International Conference on
HYDROPOWER AND DAMS DEVELOPMENT FOR WATER AND ENERGY SECURITY – UNDER CHANGING CLIMATE

THDC India Ltd.

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Indian National Committee on Large Dams

RESERVOIR TRIGGERED SEISMICITY SCENARIO WITH SPECIAL EMPHASIS TO THE HIMALAYAS

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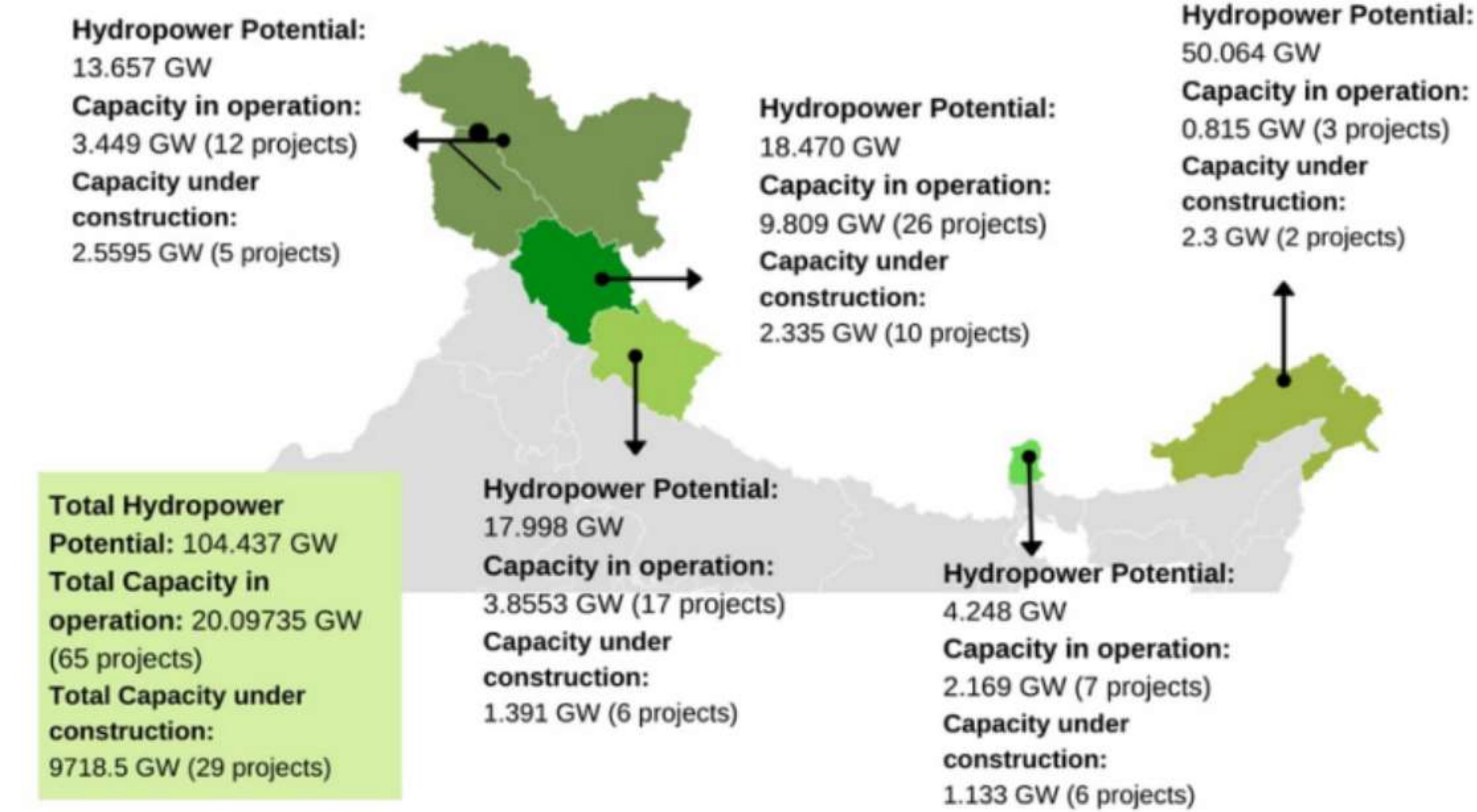
NHPC

Hydropower potential in India's Himalayan states

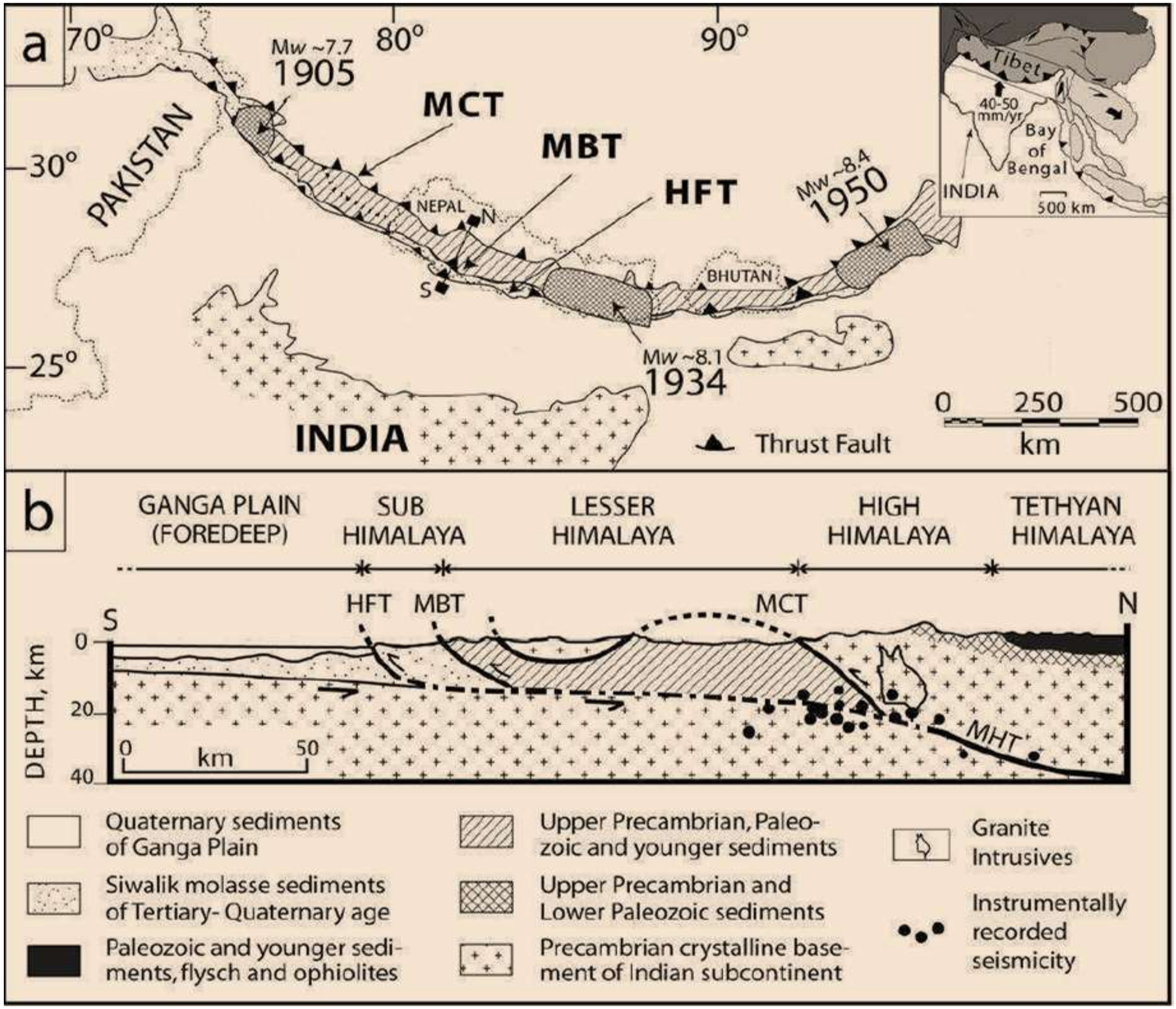


The Union power ministry statement for last financial year states that peak power demand deficit in India was almost wiped out in 2020-21 period. The ministry said the deficit stood at 0.4 per cent in 2020-21 compared to 16.6 per cent in 2007-08 and 10.6 per cent in 2011-12.

