Stress Map of India: Efforts during last 30 years

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Research Article

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Abstract

National Institute of Rock Mechanics, Bangalore, India is actively involved in conducting in-situ stress measurements for numerous projects both in India and its neighboring countries for the last 30 years. The stress measurements were conducted at various hydroelectric project sites of Himalayan areas at a depth of 350 m from the surface and recently in-situ stress measurements were carried out at a depth of 600 m from the surface at one of the proposed mining blocks of Singareni Collieries Company Limited which is first time in India. With the available data on in-situ stress measurements, the Stress Map of India has been prepared. This is a significant contribution towards design and development of World Stress Map. These stress orientation directions are advantageously useful not only for academic study and research but also for gathering the enormous information on a global perspective to comprehend the geodynamics and plate movement.

1. Introduction

In the Geological studies there are several field maps to know the ground features and various geological parameters. If the tectonic stress directions are measured at various available places and marked on Indian map, then it is called as Stress Map of India. Many countries are providing the stress data as a contribution in preparation of World Stress Map. The world stress map shows the orientations of Maximum Principal Horizontal Stress Direction measured at various places in different countries (Heidbach et al. 2016). These stress directions which are pertaining to particular country or on a global scale will be considered as reference points for academic research to know the geodynamics and plate movement.

The Indian subcontinent is an assortment of diverse geological structures such as sedimentary basins, cratons, and mobile belts, causing varied stress regimes (Yadav & Tiwari 2018). Hence the stress map of an area gives the possible indication of Maximum Principal Stress orientation which is regional in nature. Therefore, this orientation data cannot be taken into consideration for design purpose in any major underground mining or civil engineering projects. The fresh data should be collected for determining the stress measurements as case-to-case basis for a required orientation for any precise engineering purpose. Sometimes the stress orientations under consideration will be influenced by regional tectonic features such as faults, shear zones, presence of dykes etc. These orientations may be considerably varied in magnitude and directions from the trends as these are perturbed in nature.

There are two types of stresses available based on the regional and local scales. Regional stresses are also called as First order estimates which are based on the measurements of earthquake focal mechanism studies at the particular site globally or regionally. But the second order stresses are completely of local parameters generally carried out by deep hole hydrofracturing method, overcoring method for particular engineering purpose on case-to-case basis (Figure 1). However, the first and second order stress directions are mapped on the world stress map to know the possible global phenomenon in terms of plate dynamics etc. The Stress Map of India is being prepared by National Institute of Rock Mechanics (NIRM), mainly focusing on second order stress data that was generated for the last 30 years from various parts of the country. The data has been collected from various underground openings where in-situ stress measurements have been conducted by hydrofracture method. Some of the data was generated from overcoring measurements that have been conducted at underground mines and borehole breakout data that was collected from various boreholes during the course of 30 years of journey. Many of these measurements have been made for specific engineering applications (e.g., underground powerhouse orientation evaluation, mining work etc.), These orientations are quite homogeneous in broad regions except in few places where the geological anomalies occurred. In these regions where there are some geological anomalies, the horizontal stress directions seem to be completely incoherent from site to site as topography, geological disturbances like faults and dykes or nearby excavations could strongly perturb the regional stress field at these places. This anomalous data is therefore not worth considering for incorporating in the stress map and cannot be the reference to the study of present-day plate dynamics. Hence the perturbed stress data is omitted in the preparation of Stress Map.

2. Observations

Nearly 300 reliable indicators of the orientation of horizontal stress in the Indian crust have been measured at different depths to explain the regional trends of stress orientations across India (Table-1). Stress provinces were demarcated based on the trajectories throughout the country. This data has been correlated with reference to the motion of Indian plate. The possible regional pattern of stress in Indian sub-continent with reference to the first order stress, and also a number of locally measured stress orientations influenced by second-order sources of stress such as structure and topography with reference to the present-day plate dynamics, have been correlated.

