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SEISMIC AND NEOTECTONIC ACTIVITY AROUND SOME RIVER VALLEY PROJECTS — SIXTH ISET ANNUAL LECTURE

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Chairman and fellow Scientists,

At the very outset, I would like to congratulate the evergrowing Indian Society of Earthquake Technology on this occasion of its 15th Annual General Meeting. I wish the Society every success in the cause of creating mass awareness of earthquake hazards and mitigation for which it stands. I also wish to express my most sincere thanks to the Society for the honour it has conferred on me by inviting me to deliver the ISET Annual Lecture for 1985.

My first reaction on getting the request from Dr. Prem Krishna in October, 1985, was to politely decline the offer as the time available to me was hardly sufficient to prepare a write-up befitting for the occasion. Subsequently, I felt that more important than presenting an academic paper, the occasion was meant for being with the fellow scientists and sharing some thoughts with them on the vexing problem of seismicity of the river valley projects. It is for this reason that I have selected the present title for my address.

As you may be aware, the Indian Science Congress has a convention that the Sectional President who has to deliver the Presidential Address for the next congress is selected the preceding session itself. If I am permitted and if I am not taken amiss, I would like to suggest to ISET Executive Committee to adopt this practice for its Annual Lecture which will ensure that the speaker will get about an year's time to do justice to his task.

As is well known, the Indian subcontinent and particularly the Himalayan Region which forms a part of the seismically active global Alpine-Himalayan seismic belt has a complex geological and tectonic environment where numerous thrusts or faults ranging in age from Pre-Cambrian to even Recent times have been recorded. Several evidences of fault dislocations and continued creep movements during the Holocene period representing the manifestation of recent crustal adjustments or

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neotectonic activity have been picked up. Though, direct dislocations along these features were not evidenced during or correlated with the past major earthquakes, many a times the surface manifestations of recent crustal adjustments have been interpreted to be due to the seismogenic nature of these faults and thrusts and are, therefore, of paramount importance.

Planning and execution of river valley projects in any region require thorough knowledge and understanding of geological processes and assessment of their potential impacts. Amongst the varied geotechnical problems of a project, the most significant is the problem of sudden earth movement as a result of earthquake or slow creep due to release of strain along thrust and faults which either interesect the layouts of major projects or are exposed in their close vicinity Where continued movement is anticipated along certain faults, it would be advantageous to establish a network of geodetic and other types of stations on either side of the fault trace, and to triangulate and level them periodically, in order to obtain the rate of epeirogenic uplift or orogenic creep along particular faults. This line of study was recommended by J.B. Auden of the GSI some thirty years ago for the Yamuna tear fault in U.P. On the advice of the G.S.I., such geoetic observations have now been continued and extended to a number of river valley projects by the Geodetic and Research Branch of the Survey of India. Col. Dr. Arur has published a detailed account of these measurements in his paper "Results of crustal movement studies in India" published in Volume VIII of the Proceedings of Fourth IAEG Congress 1982.

Another line of study of micromovements is the installation of water tube tiltmeters. These studies, as you are well aware, are being exclusively carried out by the School of Research and Training in Earthquake Engineering, Roorkee, on some of the major hydroelectric projects.

Geoseismological studies for the river valley projects could be of regional and local nature. The regional studies would relate to the correlation of the downward extension of the tectonic features with the focii of past earthquakes, so that the locations of the more active tectonic elements could be evaluated in terms of their distance to the project features.

For local studies, it is generally necessary to carry out mapping of the concerned fault feature and their vicinity on 1 : 1000 scale but with particular reference to the Holocene deposits exposed across their trace or with reference to the known stratigraphic position of the youngest formation displaced by the fault. Mapping of terraces and geomorphological features, plotting of stream profiles across suspected activa faults and test pitting acrpss the traces of faults er thrusts combined with geochronological dating of vegetal carbonaceous material involved in the movement, would form essential part of these studies.

These data could be utilised for proper evaluation of seismic coefficient and aseismic design of river valley project structures.

Now, I will briefly describe the geoseismological set up of some of the river valley projects with which I had been personally associated or about which authentic data is available.

