Control of Earthquakes by Lakes in Himalayas and Vicinity

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ABSTRACT

The basic concept of this article is to dissipate the strain energy of earth plates near the active faults frequently in form of many earthquakes of lower intensity, rather than the uncontrolled release of strain energy as a shallow earthquake of high intensity. This appears economically feasible by building a series of large lakes at suitable distances along the active faults. The seismic data is compiled here to show that expected earthquakes of high intensity have not occurred in Himalayas in neighbourhood of dam reservoirs in India since 1970. The coefficient of friction against incremental shear stresses is negligible at the great depths along faults. The shear resistance along fault near ground surface may also be reduced by seepage pressure of lake water and deposition of clay particles along the same during the life time of lakes only. The highest seismicity may thereby be reduced by about 1 M in 40 years. More research is needed in other regions.

Keywords: Coefficient of friction; Active faults; Seepage pressure; Inter-plate boundaries; Himalayan mountain system

1. INTRODUCTION

Berline and Lennis (1980) have summarized the research on fluid injection into the oil wells and occurrence of localized earthquakes. It has been observed that the injection pressure to cause local earthquake may be estimated approximately by Coulomb's equation. Further, the study has indicated that the number of minor earthquakes decreases sharply and consistently by reducing the rate of pumping fluid into the oil well. They have also reviewed the suggestions for earthquake control along San Andreas Fault for 100 years. The suggestions have however been found to be too costly to be implemented.

A hypothesis is proposed in the present study which postulates that the maximum elastic strain energy locked up in the colliding earth plates may be reduced significantly by decreasing frictional resistance along the inter-plate boundaries and active faults. The number of high intensity catastrophic shallow earthquakes may, therefore, be reduced. The similar phenomenon also takes place in the large lakes along active faults. It is also interesting to note that very shallow earthquakes, in the region of many dam reservoirs in the lesser Himalaya, are of much lesser intensity for the last 30 years, than those before the construction of the dams. Further, the statistical analysis of earthquake occurrence before and after construction of dams proves this hypothesis (see article 6). The reservoir induced seismicity (RIS) has dissipated the strain energy significantly even in the current period of peak global seismicity. The analysis of in-situ stresses suggests that the earth crust is nearly in a state of failure in the water charged regions (see article 4). Thus, if lakes are created along dry active thrusts, faults and, especially along their intersections, the highest intensity of very shallow earthquakes (with focal depth < 20 km.) may be reduced economically and naturally from about M8 to M7 on Richter's scale, in many regions after nearly 40 years. Suitable clay minerals, say montmorillonite with very low coefficient of friction, may be added in a small quantity in the water of these lakes for coating faults with clay during seepage along the fault zones.

2. SEEPAGE ALONG FAULT

The proposed hypothesis involves enhancing seepage into colliding inter-plate boundaries to reduce frictional resistance. It is known that the temperature of rocks increases by 30° to 90°C per km depth below the ground level. As such, one should check the possibility of boiling of seepage water at great depths. According to the Clausius Clapeyron equation (Alberty, 1987), the rise in boiling temperature of water is at least 0.28°C per kPa of pressure. Hence it can be shown that the increment in boiling temperature of water is much more than the increase in the ground temperature. The water, therefore, is unlikely to boil as it seeps inside the earth crust, except where geothermal gradient is very high. The convective currents are unlikely to occur where temperature increases linearly with depth due to steady state condition.

The velocity, v of seepage of water under gravity may be expressed as:

$$v = k \sin i \tag{1}$$

where, k is the permeability of fault zone; i is the dip of the fault (≈3° for Indo-Tibetan plate) and, sin i is the hydraulic gradient of seepage along the fault.

According to Franciss (1985), the permeability of fault zone may vary between 10^{-1} to 10^{-3} cm/sec for low amount of infilling (<30 percent) if the ratio between the cube of the opening of joints (in mm) and its spacing (in metre) is greater than 0.3. Thus a seepage velocity of 0.5 km/yr is estimated from Eq. 1 for $k = 3\times10^{-2}$ cm/sec (≈10km/year). The seepage water will travel upto 15km (=30x10×Sin30°) in 30 years along the fault or the inter plate boundary. Its depth may be only 0.8 km (=15x Sin i). The actual downward seepage and extent of clay coating is likely to be more due to presence of a network of faults.

