Sarovar Project, Rs. 676.20 lakhs for 5yr Oct 2014 to Oct 2019	Rs. 676.20 lakhs
6	Gujarat Power Corporation Ltd	Magnetotelluric survey to identify Geothermal Sources Zones at selected Spring sites in Gujarat, 2014-2015, 2 sites Rs. 58.00 lakhs	18,29,700
		Sub total	
Govt. of India			
7	Space Application Centre (ISRO), Department of Space	Surface Deformation Mapping using Differential SAR Interferometry in Kachchh and Earthquake Precursory studies in Kachchh (ISRO 1) Apr2014-March 2017	4,61,000
8	Space Application Centre (ISRO), Department of Space	Development of a Cal-Val site at Desalpar in Rann of Kutch for Land and Atmosphere (ISRO 2)	25,00,000
9	Space Application Centre (ISRO), Department of Space	Development of a Multi-criteria Model to Assessing the impact of Earthquake on Human settlement (ISRO 3)	6,50,000
10	Space Application Centre (ISRO), Department of Space	GPS & GAGAN/IRNSS data analysis for Intra-Plate Geodynamic Profiling in Active Seismic Zone, between National Remote Sensing Centre, Space Applications Centre and Institute of Seismological Research (ISRO-4) Apr 2014 to Mar 2019	5,00,000.00
11	Department of Science & Technology	Morphotectonic and Geological Investigation of Inner Kumaun Lesser Himalaya, Uttarakhand: Constraints on Neotectonic Evolutions (Fast Track 1) PI: Dr. Girish Chandra Kothyari Rs. 19.95 lakhs For 4 yr, 2011-2015	3,00,000
12	Department of Science & Technology	Identification of progressively growing crustal strain zones along MCT in Uttarakhand Himalaya, Using GPS Geodesy (Fast Track 2) PI: Dr. Rakesh Dumka, Rs. 21.50 lakhs for 3 yr, 2013 to 2016	6,30,000
13	Department of Science & Technology	Aggradational-Incisional phases in the fluvial sequences of southn Saurashtra: Implications of sea level/tectonic forcings during the Late Quaternary PI: Dr. Sidhartha Prizomwala, (Fast	10,00,000

Sr. No.	Funding Agency	Project Name	Amount Rs.
		Track 3) (Rs. 24.20lakh for 3yr 2014 to 2017)	
14	Department of Science & Technology	"3-D surface wave group velocity distribution and Attenuation structures for Gujarat" (Fast Track 4) PI: **Dr. Ajay Pratap Singh** (Rs. 16,80,000 for 3 y r, 2014 to 2017)	7,00,000
15	NHPC	"Microearthquake data processing interpretation and report preparation for seismogenic sources around Subansiri Lower Project", PI: Santosh Kumar	22,50,000
16	MoES	MoES workshop on "Active Faults"	6,50,000/-
		Sub Total	
Foreign Funding Agency			
17	Department of Geoscience and Mathematics, University of Trieste, Italy	Definition of seismic and tsunami hazard scenarios by means of Indo-European e-infrastrucres (Indo-European Project)	5,81,515.00
18	Ministry of Science & Technology	DST-Germany Project, "Probabilistic Analysis of Seismic Losses for Urban Areas and Lifeline Networks in Kachchh (Gujarat), India (Indo-German Project)" PI: Dr. Kapil Mohan	5,36,201.00
19	Global Innovation & Technology Alliance(GITA), New Delhi	DST- Taiwan Project "Development of earthquake early warning system for Kachchh Region of Gujarat", PI: Mr. Santosh Kumar	7,47,100.00
20	Global Innovation & Technology Alliance(GITA), New Delhi	Taiwan Project "Full 3-D waveform tomography and Lg attenuation for Kachchh, Gujarat, India, PI: Dr. A.P. Singh	7,47,100.00

