Some Recent Results from GPS Studies for the January 2001 Bhuj Earthquake

Ami Shah*, M. N. Kulkarni, V.S. Tomar, S. Likhar
Department of Civil Engineering
Indian Institute of Technology Bombay
Mumbai-76, India
*het_shah@yahoo.com and amishah@iitb.ac.in

ABSTRACT

One of the most destructive phenomena of nature is severe earthquake and its terrible aftereffects. An earthquake is a sudden movement of the earth, caused by the abrupt release of strain that has accumulated over a long time. On 26th January 2001, a devastating earthquake of 6.9 Richter scale struck Kachchh region of Gujarat state that is one of known regions of high incidence of earthquakes in recent times and in the historical past. As per the hazard map, the area falls under moderate to high seismic hazard zone, i.e. highest seismically active zone – V. Global Positioning System (GPS) has become an important tool for various applications, including complex earthquake mechanisms which lead to crustal deformations. The data used for the study of crustal deformations was carried out by GPS team from Indian Institute of Technology Bombay (IITB) immediately after the earthquake in February. Repeat observations were taken for February 2002 and 2003. For estimating post-earthquake deformations the data has been processed by scientific software Bernese version 4.2. Some recent results from the analysis of the three epochs data are discussed here, which shows that most of the stations have moved in North-East direction by significant amount, during the period of study.

INTRODUCTION

On January 26, 2001, one of the most destructive earthquakes with 6.9 Richter scale and epicenter at 23.4^{o}N (Latitude) and 70.28^{o}E (Longitude) ever to strike India occurred in the Kachchh region of Gujarat State in western India. The earthquake was felt in nearly all parts of India and surrounding regions. The Kachchh peninsula has undergone many stages of deformation in the geological past. This crustal deformation/re-adjustment is still continuing resulting in high seismic activity in the form of earthquakes of varying magnitudes.

Among the natural calamities, earthquakes are the most destructive, in terms of loss of life and destruction of property. The Earth is formed of several layers that have very different physical and chemical properties. The outer layer, which averages about 70 kilometers in thickness, consist of irregular shaped plates that slide over, under and past each other on top of the partly molten inner layer. "Six better-known plates are: the American, the African, the Eurasian, the Arabian the Indian and the Pacific" (Hemmady, 1996). Plates directly relevant to India are the Indian, Eurasian and Arabian plates. The rocky crust of the earth is not stable, but undergoes complex movements due to continental plate movements. There are slow vertical movements of uplift and depression, the rate of which is measurable only by lengthy precise observations; the effects of which are seen at many places. The earthquakes are sudden crustal movements that can be detected and measured by special instruments. The earthquake shocks are caused mainly by adjustments to strains in crustal rocks due to movements along faults and fracture surfaces where stresses accumulate locally, in the rocks until breaking point is reached, when slip along the fracture occurs.

ROLE OF GPS FOR CRUSTAL DEFORMATION STUDIES

GPS is the satellite based surveying and navigation system for determination of precise position and time, using radio signals in both real-time and in post processing mode. GPS finds numerous applications in various fields, including navigation, surveying, mapping, remote sensing, and in earthquake hazard assessment because it gives very precise measurements related to the station location. For everyday surveying, GPS has become a highly competitive technique to the terrestrial surveying methods using theodolites and EDMs (Electronic Distance Measurements). It is highly advantages in use for determining precise horizontal positions of points more than a few tens of kms apart. Phase information in the GPS signal can be used to determine the position difference between the sites with an accuracy of a few millimeters in the horizontal and vertical directions. Thus, GPS provides an economic and efficient technique with sufficient accuracy to measure the mm-level crustal deformations produced by the earthquakes [Kulkarni, 1999]. With the high accuracy achieved by GPS in estimation of base line lengths, this relatively new geodetic positioning technique has assumed great importance in crustal dynamic studies. Precise GPS repeat measurements and data processing to achieve high accuracy yield the estimates of deformations of the Earth's crust over the period of the repeat observations, both in the horizontal and vertical directions. Thus, GPS data is valuable for understanding the complex process of Earthquakes (Kulkarni, 1999).

KACHCHH REGION

This region lies within 400 km of the active plate boundary zone between the Indian subcontinent and the Asian plate along the India-Pakistan border. The Kachchh basin is highly faulted. According to earth scientists, faults are composed of segments that may rupture individually or in groups of adjacent segments during the earthquake. The main faults in this region are: The Allah Bandh Fault, The Kachchh Mainland Fault, Vighodi Fault, Katrol Hill Fault, North Kathiawar Fault, Banni Fault, Island Belt Fault, Nagar Parker Fault (Sinvhal, 2001). The location of the epicenter and devastation indicate that the Kachchh Mainland fault or a part of it possibly was reactivated on 26th January 2001.