There may be a doubt that the geo-static pressure will try to overthrow the water. This is not quite true, as flow is a seepage process and not consolidation process. The water seeps through the pores within the fault zone. Water may flow to great depths. It is interesting to mention that the damping coefficient of a water-charged fault gouge may be higher than that of dry fault zone. Therefore, chances of shallow earthquakes of high intensity for longer duration are reduced further along active faults near water bodies.

Also, there may be a fear on possibility of liquefaction within the active fault zone if a lake is excavated over the same. In fact, even for an earthquake of magnitude 8, the maximum depth of liquefaction is not expected beyond a depth of 20m below the ground surface. Thus the depth of liquefaction is negligible compared to the length of active faults. So the liquefaction within fault zone may not aggravate the seismicity of a local region.

3. SHEAR STRENGTH OF MAJOR FAULTS

The rocks at great depths along the inter-plate boundaries are subjected to very high confining stresses. Barton (1976) suggested a theory of critical state of rock materials at very high confining stresses. It suggests that the Mohr's envelopes representing the peak shear strength of a rock material (intact) eventually reaches a point of saturation (zero gradient) on crossing a certain value of confining pressure called critical state. In other words the Mohr's envelope becomes horizontal at a maximum shear strength of $(\sigma_1 - \sigma_3)_{max} / 2$. The non-linear empirical criterion of shear strength along the discontinuities may be represented as:

$$\tau = (\sigma - u)\tan\left(\phi_r + \mathrm{JMC\,x\,JRC}\log_{10}\frac{(\sigma_1 - \sigma_3)}{(\sigma - u)}\right) \le (\sigma_1 - \sigma_3)_{max}/2 \qquad (2)$$

where τ is the shear strength along a major discontinuity i.e. fault or thrust; σ is the normal stress across the discontinuity; u is the pore water pressure inside the discontinuity; ϕ_r is the effective basic friction angle between the two smooth surfaces of the rock material; JRC is the joint roughness coefficient of the discontinuity on a scale of 0 for smooth to 20 for rough undulating discontinuity (Barton and Choubey, 1977); JMC is the joint matching coefficient which represents mismatch of adjoining surfaces of a discontinuity (Zhao, 1997), and ranges between 0.3 to 1.0, and $(\sigma_1\text{-}\sigma_3)$ is the deviator strength of the rock material.

The deviator strength of a rock material increases with increasing confining pressure. However, according to the critical state concept (Barton, 1976), there is maximum value upto which the deviator strength, for a given rock type, can increase. The deviator strength $(\sigma_1 - \sigma_3)$ for a given rock type may be expressed as (Singh and Singh, 2005):

$$(\sigma_1 - \sigma_3) = q_c + A\sigma_3 - \frac{A}{2q_c}\sigma_3^2 \qquad (3)$$

$$A = \frac{2\sin\phi_0}{1 - \sin\phi_0} \qquad (4)$$

where q_c is the UCS of the intact rock material, and A is criterion parameter, and ϕ_0 is the friction angle of the rock material at very low confining pressure ($\sigma 3 \rightarrow 0$).
It has been shown by Singh and Singh (2005) that the critical state of a given rock type is reached at $\sigma_3 \approx q_c$. The maximum value of the deviator strength for a rock may, therefore, be obtained as:

$$(\sigma_1 - \sigma_3)_{max} = \frac{q_c}{(1 - \sin\phi_0)} \tag{5}$$

Taking the friction angle, ϕ_0 ranging from 30 to 50°, the maximum deviator strength $(\sigma_1 - \sigma_3)$ is found to vary between 2 to 4.3 times the UCS of the rock material. At this stage, the Mohr's envelope (τ-σ function) becomes flat (Singh and Singh, 2005). The normal stress at which the rock reaches critical state will be $(\sigma_1 + \sigma_3)/2$, which will be equal to about 2 to 3 times the UCS of the rock material.

