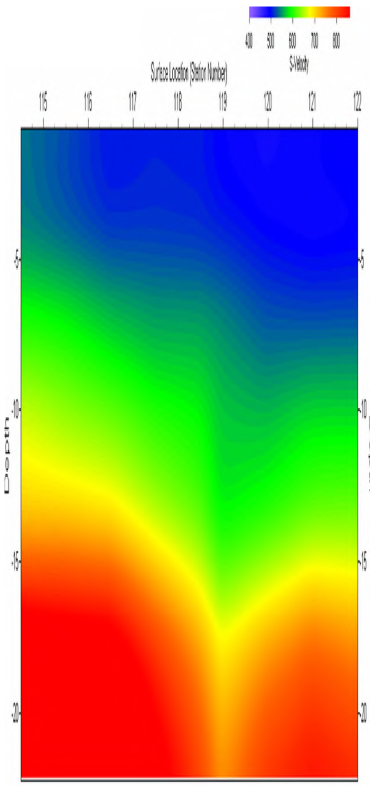
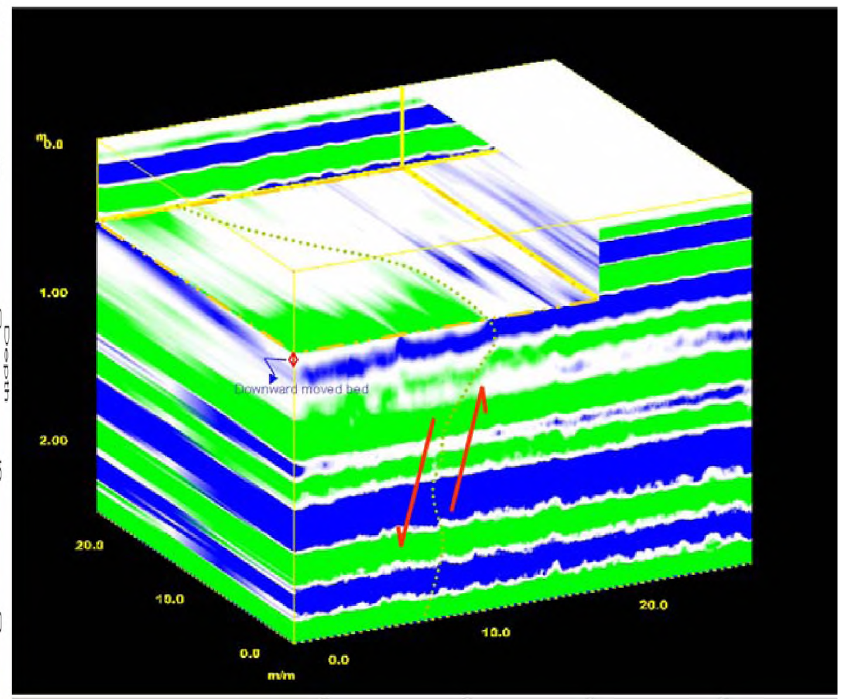
Institute of Seismological Research

ANNUAL REPORT: 2007-08





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Prologue:

Construction of ISR permanent building and residential quarters is to be completed by July 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) while projected staff is given in Annexure 2. It is the only institute in India fully dedicated to seismological research and is planned to be developed into a premier International Institute. The high points during 2007-08 are that ISR website was started, site response studies were carried out at Gandhinagar and Gandhidham, subsurface nature of faults was investigated with GPR and Engineering Seismograph, water bearing bed was delineated with GPR and active faults were identified in Kachchh. Sri Rakesh Dumka was awarded Young Scientist Award of Gov. of Uttaranchal, and Ms. Babita Sharma was awarded degree of Ph. D. (Annexure 3).

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. A state wide network of 22 Broadband Seismographs and 43 Strong Motion Accelerographs is operating since July 2006. Data of 18 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. Up to ten mobile seismic stations with Broadband Seismographs were deployed in Kachchh region which is seismically quite active. Five mobile stations were deployed in Jamnagar and Junagarh areas which experienced moderate sequences of earth tremors. Causative faults of these seismic activities were detected through detail remote sensing, geological, hypocentral patterns and GPR studies.

Crustal deformation study is being carried out through GPS measurements in seismically active belts of Gujarat. Three permanent and nine campaign mode GPS stations in Kachchh region have been established. Information about soil characteristics in Gandhinagar area is being compiled. 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 started. Site response studies were continued in Anjar- Gandhidham-Kandla area where Oyo International Corporation has carried out microzonation studies. ISR participated in trenching at 5 sites for Paleoseismology study along Katrol Hill and Kachchh Mainland Faults.

Tsunami modeling of wave arrival time and amplitude in Arabian Sea from large earthquakes in Makran has been done with better bathymetry data and coastal elevation maps are being prepared for inundation modeling. Two Multiparametric Geophysical Observatories are being established in Kachchh where eleven types of precursory parameters will be observed for earthquake prediction research.

Six research papers (3 in SCI journals), 10 technical reports (Annexure 3) 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. ISR is indebted to the Gujarat Chief Minister, Sc. & Tech. Deptt., GSDMA and various other Departments of GoG like Finance and General Administration as well as MoESc GoI, World Bank, National Geophysical Research Institute, Hyderabad for their contributions towards development of ISR.

(Dr. B. K. Rastogi)
Director General

RESEARCH ACTIVITIES DURING 2007-08

PREPARATION OF CATALOGS OF EARTHQUAKES

(R.B.S. Yadav, Sumer Chopra, Pallabee Choudhury, B.K. Rastogi)

Catalogs of earthquakes were prepared for different regions of India and kept in ISR Data Center as follows:

1 Earthquakes in India and Neighborhood (Ind. Soc. Earthq. Tech., 1983) with 17,167 entries.
2. A catalog of earthquakes in SCR of India from historical times to present
   (in two parts, part I is for magnitude ≥4.0 and part II is for magnitude ≥5.0)
3. Catalogs of A.P., Gujarat, Karnataka, Maharashtra, Orissa and TN.
4. Catalogs of Koyna and Bhuj.
5. Gupta et al. (1987) catalog for NE India Region has been updated using sources of Harvard, ISC and NEIC for the period 1963 to 2007 and Mw values assigned for the period 1897 to 1962. We established relationship between Mw with Ms and Mw with mb for this region.

Presently earthquakes of M<4 are being included in the catalog of Peninsular India for the purpose of defining source zones and estimating b-values and the catalog of Indian region and vicinity is being homogenized with Mw values using different catalogs of IMD, NEIC, Harvard, ISC and catalog of Bob Engdahl for preparation of Probabilistic Hazard Map of India, the task assigned by BIS.

RECCURENCE RATES

Stochastic analysis for Gujarat region: Using Weibull, Gamma and Lognormal models recurrence intervals of earthquake of M ≥ 5.0 in Saurashtra, Mainland Gujarat and Kachchh are estimated as 40, 20 and 13 years, respectively.

EARTHQUAKE MONITORING AND SEISMICITY PATTERNS

(Sumer Chopra, Santosh Kumar, Sandeep Agarwal, K.Madhusudhan Rao, A.K. Gupta, M.S. Gadhvi, R.B. S. Yadav, B. Sairam, Babita Sharma, K.M. Bhatt, Pawan Kumar, Ajay Pratap Singh, Srichand Prajapati, Hardik Patel, Mukesh Chauhan, Uday Bhonde)

Institute of Seismological Research is running state wide network of 22 Broadband Seismographs and 43 strong motion accelerographs since July 2006 **(Fig.1)**. Data of all these 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. A few mobile seismic stations with Broadband Seismographs have been deployed in Kachchh and Saurashtra. The Gedi fault, located in north Wagad and activated in 2006 showed low activity. Jamnagar and Junagadh district showed intense swarm activity. For the period August 2006 – April 2007 hypocenters have been re-determined by combining ISR and NGRI data.

Using the data of permanent and mobile stations hypocentral parameters of about 950 earthquakes of magnitude 0.5-5.0 have been located in Gujarat during 2007 **(Fig. 2)** out of which 260 are of M<2, 546 of M2-2.9, 136 of M3-3.9, and 8 of M4-5. Though

Kachchh had 6 tremors of M>4 and Saurashtra 2 of M>4, this year both Kachchh and Saurashtra were equally active. During later half of 2006, some 12 SMA records were obtained while in 2007 SMA records were 120 for M 2.5-5.0. Kachchh earthquake of M4.7 of 13 May 2007 was recorded at 13 stations at distances of 16 to 158 km.

Kachchh is still showing intense seismicity along the 2001 epicentral area. The Gedi fault located 50 km NE of the 2001 epicenter, that became active since 2006, continued to be active. Saurashtra became equally active as Kachchh. The area south of Jamnagar and Talala area of Junagadh showed seismic activity.

Source parameters like moment magnitude, fault length and stress drop have been determined for 230 Talala shocks (20 of which are of M≥), 10 Jamnagar shocks and 21 Kachchh shocks of magnitude about 2 and above. The Talala shocks have relatively larger source radius and smaller corner frequency and stress drop as compared to Koyna shocks (Fig.3). Large stress drop and small rupture zone was inferred for 2001 Bhuj earthquake also.

Earthquake swarm activity in Jamnagar district during Sep-Oct 2006 and Aug-Sep 2007

There has been no significant earthquake near Jamnagar barring a magnitude 4.4 (USGS) earthquake in 1886 and magnitude 5.0 (Chandra, 1977) earthquake in 1940. However, a swarm activity was noticed about 30 km SSW of Jamnagar in 2003 near Lalapur. Some 30km south of Jamnagar about 200 shocks were felt around Khankotda village in 2006 and same number was felt again in 2007 between Vijrakhi and Khankotda villages situated 15-30km south of Jamnagar. The maximum magnitude was 4.0 on September 30, 2006 (22.31°N 70.21°E) and 3.5 during 2007. The shocks were felt with blast like subterranean sounds. These shocks were of shallow depth (mostly within 6 km) and two of these caused cracks in some houses. A network of temporary seismic stations was deployed with the help of which about 40 shocks of magnitude ~2 or more were located in 2006 and over 50 in 2007. Most of the epicenters are located along a NW trending dyke **(Fig. 3).** Some shocks have occurred about 15 km west of this trend and parallel to it. The Moment Tensor Solutions agree with this trend. The shocks followed a period of heavy rainfall giving a rise in water table of 12-17m in the observation wells of the area as measured by State Ground Water Department. A 10m rise in water table causes 1 bar stress. A 1-2 bar stress change caused by rise in water table of the area is considered enough to trigger small earthquakes along pre-existing fault. The tremors are probably triggered after heavy rain fall in many instances in India in last several decades. A catalog of such sequences has been prepared.

Talala earthquake of November 6, 2007 in Junagarh District and its sequence

Talala region of Junagarh district of Gujarat experienced an earthquake of magnitude 5.0 on 6 Nov 2007 at 15:08 hrs. The earthquake was preceded by some foreshocks and a sequence of aftershocks for more than two months. The main earthquake was strongly felt in much of the Saurashtra and resulted in at least one death due to a wall collapse at Hiranvel near Talala. About 200 adobe (kachcha) houses suffered partial collapse in seven villages covering an area of 13 km x 8 km, namely, Hirenvel, Chitravad, Haripur, Chitrod, Sangodra, Jalonder and Devgam in the Talala area. Damage to houses is reported from Talala, Maliya and villages of Bhalchhel, Amrutvel, Amblash etc. Minor cracks were reported from most of Junagadh district. The earthquake was also felt widely in the districts of Amreli, Bhavnagar, Jamnagar, Porbandar, Rajkot and Surendranagar. Tremors were felt as far as Ahmedabad, Navsari and Surat. A foreshock of magnitude 4.8 that occurred about 9 hours prior to the mainshock also caused some damage. The whole sequence had about 1300 micro earthquakes (M>0.5) out of which about 250 shocks of magnitude about 1.5 and or greater were located. There were 20 shocks of $M \geq 3$. The aftershocks reduced to a low level in 15 days but have continued for more than two months. Epicenters are following NE-SW trend for a length of 15 km **(Fig. 4).** There is no major fault system near the epicenter zone. A small NE trending fault has been identified in the area from satellite imagery and field investigation for a length of 15 km which displaces E-W trending dykes by 130 m. Its southern extension is buried under soil as confirmed by GPR survey that does indicate presence of this fault in soil area **(Fig. 5).**

The area had earlier experienced swarm type of earthquake activity in 2001 and 2004-05. During Oct 4-10 and Dec 10-20, 2007 Ankolvadi area, about 20 km SE of the present activity, experienced a swarm of activity. Similarly Jamnagar has experienced earthtremors at Kalavad, Lalpur and Bhanvad. Bhavnagar and Rajkot districts had experienced several earthquake sequences since 2000 (Rastogi, 2000, 2002, 2003). It appears that faults in Saurashtra region have become activated by stress perturbation due to 2001 Bhuj earthquake of M7.7. Botad area near Bhavnagar experienced shocks during February 2007.

Sedimentary Thickness in Kachchh

(Sumer Chopra, K M Rao & B K Rastogi)

An inexpensive method using natural earthquake data is utilized for determining the thickness of sedimentary basin in Kachchh from the data from 13 broadband seismographs and two strong motion Accelerographs. The stations are within 5 to 80 km from the epicenters. We have used 128 selected earthquakes with magnitudes in the range 2.5-4.3. Besides this 15 SMA records are also used for two stations namely Bhachau and Rapar.In this study the converted phase S to P, S_P is used. This phase is generated due to large impedance contrast between sediments and basement. This phase is clear in the vertical component. The difference in the travel times of S and S_P phases and velocities of P and S waves are used for determining the sedimentary layer thickness. The thickness beneath each of these 15 stations was determined covering an area of 23,500 sq km **(Fig. 6).**

Maximum thickness was observed beneath Dhori station (2.29 km) north of KMF and minimum at Suvai (0.97 km) in Wagad. A contour plot is also made from the estimated thickness data of each station (**Fig**. 6 upper part). Sedimentary thickness calculated beneath NGRI stations by Mandal (2007) is also incorporated in this contour plot. Nakhatarana, Anjar, Bhuj, Mandvi, Bhachau, Dudhai, Fatehgarh and Lodrani showed thickness of more than a km. It is observed from the contours and depth section that there is down warping of the basement beneath Dhori station. The Dhori village is on the edge of the Banni plains. A deep well in the Banni area encountered Precambrian granite porphyry/rhyolite at a depth of 1.72 km. South of the borewell in the deepest part of Banni the sedimentary thickness is 2.29 km in Dhori. Whereas, up warping of the basement was observed beneath Suvai station. It is also inferred from the contours that the sediment thickness decreases as we move from SW to NE direction. This is in agreement with subsurface structure inferred from integrated geophysical surveys carried out by NGRI and work done by Mandal (2007) in the same area.

Three depth sections were also plotted along AA', BB' and CC' as shown in **Fig. 6 lower part**. Some signature of the KMF and KHF are seen from the section of sediment thickness between Rudramata and Dhori (section AA'). There is a sharp increase in sediment thickness of the order of 0.5 km as we move towards north and cross KMF near Dhori (section AA'). There is an increase of 0.4 km of sediment thickness around SWF which decreases as we move northwards reaching minimum at Suvai. In the EW section (CC') also, sharp increase in sediment thickness is noticed around KMF and SWF. Sharp reflections are noticed at around 1 km depth near Anjar in the seismic refraction data collected by NGRI near Anjar in 1997 which was further reprocessed to image middle and lower crust. From this it can be inferred that there is some boundary at 1 km depth with large impedance contrast. The sediment thickness at Anjar in our study using converted phases is found out to be 1.67 km.

