ISR

Institute of Seismological Research

ANNUAL REPORT 2008-09

Department of Science & Technology
Government of Gujarat

ISR

INSTITUTE OF SEISMOLOGICAL RESEARCH

Department of Science & Technology
Government of Gujarat

ANNUAL REPORT
2008-2009

DIRECTOR GENERAL
INSTITUTE OF SEISMOLOGICAL RESEARCH
Raisan, Next to Petroleum University, Gandhinagar-382009.
Phone : 079-66739001 ; 66739002 ; 66739003
E-mail : dg-isr@gujarat.gov.in ; dgisrgad@gmail.com
Web site : www.isr.gujarat.gov.in

Prologue

ISR shifted to its permanent campus in October 2008 in Raisan area of Gandhinagar. The institute has the strength of over 30 Scientists/Research Scholars and 15 Technical persons working on various aspects of seismological research (Annexure 1). The Institute activities can be broadly grouped under three categories: Earthquake Monitoring, Earthquake Prediction Research and Seismic Microzonation in Gujarat. The high points during 2008-09 are setting up of different labs at ISR like OSL, Geotechnical, Microzonation, GPS, gravity, magnetic, electrical resistivity, electromagnetic, an Earthquake Research Center at Bhachau, three multi-parametric geophysical observatories for earthquake prediction research in Kachchh, starting of microzonation at Dholera Special Investment Region, seismic vulnerability and risk assessment at Gandhidham, detection of active faults and pre-historic earthquakes in Kachchh through paleoseismological studies. It was reported that Anjar old town area situated in soil was heavily damaged in comparison to the new areas on Deccan Traps. This aspect was investigated in detail by broadband seismograph recording of earthquakes, micro-tremor array study and Vs30 measurements. Work continued towards preparation of probabilistic seismic zoning map of India, the task assigned to ISR by Bureau of Indian Standards.

The research topics include earthquake and tsunami hazard assessment, microzonation, preparation of earthquake catalogs, seismicity patterns, source mechanism of earthquakes, crustal deformation, paleoseismology, active faults, earthquake forecasting, seismic and other geophysical surveys for basement and faults, strong-motion attenuation, etc. Gujarat seismic network was expanded. It now has 50 Broadband Seismographs and 50 Strong Motion Accelerographs. Data of 19 broadband stations is brought on real-time through VSAT to ISR. The data is analyzed round the clock to determine the epicenter and magnitude of earthquakes within 10 minutes of the arrival of seismic waves.

Crustal deformation study is being carried out through GPS measurements in seismically active belts of Gujarat. Twenty permanent GPS stations were setup in Gujarat and eleven campaign mode GPS stations were occupied in Kachchh region. InSAR studies were started in Kachchh. Seismic microzonation has been carried out in Gandhinagar, Dholera Special Investment Region and Kachchh. For Gandhinagar area a number of boreholes have been drilled for soil investigations, information about soil characteristics available at different agencies has been compiled, Vs30 measurements were carried out at a few more sites and amplification due to actual earthquakes has been estimated from broadband seismographs deployed at several locations. A study of site response, amplification factor, shear-wave velocity to 30 m depth, soil strength and liquefaction potential for microzonation of Kachchh has been continued. Microzonation studies including Vs30, resistivity, and geotechnical investigations through boreholes in 2.5kmx2.5km grid were started in Dholera SIR region. Seismotectonic investigations including seismic refraction and geotechnical investigations were carried out in Mundra area. In a joint project with IITK and Oyo Intl. Corpn., the ISR carried out Paleoseismology study in 25 trenches along Katrol Hill, Kachchh Mainland and Allah Bund Faults.

seven research papers in SCI journals and seven research papers in non-SCI journals, 9 technical reports (Annexure 4) and fifteen abstracts were published and papers on these were presented by ISR scientists in seminars (Annexure 4 and 5). Several new studies were started during last year and I am confident that significant findings from these studies will help in understanding physical processes of earthquake phenomenon and seismic hazard assessment in Gujarat.

Generous World Bank Loan was provided through GSDMA for ISR buildings and procurement of a number of instruments. Area Head, World Bank, helped in many ways and ensured good ambience, quality and utility of various buildings of ISR. GSDMA made available state funds for procurement of several equipments and helped in their procurement. MoES grants were made available for several projects for which ISR thanks the Secretary MoES, Director and scientists of its Seismology Section. Director, WIHG helped in planning of MPGO observatories and procurement of instruments. ISR is indebted to the Gujarat Chief Minister, Sc. & Tech. Dept., GSDMA, GIDB, GSPC and various other Departments of GoG like Finance and General Administration as well as MoES - GoI, ISRO, NPCIL, World Bank, Asian Development Bank, National Geophysical Research Institute, Hyderabad for their contributions towards development of ISR.

Dr. B. K. Rastogi
Director General

RESEARCH ACTIVITIES DURING 2008-09

EARTHQUAKE MONITORING AND SEISMICITY PATTERNS

(Sumer Chopra, Santosh Kumar, Sandeep Aggarwal, K.Madhusudhan Rao, M.S.B.S.Prasad,A.K. Gupta, M.S. Gadhavi, R.B. S. Yadav, B. Sairam, Babita Sharma, A.P. Singh, Srichand Prajapati, Hardik Patel, Mukesh Chauhan, Uday Bhonde, Kapil Mohan)

SEISMIC NETWORK

Gujarat State Seismic Network (GS-Net) is being run by Institute of Seismological Research since July-2006 (Fig. 1). In this network there are 19 Broadband Seismological Stations (BBS) which are connected via VSAT and data is coming online to SeiDAC at ISR, Gandhinagar. The seismicity monitoring is being done by analyzing the online seismic data and reporting is done within 10 minutes of the arrival of seismic

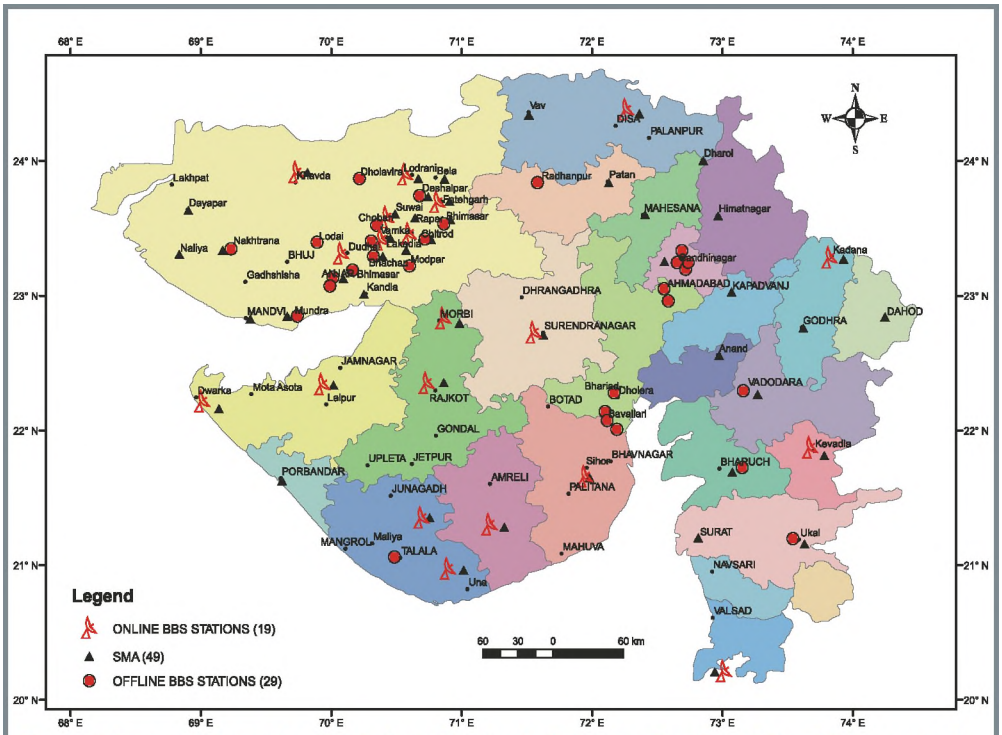


Fig. 1: Seismograph stations in Gujarat Net including 19 online Broad Band Seismographs, 3 online Very Broad Band Seismographs, 29 offline Broad Band Seismographs and 49 Accelerographs.

waves. In addition to this 29 offline broadband seismographs and 3 very broadband stations have been installed in the year 2008 and most of them are in Kachchh active region. This has increased the network detection level to M2.0 in Kachchh active area and M2.5 in rest of Gujarat. Also 50 Strong Motion Accelerographs (SMA) have been installed in this network. It is planned to connect Six Strong Motion Accelerographs through VSAT and auto location program to detect the earthquakes within seconds and for developing earthquake early warning system, whereby 30 sec or more advance warning can be given to Ahmedabad and other important cities if a great earthquake occurs in Kachchh.

STRONG MOTION ACCELEROGRAPH DATA

Strong Motion Accelerographs (SMA), which record near-source strong motion, recorded a total of 248 shocks during the year 2008. At SMA station Hirenvel (very near to epicenter of Talala earthquake) nearly 120 shocks have been recorded of magnitude range 1.0 to 3.0. The five M≥4.0 earthquakes during 2008 in Kachchh were well recorded on SMA which occurred on 1-3-08 (M4.0 recorded on 5 stations), 9-3-08 (M4.4 recorded on 12 stations with 0.2 PGA), 15-4-08 (M4.1), 20-6-08 (M4.3), 10-7-08 (M4.1 recorded on 8 stations) while 2 in Saurashtra on 31-3-08 (M4.1) and 5-10-08 M(4.4) were also well recorded.Kachchh region is still showing activity along 2001 epicentral area. The Gedi fault that became active in 2006 has continued showing seismic activity. In Saurashtra, the area south of Jamnagar has shown mild seismic activity while the Talala area of Junagadh showed strong seismic activity.

DESCRIPTION OF EARTHQUAKES IN GUJARAT DURING 2008

During 2008 the network recorded 1842 shocks of magnitude 0.5 to 4.4 in Gujarat out of which hypocentral parameters of 1598 shocks were located (Figs 2 and 3). Additional 45 regional and 199 distant earthquakes (including 33 distant earthquakes of magnitude 6.0 or greater) were recorded. This year there was no large or even moderate earthquake in Gujarat. All were small tremors or microearthquakes. Seven tremors were in the magnitude range 4 to 4.4, out of which five were in Kachchh (four near Bhachau and one near Gedi) and two in Talala area of Saurashtra. Four tremors in Bhachau area: magnitude 4.0 on 1st Mar 2008 at 18 km NW of Bhachau near village Manfara; magnitude 4.4 on 9th Mar 2008 at 18 km NW of Bhachau near village Meghpar; magnitude 4.3 on 20 Jun 2008 at 40 km NE of Bhachau near village Chitrod; magnitude 4.1 on 10th July 2008, 19 km NW of Bhachau near village

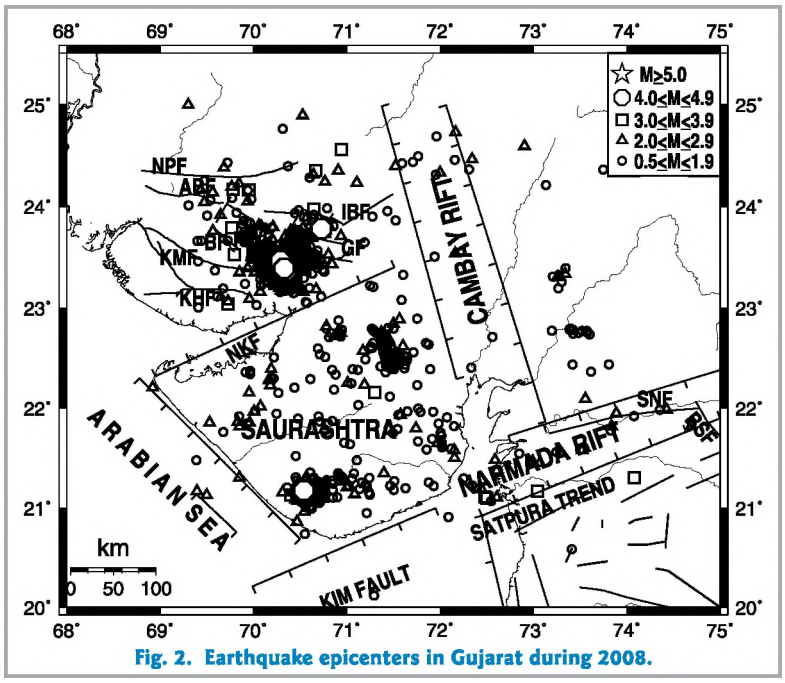


Fig. 2. Earthquake epicenters in Gujarat during 2008.

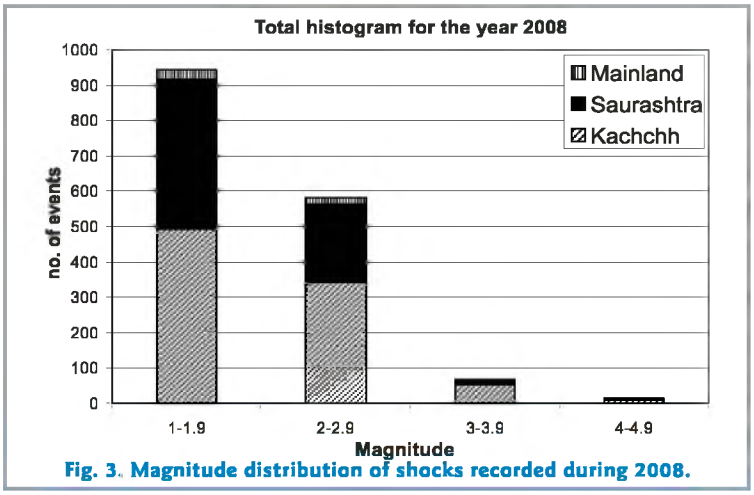


Fig. 3. Magnitude distribution of shocks recorded during 2008.

Manfara. One tremor of magnitude 4.1 occurred along Gedi fault on 15 Apr 2008, 25 km NE of Rapar near village Desalpar. A magnitude 4.3 tremor occurred on 5th Oct 2008 near Talala town in Saurashtra. Magnitude wise distribution in the three regions of Gujarat is shown in Fig. 3.

Region	M ≥ 4	3.0 to 3.9	2.0 to 2.9	< 2.0	Total
Kachchh	5	52	343	493	893
Saurashtra	2	12	221	424	659
Mainland	-	3	17	26	46
Total	**7**	**67**	**581**	**943**	**1598**

Regional Distribution

- In the Kachchh region 893 shocks were located (56% of total in Gujarat).
- In the Saurashtra region 659 shocks were located (41% of total in Gujarat).
- In the Mainland 46 shocks were located (3% of total in Gujarat).

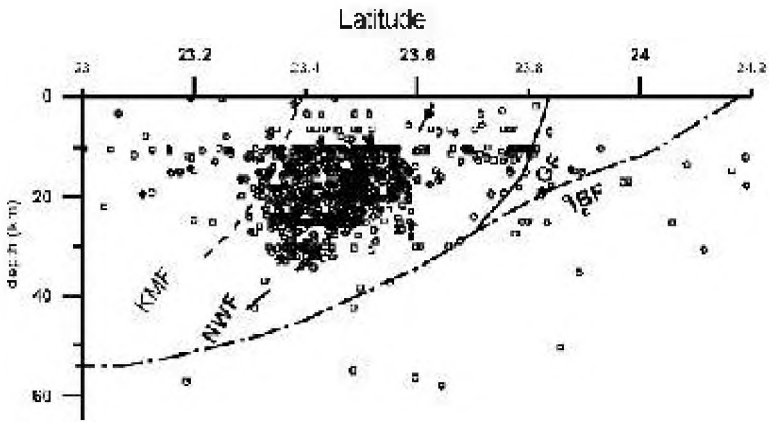


Fig. 4. Kachchh focal depth plot for year 2008

Fig. 4. Depth distribution of shocks and geological faults. A slight concentration of shocks at 10 km depth is artifact of the location program. Focal depths less than 10 km are few and almost nil greater than 35 km.

EARTHQUAKES IN KACHCHH

In the year 2008, a total of 231 earthquakes were recorded south of the Kachchh Mainland Fault (KMF). Along the North Wagad Fault (NWF) a total of 548 earthquakes were recorded. The tremors of magnitude 4.0, 4.4, 4.3 and 4.1 occurred on 1st March, 9th March, 20th June and 10th July 2008, respectively, along this fault. In the Gedi fault area, that became active since 2006, a total of 63 earthquakes of M>1.5 were recorded during 2008. The maximum magnitude 4.1 tremor occurred on 15th April 2008 along this fault. In the year 2008, a total of 22 earthquakes were recorded along the IBF, the maximum magnitude shock of 3.5 occurring on 1st Feb- 2008. The depth-distribution of earthquakes in Kachchh is shown in Fig. 4.

EARTHQUAKES IN SAURASHTRA AND TALALA IN PARTICULAR

The activity during 2008 in Saurashtra clustered around Talala extending in a sparse way to Dhari in ENE direction for 110 km. Another cluster was SW of Surendranagar for a length of 60 km. Slightly active trend was between Lalpur (Jamnagar district) to Porbander for a length of 100 km in NE direction. Microearthquakes are located around Rajkot, Morbi and SW of Bhavnagar.

During the year 2008 a total of 659 shocks have been recorded by ISR from SAURASHTRA region. A month wise distribution of shocks is given in Table below.

Month	Jamnagar	Talala	Rest of Saurashtara
Jan-08	4	147	16
Feb-08	2	91	10
Mar-08	1	20	20
Apr-08	1	20	3
May-08	2	17	12
June-08	2	19	9
July-08	2	13	20
Aug-08	7	16	10
Sept-08	4	9	5
Oct-08	3	62	7
Nov-08	4	17	31
Dec-08	3	23	27
Total	**35**	**454**	**170**

Seismic activity in and around Talala of Saurashtra in the year 2008

Aftershock activity of magnitude 5.0 earthquake of 6 Nov 2007 continued at high level until February 2008. The activity again rejuvenated in October 2008 with M 4.3 earthquake near Talala. There was a spurt of shocks during first week of March 2009. A total of 17 shocks of magnitude $\geq$ 3.0 have been recorded during 2008. The activity in this area was distributed between Latitude 21.0N to 21.4N and Longitude 71.20N to 71.6N (in an area of 89 km x 45 km) approximately.

Seismic Activity in and Around Surendranagar of Saurashtra in the Year 2008

In and around Surendranagar area a total of 170 shocks have been recorded with maximum magnitude of 1.9 recorded on 2nd Aug.08, 35 km SW of Surendranagar. The activity in this area was distributed in between Latitude 22.4N to 22.8N and Longitude 71.20N to 71.6N in an area of 36 kmx40 km.

Seismic activity in and around Jamnagar of Saurashtra in the year 2008

In Jamnagar area a total of 35 shocks of magnitude 0.5 to 2.6 have been recorded. There were two shocks of magnitude 2.6 recorded on 16th May 2008 and 22nd Sept.2008 in between Lalpur and Jamnagar. The activity in this area was distributed unevenly in between Latitude 22.1N to 22.8N and Longitude 69.85N to 71.0N in an area of 80kmx100km.

EARTHQUAKES IN MAINLAND GUJARAT

In mainland Gujarat, few shocks of M<4.0 occurred along Tapi fault near Surat and offshore. M 3.5 of May, 20, 2008 was felt in Surat and to distances of tens of km. Some shocks occurred west of Godhra and 50 km east of Gandhinagar.