GPS DATA COLLECTION

Indian Institute of Technology (IIT) Bombay has been carrying out extensive GPS survey in the Bhuj region immediately after the devastating earthquake of 26th January 2001 initiated by the “Department of Science and Technology (DST) of the Government of India. Data used for this study has been collected by the GPS team from IIT Bombay for the geodetic control network consist stations at approximately 20-40 km spacing, of the series of the Great Triangulation (GT) Network of India. During three GPS field epochs of February 2001, 2002 and 2003, data has been collected for total 15 stations (see Table 1 and Figure 1).

Table 1: GPS Stations

STATION No.	STATION NAME	STATION ID	STATUS
1	Netra	NETR	Old GT Point
2	Nara	NARA	New GPS Point
3	Roha	ROHA	Old GT Point
4	Samdhan	SAMD	New GPS Point
5	Sumatra	SUMT	New GPS Point
6	Asaparamata	ASAP	New GPS Point
7	Charakda	CHAR	New GPS Point
8	Jhuran	JHUR	New GPS Point
9	Kakarawa	KAKA	New GPS Point
10	Sukhpur	SUKH	New GPS Point
11	Chitroad	CHIT	Old GT Point
12	Kanmer	KANM	New GPS Point
13	Pir-Pita-I-Shah	PIRP	Old GT Point
14	Rapar School	RAPS	New GPS Point
15	Kanduka	KNDK	New GPS Point

Four Trimble 4000SSI and two Trimble 5700 dual frequency geodetic GPS receivers were used with the chock ring and Zephyr type of antennas respectively for this field work. The GPS data were organized into 24 hours segments with the combination of data from some of the surrounding IGS sites, namely IISC, BAHR, MALI, LHAS. to constrain the site co-ordinates. Coordinates for each IGS site for each year were calculated with the help co-ordinates and velocities in corresponding directions available in the year 2000 in Indian Terrestrial Reference Frame (ITRF).

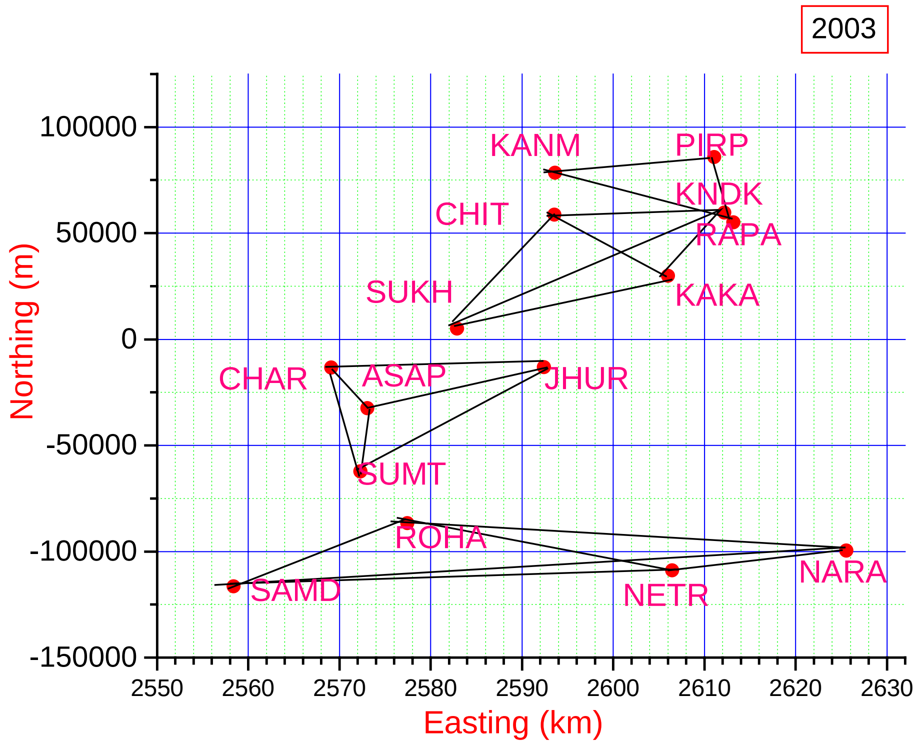


Fig. 1 Location and Network of GPS Stations for 2003 Epoch

Campaign 1: 14/02/2003 to 16/02/2003
Campaign 2: 18/02/2003 to 20/02/2003
Campaign 3: 21/02/2003 to 23/02/2003
Campaign 4: 24/02/2003 to 26/02/2003

DATA PROCESSING WITH BERNESE, ANALYSIS AND RESULTS

The data for each epoch is processed with the scientific software Bernese 4.2, developed by the University of Bern. Network considered for the different campaign for the year 2003 with the reference to their Northing and Easting is shown graphically by figure 1.