The outcome is of immense use not only for seismic hazard estimation but also for oil industry in the form of basin structure in Kachchh for which the oil industry has to spend hundreds of millions of rupees for drilling wells and seismic surveys.

MICROZONATION

(Hardik Patel, Pawan Kumar, B. Sairam, Mukesh Chauhan, A.P. Singh**)**

Site response at Gandhinagar was measured by deploying Broadband Seismographs and Strong Motion Accelerographs for microtremor survey (8hr deployment at each site) and Vs30 measurements at 40 sites. The preliminary results indicate that the fundamental frequency is 0.6 Hz. It indicates about 300-350 m basin thickness using the formula, $f = Vs/4H$. There is no amplification in the frequency range 1-7 Hz corresponding to the natural frequencies of 2-10 storey buildings. However for the taller buildings with natural frequencies < 1 Hz, amplification of 2 has to be considered. Soil testing has been done with seven boreholes. .It is inferred that soil does not posses liquefaction potential as water table is 80m even near Sabarmati river basin. The N values range from 2-58 down to 10m depth. Bore hole data about soil available with Guj. Engg. Res. Inst. have been compiled.

ISR carried out site response studies at 56 sites in Gandhidham area. Fundamental frequencies, depths and amplification of surface layer and engineering bedrock were estimated **(Fig. 7)**. The results of detail drilling program of 80 boreholes to about 80m depths of Oyo International Corporation validate the site response results. The information obtained for depths deeper than 80m, i.e. beyond the borehole penetration was invaluable. Vs30 were compared with PS logging results for two sites and were found to give a good average picture.

GPS MEASUREMENTS AND CRUSTAL DEFORMATION

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

ISR has planned to deploy 20 permanent GPS stations across different faults in Gujarat **(Fig. 8)**. During 2006-07, Institute of Seismological Research has installed three permanent stations at Gandhinagar, Khavda and Radhanpur and nine campaign stations in Kachchh region. All these stations along with their latitude, longitude and monitoring time are shown in Table1.

GPS data collected at all the stations have been processed using GAMIT10.32/ GLOBK and the velocities, azimuth of the sites are summarized in Table 2. The velocity vectors of permanent stations along with various campaign stations are shown in **Fig. 9.** Co-ordinates and velocities of all sites both permanent and campaign, were estimated in the ITRF 2000 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. Notable conclusions that arise from this study are as follows: The velocity of Gujarat is found to be 44-50±1mm/yr and that of IISC is 56mm/yr in NNE direction, which is more or less the same velocity of Indian plate, i.e., 54±4mm/yr. Velocity vectors in Gujarat do indicate a post seismic deformation of rates 6-12 mm/yr which is in agreement with the past results. No more significant inferences about the plate motion and long-term deformation can be made from the motion of GPS sites in Gujarat just from three epochs of measurements. Concurrence of the velocities of IGS stations obtained by us and those provided by IGS validates our results.

GPS Permanent Stations

1. Gandhinagar 23.21°(N) 72.66°(E)
2. Khavda 23.85°(N) 69.72°(E)
3. Radhanpur 23.83°(N) 71.60°(E)

Campaign mode stations in Kachchh:

1. Gadhada (GIBF) 23.87°(N) 70.37°(E)
2. Ekal 23.61°(N) 70.41°(E)
3. Dudhai 23.33°(N) 70.14°(E)
4. Lilpar 23.52°(N) 70.64°(E)
5. Suvai 23.61°(N) 70.49°(E)
6. Fatehgarh 23.68°(N) 70.86°(E)
7. Desalpar 23.74°(N) 70.68°(E)
8. Bela GTS 23.904°(N) 70.757°(E)
9. Bela (GADH) 23.898°(N) 70.694°(E)

GPR SURVEYS

(K.M. Bhatt, Hardik Patel)

GPR surveys were carried out at different sites for variety of purposes as described below:

i. GPR survey from Desalpar to Gedi site along a few cris-crossing profiles (100m -4.5km) depicted a zone of intense anomalies.
ii. GPR profile across Haripur fault in Talala area of Junagadh district (detected from satellite imagery and ground check after the swarm activity during October –November 2007) indicates presence of east dipping fault as already discussed and shown in **Fig.** 5. A down throw of a few tens of meters towards east is discernible.
iii. In a site in Junagadh water bearing bed was surveyed.
iv. Depths of limestone beds was mapped in Lakhpat.

VS30 AND DETECTION OF FAULTS WITH ENGINEERING SEISMOGRAPH
(B. Sairam, Mukesh Chauhan, M. S. Gadhavi, Hardik Patel and R. K. Dumka)

Engineering Seismograph has been extensively used for determining Vs30 for microzonation and soil investigation for engineering purposes through MASW (Multichannel Analysis of Surface Waves) technique. We have used it for microzonation of Gandhinagar and Gandhidham. Its potential use was successfully tested for delineation of geological structures at shallow subsurface. It is found to be an effective tool in active fault studies and paleoseismology. It has been used to estimate deformation zone of active fault trace of KMF (Kachchh Mainland Fault) near Bhachau. Along the Kodki road fault 8km west of Bhuj a sharp break/drop in velocity coincides with the location of fault on the ground **(Fig 10).** This indicates faults are typified by low velocities. Gradual velocity change in footwall in comparison to that of hanging wall indicate more deformation of footwall, and hence low velocities at greater distance from fault in footwall block in case of normal fault.

PALEOSEISMOLOY AND STUDY OF ACTIVE FAULTS
(M. S. Gadhavi)

In collaboration with Oyo international Corporation and IITk for the first time in India, we identified active fault portions in Kachchh. Highlight of the work is identification of active faults in the form of pressure ridges on the basis of stereo viewing of satellite imageries. Neotectonic activity has been confirmed by trenching near Jhura and Lodai along Kachchh Mainland fault (KMF), Wandhay and along Katrol Hill Fault (KHF), and near Bhuj along NE splay of KHF as the Bhuj Fault from Wandhay to Bhuj. Mesozoic rocks are seen overthrusting the Quaternary rocks. Trenches near Jhura, Lodai and Wandhay were shown to several geologists and other delegates during a field workshop. A large number of samples have been collected and dating of these will give the dates of events.

ATTENUATION AND HETEROGENEITY

(Babita Sharma, Sumer Chopra, K.M.Rao, Arun K.Gupta and B.K. Rastogi)

The attenuation properties of the crust in the Kachchh region have been investigated. For this purpose, forty-nine local earthquakes having focal depths in the 3-38 km range have been used. The quality factors Q_α (Quality factor using P-waves) and Q_β (Quality factor using S-waves) have been estimated using the coda normalization method. Quality factor of coda-waves (Q_c) has been used to estimate intrinsic and scattering quality factors. The multiple scattering models have been used to estimate Qi (intrinsic attenuation parameter) and Qs (scattering attenuation parameter) for the region which is based on the Wennerberg formulations. The values of Q_α, Q_β, Qi and Qs show a dependence on frequency in the range 1.5-24 Hz for the Kachchh region. The average frequency dependent relationships ($Q=Q_0f^n$) estimated for the region are $Q_\alpha=(77\pm2)f^{(0.87\pm.03)}$ and $Q_\beta=(100\pm4)f^{(0.86\pm.04)}$. The estimate of Q_c ($Q_c=(148\pm3)f^{(1.01\pm.02)}$) is found to be higher than Q_β in this region. The estimated values of Q_s and Q_i vary from 529 and 183 at 1.5 Hz to 3053 and 2668 at 24Hz respectively. The Q_c estimates lie between the estimates of Q_i and Q_s but closer to Q_i at lower frequencies. This is in agreement with the theoretical as well as laboratory measurements. A comparison between Q_i and Q_s shows that intrinsic absorption is predominant over scattering.

The quality factor Q in Kachchh has been estimated using spectral amplitudes of P and S waves from earthquakes. The earthquakes recorded at two stations – Lakadia (LAK) and Suvai (SUV) have been used. The spectral amplitude ratios have been calculated between 2 - 25 Hz and single station spectral ratio method has been applied for this purpose. As expected the results show that the quality factors for both P and S waves (Q_p and Q_s) increase as a function of frequency according to law $Q = Q_0f^n$. The frequency dependent relations estimated for the Q_p and Q_s at the two stations are : $Q_p = (111\pm1.5)f^{1\pm0.01}$, $Q_s = (107\pm4)f^{0.76\pm0.03}$ for Lakadia and $Q_p = (72\pm1.4)f^{1.22\pm0.01}$, $Q_s = (193\pm3)f^{0.86\pm0.01}$ for Suvai. The average frequency dependent relations for Q have been estimated as $Q_p = (89\pm1)f^{1.12\pm0.004}$ and $Q_s = (121\pm1)f^{0.92\pm0.004}$ in the region. The average ratio of Q_s/Q_p is more than unity. This average ratio and strong frequency dependence of estimated Q suggest that the scattering is a significant factor contributing to the attenuation of body waves in this region. The results of this study have been found to be consistent with the findings of other studies in this region using different methods.

For the Kachchh region the inversion of coda wave envelope is also carried out which is showing a clear picture of Moho discontinuity in this region at near about 38 km depth. This inversion process is based on the idea of filtered back projection algorithm which is very much famous in the medical tomography. The same technique is used here in this region to map the region which is 70.1 to 70.9^{0}E longitude wise and 23.1 to 23.9^{0}N latitude wise. In this work total 438 events recorded at 18 stations by ISR network in the period of August, 06 to March 07 are used. As an outcome the relative scattering coefficient tells about the nature of the area concerned in terms of heterogeneity. For this purpose waveform of the seismograms starting from the twice of the S wave arrival time and up to 20 seconds window is used for the inversion process. It is found that up to depth of around 40 kms the whole area is highly scattered. In addition to that a breakage in the Moho discontinuity is found which may the cause of the earthquake activity in the Kachchh region **(Figures 11 and 12).**

Attenuation studies are going on for the Saurashtra also based on the single backscattering model, coda normalization method, Wennerberg formulation and inversion of coda wave envelope. In response of that frequency dependent Qc is estimated in the frequency range of 1.5 to 18 Hz. For this purpose total of 85 events in the Junagarh region and 56 events in the Jamnagar region recorded by ISR network are considered. The Qc values vary from 104 and 156 at 1.5 Hz to 1513 and 1419 at 18 Hz for Jamnagar and Junagarh respectively. This study has to be carried out to estimate other attenuation parameters like Q_α, Q_β, Qi , Qs and also the inversion of coda wave envelope.

STRESS MODELING

(R.B.S. Yadav)

<u>Coulomb stress modeling for 1819 Allah Bund earthquake:</u> We have modeled the coulomb stress changes associated with 1819 Allah Bund earthquake on a slipping dislocation in an elastic half space for the rupture area of 90X50 km^2 and 5.5 m of slip. The coulomb stress changes were resolved on optimally oriented plane where coulomb stress changes are high. We tested our results for different values of dip of fault. Results show similar pattern of coulomb stress changes either fault is north dipping or south dipping. Coulomb stress modeling indicate an increase of stress at the epicenter of Jan 26, 2001 earthquake that might be triggered due to 1819 Allah Bund earthquake.

Coulomb stress modeling for Oct. 8, 2005 Kashmir Earthquake: Coulomb stress modeling is done for most disastrous earthquake of present century in the Indian Sub continent. We have calculated the changes in Coulomb stress due to this earthquake on rupture area of 125 X 25 Km^2 whose updip and downdip edge lies at a depth of 4.1 Km and 19.9 Km. We estimated the coulomb stress in horizontal planes at different depths and also in vertical cross-sections. We have tested the results for the sensitivity of different value of coefficient of friction ranging from 0.2 to 0.8 and different depths. Our Coulomb stress modeling on optimally oriented reverse/thrust fault shows a stress increase to the north west of the rupture along the trend of IKSZ and also to the south east of rupture in Kashmir basin. The decreased stress is observed in large regions to the southwest and northeast of the rupture area which may decelerate the future seismicity of these regions.

TSUNAMI MODELING

(A.P. Singh, Hardik Patel)

Modeling of tsunami amplitude, travel time and run-up have been made in the Indian Ocean from sources in Andaman-Sumatra and Makran using Tunami N2. The bathymetry data is taken from ETOPO-2 and near shore data from C-MAP. For tsunami run-up the land topography data was collected using SRTM data.

The fault parameters of the earthquakes for the generation of tsunami are: fault area (length and width), angle of strike, dip and slip (270°, 15° and 90°), depth of fracture (10 km), magnitude of the earthquake (8.0) are used in this study.

From the source in central part of Makran the amplitude of tsunami near the source is 6m and Gujarat coast is 4.5m or less (Jakhau 4.5 m, Porbandar 4.0 m and Dwarka 3.0 m). However, Pendse (1948) reported 11.5 m amplitude in Gulf of Kachchh. The simulation of model results show that the tsunami wave propagated initially very fast in Arabian Sea and it slowed down when it reached shallow region of Gujarat coast. The tsunami waves reach the Indian coast in 2hr that is in good agreement with the 1945 tsunami travel times given by Pendse (194**8**). At Dwarka, positive tsunami waves arrive within approximately 2 hours and 10 minutes and to Mandvi after 3 hours 10 minutes. If the tsunami strikes during high tide, we should expect more serious hazards which impacts local coastal communities.

Future Work:

1. To Improve Bathymetry data sets for Gulf of Kutch & Gulf of Cambay with inputs from National Hydrographic Charts provided by Survey of India.
2. To calculate inundation in the coastal parts of Gujarat state.
3. Geomorphological Mapping of coastal regions

ADVICE TO INDUSTRY AND INVESTIGATIONS FOR PUBLIC INTEREST

i. Sanghi Cement was advised on seismic hazard in their factory area in Kachchh.

ii. Field investigations of blowout of ONGC wells and water jets coming out from the tube wells in Gamanpura village, Mehsana district, Gujarat and explanation of the continued pumping of water by ONGC to prevent oil inflow near the tube wells and possible subsequent seepage of oil from them.

Table 1: GPS stations occupied by ISR during 2006-08.

Site name	Latitude	Longitude	Monitoring		Remarks
			From	To	
ISR (ISRG)	72.66	23.215	28.06.06	--	Permanent
Khavda (KHAV)	69.766	23.922	05.01.07	--	Permanent
Radhanpur (RADP)	71.617	23.821	23.01.07	--	Permanent
Bela (GTS) (BELA)	70.757	23.904	22.04.07	05.05.07	Campaign
Gadhada (GIBF)	70.694	23.898	22.04.07	10.05.07	Campaign
			16.01.08	20.01.08	
Desalpar (DESP)	70.684	23.746	14.11.06	19.11.06	Campaign
			17.07.07	22.07.07	
			16.01.08	20.01.08	
Dudhai (DUDH)	70.145	23.328	03.01.07	08.01.07	Campaign
			18.08.07	22.08.07	
			25.01.08	02.02.08	
Ekal (EKAL)	70.408	23.609	03.01.07	08.01.07	Campaign
			16.08.07	19.08.07	
			28.01.08	09.02.08	
Fatehgarh (FATH)	70.864	23.683	14.11.06	19.11.06	Campaign
			23.07.07	27.07.07	
			24.01.08	28.01.08	
Bela (GADH)	70.373	23.867	03.01.07	03.01.07	Campaign
			14.02.08	19.02.08	
Nilpar (LLPR)	70.636	23.526	14.11.06	19.11.06	Campaign
			18.07.07	23.07.07	
			20.01.08	24.01.08	
Suvai (SUAI)	70.492	23.614	14.11.06	19.11.06	Campaign
			22.07.07	27.07.07	
			20.01.08	24.01.08	

Table 2: The velocities and azimuth of all stations processed by ISR.