BACKGROUND OF WORK PRESENTED

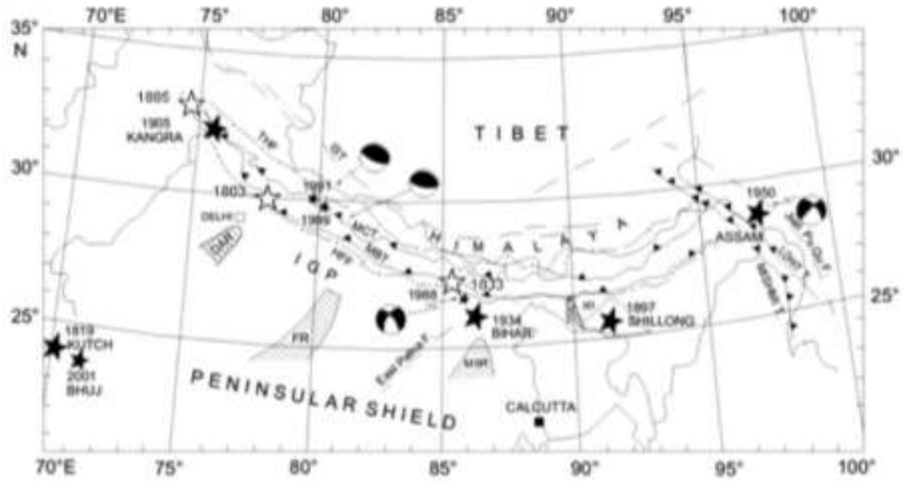
- Why does India need Dams:
  - For water storage
  - Mitigating drought
  - flood control measures.
- The natural water resources and high gradient in the Himalayas make it an ideal source for tapping hydropower.
- The entire Himalayas belt falls in the seismic zone IV & V (BIS 1893: 2016-Part I).
- This has led to questions been raised on
  - Construction of dams in seismically active Himalayas.
  - Reservoir Triggered seismicity (RTS).
- Till date there has not been any significant incidence of RTS reported for numerous hydroprojects running in the Himalayas
- To deal with the public fear scientifically, a planned seismic monitoring approach needs to be employed.
- NHPC has developed a centralized online seismic monitoring network with seismic instruments installed at all of its projects connected centrally for online monitoring on a continuous basis.

MAJOR TECTONIC FEATURES OF THE HIMALAYAS



- The continent-continent collision resulted in large fragmentation of the lithosphere in Himalaya

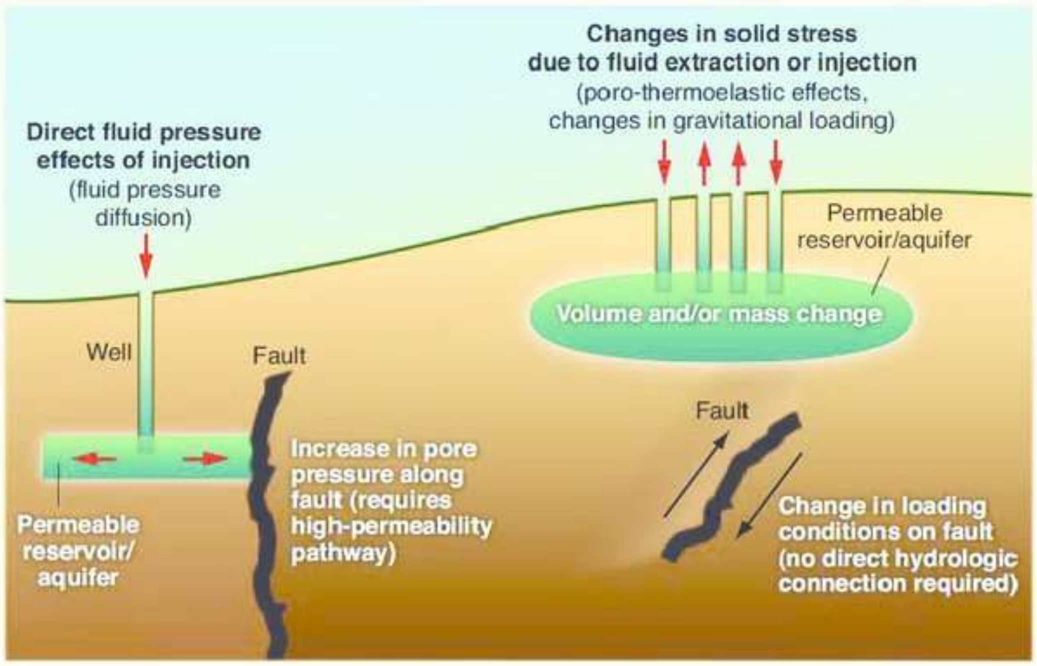
SEISMIC STATUS OF HIMALAYAS AND GREAT EARTHQUAKES IN INDIA



- **Seismicity is mainly confined to the upper & middle crustal zones near the plate boundary and also near several active NE-SW lineaments.**
- **This has resulted in occurrence of deeper strike-slip earthquakes, like the 1988 M6.8 Bihar-Nepal and the 2001 M6.9 Sikkim earthquakes.**
- **In the past century, three great earthquakes (M>8.0) have occurred in the Himalayan arc : (1905 Kangra, 1934 Bihar and 1950 Assam);**
-

RESERVOIR TRIGGERED SEISMICITY- BACKGROUND

- ✓ Low magnitude minor earthquakes
- ✓ The area is required to be already under considerable tectonic stress.
- ✓ The energy released is normal tectonic strain energy that has been prematurely released because of the reservoir.
- ✓ Causes of RTS:
  - The extra water pressure created as the reservoir fills
  - Failure caused by increasing the vertical principal stress as a result of the weight of impounded water.



FACTORS RELATED TO RESERVOIR TRIGGERED SEISMICITY

Following factors show some correlation with Reservoir Induced Seismicity:

- ***Pore Pressure***
- ***Duration of Reservoir Induced Seismicity***
- ***Volume of the Reservoir***
- ***'b' value correlation***
- ***Type of fault***