After processing with the Bernese, out put file gives the position of the stations in terms of X, Y, Z and also in form of Height, Latitude and Longitude. Deviation in northing, easting and height separately for each GPS station was calculated by converting from latitude and longitude. This is graphically represented in figure 2 (A) and (B), which shows that most of the stations are moving in the North-East direction.

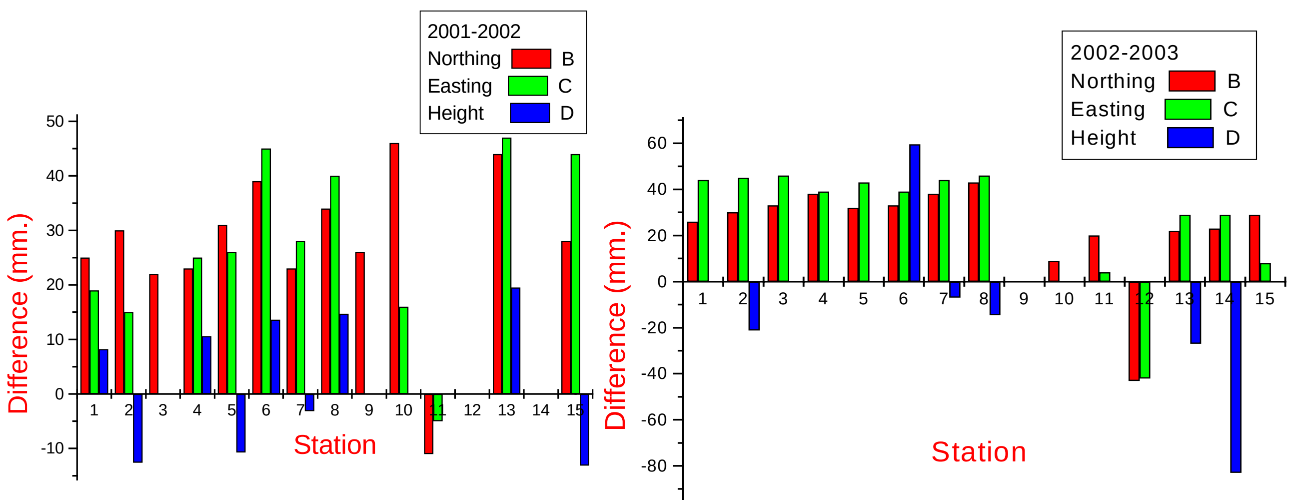
Table 2: Differences in Northing, Easting and Height

Station ID	Station No	Difference 2002-2001 (mm)			Difference 2003-2002 (mm)		
		Northing	Easting	Height	Northing	Easting	Height
NETR	1	25	19	8.2	26	44	***
NARA	2	30	15	-12.6	30	45	-21.1
ROHA	3	22	0	***	33	46	***
SAMD	4	23	25	10.6	38	39	***
SUMT	5	31	26	-10.7	32	43	***
ASAP	6	39	45	13.6	33	39	59.6

FROM STATION	TO STATION	BASELINE LENGTH 2001 (M)	BASELINE LENGTH 2002 (met)	Diff. 2001to 2002 (mm)	BASELINE LENGTH 2003 (M)	Diff. 2002to 2003 (mm)
NETR	NARA	21156.3767	21156.3793	2.6	21156.3811	1.8
	ROHA	36435.5979	36435.5896	-8.3	36435.5840	-5.6
	SAMD	48483.1890	48483.1907	1.7	48483.1778	-12.9

CHAR	7	23	28	-3.1	38	44	-6.9
JHUR	8	34	40	14.7	43	46	-14.5
KAKA	9	26	***	***	0	0	0
SUKH	10	46	16	***	9	-166	***
CHIT	11	-11	-5	***	20	4	***
KANM	12	0	0	0	-43	-42	***
PIRP	13	44	47	19.5	22	29	-26.9
RAPS	14	---	---	---	23	29	-83
KNDK	15	28	44	-13.1	29	8	***

*** Inconsistent result, being analysed.
--- RAPS station was not established in 2001 epoch so there is no data for the year 2001.