Station ID	Remarks	Lon°E	Lat°N	E-rate (mm/yr)	N-rate (mm/yr)	E±	N±	Velocity (mm/yr)	Azimuth (degree)
NTUS	IGS	103.68	1.35	10.81	-20.98	0.98	0.8	23.601	152.742
KUNM	IGS	102.80	25.03	28.18	-16.12	0.67	0.69	32.465	119.772
IISC	IGS	77.57	13.02	44.02	35.82	0.52	0.45	56.752	50.863
SELE	IGS	77.02	43.18	25.94	3.1	0.53	0.36	26.125	83.185
POL2	IGS	74.69	42.68	26.18	3.79	0.51	0.33	26.453	81.762
DGAR	IGS	72.37	-7.27	47.82	31.83	0.85	0.71	57.445	56.350
KIT3	IGS	66.89	39.14	24.44	5.0	0.49	0.33	24.946	78.437
BAHR	IGS	50.61	26.21	29.23	25.94	0.51	0.51	39.080	48.412
ISRG	Permanent	72.66	23.22	35.27	33.54	0.47	0.37	48.671	46.439
RADP	Permanent	71.62	23.82	38.15	31.94	0.51	0.41	49.755	50.062
KHAV	Permanent	69.77	23.92	33.33	36.67	0.55	0.46	49.554	42.267
LLPR	Campaign	70.64	23.53	38.24	27.06	0.98	0.88	46.846	54.714
SUAI	Campaign	70.50	23.61	32.27	37.53	0.89	0.79	49.496	40.689
EKAL	Campaign	70.41	23.61	31.32	30.93	0.77	0.66	44.018	45.358
GIBF	Campaign	70.37	23.87	33.28	31.41	0.94	0.84	45.762	46.655
DUDH	Campaign	70.15	23.31	35.28	31.93	0.84	0.73	47.584	47.852

ISRG: Gandhinagar RADP: Radhanpur KHAV: Khavda LLPR:Lilpar
SUAI:Suvai EKAL: Ekal DUDH: Dudhai GIBF: Gadhada

Annexure - 1

SCIENTIFIC STAFF

Present Scientific Staff

1. Sumer Chopra, Sc D
2. K.Madhusudhan Rao, Sc B
3. Dr. A.K. Gupta, Sc B
4. M.S.Gadhvi, Sc B
5. R.B.Yadav, Sc B
6. B.Sairam, Sc B
7. Dr. (Mrs.) Babita Sharma, Sc B
8. M.S. B. S. Prasad, Sc.B
9 Santosh Kumar, Sc.B
10. K.M. Bhatt, Geophysicist
11. Pawan Kumar, Geophysicist
12. Ajay Pratap Singh, Geophysicist
13. Srichand Prajapati, Geophysicist
14. Kapil Mohan, Geophysicist
15. Hardik Patel, Geologist
16. Dr. Uday Bhonde, Geologist
17. Mukesh Chauhan, Geologist
18. Sandeep Kumar Aggrawal, Geophysicist
19. R.K. Singh, Geophysicist
20. Rudradeb Bhattacharya, Geologist
21. Sidhartha Dimri, Geologist
22. Rakesh Kumar Dumka, Geologist
23. Ms. Rashmi Pradhan, Geologist
24. Dr.(Ms) Pallabee Choudhury, RA
25. Nagabhushan Rao, JRF
26. Vikash Kumar, JRF
27. Ms. Neha Jhala, JRF
28. Ms. Ranjna Vyas, JRF
29. Hemant Umbrani, JRF
30. Sameer Tiwari, JRF
31. Ms. Falguni Bhattacharya, JRF
32. Arvind Valand, JSA

Administrative Staff:

Mrs. Bharti Vora, AO
Mrs. Aruna Leuva, Ac.O
Sharad Thakkar, Accountant
P.M. Shrimali, Sr. Clerk
A. I. Fakir, Clerk (Superannuated on 31.12.2007)

Annexure -2

Projected Staff for the five year Period 2007-2011

Sr. No.	Year	Projected cumulative staff Permanent + Contract + Adimin. (outsource/deputation)	Total
1.	2007	14 + 30 + 7	51
2.	2008	17 + 50 + 7	74
3.	2009	20 + 60 + 7	87
4.	2010	23 + 70 + 7	100
5.	2011	26 + 80 + 7	113

Approved Manpower for 2007-2011

Category-I Core Scientists		**Category-II: Sci/Tech (On Contract)**		**Category-III: Admin. Staff (Outsourcing/Deputation)**	
Post	**No. of Posts**	**Post**	**No. of Posts**	**Post**	**No. of Posts**
Director General	1	Sr. Geophy Sr .Geologist	5	Admin. Officer	1
Director	5	Geologist Geophys.	5	Stores & Purchase Off	1
Sci-F	2	Junior Res. Fellow	20	Account Officer	1
Sci-E	2	Tech Off	2	PS to Director General	1
Sci-D	2	Tech Asst	48	Librarian	1
Sci-C	2			Clerks	2
Sci-B	12				
Total	26		80		7

Total Approved Staff = 113

Category –I (Core Staff)

Grades: Director General (22400-26000)/Contract, Director (18400-22400), Scientist-F (16000-20500), Scientist-E (14300-18300), Scientist-D (12000-16500), Scientist-C (10000-15200), Scientist-B (8000-13500)

Category –II (on contract)

Consolidated Amount: Senior Geophysicist/ Senior Geologist (26000), Geologist/Geophysicist (20000), JRF (12000), Technical Officer-B (10000), Technical Assistants (8000)

Category –III (on outsourcing)

Admin.Officer/Stores & Purchase Officer/Accounts Officer (8000-13500).

Annexure - 3

Awards /Recognitions

Rakesh K. Dumka, **Young Scientist Award** in the Earth Science discipline from the Uttarakhand Council of Science and Technology (U-COST) during 2nd State Science Congress held at Nainital, 15 -17th November 2007, on the basis of Global Positioning System (GPS) related research work.

Ph.D. Awarded:
Babita Sharma (2007), Attenuation and Site Amplification Studies for Indian Regions using Coda Waves, Kurukshetra University, Kurukshetra, 161pp.

Visits Abroad:
1. Dr. Babita Sharma (Spain, April 15 to July 15, 2007), On leave, Collaborative study on Inversion of Coda Wave Envelope for Kachchh Region Gujarat at Ebro Observatory, Tarragona, Spain.

2. Sumer Chopra (Taiwan, October 22-26, 2007), Deputation for International Training Program for Seismic Design of Structures, National Center for Research on Earthquake Engineering (NCREE), Tapei, Taiwan.

Annexure - 4

Research Papers Published
(SCI)

1. **Babita Sharma**, S. S. Teotia and Dinesh Kumar (2007). Attenuation of P,S, and coda waves in Koyna Region, India, *J. Seism.*, **11**, 327-344.
2. R. V. Karanth and **Gadhavi M. S.**, (2007) "Structural Intricacies: Emergent Thrusts and Blind Thrusts of Central Kachchh, Western India", *Current Science*, **93**, No. 9, 1271-1280.
3. A. Joshi, **K. Mohan** (2008). Simulation of accelerograms from simplified deterministic approach for the 23rdOctober 2004 Niigata-ken Chuetsu, Japan earthquake, *J.Seism.*, **12,** No.1, 35-51.

(Non-SCI)

1. Rastogi, B.K., Arun Gupta, Pawan Kumar, B. Sairam and A.P. Singh (2007). Microzonation studies in Gujarat, *Proc. Workshop on Microzonation, IISc Bangalore, 85-88.*
2. Rastogi, B.K., Arun Gupta, Pawan Kumar, B. Sairam and A.P. Singh (2007). Microzonation of vulnerable areas of Gujarat, *Proc. National Seminar on Seismic Microzonation, Ahmedabad, 8-19.*
3. Sumer Chopra, Dinesh Kumar, K. M. Rao' Attenuation of P and S waves in the Kachchh Region, *J. Ind. Geophys. Union.*

4. A. Joshi and K. Mohan (2008). Modified semi empirical technique for prediction of strong ground motion, *proceeding of Fifth International Conference on Urban Earthquake Engineering, Centre for urban earthquake engineering, Tokyo Institute of Technology, Shinagawa-Ku, Tokyo, Japan, pp.77-81.*

Research Paper (SCI) Communicated:

1. Babita Sharma, S. S. Teotia and Dinesh Kumar (2007). Attenuation study of the high frequency waves using aftershock activity of Chamoli main shock occurred in the year 1999 by means of Coda Normalization Method., *PAGEOPH* (Communicated).

2. Kaushalendra Mangal Bhatt and Santosh Kumar (2007). Two M 7.7 intraplate earthquakes of Kachchh in just 182 years: A possible cause, *Tectonophysics* (Communicated).

3. A. Joshi and K. Mohan (2008), Seismic Hazard in Uttarakhand Himalaya, India, *Natural Hazards* (Communicated).

4. Sumer Chopra, 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.* (accepted).

5. R.B.S. Yadav, 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 (communicated).*

6. Babita Sharma, Arun K. Gupta, D. Kameswari Devi, Dinesh Kumar, S.S.Teotia and B. K. Rastogi (2007). A study on attenuation of high frequency waves in Kachchh Region using Wennerberg formulation for separation of Qc in terms of Qi and Qs, *Bull. Seism. Soc. Am.* (Accepted).

Research Papers (Non-SCI) Communicated:

1. R. K. Jaiswal and B. K. Rastogi (2006). Past Tsunamis in the Arabian Sea and Future Possibilities, *J. Ind. Geophys. Union.*
2. Sandeep Kumar, (2007). Coda Q estimates in the Kachchh region, Gujarat, Western India, *J. Ind. Geophys. Union.*
3. Kaushalendra Mangal Bhatt and Santosh Kumar, (2007). Anomalous b-value in seismogenic layer of Bhuj region, *J. Ind. Geophys. Union.*
5. Kaushalendra Mangal Bhatt, (2007). Rotation of faulted block in 26 Jan 2001, Bhuj earthquake, *J. Ind. Geophys. Union.*

6. Kaushalendra Mangal Bhatt, (2007). Intersecting fault pattern and Bhuj earthquake, *J. Ind. Geophys. Union.*

7. Babita Sharma, Dinesh Kumar and S.S. Teotia (2007) Site Amplification factors in Koyna region using Coda Waves, *J. Ind. Geophys. Union.*
8. K. Mohan, A. Joshi and R. C. Patel, The assessment of seismic hazard in two seismically active regions in Himalayas using deterministic approach *J. Ind. Geophys. Union.*

Technical Reports:

1. Rastogi, B.K., Pawan Kumar, A.P. Singh, B. Sairam and Santosh Kumar (2007). First Report on Site Response Study in Gandhidham, Tech. Rep. ISR-2007-6, July, 2007.

2. Rastogi, B.K., Pawan Kumar, A.P. Singh, B. Sairam and Santosh Kumar (2007). Second Report on Site Response Study in Gandhidham, Tech. Rep. ISR-2007-7, September, 2007.

3. Rastogi, B.K., Sumer Chopra**,** R.B. S. Yadav, Santosh Kumar, A.K. Gupta and Hardik Patel (2007). Earthquake Swarm Activity in the Jamnagar District during Sep-Oct 2006 and Aug-Sep 2007, Tech. Rep. ISR-2007-8, September, 2007.

4. Gadhavi M. S. (2007) Report on preliminary field investigations of water jet coming out from tube wells in Gamanpura village, Mehsana district, Gujarat, Tech. Rep. ISR- 2007-9, December 2007.

5. Sairam B., Chauhan M., Dumka R., (2008); Technical report on Determination of Vs30 at three SMA stations near Bhachau using MASW in Kachchh, Gujarat, India, Tech. Rep. ISR-2007-10, January 2008.

6. Rastogi B.K., Chopra Sumer, Gadhavi M.S, Patel Hardik, Agrawal Sandeep, Sairam. B & Gupta A.K., (2008). Investigations of magnitude 5.0 Talala earthquake of November 6, 2007 in Junagarh District, Tech. Rep. ISR-2007-11, January 2008.

7. B. K. Rastogi, Sumer Chopra, K. Madhusudan Rao, Arun Gupta, B. Sairam, Ram Bichar Singh Yadav, M. S. B. S. Prasad, Babita Sharma, Santosh Kumar, M. S. Gadhavi (2008). 4th Progress Report for the period February 2007 – January 2008 for the Project on "Seismological Research and Applications in Gujarat", Project No: DST/23(511)/SU/2005, ISR Technical Report No.12.

8. M.S. Gadhavi and Rehmat Khan (2008). GPR and Seismic Survey at Allah Bund site, ISR Technical Report No. 13.

9. B. Sairam, M.S. Gadhavi, Pawan Kumar, Arun Gupta and B. Uday (2008). Microzonation Study using MASW in Gandhinagar, Gujarat, India, ISR Technical Report No. 14,

10. B. K. Rastogi, Sumer Chopra and Hardik Patel (2008). Preliminary Report on Seismic Activity in Saurashtra and Kachchh in 2008 beginning: with special reference to Mundra and Mandvi, ISR Technical Report No. 15.

Annexure 5

Seminars Organized:

1	National Seminar on "Seismic Microzonation" Organized by GSDMA, ISR and Oyo International	26 October 2007
2	International Workshop on Active Faults	18-19 January 2008

Special / Invited Lectures

B.K. Rastogi Hazard Assessment and Disaster Mitigation Measures by ISR – Inaugural address as Chief Guest, Sem. Disaster Risk Reduction Begins at School: Intl. Day for Reduction of Natural Disasters, Sc. City, Ahmedabad, Oct. 10, 2007

B. Rastogi, Development of Earthquake Science, National Science Day Lecture, ISR, 28 Feb. 2008.

B. Rastogi, Hazards: Minimizing Risk, Maximizing Awareness, National Science Day Lecture, Science City, 28 Feb. 2008.

Seminars Attended/Abstracts:

Sr. No.	Subject of Seminar	Attended by/Paper presented Or Paper accepted
1	Workshop on Microzonation, IISc, Bangalore, June 26-27, 2007	**B.K. Rastogi**, Arun Gupta, Pawan Kumar, B. Sairam, A.P. Singh, Microzonation Studies in Gujarat
2	*IUGG, Perugia, Italy, July 2007	Shankar, D., H.N. Singh, **RBS Yadav**, V.P. Singh, Precursory swarm is a real diagnostic parameter as seismic precursor before major shocks.
3	Natl. Sem. "Seismic Microzonation" Oct 26, Ahmedabad	**B.K. Rastogi**, Arun Gupta, Pawan Kumar, B. Sairam, A.P. Singh, Microzonation of vulnerable areas of Gujarat.
4	IGU 44th annual conference, Kurukshetra University, Nov 23-26, 2007	1.**Sumer Chopra**, Dinesh Kumar, **K. M. Rao**, Attenuation of P and S waves in the Kachchh Region 2. **K. Mohan**, A. Joshi and R. C. Patel, The assessment of seismic hazard in two seismically active regions in Himalayas using deterministic approach 3. **R. B. S. Yadav**, J. N. Tripathi, **B. K. Rastogi**, Sumer Chopra, A. P. Singh; Probabilistic assessment of earthquake hazard in Gujarat and adjoining regions 4. **R.B.S. Yadav,** D. Shanker, H.N. Singh and V. P. Singh; Application of time and magnitude predictable model for long-term earthquake prediction in Pamir - Hindukush and vicinity.