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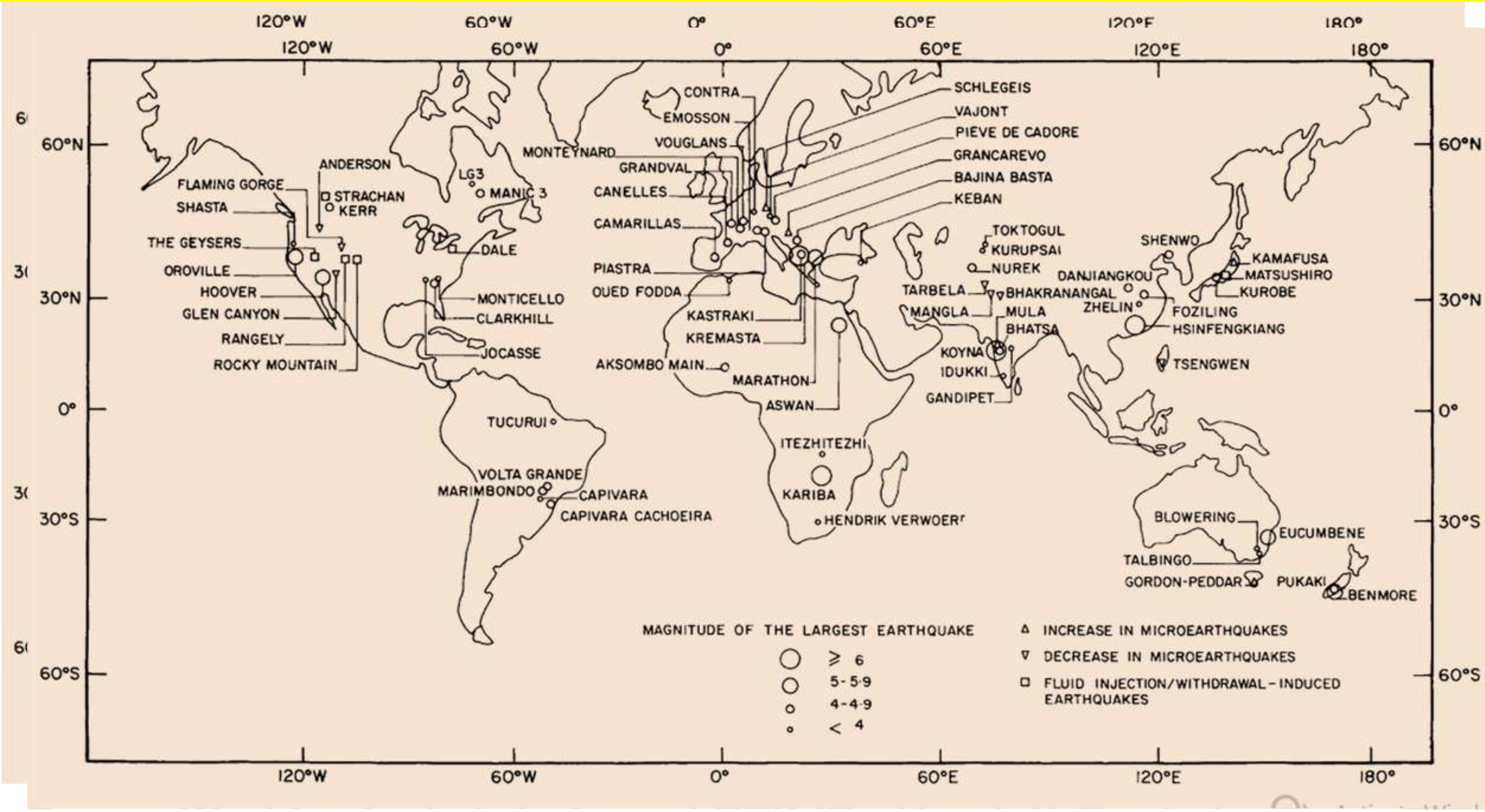
RESERVOIR TRIGGERED EARTHQUAKES WORLDWIDE



Worldwide distribution of RTS (Dr. Harsh K Gupta)

Dam reservoir	Country	Height (m)	Volume ($x10^6 m^3$)	Year of filing	Strongest Earthq.	M_{max}
Vaoint	Italy	262	168.7	1960	1963	4.9
Koyna	India	103	2.780	1964	1967	6.3
Kremasta	Greece	165	4.750	1965	1969	4.4
Oroville	California	235	59.34	1967	1975	5.7
Xingfengjiang	PR China	105	10.500	1959	1962	6.1
Kariba	Zimbabue	128	160.368	1959	1963	6.2
Hoover	USA	221	36.703	1936	1939	5.0
Marathon	Greece	63	41	1930	1938	5.7
Aswan	Egypt	115	165.000	1978	1981	5.3
Benmore	New Zealand	118	2.100	1965	1966	4.5
Monteynard	France	155	240	1962	1963	4.9
Kurobe	Japan	186	199	1960	1961	4.9
Bajina-Bašta	Serbija	89	240	1965	1967	4.7-5.0
Nurek	Iran	317	10.400	1972	1972	4.6
Mangla	Pakistan	116	7.250	1967	1967	4.2
Grandval	France	88	292	1959	1963	4.7
Canalles	Spain	150	678	1960	1962	4.7

RESERVOIR TRIGGERED SEISMICITY IN THE HIMALAYAS

- **Incidence of RTS have been observed from peninsular/central India; no major incidence has been reported from the Himalayas.**
- **The largest earthquake attributed to reservoir-Triggered seismicity occurred at Koyna Dam in Peninsular India. Decrease in seismic activity has also been reported at certain reservoir sites, as would be expected for compressive stress regimes**
- **In General Himalayas have a thrust environment and no incidence of RTS has been observed with most of the hydro projects running successfully in the Himalayas.**

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Some major hydro projects in the Himalayas in the past several decades without any incidence of RTS are

S.N	Name of Project/Country	Dam Height	Reservoir Capacity	RIS status
1	Tehri project (India)	260.5m	3.54 BCM	No RTS incidence
2	Chamera HEP-I (India)	140m	391MCM	No RTS incidence
3	Salal HEP-I&II (India)	118m	284MCM	No RTS incidence
4	Teesta V(India)	88.6m	13.25MCM	No RTS incidence
5	Bhakra nangal project (India)	226m	7.55 BCM	Reduction in seismicity post construction
6	Tarbela (Pakistan)	143m	13.69 BCM	Reduction in seismicity post construction
7	Mangla (Pakistan)	147m	9.12 BCM	Reduction in seismicity post construction

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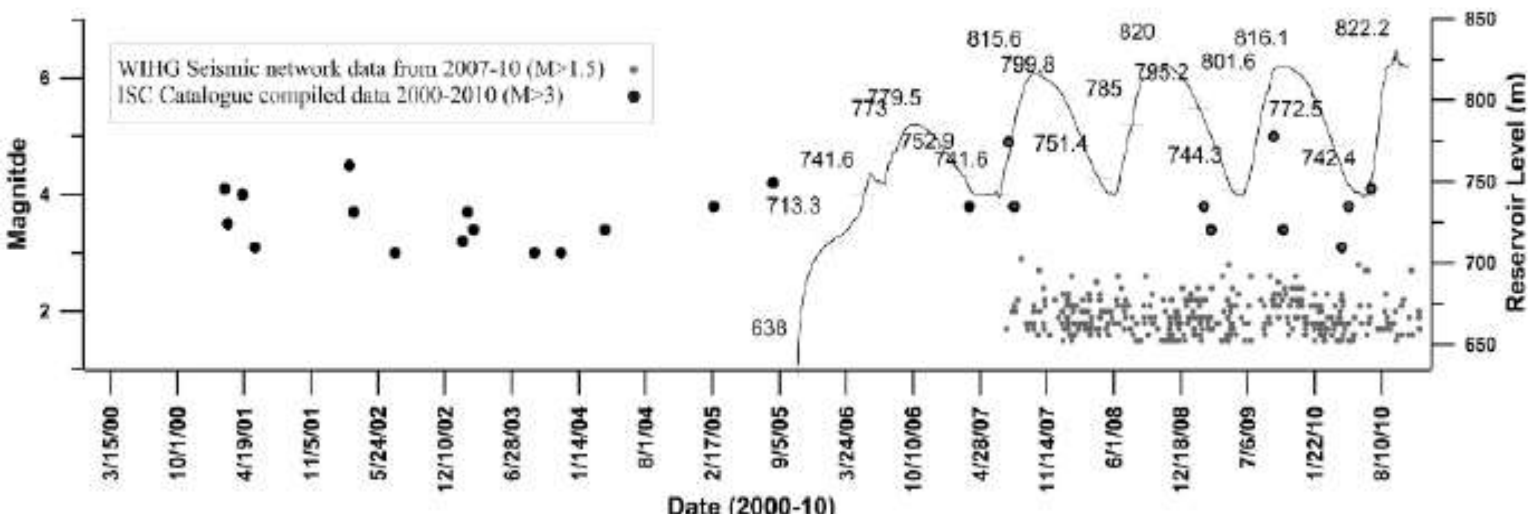
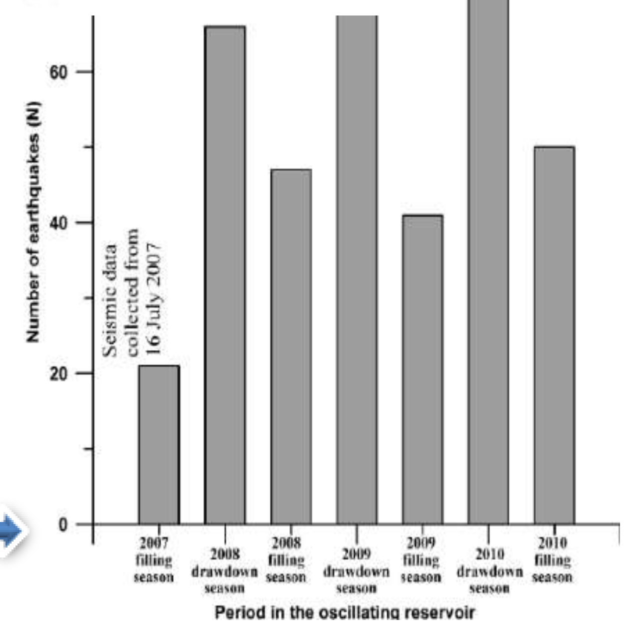
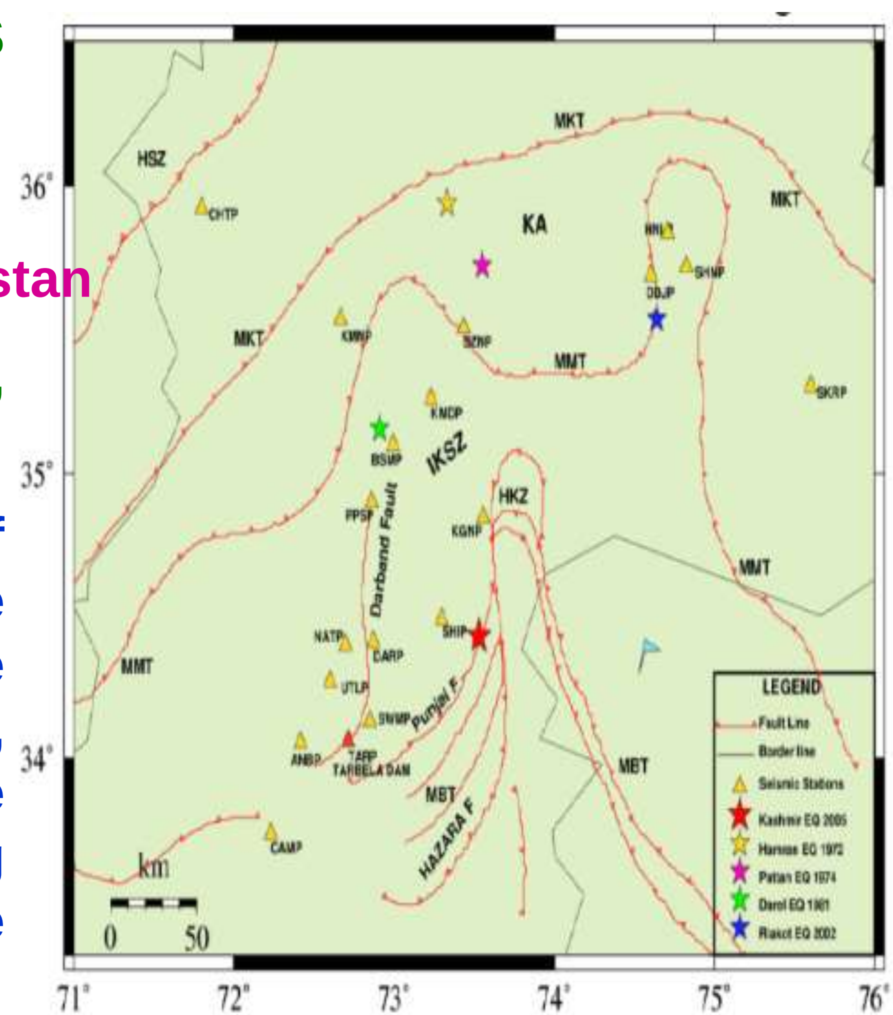