(A) **(B)**

Fig. 2 Difference in Co-ordinates of the Stations

Table 3: Local Deformations for station

In figure 3, baseline length is plotted for the station NETR to NARA, ROHA and SAMD to scale in meter. Separately the movement of the stations NARA and NETR is shown for the three years with their directions through arrows (to the scale in cm from table 2). Change in baseline lengths of three years is achieved by joining these points for NARA and NETR (for values refer table 3). For the results in table 3, rms values are ranging from minimum 0.1 mm to maximum 0.5 mm with the mean value of 0.367 mm.

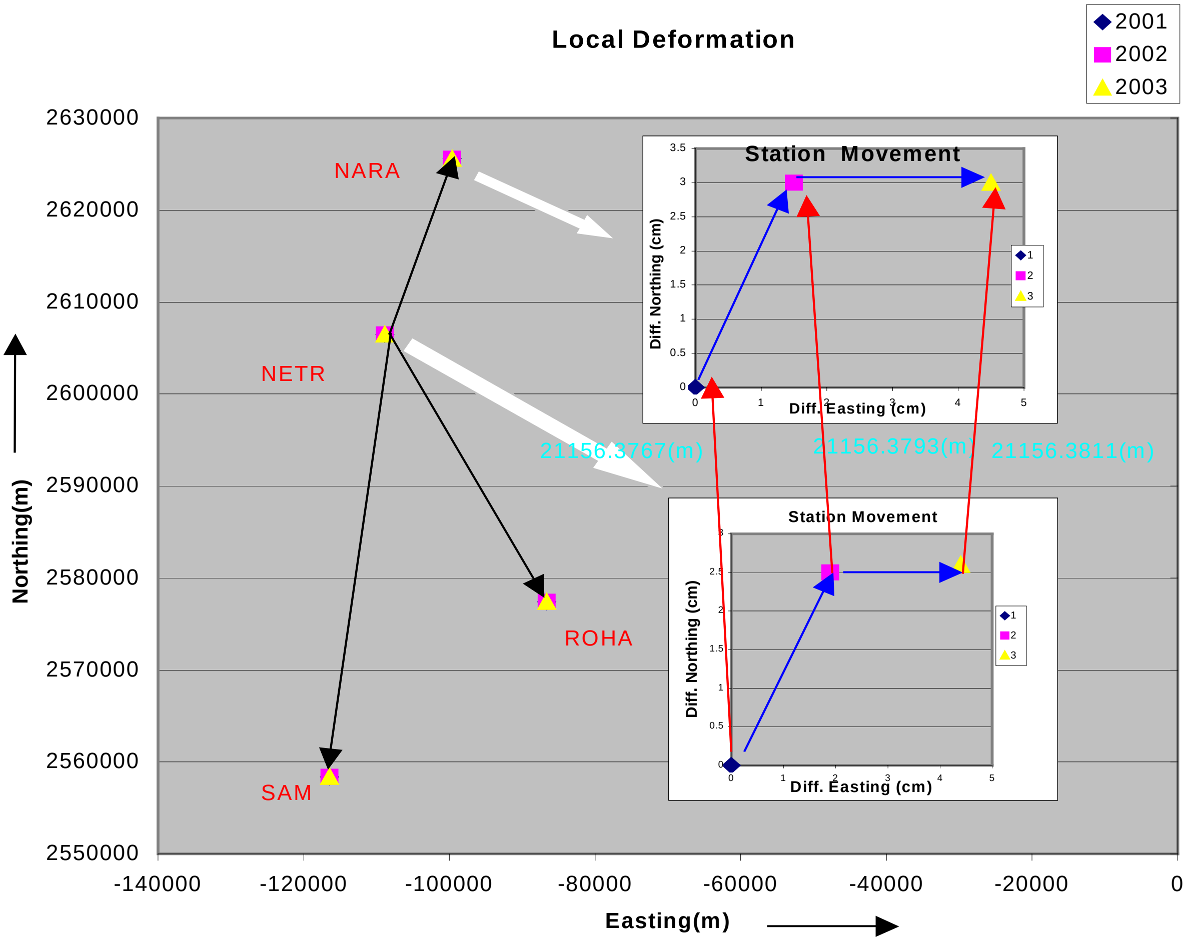


Fig. 3 Local Deformations for NETR to NARA, SAMD and ROHA

Table 4 gives the baseline length for some of the stations of the network w.r.t two IGS stations IISC, LHAS for 3 epochs and also gives the change in length for two consecutive years in mm. It is presented as a regional and global deformation in the figure 4 (A) and (B) respectively.

