Geotechnical Problems of Dam Sites and Their Solution with Reference to the Projects of Eastern India

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Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 2.43

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SYNOPSIS : Geotechnical problems of dam construction are associated with adverse geological conditions of the dam site like soft rock, fault, shear zone, joints, weathering, permeable bouldery deposit, soluble rocks, ancient slide etc. In many of the dam sites of eastern India where one or more of such adverse conditions exist, the dam could be safely constructed by treatment of foundation defects. In some cases, however, a new site with less geologic problem was chosen with consequent modification in the project scheme.

INTRODUCTION

The geotechnical problems of a dam site may be many and varied in nature. ICOLD (1973) has recorded several cases of dam incidents in different parts of the world due to geological defects of dam foundation. In India also there are instances of mishaps in some old dams due to adverse foundation condition (Mehta and Pradhan, 1972). From engineering consideration, these problems may be stated as stability, subsidence, settlement, slide, seepage, leakage, piping, uplift etc. In fact, most of these problems of dam construction are geologic or geology-dependent. A detailed geological study of the site is very important to recognise these problems prior to final selection of the site for dam construction.

The geological set-up of dam sites and associated geotechnical problems are variable from place to place. Thick mantle of overburden and weathered rock, presence of soft layered strata, structural defects like fault, thrust, shear zones and joints are some of the common geotechnical problems faced during dam construction. Old slides, deep zones of kaolinisation, permeable boulder bed, buried channel and karstic condition are adverse geological features of a dam site. To construct a dam in such a geologically adverse situation, it may involve expensive foundation treatment, In some cases of highly problematic sites, the cost of treatment may be so prohibitive that it may affect the very feasibility of the project.

Inspite of the presence of adverse geological features under varied geological set-up, numerous dams have been constructed in the vast terrain of the eastern India including a part of the Himalayas for the purpose of irrigation, hydel power-generation, flood moderation etc. Of these, only some typical cases are presented in this paper to highlight the various types of geotechnical problems faced in the dam building history of eastern India and to show how these problems were solved.

IDENTIFICATION OF THE PROBLEMS

Engineering geological investigation of a dam site is essential to evaluate its precise geological conditions before the site is taken up for construction. Such investigation is generally done in different stages. At the initial stage, photogeological study of the site is undertaken followed by reconnaissance of the site. Engineering geological mapping of the site is then prepared to identify and record the lithological and structural set-up including all the visible geologic defects at the surface (Gangopadhyay, 1978). In the subsequent stages, exploratory drilling and sometimes geophysical works are done to identify the subsurface weakness of the site.

In some sites with weak foundation or adverse geological structures, in-situ shear test is conducted to evaluate the rock/soil behaviour under stress condition. In the words of Deere (1973), "Engineering Geologist is not responsible for the presence of adverse geology of a site but he is responsible for finding out that such adverse features do occur". In fact, it is the responsibility of engineering geologist to detect all the possible defects of a dam site and record them in a very clear manner understandable to the construction engineers for adopting suitable measures to rectify the defects and design the dam ensuring its safety and stability.

THE PROBLEMS WITH CASE HISTORIES

The problems actually experienced while working in different dam projects of Eastern India have been outlined under ten headings : (i) weak structural features, (ii) thick mantle of overburden, (iii) deep weathering of bed rock, (iv) karstic condition and cavities, (v) permeable boulder bed, (vi) soft sedimentary rock, (vii) buried channel, (viii) Kaolinisation, (ix) old slides and (x) reservoir siltation. Case histories of dam sites of Eastern India representing each type of these adverse site conditions are given in the following paragraph to show the seriousness of the problems and their rational solution.

(i) WEAK STRUCTURAL FEATURES

Folding, faulting, shear zones and joints are unfavourable geological structures for a dam site. Folds and faults develop several fractures and crushing of rock which are responsible for the problems of settlement, uplift and leakage. Shear zones and joints when present in dam site rocks bring weakness to the dam foundation. Terzagi (1929) has pointed out that in case of two dam sites (say site 'A' and 'B') with identical geological conditions, the site 'A' remains sound but the dam 'B' may collapse due to "chance factor of arrangements and relative flow capacity of the joints and fractures".