Table-1 Data Collected from different parts of the country

Place	Locality	Latitude	Longitude	Test	Depth in m	Local Magnitude MPa	Regime	Quality	Direction
India	Dibang Valley District, Arunachal Pradesh	28°36'33"N	95°52'21"E	HF	307	12.67	SS	A	N50°
India	Uttarakashi District, Uttarakhand	31°03'35"N	78°05'43"E	HF	144	7.45	TF	A	N40°
India	Kinnaur District, Himachal Pradesh	31°32'30"N	78°16'50"E	HF	191	16.125	TF	A	N150°
India	Singtam, Sikkim	27°09'00"N	88°22'48"E	HF	185	7.52	SS	A	N160°
India	Mangan, North District, Sikkim	27°31'44"N	88°32'26"E	HF	518	13.67	SS	A	N30°
Bhutan, Near to India	Trongsa District, Bhutan	27°15'59"N	90°31'32"E	HF	150	8.38	TF	A	N70°
India	Sangareddy, Telangana	17°37'28"N	78° 05'17"E	HF	100	8.07	SS	B	N30°
Bhutan, Near to India	WangdiPhodrang District, Bhutan	27°27'20"N	90° 04'28"E	HF	100	7.14	SS	A	N150°
India	West District, Sikkim	27°17'41"	88°17'31"E	HF	150	2.13	TF	A	N50°
India	Udaipur, Rajasthan	24°17'52"N	73°46'02"E	HF	62	7.74	TF	A	N140°
India	Vedanta, Rajasthan	26°02'28"N	74°01'11"E	HF	557	36.88	TF	A	N120°
India	Chamoli District, Uttarakhand	30°30'50"N	79°29'30"	HF	60	5.19	SS	A	N30°
India	Chamoli District, Uttarakhand	30° 30' 0" N	79° 30' 0" E	HF	150	5.93	SS	A	N40°
India	Doda District, Jammu & Kashmir	33°10'58"N	75°18'53"E	HF	365	5.48	SS	A	N50°
India	Kashmir	33°17'12"N	75°45'43"E	HF	80	9.7	TF	A	N40°
India	Sikkim	27°23'59"N	88°31'10"E	HF	239.674	8.95	SS	A	N110°
India	Dehradun, Uttarkhand	30°32'04"N	77°57'39"E	HF	90	8.2	TF	B	N70°
India	Shimla District, H.P	31°05'40"N	77°47'15"E	HF	150	8.855	SS	A	N140°
India	Udaipur, Rajasthan	24.95°00"N	74.13°00"E	HF	504	22.76	SS	A	N30°
India	Malana, Himachal Pradesh	32°03'42"N	77°15'40"E	HF	100	3.15	SS	A	N50°
India	Dibang, Arunachal Pradesh	28°48'45"N	96°09'05"E	HF	270	10.125	SS	A	N150°
India	Ramban District, Jammu & Kashmir	33°09'43"N	75°19'40"E	HF	258.687	5.62	NF	A	N40°
India	Shimla & Kullu, H.P.	31°26'00"N	77°39'00"E	HF	107.3	7.29	TF	A	N150°
India	Chamba District, H.P.	32°24'00"	76°12'00"E	HF		9.9	SS	A	N40°
India	Kishtwar, Jammu	33°22'06" N	75°47'55" E	HF	132.37	9.7	TF	A	N40°
India	Chungthang, Sikkim	27°36'29"N	88°38'36"E	HF	156	8.5933	TF	A	N153.03°
India	Joshimath, Uttarakhand	30°39'26"N	79°31'01"E	HF	248	9.64	SS	A	N40°
India	Bhatwari, Uttarakhand	30° 49' 0"N	78° 37' 0"E	HF	100	6.606	TF	A	N50°
Bhutan, Near to India	ChukhaDzongkhag, Bhutan	26°52'14"N	89°34'55"	HF	410	14.205	SS	B	N130°
India	Upper Subansri District, Arunachal Pradesh	27°47'12"N	94°20'09"E	HF	270	8.61	SS	A	N170°
India	Kullu District, H.P.	31°45'03"N	77°14'32"E	HF	240	15.78	SS	A	N60°
India	Bhunter, H.P.	31°51'36"N	77°09'00" E	HF	416.79	15.45	SS	A	N60°
India	Joshimath, Uttarakhand	30°40'21"N	79°30'48"E	HF	248	11.966	SS	A	N20°
India	Manali, H.P.	32° 16' 12" N	77° 10' 12" E	HF	180	7.329	SS	A	N50°
India	Bhunter, H.P.	31°51'36"N	77°09'00" E	HF	100	3.15	SS	A	N50°
India	Nilgiri District, T.N.	11° 25' 0" N	76° 41' 0" E	HF	532	26.5	SS	A	N100°
India	KalvarPadavu, Karnataka	12° 52' 12" N	74° 52' 48" E	HF	106.5	6.82	TF	A	N150°
India	Love Garden, Visakhapatnam	17° 39' 40"N	83° 15' 47" E	HF	147.2	9.17	TF	A	N20°
India	Rohru Tehsil, H.P.	31°05'42"N	77°47'16"E	HF	150	8	SS	A	N140°
India	Mora, Maharastra	18°53'20"N	72°56'02"E	HF	107	25.5	TF	A	N130°
India	Bhatwari, Uttarakhand	30° 49' 0"N	78° 37' 0"E	HF	144	7.05	TF	A	N50°
India	Mangalore, Karnataka	12°52'00"N	74°53'00"E	HF	146.57	6.22	TF	A	N140°