If triaxial tests were conducted at very high temperature and pressure representing earth crust, the rock will melt and change from ductile to fluid with negligible deviator strength. The melting temperature of rock depends upon confining stress. The frictional resistance is due to the molecular bond between molecules of adjoining smooth surfaces. The molecular bond is more when surfaces are close due to increase in the normal stress. So the frictional resistance may not exceed the strength of molecular bonds.

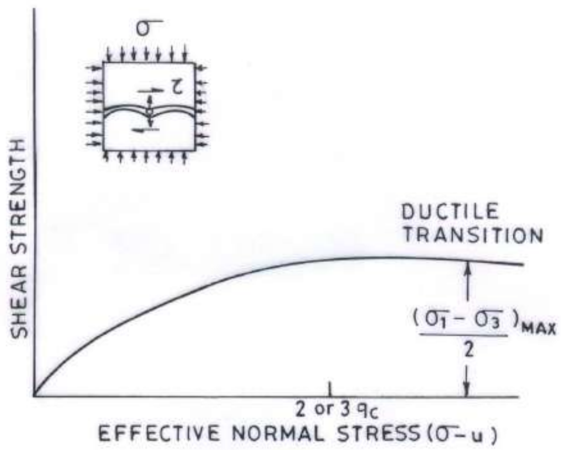

Fig.1 - Shear strength of discontinuities at very high confining stress (Barton, 1976)

Thus there is an ultimate limit of shear strength of a major discontinuity, which cannot be higher than the shear strength of the weaker rock material at very high confining stress. Figure 1 shows the empirical criterion of shear strength (Eq. 2), subject to the shear strength, τ approaching saturation (peak limit) line (Barton, 1976). The shear strength of a ductile material like metals is independent of confining stress.

It follows that the sliding angle of friction, ϕ (tangential and not secant) and so the coefficient of friction, μ (= tan ϕ) is nearly zero at very high confining stresses, equal to σ_{ci}, which exists at great depths in the earth plates. The coefficient of friction, in terms of the incremental shear stresses along the faults, decreases with depth. It can be expressed in terms of increments in the shear strength $\Delta\tau$ and the normal stress $\Delta\overline{\sigma_n}$, which can be estimated empirically as follows (Singh et al., 2005):

$$|\Delta\tau| = \mu\, \Delta\overline{\sigma}_n \tag{6}$$

$$\mu = \mu_o \left[1 - \left(\frac{\sigma_3}{\sigma_{ci}} \right)^{\pi/2} \right] \text{ for } \mu < 2 \tag{7}$$

$$\approx 0 \qquad \text{for } \sigma_3 \geq \sigma_{ci}\ .$$

where μ_0 is the initial coefficient of friction at $\overline{\sigma_3} \rightarrow 0$; $\overline{\sigma_3}$ is the effective in-situ minor principal stress at any point under consideration along a fault/thrust; u is the in-situ pore water pressure at the same point, and will zero in dry fault/thrust.

The above correlation is based on results of triaxial tests on more than 130 rock types all over the world. It is interesting to note that the back-analysed sliding angle of friction at depths more than 40 km has been found to be as low as 5° in the Tibet Himalayan plate (Shanker, et al. 2002). Such low value of tangential friction angle supports the critical state concept suggested by Singh and Singh (2005) and Singh et al. (2005). It is interesting to realise that the lesser the frictional resistance along the colliding inter-plate boundaries, lesser will be the locked up elastic strain energy in the large earth plates, and so lesser will the chances of high intensity earthquakes in that area. In fact, a highest intensity of earthquake of only 7 on Richter's scale has been observed in Tibetan plateau. It may be noted that the coefficient of friction against incremental shear stresses is negligible along the plate boundary, below about a depth of 40 km and upto 100 km. It is interesting to see that the nature, in itself, has developed a delicate balancing mechanism to avoid too high intensity of earthquakes.