Umiam dam site

The construction of 71m high and 171m long Umiam dam of Meghalaya faced a multitude of geotechnical problems associated with weak geological features in the dam foundation. The concrete dam is located across the Umiam river in hard quartzite interbanded with soft phyllite, both the rocks being open jointed. After the foundation was opened, a 2m to 3m wide fault zone with soft gougy material was detected at the central part of the dam site aligned across the river (fig 1). Another fault was identified at the upstream end. The fault zones posed problems of differential settlement, development of cracks and leakage of stored water.

As remedial measures, the design of the dam was modified specially to accommodate the spillway structure mainly on hard bands of quartzitic rocks and matting was provided in parts of the soft phyllite. A 4-6m deep trench (twice the width of the fault) was excavated along the fault zone, the gougy and shattered material was scooped out and the trench was back-filled with lean concrete. The affected rocks on either sides of the fault were grouted by the cross-holes of 9m. Curtain grouting was provided for the upstream fault.

Foundation treatment by vertical grout holes at 3m intervals did not help for any grout-intake though the joints were open. The grout holes were then made inclined by 50° - 70° and oriented normal to strike direction. Consolidation of jointed rock down to 6m was then fully achieved. Due to the high seismicity of the area a very high seismic factor (0.18g) was incorporated in the design of the dam. The dam constructed nearly three decades back is functioning till date without any trouble.

North Koel dam site

The site of the recently completed 70m high and 762m long concrete dam across the North Koel river of Bihar consists of granite gneiss affected by extensive joints and innumerable shear zones. The joints are close spaced, wide-open at the surface (fig 2) but less open downward. Foundation treatment included removal of these highly jointed rocks followed by cement grouting. Curtain grouting (Three rows of staggered holes at 6m intervals) and consolidation cement grouting by inclined holes down to 6m were very effectively carried out to strengthen the foundation.

River action on a fault at the downstream has given rise to 'trench' (fig 3) of 2-3m wide, 3-6m deep and 80m length. During dam site selection, the dam axis was fixed as far as practicable towards the upstream so that this trench can be avoided from coming within dam foundation. But a portion still comes at the left bank toe portion of the dam. As a precautionary measures after excavating out the in-filled material from the trench, it was treated with concrete plug.

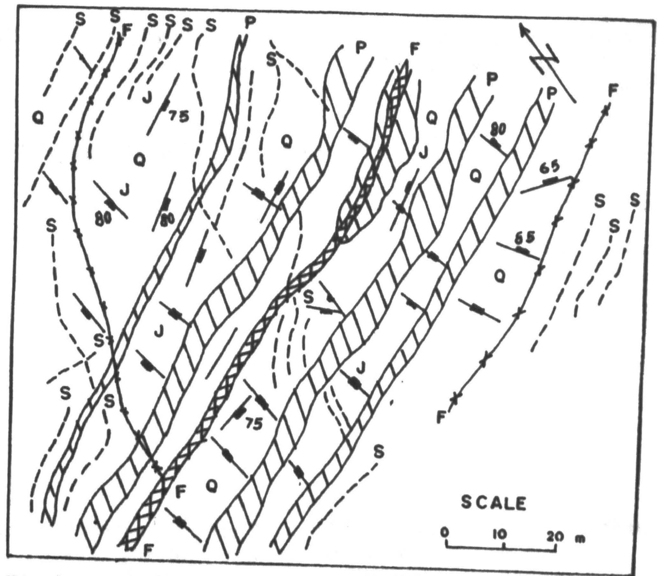

Fig.1 : Umiam Dam foundation with fault(F) shear zone(S), joint(J) and soft Phyllite(P) with quartzite(Q).