TREND OF SEISMICITY IN KACHCHH

The current seismicity in Kachchh is mostly aftershocks activity of 2001 earthquake occurring north of Bhachau. Seismicity is much reduced after 2006 (Fig. 5 and Table below). During 2006 there were 3 damaging earthquakes of magnitude 5.0 to 5.7, 49 slightly damaging earthquakes of M4-4.9 and 312 strongly felt shocks of M3-3.9. During 2007 there were 6 slightly damaging earthquakes of M4-4.9 and 82 strongly felt shocks of M3-3.9. During 2008 there were 5 slightly damaging earthquakes of M4-4.9 and 66 strongly felt shocks of M3-3.9. In 2009 there are 13 strongly felt shocks of M3-3.9 as shown in table below. In spite of 8 years of aftershocks activity a damaging earthquake of magnitude 6.0 near Bhachau is still a possibility. However a bigger earthquake is possible east of Bhachau near Samkhiali-Chitrod area as the seismicity during 2004-06 migrated in that area. Another area having a potential for large earthquake of M 6-7 is near Lodrani-Gedi area located 25 km North of Rapar (Fig. 6).

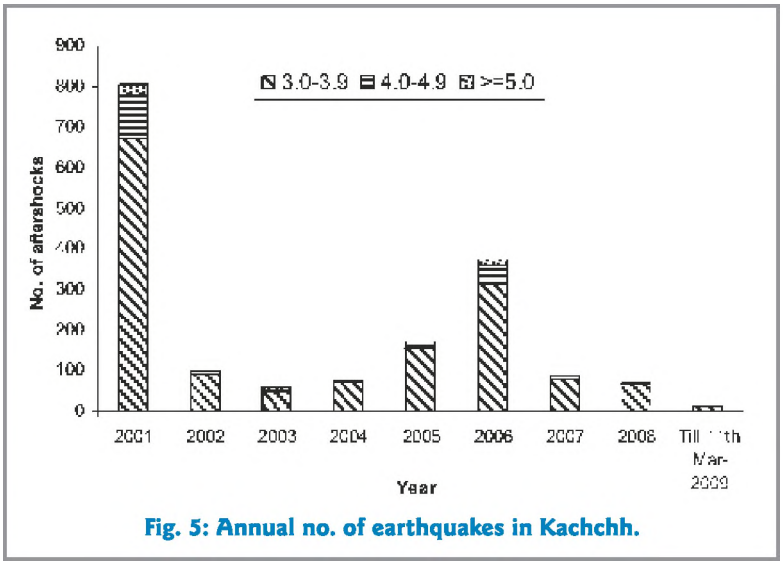


Fig. 5: Annual no. of earthquakes in Kachchh.

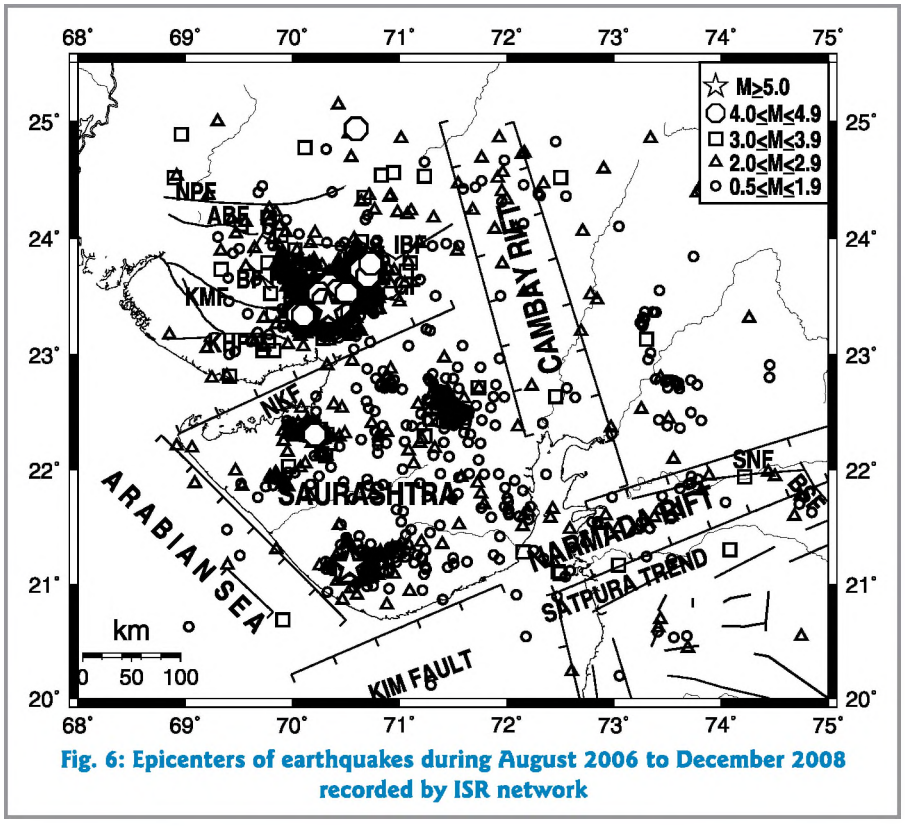


Fig. 6: Epicenters of earthquakes during August 2006 to December 2008 recorded by ISR network

Year M	2001	2002	2003	2004	2005	2006	2007	2008	Till 11th Mar-2009
3.0-3.9	674	91	47	70	155	312	82	52	13
4.0-4.9	106	11	3	5	16	49	6	5	—
>=5.0	12	—	1	—	—	3	—	—	—

TREND OF SEISMICITY IN SAURASHTRA

Currently tremors are concentrating at Talala (Mmax 5.0 so far), South of Jamnagar (Mmax 4.0 so far) and Surendranagar (Mmax 3.2 so far). Locally damaging earthquakes of magnitude 6.0 are possible in any of these areas.

SOURCE MECHANISM STUDIES

CMT Solutions with local stations (Sandeep Aggarwal)

Centroid Moment Tensor (CMT) Solutions of earthquake mechanism were obtained for 10 earthquakes of 2008 in Kachchh. Five of which are of Mw 4 or greater and five are of magnitude 2 to 3.5. CMT solutions were obtained for 8 Talala earthquakes of magnitude >3 that occurred during 2007.

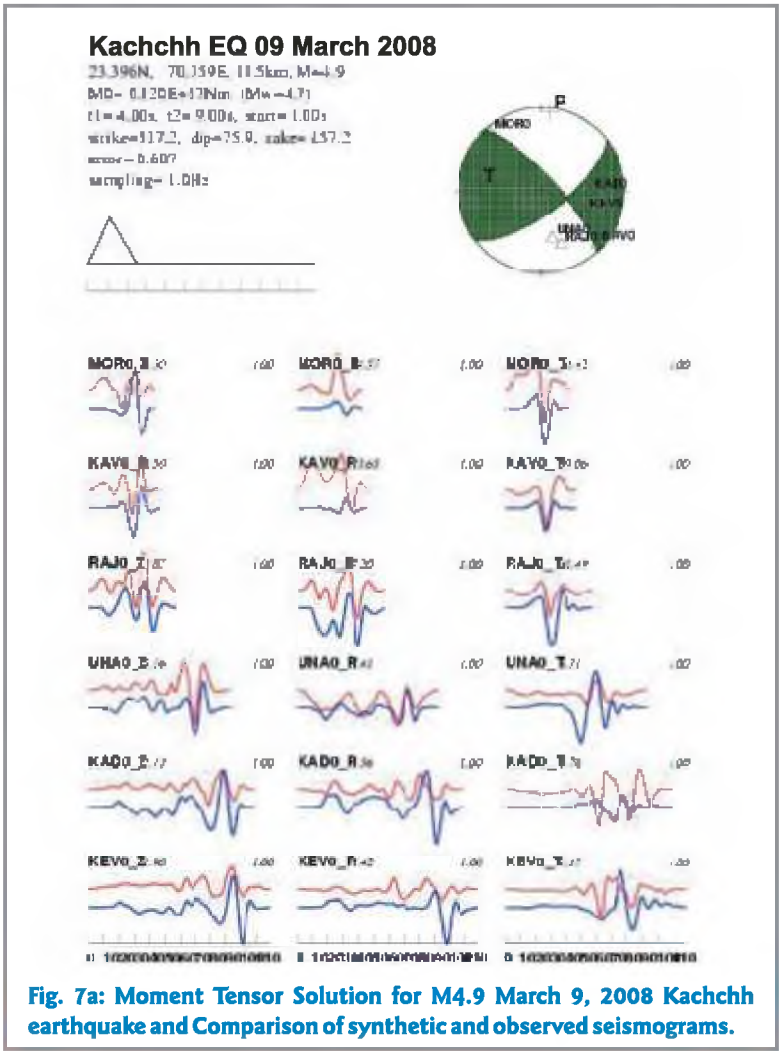


Fig. 7a: Moment Tensor Solution for M4.9 March 9, 2008 Kachchh earthquake and Comparison of synthetic and observed seismograms.

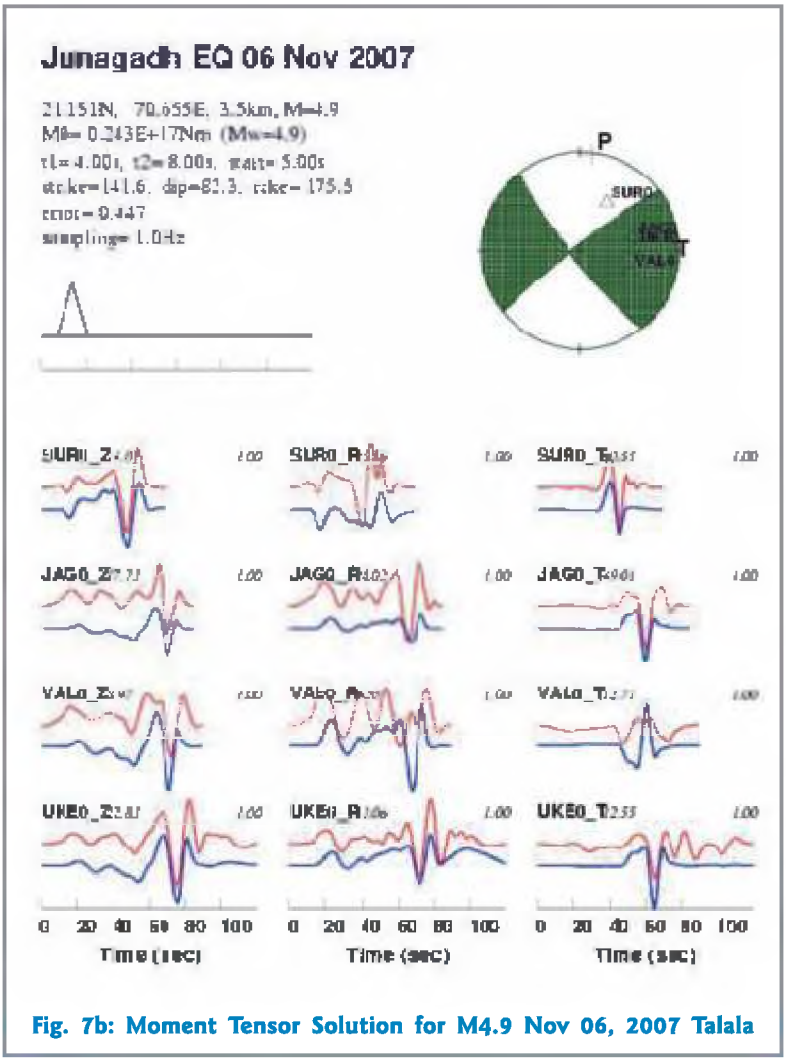


Fig. 7b: Moment Tensor Solution for M4.9 Nov 06, 2007 Talala

CMT Solutions using regional data (Nagabhushana Rao, B.K. Rastogi and Purnachandra Rao)

Centroid Moment Tensor (CMT) Solutions have been determined for three earthquakes in Kachchh (one shown in Fig. 7a) using regional data of 5-6 Stations at distances of 50 to 250 km. The earthquakes occurred during 2007 and 2008 and are of magnitudes 4.1-4.9. The Synthetic Seismograms are generated by wave number integration method of Bouchoun. Inversion programme of Kikuchi and Kanamori is used. The earthquakes in Kachchh indicate thrust faulting along south dipping (NE or NW trending)) planes. The regional CMT method is found to be excellent in determining focal depth and faulting mechanism of earthquakes.

Moment Tensor Solutions of two Talala Moderate Earthquakes and Correlation with Gravity Field

(Madhusudhan Rao, Nagabhushana Rao and B.K. Rastogi in collaboration with Ramesh Ghosh, N. Purnachandra Rao and V. M. Tiwari of *National Geophysical Research Institute, Hyderabad)*

Two earthquakes of magnitudes 4.8 and 5.0 occurred on 6 November 2007 in the southern Saurashtra region of western India. The region lies 350 km south of the devastating 1819 Kachchh earthquake of M8.0 and 270 km south of the 2001 Bhuj earthquake of M7.8. It is an unusual occurrence of two

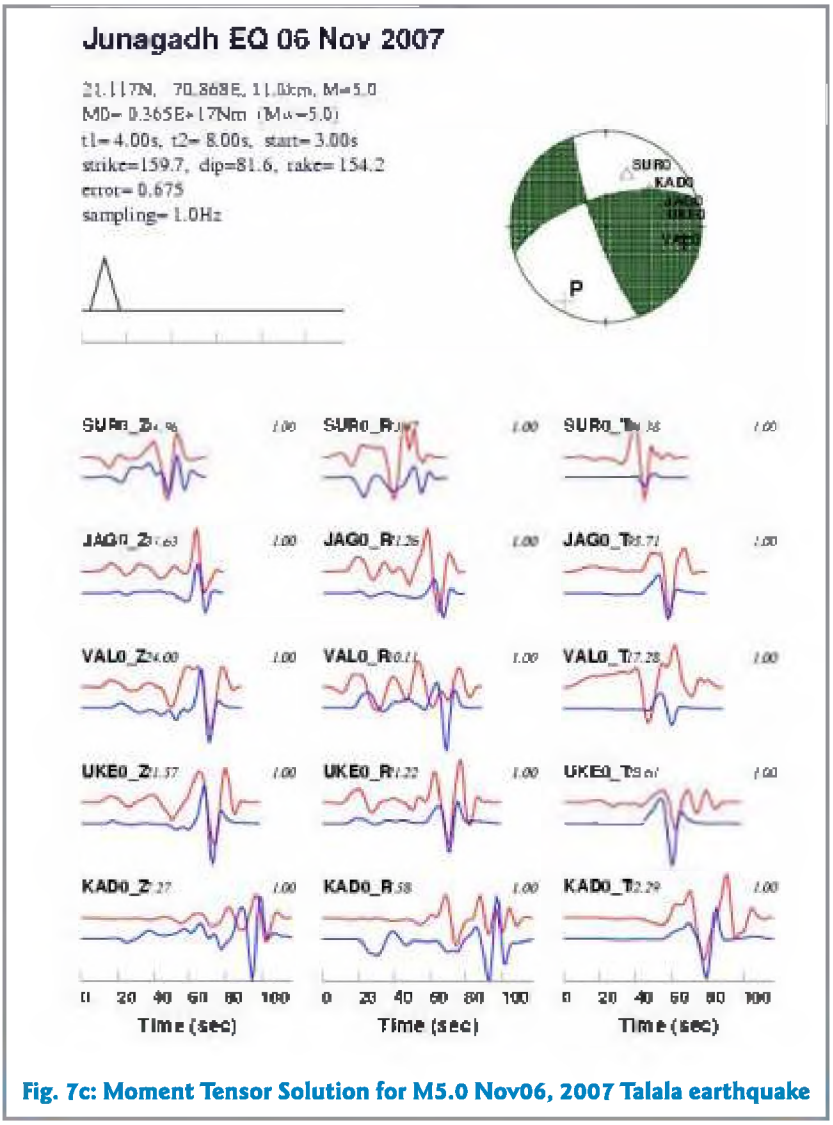


Fig. 7c: Moment Tensor Solution for M5.0 Nov06, 2007 Talala earthquake

earthquakes of moderate size on the same day and same location, although with different focal depths. A similar mechanism of strike-slip faulting is obtained for both earthquakes with focal depths at 3.5 km and 10 km respectively (Fig 7b,c), using moment tensor inversion approach based on the discrete wave-number summation method for computation of synthetic seismograms. The EW trending left-lateral fault plane of the focal mechanism coincides very well with both, the foreshock-aftershock trend in a region previously devoid of any significant seismicity. The spatial distribution of the events also indicates a near-vertical deep seated fault parallel to the trend of the regional faults. A strong correlation is observed between seismicity trend and lobes of low Bouguer gravity anomaly, also trending EW.

Focal Mechanism Solution from first Motion of P-phase (Sandeep Aggarwal)

Focal mechanism solution from first motion of P-phase for 55 Kachchh earthquakes of Mw 1.6 to 3.8 of 2006, 22 Kachchh earthquakes of magnitude 2.3 to 4.7 of 2007 and 17 Talala earthquakes of magnitude 2 to 5 of 2007. The earthquakes were recorded at 9-18 stations. The majority of solutions in Kachchh are reverse fault close to KMF. Northward in Wagad area some earthquakes show strike-slip and normal faulting. Majority of Talala earthquakes show strike-slip faulting.