4. TECTONIC INSTABILITY IN WATER CHARGED REGION

The basic concept being proposed in this article is that the tectonic activity in water charged regions causes less severe earthquakes. Nedoma (1997) analyzed the state of stresses in the earth plates by considering non-linear elasto-plastic thermal behaviour of the rocks. Figure 2 approximately depicts the typical geo-dynamics of colliding earth plates. The upper plate bends downward, relaxing the horizontal in-situ stress, which becomes minor principal stress. Thus there is subsidence and normal faulting in the (lower) sub-ducting plate in the neighbourhood of the upper earth plate. On the contrary, the upper plate bends upward, resulting in compression and higher horizontal in-situ (tectonic) stress, which become major principal stress. Hence this is the region of uplifting (in the form of mountainous terrain) and thrust faulting. Simultaneously, its bottom part also bends upward, thereby releasing tangential stresses. Two de-stressed (de-compressed) zones are indicated by the stress analysis of Nedoma (1997). The melting temperature reduces due to increase in the confining stress. Consequently, the rock melts in these de-stressed zones. Therefore molten rock may come out on the surface due to volcano at some favourable geological situation. However, the incremental sliding angle of friction along the plate boundary within this zone of molten rock may be reduced to a negligible limit.

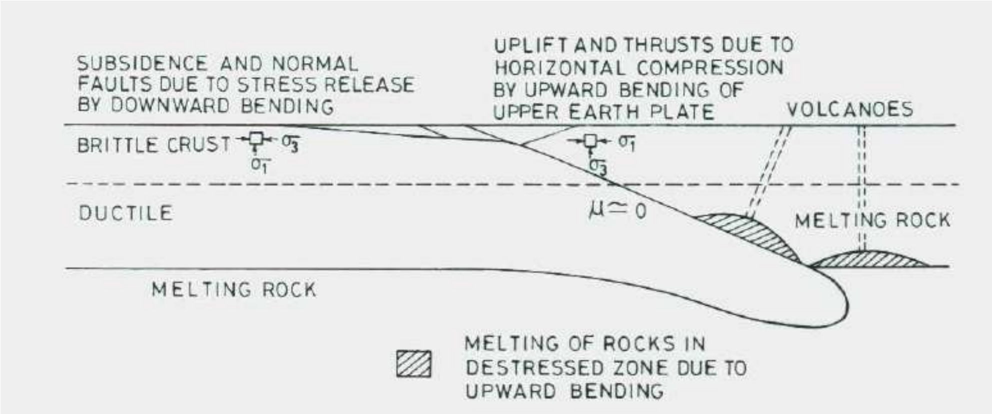

Fig. 2 - State of stresses in colliding inter-plate boundaries

Sheorey (1994) analyzed the state of in-situ stresses in the anisotropic earth crust by taking into account the cooling of earth planet. It has been shown that the temperature stresses generate the tectonic stresses. Further, the relative tectonic movement between the earth plates also alters this state of stress. The measurement of stresses indicates two components of in-situ stresses namely:

(i) a constant tectonic stress with depth, and
(ii) linearly varying stress (induced by gravity and thermal gradients etc.).

Let one make a plot of deviator stress (σ_1-σ_3) and the effective confining stress (σ_2+σ_3-2u), where σ_1, σ_2, σ_3 are the total major, intermediate and minor in-situ principal stresses, and u is the pore water pressure in the rock mass (Fig. 3). Assuming that the ground water table was near the ground surface in long past, it appears that there is an upper limit to the in-situ stresses as follows:

$$(\sigma_1 - \sigma_3) \le 3 + 2.5\left(\frac{\sigma_2 + \sigma_3 - 2u}{2}\right), \text{MPa} \tag{8}$$

The tectonic stress in a water-changed region is estimated to be about 3 MPa near ground. In fact Eq. 8 represents a poly-axial strength criterion. It is modified Mohr's theory in which effective minor principal stress is replaced by average confining stress [(σ_2+σ_3-2u)/2]. The poly-axial theory is postulated and proved experimentally by Singh et al. (1998).