		5. **Babita Sharma**, Dinesh Kumar and S. S. Teotia, Site Amplification study in Koyna region using Reference Site Method. 6. Agarwal, Sandeep Kumar, Coda Q estimates in the Kachchh region 7. K M Bhatt and Santosh Kumar, Anomalous b-value in seismogenic layer of Bhuj region. 8. K M Bhatt, Rotation of faulted block in 26 Jan 2001, Bhuj earthquake. 9. K M Bhatt, Intersecting fault pattern and Bhuj earthquake.
4	2nd International Conference on "Nonlinear Dynamics in Geosciences" Heraklion, Crete, Greece, July 1-6,2008	**Arun Gupta** and Avadh Ram, Application of chaotic system for the analysis of Himalayan Earthquakes
5	15th National Space Science Symposium (NSSS-2008) at Radio Astronomy Centre (NCRA – TIFR), Ooty-643001 during February 26-29, 2008.	**Bhattacharyya Rudradeb** and Majumdar Tapan Jyoti, Satellite Geoid/Gravity for Offshore Exploration
6	Geomatics – 2008,National Conference on Geomatics for Planet Earth & Annual Convention of Indian Society of Geomatics, 18-20 Feb.,2008 at Bhopal (M.P.)	**Ranjana Vyas** and Dr. Pramendra Dev, Management of Groundwater Resource of Kolwa – Sawakhera Drainage Basin, Mandsaur District, M.P.

***Abstracts accepted for presentation, but did not attend the Seminar.**

Seminar Talks by visitors

Dr. D. V. Reddy, Scientist NGRI, Hyderabad Geo-chemical precursors of earthquakes, 20th July 2007

Dr. V. Gahalaut, Scientist, NGRI, Hyderabad, Seismic Interpretations of geodetic data, 24th July, 2007

Dr. P. Banerjee, Scientist Wadia Institute of Himalayan Geology, Dehradun GPS in understanding the great 2004 Sumatra-Andaman Earthquake, 25th July, 2007

Prof. R.N. Iyengar, IISc Bangalore, Ground Motion Attenuation in Peninsular India, 27th Oct 2007

Dr. Anand Joshi, IIT Roorkee delievered lectures covering following topics on 20th and 21st December, 2007

(i) Modified semi empirical method of simulation of strong motion.
(ii) Empirical Greens function – Points to remember.
(iii) A simulation based deterministic approach of seismic zonation.
(iv) Processing of strong motion data.
(v) Use of intensity data for determination of three dimensional attenuation structures.
(vi) Inversion of strong motion data for frequency dependent Qb (f) relation.

Dr. J. Chetlain, Scientist, LGIT, Grenoble, France; 10th and 11th December, 2007.

- Ambient vibrations: a providential tool for earthquake hazard assessment.
- Discussion on GEOPSY software.

Discussion Meetings

30th July, 2007	Discussions for the ongoing work in Kandla region.	Dr. Kaneko, Oyo International, Japan
7th August, 2007	Discussions for the drilling work at Kachchh	Mr. Om Behari Srivastava, Geo-hydrologist, GWSSB Gujarat
11th Feb 2008	Discussions on Vulnerability analysis of ports and jetties in Gulf of Kachchh with regard to oil supply to North India.	Prof. Alok Goyal, Civil Engg., IITb Prof. Nirjhar Dhang, IITkh Dr. Pradeep Kumar, IIIT, Hyderabad

Seminar Talks by ISR Staff

1. M.S. Gadhavi “
2. K.M. Bhatt “
3. R.K. Singh “Gravity surveys to map the subsurface geology” on 6th Dec 2007.
4. Babita Sharma “Inversion of Coda wave envelope in Kachchh Region” on 2nd Jan 2008.

Distinguished Visitors:

1. Prof. Roger Bilham, Colorado Univ., 19.4.2007
2. Prof. Vinod Gaur, Inst Astro Physics, Bangalore, 19.4.2007

Inhouse training lectures

Jun 2007	B.K. Rastogi: Elastic Rebound Theory of Earthquake Mechanism, Seismic waves, magnitude and intensity.
8-12.7.07	V.M. Maru, Series of lectures on Instrumentation and Office automization
07-08-07	A.K. Gupta, Introductory lecture on different types of Geophysical & seismological of instruments & branches of Geophysics
08-08-07	R.B.S. Yadav, Solar system & structure of earth
09-08-07	A.K. Gupta, Seismology & Seismic Instrumentations
10-08-07	R.B.S. Yadav, Plate tectonics & continental drift theory
10-08-07	Santosh Kumar, Analysis of Delta-Geon data
11-08-07	R.B.S. Yadav, Basic of Seismology & seismic wave phases
14-08-07	A.K. Gupta, GPS instrumentation

22-08-07	R.B.S. Yadav and A.K. Gupta, Gravity methods & Gravimeters
23-08-07	R.B.S. Yadav, Theory of magnetic methods
23-08-07	A.K. Gupta, Geomagnetism , Palaeomagnatism & magnetometer
21-08-07	A.P. Singh, Basics of Unix
29-08-07	A.K. Gupta, Electromagnetic waves, Time domain Electromagnetism (TDEM), Magnetotellurics (MT) and Electromagnetic Surveys, Resistivity methods, Resistivity meter and GPR
30-08-07	A.K. Gupta, Establishment of MPGO and superconducting gravimeter
28-01-08	Dr. Arun Gupta: Geophysical science & various branches Dr. Uday Bhonde: Introduction to Geological Science
29-01-08	Mr. Santosh Kumar: Introduction to SCREAM & SEISAN software (Theory) Mr. Pawan Kumar: Introduction to SCREAM & SEISAN software (Practical)
30-01-08	Dr. Babita Sharma: Earth's Interior & Plate Tectonics
31-01-08	Mr. Rudradeb Bhattacharya: Geodynamics of the earth Dr. Arun Gupta: Introduction to Seismology
01-02-08	Dr. Babita Sharma: Seismology: Essentials to know the earth Mr. Srichand Prajapati: Earthquakes and GPS Mr. Kapil Mohan (Practical-----SMA data)
02-02-08	Dr.Uday Bhonde: Geological Time Scale in detail Mr. Rakesh Dumka: Global Positioning System Dr. Arun Gupta (Practical------Reftek, BBS data)
04-02-08	Mr.R.K.Singh: Geophysical prospecting Mr.K.M.Bhatt: Electromagnetic methods
05-02-08	Mr. M.S.B.S.Prasad: Geomagnetism & Magnetometers Mr.Santosh Kumar: SMA (GeoSig) installation & Data processing.
06-02-08	Seisan Test
07-02-08	Dr. Pallabee Choudhury: GPS study at ISR
08-02-08	Visit to seismological observatory in Gandhinagar and field setup of engineering seismograph at Raisan
12-02-08	Mr. R.B.S.Yadav: Solar system and interior of the earth
13-02-08	Dr. Pallabee Choudhury: GPS reference frame and data processing
14-02-08	Mr. A.P.Singh: Introduction to various Hazards
15-02-08	Mr. Sandeep Aggrawal: Modern seismological instruments and seismology
16-02-08	Mr.R.K.Singh: Gravity Prospecting
18-02-08	Mr.R.K.Singh: Gravity corrections
19-02-08	Mr.V.M.Maru: Efficient and effective method for handing the geophysical instruments
20-02-08	Mr.R.K.Singh: Geodynamical processes
21-02-08	Mr.V.M.Maru: Efficient and effective method for handing the geophysical instruments
22-02-08	Dr. Uday Bhonde: Petrology: Minerals and Rocks
25-02-08	Mr. M.S.Gadhvi: SAR Interferometry
27-02-08	Mr.R.K.Singh: Electrical prospecting
28-02-08	Dr. V.M.Maru: Computers & Number System
29-02-08	Mr. R.K.Singh: Geological Application of Geophysical Methods
01-03-08	Mr. Mahendra Gadhvi: Structural set up of Kachchh Dr. V.M.Maru: Geophysical instruments
03-03-08	Dr.Uday Bhonde: Geological set up of Gujarat Dr.V.M.Maru: Geophysical instruments

Projects:

Project	Sponsoring Agency	Period	Value Rs. L
Paleoseismology in Kutch	GoG	Apr.2007-Mar.2010	
Microzonation in Gandhinagar and a few towns in Kutch like Gandhidham, Bhachau and Rapar	GoG	Apr.2007-Mar.2010	
Seismicity Research & Applications in Gujarat	GoI	Feb.2006-Mar 2009	250
Crustal Deformation in Kutch and Narmada	GoI	Apr 2007- Mar 2010	65
Surface Deformation in Wagad area of Kutch using InSAR	SAC, ISRO	Apr. 2008-Mar.2011	19

Annexure 6

BUDGET FOR 2007-08

A) Non-recurring

World Bank loan for ISR Building	20.00 Crore
World Bank Loan for Instruments	30.00 Crore
Corpus fund (Fixed deposit)	8.00 Crore
DST, Delhi (Instruments: GPS)	0.50 Crore
GoG (Instruments: OSL and Microearthq. Recorder)	1.00 Crore
Total	Rs. 59.50 Crore

B) Recurring

Agency	**Amount Rs. In lakhs**	**Title**
DST- GoI	40	Seismological Research and Applications in Gujarat
DST-GoI	4	GPS studies
GoG	80	Recurring, running of network, Paleoseismology and Microzonation Studies
GoG	72	Corpus Fund Interest
GSDMA	3	Site Response at Gandhidham
ISRO	1	InSAR studies at Wagad
Total	200	

Books and Journals:
The amount spent in books and journals is as follows:

For the year 2006-07………….Rs. 8.41 L
For the year 2007-08………….Rs. 15.45 L

Details of instruments of ISR:

Sr No	Name	Model No	Manufacturer	QTY	Cost lacs (Rs)	Funding Agency
INSTRUMENT PROCURED						
1	Broad Band Seismometer	CMG-3T 120 sec	GURALP, U.K	48	286.8	19-ADB, 25-WB, 4-GOI
2	Broad Band Seismometer	CMG-3T 360 sec	GURALP, U.K	3	22.8	3-WB
3	Digital Acquisition System for BBS	REFTEK DAS-130	REFTEK, U.S.A	29	129.7	25-WB, 4-GOI
4	Digital Acquisition System for BBS	DM-24	GURALP, U.K	22	128.7	19-ADB, 3-WB
5	Strong Motion Accelerographs	GSR-18	GEOSIG, Switzerland	46	167.98	40-ADB, 6-WB
6	Strong Motion Accelerographs	ETNA	Kinematics, USA	4	14.5	4-GOI
7	Global Positioning Systems	GRX1200 GG-PRO	LEICA, Switzerland	36	189.67	32-WB, 4-GOI
8	Global Positioning Systems		Topcon, Singapore	6	36	6-GOI
9	Global Positioning Systems RTK enabled	RTK	LEICA , Switzerland	2	18.85	2-GOI
10	Engineering Seismograph 48 channel		Geometrics, USA	1	65	1-GOI
11	Ground Penetrating Radar (GPR) 100 MH and 200 MH antenna		GSSI, USA	1	45	1-GOI
12	5 SEC SEISMOMETERS	LE-3D/5S	LENNARTZ , Germany	8	30.99	8-GOG
13	MICROTREMOR RECORDER	CITY SHARK-II	LEAS, FRANCE	8	28.22	8-GOG
14	Resistivitymeter		IGIS, Hyderabad	1	0.37	1-GOG
15	ARCGIS software			1	12	1-GOG
			TOTAL		**1176.58**	
ORDERS PLACED						
1	MAGNETO TELLURIC UNIT	ADU06	METRONIX	1	39.84	1-WB
2	GRAVIMETER	CG-5	SCINTREX , CANADA	2	64.446	2-WB
3	Triaxial Fluxgate Magnetometer		Magson, Germany	2	29.232	2-WB
4	Time Domain E.M profiling system		ZONGE , USA	2	81	2-WB
5	RESISTIVITY IMAGING SYSTEM	SYSCAL PRO	IRIS, FRANCE	1	39.161	1-WB
6	DIGITAL WATER LEVEL RECORDERS		IRIS, FRANCE	7	7.1166	7-WB
7	ELECTRONIC AUTO RADON MONITOR		SHARAD Germany	5	15.9935	5-WB
8	TL/OSL DATING SYSTEM		Riso Nat Lab Denmark	2	103.68	1-WB, 1-GOG

9	Super Conducting Gravimeter		GWR, USA	1	420.288	1-WB
10	Borehole Strainmeters		GTSM Tech, Australia **TOTAL**	3	450 **1250.76**	3-WB
GOODS UNDER PROCUREMENT						
1	Proton Precision Magnetometer			2	7	2-WB
2	Over Hauser Magnetometer			2	24	2-WB
3	Auto Helium Monitor			5	60	5-WB
4	LONG PERIOD MAGNETO-TELLURIC UNIT		Lviv Institute of Space Research, Ukrain	2	30	2-WB
5	ULF MAGNETOMETER		Lviv Institute of Space Research, Ukrain	2	13	2-WB
6	DECLINATION / INCLINATION MAGNETOMETERS		Lviv Institute Of Space Research, Ukrain	2	1.3	2-WB
7	Total Station			1	5	1-WB
8	PS logging unit			1	40	1-WB
9	Cyclic Triaxial testing system			1	48	1-WB
10	ABSOLUTE GRAVIMETER	FG-5	SCINTREX, CANADA	1	225	1-WB/GSDMA
11	AUTO LOCATION SOFTWARE		KINEMETRICS, USA	1	80	1-WB
12	Magnetic Separator		Frank-Hertz, USA	1	10	1-WB
			TOTAL		**543.3**	

WB – World Bank	Rs. 21.0 crore
ADB – Asian Development Bank	Rs. 5.0 crore
GoI – Government of India	Rs. 2.5 crore
GoG – Government of Gujarat	Rs. 1.5 crore
Total	**Rs. 30.0 crore**

Annexure - 7

A report on

"National Seminar on Seismic Microzonation" held on October 26, 2007

After welcoming the delegates Mr. Rajesh Kishore, CEO, Gujarat State Disaster Management Authority (GSDMA) discussed the importance and the theme of the workshop, the role of GSDMA towards seismic hazard and microzonation studies in Gujarat state particularly after the Bhuj earthquake. He said the concept of ISR conceived during 2002 to have an institute dedicated to seismological research and finally in 2003, ISR was established. He also said that the new building of ISR will be ready by June 2008 and GSDMA continues to support financially towards ISR's infrastructure.

The seminar was officially inaugurated with the opening remarks by the chief guest Padmashree Prof A S Arya. He advised all the delegates to discuss the important issues of microzonation and asked a question that "What is the value and social benefit of microzonation".

Prof. R. N. Iyengar presented the first technical presentation on seismic microzonation of vulnerable cities of India. He expressed on the importance of mapping of city level hazard, vulnerability and risk maps as a tool to plan, design and protect the built environment from possible future earthquake disaster. He stressed to adopt rational methods to map the prevailing hazard in cities. Prof. Iyengar also discussed on the steps involved in microzonation studies which includes identification of active faults and past epicenters within 300 km of the city, fault deaggregation, suitable attenuation law, site classification based on shear velocity in top 30m etc. He said, a good hazard microzonation map can be a decision making tool for municipal administrators on land use planning and in enforcing desired earthquake resistant measures as per relevant building codes.

Prof A S Arya presented the next technical presentation and discussed the issues in seismic microzonation studies in India. He presented the critical aspects of hazard parameters; e.g what should be the threshold upper limit of magnitude in Gutenberg Richter law, the scope and issues involved in seismic microzonation, vulnerability of built environment, what should be taken as bedrock level, determination of shear wave velocity, the upper limit of soil amplification factor etc. He also showed the thumb rule to estimate the design horizontal seismic coefficient for different seismic zones.