Earthquake data along with water level history of the Tehri from Oct. 2005 (since filling) to 2010.

Number of earthquake events per filling period (filling and drawdown cycles) around the Tehri Reservoir, India. Seismicity appears to be more pronounced in the drawdown periods.



- **The three identified cases of RTS in the Himalayan region :**
  - **Mangla dam (118m,7.25BCM)**
  - **Tarbela dam (143m, 1367MCM)** } **Pakistan**
  - **Bhakra Nangal dam in India.(226m, 9868MCM)**
- **In all these cases the effect of reservoir in the seismicity of the area is the reduction in the earthquake activity (Gupta H. K. , 1992). Construction of these projects has resulted in mobilizing the stresses towards a stable environment.**
- **All the reported cases of RTS in India are from peninsular India.**



Micro seismic network around Tarbela

SEISMIC STUDIES UNDERTAKEN AT NHPC PROJECTS

A. PRE- CONSTRUCTION STAGE:

- Specialized seismicity studies like Micro Earthquake (MEQ) Studies and Local Earthquake Tomography (LET) studies are carried out by installation of seismographs to record the seismic activity in the area within 50km radius of the dam site.
- The studies are planned as per the guidelines laid down by National Committee on Seismic Design Parameter Studies for river valley projects (NCSDP), CWC, GoI.
- These studies assess in a precise way the :
  - ✓ seismo-tectonic setup,
  - ✓ status of various faults/ thrusts
  - ✓ identification of the location and geometry of the faults in the area.
- These studies are carried out in association with institutes like Department of Earthquake Engineering (DEQ), IIT-Roorkee, CWPRS-Pune, Institute of Seismological Research (ISR) Gandhinagar and Wadia Institute of Himalayan Geology (WIHG), Dehradun etc.

- **The seismicity studies play an important role in the determination of design earthquake parameters for hydroelectric projects as well for understanding the periodic seismogenic activities in and around the project site.**
- **These studies give finer, detailed picture of the present activity status of various thrusts/faults in and around the project area.**
- **Mapping of the activity levels of these faults/lineaments etc provide a background seismicity data for the area which is later compared with the post impoundment seismicity data to assess changes in the seismicity levels due to the project if any.**

The details of studies undertaken for some big NHPC projects (Dam height >100m; Reservoir Volume >500m^3)

S. No.	Name of Project	Project Highlights	Seismological studies undertaken by NHPC	Remarks
1	Bursar project, Jammu & Kashmir (800MW)	Seismic zone IV; 289m high concrete gravity dam	MEQ/LET studies carried out by ISR, Gandhinagar, Gujarat; Nine months seismic data was collected.	▪ This data will form the base data of pre impoundment seismicity. ▪ Further seismic monitoring can be carried out after reservoir filling ▪ Pre-impoundment seismicity can be compared with the post impoundment data to establish RTS if any
2	Kwar Project, Kishtwar region of Jammu & Kashmir	Seismic zone IV; 109m high concrete gravity dam on river Chenab	MEQ studies by Wadia Institute of Himalayan Geology Dehradun; six months seismic data was collected	
3	Dibang MPP, Arunachal Pradesh (3000MW)	Seismic zone V; 279m high concrete gravity dam on Dibang.	MEQ studies along with LET carried out by GSI; six months seismic data collected	
4	Subansiri Lower Project, Assam/Arunachal Pradesh (2000MW)	seismic zone V; 125m high concrete gravity dam across the river Subansiri.	A seismic network of six broadband seismographs and an accelerograph has been deployed permanently since May 2006	

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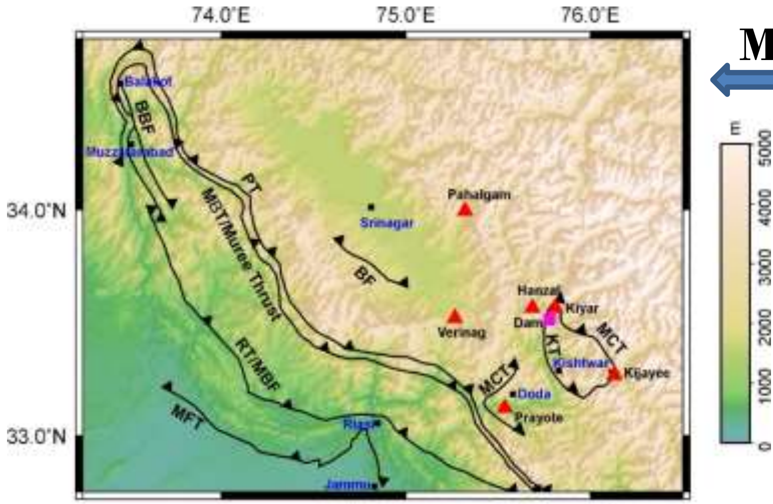
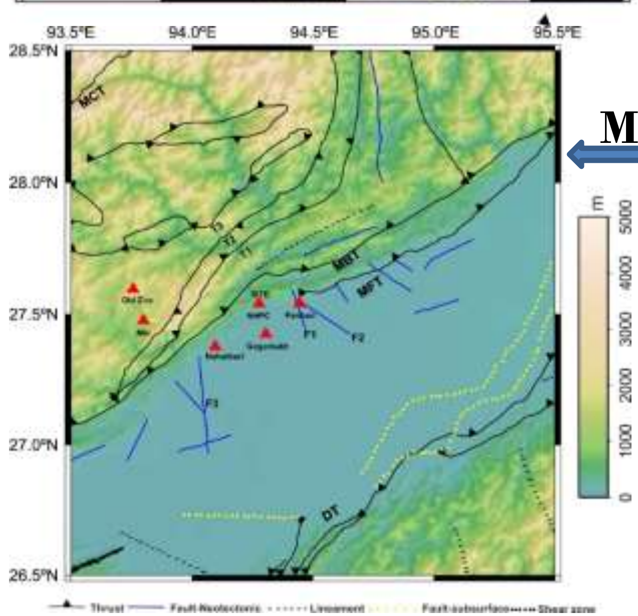
MAP SHOWING LOCATION OF SEISMOGRAPH STATIONS FOR