SALAL DAM

The Salal Dam site on the Chenab river in J & K is located on the dolomites and limestones of the Great Limestone Group of rocks. These rocks have overridden the Siwaliks in Riasi area. Evidences of neotectonic activity along this tectonic lineament have been recorded in the form of (i) thrusting of dolomites of Great Limestone over the sub-Recent landslide debris (ii) tilting of the river terraces at steep angles on either side of the trace of the Riasi thrust. The following evidences show that the Riasi thrust was activated as late as in the Pleistocence and even Recent times. In the aghar nala near Riasi it has been observed that the terrace deposits and the dolomite scree have got tilted at 60° angle both in the southwest and northeast direction on the southern and northern sides of this thrust respectively. In Dogala nala, further west, the dolomites are overriding the boulder beds, though the age of these beds is controversial, some consider these to be of upper Siwalik age while others consider it to be sub-Recent material. The epicentres of the Bhadarwah (1947), Badgam (1963) and Kangra (1905) earthquakes were located at 63 km, 67 km and 164 km, respectively from the dam site and the maximum intensity of these earthquakes varied from VI to X on MM scale. Assuming maximum intensity of the shocks to be 6.5 at Riasi and allowing a factor of safety of upto 8.0 intensity, Auden (1944) had considered a seismic coefficient of 0.12 to 0.16 g to be appropriate for the Dhyangarh (Salal) dam site. Further studies have indicated that ground accelerations of 0.14 g could be expected at the dam site from an earthquake of magnitude VII at a distance of 50km and a seismic coefficient of 0.15 g for rockfill and 0.22 g for concrete strutures of the project have been considered.

BEAS DAM

Upper Siwalik sand rock and clay shale beds exposed at the dam site have been folded into minor anticlines and synclines and have been thrust over the sub-Recent to Recent alluvial deposits along the Satlitta thrust. This thrust is exposed at a distance of about 2.7 km downstream of the dam axis and dips at an angle of 20° - 30° in the northerly (upstream) direction, although locally, dips of upto 60°-70° have also been observed. The thrust is expected to lie at a depth of about 1 5 km below the dam foundation. Three periods of movement along the thrust have been inferred. A cumulative vertical throw of above 1.5 km is believed to tave taken place as a result of the first movement when the upper Siwalik sandrock and clayshale beds were thrust over the upper Siwalik boulder conglomerates probably during the Mid-Pleistocene. The second and third movements during which the Upper Siwalik Formation has been thrust over the sub-Recent and Recent deposits are considered to have had lesser displacements and might have taken place during the late Pleistocene and even Recent times. During the 1905 Kangra earthquake of magnitude 8, the epicentre of which was located about 60 km to the northeast of the dam site no ground displacements were recorded along the trace of the thrust although it is considered possible that the focus of the shock could be related to the downward extension of the thrust. Periodic geodetic observations and high precision levelling are being carried out to monitor the activity along the thrust.

The Beas dam site was located within isoseismal VII and VIII of Rossi Forrell scale during the Kangra earthquake and within isoseismals V and VI of the recent Kathua earthquake whose epicentre was located about 30 km from the dam site The arc has also experienced another shock in 1945 whose epicentre was located at Chamba. Considering the general seismicity of the area and the geologically recent status of activity of the Satlitta thrust a seismic coefficient of 0.12 g for the rockfill dam and 0.15 g to 0.20 g for the concrete appurtenant structures has been provided. An earth core and gravel shell structure with increased free board and core width which shall permit deformation without rupture and flexibility against unequal settlement in the foundation has been constructed at this site.

BHAKRA DAM

The Bhakra straight gravity concrete dam on Satluj river is located on the Lower Siwalik rocks. The Bhakra thrust is exposed in the reservior area close to the dam site and is estimated to lie at a depth of about 1500 m below the dam foundations. It has a doubtful seismic status. The dam site fell within isoseismal VIII of Rossi Forrell scale during the Kangra earthquake of 1905. The epicentre of the shock was located about 80 km northwest of the dam site which had an estimated acceleration of 1000 mm/sec^2. A seismic coefficient of 0.15 g has been incorporated in the design of the dam.

GIRI HYDEL PROJECT

Three major tectonic features, the Markanda, Nahan and Krol thrust are exposed in the Giri Hydel project area. The Markanda thrust of probable upper Pleistocene age has brought the upper Siwalik rocks over the sub-Recent Dun deposits The trace of the Markanda thrust, itself, has been shifted by the Sile cross tear fault which, therefore, has been interpreted to be the youngest tectonic feature of sub-Recent to Recent age. The other important tear faults in the area are Dagrag, Marar and Doyonwala faults. These tears have horizontal displacements from a few metres to 300 m.