Estimation of Source Parameters for the Aftershocks of the 2001 Bhuj Earthquake

(B. Sairam and M.S.B.S. Prasad)

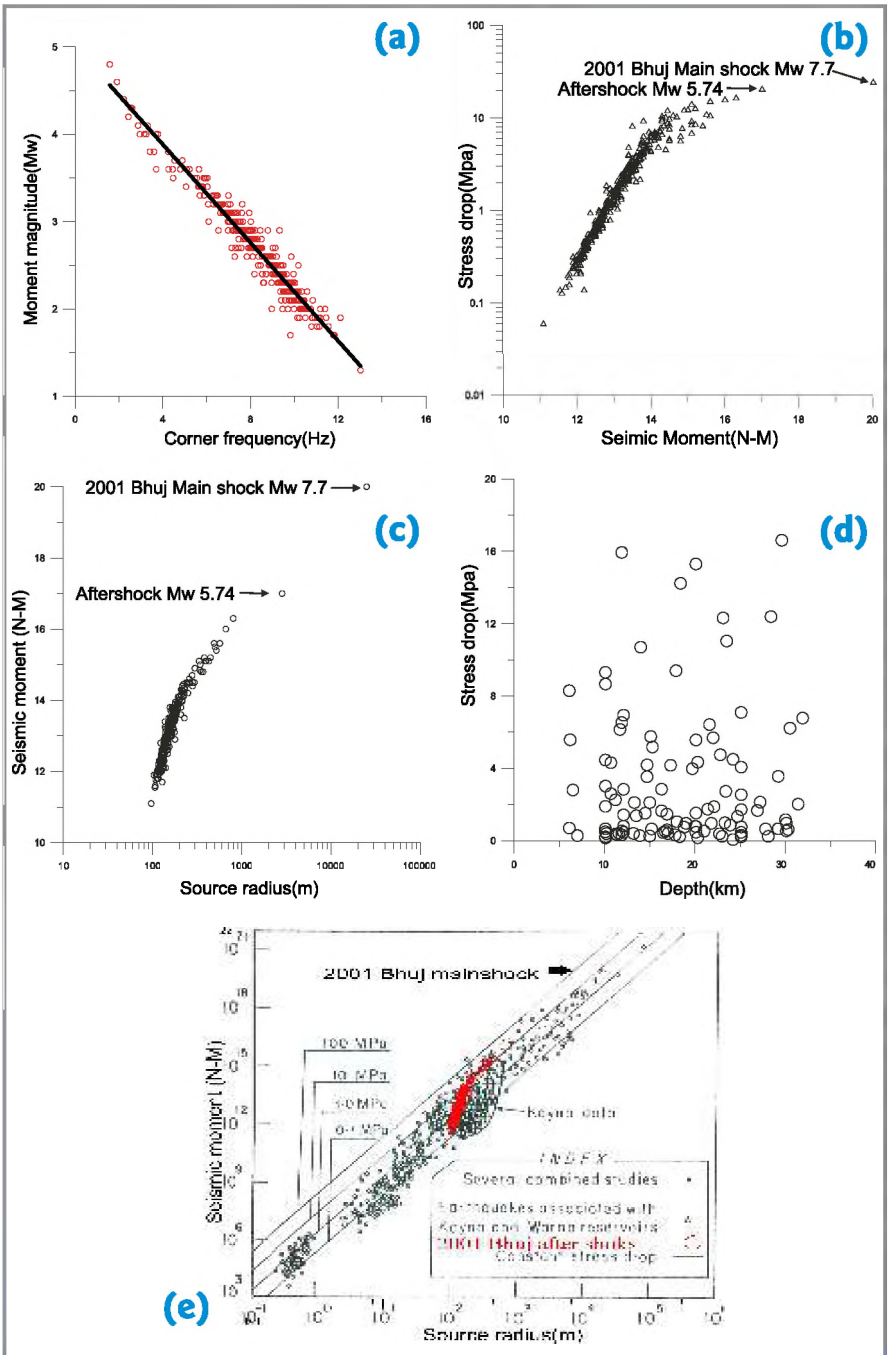


Fig. 8 a. Source parameters of earthquakes in Kachchh from 2001 to 2008 and their comparison with Koyna earthquakes and also from different parts of the World, (a) corner frequency vs. Mw, (b)logarithm of Mo vs. logarithm of stress drop, (c) logarithm of source radius vs. logarithm of seismic moment Mo, (d) depth distribution of estimated stress drops and e) logarithm of source radius versus logarithm of seismic moment (Source parameters of 2001 main shock of Mw 7.7 and an aftershock of Mw 5.7 have been taken from Mandal and Johnstan, 2006)

The intense aftershock activity for eight years enabled us to work on a reliable digital waveform data set to estimate the source parameters. Source parameters have been studied using the spectral analysis of SH-waveforms from Broad band seismograph records of 415 selected aftershocks of the period 2nd August 2002 to 3rd November 2004 (NGRI data of 298 events is used) and 3rd September 2006 to 20th June 2008 (ISR data of 117 events). The estimated source parameters via, seismic moment (Mo), stress drop (Sdr), source radius (r) and corner frequency for aftershocks of moment magnitude 1.3 to 4.8 range from 1.25 x 1011 to 1.99 1016 N-m, 0.06 to 16.61 MPa, r=96.8 to 800 m and f=13.0 to 1.6 Hz (Fig. 8a). The near-surface attenuation factor (k) is found to be large of the order of 0.025 to 0.03. Finally, these estimated source parameters were interpreted in terms of source process and tectonics of the region.

Estimation of Source Parameters for the Aftershocks of the 6 Nov 2007 Talala Earthquake

Source parameter for 400 Talala earthquakes of magnitude Mw 1.5 to 5.0 of 2007 and 2008 are estimated, these shocks depict larger fault radius as compared to Koyna and Kachchh shocks (Fig. 8b).

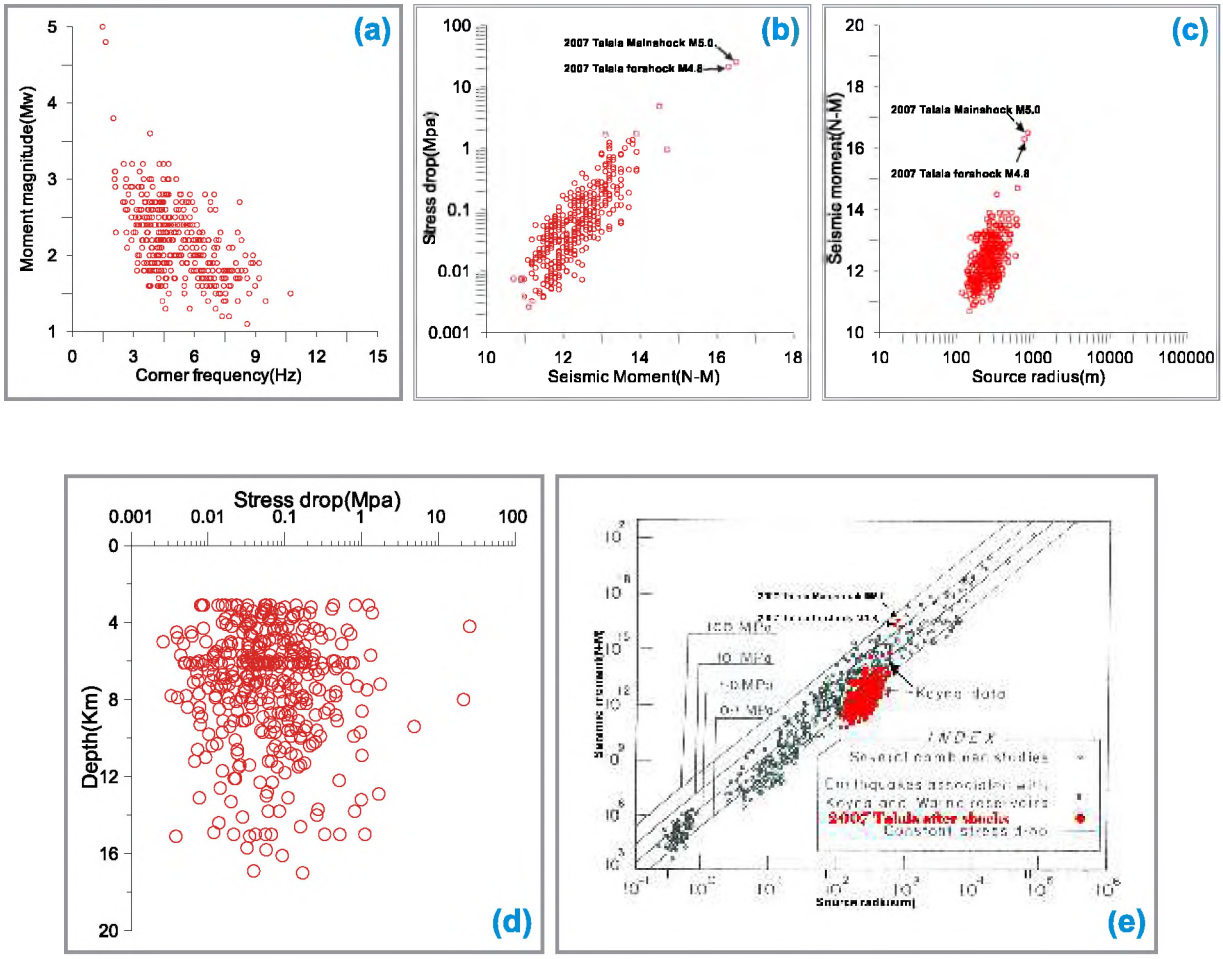


Fig. 8b. Source parameters of earthquakes in Talala, Saurashtra from 2007 to 2008 and their comparison with Koyna earthquakes and also from different parts of the world, (a) corner frequency vs. Mw, (b) logarithm of Mo vs. logarithm of stress drop, (c) logarithm of source radius vs. logarithm of seismic moment Mo, (d) depth distribution of estimated stress drop and e) logarithm of source radius vs. logarithm of seismic moment.

PREPARATION OF CATALOGUES OF EARTHQUAKES AND THEIR STUDIES (R.B.S. Yadav, Sumer Chopra, B.K. Rastogi)

CATALOGUES OF INDIAN REGION

A catalogue for Indian sub-continent (0-40° N and 65-100° E) is being prepared for all magnitude ranges from earliest time to present using the sources of ISC (from 1900 to present), NEIC of USGS (from Dec. 2005 to present), Harvard CMT catalogue for Mw, IMD, catalogue of Bob Engdahl and several literatures. The catalogue is under process of homogeneity, completeness and declustering. The source zones are being identified on the basis of seismicity, focal mechanism and tectonics. This is for preparation of Probabilistic Hazard Map of India, the task assigned by BIS.

The new catalogues of earthquakes kept in ISR data center and website are as follows:

1. The catalogue of Gujarat (in three parts-Kachchh, Saurashtra and Mainland), Karnataka, Maharashtra, Orissa and TN was updated.
2. The aftershocks catalogue of Bhuj prepared earlier was updated with the data of ISR.
3. A declustured, homogeneous and complete catalogue of NE India for the period 1897 to 2007 is prepared and kept on ISR website, describing details about declustering procedure, empirical relationships among magnitude scales and completeness with respect to magnitude and time.

Under a collaborative study with NPCIL a catalogue consisting magnitude and intensity has been prepared for hard rock and soft soil areas of Indian region and relationships have been developed between magnitude (M) and epicentral intensity (I_0) for both types of rocks. The estimated relationship for hard rock is observed as $M = 0.598\ I_0 + 1.474$ and for soft soil as $M = 0.431\ I_0 + 3.001$. After comparing these relationships with US relationship for hard and soft rock, it is observed that a slightly higher magnitude is observed for same intensity value for Indian region as compared to US. Further, these relationships have also been developed for Himalayan seismic belt and stable continental region of Peninsular India.

RECCURENCE RATES IN NE INDIA

Stochastic analysis for NE India region: Using Weibull, Gamma and Lognormal models, recurrence intervals of earthquake of $M \geq 7.0$ in NE India are estimated as 13 - 20 years with cumulative and conditional probabilities as 0.8 - 0.9 from the occurrence of last earthquake in the region. This indicates that the next M7 earthquake may occur during 2008 - 2015 as the last earthquake was in 1995. Using Gumbel's extreme value theory, the estimated return period of magnitude 6.5 is observed as 6-7 years somewhere in the entire region, 9-10 years in Arakan-Yoma subduction belt, 59-78 years in the Himalayan thrust belt, 72-115 years in the Shillong Plateau, and, 88-127 years in the Eastern Syntaxis, respectively. The estimated seismic risk (probability of occurrence of an earthquake in a specified time interval) in Arakan-Yoma subduction belt is observed high as compared to other zones. For this study catalogue of Gupta et al. (1987) for NE India Region has been updated using sources of Harvard, ISC and NEIC for the period 1963 to 2007 and Mw values have been assigned for the period 1897 to 1962.

COULOMB STRESS MODELING OF NOVEMBER 6, 2007 TALALA, SAURASHTRA EARTHQUAKE SEQUENCE: EVIDENCE OF SEISMICITY TRIGGERING

A widely felt moderate size earthquake of magnitude Mw 5.0 occurred in the Talala region of Saurashtra, Gujarat (India) on November 6, 2007. The mainshock preceded a foreshock of magnitude Mw 4.8, which occurred about 9 hrs prior to the mainshock. The aftershock sequence of this earthquake is studied to analyze the seismic parameters like the p-value describing the temporal decay of aftershocks, b-value of frequency-magnitude distribution and D-value describing clustering/declustering of aftershocks. The high p-value (1.10 ± 0.39) suggests the tectonic origin of this sequence with faster decay rate of aftershocks activity and high heat flow. The b-value is found as 1.18 ± 0.1 with magnitude of completeness as Mc = 1.8. The high b-value may be caused by the paucity of the larger aftershocks with magnitude M ≥ 3.5. Also, the fractal dimension (D) for these aftershocks has been calculated and observed as high as 2.21 ± 0.02, suggesting the random distribution of these aftershocks on a two-dimensional planar surface.

The static Coulomb stress changes due to foreshock are calculated using a uniform slip model for vertical left-lateral strike slip fault striking NNE direction. We found that the static stress changes caused by the foreshock are more than 0.1 bars at the location of mainshock (Fig. 9 a), promoting the failure of the fault. A sensitivity analysis was also carried out for different values of strike, dip and rake showing again increased stress (0.05-0.1 bars) at the epicenter of mainshock, evidencing triggering of mainshock due to foreshock. The Coulomb stress modeling for mainshock shows that the locations of aftershocks agree well with the area of increased Coulomb failure stress (Fig. 9 b). Our calculation indicate that positive stress changes due to the foreshock and mainshock make the area SSW and SE of mainshock rupture the most likely sites for the next moderate earthquake in the region. The occurrence of a moderate earthquake of magnitude Mw 4.3 on October 5, 2008 to the SE of mainshock rupture in the region of increased stress validates our postulation.

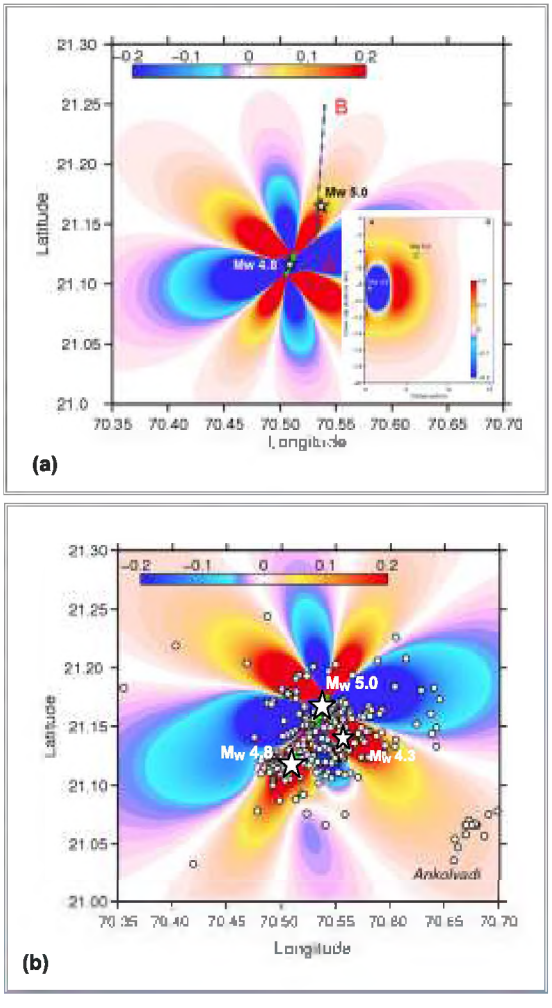


Figure: 9 (a) Static Coulomb stress changes (in bars), due to foreshock of magnitude Mw 4.8 that occurred about 9 hours prior to the mainshock of magnitude Mw 5.0, at a depth of 8.5 km for vertical NNE oriented left-lateral strike slip fault. Figure in inset shows Cross-sectional view along line AB. (b) Coseismic Coulomb stress changes (in bars) due to both foreshock of magnitude Mw 4.8 and mainshock (big star) of magnitude Mw 5.0 calculated at the depth of 4.5 Km (focal depth of mainshock) for vertical NNE fault with left-lateral strike-slip motion, in association with locations of aftershocks.

COULOMB STRESS MODELING IN NW HIMALAYA AND ADJOINING REGION

The Coulomb stress modeling has been carried out to perceive the earthquake interaction processes for 14 shallow, moderate to large earthquakes (Mw ≥ 6.5) with their subsequent smaller earthquakes in northwest Himalaya and adjoining region. The regions of increased and decreased stress have been identified and it is observed that the distribution of regional seismicity (or aftershocks) fall in the increased Coulomb stress region suggesting the earthquake triggering. The study reveals that the occurrence of majority of aftershocks for the Himalayan Frontal Arc earthquakes (Uttarkashi and Chamoli) near updip edge of fault rupture is due to the high Coulomb stress at the up-dip edge. The most of the aftershocks of Kashmir (2005) earthquake are concentrated in the lower part of the updip edge of high Coulomb stress region which indicates that the earthquakes generation source lies deeper than the Himalayan Frontal Arc earthquakes. From this study, it may be possible to predict the regions of future earthquake occurrences and aftershocks area.

CRUSTAL DEFORMATION STUDIES

GPS MEASUREMENTS

(Sumer Chopra, Pallabee Choudhury, Srichand Prajapati and Rakesh Dumka)

Post seismic deformations are going on in Kachchh region due to relaxation process of the 2001 great earthquake. Moreover, some newly active faults in Saurashtra, Gujarat; faults along Narmada, Gujarat and Madhya Pradesh also show substantial seismic activity. Hence, for monitoring the crustal deformation in and around Gujarat Institute of Seismological Research (ISR) has deployed at total of 20 permanent GPS stations and eleven campaign stations starting 2006. All the permanent and campaign stations deployed by ISR are exhibited in Fig. 10 (a) and listed in Tables 1 to 3.

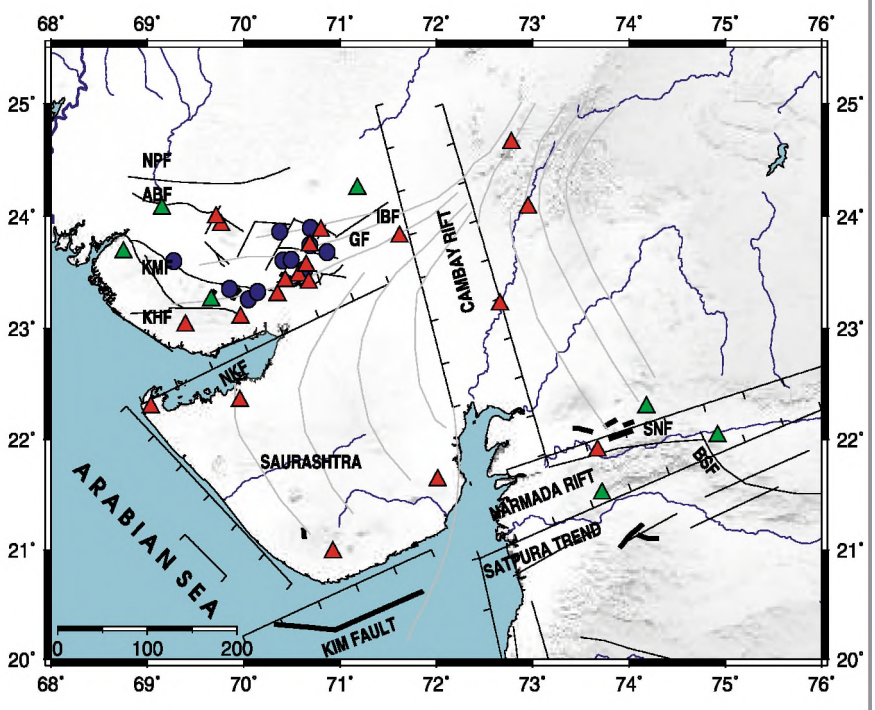


Fig. 10 (a): GPS permanent (red triangles), campaign (blue dots) and proposed permanent (green triangles) stations installed by ISR.