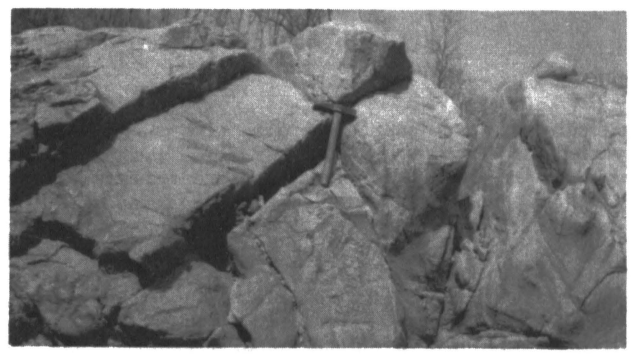

Fig.2 : Open-jointed rock with dislodged blocks in North Koel dam foundation.

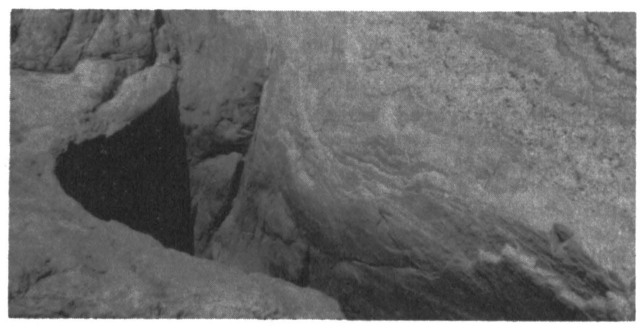

Fig.3 : A deep trench (3mx6mx80m) formed by the stream action along a fault at the downstream (toe) part of the North Koel dam site.

The dam foundation had got also several pot holes, one of which was nearly 10m deep having a circular cross section of 1.5m dia. This consumed huge quantity of cement to plug this by concrete. All these foundation treatment undertaken at the dam site increased the overall project cost but it ensured safety of the dam.

(ii) THICK MANTLE OF OVERBURDEN

Overburden in a dam site includes the loose river sand and silt at the valley floor and the unconsolidated material in the abutments, formed by in-situ disintegration of the parent rock or by transportation from higher reaches. If the overburden in a dam site is very thick compared to the dam height, the construction of the concrete or masonry dams here involves deep excavation to obtain bed rock with consequent increase in the dam height and project cost. Even an earth dam if founded on such permeable overburden, it will create problem of leakage. The cut-off trench for the 3.2 km long Dudhawa earth dam of Central India was kept on loose river bed sand which was responsible for the large scale leakage from this dam foundation (Mehta and Pradhan, 1972).

Kesho dam site

This 2 km long and 16m high dam located across the Kesho river and its tributary Sakri in Bihar is in final stage of construction. Both these rivers have sand deposit of 8m to 12m thickness. Excavation in the banks met overburden of about 10m consisting of highly permeable micaceous soil and loose sand. Below the overburden in the river section as well as the banks there is a thick zone of highly weathered and soft schistose bed rock. An earthen structure was designed at this site with a cut-off trench extended down to this bed rock having permeability co-efficient varying between 1.32×10^{-4} and 3.64×10^{-4} cm/sec. Due to this thick and very porous overburden cover and permeable bed rock below, excessive leakage was anticipated.

Impervious blanket of 1.5m thick soil along the entire 2 km section of the dam covering nearly 100m stretch towards the upstream part of the dam section was suggested to minimise the chance of leakage. In addition, a single concrete diaphram wall along the dam axis in the river section was recommended.

Kyrdemkulai dam site

The site for the proposed 45m high and 198m long concrete dam at Kyrdemkulai in Meghalaya is a morphologically good site. But, exploratory drill holes indicated that the lower parts of the two abutments have 10m to 15m thick overburden comprising permeable sandy and micaceous soil. At further higher reaches the overburden mantle is 21m to 28m in thickness. The bed rock and fresh rock profiles are almost flat or curve downward (fig 4).

