

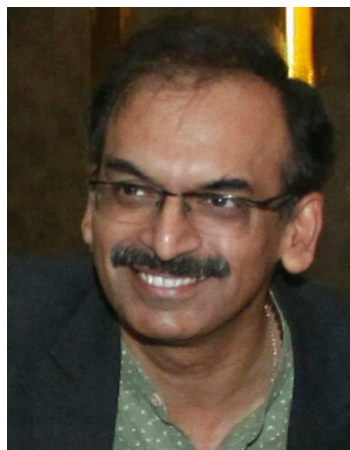
## Dr. N. Purnachandra Rao

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### Academic Qualifications:

Degree	Year	Class	University
<b>D.Sc.</b> Seismology	2000	JSPS Fellowship	University of Tokyo, Tokyo, Japan
<b>Ph.D.</b> Geophysics	1997	ONGC-AEG Best Ph.D. award	Osmania University, Hyderabad, India
<b>M.Sc. (Tech.)</b> Geophysics	1987	Ist Class and 3 <sup>rd</sup> rank in University	Osmania University, Hyderabad, India
<b>B.Sc.</b>	1983	Maths, Physics, Chemistry	Osmania University, Hyderabad, India

Title of D.Sc. Thesis : Active tectonics of the plate margins and the stable continental region of the Indian plate. University of Tokyo, Tokyo, Japan.

Supervisor : Prof. Tameshige Tsukuda, ERI, University of Tokyo, Japan.

Title of Ph.D. Thesis : Mean Slip Angle technique : A new approach to analysis of earthquake source mechanism data. Osmania University, Hyderabad.

Supervisor : Prof. Harsh K. Gupta, NGRI, Hyderabad, India.

### Area of specialization: Seismology (Geophysics)

#### Fields of interest:

- (i) Seismic ambient noise correlation tomography
- (ii) Reservoir triggered seismicity and Earthquake forecast
- (iii) Scientific deep drilling for earthquake studies
- (iv) Seismic Hazard Assessment and Microzonation Studies
- (v) Moment tensor inversion studies for earthquake source mechanism
- (vi) Seismic waveform modeling to study earth's internal structure
- (vii) Stress field and Seismotectonics

Google Scholar:

<https://scholar.google.co.in/citations?user=lefgackAAAAJ&hl=en>

### Academic / Research Experience / Employment

S.No.	From	To	Name of organization	Position
1.	1989	1994	National Geophysical Research Institute	Scientist B
2.	1994	1999	National Geophysical Research Institute	Scientist C
3.	1999	2003	National Geophysical Research Institute	Scientist E1
4.	2003	2007	National Geophysical Research Institute	Scientist E2
5.	2007	2012	National Geophysical Research Institute	Scientist F
6.	2012	2017	National Geophysical Research Institute	Scientist G
7	2017	Present	National Centre for Earth Science Studies	Director

### Research Projects:

S.no.	Title of the project	Role	Sponsor
1.	Geophysical investigations towards establishment of a deep borehole observatory for earthquake studies in the Koyna-Warna region	Project Leader	Ministry of Earth Sciences, Government of India
2.	Real time monitoring of earthquakes for short term forecast and understanding seismogenesis in the Koyna region	Project Leader	Ministry of Earth Sciences, Government of India
3.	Crust-mantle structure and seismic hazard of the Indian region.	Project Leader	Main Lab Project, NGRI
4.	Seismic structure and tectonics of the Indian plate in the Arunachal Himalaya	Project Leader	Ministry of Earth Sciences, Government of India
5.	Lithospheric structure and deformation in the Andaman region	Project Leader	Indian National Center for Ocean Information Services (MoES), Government of India
6.	Intra-plate seismicity in the Indian and Norwegian regions	Project Leader	Ministry of Earth Sciences, Government of India
7.	Geodynamics of the Northeast India and the Andamans (GENIAS)	Co- Project Leader	Council of Scientific and Industrial Research (CSIR)