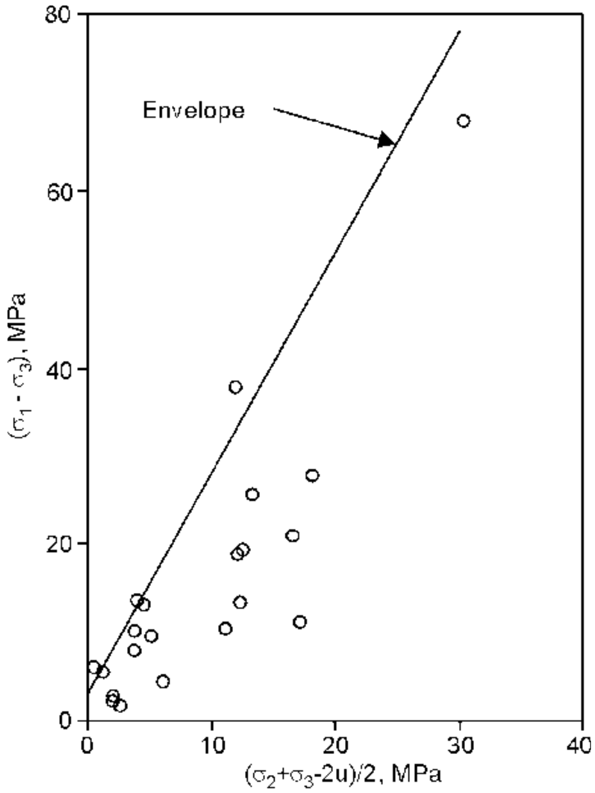

Fig. 3- Plot of in-situ stresses showing upper bound

Table 1 - Estimated value of tectonic stress near ground surface in water charged regions

S. No.	Reference	Expression for tectonic stress	Expression for strength of rock mass	Parameters in saturated condition	Approximate tectonic stress
1	Shanker et al., (2000)	3MPa			3MPa
2	Mc Cutchin (1982)	$0.007\ \gamma\ E_d$		γ =25kN/m^3 E_d = 10-20 GPa	1.75-3MPa
3	Singh (1997)		0.05-0.07 q_c in a region of critically oriented discontinuity	q_c=50 MPa	Strength of weakest link of rock mass near ground surface = 2.5-3.5 MPa for a rock with q_c = 50 MPa.
Notations: γ = unit weight of rock mass, E_d = modulus of deformation of rock mass, q_c = uniaxial compressive strength of rock material					

Table 1 compares the range of tectonic stresses with the estimated compressive strength of rock mass with a critically oriented discontinuity (Singh, 1997). The comparison of tectonic stress with the strength indicates that tectonic stress is near failure limit. Further the constant 2.5 in Eq. 8 corresponds to an internal angle of friction of rock mass ϕ_0 of 34°, which is a typical value. So it may be inferred that the upper earth crust may be near state of failure in a water-changed region. This appears to be valid in young mountainous regions, which are rising up due to tectonic stresses. Zoback et al. (1993) have also inferred from deep in-situ stress measurements that upper crust is in state of failure. Thus slight increase of tectonic stresses may cause fault slips, leading to tectonic instability temporarily.

The epicentres of shallow earthquakes of highest intensity are located along the inter-plate boundaries where the shear stresses exceed the frictional resistance along the same. Wieland (2001), chairman ICOLD committee on seismic Aspects of Dam Design reported that earthquake of M8 may not cause higher acceleration than an earthquake of intensity M6.5. However, the duration of strong ground shaking of a severe earthquake will be longer. The reason is that epicentre is not a point but a large length of rupture area of a critical fault. Hence there is saturation limit to the peak ground acceleration at a point near the active fault, as effect of slip along longer fault may not affect the peak acceleration near its middle part.

It may be noted that seismicity of the whole earth is decreasing cyclically with time due to the law of minimum potential energy of mechanics (Jaeger and Cook, 1969). Catastrophic events (volcanoes and great earthquakes) have been reducing over a long span of time all over the earth.