Details of Projects for Financial Year 2014-2015

Sr.	Project	D. o. C.	Durations	Total Sanction	Sanction/ year	Received in Current Year	Expenditure in Current Year
A	**Govt. of Gujarat Projects**						
1	SSNNL – 02	October 14	5 Years	676.20 Lac	1,35,24,000/	3,04,29,000/-	9,24,411/-
2	Geo-Thermal	24-09-2013	2 Years	58,08,800/-	29,04,400/	16,26,400/-	12,43,735/-
B	**Govt. of India Sponsored projects**						
1	ISRO – 01	February 13	3 Years	25,47,000/-	8,49,000/	4,61,000/-	5,65,860/-
2	ISRO -02 (Cal Val)	07-05-2012	5 Years	64,50,000/-	12,90,000/	0	5,56,067/-
3	ISRO – 04	08-01-2014	5 Years	30,00,000/-	6,00,000/	5,00,000/-	2,94,314/-
4	Young Sci. 01	05-09-2011	4 Years	21,00,000/-	5,25,000/	4,00,000/-	40,733/-
5	Young Sci. 02	07-10-2013	3 Years	21,50,000/-	7,16,700/	7,50,000/-	2,60,755/-
6	Young Sci. 03	20-02-2014	3 Years	16,80,000/-	5,60,000/	7,00,000/-	2,50,013/-
7	Young Sci. 04	20-02-2014	3 Years	24,20,000/-	8,07,000/	10,00,000/-	6,39,096/-*
8	NHPC Ltd.		3 Years	22,50,000/-	7,50,000/	20,25,000/-	0+
C	**Foreign Projects**						
1	Indo-German	02-09-2013	2 Years	5,45,000/-	2,72,500/	0	1,26,550/-
2	Indo-Taiwan 01	01-04-2014	3 Years	22,41,300/-	7,47,100/	7,47,100/-	1,52,984/-
3	Indo-Taiwan 02	01-04-2014	3 Years	22,41,300/-	7,47,100/	7,47,100/-	2,32,869/-
	Total Sanction Amount for per Year in Rs.					**2,42,92,800/-**	

Note: Mostly expenditure is on salary and tour.

*Pur. Work Station of Rs.2.01 Lac

+ Transfer to Res. Fund

CHAPTER 14

INSTRUMENTS/COMPUTERS/ACCESSORIES AND SOFTWARE PROCURED

Instruments/ Motor Vehicles/ Computers/ Accessories and Software procured

❖ Computer/ Software procured during 2014

Sr.	Item	Supplier	Qty.	Amount	Project
1	Dell Laptop	Kalp Systems	01	49,350.00	FAST TRACK 2
2	Dell Desktop	Kalp Systems	01	52,750.00	GoG Plan
3	HP Laptop	Beget Computers	01	48,350.00	FAST TRACK 4
4	HP Printer & Antivirus	Beget Computers	01	27,450.00	FAST TRACK 4
5	Work Station	Agmatel India Pvt. Ltd.	01	2,01,113.00	FAST TRACK 3
6	Dell Desktops	iValue Systech Pvt. Ltd.	03	1,66,463.00	FAST & GoG Plan
7	SMS Software	Kalp Systems	01	11,798.00	GoG Plan
8	Data Recovery Software	Steller Information Tech. Pvt. Ltd.	01	26,307.00	GoG Plan

9	Net Gear Storage	Wellmark Technologies	01	3,49,650	GoG Plan

❖ Motor Vehicle procured during 2014

Sr.	Vehicle	Supplier	Qty.	Amount	Project
1	TATA Sumo Gold	Cargo Motors Pvt. Ltd.	02	13,49,128.00	GoG Plan
2	M & M Bolero Camper	Mahindra & Mahindra	01	5,66,927.00	GoG Plan

❖ Instruments procured during 2014

Sr.	Party Name	Instrument	Qty.	Foreign Currency	Amount	Project
1	EIE Instruments Pvt. Ltd.	Oven & Sieve Shaker	02		1,28,480.00	GoG Plan
2	Guralp Systems	SMA	16	104110.99 USD	63,69,610.00	SSNNL & Corpus

❖ Other misc. Assets procured during 2014

Sr.	Instrument	Party Name	Qty.	Amount	Project
1	Nikon Camera	Dream Electricals	02	52,450.00	FAST
2	EPBAX Systems	Wellmark Technologies	01	93,900.00	GoG Plan
3	Batteries	Battery Boys	34	1,11,200.00	Fast & ISRO
4	Diesel Pump	Krishna Machinery Stores	01	35,500.00	GoG Plan