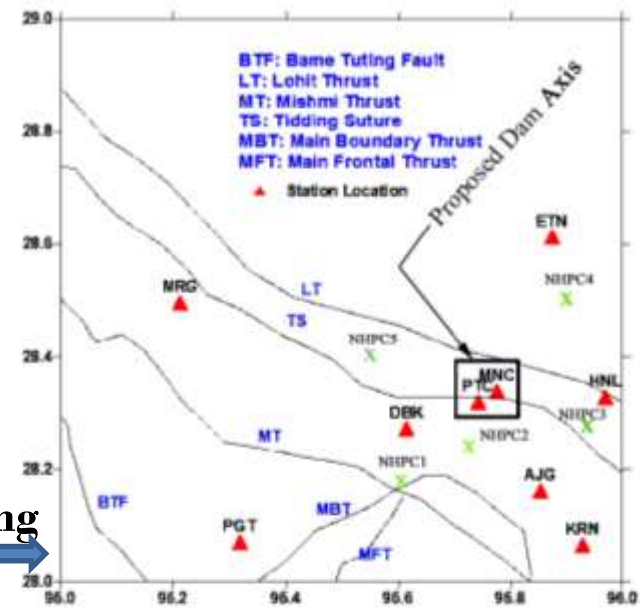


MEQ-LET -Bursar

MEQ -Kwar

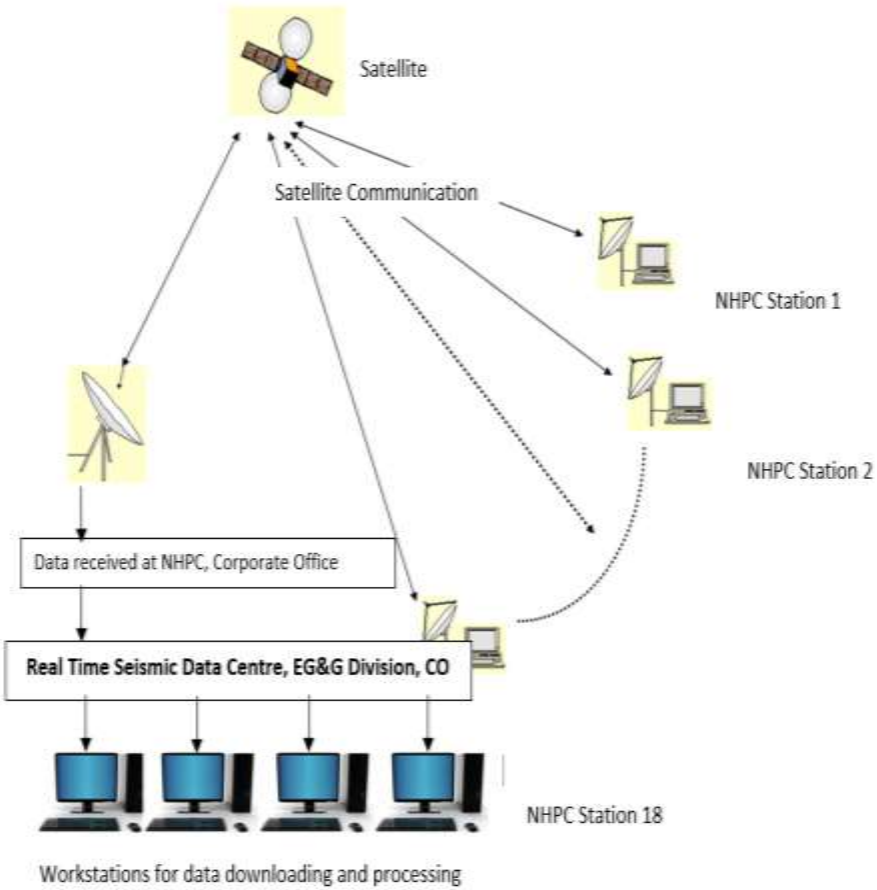


MEQ -Subansiri



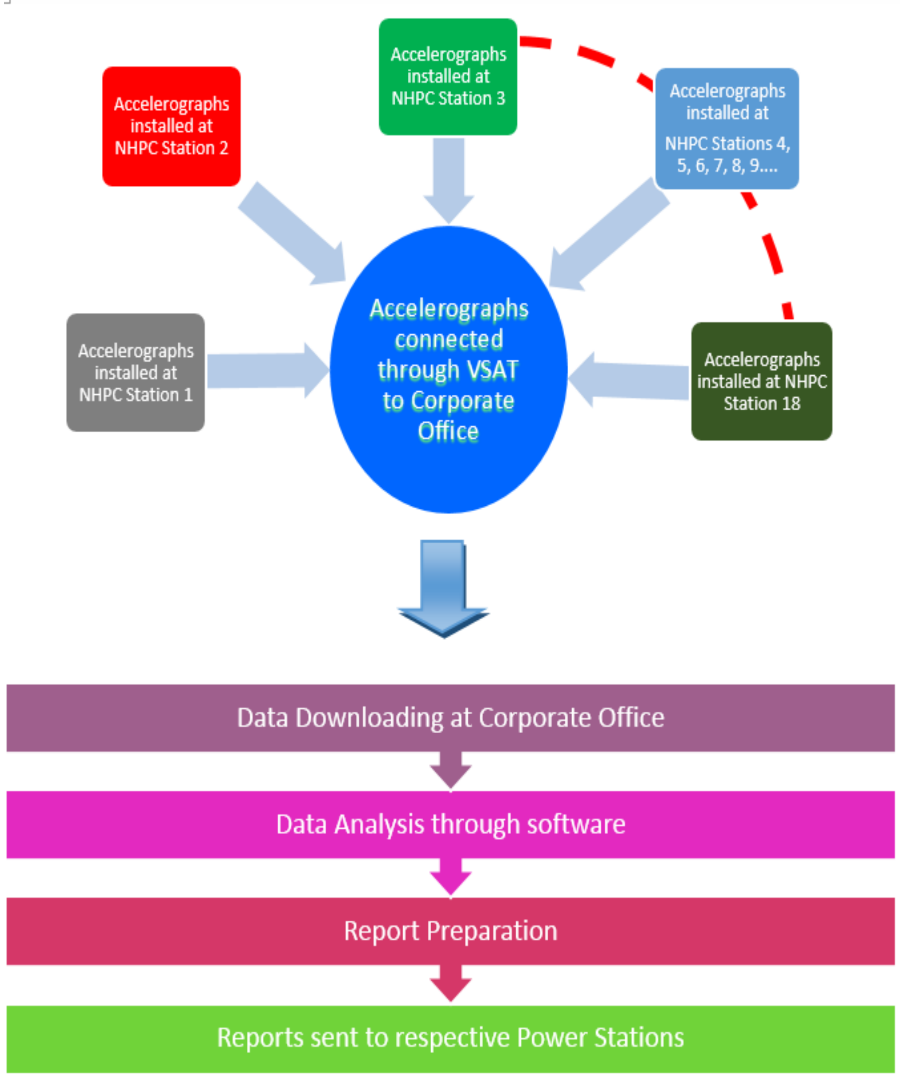
MEQ-LET -Dibang

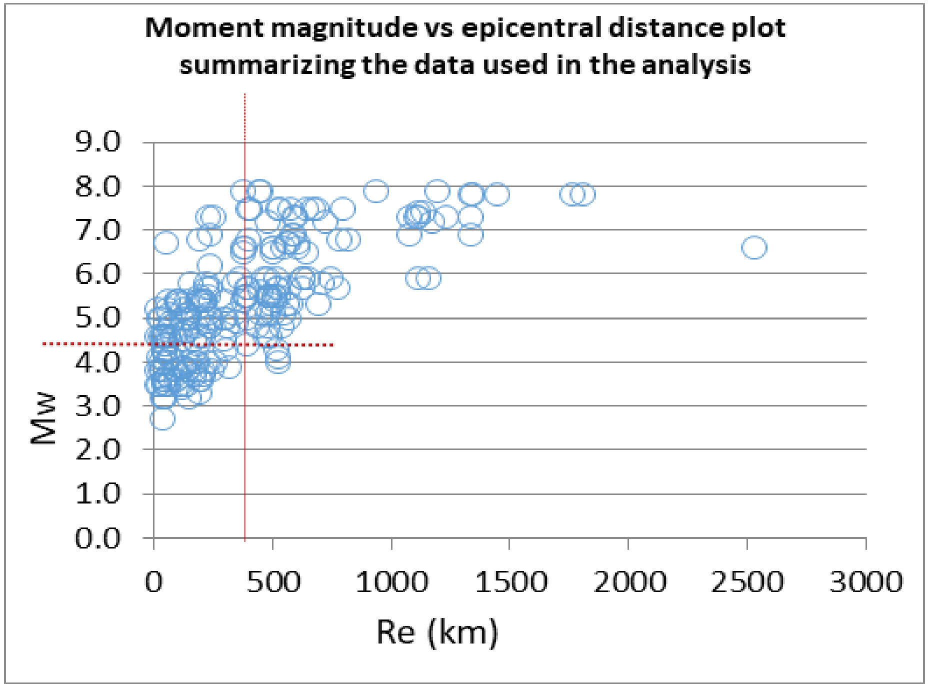
B: POST CONSTRUCTION SEISMIC MONITORING BY NHPC



Schematic representation of the NHPC network

- NHPC has installed accelerographs at all its power stations (22 nos.) for seismic monitoring.
- In order to handle proper maintenance of installed accelerographs and earthquake data analysis in an organized and efficient way, Real Time Seismic Data Center has been developed at NHPC Corporate Office, Faridabad and about 54 seismic monitoring instruments (accelerographs) installed