The structural evolution and tectonics of Kutch peninsula was presented by the next speaker Dr S. K. Biswas. He discussed very broadly the regional tectonic setup, tectonic framework and structure, tectonic model, history of tectonic evolution, tectonic and morphotectnic map of Kutch. He also showed and discussed the major tectonic trends in western Indian craton, Saurashtra horst and rift basin of India showing intraplate dynamics. He finally gave a conceptual tectonic model of Kutch.

Dr B K Rastogi, Director General, ISR delivered the keynote address on microzonation studies in Gujarat. He explained that the Gujarat region has earthquake hazard of different levels from moderate to high as zones III to V are assigned to it in the seismic zoning map of India. He showed the first order probabilistic zoning map including assessment of vulnerability and hazard maps prepared by GSDMA and TARU consultants. He also presented the microzonation studies carried out by different organizations in different parts of Gujarat state including Gandhinagar, Ahmedabad, Kachchh, Anjar, Gandhidham, Kandla and Bhuj. Ahmedabad and Gandhinagar cities fall within the Cambay sedimentary basin with about 400 m thick Quaternary sediments of Sabarmati river basin. The fundamental frequency has been shown around 0.6 Hz in both the cities, indicates that 2-10 buildings can be constructed with the existing seismic safety factor norms. The strong motion attenuation estimated by analytical methods for Kachchh region has also been presented by Dr Rastogi and it is found that at Bhuj, PGA would have been 0.31-0.37 g.

Fumio Kaneko from Oyo International presented the seismic microzonation results of Gandhidham project. He started with the source definition showing the slides of historical earthquakes, instrumental seismicity, active faults, trench works and possible earthquake scenarios. He presented the various fault models for seismic ground motion and parameters to be set for macroscopic (empirical attenuation) and microscopic (theoretical & Dynamic: Green's function method). He also showed the flowchart for soil modeling to get soil layer structure and distribution. He presented the geomorphological map, location of drillings and microtremor observation used in microzonation of Gandhidham. He showed the estimated PGA (gal) at engineering bedrock by attenuation law and by Green's function and finally showed the site amplification map of Gandhidham and scope of his presentation to future such study in Gujarat. Dr Siva Subramaniam of RMSI showed various satellite maps of Gandhidham.

Dr J N Malik presented his work on active fault, paleoseismic investigations in Kachchh. He began with the historical and instrumental seismicity of Kachchh region including 2001 Bhuj earthquake. He focused on the significance of active fault study and its definition. He showed the results of his recent study on active faults based on trenches in Lodai and Jhura on Kuchchh Mainland fault and Wandhay on Katrol Hill fault and Bhuj on Bhuj fault. He found three events during historic past from North to South on Kuchchh Mainland fault and showed the displacement of 10, 42-50 and 60-70 cm respectively. Finally, Dr Malik validated his results with GPR study and showed the agreement of his findings of Trench study.

The last presentation before the lunch was made by Dr Prantik Mandal of NGRI. He presented his findings on the spatial variation of site response in the Kachchh seismic zone based on horizontal components of S waves at two frequency band 0.2-1.8 Hz and 3-7 Hz from 38 aftershocks recorder by digital strong motion accelerographs. He found larger site response between 1.0-1.7 In the region of south of Kachchh mainland fault, whereas the regions north to KMF shows smaller site response and the maximum at Sikara site. Dr Mandal found a good correlation with the estimated site response with sedimentary thickness except Amarsar where he found de-amplification. He also used generalized inversion technique and found 2-3 time less site response compared to spectral ratio method.

Dr. Amod Mani Dixit, NSET, Nepal, chaired the technical session – II, wherein, a total of five papers were presented. In the first presentation, the chairman drew attention toward the importance of the seismic hazard mitigation of the seismically active Nepal Himalaya. He also presented results from their probabilistic hazard mapping, risk assessment and vulnerability studies in the Kathmandu valley in particular and Nepal in general. In the first presentation, Dr. Sushil Gupta, RMSI, Delhi gave an overview of RMSI's activities for the natural disaster management in India. He presented the first earthquake loss estimation model for India, which was developed by RMSI at state, district, block and major city level, using the existing seismic sources, a comprehensive historical earthquake catalog, a modified attenuation relationship and a varying resolution grid. He also pointed toward the fact that the loss model was validated by comparing the historical losses against the modeled loses particularly for the recent Indian earthquakes. In another presentation, Dr. Ravi Kumar, NGRI, Hyderabad, presented the results from the Jabalpur Microzonation experiment. He drew attention toward the importance of near surface ground characterization in terms of geomorphology, liquefaction, site response, and shear velocity structure for top 30m, for the seismic microzonation study. He also presented the 1st level microzonation map for the Jabalpur area, which classified this region into 9 zones and 22 units of low, moderate and high hazard. In the next presentation, Mr. Shukyo Segawa, Oyo Int. Corp., gave a comprehensive overview of their microzonation studies in west Japan and Istanbul. He also presented the microzonation seismic hazard maps, shear velocity structures (delineated using SPT, PS logging and array microtremor survey) and site response values (estimated using SHAKE) for Istanbul and west Japan. In the last presentation of the technical session-I, Dr. Prabhas Pande, GSI, Lucknow, drew attention toward the importance of various geological methods in studying the microzonation of any area. He gave an overview of the microzonation studies, which are already being initiated by the Geological Survey of India for 11 cities in India, which fall in the seismic zones III, IV and V. He also presented the results of their microzonation studies in Dehradun and Delhi. He proposed that preparation of a detailed geotechnical map of any area would be very useful for the microzonation study in future.

Dr. A.K. Ghosh, BARC, Mumbai chaired the technical session-III. In this session, Prof. Sitharam, IISc, Bangalore made the only presentation. He drew attention toward the scopes for improving the seismic microzonation practices in India. He presented the results of their Bangalore microzonation study. He also suggested that more importance should be given for geotechnical part of any microzonation study.

Mr. M. Mohanty, DST, Delhi chaired the concluding session. There were two presentations in this session. In the first presentation, Dr. S.K. Jain, IIT, Kanpur, drew attention toward the fact that the surface geology can affect the ground motion significantly. He cited two examples of the local amplification of ground motion causing large death toll due to the unconsolidated sediments in Mexico city and San Fransisco, USA, during the distant 1985 Guerrero Michoacan earthquake and the 1989 Loma Preita earthquake, respectively. In the last presentation, Miss Alpha Seth, Structural Engineer, Mumbai, drew attention toward the importance of the inclusion of microzonation in the town planning and insurance policy in India. She also gave examples of Turkey and Mexico, where microzonation have already been included in the town planning and insurance policy. The conference concluded with the comments of Prof. Arya stressing the need for microzonation / seismic hazard studies in India in general and Gujarat, in particular.

International Workshop on Active Fault Studies in Kachchh

January 18-19, 2008 at Bhuj

Gujarat State Disaster Management Authority (GSDMA) in association with Institute of Seismological Research (ISR), Gandhinagar and Oyo International, Japan organized an International workshop on active faults in Kachchh. The workshop was attended by 35 delegates from India and Japan.

Microzonation of Kandla-Gandhidham-Anjar area of Kachchh is being done by Oyo International Corporation. Paleoseismology and mapping of active faults is an essential part of microzonation to identify neotectonically active faults, their fault lengths and the recurrence rate of earthquakes. In the Kachchh region where the data from historical earthquakes is lacking, trenching near active faults can reveal the seismic parameters like location, magnitude, dislocation, direction of movement, date of event. Dr. M. Morino of Oyo international in collaboration with Javed Malik of IITk and M. S. Gadhavi of ISR for the first time in India identified active fault portions in Kachchh on the basis of stereo viewing of satellite imageries in the form of pressure ridges. Neotectonic activity has been confirmed by trenching near Jhura and Lodai along Kachchh Mainland fault (KMF), Wandhay and along Katrol Hill Fault (KHF), and near Bhuj along NE splay of KHF as the Bhuj Fault from Wandhay to Bhuj. Trenches near Jhura, Lodai and Wandhay were shown to the delegates in the mornings and lectures were held in the afternoon. A large number of samples have been collected and dating of these will give the dates of events.

Vinod Gaur and Roger Bilham opined that the1819 earthquake might have occurred along the KMF as there is evidence of some deformation and tsunami near Lakhpat. Allah Bund some 80km north of it might have been caused by wedge thrusting.

M. Morino showed that in Jhura trench along KMF the Quaternary deposits were widely deformed and three small faults were identified indicating three seismic events with a net slip of about 60-70cm. Pressure ridges were observed with 3-5m height extending in EW direction near Lodai village. A trench was excavated in the northern edge of the ridge. Three fault strands were identified in the trench. These are typical reverse faults with dip of 10°-60° inclined to south. The southern fault strand demarcates boundary between Jurassic rocks and Quaternary deposits. At least two seismic events were detected in the trench.

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. This will throw some light on the faulting history of KHF.

The E-W trending KHF branches as NE-SW extending Bhuj fault at Wandhay village. Two parallel faults, southern and northern were found south of Bhuj town across road cuttings. The southern one is a low angle reverse fault. The northern one is associated with low fault scarp with 1-1.5m height and is 100m north of earlier one. A trench was excavated across the northern fault. The exposed sedimentary succession in the trench is Mesozoic rocks and thin channel deposits. The fault displaced all units except top soil cover. Only one event was detected in the trench. The Bhuj fault is an important active fault from the seismic hazard perspective due to its proximity to the Bhuj town.

The trench investigations revealed the faulting history of the western and central part of KMF but the eastern part needs to be explored. Exposure of eroded fault along eastern part of KHF is found in the field. This eastern part of KHF is suggested as inactive. The Bhuj fault is the active foreland migration of KHF.

Javed Malik et al. reported finding of three events on the basis of cross-cutting of liquefaction features in the few trenches excavated around Vigukot in the hanging wall of ABF by IITK and ISR team.

S.K. Biswas gave talk on tectonic cycles, stress dynamics and active faults in Kachchh graben. The rifting of Kachchh basin took place during the breakup of Indo-African plate in late Triassic - Early Cretaceous period. The Kachchh rift is oriented EW and is bounded by Nagar Parkar Fault (NPF) in the north and North Kathiawar fault (NKF) to the south. The basin terminates against Radhanpur-Barmer arch to the east. Tilted blocks along sub-parallel faults within the basin formed horst-graben-half graben system. The tilted blocks and horsts are the uplifts and graben/half grabens are low lying areas. Huge sediments were accumulated along Banni and Gulf of Kachchh half grabens which has given south tilted asymmetry to this rift. Most of the faults in the basin are deep seated basement faults not exposed to the surface. Major faults are Nagar Parkar fault (NPF), Island Belt fault (IBF), Kachchh Mainland-South Wagad fault (KM-SWF), Katrol Hill fault (KHF), Gedi fault (GF) and Goradongar fault (GDF). The rifting occurred from north to south by reactivation of these faults along the primordial trend of the Delhi fold belt. Biswas attributes major strike-slip movement along the faults in Kachchh. The KM-SWF and NKF remained most active since mid Jurassic till recent. KM-SWF is the most active fault in the present neotectonic cycle as evident from morphotectonic and earthquake activity associated with it. The KHF and GDF have been activated by the upthrust of the mainland and Pancham island block during late Cretaceous rift inversion stage which is continuing till present. The morphotectonic features indicate Quaternary uplift along above mentioned faults. There is also a median high running NNE-SSW in the middle of Kachchh basin. Radhanpur-Barmer arch and median high act as stress barrier and that is the reason for higher seismicicty in the eastern part of Kachchh. Most of the damage during 2001 Bhuj earthquake was to the right of median high. Most of the uplifts and tectonic activities are also to the right of it. Most of the fractures are also aligned with this high. The Bhachau-Samkhiali zone is highly stressed region which is a step over zone.

Prof.R.V.Karanth gave talk on active tectonics and paleoseismicity of Kachchh mainland and its implications for late quaternary landscape evolution. He said that there are numerous instances of fault propagation folds, fault bend folds, detachable folds and bending movement faults which control the present topography on surface. The Kachchh peninsula is an example of active fold and thrust tectonism and there is major reverse movement. There are four major EW oriented hill ranges characterized by fault propagation folds with steeply dipping northern limbs and gently dipping southern limbs. Rocks older than Jurassic are not exposed in Kachchh. The sedimentary rocks are gently dipping and dissected by faults. Low angle reverse faults are found with asymmetric folds at several places along linear hill ranges. From the gradual increasing dimension of linear chain of hillocks towards west along KMF, it is suggested that eastern part of KMF is progressively emerging upward. Due to absence of surface rupture during 1956 Anjar and 2001 Bhuj earthquakes, it is inferred that the movements have taken place along a blind thrust. Series of villages situated on the blind thrust in the eastern part of KMF were completely destroyed.

Koji Okumura of Hiroshima University, Japan explained the paleoseismological studies and hazard assessment of active blind faults on the North Anatolian fault (NAF), Turkey. Trenching work was carried out on 1944 Bolu-Gerede earthquake rupture site in order to examine recurrence behavior of active fault system through several earthquake cycles. Four paleo-faulting events were detected in these trenches. Radiocarbon dating was obtained to calculate probability distribution of ages of each event. The most recent one was 1944 event. The penultimate event occurred after AD 1640 preceded by two events between AD 1210 and AD 1460 and AD 840 and AD 960, respectively. He opined that blind faults are significant for evaluating long term earthquake hazard assessment of a region. During 1995 Kobe earthquake half of the inferred fault in Quaternary area had no surface rupture. Significant slip took place in deeper part of the fault.

Fumio Kaneko from Oyo International Corporation gave talk on microzonation of Anjar-Gandhidham- Kandla area including soil modeling, site response and seismic motion estimation. Soil modeling in any region requires the compilation of existing data, finding soil layer arrangement and finally liquefaction modeling. Existing data is Toposheets/DEM, Geological maps, Geomorphic maps, Drilling data, Shear wave analysis, water level data and amplification measurements. Oyo drilled 80 boreholes in 400 sq km of area and have done PS logging for shear wave analysis in 16 boreholes. Beside this SPT measurements and soil tests both physical and mechanical were carried out. ISR has done amplification studies by H/V Nakamura technique at 50 sites. Basin thickness of the order of 400m was detected. Soil layer arrangement is found using logs from 80 boreholes. If we draw a section from west to east, one layer of Mesozoic in the western side of Gandhidham is found and as we move towards eastern side three sub layers of Deccan Trap with varied shear wave velocity and three sub layers of Tertiary were encountered. For response analysis shear wave Velocity, relation between Vs and N value of SPT, density of the strata and deformation characteristics are required (G/G_0-strain, h-strain). These values are found from borehole logs, PS logging, SPT tests and laboratory measurements. For Gandhidham this work is completed. Contour map of engineering bed rock (Vs>2.2 km/sec) and average Vs30 maps are prepared for Gandhidham. Shear wave velocity of Holocene deposits in the area varies from 80 to 450 m/sec while tertiary deposits are having 350-800 m/sec, basalts 790-2300 m/sec and Bhuj formation 640-870 m/sec. Finally liquefaction modeling is carried out from the above data. It is seen that southern part of Gandhidham area (Kandla) is prone to liquefaction. He also discussed about the estimation of seismic motion at surface. For this a target earthquake needs to be identified. Path and site effects are to be estimated for getting ground motion at the surface. Attenuation relationships and amplification factors need to be estimated. For Gandhidham, five source zones namely, ABF, IBF, KMF, KHF and 2001 source are selected with asperity model. Shear wave velocity measurements are converted into amplification (Matsuoka and Midorikava, 1994). Based on these measurements it is inferred that single storey buildings will not be affected in future large earthquakes but 3 to 5 storeys are prone to damages.