Table 4: Difference in Baseline Length for w.r.t IISC, LHAS

From Station	To Station		Baseline 2001 (M)	Baseline 2002 (M)	Diff. (mm) 2001-2002	Baseline 2003 (M)	Diff. (mm) 2002-2003
	No	ID.					
IISC	1	NETR	1460892.3945	1460892.4017	7.2	1460892.3605	-41.2
	2	NARA	1470561.2775	1470561.2884	10.9	1470561.2826	-5.8
	3	ROHA	1424697.1500	1424697.1908	40.8	1424697.1655	-25.3
	4	SAMD	1427834.3385	1427834.3415	3.0	1427834.3704	28.9

LHAS	1	NETR	2286695.1315	2286695.1513	19.8	2286695.0922	-59.1
	2	NARA	2271828.7875	2271828.8061	18.6	2271828.7956	-10.5
	4	SAMD	2309968.4005	2309968.4168	16.3	2309968.4499	33.1
	5	SUMT	2255490.4772	2255490.4838	6.6	2255490.4424	-41.4

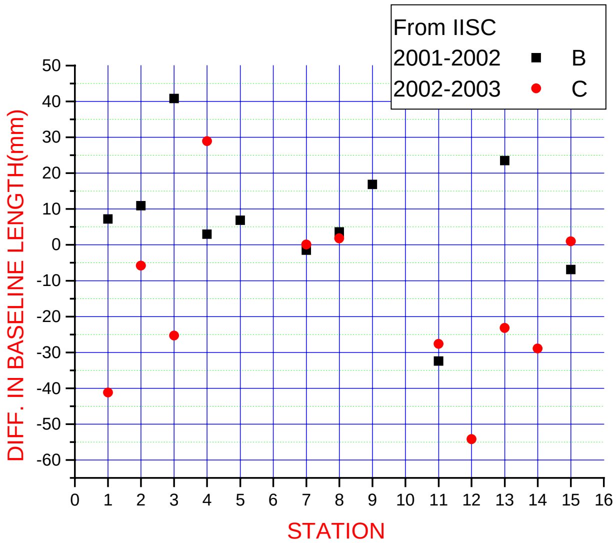


Fig 4(A) Regional Deformation w.r.t. IISC

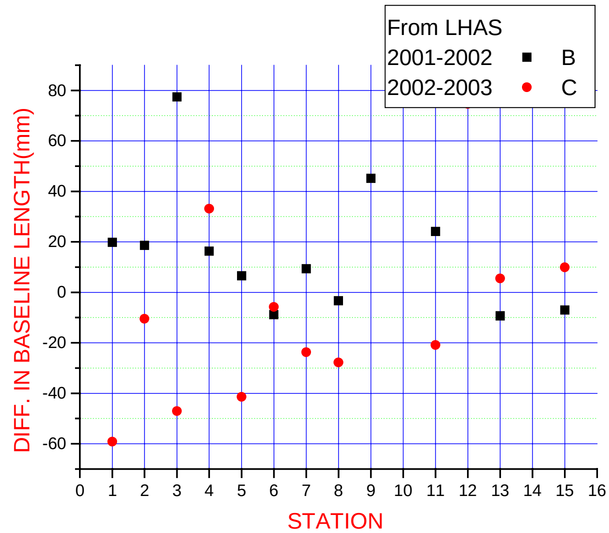


Fig. 4(B) Global Deformation w.r.t. LHAS

CONCLUSIONS

By processing post-earthquake GPS data collected for February 2001, 2002 and 2003, changes in baseline length are calculated with 0.5mm RMS value. The estimation of horizontal regional and global deformation in baseline is done with the help of IGS sites IISC, MALI, BAHR and LHAS. Standard ionospheric and tropospheric models were taken into consideration during processing the data.

Local deformation shows an expansion for NETR to NARA and contraction for NETR to ROHA from 2001 to 2003.

Regional (Intra-Plate) deformation is estimated between different stations of Bhuj region and IISC; both on the Indian plate. The deformation is in the range of -54.2 mm to 40.8 mm with average of -4.65 mm. The baseline between IISC-SAMD, JHUR, KAKA, and SUMT expanded, IISC-NETR, NARA, ROHA, PIRP, CHAR, and KNDK have expansion and contraction, and IISC-KANM, RAPS, CHIT have contraction from 2001 to 2003.

The estimated horizontal global deformation in baseline length from IGS stations LHAS, BAHR, and MALI is -79.3 mm (minimum) to 40.8 mm (maximum) with a mean value of -1.98 mm. Global (Inter-Plate) deformation means the deformation studies w.r.t. different plates. The baseline lengths from LHAS to different stations of Bhuj region have expansion for 2001to 2002 and contraction for 2002 to 2003 in majority. The deformations are in the range of -59.1 mm to 24.1 mm.

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