Table 1: Existing Permanent Stations deployed by ISR

Sl No.	Station Name	Lat (°N)	Long (°E)	Date of Installation	Remarks
1.	Anjar	23.094	69.966	05.04.09	Kachchh
2.	Badargadh	23.475	70.571	27.11.08	Kachchh
3.	Bela	23.873	70.801	26.11.08	Kachchh
4.	Bhachau	23.369	70.349	28.06.08	Kachchh
5.	Chitrod	23.407	70.674	06.04.09	Kachchh
6.	Desalpar	23.742	70.687	18.10.08	Kachchh
7.	Khavda	23.922	69.766	05.01.07	Kachchh
8.	Kuwar Bet	23.991	69.713	31.03.09	Kachchh
9.	Rapar	23.563	70.652	28.06.08	Kachchh
10.	Vamka	23.425	70.431	18.10.08	Kachchh
11.	Vandh	23.025	69.395	07.04.09	Kachchh
12.	Bhavnagar	21.635	72.012	17.10.08	Saurashtra
13.	Dwarka	22.289	69.037	01.09.08	Saurashtra
14.	Lalpur	22.347	69.961	27.06.08	Saurashtra
15.	Una	20.978	70.926	26.06.08	Saurashtra
16.	Dharoi	24.077	72.952	04.08.08	MLG
17.	Gandhinagar	23.215	72.665	26.06.06	MLG
18.	Radhanpur	23.829	71.617	23.01.07	MLG
19.	Mt. Abu	24.653	72.780	06.08.08	North Gujarat
20.	Kevadia	21.899	73.674	16.10.08	Narmada

Table 2: Proposed Permanent Stations

Sl No.	Station Name	Lat (°N)	Long (°E)	Remarks
1.	Vigu Kot	24.072	69.151	Kachchh
2.	Panandhro	23.684	68.752	Kachchh
3.	Bhuj	23.252	69.663	Kachchh
4.	Nada Bet	24.245	71.179	Kachchh
5.	Alirajpur	22.294	74.184	Narmada
6.	Sagbara	21.518	73.726	Narmada
7.	Barwani	22.030	74.928	Narmada

Table 3: Campaign mode stations in Kachchh deployed by ISR

Sl. No.	Station Name	Lat (°N)	Long (°E)	Remarks
1.	Bela (gadh)	23.898	70.694	2 epochs
2.	Chandrani (chan)	23.267	70.051	2 epochs
3.	Desalpar (desp)	23.746	70.684	2 epochs
4.	Dudhai (dudh)	23.328	70.145	4 epochs
5.	Ekal (ekal)	23.609	70.408	4 epochs
6.	Fatehgarh (fath)	23.683	70.864	4 epochs
7.	Gadhada (gibf)	23.867	70.373	3 epochs
8.	Hubai (huba)	23.354	69.852	2 epoch
9.	Nilpar (llpr)	23.526	70.636	4 epochs
10.	Palanpur (paln)	23.603	69.273	1 epoch
11.	Suvai (suai)	23.614	70.492	3 epochs

Table 4: The velocities and azimuth of all stations processed by ISR

Sl. No.	Stations	Latitude (°N)	Longitude (°E)	N-comp (mm/yr)	E-comp (mm/yr)	Velocity (mm/yr)	Azimuth (degree)	Remarks
1.	HYDE	17.417	78.551	28.92	39.75	49.16	53.99	IGS
2.	IISC	13.021	77.570	35.44	41.31	54.43	49.40	IGS
3.	ISRG	23.215	72.665	32.99	34.84	47.98	46.59	PER
4.	RADP	23.829	71.617	32.26	35.88	48.25	48.07	PER
5.	KHAV	23.922	69.766	31.22	31.22	44.15	45.02	PER
6.	FATH	23.683	70.864	32.05	34.93	47.41	47.49	CAM
7.	GADH	23.898	70.694	22.26	39.60	45.43	60.69	CAM
8.	DESP	23.746	70.684	33.21	32.51	46.47	44.41	CAM
9.	LLPR	23.526	70.636	25.66	39.14	46.80	56.78	CAM
10.	SUAI	23.614	70.492	33.23	33.26	47.02	45.05	CAM
11.	EKAL	23.609	70.408	32.26	31.48	45.07	44.32	CAM
12.	GIBF	23.867	70.373	27.85	32.59	42.87	49.51	CAM
13.	DUDH	23.328	70.145	34.20	34.74	48.75	45.47	CAM
14.	HUBA	23.354	69.852	29.13	40.53	49.91	54.32	CAM

GPS data collected at all the stations have been processed using GAMIT10.34/ GLOBK and the velocities, azimuth of the sites are summarized in Table 4. The velocity vectors of permanent stations along with various campaign stations are shown in Fig. 10(b). Co-ordinates and velocities of all sites both permanent and campaign, were estimated in the ITRF 2005 reference frame by constraining IGS reference stations position and velocities in the region to reported values in that frame with standard errors provided by IGS.

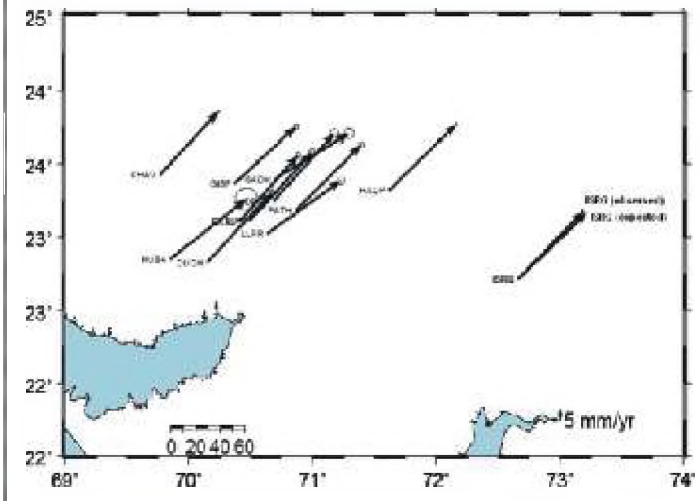
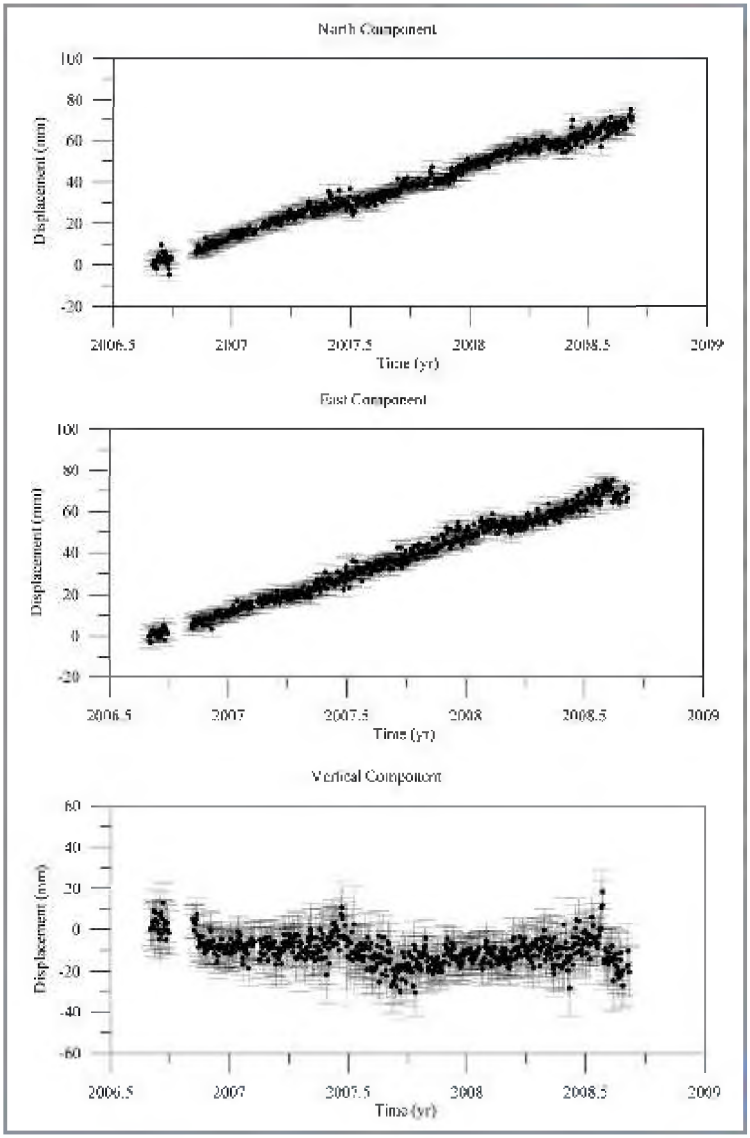


Fig. 10(b) : Velocity vectors of three permanent stations and various campaign stations in Kachchh region in ITRF05.



GPS measurements from 3 permanent and 11 campaign sites (total 14 sites) reflect Indian plate velocity of about 46-50±1mm/yr towards NNE direction. Concurrence of the velocities and time series of IGS stations obtained by us and those provided by SOPAC validates our results. The time series of ISRG permanent station is shown in Fig. 10(c). The observed velocity of ISRG is found almost equal in magnitude and direction with the expected velocity for that point (Banerjee, 2008). To estimate local deformation in this region, the Indian plate motion was subtracted from these measurements. All sites show very small movement of the order of 2- 5 mm/year in Indian reference frame.

Fig. 10(c): The variation of North, East and Up component of ISRG permanent Station

InSAR STUDY IN KACHCHH

(Neha Jhala, Rudradeb Bhattacharyya, Mahendrasinh Gadhavi, B. K. Rastogi in collaboration with K. M. Sreejith and T. J. Majumadar of SAC, ISRO)

Five 1-m width trihedral passive corner reflectors were deployed at Vamka, Bhachau, Chobari, Sinogra, Dholavira and Dudhai over the seismologically active Kachchh region. The geographic locations of the reflectors were measured using differential GPS. Applicability of using small, reflectors for geometric correction of ENVISAT Fine Mode ASAR data was assessed covering the two ENVISAT scenes dtd. 22-06-08 and 26-06-08 descending and ascending passes respectively. It is usually difficult to tie-in such measurements to traditional ground surveying methods, such as GPS or leveling from the remote sensing data alone. If trihedral corner reflectors are used, they can be precisely surveyed. The optimization of reflector networks will depend on a number of factors such as the geodetic positioning of the reflectors including the relationship between the GPS antenna and reflector, the relative geometry of the reflector network, establishing reflector alignment in azimuth and elevation, site selection and stability, and positioning the reflectors at the test sites before the satellite pass.

The performances of the corner reflectors were evaluated by analyzing the ENVISAT Fine Mode ASAR data. The results obtained indicate that the small, passive, trihedral corner reflectors are sufficient to generate near saturate backscatter information of a ground pixel, making them identifiable as point targets in the processed ASAR image. At 29 dB larger than the power scattered from the background area, most of the corner reflectors could be readily identified. Contrast enhancement of the SAR image was necessary to identify the corner reflectors when the difference between the powers scattered from the reflector's resolution cell and the background targets narrow down to 12 dB. Below 12 dB difference, it becomes fairly difficult to identify exact locations of the corner reflectors in the image. Geometric corrections of the SAR data using the GPS locations of five corner reflectors were found satisfactory, with a RMS error of less than half a pixel. The study will be useful for calibration of ENVISAT ASAR images and generation of InSAR/DInSAR images for subsidence monitoring in this region.

GEOPHYSICAL SURVEYS

GPR SURVEYS

(Hardik Patel)

GPR profiles were taken across Nana Asambia enechelon fault at Matiyadev near Pragpar village in Kachchh. The area, about 20 km north of Mundra comprises of steeply inclined Tertiary beds exposed in road and nala cutting. Total eleven GPR profiles were taken across the fault. The profiles were from 26m to 48m in length.

GRAVITY SURVEYS

(R. K. Singh, Sameer Tiwari and Rashmi Pradhan)

Fourteen bases were established from Anjar to Rapar and they all are tied up with known bases at Anjar established by National Geophysical Research Institute (NGRI), Hyderabad.

Apart from this, a 20 km long gravity section (Bhachau- Kharoi- Chobari) is also taken by gravimeter (CG-5, Autograv) in which observations were made at an interval of 1 km.

PALEOSEISMOLOGICAL AND ACTIVE FAULT INVESTIGATIONS IN KACHCHH

(Rastogi B. K.[1], M. S. Gadhvi[1], J. N. Malik[2], A.K. Tyagi[3], A.K. Singhvi[3], M. Morino[4]

[1]Institute of Seismological Research, Raisan, Gandhinagar, [2]Indian Institute of Technology, Kanpur, [3]Physical Research Laboratory, Ahmedabad, [4]Oyo International Corpn.)

Paleoseismology, Geomorphology and dating of recent tectonic features will establish return periods of earthquakes and help in forecasting of earthquakes by determining ages of pre-historic earthquakes in Kachchh and rates of movements along geological faults. For this study, after due observation of land by

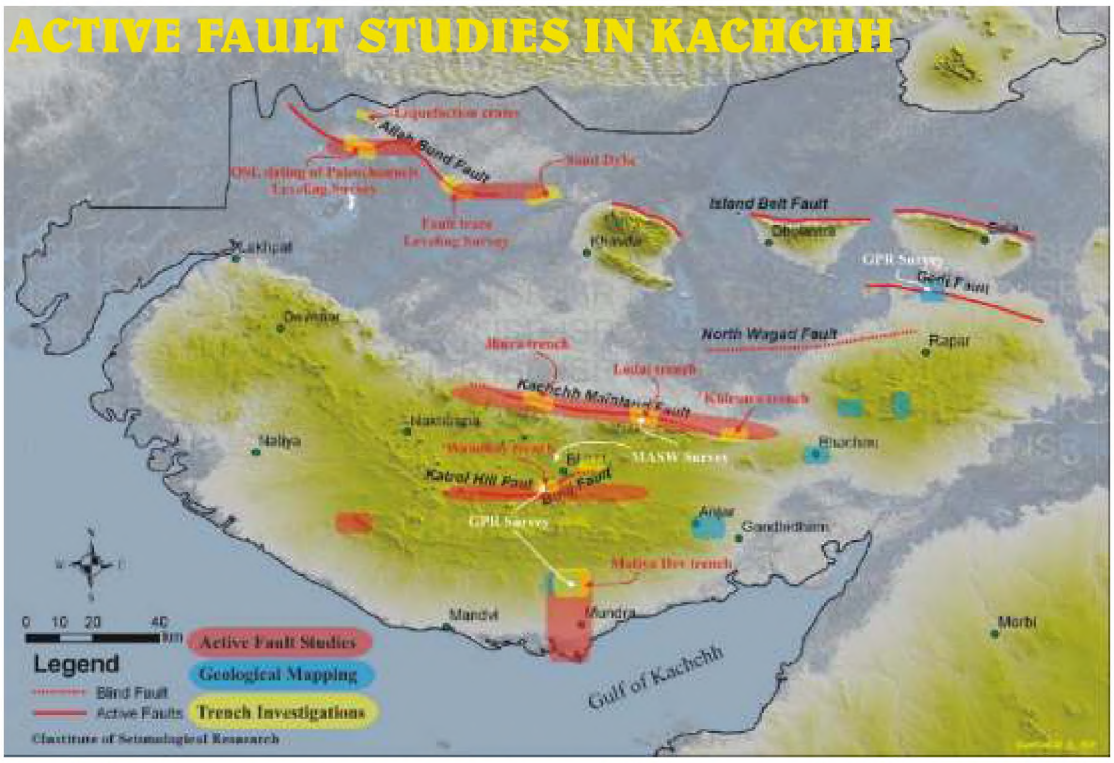


Fig. 11: First time ever produced active fault map of Kachchh region. Highlighted areas indicate locations of trench investigations carried out on three major faults of the area.

satellite stereo images and then ground combing in earthquake stricken area of Kachchh, samples have been collected from trenches. Analysis of these samples is done in OSL Lab for determining the ages of the sediments and how they were formed. Paleoseismology studies in more than 25 trenches along with geophysical investigations such as GPR and MASW survey, leveling measurements were carried out along Katrol Hill, Kachchh Mainland and Allah Bund Faults. The study revealed, for the first time in India, clear evidences of neotectonic activity and pre-historic earthquakes and an active fault map of Kachchh has been prepared (Fig. 11). The highlight of the study was first to identify pressure ridges along faults by stereo images and then go for trenching. This tremendously increased chances of finding neotectonic features.

Kachchh Mainland: Pressure ridges were observed with 2-3 m height extending in E-W direction near Lodai village on KMF (NNE of Bhuj). In a trench, the Quaternary deposits were observed to be widely deformed and three small faults were identified indicating three seismic events with a net slip of about 60-70cm. These are typical reverse faults with dip of 10°-60° inclined to south.

At Jhura on KMF (NNW of Bhuj) pressure ridges were identified in the fan deposits of Kaila River from Satellite data. Trenching showed two events on a fault with 70 cm slip for each event (Fig. 12). From this a slip of 6 m can be inferred for hard rock at depth. Some 12 m south an older fault indicates similar slip.

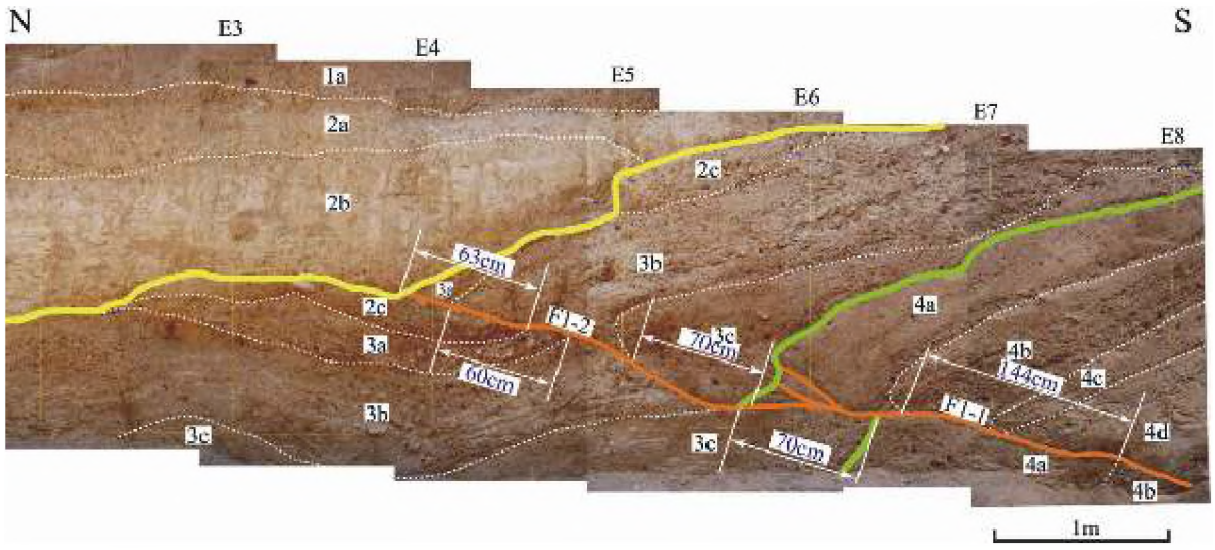


Fig. 12: Observed slip along the fault traces in Jhura Trench. Slip of 144 cm observed on fault F1-1 is cumulative slip for the two events.

An active fault trace demarcating boundary between Katrol Hill and fluvial terrace is observed near Wandhay village. A warping scarp was observed on the terrace. A trench was excavated across this scarp. Three major fault strands were identified in the trench. Three seismic events were inferred along these. The northern fault strand displaces the terrace deposits along all units of the younger sequence except top layer.

The eastern part of KHF is suggested as inactive. The NE-SW extending Bhuj fault at Wandhay village is the active foreland migration of KHF. A trench across the Bhuj fault indicated one event. The fault displaced all sedimentary succession in the trench from Mesozoic rocks to thin channel deposits except the top soil cover

Allah-Bund: Indications of pre 1819 uplift along western segment of Allah-Bund were observed. Numerous paleo-channels recognized from satellite data were found to have uplifted on ground checking. These uplifts are 40 cm to 290 cm and might have occurred < 2ka. [Existence of paleo-channels was pointed out to us by Roger Bilham].