at all of its power stations and JV projects (NHDC) has been connected to the data center for continuous online monitoring.
- In case of occurrence of an earthquake event at and around the project site the data is downloaded at the Real Time Seismic Data Center and a detailed report is prepared.

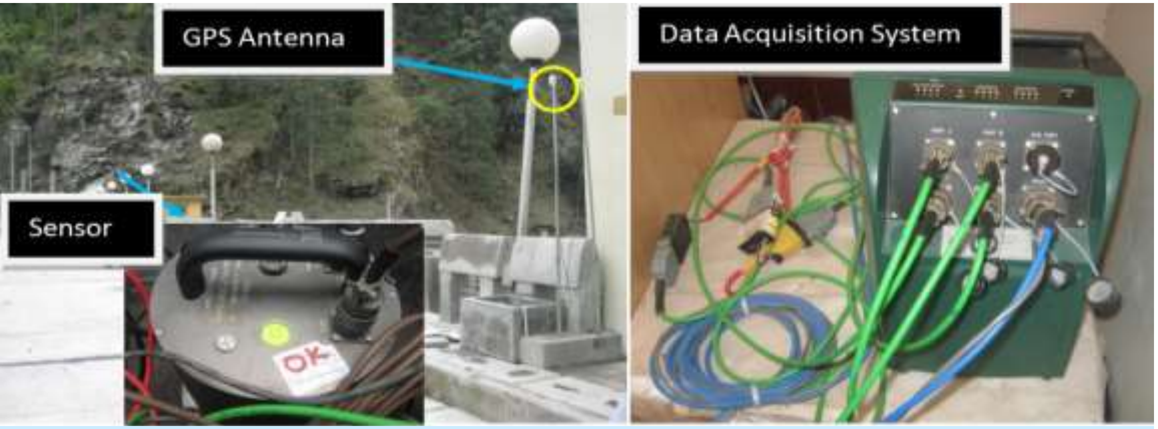




Epicentral distance vs. magnitude plot for events recorded by NHPC network

Flow chart for data collection processing and report preparation.

POST CONSTRUCTION MONITORING INSTRUMENTS AT SOME NHPC POWER STATIONS



Accelerograph installed at Sewa Power station

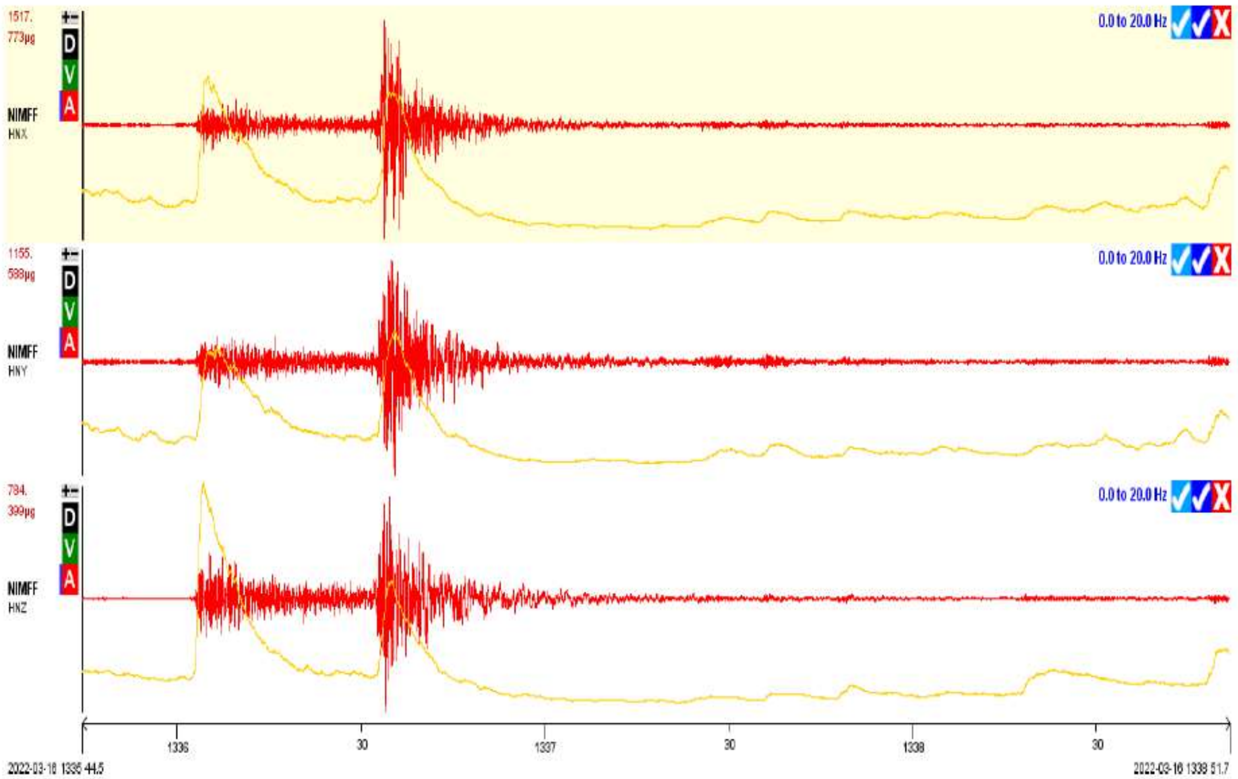
Accelerograph installed at Baira Siul Power station