### **Awards / Honours / Fellowships :**

- National Geoscience Award 2016 (Geophysics) from Ministry of mines, Govt of India
- Doctor of Science (D.Sc.) from University of Tokyo
- Alexander von Humboldt (AvH) fellow, Germany
- Visiting Professor, Univ. of Tokyo, Japan
- Professor, Academy of Scientific Innovative Research
- Raman Research Fellow at University of California, USA
- Recipient of the 'ONGC-AEG Best Ph.D. award', 1997
- Recipient of the JSPS doctoral fellowship of Japan, 1995
- Recipient of the KFA fellowship of Germany, 1991

### **Memberships :**

- Fellow of Geological Society of India
- Fellow of Andhra Pradesh Akademi of Sciences
- Fellow of Telangana State Akademi of Sciences
- Member of the International Lithosphere Programme (ILP) Project
- Associate Editor Journal of Earth System Science
- Member of Editorial Board, Journal of Asian Earth Sciences
- Advisory member of Editorial Board, Indian Journal of Earth Sciences
- Member of Department of Atomic Energy committee for Tsunami studies
- Member of Earthquake Engineering Sectional Committee of the Bureau of Indian Standards, Government of India.
- Member of CED-39 working group for standardization of post-earthquake damage assessment of buildings, Bureau of Indian Standards, Government of India
- Member of Project review committee "Remote sensing and GIS for Chennai city", Govt. of Tamilnadu
- Guest Editor, Special Issue on 2005 Kashmir earthquake in the Journal of Seismology
- Guest Editor, Special Issue on 2015 Nepal earthquake in the Journal of Asian Earth Sciences

### **Special distinctions:**

- First recipient of the ONGC-AEG Best Ph.D. award in 1997
- First Indian scientist to publish on the cover page of the prestigious journal of the American Geophysical Union "Geophysical Research Letters. (Rao and Kalpna, 2005, Vol. 32, No. 5, 16 March 2005".
- Published a paper in Science on the 2001 Bhuj earthquake titled "The deadliest intra-plate earthquake"
- Contributed an invited Focus paper (Topic: The 8 October 2005 Himalayan earthquake) in the "Gondwana Research", a prestigious journal from Elsevier publishers.
- Project Leader from NGRI for the first multi-disciplinary and multi-Institutional Seismic Microzonation study of the country (for Jabalpur city), supported by the Department of Science and Technology, New Delhi.
- Project Leader of one of the most prestigious projects of MoES for Scientific deep drilling in Koyna for earthquake studies

## Visits Abroad:

Country Visited	Year	Program / Fellowship
Vietnam (Hanoi)	2016	International Conference of Vietnam Academy of Geosciences
Nepal (Kathmandu)	2016	Conference on Nepal earthquake by Alexander von Humboldt Foundation
France (Paris)	2014	Indo-French programme of CEFIPRA
New Zealand (Auckland)	2013	Borehole Seismology, Koyna Project, NGRI
USA (San Francisco)	2012	AGU Fall Meeting, San Francisco, USA
Japan (Tokyo)	2011	Indo-Japan Programme on Seismic Hazard in Himalaya Supported by JICA
Japan (Tokyo)	2010	Indo-Japan Programme on Seismic Hazard in Himalaya Supported by JICA
USA (San Diego)	2009-2010	Raman Research Fellow at Univ of California
Pakistan (Islamabad)	2009	SAARC delegate "Earthquake Risk Mitigation and Management in South Asia"
Japan (Tokyo)	2007	Visiting Professor, Univ. of Tokyo
Germany (Hannover)	2006	International conference on the Indian Ocean Tsunami and future studies in the Offshore
France (Paris)	2006	Meeting of cruise participants for the offshore Sumatra region at IPGP
France (Nice)	2004	International Conference of European Geosciences Union (EGU)
Germany (Berlin)	2003 – 2004	Alexander von Humboldt (AvH) Fellowship
Italy (Trieste)	2003	Indo-Italian Joint Cooperation in Seismic Microzonation
Japan (Tokyo)	2000	Western Pacific Geophysics AGU Meeting
Japan (Tokyo)	1995 – 2000 (3 months / yr.)	JSPS (RONPAKU) Doctoral Program
Norway (Bergen)	1997	DST Program, Govt. of India
Nepal (Kathmandu)	1993	International Conference on Himalaya-Tibet
The Netherlands (Hague)	1992	International Conference in Geodesy
Germany (Bonn)	1991 – 1992	KFA Fellowship for VLBI studies
U. S. S. R. (Moscow)	1989	Indo-USSR Exchange Program, for seismicity studies