The 7.1 km long Giri-Bata tunnel constructed in the area passes through Infra Krol, Dadahu, Trawali, Subathu and Nahan rock units. The complex tectonic set up of the area has posed major problems of safeguarding the tunnel lining against high squeezing pressures and of future seismic adjustments along the tear faults cutting across the tunnel alignments Serious tunnelling problems including bending and twisting of steel ribs and reduction in tunnel diameter due to excessive dialation of the rock were faced during the construction stage. Measurements of rock loads and the depth of loosening of rocks by load cells and multiple point borehole extensometers had given useful information for evolving proper design of tunnel supports.

YAMUNA HYDEL PROJECT

The Chibro-Khodri tunnel of the Yamuna Hydel Scheme, Stage Part II, has been driven through Mandhali, Subathu and Nahan rock units. These rocks are separated from each other by the Krol and Nahan thrusts, respectively. The Nahan thrust is also known as the Main Boundary Fault. Detailed geological investigations and extensive instrumentation had established the presence of neotectonic activity in this region. Consequently excessive closure, squeezing and continued tectonic creep in the rock units within the intra-thrust zone were apprehended.

The actual tunnelling problems were caused by very high closures of upto 15 cms of the excavated section of the tunnel leading to development of distress in the steel supports. As a counter measure, flexible lining which could cater to creep adjustments of upto 50 cms in a period of 100 years, a rate that had been extrapolated from the instrumentation data has been provided in some reaches of the tunnel. The Subathu rocks have been repeated thrice at the tunnel grade because of two cross tear faults which have shifted both the Krol ahd Nahan thrusts.

RAMGANGA DAM

The Ramganga Dam Project on the Middle Siwalik rocks is located in a tectonically disturbed area. Majority of these tectonic features in the area are considered to be geologically young in age. The Sarpduli-Dhikala thrust located 6-8 km north and the Kalagarh thrust located 3-4 km south of the dam site have been active in geologically Recent times. In consideration of these features a seismic coefficient of 0.12 g has been adopted in the design of the dam.

KOYNA DAM

The Peninsular shield of India in which Koyna Hydroelectric Project is located was generally regarded to be stable segment of the earth's crust, as major earthquakes had not been experienced in the area in the recent past. Only minor tremors, such as, those of Satara district in 1953 and of Ratnagiri in 1962 have been reported from time to time. The Bombay city is also reported to have experienced some minor tremors in the past.

Prior to 1962 no earth tremors were recorded in the Koyna Project area. Many small shocks began to be felt in the immediate neighbourhood of the Koyna dam from the initial impounding of Sivajisagar Lake of the Koyna Dam. Isolated events of magnitude upto 3.7 continued to be recorded till 13th Sept. 1967 when an earthquake of magnitude 5.9 occurred. This level of seismicity which was hitherto unknown in this region soon culminated in a large event of magnitude 6.5 on Richter scale on 11th December, 1967. The epicentre of the earthquake lay very close to the Koyna Dam.

Although permanent residential structures in the Koyna colony were badly damaged, the main dam and the underground power house for which a seismic coefficient of only 0.05 g had been provided in the design withstood the shock without any major damage except for a few fissures and displacement of the parapet wall of the dam. Sever to moderate shocks have continued to be recorded for several years after the main shock of December 1967, though the frequency and magnitude of these shocks had been on the decline. This general trend was occasionally broken by spurts of February and September 1980 when three events of magnitude more than 4 were recorded.

Though as a precautionary measure the Koyna Dam has now been suitably strengthened by providing buttresses on the downstream side, this earthquake has drawn the attention of earth scientists from all over the world as it has taken place in an area where it was not expected. On retrospect it is seen that the tectonic set up of the western part of Indian Peninsula, consisting of several rift zones culminating near the Gulf of Cambay, indicates that a critical state of tectonic balance could have been existing in the region. The imposed water load might have only helped in triggering off the occurrence of the earthquake at an early date. This postulate, however, is not universally accepted by all the investigators.

DAMS IN THE SON-NARMADA-TAPTI RIFT

The Navagam dam across river Narmada and the Ukai dam across the river Tapti are both located in the Deccan trap terrain having the tectonic imprint of the seismogenic Narmada-Tapti rift zone.

The Tapi river has been guided in its course along a series of faults which define the southern boundary of the Narmada-Son-Damodar Graben complex. In a certain reach at the Ukai dam site the river course lies along a fault, the right bank forming the downthrown block. In addition, a number of ENE-WSW trending en-echelon shear zone, parallel to the river flow are all present at the dam site.