Report generated at the Real Time Seismic Data Center

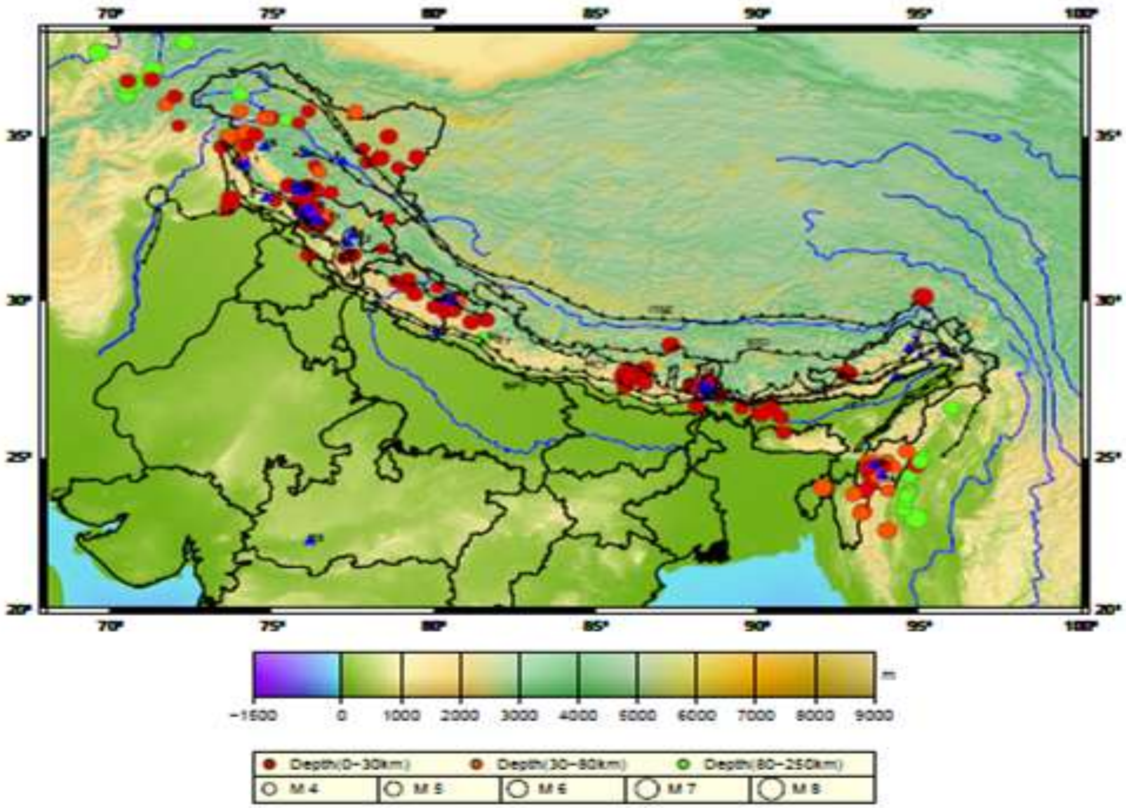
त्वरक (ACCELEROGRAM) विवरण

REAL TIME SEISMIC DATA CENTRE
Accelerating Innovation in Seismology

NIMMO BAZGO PS, 183KM NNW OF KARGIL, LADAKH, 16-03-2022, 13:35:23 UTC ,Depth- 110 Km, M 5.2, PGA- 0.0008 g (Free Field)



Earthquake of 16.3.2022, M=5.2 recorded at Nimmo Baazgo PS, PGA=0.0008g



MBT-Main Boundary Thrust	MCT-Main Central Thrust	MFT-Main Frontal Thrust
HFT-Himalayan Frontal Thrust	ITSZ-Indus-Tsangpo Suture Zone	STD-South Tibetan Detachment

▲ NHPC POWER STATIONS/PROJECT			
1. Uri Power Station	2. Uri-II Power Station	3. Salal Power Station	4. Dulhasti Power Station
5. Nimmo Bazgo Power Station	6. Chutak Power Station	7. Sewa Power Station	8. Bairasiul Power Station
9. Chamera-I Power Station	10. Chamera-II Power Station	11. Chamera-III Power Station	12. Parbati-III Power Station
13. Tanakpur Power Station	14. Dhauliganga Power Station	15. Rangit Power Station	16. Teesta-V Power Station
17. TLD-III Power Station	18. TLD-IV Power Station	19. Loktak Power Station	20. Subansiri Lower HE Project
21. Dibang M Project	22. Middle Siang	23. Omkareshwar Power Station	24. Parbati-II
25. Kishanganga Power Station	26. Kwar	27. Kiru	28. Pakal Dul
29. Loktak Downstream	30. Goriganga-IIIA		

Location of NHPC Power Stations and Epicenters of the Events recorded by its SMA network

Total 372 Himalayan earthquake events with 739 records till date are available with NHPC network

- The recorded acceleration data is further compared with the design acceleration of the project to ensure adequate safety of its structures.

- One of the largest event of this decade in the Indian subcontinent recorded by NHPC data center was that of M=7.9, Gorkha Nepal earthquake. PGA value recorded at Rangit power station for this event was of the order of 0.0548g which is much less than the design value for the project. Other projects recorded even lower values.

- Our projects are designed to withstand much higher PGA values and are completely safe in case of any RTS event.

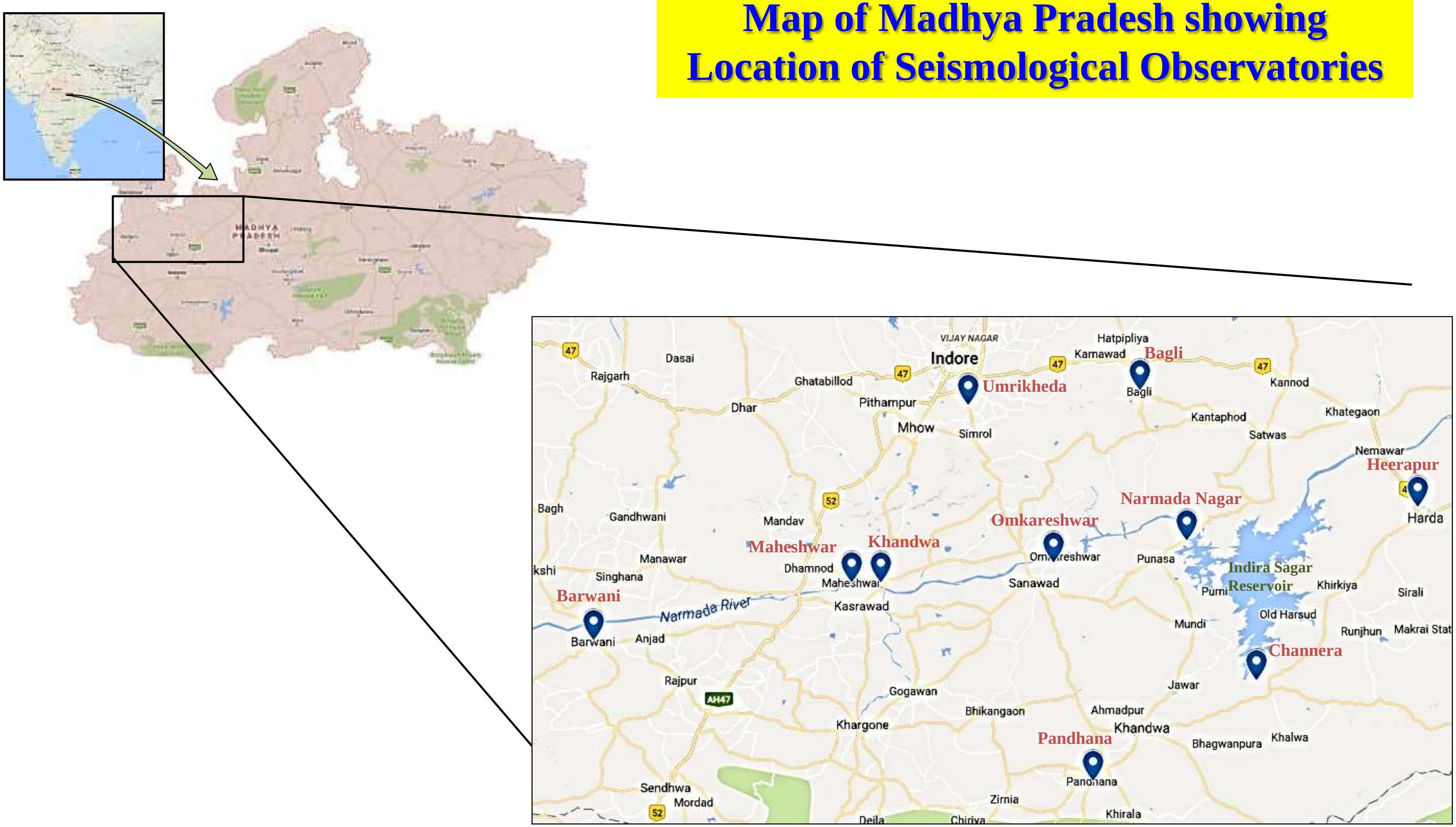
- NHPC is also committed towards seismic safety of its JV projects at NHDC & CVPPPL. The seismic observatories at Omkareshwar, NHDC have been connected with the RTSDC & efforts are on for Indirasagar instruments also.