## **Significant Contributions and achievements in R&D:**

Made significant contributions in earthquake studies towards understanding the geodynamics of the Indian plate margins, particularly the Burma-Andaman arc, the Himalaya-Tibet region and the diffuse Indian Ocean deformation zone. Brought in application of new methodologies in the country like seismic moment tensor inversion and seismic ambient noise correlation. Played a lead role in the first Seismic Microzonation study of the country in Jabalpur city supported by DST. Currently heading the prestigious Koyna project of MoES aimed at scientific deep drilling to study reservoir triggered intra-plate earthquakes.

One of my major contributions has been in bringing out the uniqueness of the tectonically complex Burmese arc in comparison to worldwide subduction zones. Demonstrated that an eastward subducted lithospheric slab exists but the subduction process has come to an end. Instead, an overturned lithospheric configuration has been attained due to an unusual resistance to slab penetration at the 410 km discontinuity in the mantle, in course of the clockwise rotation of the Sundaland and westward migration of the arc. This feature is convincingly evidenced also by images of seismic tomography in this region. This result was selected for the cover page of the *Geophysical Research Letters*, a prestigious journal of the American Geophysical Union (Rao and Kalpna, 2005, Vol. 32, No.5, 16 March 2005), for the first time from India.

I was heading one of the most important mega-projects of our Institute from the MoES, namely "Scientific deep drilling for earthquake studies in the Koyna-Warna region" during its preparatory phase. The project aims at developing an earthquake model, specifically for an intra-plate RTS zone using inputs from drilling and various geophysical studies. We have successfully installed borehole seismometers at depths of ~ 1.5 km and are going to establish a unique borehole seismic network at such depths for precise monitoring of seismicity. New results obtained from drilling of 5 boreholes up to 1.5 km deep has indicated Deccan trap thickness of about 1 km on an average, with variation mostly confined to topography, which implies a fairly flat basement prior to Deccan volcanic eruption in this region. Also, a complete absence of sediments between the traps and the basement is a new finding. Further, airborne gravity-gradiometry survey, has been carried out for the first time in the country, in the Koyna-Warna region, which has provided a regional 3D model. Airborne Lidar survey has just been concluded which is expected to provide precise surface geomorphology of the region (Rao et al., 2013; Roy et al., 2013).

Initiated broadband seismic waveform modeling and moment tensor inversion studies for the Indian regional / local broadband earthquake data. In the Koyna region moment tensor inversion studies have provided accurate focal mechanism solutions. Additionally they have helped in precise delineation of focal depths (Shashidhar et al., 2011). This has enabled selection of the most suitable zone for the scientific deep drilling planned for future, which is in the Warna area. This apart, our work using JHD and double-difference methods has clearly delineated the geometry of the fault zone for the first time, both in Koyna and Warna region. Based on this study it has been inferred that the Donachiwada fissure zone is responsible for earthquakes in the Koyna region, including the 1967 M6.3 earthquake.

Waveform modeling in the Kutch-Saurashtra region has brought in fresh understanding of the tectonics in this region. While the Girnar mountain is recognized as a left-lateral strike slip fault system, it is demonstrated that the Kutch-Saurashtra region is experiencing 'escape tectonics' in the westward direction (Rao et al., 2013, JAES).

I was also Principal investigator of the Koyna earthquake precursory programme supported by the Ministry of Earth Sciences. Under this programme earthquakes in the Koyna-Warna region of Maharashtra are being continuously monitored in real time through satellite network, which has led to successful short term earthquake forecasts based on an earthquake precursory phenomenon referred as nucleation (Gupta et al., 2005, Current Science).