5. INFLUENCE OF DAM RESERVOIRS IN REDUCING HIGHEST INTENSITY OF EARTHQUAKES

Himalaya is an ideal example of reduced seismicity after building high dam reservoirs. Great earthquakes of very high intensity do not occur regularly in Himalaya as in other mountainous ranges like Rockies and Alps which are much older and stable. The Himalayan mountain system is young, weak and unstable. Table 2 shows the return periods of great earthquakes (≈M8) in entire Himalaya, which varies from 1 to 51 years. The average return period of severe earthquakes is about 18 years although database is inadequate. As such, a severe earthquake was expected around 1968 (after 18 years of peak earthquake in Assam) anywhere in Himalaya from Burma to Afghanistan. Some seismologists have predicated another major earthquake between Nepal and India because of a peak in continental drift, which seems to be Muzaffarabad earthquake (M7.6) in Pakistan, killing about 79,000 persons. So, more major earthquakes are also expected.

The fact is that no major earthquake (≈M8) has visited the entire region in Himalayan range. It is interesting to note that major earthquakes have not occurred since 1970 in the regions of concentration of dam reservoirs. There should be some arresting mechanism of major earthquakes. The large dam reservoir lakes appear to be the arresting mechanism. Majority of the high dams have been built during the period 1960-1970 in this area of highest seismicity (Table 3). Figure 4 shows a map of locations of high dam reservoirs in Indian Himalaya. The concentration of dam reservoirs raises ground water table in these regions. The seepage of water and clay particle deposition seems to have reduced the seismicity in active faults in this region. It appears that the dam reservoirs are acting as safety valves and releasing locked up elastic strain energy in the earth plates due to the continental drift. Contrary to popular belief, the reservoir induced seismicity (RIS) proves to be good in long run as it releases strain energy frequently rather than accumulating the same which results in a high intensity earthquake. RIS is observed to release the strain energy of local regions extending to a maximum of about 10 km all around the reservoir. The great earthquakes may, therefore, not occur in the regions where there is a concentration of high dam reservoirs. It was feared in the past that dam reservoirs might activate inactive faults causing earthquake (M6.7) for example after building Koyna dam. The fact is that the RIS cannot exceed the highest intensity of earthquake in that region, even in hard brittle rocks. A high dam reservoir serves two functions along major active faults, thrusts and inter-plate boundaries namely:

(i) Seepage of water reduces effective stresses along major active faults,
(ii) The surface of faults is coated with silt or clay particles. This further reduces significantly the shear strength of the major active faults.

Table 2 - Great earthquakes in Himalaya (Thakur et al., 2001)

Place of occurrence of great earthquakes	Year of occurrence of great earthquakes	Return period in entire Himalaya (years)	Slip along fault (in meter)	Rupture zone (km x km)	Remarks
Assam	1897				Average return period in whole Himalaya = 18 years
		8			
Kangra	1905		5.0	120 x 100	
		29			
Kathmandu	1934				
		<1			
Bihar	1934		6.2	200 x 100	
		16			
Assam	1950		9.0	400 x 100	
		51			
Bhuj	2001				
		4			
Muzaffrabad (Pakistan)	2005				

As such, a significant reduction of shear strength along the major active faults and inter plate boundaries might have been the cause of observed reduction in the highest intensity of the earthquakes in the regions where there is concentration of reservoirs. The significant reduction in high intensity earthquake occurrence in the Himalayas has been observed after 30 to 40 years after filling of the reservoirs. It is heartening to note that no well-compacted high earth dam has failed in the last 4 decades due to earthquakes all over the world. Their settlement has been observed to be less than the design settlement (Jansen, 1990). It is suggested that that fundamental research should be done on the feasibility of controlling the earthquakes by building large lakes along active faults at suitable intervals. The aim of the research should be to find quantitative reduction in magnitude of high intensity earthquakes due to presence of man-made lakes. The recent Muzaffarabad earthquake in the year 2005 was of intensity 7.6 M only against the expected earthquake of 8.5M. Thus it appears that the large dam reservoirs tend to reduce the seismicity of the local region by about 0.9 M perhaps. Further studies are, however, required on this aspect.