India	Pithoragarh District, Uttar Pradesh	29°58'41"N	80°34'21"E	HF	255	3.09	SS	A	N140°
India	Hutti, Karnataka	16°12'05"N	76°38'57"E	HF	721	23.54	SS	A	N20°
India	Srisaillam Andhra Pradesh	16°05'13"N	78°53'50"E	HF	231	9.77	TF	A	N50°
India	Srinagar, Jammu & Kashmir	34°08'40"N	74°11'08"E	HF	310	9.16	SS	A	N130°
India	Kinnaur District, Himachal Pradesh	31°30'00"N	78°10'39"E	HF	269	3.79	SS	A	N10°
India	Bihar	22°38'00"N	86°22'00"E	HF	200	12.95	TF	A	N50°
India	Kinnaur District, Himachal Pradesh	31°25'50"	78°14'28"E	HF	259.68	10.8	SS	A	180(N-S)
India	Khetri, Rajasthan	27°59'00"	75°48'00"E	HF	300	8.89	TF	A	N30°
India	Kinnaur District, Himachal Pradesh	31°33'50"N	77°58'49"E	HF	300	10.22	SS	A	N30°
India	Kinnaur District, H.P	31°33'50"N	77°58'49"E	HF	190	7.5	SS	A	N10°
India	Mumbai, Maharastra	19°22'22"	73°50'04"	HF	200	6.24	SS	A	N140°
India	Arunachal Pradesh	28°08'40"N	95°50'30"E	HF	247.75	10.98	TF	A	N30°
India	Nepal	27° 42' 43.2756" N	85° 18' 46.62" E	HF	150	7.21	TF	A	N20°
India	Bhutan	26°52'14"N	89°34'55"E	HF	140	14.2	TF	A	N50°
India	Trongsa district, Bhutan	27°26'54"N	90°22'24"E	HF	327	12.24	SS	A	N60°
India	Nilgiri District, T.N.	11° 25' 0" N	76° 41' 0" E	HF	532	10.782	SS	A	N110°
India	Mahabubnagar District, Telangana	16 44' 15 " N	78° 0' 29" E.	HF	82	3.044	SS	A	N50°
India	Uttarakashi District, Uttarakhand	31°03'35"N	78°05'43"E	HF	164.5	5.62	SS	A	N40°
India	Telangana	16 44' 15 " N	78° 0' 29" E.	HF	60	2.541	TF	A	N50°
India	Telangana	16 44' 15 " N	78° 0' 29" E.	HF	130	5.46	TF	A	N30°
India	Joshimath, Uttarakhand	30°40'21"N	79°30'48"E	HF	414	11.966	SS	A	N20°
India	Dibang Valley District, Arunachal Pradesh	28°36'33"N	95°52'21"E	HF	166	8.52	SS	A	N50°
India	Chamoli District, Uttarakhand	30°15'00"N	80°15'00"E	HF	226	8.14	SS	A	N130°
India	Warangal Nalagonda district, Telangana	18° 2' 8.4084" N	79° 32' 14.6364" E	HF	92	3.02	SS	A	N100°
India	chamoli district of Uttarakhand	38° 53' 36.42" N	77° 0' 52.956" W	HF	205	7.146	SS	A	N120°
India	Mahabubnagar district, Telangana	16° 45' 20.844" N	77° 59' 58.056" E	HF	96	4.245	TF	A	N40°
India	Raichur District, Karnataka	16°11'49.5"N	76°39'06.2"E	HF	832.69	25.635	SS	A	N80°
India	Nalgonda districts, Andhra Pradesh	16° 14' 18.06" N	80° 38' 31.848" E	HF	70	2.94	TF	A	N100°
India	Himachal Pradesh	32°14' 00' ' N	77°13' 00' ' E	HF	180	7.329	SS	A	N140°
India	Pithoragarh District, Uttar Pradesh	25° 21' 45.36" N	82° 11' 23.64" E	HF	105	2.864	SS	A	N20°
India	Mumbai, Maharastra	19°22'22"	73°50'04"	HF	200	8.31	SS	A	N140°
India	Singareni Collieries	17° 21' 30.24" N	78° 31' 17.184" E	HF	596	17.798	TF	A	N20°
India	Kullu District, H.P.	31° 54' 46.08" N	77° 10' 27.4836" E	HF	100	7.42	TF	A	N35°
India	Mandamarri Telangana	18° 58' 45.12" N	79° 28' 50.16" E	HF	300	4.08	NF	A	N18°
India	Godavarikhani Telangana	18° 45' 36.432" N	79° 30' 45" E	HF	250	5.3	SS	A	N15°
India	Godavarikhani Telangana	18° 45' 36.432" N	79° 30' 45" E	HF	450	3.13	NF	A	N24°
India	Bhupalpally telangana	17° 52' 29.35" N	79° 31' 15.6144" E	HF	300	3.2	NF	A	N10°
India	Bhupalpally telangana	17° 52' 29.35" N	79° 31' 15.6144" E	HF	320	9.52	SS	A	N50°
India	Bhupalpally telangana	17° 52' 29.35" N	79° 31' 15.6144" E	HF	360	1.7	NF	A	N50°
India		31°25'50"	78°14'28"E	Thrust fault	180		TF		
India		31°33'50"N	77°58'49"E	strike fault	125		SS		
India		33°17'12"N	75°45'43"E	Thrust fault	45		TF		
India		22°38'00"N	86°22'00"E	Normal Fault	120		NF		
India		30°32'04"N	77°57'39"E	Dyke	100		Dyke		