Around Vigukot, 10 km north of the western segment of ABF, three events were identified in two trenches on the basis of cross-cutting of liquefaction features. A few small or distant events are envisaged on the basis of small sand blows. Dating of charcoal and sediments is in progress.

Satellite imageries for the eastern segment of Allah-Bund SSE of Karimsahi indicated younger drainage south of scarp (which is normally not expected). Leveling indicated abrupt slope change (20cm uplift) for a 70 m length. A trench exhibited > 2m upthrusting from north. In the easternmost section of the Allah-Bund (8 km west of Dharamsala) numerous sand blows and dykes were observed for lengths of 70-80m which are seen to extend to shallow depths in trenches.

ESTABLISHMENT OF OPTICALLY STIMULATED LUMINESCENCE LAB

For age determination of seismically disturbed sediments, two numbers of Risoe TL/OSL Readers (model TL/ OSL DA-20) are acquired from Denmark (Fig. 13). The Risoe TL/OSL measurement system enables measurement of both thermoluminescence and optically stimulated luminescence. With the help of this technology samples as old as 2.5 MY can be dated. This technique is very suitable for dating of paleoseismic events because silicate sediments which are used as samples are abundantly available. Moreover signals from the older samples are found to be stronger, which is an added advantage over other dating techniques such as ^{14}C.

Fig. 13: TL/OSL reader installed at ISR

ATTENUATION AND HETEROGENEITY

(Babita Sharma)

Seismic wave attenuation is performed from the time domain decay of coda wave amplitude on narrow band pass filtered seismograms of local earthquakes for Saurashtra. For this purpose we took data sets for two different areas associated with Saurashtra i.e. Junagarh and Jamnagar. Digital seismograms related to vertical component for Junagarh and Jamnagar recorded by the broadband Guralp network of ISR (Institute of Seismological Research) with magnitude range $2<Mw<5$ and up to 25 km focal depths have been used for the present study. The frequency band of interest was 1.5 to 18 Hz. For a 30 second time window of coda wave propagation starting from the twice of S wave arrival time, the $Q_c(f)$ is found to be strongly dependent on frequency. Frequency dependent relationships in form of $Q_c=Q_of^n$ are also estimated for Junagarh and Jamnagar which are $Q_c=191f^{1.01}$ and $Q_c=224f^{0.98}$ respectively. Although the region selected for the present study falls in the stable continental area in western India, but still it shows a considerable seismicity which should be taken seriously for future. So this study is an effort to estimate the attenuation in the area for the first time. The results show that the level of heterogeneity for Saurashtra is low as compared to the adjacent Kachchh area as the Q value is more for Saurashtra than Kachchh. If we compare the attenuation criteria for Jamnagar and Junagarh, it is clear that the Junagarh region is more attenuative than the Jamnagar. Saurashtra region mainly consists of deccan traps which is showing low attenuation. So the present results are consistent with the local geological attributes of the area of concern.

SEISMIC MICROZONATION

(Sumer Chopra, Santosh Kumar, RBS Yadav, Hardik Patel, B. Sairam, Mukesh Chauhan, A.P. Singh and Kapil Mohan)

ISR carried out investigations for seismic hazard assessment in India as a whole and Gujarat state in particular. ISR continued seismic microzonation studies in Gandhinagar and Anjar-Gandhidham-Kandla area. The latter study was done in collaboration with GSDMA and Oyo International Corporation. ISR carried out several types of investigations. Seismic microzonation work was also started in Dholera Special Investment Region located about 100 km south of Ahmedabad. The drilling work in progress near ISR campus is shown in **Fig. 14.** The areas of microzonation study currently undertaken and to be taken in 1-2 years are shown in **Fig. 15.**

Fig. 14: Drilling work in progress for microzonation near ISR campus.

SALIENT RESULTS OF MICROZONATION STUDIES

1. An attenuation relation has been prepared for Gujarat using hundreds of recorded accelerations for M 3 to 5.7 earthquakes
2. Maps of 2% and 10% probability of exceedance of PGA in 50 yr for Gujarat have been prepared.
3. ISR participated in the seismic microzonation program of Anjar-Gandhidham-Kandla area by G.S.D.M.A. and OYO International Corporation. Seismic microzonation has been done with geotechnical investigation in 80 boreholes of 50 - 100 m depth, velocity measurement by shallow seismic, P-S logging and by

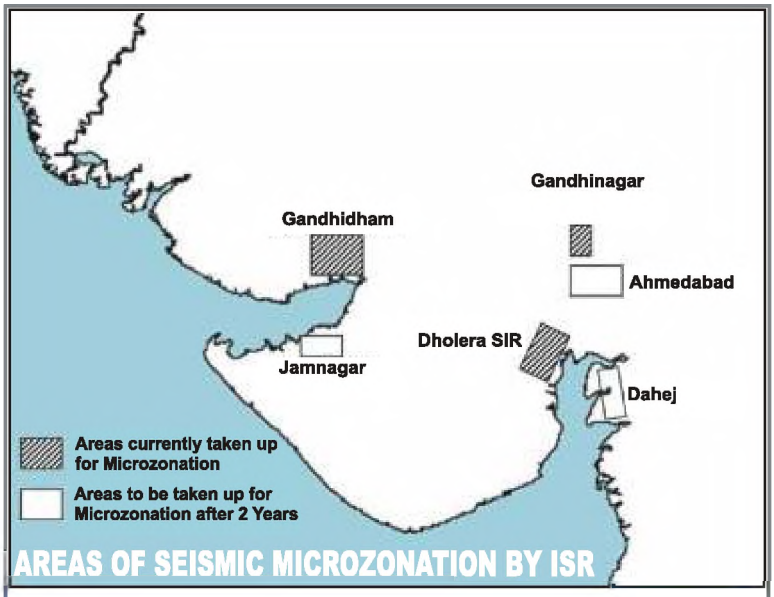


Fig 15: Locations of areas taken up and to be taken up for microzonation by ISR

estimating fundamental period of the soil layer by Nakamura method using broadband seismographs and microtremor recorders. Following are major outcomes:

- PGA at engineering bed rock has been found.
- Depth to Engineering bedrock has been found.
- Soil amplification has been found.
- Response spectra are obtained for different sites.
- Liquefaction Potential is found to be high in Kandla area.
- In Anjar the damaged areas are found to have lower Vs 30 to 15 m depth as compared to the non-damaged areas. The old residents informed that the damaged areas of the old town area were on reclaimed land where a pond used to be there. Actual earthquake recording on broadband seismographs indicate 1.5 to 3 times amplification in frequency range of 5 to 10 Hz and 1.5 times amplification for the frequency of 0.9 Hz. No amplification observed for non damaged area.

4. In Gandhinagar preliminary results indicate 3- 4 times amplifications in frequency range 1-2 Hz and 0.4 - 0.8 Hz from actual earthquake recording on broadband seismographs. The soil has strong bearing capacity even at shallow depths of a few meters.
5. In about 800 km^2 area of Dholera Special Investment Region (SIR), 100 km south of Ahmedabad seismic microzonation has started in the same way as in Gandhidham area as mentioned above. Twenty-five boreholes have already been drilled to 50 m depth. PS logging has been done in 7 boreholes. Vs30 measurements have been done at 25 sites and repeat Resistivity profiling taken at 12 sites. Further work is under progress.

Some significant studies are described in detail as follows:

PROBABILISTIC SEISMIC HAZARD MAP OF INDIA

(RBS Yadav, Vikas Kumar, B. K. Rastogi)

The Bureau of Indian Standards under maps Sub-Committee 39.4 has assigned the job of preparing the Probabilistic Seismic Hazard Map for India. The other participating agencies are: NGRI-Hyderabad, CWPRS-Pune, GSI and CMMACS-Bangalore. Catalogue of earthquakes in India and vicinity has been prepared, seismic zones have been assigned and seismicity parameters like recurrence rates and the 'a' and 'b' values are being estimated for different regions.

ATTENUATION OF ACCELERATION RELATION FOR GUJARAT AND PROBABILISTIC AND DETERMINISTIC SEISMIC HAZARD MAPS FOR GUJARAT

(Sumer Chopra, RBS Yadav and Kapil Mohan)

An attenuation relation has been prepared for Gujarat using about 300 recorded accelerations for M 3 to 5.7 earthquakes (**Fig. 16**).

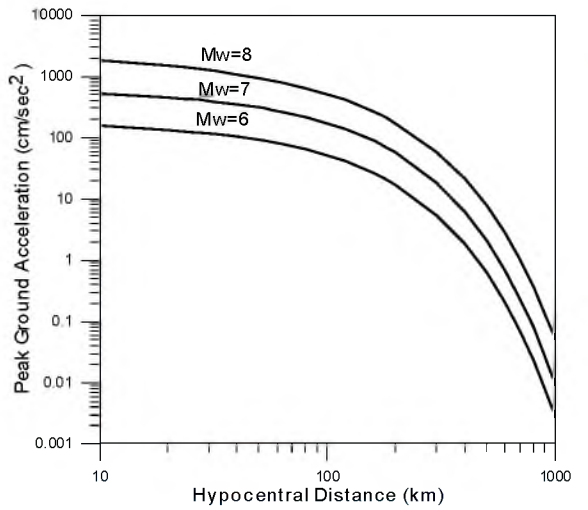


Fig. 16: Attenuation relationship estimated for Gujarat region from using hundreds of recorded acceleration for M 3 - 5.7 earthquakes.

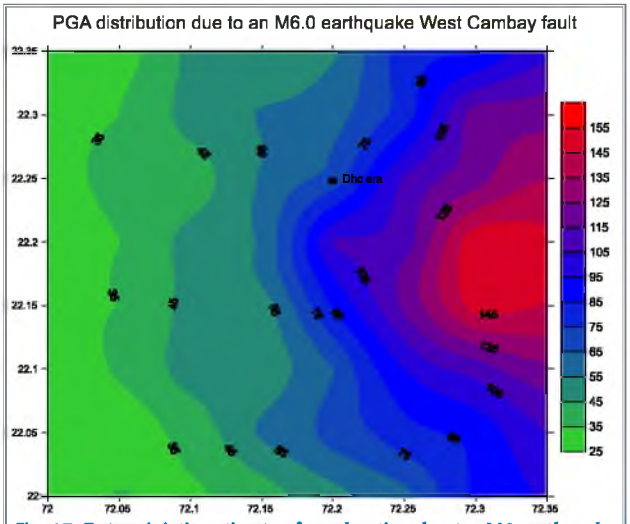


Fig. 17: Deterministic estimate of acceleration due to M6 earthquake along West Cambay in Dholera SIR.

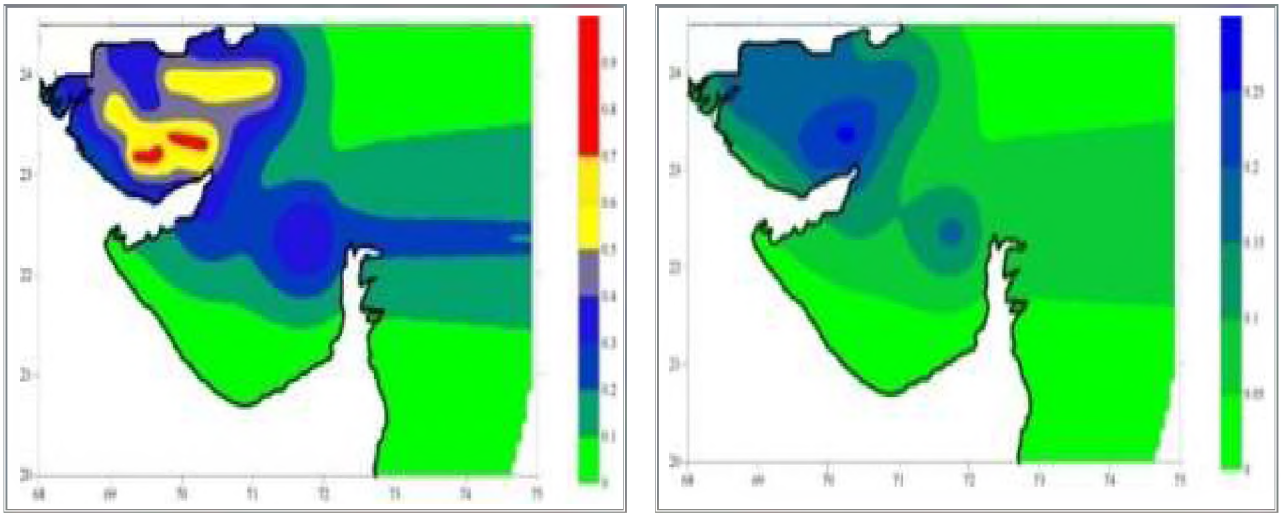


Fig. 18: Peak ground Acceleration (PGA) is estimated for 50yr return period at (a) 2% and (b) 10% probability in Gujarat taking into account the past seismicity

Deterministic seismic hazard maps for small areas have been estimated for expected magnitudes along nearby faults. One such example for Dholera area is shown in **Fig. 17.** Maps of 2% **(Fig.18 a)** and 10% probability **(Fig.18 b)** of exceedence of PGA in 50 yr for Gujarat have been prepared incorporating seismicity data, recurrence rates, 'a' and 'b' values and using Hazard Assessment program of USGS.

MICROZONATION OF GANDHINAGAR

(B.K. Rastogi, Sumer Chopra, B.Sairam, R.B.S. Yadav, Kapil Mohan, Mukesh Chauhan and Uday Bhonde)

For microzonation study of Gandhinagar soil testing has been done with 15 boreholes. It is inferred that soil does not possess liquefaction potential as water table is 80m even near Sabarmati river basin. The N values range from 2-58 down to 10m depth and high values below that. Borehole data about soil available with Guj. Engg. Res. Inst. has been compiled. It shows 1m thick silt top layer below which fine coarse grained sand layer exists and it is inferred that the Gandhinagar area has good soil with safe Bearing Capacity (SBC) = 13 t/m^2.

The preliminary results of microzonation at Gandhinagar indicate that the fundamental frequency is 0.6 Hz. It indicates about 300-350 m basin thickness using the formula, f = Vs/4H. In Gandhinagar preliminary results indicate 3 to 4 times amplifications in frequency range 1 - 2 Hz and also for 0.4 - 0. 8 Hz from actual earthquake recordings on broadband seismographs. These frequency ranges correspond to 5-20 storey buildings. The soil has strong bearing capacity even at shallow depths of a few meters.

VULNERABILITY AND LOSS ASSESSMENT OF BUILDINGS IN GANDHIDHAM

(Santosh Kumar, Hardik Patel, Pawan Kumar, A.P. Singh, Neha Jhala, Ranjana Vyas, Siddharth Dimri)

ISR carried out Rapid Visual Survey (RVS) of 20,000 buildings at Gandhidham and Adipur area. This study is done for Vulnerability and Loss Assessment due to different magnitude earthquakes. The whole program was arranged by ISR Geophysicists and staff. In this survey 200 engineering students of Tolani Polytechnic at Gandhidham and Nirma University participated. Three Professors of IIIT Hyderabad, Nirma University and Tolani Polytechnic also participated. Overall guidance was given by IIT Kanpur. A temporary office was set up at Gandhidham for one month having computer, scanner, printer and internet facility. Daily 20 teams of civil engineering students visited houses and other buildings of Gandhidham. The professors of Nirma University and IIIT, Hyderabad and scientists from ISR accompanied the parties in field. RVS of approximately 20,000 houses and buildings of Gandhidham as well as of Adipur was completed. Proforma in detail have been prepared for 20,000 buildings leaving same number of buildings of similar design and characteristics. A large number of buildings were photographed and geo-referenced by GPS. Processing of these forms is under progress.

COMPARISON OF SHEAR WAVE VELOCITY MEASURED BY MASW AND P-S LOGGING IN KANDLA AREA (B. Sairam)

Shear wave velocity (Vs) variation with depth has been obtained at two different sites in Gandhidham; one site near railway station and another at Gandhidham-Kandla road using Multichannel Analysis of Surface waves (MASW) and also by PS Logging with an objective to compare the velocity with these two methods. The velocities are found to range from 300-900m/s at a site near railway station (PS logging site Bh 13) to a depth of 37m and 120 600 m/sec at another site on Gandhidham-Kandla road (PS logging site Bh 14) to a depth of 22m (Fig. 19). The Vs obtained by MASW technique are comparable to or even better than that of PS logging. PS logging gives 1D velocity model, while MASW gives 2D Vs. Moreover, the MASW technique is less expensive and faster compared to PS logging.

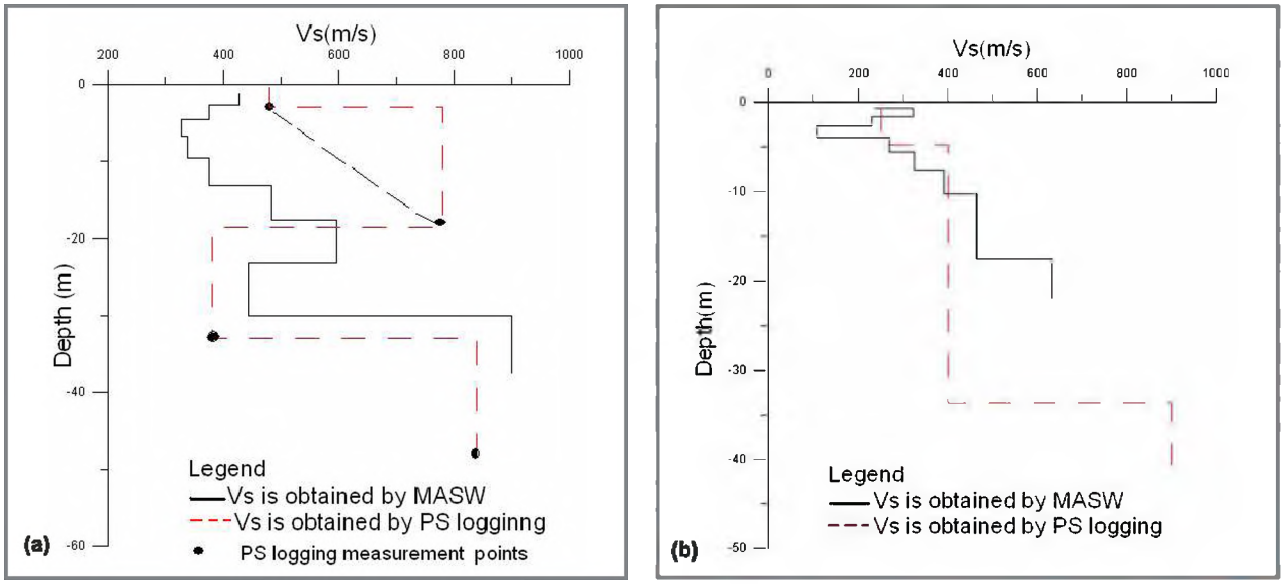


Fig. 19. Comparison of shear wave velocity (Vs) obtained by MASW and PS logging at BH-13(fig-a) and BH-14(fig-b).

Note: PS logging in BH-13 down to 18 m has two observations. The shear wave velocity at 18 m depth by PS logging is higher compared to MASW measurement. It may be due to a local small patch. Other than this anomalous velocity reaming velocities at respective depth are matching quite well.

