Cloud Publications
International Journal of Advanced Earth Science and Engineering
2014, Volume 3, Issue 1, pp. 108-113, Article ID Sci-158
ISSN 2320 - 3609

Research Article **Open Access**

Stress Provinces of India– Contribution to World Stress Map

D.S. Subrahmanyam

National Institute of Rock Mechanics, Bangalore, Karnataka, India

Correspondence should be addressed to D.S. Subrahmanyam, subbu3268@gmail.com

Publication Date: 21 January 2014

Article Link: http://scientific.cloud-journals.com/index.php/IJAESE/article/view/Sci-158

Abstract In the Geological studies there are several field maps that are available to know the ground features and various geological parameters, but if the tectonic stress directions are measured at various available places and marked globally on a world map then it is called World Stress Map (WSM). These stress directions are helpful not only for academic research but also for compiling the vast data on a global scale to know the geodynamics and plate movement. The world stress map shows the orientations of Maximum Principal Horizontal Stress Direction measured at various places in different countries. There are two types of stresses available based on the regional and local scales. Regional stresses are also called first order estimates which are based on the measurements of earth quake focal mechanism studies at the particular site globally or regionally. But the second order stresses are completely local parameters generally carried out for specific engineering purpose. To prepare the world stress map the first order stresses are very important and generally incorporated in the world stress map and the less importance is given for second order stress, since these measurements are most of the times determined at shallow depths and are not reliable indicators to include in the stress map. However the first and second order stress directions are mapped on the world stress map to know the possible global phenomenon like plate dynamics. The world stress map is being prepared and updated periodically by WSM project. The 1992 version of the World Stress Map was derived mainly from geological observations on earthquake focal mechanisms, volcanic alignments and fault slip interpretations. Less than 5% of the data was based upon hydraulic fracturing or overcoring measurements of the type commonly used in mining and civil engineering projects. The 2005 version of world stress map shows the huge number of data collected from hydrofracturing, overcoring, borehole breakout etc.
Keywords *First Order Stress; Focal Mechanism; Horizontal Compressive Stress; National Institute of Rock Mechanics; Second Order Stress; World Stress Map*

1. Introduction

The stress map of an area gives the possible indication of Maximum Principal Stress orientation which is regional in nature. This orientation data can’t be considered for design purpose in any major underground mining or civil engineering project. Hence it clearly indicates that the stress measurements should be conducted for a required orientation for any specific engineering purpose. The stress directions under consideration will be influenced by regional tectonic features such as faults, shear zones, presence of dykes etc. These stresses may be considerably varied in magnitude and directions from the trends described in first order stress maps. The insitu stress measurements play a vital role in overall design process during the construction of major underground structures.

It is therefore worth considering the first and second order stresses with reference to the study of present day plate dynamics. The Stress Map of India is being prepared by National Institute of Rock Mechanics (NIRM), mainly focusing on second order stress data that is available 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. Many of these measurements have been made for specific engineering applications (e.g. dam site evaluation, mining work), places where topography, fracturing or nearby excavations could strongly perturb the regional stress field.

Nearly 300 reliable indicators of the orientation of horizontal stress in the Indian crust have been collected in-order to explain the regional trends of stress orientations across India. 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 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.

2. World Stress Map

The latest and updated World Stress Map (WSM) is to be prepared in the year 2014 by incorporating the available data from different countries. Due to the structure of the database the data can be selected according to a number of criteria such as type, location, regime, depth, and so on.

This updated world stress map is expected to provide not only the possible information of Maximum Principal Stress direction of various places, but also information about the depth of the measurement, the magnitude of the maximum horizontal compression and also available lithology of the particular area. The data will be generated from different types of stress measurements like focal mechanism, borehole breakouts, hydrofracturing, overcoring etc.

The reliability and compatibility of the data are indicated by a quality ranking from A to E, with A being the highest quality and E the lowest (for further investigations only the most reliable data with a quality of A, B or C should be used). An overview about the quality ranking scheme is given by Zoback (1992) as well as on the World Stress Map (WSM) website *(http://www.world-stressmap.org)*. The new release of the WSM (Muller et al., 2000) encompasses 10 920 data records, each with up to 56 detail entries.