The arrows indicate the maximum compressive horizontal stress (σ_H max) orientation as generated from hydrofracturing stress measurements. The lines indicate different stress provinces as revealed by stress analysis. The in-situ stress orientation data was collected from the hydro-fracture measurements, borehole breakouts and focal mechanisms data from different part of India. The data was in turn compared with the other countries who provided for preparation of world stress map (Zoback MD *et.al* 1985) and observed that Maximum landmasses from different continents reveal parallel stress orientations to absolute plate velocity. This argument leads to the assumption that Maximum Horizontal Principal Stress (σ_H) orientations are the consequence of dominant plate driving forces that are acting along plate boundaries (Zoback ML 1992). But apparently, the stress orientations derived from India and Australian continents are not consistent and not abide by the absolute plate velocity implying that plate boundary forces are not adequate or sufficient to understand intraplate stress (Dyksterhuis et al. 2005a, b; Heidbach et al. 2007; Jade *et. al* 2017). This clearly indicates that the Indian subcontinent is portrayed by scarce distributions of the σ_H orientations (Figure 2), and therefore, Yadav and Tiwari modeled the orientations and magnitude of Maximum Horizontal Principal Stress (σ_H) through finite element modeling integrating heterogeneities in elastic property of the Indian continent and plain stress calculation to understand the inconsistency of σ_H . They have considered four different situations in their simulation studies, these are

The estimated orientation and magnitude of Maximum Horizontal Principal Stress σ_H with a heterogeneous plate with boundary forces in the Himalayan region and an eastern plate boundary comprising the Indo-Burmese arc and Andaman subduction zone are reliable and consistent with measured maximum horizontal stress data that was provided by NIRM. This study suggests that plate boundary force varies along the northern Indian plate margin and also indicates a constraint on the intraplate stress field in the Indian subcontinent (Yadav & Tiwari 2018).