SITE AMPLIFICATION AT ANJAR

(B.Sairam, Mukesh Chauhan, Santosh Kumar and A.P. Singh)

It was reported that Anjar old town area situated in soil was heavily damaged in comparison to the new areas on Deccan Traps during 2001 earthquake (Fig. 20). During 1956 earthquake GSI and IMD reported that old town area was totally destroyed while the surrounding areas were relatively much less damaged. The difference was attributed to site effect. The same type of damage was observed due to 1819 Kachchh earthquake at Anjar and for the first time site effect was mentioned as a cause of different damage pattern in any area. However based on noise survey by array tremor measurements Chatlain et al. reported no difference in site amplification at damaged vs. undamaged areas using the Nakamura method. As this

method has limitations, this aspect needed thorough investigation. Vs30 measurements were carried out along 12 profiles with 48 no. 4.5 Hz geophones. These measurements confirmed the observations made about different damage patterns in soil and hard rock areas. The damaged area has about 15 m thick soil cover (Fig. 21). The old residents informed existence of a lake in this area which was reclaimed for the development of the city.

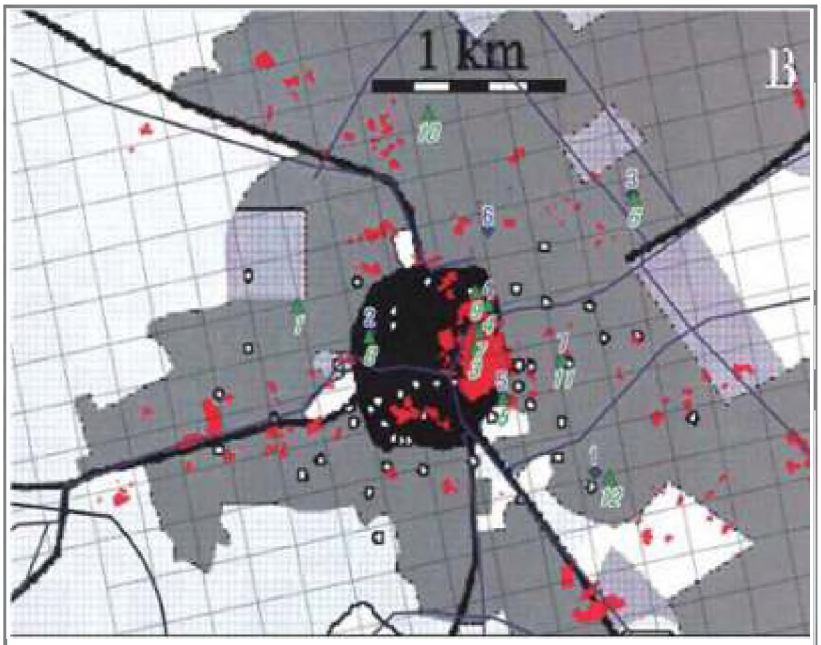
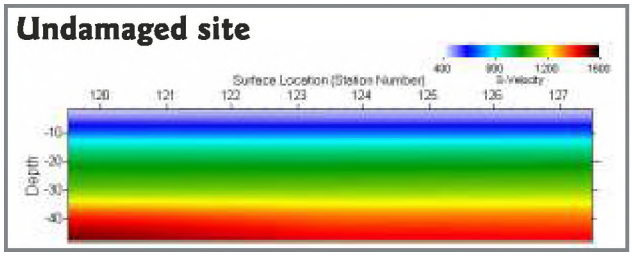


Fig. 20: Locations of seismic survey for MASW, BBS, Microtremor Survey, Geology of damaged and undamaged area at Anjar.

Micro-tremor array measurements were also carried out at 12 locations with 50m spread to test their efficacy. These measurements did not show any difference in damaged and non-damaged areas.

ISR deployed broadband seismographs at three damaged and one non-damaged sites (Fig. 20) and



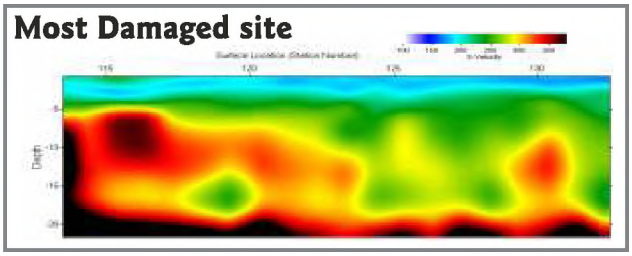
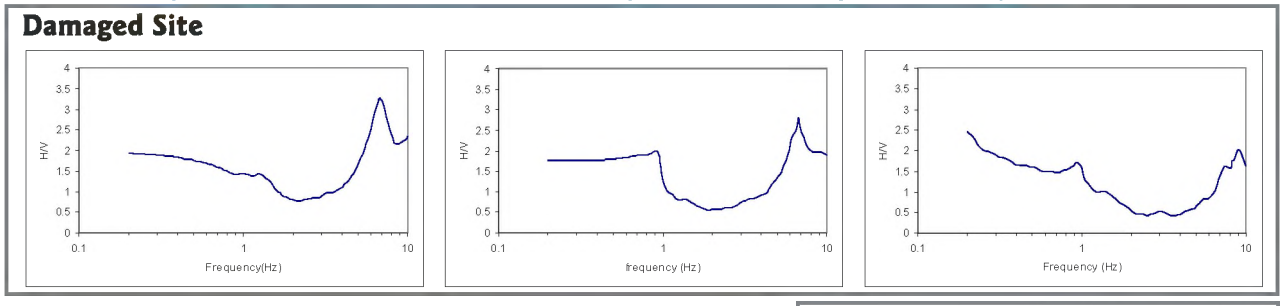


Fig. 21: Typical 2-D Vs Structure at undamaged and most damaged sites at Anjar.



estimated site response for earthquakes. Total thirty six events of Magnitude M2.5 to M4.1 have been recorded during April 2008 to Feb. 2009 originating from Kachchh region. Minimum eight events have been recorded at each site. The mathematical formulation of H/V ratio method (Nogoshi and Igarashi, 1971, Nakamura, 1989) is applied which is based on spectral ratio

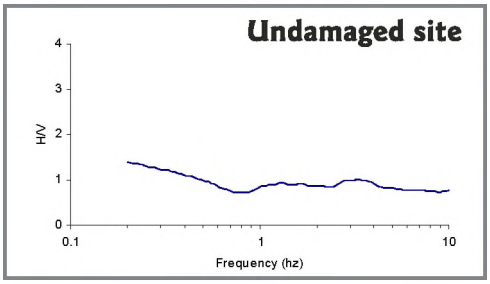


Fig. 22: Site amplification at Anjar

(Rhv) between the smoothed horizontal components and the smoothed vertical component. A time window of 10.5 sec starting 0.5 sec before S arrival is used for all components. Site amplification is computed at both damaged and undamaged sites using the local earthquakes which are recorded in BBS. We have used total thirty six earthquakes to compute site amplification. Site amplification at damaged region is 2.5-3.5 at 7 Hz while it is 1.2 at undamaged site (Fig.22). From our results it is inferred that soil covered areas are damaged more than hard rock areas.

SEISMIC MICROZONATION OF DHOLERA SPECIAL INVESTMENT REGION

(Most of the scientific staff of ISR is participating in this study)

The work of Seismic Microzonation of Dholera SIR (Special Investment Region) is sponsored by Gujarat Infrastructure Development Board. Total Area is around 600 sq. km (Fig. 23). SIR falls in Zone III of Seismic Zoning Map of India. Microzonation in SIR involves detailed study on (i) Seismic Hazard Assessment, (ii) Site Amplification, (iii) Soil Strength and (iv) Liquefaction potential.

Drilling of most of planned 100 boreholes to 30 -100m depth has been completed for geotechnical investigations and engineering properties of the soil will be assessed with detailed geotechnical investigations in the SIR region which involves drilling of 100 boreholes (BH) in the study area. The number of planned boreholes and planned 955 soil samples in this exercise may have to be reduced depending upon the ground condition. The physical tests on soil samples include water content, grain size, unit weight, Atterberg limit, while, the mechanical tests include unconfined and triaxial cyclic tests on limited no. of samples. PS logging has been carried out in 6 number of BH.

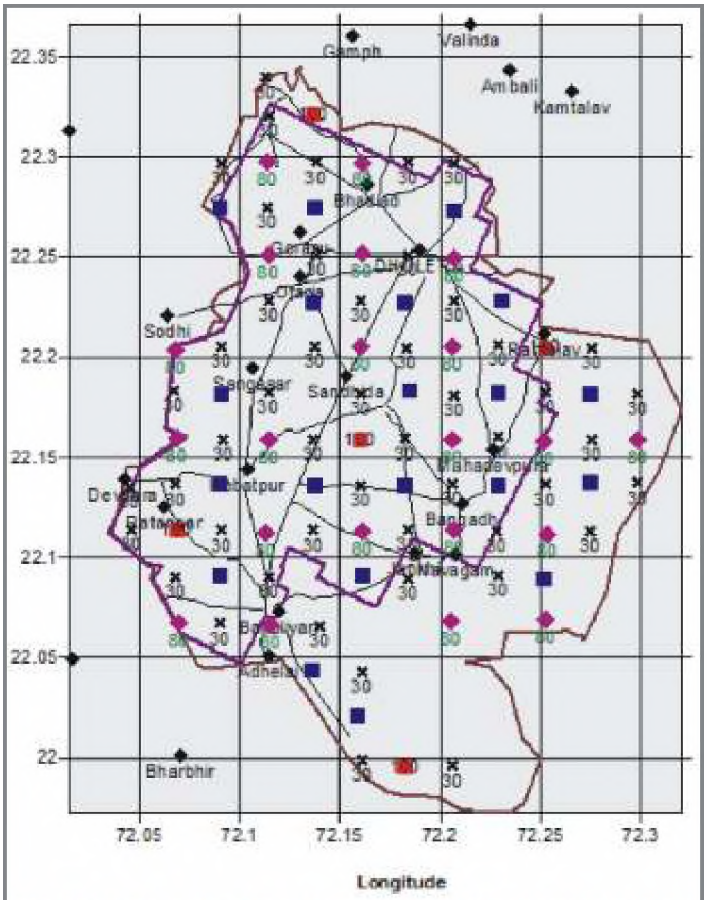


Fig. 23: Drilling sites for microzonation in Dholera SIR region. The locations of 20 boreholes of 50 m depth are shown by blue squares, those of 30 m boreholes by cross, those of 80 m depth by pink diamond and of 100 m depth by red square.

Resistivity profiles numbering 15 have been carried out for assessing the ground water depth in pre and post monsoon periods and quality of soil.

Shear wave velocity measurements to 30m depth, Vs30 measurements with 100-200m profile lengths at 13 sites have been carried out. One refraction profile for 500m length has been completed using explosive source of energy.

Site amplification studies are being carried out by recording earthquakes of magnitude ≥ 3.5 on five Broad Band Seismographs (BBS) deployed in SIR. The local microearthquakes recorded on these stations will provide information on the activeness of the faults in surrounding region of SIR. One station provides on-line/ real time data via V-SAT at Gandhinagar, whereas other stations are kept in mobile mode.

Geological, geomorphic and seismotectonic features are assessed. For the strong motion characteristics at engineering bed rock the deterministic and probabilistic Peak Ground Acceleration (PGA) maps are prepared.

GEOTECHNICAL STUDIES AT ISR

(Hardik Patel, Tarusikha Singh, Sunita Harsh, Vasu Pancholi, J. M. Suthar)

Fig. 24 shows the suspension PS logging unit procured at ISR. The Geotechnical Laboratory is equipped for: Grain size analysis (Hydrometer, Sieve analysis), Atterberg's limit,

Direct shear test, Consolidation test. The Tri-axial Cyclic Test machine is being procured.

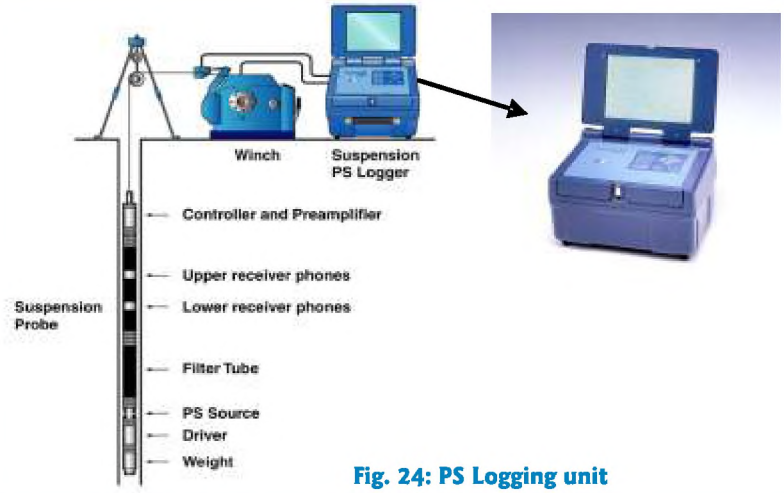


Fig. 24: PS Logging unit

MULTIPARAMETRIC GEOPHYSICAL OBSERVATORIES (MPGO)

(K.M.Rao, Dr.A.K.Gupta, M.S.B.S.Prasad, Rashmi Pradhan)

ISR is establishing three Multiparametric Observatories in Kachchh for Earthquake Prediction Research at Badargadh, Vamka and Desalpar (Fig. 23). The one at Desalpar is being sponsored by Ministry of Earth Science while the other two are sponsored by GSDMA and State Government of Gujarat. These Observatories have been equipped with BBS, SMA, GPS, and Radon detectors. Flux-gate magnetometer and Super Conducting Gravimeter have been installed at Badargadh. Water-level recorders are being installed. Three number Borehole Strain Meters have been procured and are to be installed. Overhauser magnetometer, Declination/Inclination Magnetometers, ULF & VLF Magnetometers and Helium recorders

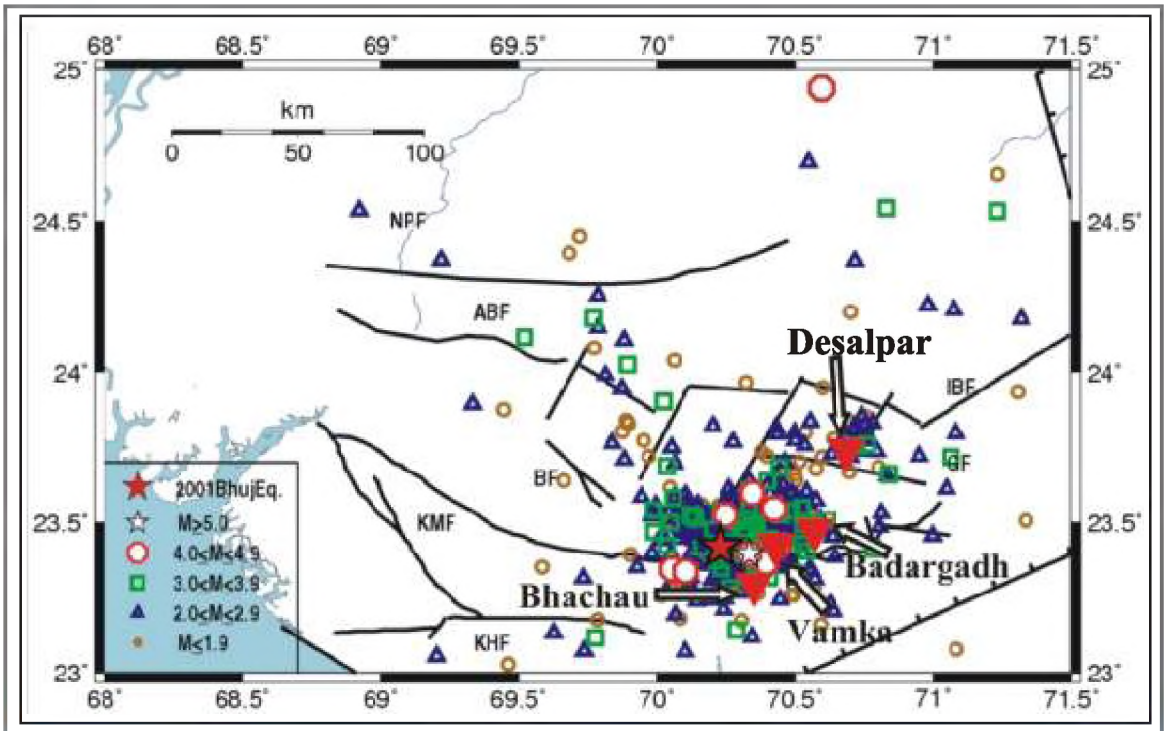


Fig. 23: Locations of three MPGO sites at Vamka, Badargadh and Desalpar as well as ERC centre at Bhachau in Kachchh.

Fig. 24. Drilling at Badargadh MPGO

are to be procured. Also ISR has started Earthquake Research Centre at Bhachau. Fig. 24 shows the drilling in progress of bore hole for water level recorder while Fig. 25 shows the type of porta-cabins erected for housing the instruments and staff.

Fig. 25. Vamka MPGO site

GEOPHYSICAL SURVEYS FOR DELINEATION OF LIMESTONE DEPOSITS IN ABDASA AND LAKHPAT TALUKA OF KACHCHH DISTRICT

(B.Sairam, Mukesh Chauhan, Uday Bhonde, Hardik Patel and N. Sharma)

Geophysical survey techniques of Seismic and GPR were applied by the Institute of Seismological Research (ISR), Gandhinagar to determine the Limestone thickness in the available and applied mining lease areas for limestone in Abdasa and Lakhpat Taluka of Kachchh District. The work was carried out as a test of applicability of geophysical techniques in mineral exploration in this region. As there is a high need of limestone for cement industries the priority areas were chosen for the investigation. We have used seismic method of MASW (Multi-channel Analysis of Surface Waves) technique and seismic refraction method as well as Ground Penetrating Radar survey with 200 MHz antenna to investigate the limestone thickness at Vagapadhar, Huradi and Mundahvay. Weathered limestone is inferred to be present to 10m depth and fresh limestone from 10 to 40m depth.

ESTIMATION OF ATTENUATION RELATION WITH SHEAR VELOCITY MEASUREMENTS IN GUJARAT STATE (Sponsored by NPCIL)

(B.Sairam and Mukesh Chauhan)

Shear wave velocity has been measured at four SMA stations (Bhachau, Kunjisar, Kharoi and Gandhinagar), and one at thermal power station, Gandhinagar. Their NERHP classes and average shear wave velocity has been given in the following table.

Location	Vs30	NERHP Class
Bhachau	729	C
Kunjisar	693	C
Kharoi	318	D
ISR, Gandhinagar	260	D
Sector-30 Gandhinagar	324	D

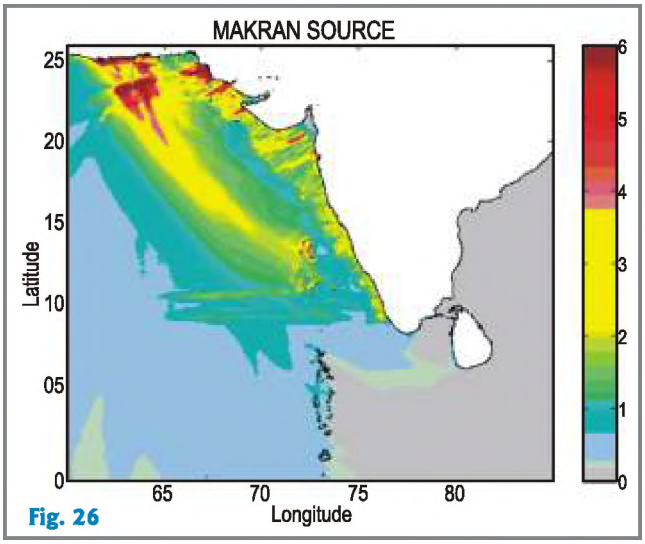


Fig. 26

TSUNAMI STUDIES

(A.P. Singh)

Directivity of Tsunami generated by M8 earthquake along Makran Coast has been modeled (Fig. 26).