CHAPTER 15

SEMINARS, SYMPOSIA, SPECIAL EVENTS ORGANISED

15.1 LIST OF NATIONAL / INTERNATIONAL SYMPOSIA / SEMINARS HOSTED BY ISR ARE AS FOLLOWS:

i) **Seminar on "Paleoseismology and Active Faults", Cambay Hotel, September 16, 2006.**

ii) **Seminar on "Seismology in India", Cambay Hotel, March 12, 2007**

iii) "National Seminar on Seismic Microzonation", Inst. Entrepreneurs, October 26, 2007

iv) International Workshop on Active Fault Studies in Kachchh, January 18-19, 2008 at Bhuj

v) National Training Program on "Introduction to Seismic Microzonation with Special Reference to Gandhidham" Co-organized with Oyo Intl. Corporation, March 26-April 1, 2008.

vi) MoES Workshop on GPS Networks in India, August 3, 2009

vii) 1st International Seminar 'Advances in Earthquake Science' (AES-2011), January 22-24, 2011

viii) Indo-US Workshop on Intraplate Earthquakes, January 15-18, 2012.

ix) Co-hosting of 2 days Indian Geophysical Union Annual convention and symposium, October 2012.

x) Indo-German Workshop on "Magnetotelluric Data Acquisition, Processing and Modeling", November 1-3,, 2012.

xi) 2nd International Symposium 'Advances in Earthquake Science' (AES-2013), February 1-2, 2013.

xii) International training school on "Use of e-infrastructures for advanced seismic hazard assessment in Indian Subcontinent" February 4-7, 2013. Co-hosted with Trieste Univ., Italy

xiii) 3rd International Symposium 'Advances in Earthquake Science and Seismic Microzonation' (AES-2014), January 4-6, 2014

xiv) Workshop on "Earthquake Engineering" attended by around 200 civil engineering teachers and students on March 29, 2014. The delegates were shown different labs of ISR. Practical demo of engineering geophysics and geotechnical aspects were given. Lectures were given by experts.

Seminars / Symposia / Workshops organized during 2014-15

xv) Organized one day workshop by Institute of Seismological Resaerch (ISR), Gandhinagar at Shankersingh Veghela Bapu Institute of Technology (SVBIT), Gandhinagar "Building Vulnerability and Site Response Analysis" (Dr. A. P. Singh & Mr. Vasu Pancholi, ISR), on 10.10.2014

xvi) Workshop on "Active Fault Studies", attended by 25 experts from India and NGRI, Oct 20-21, 2014

XVII) International Symposium on "Reducing Earthquake Losses" and 4th International Convention on Advances in Earthquake Science as a part of the Vibrant Gujarat Summit 2015. Jan5-7 , 2015

Gujarat is prone to damaging earthquakes. After the devastating 2001 Bhuj earthquake the Gujarat Government established Institute of Seismological Research to understand the earthquake hazard in Gujarat and to assure sustainable development of rapidly growing State by suggesting earthquake-resistant designs of buildings and important structures.

The Institute informs earthquake magnitude and location within minutes and explains to public the expected hazard. The Institute also advices on seismic safety factor for different heights of buildings and also to industry, new railway stations, ports, nuclear power plants and LNG storage terminals. It has assessed geotechnical nature of soil in different parts of Gujarat. Maps have been prepared giving details of earthquake effect on different heights of buildings from different levels of earthquakes in different earthquake zones.

Purpose of the symposium was to inform new findings of ISR and other agencies in India and the World on earthquake hazard to buildings and how to safeguard them. Experiences worldwide were shared by experts from India and different countries. Buildings considered were not only high rise but also of mass housing projects. Ideas on earthquake resistant features like dampers or base isolators and new designs as well as new inexpensive but earthquake-resistant materials were also discussed. Retrofitting of important structures was described. ISR investigations like seismic Microzonation, geotechnical work, geological studies and geophysical surveys as well as Seismic hazard assessment for tall buildings, LNG storage terminals and nuclear power plants were highlighted. Expertise for 'Performance-based Designs' including 'soil- structure interaction' and 'dynamic analysis of building designs' available at ISR in collaboration with IIIT Hyderabad was recommended to be used.