In the previous stress maps prepared by Zoback in the year 1992 and Muller in the year 1997 (Figure 1) most of the data has been generated by taking into consideration of 63% from earthquakes, 22% from borehole breakouts. Second order stress data has not been considered in the preparation of the map. However new data mainly which is coming from Europe, Australia and America additionally included data from mid-ocean ridges which may be directly related to plate boundary processes and which had so far been excluded from the WSM database are now included.

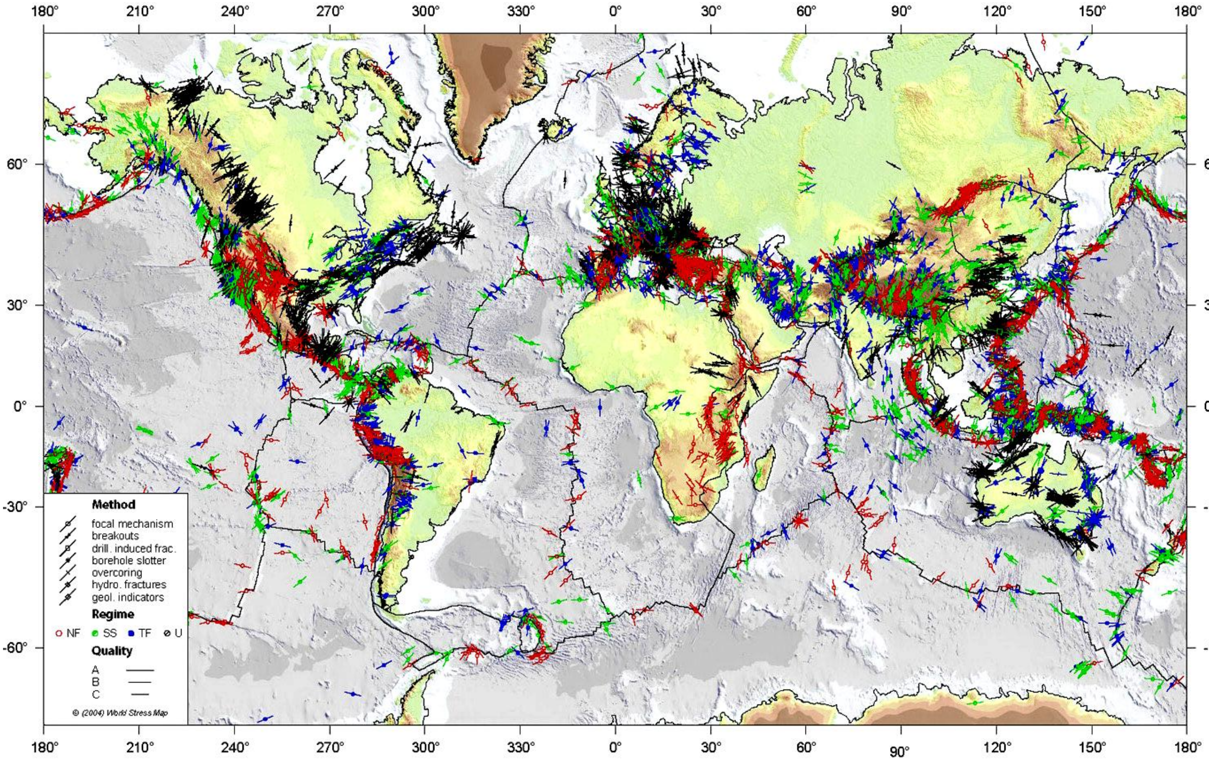

Figure 1: *World Stress Map Giving Orientations of the Maximum Horizontal Compressive Stress, Courtesy from www.world-stress-map.org*

2.1. Benefits of World Stress Map

The World Stress Map project offers not only free access to this global database via the Internet, but also continue in its effort to expand and improve the database, to develop new quality criteria.

The database that is available from World stress map will not only be helpful in both academic researches but also for commercial and economical investigations. In academic research these data will contribute to know the possible movement of plates. In commercial way these data will be helpful in providing information about the stability of underground structures, to locate the suitable sites for nuclear repositories. In underground constructions the long axis of the cavern should be parallel to maximum compression; hence the tunnels and big caverns will be oriented in suitable areas as per the data available in the world stress map. In the hydrocarbon reservoirs, the possible direction of fluid flow will be based on the direction of maximum principal stress direction, hence the knowledge about the direction will be helpful in monitoring the production of oil wells. In the hydrocarbon industry, hydraulic fracturing studies are conducted to create the fractures for enhancing the yielding of the reservoirs; these fractures will be extended parallel to the Maximum principal stress direction. If the data is readily available in the maximum possible areas globally it becomes an easier task and diliniates many hydrocarbon reservoirs.