Annexure - I

SCIENTIFIC STAFF

Present Scientific Staff

S.N.	Name & Designation	Research activities
1.	Sumer Chopra, Sc.D	Probabilistic and deterministic seismic hazard analysis, Strong motion seismology, site –specific response spectrum, attenuation and crustal deformation studies
2.	K.Madhusudhan Rao, Sc.B	Mantle deformation & lithospheric structure using SKS splitting, receiver Function and teleseismic tomography
3.	Dr. A.K. Gupta, Sc.B	Multi-Parametric Geophysical studies
4.	M.S.Gadhavi, ScB	TL/OSL dating, Paleoseismology, Active fault studies, SAR Inferometry, structural geology
5.	R.B.S. Yadav, Sc .B	Earthquake interaction process, seismic hazard assessment and Stochastic analysis
6.	B.Sairam, Sc. B	Source parameters and Shear-wave velocity estimation
7.	Dr. (Mrs.) Babita Sharma, Sc.B	Attenuation and Heterogeneity study
8.	M.S. B. S. Prasad, Sc.B	Electromagnetic and magnetic studies
9.	Santosh Kumar, Sc.B	Source parameter study, site amplification, strong motion seismology and Noise analysis
10.	Ajay Pratap Singh, Geophysicist	Tsunami modeling, seismic tomography, Microzonation
11.	Srichand Prajapati, Geophysicist	Crustal deformation study using GPS/Geodesy
12.	Kapil Mohan, Geophysicist	Strong motion Seismology, seismic hazard assessment and Magneto-Telluric studies
13.	Hardik Patel, Geologist	Seismotectonic investigation, GPR, GIS, PS logging, Geotechnical studies & Remote Sensing, Drilling work
14.	Dr. Uday Bhonde, Geologist	Geotechnical investigations
15.	Mukesh Chauhan, Geologist	Shear-wave estimation using Engg. Seismograph
16.	Sandeep Kumar Aggarwal, Geophysicist	Seismic data analysis
17.	R.K. Singh, Geophysicist	Geophysical (Gravity, Resistivity and Electrical) studies
18.	Siddharth Dimri, Geologist	GIS, not cana hut & Remote sensing
19.	Rakesh Kumar Dumka, Geologist	GPS studies
20.	Mrs. Rashmi Pradhan,Geologist	Multi-Parametric Geophysical studies, Gravimetry
21.	Dr.(Ms) Pallabee Choudhury, RA	GPS data processing and analysis
22.	Dr. (Mrs.) Bornali Sharma, Geophysicist	Gravimetry
23.	Dr. (Mrs) Sunita Harsh,Chemist	Geotechnical Investigations
24.	Vasu Pancholi	Geotechnical Investigations

Scientific Assisstants

1. Arvind Valand, JSA
2. Jaydev Mangaldas Suthar, SSA

Technical Officer

1. Ganpat Parmar, BE
2. Jignesh B.Patel,BE (Computer Sc.)

Technical Assistant

1 Gaurang K. Bhakhariya, BSc
2 Dilip Chaudhari, Dipl. Electrical
3. Ankit Jadav, Dipl. Electrical
4. Bharat Kumar D. Mevada
5. Jay Pandit, B.Com.
6. Sandip Parmar, Dipl.Electrical
7. Nirav Patel, Dipl. Electrical
8. Sandip Prajapati, Dipl. Electronic & Commu.
9. Tejendra Vaghela, Dipl. Electrical
10. Vijaysinh Vaghela, Dipl. Electrical
11. Dharmendra Solanki, Dipl. Electrical
12. Jignesh P. Patel, BE
13. Gaurav Parmar, Advance Dipl. in Medical
14. Paresh A. Paradiya, Dipl. Electronic & Commu.
15. Mahesh Valekar, Dipl Elect.

List of Jr Res Fellows (JRF)

1. Vikas Kumar (M.Sc., Phys.),
2. Ms. Neha Jhala (M.Sc., Phys),
3. Sameer Tiwari (M.Sc. Geol),
4. Ms. Falguni Bhattacharjee (M.Sc. Geol)
5. Nagabhushan Rao (M.Sc., Phys)
6. Ms. Taru Shikha Singh (M.Sc. Geol)
7. Miss Vandana Patel (M.Sc., Phys)
8. Kishansinh Zala (M.Sc., Phys)
9. Siddharth Pandya, (M.Sc., Phys)
10. Gagan Bhatia (M.Sc. Electronics)
11. Tarak Shah (M.Sc. Phys)
12. Dhruvkumar N. Rajyaguru (M. Sc. Phys.)
13. Girish B. Patel (M. Sc. Phys.)
14. Mehul K. Jagad (M. Sc. Phys.)

Administrative Staff:

1. Mrs. Bharti Vora, AO
2. S.R. Shukla, Ac.O
3. G.C. Bhavsar, SPO (transferred on 3.3.2009)
4. Mrs. Aruna Leuva, Jr. Ac.O.
5. Sharad Thakkar, Accountant
6. Miss Daxa Parmar, Librarian
7. Mrs. Seema Rao, Computer Operator
8. Vimal Bidholiya, Computer Operator
9. Miss Parulata, Computer Operator
9. Manish Jadav, Jr. Clerk
10. P.M. Shrimali, Sr. Clerk (reverted back to the parent Department on 4.1. 2009)

Visiting Professor:

Dr. Roger Bilham, Univ. Colorado

Consultants:

1. Dr. S.K. Biswas, Ex-Director KDMIPE, ONGC,
2. Sri Sitharamaiah, Ex-Sr. Geophysicist, GWRDC
3. Sri V.M Maru, Honorary Geophysicist

List of Scientific staff that resigned from ISR during this year

1. K.M. Bhatt, Geophysicist
   (Resigned with effect from 29.4.2008)
2. Pawan Kumar, Geophysicist
   (Resigned with effect from 30.6.2008)
3. Mr. Sanjay Kumar, Geophysicist
   (Resigned with effect from 2.9.2008)
4. Dr. (Mrs.) Bornali Sharma, Geophysicist
   (Resigned with effect from 5.3.2009)
5. Rudradeb Bhattacharya, Geologist
   (Resigned with effect from 7.12.2008)
6. Ms. Ranjna Vyas, JRF
   (Resigned with effect from 29.8.2008)
7. Hemant Umbrani, JRF
   (Resigned with effect from 20.9.2008)

Annexure 2

Training of ISR scientists and Technicians outside ISR

i. M.S. Gadhavi, International School on LiDAR Technology, from 31st March to 4 April, 2008 at IIT, Kanpur.

ii. Kapil Mohan, MSBS Prasad, Vikas and Ganpat Parmar, Training on resistivity imaging, Magneto-telluric and Time Domain Electro-Magnetic systems, at NGRI, Hyderabad during 18 Aug - 17 Sep 2008.

iii. A.P. Singh, RBS Yadav, Vikas and Jignesh Patel: Training on Assessment of Seismic Vulnerability of Buildings, IIIT, Hyderabad, during 20th -26th November, 2008

iv. M. S. Gadhavi and Miss Falguni Bhattacharjee, 'Radiation Safety Aspects of Nucleonic Gauges, NG-77', from 25th August to 2nd September 2008 at BARC, Mumbai.

v. MSBS Prasad, Neha Jhala, Bharat Mevada and Gourang Bhakaria, Training on Magnetometers at Magnetic Observatory of IIG at Rajkot, during 10th - 15th November 2008

vi. Miss Neha Jhala, RISAT (remote sensing) Utilization Plan Training at ISRO, Ahmedabad, 1-12 December 2008.

vii. Miss Pallabee Choudhury, Training on GPS interpretation, at NGRI Hyderabad, during October 2008, March 2009 and GAMIT/GLOBK advanced user's workshop at C-MMACS, Bangalore during March 7-10, 2009.

viii. R. K. Singh, Sameer Tiwari and Miss Rashmi Pradhan, Training on gravity surveys and interpretation, at NGRI during 26 Dec 2008- 9 Jan 2009.

ix. Nagbhushan Rao, Training on Lg tomography and moment-tensor analysis with regional data, NGRI

x. A.P. Singh Tsunami Mitigation and Management at Gujarat Institute of Disaster Management (GIDM), SPIPA Campus, Ahmedabad during 05-07 January 2009

xi. Kapil Mohan, Babita Sharma, RBS Yadav, A. P. Singh, Sumer Chopra Earthquake Mitigation & Management at SPIPA, Ahmedabad, during 02-06 March, 2009.

Training of ISR Scientists and Technicians at ISR

i. Introduction to Superconducting Gravimeter by Dr. Jurgen Neumeyer, 12 Mar 2007.

ii. Mr. Giuliano, Instrumentation Engineer, Refraction Techonology Inc, USA, 4/03/08

iii. Training on ' Operation & Maintenance of REFTEK DAS and REFTEK utilities for handling digital seismic data' by Mr. Ian Billings, Senior Engineer, Refraction Techonology Inc, USA at ISR campus, Gandhinagar during 23 - 27 June 2008.

iv. Basics of electronic instruments by VM Maru, Ex-Scientist, NGRI, June 17 - July 7, 2008.

v. Training on Magnetotelluric system (ADU07) by Dr. Bernhard of Metronix, Germany, 4 - 9 August 2008.

vi. Training on 'Resistivity Imaging System (Syscal Pro switch-72) by Mr. L.D. Mohapatra of Paras Equipments & Engineering Pvt. Ltd., New Delhi at ISR new campus, 21 to 24 October 2008.

vii. 'Gravimetry data acquisition & analysis' by Dr. Richard Lachapelle of Scintrex Ltd, Canada, 6 - 10 October 2008.

viii. A training program on GPS Installation and use of the spider software, Mr. Bhatt and Mr. Vikram from M/S Elcome New Delhi, the representative of Leica Geosystem, Switzerland at ISR, 22 to 23 Oct 2008.

ix. A lecture on 'Gravity meters' by CJM (Chris) Nind, President and CEO of Scintrex Ltd, Canada, 21 November 2008.

x. Use of Total Station for surveying Mr. Adesh Dhar, from M/S Elcome New Delhi, the representative of Leica Geosystem, Switzerland at ISR, 16 Jan 2009.

xi Gravity surveys with CG-5 by Peter Mistry of Scintrex Ltd, Canada, 19 Jan 2009.

xii. Time Domain Electromagnetic Survey by Dr. Fleming of M/S Zonge, USA, 19 Jan 2009

xiii. Under World Bank Funding GSDMA assigned the work of microzonation of Anjar-Gandhidham-Kandla area to Oyo International Corporation. ISR was associated with this work. As a knowledge transfer component of this project, Oyo Intl. Corporation organized a Training Program on "Introduction to Seismic Microzonation with Special Reference to Gandhidham" for seven days from 26th March, 2008 to 1st April, 2008.

List of non-ISR Participants

Dr. I.D.Gupta, CWPRS, Pune, Dr. Sushil Gupta, RMSI, Noida

Dr. Pradeep Kumar, IIIT, Hyderabad, Dr. Indra Prakash, GSI, Gandhinagar

ISR Participants

1. Sumer Chopra	2. B Sairam	3. Rakesh Dumka	4. Pawan Kumar
5. A. P. Singh	6. Hardik Patel	7. Mukesh Chauhan	8. Kapil Mohan
9. Santosh Kumar	10. Siddharth Dimri	11. Dr. Uday Bhonde	12. Dr. Arun Gupta
13. Vikas Kumar	14. Nagbhushan Rao	15. Miss. Ranjana Vyas	16. Miss Neha Jhala

Training Schedule

1st Day (Shukyo Segawa)

26, March, Wednesday	am	Outline of Seismic Microzonation: Why, How and What?
	pm	Seismic sources
		Attenuation
		Green's function method
		Probabilistic/Deterministic
		Seismic observation, seismic records

2nd Day (Michio Morino)

27, March, Thursday	am	Geology for microzonation
		Deep structure
		Active Fault mapping
	pm	Trenching
		Dating
		source parameters setting

3rd Day **(Takaho Kita; geophysicist working at Istanbul)**

28, March, Friday	am	Geophysical prospecting
		PS-logging,
		Vs - N value
	pm	Seismic prospecting (MASW, ReMi etc.)
		Microtremor (Array, H/V),

4th Day **(Fumio Kaneko, Koichi Hasegawa)**

31, March, Monday	am	Soil Modeling (structure and properties)
		Geology, topography, geomorphology, geophysical data
		Vs - N value
	pm	Soil amplification
		Application of geomorphology
		AVS30 - Amplification
		H/V interpretation
		response analysis
		deformation characters (non linearity)
		predominant frequencies

5th Day **(Fumio Kaneko, Koichi Hasegawa)**

1, April, Tuesday	am	Collateral hazards
		liquefaction, slope failure, tsunami etc.
		Total verification by historical events
		Damage assessment, disaster management
	pm	Discussion

Comments:

The training was extremely useful. The participants came to know various aspects of microzonation of the work done in Gandhidham. The methodology for preparation of probabilistic hazard map was explained by S. Segawa. He has also installed the USGS program used by him at ISR. T. Kita explained in detail the geophysical surveys by engineering seismograph and micro-tremor survey. Two days tutorial by him on these topics gave good practical experience to the participants. They experienced different software used for different methods of surveys like triangular array, L-array and linear profile. F. Kaneko explained assessment of seismic hazard risk through source identification, path effects and site response assessment.

Excerpts of lecture by F. Kaneko for Review of Seismic Microzonation in India.

F. Kaneko in a lecture expressed that in the country the microzonation work done by various organizations is not up to the mark. He expressed his views on microzonation work in India by quoting examples of Jabalpur, Guwahati, Dehradun, Delhi, Madras, Ahmedabad, Gandhinagar, Bangalore etc. and also mentioned that very scanty reports are available for a few sites and no information for most of them. He is of the opinion that only in one or two places multiphased aspects of microzonation have been carried out. The important aspect of geotechnical investigation is missing. By reviewing the available reports he gave his comments on status of seismological work, study of faults, geology, soils, response analysis, amplification and collateral hazards (Table below), which are important aspects in carrying out seismic microzonation work in various organizations in India. He felt that the stage of work for seismic microzonation in India is comparable to 1970's and 1980's state of Japan. He ranked the status of work and expertise under Lower and Middle level and his suggestion on improving this included multiple and total co-ordination among scientists, engineers and government authorities.

Subject area	Status	Scope of improvement
Seismology	Almost OK	Seismic Observation. Historical Seismicity.
Fault study	Improving	Interpretation of the available data. Mutual understanding and collaboration.
Geology	Mostly OK	Wider publication of available data. Mutual Understanding and collaboration.
Soil	To be improved	Data on dynamic properties of soils. Data accuracy and its resolution.
Response Analysis	To be improved	Practical understanding. Mutual understanding.
Amplification	Must be improved	Technical understanding.
Collateral Hazards	To be improved	Raw data generation and its interpretation.

TRAINING TO STUDENTS

M. Tech. students in Computational Seismology

The three M.Tech students who carried out their studies during 09-08-07 to 17-05-08, submitted their thesis as given below:

Rajiv Lochan Bikash Roy (2008).3-D Seismic Imaging of the Kachchh Region from P and S-Wave Travel times of 2001 Bhuj Earthquake Aftershocks Date: 16-05-08

Mridul Chandra Das (2008).Seismic Characterization and Probabilistic Assessment of Earthquake Hazard in North-East India and Adjoining Region.

Moheswar Borah (2008).Site Specific Response Estimation of Gujarat Using H/V Technique.

The three M. Tech students currently pursuing their dissertation during July 15, 2008 May 31, 2009

1. Jwngsar Brahma (2009). Multi-channel Analysis of Surface Wave (MASW) Technique and Its Application.
2. Ketan Singha Roy (2009). Seismic Refraction Travel-time Tomography and Its Application.
3. Chintha Naresh (2009). Shallow Seismics in Earthquake Engineering

M. Sc. dissertation

Two M.Sc students of Department of Geology, M. G. Science Institute, Ahmedabad did their M.Sc dissertation on GIS at ISR.

B.Tech project:

Four B.Tech students of Department of Civil Engineering. Nirma University carried out project work on "Assessment of Seismic Vulnerability of RCC and Masonry Buildings and its Application: A Case Study of Gandhidham City".

Name of the students are as given below:

(1) Abhishek Yadav
(2) Adil Sheikh
(3) Ashish Dwivedi
(4) Akshay Jain

B.Tech dissertation:

Two B.Tech, students from Institute of Petroleum Technology, Pandit Deen Dayal Petroleum University, carried out B.Tech dissertation. Names and topics are given below:\

(1) Kumar Abhinav; Geology and petroliferous formations of Cambay Basin and interpretation of seismic data.
(2) Jadeja Girirajsinh; Geology of Kachchh and interpretation of bore log data.

Annexure - 3

Awards /Recognitions

Dr. B.K. Rastogi, nominated as member of the BIS Committee for Draft Revision of IS 4967:1968 Recommendations for Seismic Instrumentation for River Valley Projects.

Visits Abroad:

Dr. (Mrs.) Babita Sharma (Tokyo, Japan, Nov. 24-28, 2008) attended and presented a paper in Asian Seismological Commission's Meeting.

Dr. B.K. Rastogi, Sri K.M. Rao and Dr. Arun Kumar Gupta (St. Louis and San Diego, USA) for training on operation, processing of data and data interpretation of Super Conducting Gravimeter.

Annexure - 4

Research Paper Published in Scientific Citation Index Journals

1. Chopra, Sumer K. Madhusudhan Rao, B. Sairam, Santosh Kumar, A.K. Gupta, Hardik Patel, M.S. Gadhavi and B.K.Rastogi (2008), Earthquake Swarm Activities after Rains in Peninsular India and a Case Study from Jamnagar, *J. Geol. Soc. In.*, 72, 245-252.
2. Jaiswal, R.K., B.K. Rastogi, Tad Murthy (2008). Tsunamigenic sources in the Indian Ocean, J. Science of Tsunami Hazards, 27(2), 32-50.
3. Yadav R.B.S., J.N. Tripathi, B.K. Rastogi and S. Chopra (2008), Probabilistic assessment of earthquake hazard in Gujarat and adjoining region, India, Pure and Applied Geophysics , 165, 1813 1833.
4. Sharma, Babita, Arun K. Gupta, D. Kameswari Devi, Dinesh Kumar, S.S.Teotia and B. K. Rastogi (2008). Attenuation of high frequency seismic waves in Kachchh Region, Gujarat, India, Bull. Seism. Soc. Am. 98 (5), 2325-2340.
5. S. Chopra, R. B. S. Yadav, Hardik Patel, Santosh Kumar, K. M. Rao, B. K. Rastogi, Abdul Hameed and Sanjay Srivastava, (2008) The Gujarat (India) Seismic Network, Seismol. Res. Lett. 79 (6), 806-815.
6. Bhatt, Kaushalendra Mangal, Andreas Hordt and Santosh Kumar (2008). Seismicity analysis of the Kachchh aftershock zone and tectonic implication for 26 Jan 2001 Bhuj earthquake, Tectonophysics, 465, 75-83.
7. K. Kumar, M. Pant & Rakesh Dumka, comparisons of Digital Surface Modeling Techniques for sloping hill terrain using GPS data, International Journal of Modeling & Simulation on, 2008-Vol. 28, No. 4.