Some of ISR new findings are:

1. Near the geological faults there is 50-100% higher hazard than recommended in the national code. Hence, national code needs to be modified.
2. Geotechnical investigations are required to know soil/rock layers which amplify the seismic waves and if there is any weak layer that can cause large amplification.
3. In Kachchh special investigations and care is needed due to possibility of great earthquakes of Magnitude 8. Along Narmada also moderate earthquakes of Magnitude up to 6.5 are expected.
4. In rest of Gujarat the earthquakes are of Magnitude 6 or less. Such earthquakes do no generate seismic waves close to natural periods of high rise buildings. Hence damage is more to low-rise buildings. Greater than 10 storey buildings may not collapse if built as per national code. They may be rattled badly and different floors may shake differently. Details can be worked out by dynamic analysis.

The foreign delegates included Dr. Susan Hough from US Geological Survey, Prof. Friedemann Wenzel, Director Karlsruhe Institute of Technology, Prof. Antonella Peresan of Trieste Univ. Italy, Prof. Gian Paolo Cimellaro, Earthquake Engineer from Turin, Italy (presently at Berkley), Dr. M. Seki, Structural Engineer at Building Res. Inst., Tokyo, Japan who has designed many tall buildings, Dr. Amod Mani Dixit, General Secretary and Dr. Minesh Ratna Tamrakar, Structural Engg., both of Nepal Society of Earthquake Technology.

Indian delegates included Prof. DK Paul of IIT Roorkee and Chairman of BIS Committee on Earthquakes, Mr. Anil Sinha, Vice-Chairman, Bihar State Disaster Management Authority, Prof. Atul Desai of Surat, Mr. Anand Tatu, President Guj. Inst. of Civil Engineers, Ms Rita Teotia, Special Secretary Telecommunication, GoI, Ms. Anju Sharma, CEO, Gujarat State Disaster Management Authority, Sri S.J. Haider, Secretary, Dept. S&T. Due to tremendous interest in the topic some 400 delegates attended. There were 30 oral an 15 poster presentations and 5 Panel Discussions.

15.2 RECOMMENDATIONS OF THE SYMPOSIUM

1. Consider 50-100% higher acceleration than that recommended in national code for a distance of 20 km from the geological fault lines producing moderate earthquakes and 40 km from fault lines producing large earthquakes.

2. National codes have to be changed (i) Codes are needed for non-structural elements (ii) Increase of seismic hazard is needed near fault. Codes have to be made for chemical industry to avoid Bhopal type tragedy. Also manufacturers of equipments need to be told about the safety requirements. Various other codes need to be modernized. Last modification was done in 2000.

3. Geotechnical investigations need to be done in detail up to 50m depth. These need to be done for high rise buildings. Geotechnical investigations need to be done for Government Mass housing projects also.

4. Base isolation and vibration controlling dampers are recommended. These have been proved highly effective worldwide.

5. Structural engineers need to be given licenses in different categories depending upon experience.

6. Research on Vernacular buildings needs to be done and propagated.

7. Earthquake safety clinics and e- engineering services need to be started for general/ common guidance for Vernacular and the residential houses.

9. In any building project 80% cost is of land. This leads to shady practices compromising earthquake- resistant features. Government price control is required for land cost.

10. Municipal laws need to be made for earthquake-resistant constructions and need to be enforced.

11. Collaborative study with USA is very much needed for comparative investigations of Kachchh and New Madrid, Missouri region.

12. Disaster preparedness drills are required frequently and at least once a year. In many countries “drop- hide-stay” like drills are carried out. Safety precautions of practiced help forming safe habits at the tin=me of emergency. Otherwise people freeze mentally.

13. Professors of several engineering colleges mentioned that “Earthquake resistant designing” is not taught, it has been removed from syllabus of BE (Civil Engg). It needs to be taught. Students are not aware of codes.

12. Recommendations for Municipal Authorities and Housing Projects:

* Codes need to be followed for mass housing projects. There should also be geotechnical studies.
* G+10 are not needed for mass housing projects. In absence of safety precautions, these become risky. The G+3 are proven and should be preferred.
* The government should not go for lowest bid. Quality construction should be ensured.
* The municipal authorities need to have "Design Basis Report" as per the Performa prepared by Prof. A.S. Arya for GSDMA.