Prabhas Pande reiterated that Kachchh is an intraplate region but showing lot of seismicity. It is comparable with New Madrid region. Total energy released is of the order of 9.90 x 10^{20} ergs per year. Most of the habitats and civil structures are on Quaternary sediments so seismic hazard assessment is necessary. The major fault in the Kachchh is KMF which is around 120 km long. This fault was reactivated in segments during different regimes which are seen on surface traces. Scarps are seen in case of strike slip movement. Transform faults displaced KMF at several places during change of stress regime from extension to compression. Maximum earthquake generating capacity is reduced due to segmentation of KMF at several places due to transform faults. Pande gave details of tectonic ground deformation mapping by GSI consequent to 2001 Bhuj earthquake. They mapped 350m long Budhamora deformation zone. Open fissures were found in Pliocene sandstone. An 8 km Manfara-Kharoi rupture zone was marked trending NNW. Coseismic displacement of the order of 18 cm was noticed in a trench across Manfara-Kharoi section. No trace of Helium was found by NGRI on this section indicating that this rupture is not associated with source zone. It seems there are number of Seismotectonic blocks at deeper and shallower crustal levels in Kachchh. At deeper crustal levels there are 8 no. of Seismotectonic blocks. It is seen that maximum strain is along the intersection of these blocks. At shallow crustal level there are 26 Seismotectonic blocks. Maximum generating capacity from deeper crustal blocks is of the order of M8.0 with larger recurrence interval. At shallow crustal level at the most 7.0 magnitude earthquakes are expected with less recurrence interval. At deeper crustal levels the Aravalli trends prevailing in the Kachchh region are not disturbed whereas at shallower level the disturbance is in segments.

Sujit Dasgupta demonstrated neotectonic features in the Western part of West Bengal foothills in recent past which changed the course of rivers like near Ultapani. **George Philip** informed that WIHG, Dehradun has dated a great earthquake in Dun valley during 600BP with a 40m slip. There is no description of such an earthquake in historical records. In Pinjor a vertical slip of 2m has been detected.

An important recommendation of the workshop was formation of Indian Society of Earthquake Science and working groups on Active faults, Microzonation, Crustal Deformation and Geophysical Surveys for multidisciplinary and multi-institutional efforts.

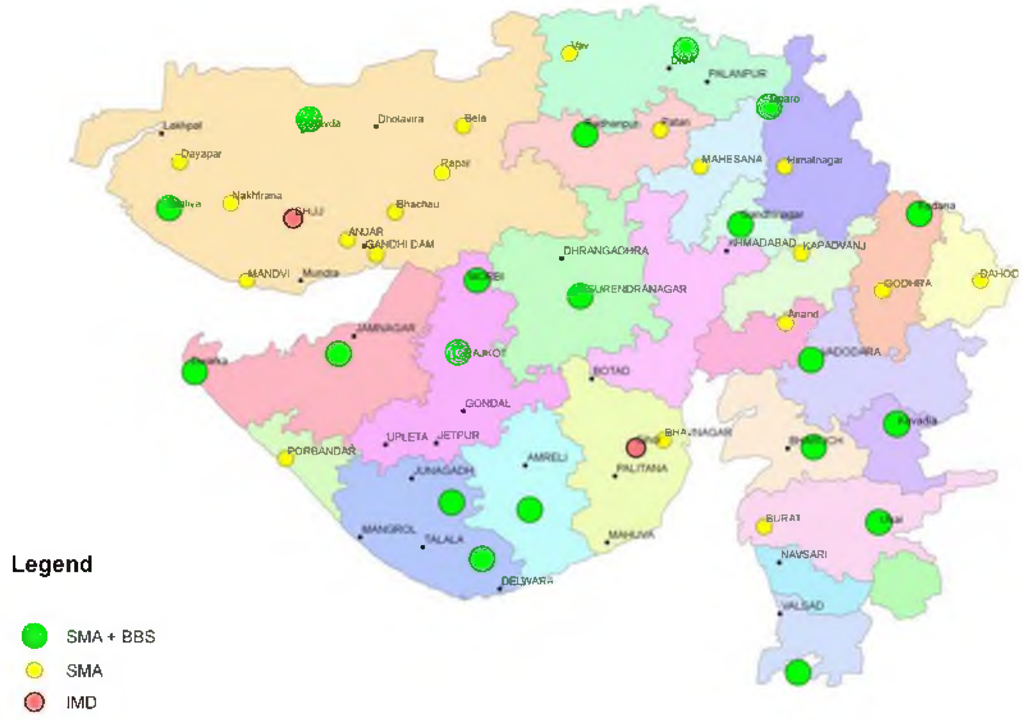


Fig. 1: Seismic Stations in Gujarat.

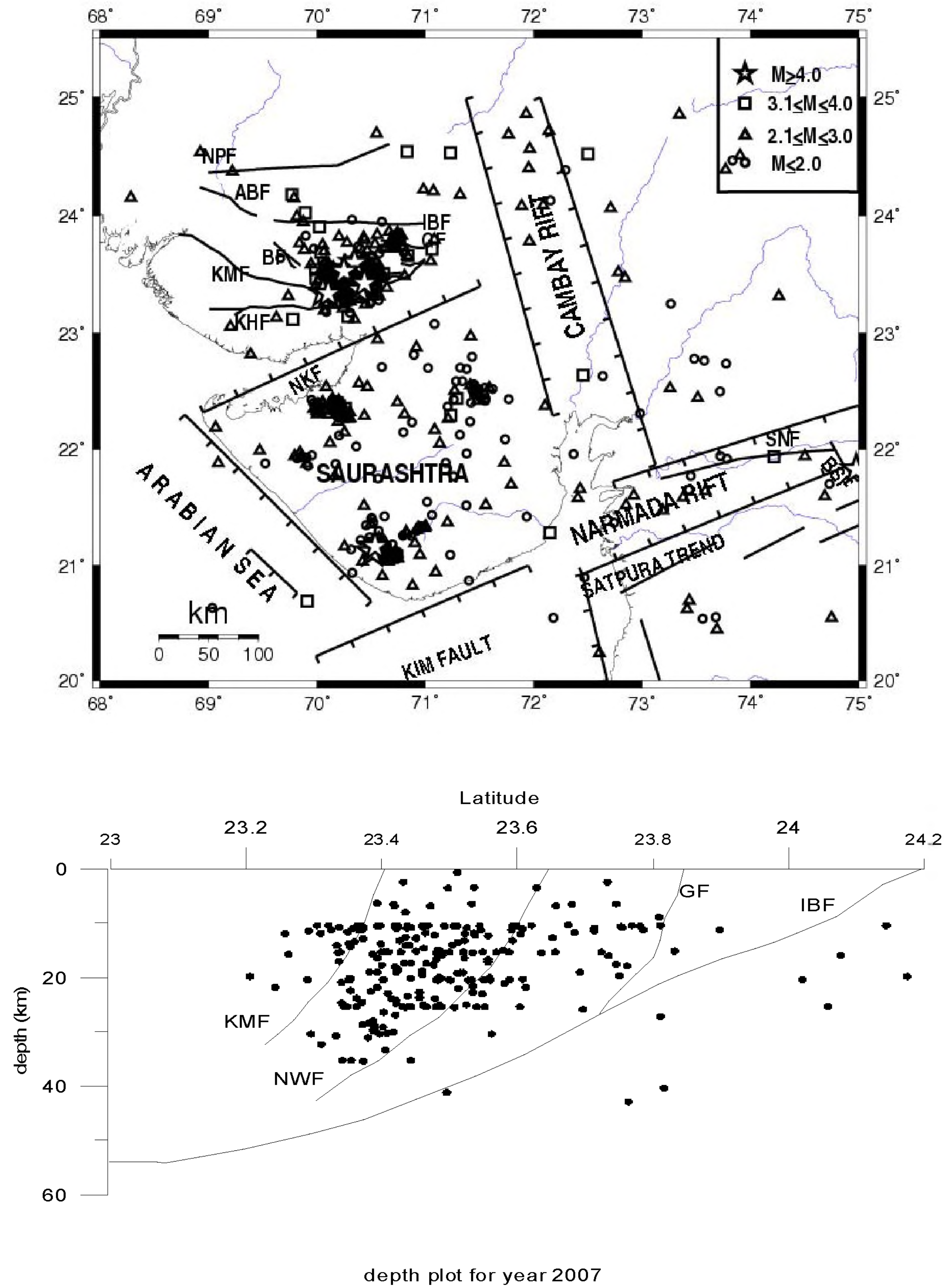


Fig. 2: Epicenters and depths of earthquakes recorded during 2007 in Gujarat.

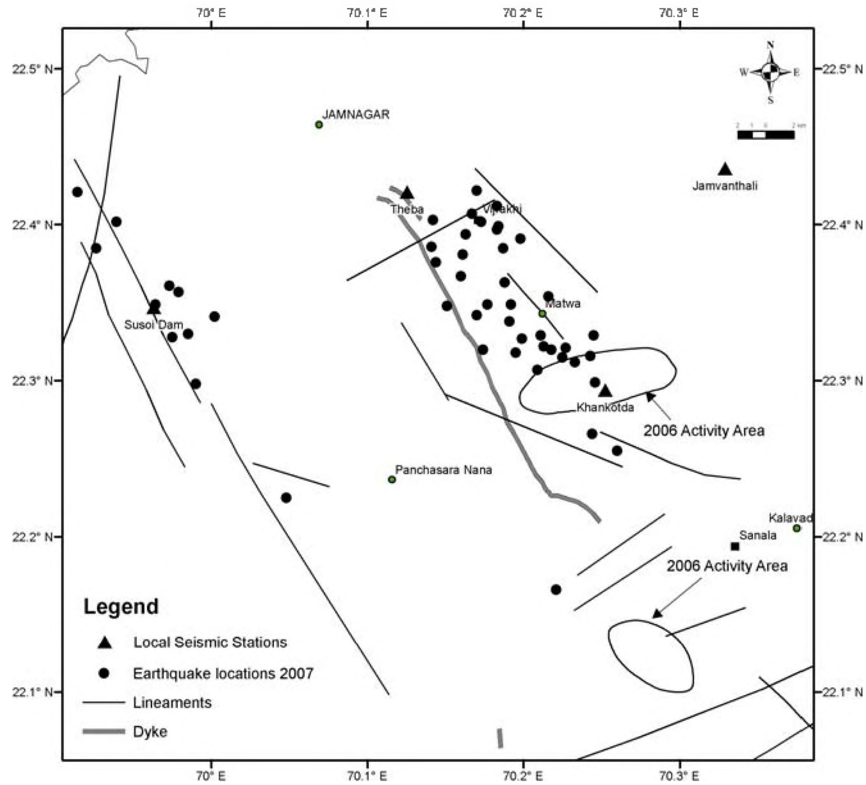


Fig. 3: Epicentres in Jamnagar district during 2007. Epicenters during 2006 were confined within the eliptical areas.

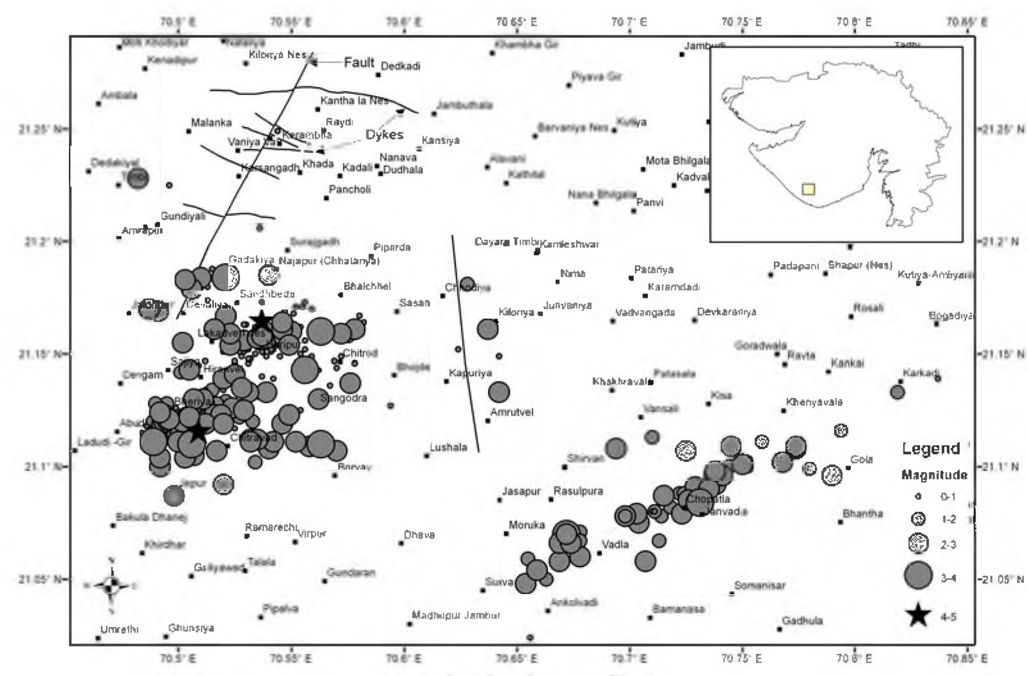


Fig. 4: Epicenters in Talala area of Junagadh dt. during Nov-Dec 2007 and causative faults. The western most fault is Haripur fault which was first detected from satellite imagery and along which M5 earthquake occurred on 5 Nov 2007. GPR survey was carried out across at it’s southern end.