In India's first detailed Seismic Microzonation study which was carried out for Jabalpur city, I was the Principal Investigator from NGRI and played a major role in carrying out site response studies and 2D modeling of seismic ground motion, in the Jabalpur region (Rao and Kumar, 2012). The study has brought out the detailed seismic hazard and risk maps of the region. We also demonstrate how numerical modeling can be used to confirm results from the empirical approaches (Rao et al., 2011, JPCE).

I also initiated seismic ambient noise correlation studies in the country during my visit to the University of California, San Diego, USA, in 2009, as a Raman Research fellow. Studied the seismic source directionality in the Indian subcontinent and demonstrated for the first time that distribution of noise sources in the Indian subcontinent is anisotropic, predominantly towards the SW Indian Ocean (Rao et al., 2009, AGU).

#### Summary of Contributions

- Numerical modeling of global plate kinematics with special reference to Indian plate
- Development of Mean-Slip-Angle technique for analysis of earthquake source mechanisms
- Analyzed earthquake focal mechanisms of worldwide subduction zones and demonstrated the uniqueness of the Burmese
- Demonstrated a distinct segregation of strike-slip and normal type focal mechanisms in the upper (<90km) and lower (>90km) parts of the subducted Indian plate beneath Burma.
- Carried out a detailed seismotectonic study of the Burma and Andaman arc regions using centroid moment tensor data
- Proposed a combination of wrench fault tectonics and Euler pole rotation model for the Indian Ocean diffuse deformation zone.
- Demonstrated a pop-up uplift mechanism for the Shillong plateau due to India-Eurasia and India-Burma plate forces
- Strain rate analysis of earthquake data in Himalaya, Tibet and Burmese arc regions
- Demonstrated the efficacy of Single station moment tensor inversion for focal mechanisms of Indian intra-plate earthquakes
- Provided evidences for cessation of Indian plate subduction in the Burmese arc region

- Computed the moment tensor and provided tectonic interpretation of the Bhuj earthquake of 26 January, 2001.
- Established the deep lower crustal occurrence of earthquakes in the central part of the Indian shield using waveform modeling.
- Provided interpretation of serpentized mafic intrusives in the lower crust to explain the occurrence of deep earthquakes in central India
- Proposed the plate junction theory to explain occurrence of great earthquakes like the 2004 Sumatra earthquake near the junction of three or more plates.
- Stress inversion of earthquakes in the Burmese arc to provide new interpretation for occurrence of reverse fault earthquakes at deeper levels of the subducted Indian slab.
- Forecasted 6 earthquakes in the Koyna reservoir triggered seismic zone based on the concept of foreshock clustering called nucleation.
- Analyzed the 2005 Muzaffarabad (Kashmir) earthquake and reviewed the status of seismicity, tectonics and hazard in the Himalaya
- Modelled the stress build-up near a triple plate junction like India-Australia-Sunda, using Applied Element technique
- Analyzed the 2006 Sikkim earthquake and its aftershocks, and inferred the causative factors of seismogenesis
- Proposed the concept of transverse tectonics in Sikkim Himalaya to explain the partitioning of Indian plate convergence in the form of strike-slip earthquakes
- Analyzed the disastrous 2007 Sichuan earthquake, China, to infer its aftershock pattern
- Modelled the sPn phases of regional earthquakes in the northeast India to estimate reliable focal depths of significant earthquakes
- Based on reliable focal depths from sPn modeling, concluded that earthquakes in the northeast India are all within the crust
- Delineated the precise focal depths in Koyna (8-13 km) and Warna (4-6 km) based on waveform modeling
- Estimated the stress field in different parts of Himalaya using stress inversion
- Computation of Seismic hazard and risk microzonation maps of Jabalpur, Central India
- Computed the Shear wave anisotropy of the Godavari rift in the south Indian shield and provided interpretation for the strains
- Computed a new model for the Structure and Tectonics of the Andaman Subduction Zone using Seismological and Gravity Data.
- Initiated a mega-programme of Deep Scientific Drilling to Study Reservoir-Triggered Earthquakes in Koyna, Western India
- Initiated local moment tensor inversion of earthquakes in the Koyna-Warna region
- Site response studies in Jabalpur, central India to estimate the seismic wave amplifications
- Studied the temporal variation of b value in the Koyna–Warna region, Western India, and demonstrated drastic falls for RTS zones.
- Analyzed the 2011 Talala earthquake in Saurashtra region and demonstrated that the Girnar mountains represent a left-lateral strike-slip fault system