15.3 ISES ORDER OF MERIT AWARDS 2015

During the symposium the Indian Society Earthquake Science honored outstanding original research works in different fields of Earthquake Science in India **the ISES Order of Merit Award to** Young Scientists: Dr. Panzamani Anbazhagan, Dr. Devajit Hazarika, Dr. Bhaskar Kundu, Dr. Kapil Mohan and Senior scientists: Dr. V.K. Gahalaut, Dr. K. Madhusudhana Rao, Mr. G. Suresh


International
Symposium on
Reducing


Symposium on
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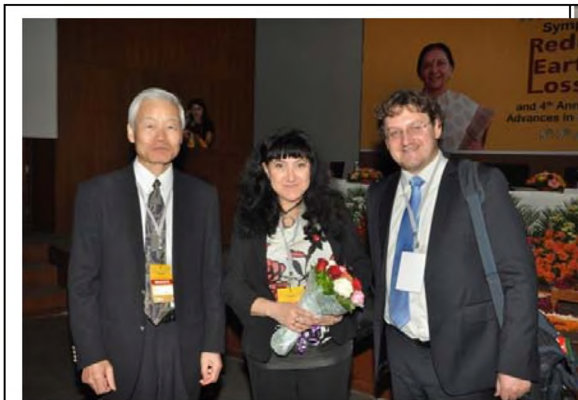







January 2015
Topics for Discussion


Welcome to
International
Reducing
Earthquake
Losses


Welcome to
International
Symposium on
Reducing
Losses


Welcome to
International
Symposium
on
Reducing
Earthquake
Losses
and
January 2015


Welcome to
International
Symposium
on
Reducing
Earthquake
Losses
and
4th Annual Convention on
Advances in Earthquake Science
I S R

VIBRANT GUJARAT SUMMIT 2015

ISR had put up a stall of 200 sq. mtrs area in the Exhibition for Vibrant Gujarat Summit 2015. The exhibition was inaugurated by Ms. Sushma Swaraj, Hon'ble Minister External Affairs, GoI and Hon'ble CM on Jan 7, 2015. Our stall was inaugurated by Dr. Shailesh Nayak, Secretary MoES and Chairman ISRO at 6:30PM on 7.1.2015. Our stall was visited by Honorable Ministers Nitin Patel, Bhupendrasinh Chudasama, Govindbhai Patel. Secretaries who visited include SJ Haider, JN Singh, PK Taneja, DN Pandey.

ISR does flag hoisting and celebration on Independence day and Republic Day. On Republic Day the Chief Guest was Mr. Ashok Narayan (former ACS and Vigilance Commissioner) and Guest of Honor Dr. Indrajit Ghosh (Nuclear Structural Engineer from USA and Visiting Faculty at IITgn).

Happy Street (Rahgiri) Events organized on Sunday mornings with several events.

Appendix I

List of main-shocks recorded in Gujarat in 2014.