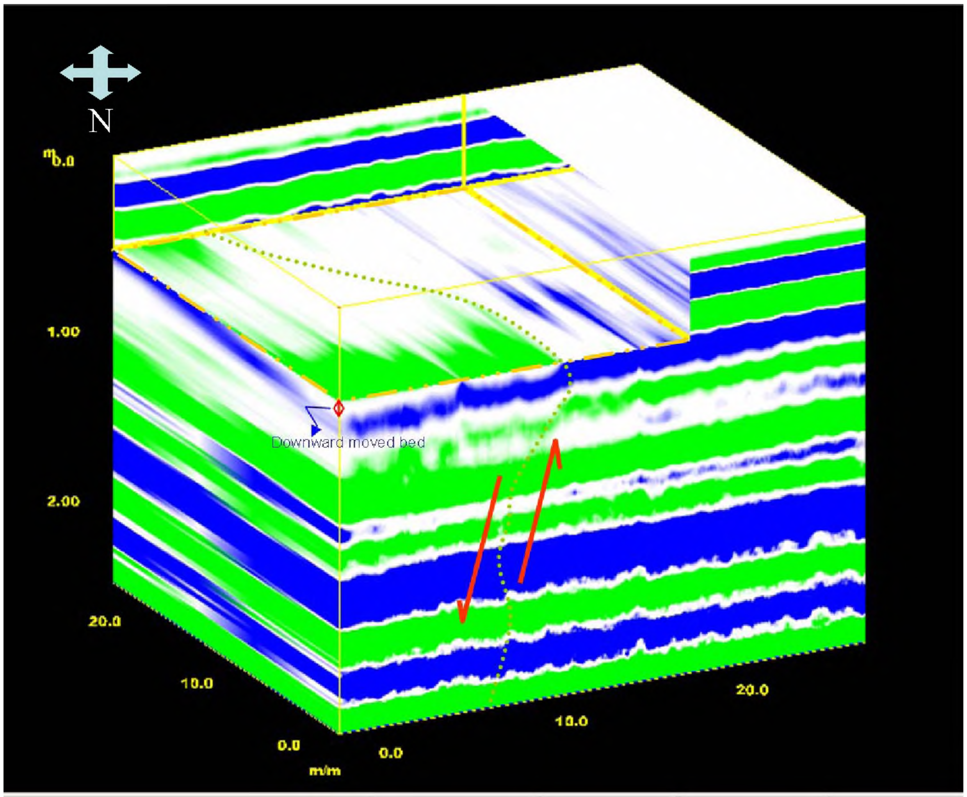
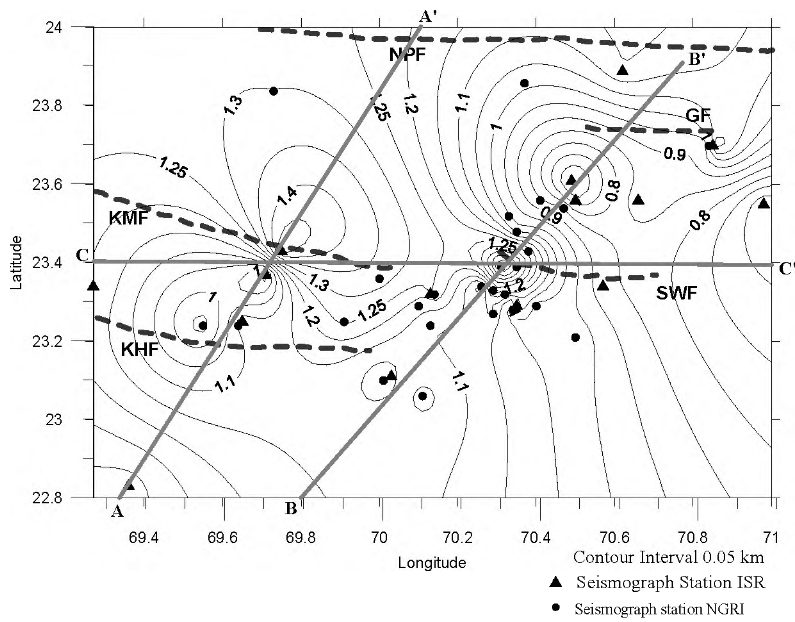


Fig. 5:Epicenters in Talala area of Junagadh dt. During Nov-Dec 2007 and GPR survey across Haripur fault which was first detected from satellite imagery and along which M5 earthquake occurred on 5 Nov 2007. A few tens of meters down throw is discernable towards northeast. Sudden change of blue to green color indicates strike slip along a N-S line.

(a)



(b)

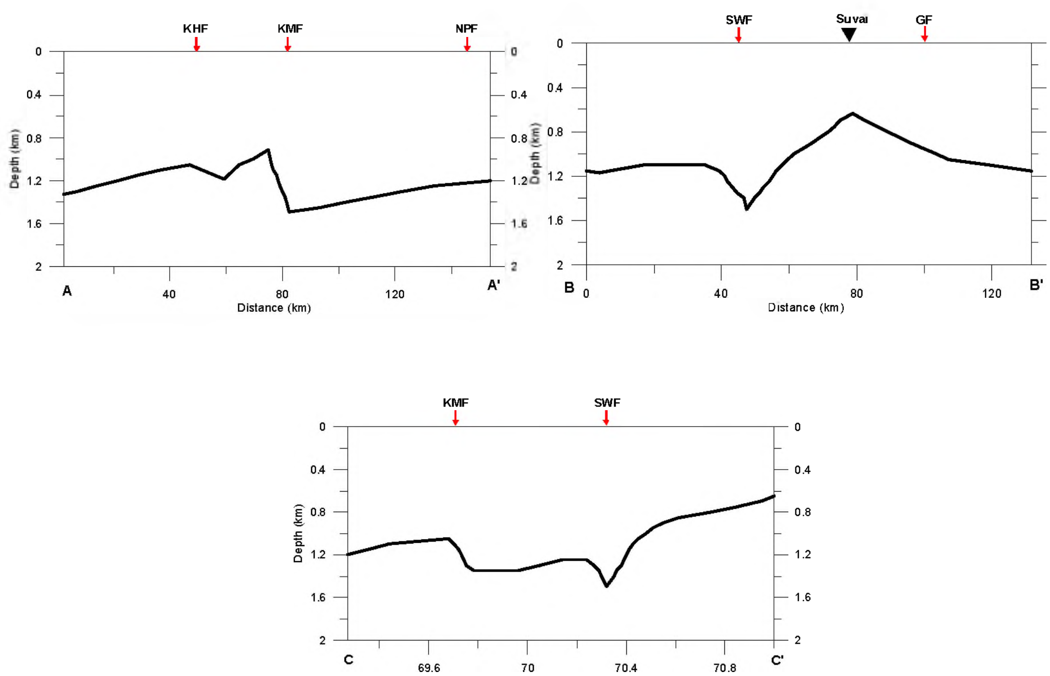
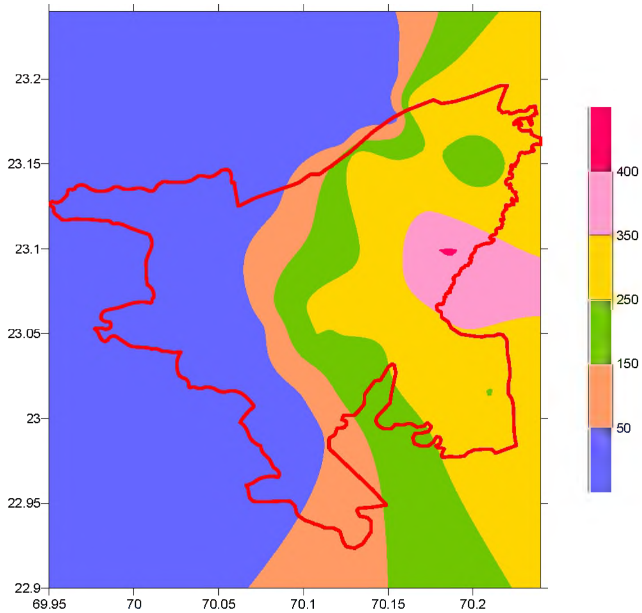


Figure 6: (a) Contour plot depicting the thickness of sediments in Kachchh region
(b) Depth sections along AA', BB' and CC' as shown in (a).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400
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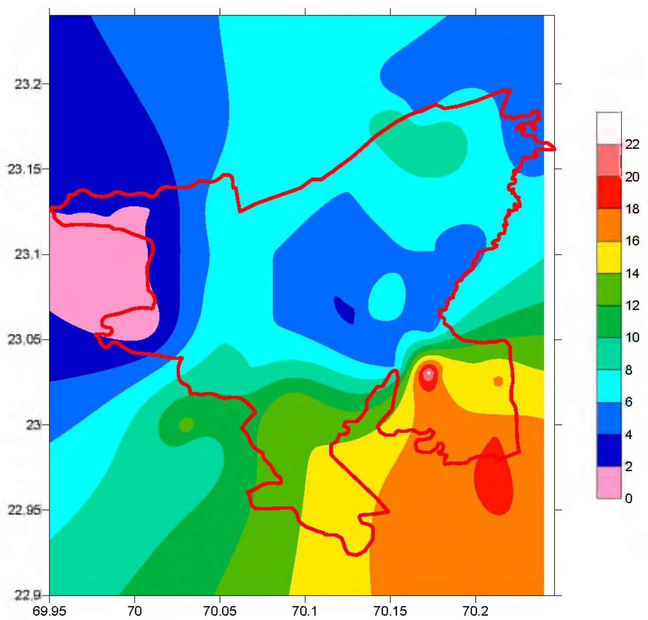
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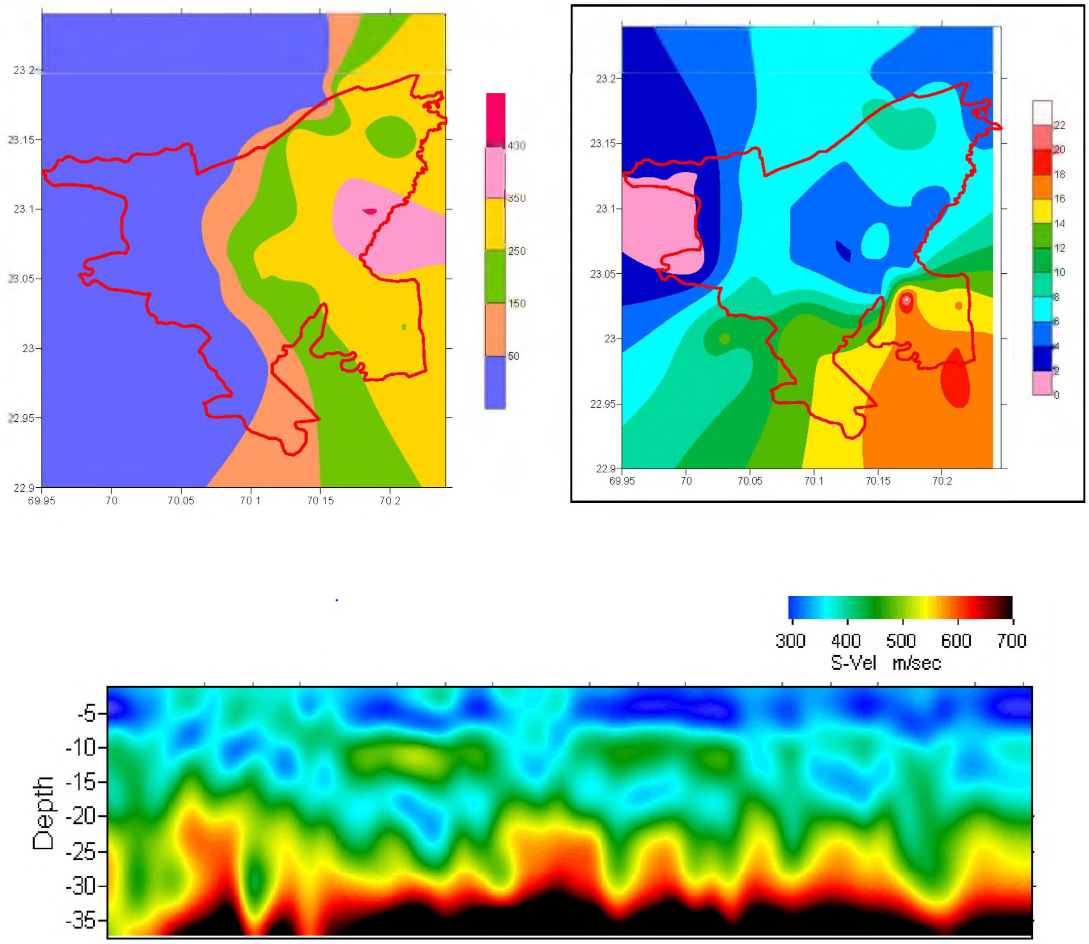


Fig.7: Site response studies in Gandhidham. The upper left figure indicates depth to engineering bedrock whose thickness varies from 250 m depth in Kandla-Gandhidham area (max 450m in coastal region) to <30m in the west. The upper right figure indicates depth of Quaternary deposits. The shear wave velocities of soil and sediments are quite high ranging from 300-500m/s at 0-25 m depth to 700m/s at 30m. The velocities derived from engineering seismograph (lower fig.) tally well with the average derived from PS logging.

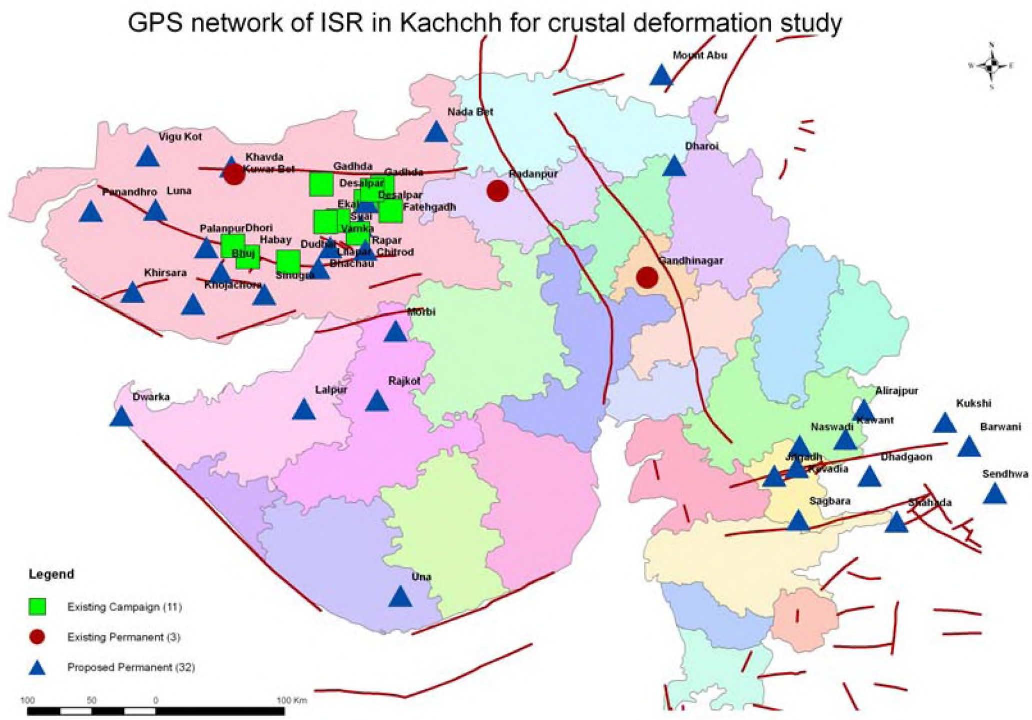


Fig. 8: Locations of permanent GPS stations planned to be installed.