Table 3 - Major hydroelectric projects in Himalaya

Project	River	Installed Capacity (MW)	Status	Location Long °E, Lat °N)
Dulhasti (J&K)	Chenab	390	Under Construction	75° 45′, 32°2′
Salal I & II (J&K)	Chenab	345 & 345	In operation	74°48′, 33°5′
Baira Siul (HP)	Baira & Siul	198	In operation	76°7′, 32°45′
BSL Project (HP)	Beas	990	In operation	
Vishnu Prayag (UA) Joshimath Distt. Chamoli	Alaknanda	400	In operation	
Jaldhaka (W. Bengal)	Teesta	27	In operation	
Loktak (Manipur)	Barak	105	In operation	93°35′25′′ 34°44′50′′
Loktak D/S	-do-	90	Under construction	
Tehri (UA)	Bhagirathi	2400	In operation	78°5', 30°38′
Chemera-I (HP)	Ravi	540	In operation	75°55′, 32°37′
Chemera-II (HP)	Ravi	300	Under construction	
Ranjit Sagar (Pb)	Ravi	600	In operation	
Dhauliganga-I, UA	Dhauliganga	280	Under construction	80°15′, 29°55′
Nathapa Jhakri, HP	Satluj	1500	In operation	
Uri-I (J&K)	Jhelum	600	In operation	72°40′, 32°17′
Uri-II (J&K)	Jhelum	280	Under investigation	
Baspa, HP	Baspa	300	Under investigation	
Kopili-I&II, Assam	Kopili	200 &50	In operation	92°47′, 25°40′
Parbati-I, HP	Parbati-I,HP	750	Under investigation	77°8′, 31°40′
Parbati-II, HP	-do-	800	Upcoming	
Parbati-III, HP	-do-	501	Under investigation	
Chukha, Bhutan		336	In operation	
Tala, Bhutan	Wangchu	1020	In operation	88°10′, 26°45′
Pancheshwer, Nepal	Maha Kali	5600	Under investigation	80°28′, 29°4′
Maneri-Bhali, UA	Bhagirathi	90	In operation	78°32′,30°44.5′
Ranganadi, AP	Ranganadi	180	Revised DPR Under preparation	93°49’, 27°20'
Ramganga, U.P.	Ramganga	198	In operation	78°46′ ,29°32′