Date	OT	Lat	Long	M	Loc
05-Jan-14	6:20 AM	21.88	70.20	3.4	17 km NNW from Upleta, Saurashtra
07-Jan-14	7:19 PM	20.55	73.81	3.5	07 km ESE from Saputara, South Gujarat
08-Jan-14	3:16 AM	21.06	74.95	2.7	135 km ENE from Saputara, Sourth Gujarat
10-Jan-14	1:53 AM	24.52	72.30	2.8	31 km NNE from Deesa, Banaskantha
10-Jan-14	5:55 PM	22.51	71.43	2.1	31 km SSW from Surendranagar, Saurashtra
22-Jan-14	4:40 PM	22.43	71.41	2.0	38 km NNW from Botad, Saurashtra
23-Jan-14	4:19 PM	24.87	73.19	2.8	102 km NNE from Dharoi, North Gujarat
26-Jan-14	7:25 PM	22.48	71.47	2.4	32 km SSW from Surendranagar, Saurashtra
01-Feb-14	12:53 AM	22.86	73.63	3.1	10 Km NNE from Godhra, Panchmahals
04-Feb-14	2:26 PM	23.23	72.01	2.6	56 km SSW from Mehsana, Mehsana
05-Feb-14	1:29 PM	22.45	69.04	2.7	24 km NNE from Dwarika, Saurashtra
10-Feb-14	12:34 AM	21.47	71.68	2.9	16 km WSW from Palitana, Saurashtra
15-Feb-14	11:41 AM	23.70	74.79	2.0	107 Km ENE from Kadana
25-Feb-14	2:37 PM	20.75	73.46	2.1	60 Km NE from Valsad, South Gujarat
27-Feb-14	10:55 AM	21.80	74.20	2.3	48 km ESE from SSNNL Dam, South Gujarat
27-Feb-14	10:50 AM	23.45	70.26	2.2	19 km NNW from Bhachau, Kachchh
05-Mar-14	9:34 AM	18.75	70.10	3.0	251 Km SSW from Una, Saurashtra
06-Mar-14	6:59 PM	21.81	74.34	3.0	66 Km ESE from Kevadiya, South Gujarat
09-Mar-14	00:31 AM	23.36	70.29	4.1	08 km NNW from Bhachau,Kachchh
12-Mar-14	2:33 PM	22.49	71.47	2.0	31 km SSW from Surendranagar, Saurashtra
13-Mar-14	6:47 PM	22.47	71.55	2.0	29 km SSW from Surendranagar, Saurashtra
14-Mar-14	6:52 PM	22.52	71.65	2.0	23 km SSE from Surendranagar, Saurashtra
03-Apr-14	7:24 AM	24.95	70.70	2.1	104 km WNW from Vav
03-Apr-14	9:33 AM	24.81	72.53	2.6	70 km NNE from Deesa,North Gujarat
08-Apr-14	12:28 AM	23.12	69.69	3.0	16 Km SSE from Bhuj, Kachchh
12-Apr-14	8:07 AM	22.52	71.67	2.0	24 km SSE from Surendranagar, Saurashtra
21-Apr-14	3:38 AM	20.97	70.94	2.4	19 km NNW from Una, Saurashtra
22-Apr-14	2:00 PM	24.67	70.04	2.1	142 km NNE from Dharoi, North Gujarat
22-Apr-14	4:52 PM	22.05	72.40	2.3	41 km NNE from Bhavnagar, Saurashtra
23-Apr-14	12:20 AM	21.95	72.37	2.7	30 km ENE from Bhavnagar, Saurashtra
01-May-14	10:33 AM	24.54	72.30	2.8	34 km NNE from Deesa, North Gujarat
12-May-14	11:36 AM	22.31	70.05	3.4	16 km NNE from Lalpur,Jamnagar
18-May-14	1:57 AM	22.12	70.78	2.3	18 km NNW from Gondal, Saurashtra
20-May-14	9:19 AM	22.13	70.78	2.8	19 km NNW from Gondal, Saurashtra