Several earthquakes have been recorded in the area. The 5.4 magnitude Broach earthquake of March 1970 had a maximum intensity of VII on MM scale and its epicentre was located about 10 km. northeast of Ukai dam. A seismic coefficient of 0.15 g has been provided in the design of the dam.

The Navagam dam site is also prone to severe earthquakes and was shaken by the Broach earthquake. The Cutch-Mehsana-Surat Graben fault system and Narmada-Tapti-Graben fault systems in the project area are considered to be tectonically active. The river bed fault, the

Narmada lineament and the Akalbar fault are considered to be features along which adjustments could take place in the event of a severe shock. Aerial photo-interpretation has indicated neotectonic activity on the upstream of the dam site and has revealed tilting of terraces on both banks of the Narmada river Micro-earthquake studies and geodetic surveys across the river bed fault, Akalbar fault and Narmada lineament are underway. A seismic coefficient of 0.15 g has been provided in the design of the project structures.

Large number of evidences are also available of sub-Recent/Recent activity during the construction of dam sites on the Vindhyan plateau north of the Son Valley At Meja Dam site in Mirzapur district, fluvio-glacial deposits representing the last Pleistocene glaciation were recorded during excavation across a buried channel course Surprisingly, the rock debris in the channel course belongs to rock occurring a few hundred metres below the level of the Vindhyan Plateau, south of the Son river. Similarly iron age implements with peaty clays were found along buried channels lying across the Karamnasa river course at the Moosakhand Dam Site, indicating thereby major change in the river regimes due to neo-tectonic activity along the Son-Narmada lineament.

MAHAWELI GANGA PROJECTS, SRI LANKA

Though Sri Lanka form an extension of the stable Peninsular shield, there are historical reports and archaeological evidences to indicate that major earthquakes had frequented this land

In the chronic ales of Sri Lanka three earth movements have been mentioned. The first one in the Ravana epoch, sometime between 5th and 2nd millenium B C. when Sri Lanka is reported to have been separated from the mainland of India. The second is ascribed to the period of Panduwasa in the 4th Century B.C. and the third during the reign of Kalantissa during the 2nd Century B C. causing subsidence of Colombo. Reference is also made in 'Sasanawamsa' of an earthquake around 368 A.D.

During my study in 1978 of Maduru Oya Project close to the east coast area of Sri Lanka, remanants of an ancient earth dam constructed sometime in B.C. were observed. There are enough evidences to indicate failure of the structure during a majar seismic event. The Pollonaruwa ruins in the area also show shift of besements slabs and twisted pillars in the ruins of temples of about 8th-10th Century A.D. also indicating there by a major seismic shock. A number of hot springs showing linear pattern in the region also indicate presence of deep seated crustal fractures.

Danis N. Fernando (1982) during the coures of his studies of the Mahaweli Projects south of Trincomalee had inferred major changes in the Mahaweli river course due to earthquakes. During this event monastries with cave inscription of 700 A.D. and Kalinga irrigation system were destroyed. The irrigation system was later restored by Parakrama Bahu in 1186 A.D.

In the design of dams for Mahaweli Project a seismic coefficient of 0.15g has been considered keeping in view the seismic proneness of the region.

While the foregoing accounts were not meant to be exhaustive listing of all the work which is being carried out in the field of neotectonic study and its implications in the development of river valley projects, one point could be seen very clearly that the peninsular area which was considered to be stable shield by the earlier earth scientists can by no means be regarded as such. Shocks similar to Koyna could take place at other locations in the peninsula as well. It is a great challenge to the earth scientists to identify the clues which could provide a forwarning for such occurrences It is heartening to note that there is considerable amount of awakening in this direction in the country. In addition, to the investigations which are being carried out by the GSI and the recordings which are being maintained by the India Meteorological Department, the School of Research and Training in Earthquake Engineering is playing a very vital role in this direction. Its services are not only being utilised in India but are also in demand in adjoining countries. The Deptt of Science and Technology has also started a project which will give a further fillip to these studies.

The ISET has got a very major responsibility. It has to synthesise and coordinate the activities of the various organizations and has to ensure that the benefit of these are made available and utilised by the common masses as a whole.

I have taken too much of your valuable time and taxed your patience but the subject is of such vital interest to the Nation that it could not be helped.

Thank you all.