- Established the ISLANDS seismic network in the Andaman–Nicobar subduction zone which contributes to the national Tsunami warning Center.
- Demonstrated seismic signatures of an altered crust and a normal transition zone structure beneath the Godavari Rift using receiver function analysis
- Initiated scientific deep drilling in Koyna-Warna region with 8 boreholes to ~ 1.5 km depth penetrating the Deccan basalts into the granite-gneiss basement
- Provided evidence for right-lateral strike-slip environment in the Kutch basin of northwestern India from moment tensor inversion studies
- Demonstrated evidence for west-ward escape tectonics in the Saurashtra plateau supported by left-lateral motion in the north and right-lateral motion in the south
- Estimated the source parameters of earthquakes in the reservoir-triggered seismic (RTS) zone of Koyna–Warna, Western India and their relationships
- Analyzed the waveforms of the April 2012 Koyna earthquake which is the best monitored earthquake in Koyna till date
- Demonstrated that Donachiwada fault is a NNE trending, west dipping left-lateral strike-slip fault which is responsible for most seismicity in Koyna, including the 1967 M6.3 earthquake
- Annual periodicity in the seismicity and water levels of the Koyna and Warna reservoirs, western India using singular spectrum analysis
- Detailed airborne Gravity, magnetic, Lidar, magnetotelluric, seismic and borehole seismic studies in the Koyna-Warna region.
- Obtained the detailed lineament structure and geomorphology of the Koyna-Warna region
- Waveform modeling of the 2014 Bay of Bengal earthquake to obtain the structure and tectonics
- Obtained the shear-wave velocity structure of the Koyna–Warna region in Western India using Ambient Noise Correlation and Surface-Wave Dispersion methods
- Established a unique network of 6 borehole seismometers surrounding the seismic zone in the Koyna-Warna region for precise hypocentral location
- Developed a comprehensive catalog of 50 focal mechanism solutions for the Koyna-Warna region
- Demonstrated a periodic variation of stress field in the Koyna–Warna seismic zone with alternating strike-slip (6 years) and normal faulting (16 years) mechanism