Date	OT	Lat	Long	M	Loc
31-May-14	1:03 PM	22.68	71.69	2.0	8 km ESE from Surendranagar, Saurashtra
02-Jun-14	2:13 PM	22.45	71.39	2.0	39 km SSW from Surendranagar, Saurashtra
04-Jun-14	5:47 AM	23.56	71.79	2.0	36 km SSE from Radhanpur, North Gujarat
13-Jun-14	11:47 PM	21.13	70.57	3.2	09 km NNE from Talala, Saurashtra
18-Jun-14	12:41 AM	21.84	70.75	2.0	14 km SSW from Gondal, Saurashtra
21-Jun-14	9:29 PM	21.55	73.30	3.6	38 km ESE from Bharuch, South Gujarat
22-Jun-14	11:10 PM	22.29	69.86	3.0	15 km NNE from Lalpur,Saurashtra
01-Jul-14	7:35 PM	24.11	71.74	2.0	33 km NNE from Radhanpur,North Gujarat
08-Jul-14	1:28 AM	24.70	72.13	2.3	49 km NNW from Deesa, North Gujarat
15-Jul-14	8:00 PM	24.44	72.55	2.2	32 km NNE from Palanpur,North Guajarat
16-Jul-14	12:31 PM	22.43	71.42	2.0	30 km NNW from Botad,Saurashtra
18-Jul-14	1:58 PM	24.36	73.70	2.0	95 km ENE from Dharoi, North Gujarat
24-Jul-14	4:07 PM	24.04	68.43	3.8	42 km WNW from Lakhpat,Kachchh (Indo-Pak Border)
25-Jul-14	6:50 PM	21.79	69.30	2.0	36 Km. WNW from Porbandar, Saurashtra
04-Aug-14	3:43 PM	24.57	72.03	2.7	38 km NNW from Deesa, Banaskantha
05-Aug-14	9:43 AM	22.49	71.76	2.5	30 km SSE from Surendranagar, Saurashtra
26-Aug-14	12:09 PM	21.03	69.74	2.2	40 Km WSW from Mangrol, Saurashtra
28-Aug-14	12:04 AM	21.23	70.89	3.0	42 km ENE from Talala, Saurashtra
12-Sep-14	8:32 PM	21.31	72.35	2.0	50 km WNW from Surat, South Gujarat
13-Sep-14	5:26 AM	23.39	70.35	2.3	10 km NNE from Bhachau, Kachchh
14-Sep-14	12:25 AM	23.38	70.41	2.0	11 km NNE from Bhachau, Kachchh
14-Sep-14	1:18 PM	23.70	70.70	2.0	14 km NNE from Rapar, Kachchh
15-Sep-14	1:28 AM	23.79	68.42	2.4	37 km WSW from Lakhpat, kachchh
18-Sep-14	6:22 PM	24.25	72.93	2.0	28 km NNE from Dharoi, North Gujarat
19-Sep-14	12:10 PM	22.45	71.43	2.0	37 km SSW from Surendranagar, Saurashtra
22-Sep-14	1:52 PM	24.24	72.97	2.1	29 km NNE from Dharoi, North Gujarat
23-Sep-14	7:22 PM	22.38	69.88	2.9	22 km WSW from Jamnagar, Saurashtra
24-Sep-14	12:05 PM	22.46	71.44	2.0	36 km SSW from Surendranagar, Saurashtra
28-Sep-14	4:35 PM	22.44	71.46	2.0	36 km SSW from Surendranagar, Saurashtra
02-Oct-14	11:33 AM	22.17	71.16	2.4	40 km ESE from Rajkot, Saurashtra
07-Oct-14	2:29 PM	24.61	71.72	2.4	34 km NNE from Vav, North Gujarat
20-Oct-14	4:00 PM	20.84	69.62	2.9	58 km WSW from Mangrol, saurashtra
20-Oct-14	3:57 PM	22.41	71.37	2.0	40 km WNW from Botad, Saurashtra
20-Oct-14	3:53 PM	20.82	69.60	3.6	63 km WSW from Mangrol, Saurashtra
20-Oct-14	8:47 AM	23.85	70.13	2.0	9 km WSW from Dholavira, Kachchh
01-Nov-14	3:22 PM	25.42	71.76	3.7	120 Km NNE from Vav,In Rajasthan

Date	OT	Lat	Long	M	Loc
05-Nov-14	1:25 AM	23.73	71.80	2.4	23 km ESE from Radhanpur, North Gujarat
07-Nov-14	11:21 PM	22.64	71.61	2.0	10 Km SSW From Surendranagar, Saurashtra
07-Nov-14	10:07 PM	22.50	71.27	2.1	17 Km ENE From Rajkot,Saurashtra
10-Nov-14	8:18 PM	22.46	71.44	2.0	35 Km SSW From Surendranagar, Saurashtra
15-Nov-14	10:24 AM	22.08	70.12	2.0	20 km ESE from Lalpur,Saurashtra
18-Nov-14	5:12 PM	22.32	70.69	2.2	12 km WNW from Rajkot, Saurashtra
19-Nov-14	8:56 PM	24.47	72.18	3.0	23 km NNE from Deesa, Banaskantha
19-Nov-14	4:39 PM	22.46	71.42	2.2	37 km SSW from Surendranagar, Saurashtra
25-Nov-14	3:50 PM	21.88	70.82	2.3	10 km SSE from Gondal, Saurashtra
25-Nov-14	1:41 PM	22.50	71.50	2.0	28 km SSW from Surendranagar, Saurashtra
27-Nov-14	6:03 PM	22.42	71.41	2.0	37 km NNW from Botad, Saurashtra
29-Nov-14	10:00 AM	22.51	71.95	2.1	41 km ESE from Surendranagar, Saurashtra
05-Dec-14	1:14 PM	22.52	71.59	2.0	23 km SSW from Surendranagar, Saurashtra
06-Dec-14	10:28 AM	22.51	71.82	2.0	31 Km SSE from Surendranagar, Saurashtra