SEISMOLOGICAL OBSERVATORIES AROUND INDIRA SAGAR AND OMKARESHWAR PROJECT AREA MADHYA PRADESH

Taking into consideration the known geological and seismotectonic features in the reservoir area, a local network of ten seismological observatories was established in 1995 around Indira Sagar and Omkareshwar project area to assess seismicity of the area and effect of reservoir. Till date no effect of reservoir filling has been observed on the seismicity of the area.

- Narmada Nagar
- OmkareShwar (Shiv Kothi)
- Mandleshwar
- Khandwa
- Indore (Umrikheda)
- Barwani
- Hirapur
- Bagli
- Channera
- Pandhana

Map of Madhya Pradesh showing Location of Seismological Observatories



SOME SITE PHOTOGRAPHS OF SEISMOLOGICAL OBSERVATORIES

The earlier analog instruments have been replaced by digital instruments and online connectivity to RTSDC ensures continuous data transmission

ONGOING MAJOR RESEARCH AND DEVELOPMENT PROJECT IN RTSDC

- **Utilizing collected data, a comparative analysis was done with the recorded PGA values & the empirical PGA values used in the design. The results were presented in ICOLD 2019 titled "*Comparative analysis of observed and estimated PGA for Himalayan earthquakes" Sustainable and Safe Dams Around the World – Tournier, Bennett & Bibeau (Eds) © 2019 Canadian Dam Association, ISBN 978-0-367-33422-2.***

- **Taking this study further an R&D project is been taken up titled "*Analysis of Strong Motion Accelerograph Data recorded at NHPC Power Station for development of site specific Peak Ground Acceleration Attenuation Relationship for Himalayan Region*" in consultation with Department of Earthquake Engg. IIT Roorkee for development of Himalayan specific attenuation relationships which can be further utilized for optimizing the seismic design of our structures.**

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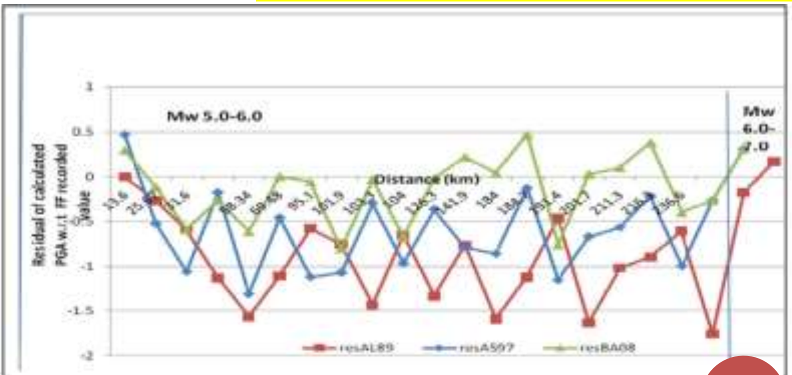
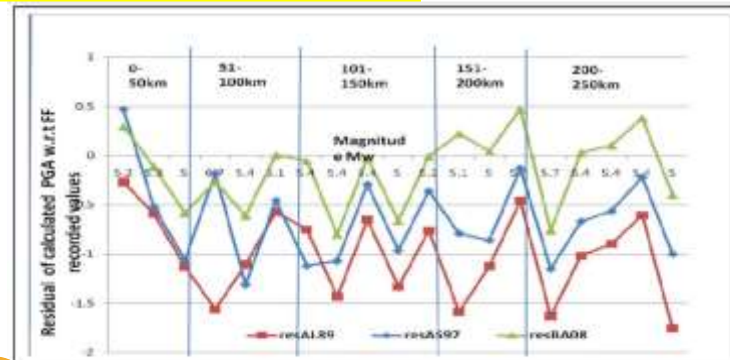
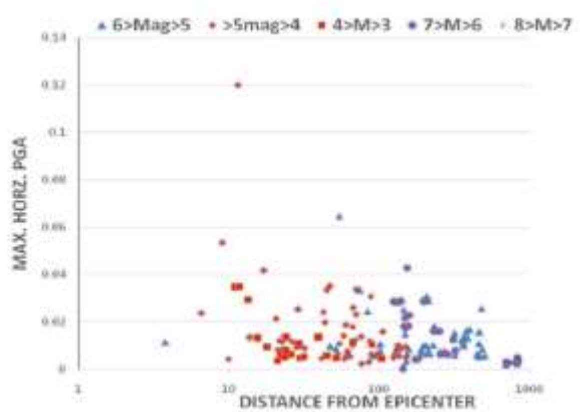
RESULTS OF INHOUSE ANALYSIS OF EARTHQUAKE DATA FROM NHPC NETWORK



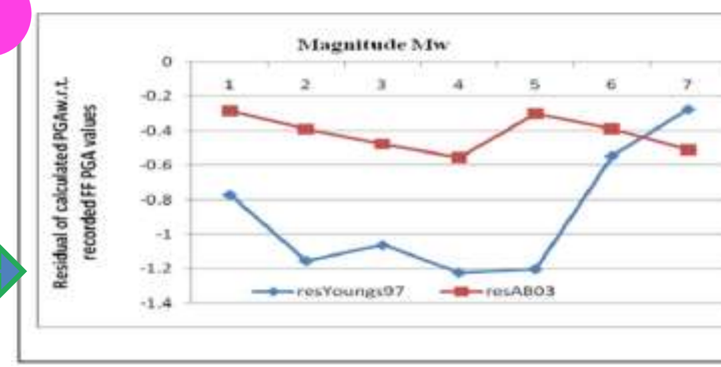


Plot of distance vs residual PGA for three attenuation relationships as compared with FF data of NHPC network for events in different magnitude bins

Plot of distance vs residual PGA for three attenuation relationships as compared with FF data of NHPC network for events in different distance bins



Plot of Max. Horz. PGA vs Epicentral Distance for PESMOS data of DEQ-IITR.



Plot of Magnitude vs. residual PGA for subduction attenuation relationship with FF data of NHPC network for subduction events.

CONCLUSIONS:

- Himalayas have high potential for development of hydropower which is essential to augment the power crisis in the country.
- Himalayan belt also lies in the highest seismic zone of the country i.e. Zone IV/V as per the seismic zoning map of India. In view of this whenever any large dam construction is undertaken lot of public speculations arise regarding the effect of such projects on the seismicity of the region.
- Considering this, NHPC has taken an initiative to assess the Reservoir Trigerred Seismicity factors in the Himalayas

- **It is observed that incidences of RTS in the Himalayas is not common. Moreover, the few incidences of RTS in the Himalayan region have resulted in the decrease in the overall seismicity of the region. This is because of the prevalence of thrust environment which results in mobilization of stresses towards stability on reservoir impoundment which is evident from the cases of Bhakra, Mangla and Tarbela reservoirs in the Himalayas.**
- **NHPC has established online Real Time Monitoring of its projects by setting up of a Real Time Seismic Data Center and connecting online all the accelerographs installed at its and its JV power stations.**

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