3. Stress Provinces in India

So far the data has been generated by other organisations to contribute in preparation of world stress map, based on the studies of Focal Mechanism i.e. first order stress. A little contribution was made towards the second order stress because of the lack of data. National Institute of Rock Mechanics (NIRM) has conducted in-situ stress measurements at various places like central India, southern shield and east and west Himalayas.

In-situ stress measurements were conducted at various places by hydro fracturing method at the depth ranging from 30 to 350m for various specific engineering design purposes. These orientations are quite homogeneous in broad regions except in few places where the geological anomalies occurred. Over other regions the horizontal stress directions seem to be completely incoherent from site to site.

Figure 2, Index map of India showing the physiographic/tectonic provinces referred in this paper. The arrows indicate the maximum compressive horizontal stress (σ_H max) orientation as generated from hydrofracturing stress measurements. The blue lines indicate different stress provinces as revealed by stress analysis. NIRM has proposed three broad regions based on regionally consistent Maximum Principal Horizontal stress σ_H orientations as given below

- The Himalayas
- Mid-continent Stress Province
- Southern Shield

The Himalayas are further divided into North Western Himalayas, Central Himalayas and Eastern Himalayas.

Figure 2: *Index Map of India Showing Stress Provinces (to be updated), Courtesy from NIRM*

4. NIRM's Contribution to World Stress Map

NIRM has collected nearly 300 reference points and their orientations along with magnitude have been indicated on Indian map. The orientations are derived from the data generated from different states of India i.e., Himachal Pradesh, Jammu & Kashmir, Uttaranchal, Sikkim, Arunachal Pradesh and also from the neighbouring countries i.e. Bhutan and Nepal. Whatever data collected at NIRM, Stress orientations are intrinsically much more amenable to analysis than magnitudes because measurements of stress directions at all depths can be meaningfully compared. Besides that, measured stress orientations can be compared to directions from earthquake fault plane solutions and directions inferred from geologic indicator of stress. **The final stress map will be prepared by incorporating the First and second order stress data by collecting data from various other organisations in India. The updated map will be sent to World stress map to incorporate in the same.**

The project authorities of World stress map urged that there is little information in the WSM apart from data from focal mechanism solutions. They would like to collect intensively new data from Indian sub-continent.

Dr. Oliver Heidbach who is Head of the World stress Map project coordinated with National Institute of Rock Mechanics and asked to contribute for a new WSM database which is going to be published in 2014.

5. Conclusions

Nearly 300 stress indicators along with their magnitude, depth of the investigations conducted, and the direction of Maximum principal stress are available with NIRM. Some of the data has been plotted in the given map and remaining data is under review. The data is being compiled to prepare the latest map and periodical updating is required on timely basis once the new data is acquired from the projects. The regional pattern of Maximum Principal Horizontal stress (σ_H) direction can be delineated from the given data. The average orientation of σ_H shows the more or less in correlation with the direction of movement of Indian plate.

On the basis of regionally consistent orientations three stress provinces are recognized in a broader term: The Himalayas, the mid-continent stress province and southern shield. The Himalayas are further divided into Northwestern Himalayas, Central Himalayas and Eastern Himalayas.

In general the σ_H orientation is NNE-NE throughout the central and Northern India with a mean direction of about N23^{0}E. This orientation is sub parallel to the direction of compression expected from the forces present along the Himalayan collision, which resist the northward movement of the IAP. There is however a large amount of scatter in σ_H orientations throughout the Indian subcontinent suggesting that some of the stress indicators reflect local sources of stress rather than the collisional tectonics.

The Himalayas where we are having maximum data (Around 150) is having orientation varying from N20°- 30°E. In the central part of India the average orientation N10°-20°W is derived from the data generated from the measurements around Aaravali region, Hyderabad and also some parts of Eastern Ghats. In the shield area, the average orientation- N20°E, is the result of data compiled from KGF (Karnataka), Mumbai and Mangalore (Karnataka). 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.

Acknowledgements

The author is thankful to Dr. V. Venkateswarlu, Director, National Institute of Rock Mechanics (NIRM), for his encouragement and necessary corrections in the manuscript. Also thankful to Dr. S. Sengupta for sharing the important technical information and inputs in the preparation of the stress provinces of India.

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