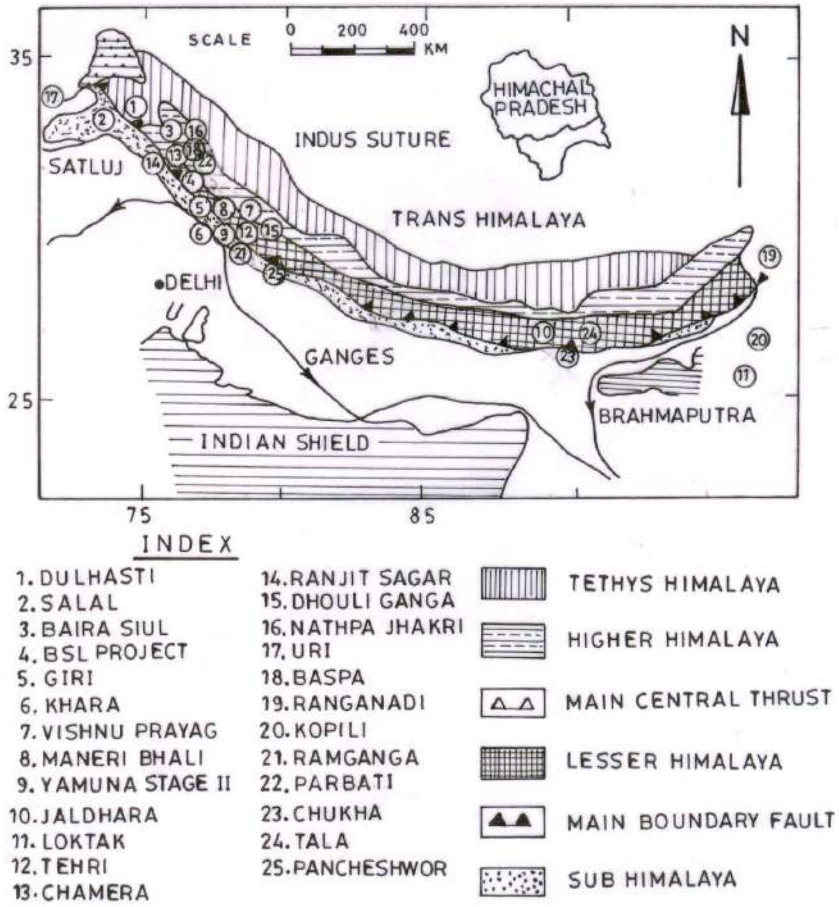

Fig. 4 - Locations of high dam reservoirs in Indian Himalaya

6. SUGGESTED MODEL

The Fig. 2 shows typical interaction of colliding boundaries of the earth plates. The top brittle crust is expected upto about 30 km in the granite below ground surface. When the lake water seeps down this boundary fault zone, its shear strength will be reduced. Thus the strain energy stored in the earth plates will be reduced in proportion to the length of the seepage travel, which depends on the time (t) of seepage from the lake. The Table 4 offers the scant data available for Himalayan region near the dam reservoir lakes and natural lakes. The table presents the reduction in high intensity of earthquakes due to reservoirs in different parts of Himalayan region. The reduction in the intensity of high earthquake may be represented by the following equation:

$$M = M_{max} - \eta t, \quad t < t_c \tag{9}$$

where M is the maximum intensity of the earthquake, t = years after filling the reservoir; η is an empirical intensity reduction coefficient which represents the reduction in the maximum intensity per year due to reservoir, and t_c is the time of seepage travel through brittle top crust ($t_c \approx 100$ years).

Table 4 - Reduction in seismicity due to new lakes in Himalaya

S.N.	Region around concentration of lakes	Expected earthquake magnitude M_{max}	Actual earthquake magnitude M	Earthquake magnitude from statistical analysis	Approximate time of seepage, years	Earthquake intensity reduction coefficient, η, per year
1	Uttaranchal, India	7.5-8.0	6.8	6.2 (Shankerand Singh, 1997)	40	0.024
2	Muzzafarabad, Pakistan	8.5	7.6	7.5 (Shanker and Papadimitriou, 2004)	30	0.03
3	Natural lake series in Himalaya	8.5	5.5 – 6.5	---	>100	0.025
4	Assam	8.7	6.8	6.6 (Shanker and Singh, 1996)	25	0.076
5	Koyna region	6.5 - 6.7	4.0 – 4.5	5.5 (Shanker, 1998)	40	0.053

Table 4 also presents the values of the coefficient η for different reservoirs in the Himalayan region. The value has been found to vary between 0.024 and 0.076 per year with an average of 0.042 per year. This will vary with the rock type and its hydraulics and more appropriate values may be taken with more data available in future. The analysis of the above data indicates that the seismicity due to shallow devastating earthquakes is likely to reduce significantly by about 2.1 M in 50 years after filling of lake, upto about 10 km from the rim of the lake.

7. CONCLUDING REMARKS

The maximum intensity of the earthquakes can be reduced if the failure of the faults could be ensured at lower strain energy stored near the inter-plate boundary. It is proposed that this is possible by reducing shear strength of the inter-plate boundary. One way is to reduce the effective stress by constructing artificial lakes along the active fault boundaries. The shear strength of faults will further reduce due to coating of clay particles in due coarse of time. More data needs to be collected world wide and further research is required on reduction of peak seismicity due to the natural and man-made lakes near or along the active faults. The process may take many decades for water and the clay particles to seep into the active faults upto considerable distances. The proposed hypothesis is that the reduction in the shear resistance along active faults will dissipate the stored strain energy frequently as reservoir induced seismicity, rather than helping the strain energy to accumulate in the earth plates, which would release in form of an uncontrolled earthquake of high intensity. This hypothesis needs to be tested in other tectonically active mountainous regions also.

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