The data generated from nearly 300 consistent indicators of the orientation of horizontal stress in the Indian crust have been gathered to explain the provincial trends of stress orientations across India. Stress provinces were demarcated based on the trajectories all over the country. This data has been correlated with reference to the movement of Indian plate. The possible regional pattern of stress in Indian sub-continent with reference to the first order stress, and also a number of locally anomalous stress orientations influenced by second-order sources of stress such as structure and topography with reference to the present-day plate dynamics, have been correlated (Subrahmanyam DS 2014).

The Himalayas where we are having maximum data (Around 150) is having orientation varying from $N20^{\circ}$ - 30° E. In the central part of India, the average orientation $N10^{\circ}$ - 20° W is derived from the data generated from the measurements around Aravalli region, Hyderabad and some parts of Eastern Ghats. In the Shield area, the average orientation - $N20^{\circ}$ E, is the result of data compiled from Kolar Gold Fields (Karnataka), Mumbai and Mangalore. The thick lithosphere in India is associated with far field tectonic forces allow the stress field to be more easily perturbed by local effects of geological discontinuities like great thrusts of Himalayas and topography.

Based on the studies, it has been emphasized that the mean orientation is $N25^{\circ}$ E which shows clear correlation with the direction of motion of the Indian plate.

Dr. Oliver Heidbach who is Head of the World stress Map project will be compiling data generated by National Institute of Rock Mechanics to prepare World Stress Map, which is expected to be released by this year-end 2022. Figure-3 shows the rough sketch of Stress Map prepared by WSM

The database that is available from Stress map of India will not only be beneficial in academic research but also for commercial and economical investigations. In academic research, this data will contribute to know the possible movement of plate tectonics. The stress map of India will be updated periodically by incorporating data acquired not only from NIRM, but other organisations like CSMRS, NGRI etc for next update in the year 2021.

Declarations

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References

- Dyksterhuis S, Albert RA, Müller RD (2005a) Finite-element modelling of contemporary and palaeo-intraplate stress using ABAQUS™. *Comput Geosci* 31(3):297–307
- Gowd T N, Srirama Rao S V, and Gaur V K 1992 Tectonic Stress Field in Indian Subcontinent; *Journal of Geophysical Research*, **97**, 11879-11888.
- Heidbach O, Reinecker J, Tingay M, Müller B, Sperner B, Fuchs K, Wenzel F (2007) Plate boundary forces are not enough: second and third-order stress patterns highlighted in the World stress map database. *Tectonics* 26:TC6014
- Heidbach O, Rajabi M, Reiter K, Ziegler M, and the WSM Team 2016 World Stress Map Database Release 2016, GFZ Data Services.
- Jade S, Shringeshwara TS, Kumar K, Choudhury P, Dumka RK, Bhu H (2017) India plate angular velocity and contemporary deformation rates from continuous GPS measurements from 1996 to 2015. *SciRep* 7:11439
- Subrahmanyam D S, 2014 Stress provinces of India-contribution of World stress map. *Int J Adv Earth Sci Eng* **3(1)**, 108–113.
- Yadav R, and Tiwari V M, 2018 Numerical simulation of present day tectonic stress across the Indian subcontinent. *International Journal of Earth Sciences*, 107, 2449-2462.
- Zoback ML (1992) First- and second-order patterns of stress in the lithosphere: the world stress map project. *J Geophys Res* 97(B8):11703
- Zoback, M D, Moos D, Mastin L, and Anderson R N, 1985 Wellbore Breakouts and in situ Stress; *Journal of Geophysics Research*, **90**, 5523-5530.

Figures

Figure 1

In-situ stress investigations at the depth of 600 m from surface

Figure 2

Stress Map of India

Figure 3

Rough sketch of Stress Map of India, prepared by WSM (to be updated)