Research Paper Published in Non-Scientific Citation Index Journals

1. Shanker, D., and Yadav R.B.S. (2008) Probable evidence for periodicities in seismicity in Gujarat and adjoining region, India: implications on future earthquake hazard, 14th World Conference on Earthquake Engineering, Beijing, China, Oct. 12-17.
2. K. Mohan, A. Joshi and R. C. Patel (2008) The assessment of seismic hazard in two seismically active regions in Himalayas using deterministic approach J. Geophys. 12(3), 97-107
3. Singh A.P., Uday Bhonde, B.K.Rastogi and R.K.Jaiswal (2008). Possible Inundation map of Coastal areas of Gujarat with a Tsunamigenic Earthquake, Special issue of J. Geoscience, Volume 61 (2 & 3),2008 under thematic issue of Recent trends and Advancements in Geophysics.
4. Jaiswal R.K. and B.K.Rastogi (2008), Energy realese and strain recovery in Indian Earthquake sequences is accepted for final publication in Special issue of J. Indian Minerals, Volume 61 (2 & 3), 2008 under thematic issue of Recent trends and advancements in Geophysics.
5. Jaiswal, R.K. and B.K. Rastogi (2008). Past Tsunamis in the Arabian Sea and future possibilities, Special issue of J. Geoscience, Volume 61 (2 & 3), 2008 under thematic issue of Recent trends and advancements in Geophysics
6. Michio Morino, Malik J. N., Gadhavi M S, Khalid Ansari, Chandrashekhar Bhuiyan, Prashant Mishra and Fumio Kaneko (2008). Active Low-Angle Reverse Fault and Wide Quaternary Deformation Identified in Jhura Trench across Kachchh Mainland Fault, Kachchh, Gujarat, India, *Journal of Active Fault Research, Japan, 29, 71-77.*
7. Babita Sharma, S.S.Teotia amd Dinesh Kumar (Oct, 2008), Site Amplification Study in the Koyna Region by using Coda Waves, J. Indian Geophysical Union.

Research Papers Communicated (SCI)

1. Sharma, Babita, S. S. Teotia and Dinesh Kumar (2009). Attenuation of P and S waves in the Chamoli region, Himalaya, India., PAGEOPH (Accepted).
2. Yadav, R.B.S., B.K. Rastogi, M.C. Das and S. Chopra (2008) On the homogeneity and completeness of earthquake catalogue in northeast India and adjoining region, Seismological Research Letters (communicated)
3. Yadav R.B.S., D. Shanker, B. K. Rastogi and M. C. Das (2008), Probabilities for the occurrences of medium to large earthquakes in Northeast India and adjoining region, *Natrural Hazard*, (under review)
4. Yadav R.B.S., D. Shanker and S. Chopra, An application of regional time and magnitude predictable model for long-term earthquake prediction in the vicinity of October 8, 2005 Kashmir Himalaya earthquake, Natural Hazard, 2008 (under review)
5. Yadav R.B.S., J. N. Tripathi, B. K. Rastogi, M. C. Das and S. Chopra, Probabilistic assessment of earthquake hazard in Northeast India and adjoining region, Pure and Applied Geophysics, 2008 (communicated)
6. B. Sharma, E. Carcolé, A. Ugalde and B. K. Rastogi (2008) Spatial distribution of scatterers in the crust of Kachchh region (western India) by inversion analysis of coda envelopes, Geophys. J. Intl. (communicated).

Technical Reports

1. Rastogi, B.K. (2008). Surat earthquake of M3.5 of May 20. 2008 and implications, ISR Tech Rep. 16.
2. Sameer Tiwari, R.K.Singh, and Sita Ramayya (2008). Report on Resistivity Survey Carried out at Proposed Sites for Multi Purpose Geophysical Observatory Kachchh Dist, Gujarat .ISR Technical Report No.17.
3. B. K. Rastogi, Hardik Patel and Sumer Chopra (2008). Preliminary Investigation report on Seismic, Geophysical and Geotechnical investigations of Mundra LNG Terminal site, ISR-2008-18.
4. M. S. Gadhavi, B. Sairam, Rakesh Dumka. and Hardik Patel (2008). Delineation of fault features using MASW technique in Kachchh region, Gujarat, ISR Technical Report No.18A.
5. B. K. Rastogi, Uday Bhonde, Sumer Chopra (2008). Preliminary Investigation Report for the Seismic Microzonation of Dholera, Ahmedabad District for Special Investment Region, ISR-2008-19, pp. 46.
6. B.K. Rastogi, A.P. Singh, Sumer Chopra, Kapil Mohan and Hardik Patel (2008). Preliminary report on assessment of Vulnerability of installation Near Gujarat Coast Vis-à-Vis Seismic Disturbances, ISR-2008-20, pp 49.
7. Sameer Tiwari and R. K. Singh (2008). Report on Resistivity Survey (Geoelectrical Sounding) In Special Investment Region Dholera Area Ahmedabad Dist, Gujarat. ISR-2008-21.
8. M. Morino, J. N. Malik, H. Patel, Gadhavi M. S., Taru Shikha Singh, Falguni Bhattacharjee and S. K. Biswas (2008). Active fault survey around Mundra, Southern Kachchh, Gujarat: LNG storage terminal GSPCL. ISR-2008-22.
9. B. K. Rastogi, Sumer Chopra and Hardik Patel (2008). Preliminary Report on blast sounds in southern Kachchh and in Jamnagar in March and December 2008, ISR Technical Report No. 23.

Abstracts/ papers presented in seminars

1. Rastogi B. K. and M. S. Gadhvi (ISR), J. N. Malik (IITk), A.K. Tyagi and A.K. Singhvi (PRL), M. Morino (Oyo Intl. Corpn.) "Paleoseismic studies in Kachchh" Golden Jubilee Seminar of Geological Society of India at NGRI, Hyderabad during 25 and 26 June 2008.
2. *Arun Gupta and Avadh Ram, Application of chaotic system for the analysis of Himalayan Earthquakes, 2nd International Conference on "Nonlinear Dynamics in Geosciences" Heraklion, Crete, Greece, July 1-6, 2008
3. Babita Sharma, Eduard Carcole, Arantza Ugalde and B.K.Rastogi, Coda Envelope Inversion and Deep Crustal Heterogeneity in the Kachchh region, India, Asian Seismological Commission, from 24th to 27th November, 2008.
4. D. Shanker, R.B.S. Yadav and H.N. Singh, "Occurrence probability and earthquake forecast in Hindukush-Pamir Himalaya and vicinity", 7th General Assembly of Asian and Seismological Commission and Seismological Society of Japan, 2008 fall meeting, November 24-27, 2008.

* Abstract accepted for publication but did not attend the seminar.

5. Jhala, Neha, Rudradeb Bhattacharyya, Mahendrasinh Gadhavi, K. M. Sreejith, T. J. Majumadar, B. K. Rastogi "Deployment of small and passive corner reflectors for geometric correction of ENVISAT Fine Mode ASAR data a case study in Kachchh district, Gujarat" for in the National Symposium on 'Advances in Remote Sensing Technology and Applications with Special Emphasis on Microwave Remote Sensing', held at Nirma University, Ahmedabad, Dec. 18-20, 2008.
6. Rakesh Dumka, "20 ka history of selected low-lying humid and high arid valleys of the Indian Himalaya : Variation in inception and duration of the events." In the theme of "Tectonics & Climate" during the 3rd international conference of LIMPACS at Chandigadh during 6 - 9 March, 2009.

Visitors and their seminar talks

1. Prof. Srikrishna Singh, Unam University, Mexico, Prediction of strong motion in India 10/06/2008
2. Dr. K.S. Siva Subramanian, Asst. Vice President-ANR, RMSI, Hyderabad, Vulnerability assessment from satellite data Dt: 02/07/2008
3. Dr. G.V. Ramana, Associate Professor-IITD, Soil amplification and use of Shake programme Dt.: 07/07/008
4. Dr. Jawahar, GSI, Well logging techniques: with especial emphasis on PS logging Dt.: 09/07/2008
5. Dr. V.P. Dimri, NGRI, Tsunami propagation and inundation modeling for west and east coast of India due to Tsunamigenic earthquakes. 29/11/2008
6. Dr. Tad Murty, Development of Tsunami Early-Warning System in India and Canada, 29/11/2007

Institute Seminars

1. Rajiv Lochan Bikash Roy (2008).3-D Seismic Imaging of the Kachchh Region from P and S-Wave Travel times of 2001 Bhuj Earthquake Aftershocks, 16-05-08
2. Mridul Chandra Das (2008).Seismic Characterization and Probabilistic Assessment of Earthquake Hazard in North-East India and Adjoining Region,
3. B.K. Rastogi, Faulting Process, 23 Apr 2008
4. B.K. Rastogi, Earthquake Interactions, 30 Apr 2008
5. B.K. Rastogi, Ground Motions
6. B.K. Rastogi, Site Response
7. B.K. Rastogi, Seismic Hazard
8. B.K. Rastogi, Earthquake Prediction
9. B.K. Rastogi, The Physics of earthquakes, 17 Dec 2008.
10. R.K. Singh, Fundamental of E.M and M.T. techniques 18 Dec 2008,
11. R.K. Singh, Gravity surveys and interpretation of field data through Geosoft. 17 Jan 2009,
12. R.K. Singh, Presentation of gravity data of Kachchh area along Bhachau- Chobari section, 3 Mar 2009,
13. R.K. Singh, Gravity prospecting and its use to trainees of Gujarat Institute of Disaster Management, 3 Mar 2009,
14. R.K. Singh, Applied geophysics for Geologists and Seismologists, 21 Mar2009

Special / Invited Lectures

1. B.K. Rastogi, "Natural Disasters: Risk, Mitigation, In: Training Program on Planet Earth, Science City, Ahmedabad, 10 May 2008.
2. B.K. Rastogi, Keynote address "Earthquake Risk in Himalaya: some suggestions for mitigation", National Conference on Mass Instability and Earthquake Risk Management in Mountainous Regions: Challenges, Lessons Learnt and Future Strategy, Dehradun, 27th 28th June, 2008.
3. B.K. Rastogi, Natural Hazards in "Outreach campaign for understanding planet Earth western region master resources person' training program" Gujarat Council of Science City, Ahmedabad, 4th to 6th December, 2008
4. B.K. Rastogi, Physical Research Laboratory, Colloquium Series Lecture, Physics of earthquakes, 17 Dec 2008.
5. B.K.Rastogi, Seismic Hazard Investigations in Gujarat, Lecture Series on "Environmental Problems and Mitigation", Institute of Science and Technology for Advanced Studies & Research (ISTAR), Vallabh Vidhyanagar, Anand, 23 December, 2008.
6. B. K. Rastogi, Two lectures: 1. Tsunami occurrence and their propagation, 2. Tsunami early warning system in the training course on "Tsunami Mitigation and Management" organized by Gujarat Institute of Disaster Management (GIDM) at Sardar Patel Institute of Public Administration (SPIPA), Ahmedbad, 6th January, 2009.
7. B. K. Rastogi, Geophysical exploration for oil: An Introduction, Distinguished Guest Lecture, PD Petroleum University, Gandhinagar, 18 Feb 2009.

Annexure 5

Projects:

Project	Sponsoring Agency	Period	Value Rs. L
Paleoseismology in Kutch	GoG	Apr.2007-Mar.2010	300.00
Microzonation in Gandhinagar and a few towns in Kutch like Gandhidham, Bhachau and Rapar	GoG	Apr.2007-Mar.2010	300.00
Seismicity Research & Applications in Gujarat	MoES. GoI	Feb.2006-Mar 2009	256.91
Crustal Deformation in Kutch and Narmada	MoES. GoI	Apr 2007- Mar 2010	65.00
Assessment of Vulnerability of Installations near Gujarat Coast vis-à-vis Seismic Disturbances	MoES. GoI	April 2009 – March 2012	153.84
Surface Deformation in Wagad area of Kutch using InSAR	SAC, ISRO	Apr. 2008-Mar.2011	19.00
Vs30 measurements at sites of SMA stations, Power Distribution hubs etc.	NPCIL	Jan-Dec 2009	12.00
Rapid Visual Survey of Buildings for Vulnerability & Loss Analysis at Gandhidham	GSDMA	Apr-July 2008	8.65
Site Response at Anjar	GSDMA	June – July 2008	2.17
Seismic Study for Dholera Special Investment Region	GIDB	Dec. 2008- Nov 2009	125.00
Seismotectonic Study around Mundra	GSPC	Oct 2008-Sep 2009	130.00
Scenario strong motion estimation for Gujarat-India	DST-GoG NCREE Govt of Taiwan	March – 2009 March – 2012	41.00
		Total :	**1413.57**

Annexure 6

BUDGET FOR 2008-09

A) Non-recurring

*World Bank loan for ISR Building	Rs.	20.00 Crore
*World Bank Loan for Instruments	Rs.	21.00 Crore
Corpus fund (Fixed deposit)	Rs.	16.00 Crore
	Total Rs.	**57.00 Crore**

*(Continued from last year)

B) Recurring

Agency	Amount Rs. In lakhs	Title
MoES. - GoI	50.00	Seismological Research and Applications in Gujarat
MoES. - GoI	15.00	GPS studies
GoG	220.00	Establishment, Running of network, Paleoseismology and Microzonation Studies
GoG	72.00	Corpus Fund Interest
GSDMA	2.17	Site Response at Anjar
GSDMA	8.65	Vulnerability of Buildings in Gandhidham
ISRO	8.00	InSAR studies at Wagad
Total :	**375.82**	

Books and Journals:

The amount spent in books and journals is as follows:

For the year 2006-07.....Rs. 8.41 lakhs

For the year 2007-08.....Rs. 19.15 lakhs

For the year 2008-09.....Rs. 17.78 lakhs

Details of instruments of ISR:

Sr No	Name	Model No	Manufacturer	QTY	Cost lacs (Rs)	Funding Agency
Instruments procured during 2006 and 2007.						
1	Broad Band Seismometer	CMG-3T 120 sec	GURALP, U.K	48	93.70 196.60 27.85	19-ADB, 25-WB, 4-GOI
2	Very Broad Band Seismometer	CMG-3T 360 sec	GURALP, U.K	3	22.80	3-WB
3	Digital Acquisition System for BBS	REFTEK DAS-130	REFTEK, U.S.A	29	123.40 21.14	25-WB, 4-GOI
4	Digital Acquisition System for BBS	DM-24	GURALP, U.K	22	75.30 20.50	19-ADB, 3-WB
5	Strong Motion Accelerographs	GSR-18	GEOSIG, Switzerland	46	94.70 19.40	40-ADB, 6-WB
6	Strong Motion Accelerographs	ETNA	Kinemetrics, USA	4	15.82	4-GOI
7	Global Positioning Systems	GRX1200 GG-PRO	LEICA, Switzerland	36	354.20 30.54	32 from WB, 4 from GOI
8	Global Positioning Systems		Topcon, Singapore	6	36.00	GOI
9	Global Positioning Systems RTK enabled	RTK	LEICA , Switzerland	2	19.46 9.97	GOI GOG
10	Engineering Seismograph 48 channel 10 m spacing cable		Geometrics, USA	1 1	65.00 5.00	GOI GOG
11	Ground Penetrating Radar (GPR) with 100 MH 200 MH antenna		GSSI, USA	1 1	45.00 5.00	GOI GOG
12	5 SEC SEISMOMETERS	LE-3D/5S	LENNARTZ , Germany	8	30.99	GOG
13	MICROTREMOR RECORDER	CITY SHARK-II	LEAS, FRANCE	8	28.22	GOG
14	Resistivitymeter		IGIS, Hyderabad	1	0.37	GOG
15	ARCGIS software			1	12.00	GOG
			TOTAL		**1352.96**	

Sr No	Name	Model No	Manufacturer	QTY	Cost lacs (Rs)	Funding Agency
Instruments procured during 2008						
1	MAGNETO TELLURIC UNIT	ADU07	METRONIX	1	39.84	WB
2	GRAVIMETER	CG-5	SCINTREX , CANADA	2	64.446	WB
3	Triaxial Fluxgate Magnetometer	MJGSON	Magson, Germany	2	29.232	WB
4	Time Domain E.M profiling system		ZONGE , USA	2	81.00	WB
5	RESISTIVITY IMAGING SYSTEM	SYSCAL PRO	IRIS, FRANCE	1	39.161	WB
6	DIGITAL WATER LEVEL RECORDERS	NVDO FIL	IRIS, FRANCE	7	7.1166	WB
7	ELECTRONIC AUTO RADON MONITOR		SHARAD Germany	5	15.9935	WB
8	TL/OSL DATING SYSTEM	DA-20	Riso Nat Lab Denmark	2	103.68	1 from WB, 1from GOG
9	Super Conducting Gravimeter	OSG -55	GWR, US	1	420.288	WB
10	Borehole Strainmeters	GTSM	GTSM Tech, Australia	3	450.00	WB
11	Total Station	TCR-1202	LEICA, Switzerland	1	5.00	WB
12	Suspension PS Logger		OYO, Japan	1	40.00	
			TOTAL		**1295.76**	

Sr No	Name	QTY	Cost lacs (Rs)	Expected Funding Agency
GOODS UNDER PROCUREMENT				
1.	Broadband Seismometers and DAS	3	36	GoG
2.	Cyclic Triaxial testing system	1	48	MoES
3.	Magnetic Separator	1	18	GoG
	TOTAL		**102**	

WB World Bank	Rs.	21.00	crore
ADB Asian Development Bank	Rs.	5.00	crore
GoI Government of India	Rs.	9.47	crore
GoG Government of Gujarat	Rs.	2.60	crore
Total	**Rs.**	**38.07**	**crore**

SITES OF EARTHQUAKE PREDICTION RESEARCH (MPGOs)

Badargadh site


Vamka site


Desalpar site

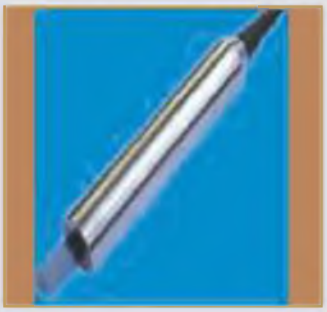

Earthquake Research Center (ERC), Bhachau


INSTRUMENTS DEPLOYED AT MPGOs

Very Broad Band Seismograph

Strong Motion Accelerograph

Radon Alpha-logger

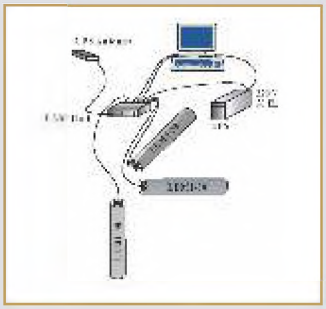


Ground water level recorder

Superconducting Gravimeter

Global Positioning System (GPS)

Gladwin Borehole Tensor Strain Meter (GTSM)



Induction coil Magnetometer

Declination Inclination Magnetometer

Flux Gate Magnetometer

Overhauser Magnetometer

DIRECTOR GENERAL
INSTITUTE OF SEISMOLOGICAL RESEARCH
Raisan, Next to Petroleum University, Gandhinagar-382009.
Phone : 079-66739001 ; 66739002 ; 66739003 Fax : 079-66739015
E-mail : dg-isr@gujarat.gov.in ; dgisrgad@gmail.com
Web site : www.isr.gujarat.gov.in