## List of publications

1. Rao, N. P., Kumar, M. R. and Arora, K. (2017). Discovery of a massive ancient tectonic slab in the southeastern Indian Ocean: implications for the Indian Ocean geoid low. *Current Science*, 112, 449-450.
2. Rao, N.P., Bürgmann, R., Mugnier, J.L., Gahalaut, V.K., Pandey, A.K. (2017). 25 April 2015 Gorkha Earthquake in Nepal Himalaya (Part I) - Preface. *J. Asian Earth Sci.*, 133, pp1.
3. Gupta, H.K., Shashidhar, D., Mahato, C.R., Satyanarayana, H. V. S., Mallika, K., Rao, N.P., Maity, B.S., Navitha, K. (2017). Location of the pilot borehole for investigations of reservoir triggered seismicity at Koyna, India. *Gondwana Research*, 42, 133-139.
4. Singh, A.P., Rao, N.P., Kumar, M.R., Hsieh, M.C. and Zhao, L. (2017). Role of Kopili fault in the deformation tectonics of the Indo-Burmese arc inferred from rupture process of the 3 January 2016 (MW 6.7) Imphal earthquake. *Bull. Seismol. Soc. Am.* doi:10.1785/0120160276.
5. Rao, N. P. and Shashidhar, D. (2016). Periodic variation of stress field in the Koyna–Warna reservoir triggered seismic zone inferred from focal mechanism studies, *Tectonophysics* 679, 29-40.
6. D Shashidhar, HVS Satyanarayana, CR Mahato, K Mallika, Rao N.P. (2016). Borehole Seismic Network at Koyna, India, *Seismological Res. Lett.* 87 (3), 661-667.
7. Maurya, S., Montagner, J.P., Ravi Kumar, M., Stutzmann, E., Kiselev, S., Burgos, G., Rao, N. P. and Srinagesh, D. (2016). Imaging the lithospheric structure beneath the Indian continent, *J. Geophys. Res.* 121, doi:10.1002/2016JB012948.
8. Gupta, H.K., Arora, K., Rao, N. P., and others (2016). Investigations of continued reservoir triggered seismicity at Koyna, India. Geological Society, London, Spl. Pub., 445.
9. Gahalaut, K., Tuan, T. A., Rao, N. P. (2016). Rapid and Delayed Earthquake Triggering by the Song Tranh 2 Reservoir, Vietnam. *Bull. Seismol. Soc. Am.*, 106, 2389-2394.
10. Rao, N.P., Tiwari, V.M., Kumar, M.R., Hazarika, P., Saikia, D., Chadha, R.K., Rao, Y.J.B. (2015). The  $M_w$  6.9 Sikkim-Nepal earthquake of September 2011: A perspective for wrench faulting in the Himalayan thrust zone. *Natural Hazards*, 77.
11. Rao, C.N., Rao, N.P., Kumar, M.R., Prasanna S., Srinagesh, D. (2015). Structure and tectonics of the Bay of Bengal through waveform modeling of the 21 May 2014 earthquake of magnitude 6.0. *Seismological Res. Lett.*, 86.
12. Rohilla, S., Rao, N.P., Gerstoft, P., Shashidhar, D., Satyanarayana, H.V.S. (2015). Shear wave velocity structure of the Koyna-Warna region in western India using Ambient Noise correlation and Surface Wave Dispersion. *Bulletin of Seismological Society of America*, 105, 473-477.
13. Yadav, A., Gahalaut, K., Mallika, K, Rao, N.P. (2015). Annual periodicity in the seismicity and water levels of Koyna and Warna reservoirs, Western India: A Singular Spectrum Analysis approach. *Bulletin of Seismological Society of America*, 105, 464-472.
14. Rao, N. P. (2015). Earthquakes. *Amaravathi Popular Science Series*, A.P. Akademi of Sciences, 26 pp.
15. Shashidhar, D., Mallika, K., Rao, N.P., Satyanarayana, H.V.S., Gupta, H. K. (2014). Detection of Quarry Blasts in the Koyna-Warna Region, Western India. *Open Journal of Earthquake Research*, 3, 162-169.
16. Gupta, H.K., Nayak, S., Ellsworth, W., Rao, Y.J.B., Rajan, S., Bansal, B.K., Rao, N.P., Roy, S., Arora, K., Mohan, R., Tiwari, V.M., Satyanarayana, H.V.S., Patro, B.P.K., Shashidhar, D., Mallika, K. (2014). Probing Reservoir Triggered Earthquakes at Koyna, India through Scientific Deep Drilling. *Scientific Drilling*, 18, 5.