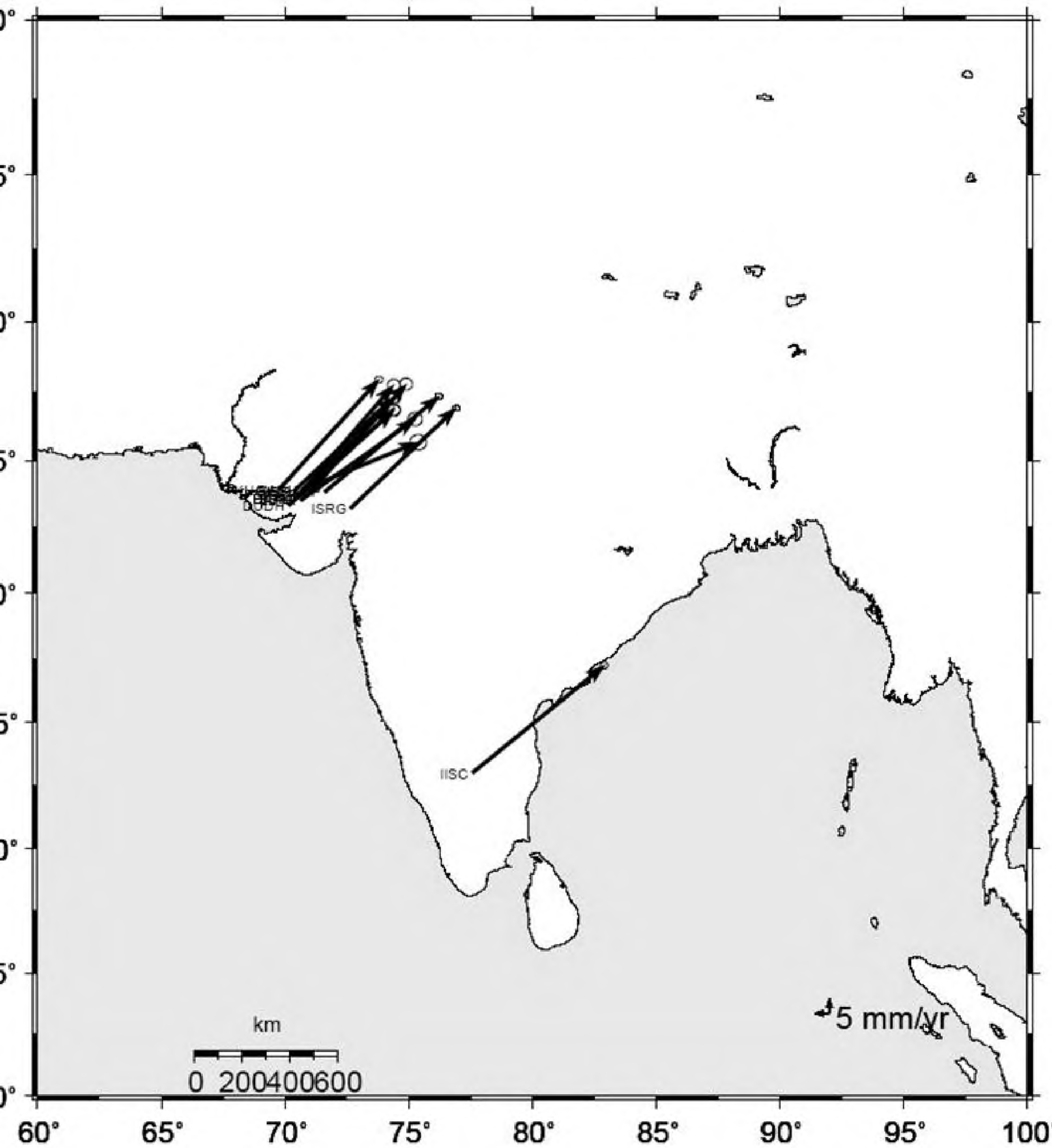


Fig. 9: Velocity vectors (~50mm/yr) of three permanent stations and various campaign stations in Kachchh region.

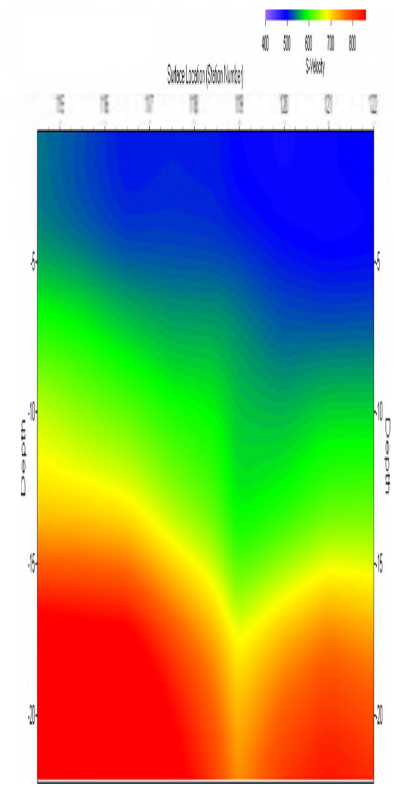


Fig10. Exposure of **Kodki Road Fault** 8 km west of Bhuj. Intercalated layers of shale-sandstone are displaced by 2.15 m due to normal faulting. Down throw side is towards west. Fractured rocks near the fault give low velocities. Away from the fault zone the beds appear horizontal.

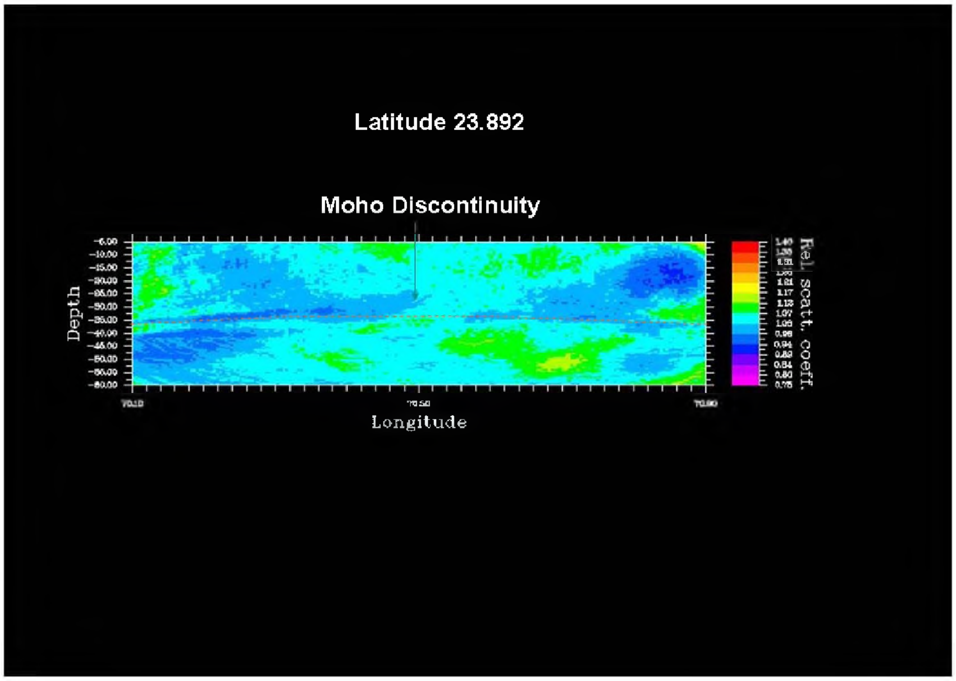


Figure 11: Moho discontinuity in Kachchh region.

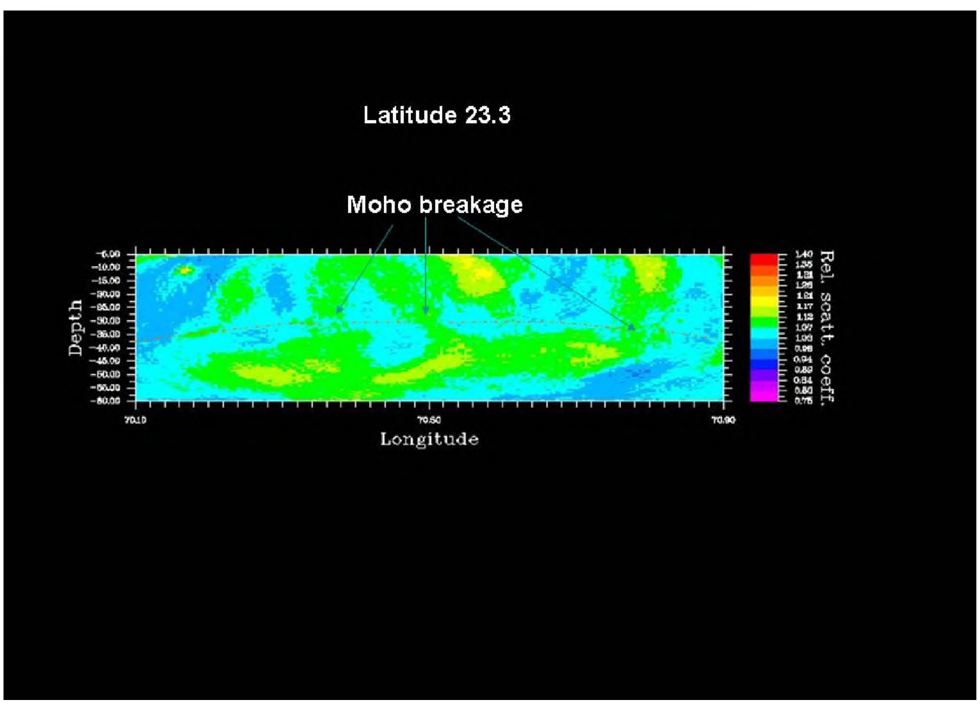


Figure 12: Disturbed Moho discontinuity in Kachchh region.

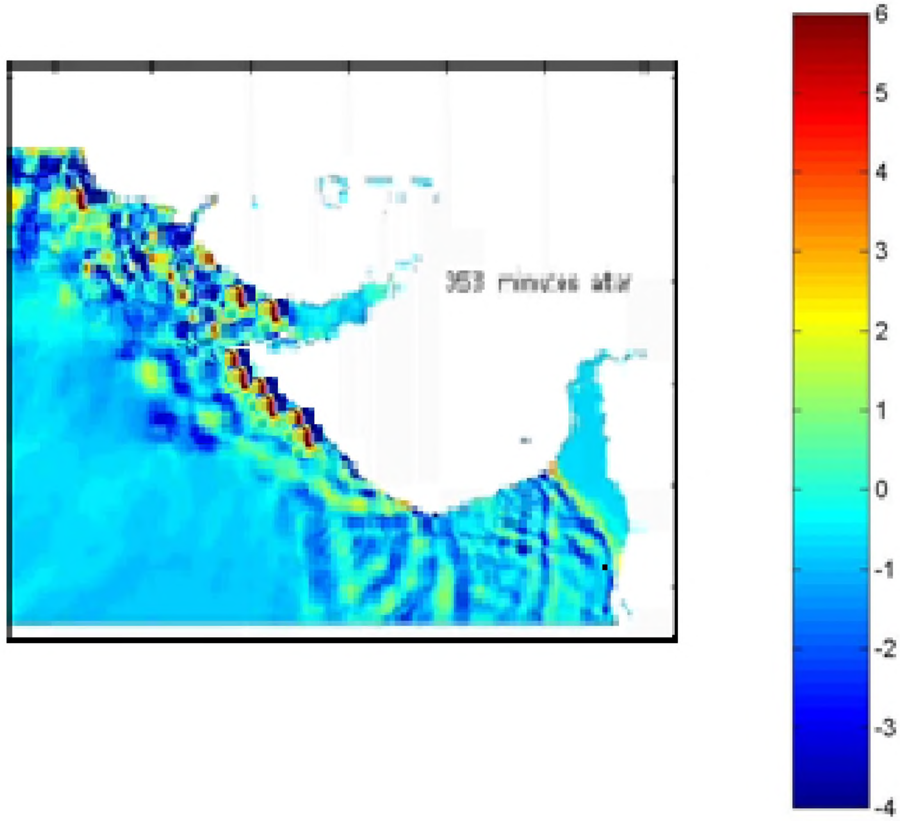


Figure13. Prediction of tsunami amplitude near the coasts of Gujarat 352 minutes after a great earthquake in Makran. Color bar indicates amplitude in m.

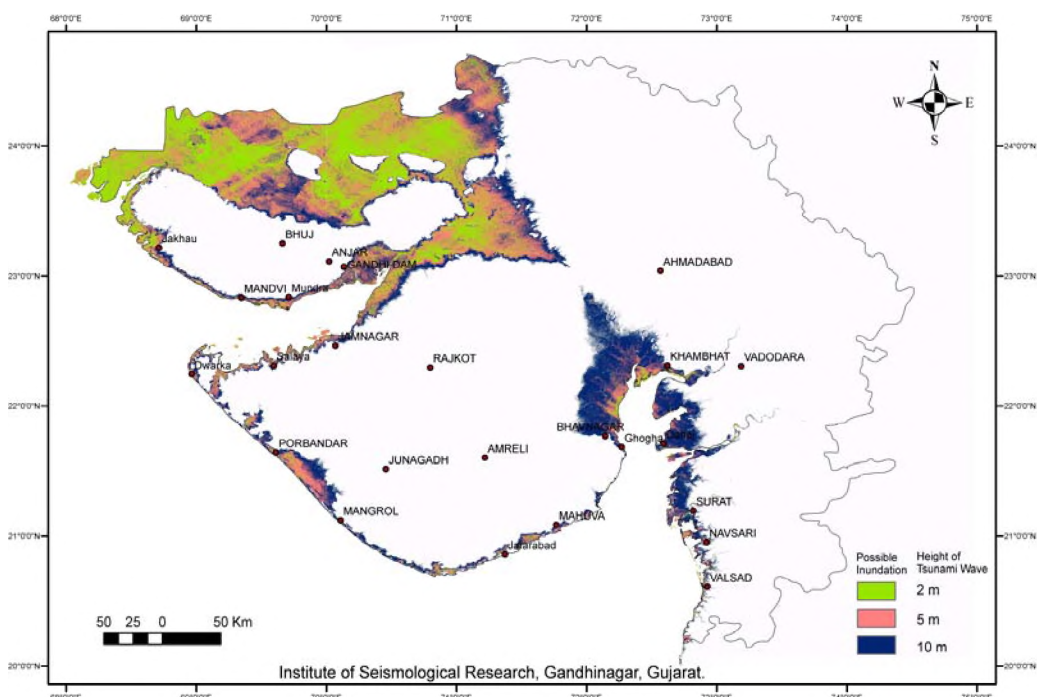
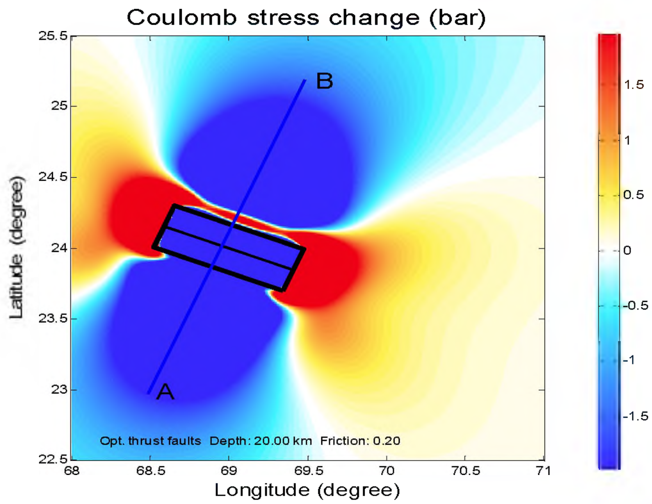
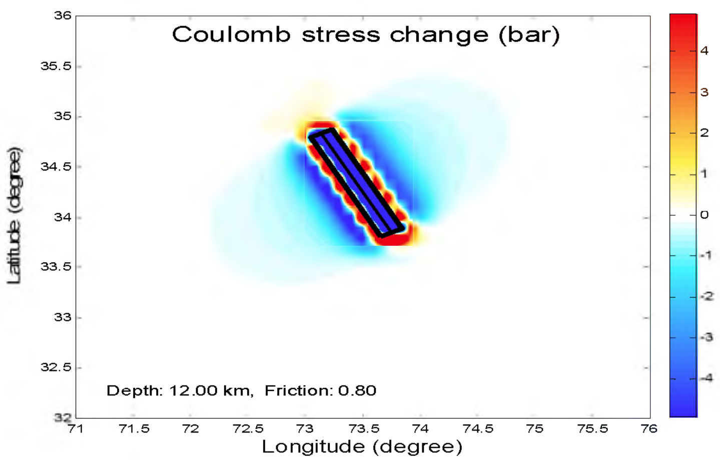


Fig. 14: Map showing possible inundation due to Tsunami.



(a)



(b)

Figure: 15 (a). Coulomb stress changes associated with 1819 Allah Bund earthquake, which show increase of coulomb stress at the epicenter of Jan 26, 2001 earthquake. **(b).** Coulomb stress changes associated with Oct. 8, 2005 Kashmir earthquake.