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18. Shashidhar, D., Rao, N.P., Srinagesh, D., Gupta, H., Satyanarayana, H.V.S., Suresh, G., Satish, A. (2013). The 14 April 2012 Koyna Earthquake of Mw 4.8: insights into active tectonics of the Koyna region, *J. of seismology*, 17(4),1345-1353.
19. Rao, C.N., Rao, N.P., Rastogi, B.K. (2013). Evidence for Right Lateral Strike Slip Environment in the Kutch Rift of Northwestern India from Moment Tensor Inversion Studies. *J. Asian Earth Sci.*, 64, 158-167.
20. Rao, N.P., Roy, S., Arora, K. (2013). Deep Scientific drilling in Koyna,India - Brainstorming workshop on geological investigations 19-20 March 2013, *J. Geol. Soc. India*, 81(5). 722-723.
21. Roy, S., Rao, N.P., Vyasulu, V.A., Goswami, D., Sen, M., Gupta, H., Bansal, B.K., Nayak, S. (2013). Granitic basement below Deccan Traps Unearthed by drilling in the Koyna seismic zone, Western India, *J. Geol. Soc. India*, 81(2), 289-290.
22. Yadav, A., D Shashidhar, K Mallika, N P. Rao, S. Rohilla, HVS Satyanarayana, D Srinagesh, Gupta, H., (2013). Source parameters of earthquakes in the reservoir-triggered seismic (RTS) zone of Koyna-Warna, Western India, *Natural hazards*, 69(1), 965-979.
23. Mallika, K, Gupta, H., Shashidhar, D., Rao, N.P., Yadav, A., Satyanarayana, H.V.S., Srinagesh, D. (2013). Variation of b-value near the Source zone in the Reservoir Triggered Seismic Environment of the Koyna-Warna Region, Western India. *J. of Seismology*, 17, 189-195.
24. Srijayanthi, G., Kumar, M. R., Sirisha, T., Sushini, K., Srihari Prasad, G., P. Solomon Raju, Singh,A., and Rao, N. P. (2012). The ISLANDS Network in the Andaman-Nicobar Subduction Zone. *Seismological Research Letters*, 83, 686-696.
25. Gupta, H., Rao, N.P., Shashidhar, D., Mallika, K., Ros, S. (2012). Deep Scientific Drilling to study Reservoir Triggered Earthquakes at Koyna, India. *DCS-DST News*.
26. Rao, N.P. and Kumar, M.R. (2012). Seismic Microzonation of Jabalpur of Jabalpur urban area. *Geol. Soc. India*, pp70.
27. Rao, N.P., Kumar, M.R., Seshunarayana, T., Shukla, A.K., Suresh, G., Pandey, Y., Raju, D., Pimprikar, S.D., Das, C., Gahalaut, K., Mishra, P.S. and Gupta, H. (2011). Site amplification studies towards seismic microzonation in Jabalpur urban area, central India. *J. Phys. Chem. of Earth*, doi:10.1016/j.jpce.2011.01.002.
28. Shashidhar, D., Rao, N.P. and Gupta, H.K. (2011). Waveform inversion of broadband data of local earthquakes in the Koyna-Warna region, western India. *Geophys. J. Int.*, doi:10.1111/j.1365-246X.2011.04935.x.
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30. Gupta, H., Nayak, S., Rao, Y.J.B., Chadha, R.K., Bansal, B. K., Srinagesh, D., Rao, N.P., and Roy, S. (2011). International workshop on deep scientific drilling to study reservoir triggered earthquakes in Koyna, India. *J. Geol. Soc. India*, 77, 488-490.
31. Gupta, H., Shashidhar, D., Mallika, K., Rao, N.P., Srinagesh, D., Satyanarayana, H.V.S., Saha, S. and Naik, R.T.B. (2011). Short term earthquake forecasts at Koyna, India. *J. Geol. Soc. India*, 77, 5-11.

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33. Hazarika, P., Kumar, M.R., Srijayanthi, G., Raju, P.S., Rao, N.P., Srinagesh, D. (2010). Transverse tectonics in the Sikkim Himalaya: evidence from seismicity and focal mechanism data. *Bull. Seism. Soc. Am.*, 100, 1816-1822.
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35. Devi, E. U., Rao, N. P. and Kumar, M. R. (2009). Modeling of sPn phases for reliable estimation of focal depths in northeastern India. *Current Science*, 96, 1251-1254.
36. Gupta, H. K., Rao, N. P. and Yeats, R. (2009). Guest Editorial in “8 October 2005 Muzaffarabad earthquake” Ed: Gupta et al., *J. Seismol.*, 13, 313–314.
37. Gahalaut, K. and Rao, N.P. (2008). Stress field in the western Himalaya with special reference to the 8 October 2005 Muzaffarabad earthquake. *J. Seismology*. DOI 10.1007/s10950-008-9107-1.
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## List of Technical Reports

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2.	<b>N.P. Rao</b> and others	Seismic microzonation of Jabalpur urban area, Madhya Pradesh	Tech. Rep., 2005, Department of Science and Technology, New Delhi.
3.	Kumar, M. R., <b>N.P. Rao</b> , Vaccari, F. and Panza, G. F.	Modeling of seismic ground motion in Jabalpur Central India using laterally heterogenous shallow structural models	Tech. Rep., 2003, MEA, Italy and DST New Delhi.
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