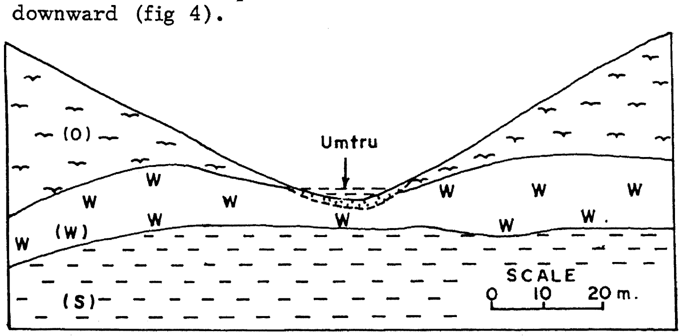

Fig.4 : A geological section along Kyrdemkulai dam axis showing thick mantle of overburden(O) and weathering(W) of mica schist(S).

Due to such deep zone of overburden compared to the dam height, construction of the proposed dam was not found to be economically feasible at this site. The dam was ultimately constructed in a new site nearly 50m upstream which was not topographically a good site but with less overburden cover.

(iii) **DEEP WEATHERING OF BED ROCK**

If the bed rock is highly weathered, it becomes soft with reduction of its strength to sufficient extent. When a heavy structure like the concrete or masonry dam is founded on such soft rock mass, it may create problem of settlement and crack of the dam body. For the dam foundation, it is necessary to excavate the weathered rock and expose the fresh bed rock. If the depth of weathering is very high, it may involve deep excavation and consequent increase of the dam height and escalation of construction cost.

Umling dam site

The Umling hydel project of Meghalaya is contemplated construction of a 91m high dam across the Umling river. The dam site is beset with the problems of deep and extensive weathering of rock and unfavourable geological structures at dam site. The right abutment of the proposed dam has high and steeply rising hill with fairly hard gneissic rock available within a depth of 5 to 10m but the left abutment exhibits low undulating mounds of soft mica schist where the foundation grade rock is very deep seated.

Exploratory drilling in the left bank encountered highly weathered and decomposed rock down to 32m. Large number of drifts in this abutment have also met only soft and decayed rock for a horizontal stretch of 25m to 30m. It will be a very costly proposition to strengthen this soft rock mass or excavate the 25m to 32m thick zone of weathering and raise the dam to its full height.

The central part of the river has also 10m to 20m thick deposit of riverine material and below this there is a 6m to 10m wide fault (fig 5) proved by drilling and water pumping test (Gangopadhyay, 1981). Extensive leakage is anticipated through this fault zone under reservoir condition. The construction of the dam at this site was found to be uneconomic due to the high cost involved in foundation treatment.

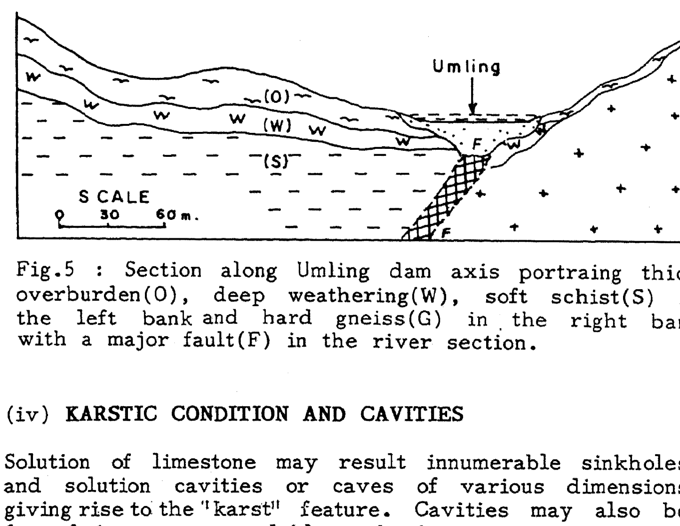

Fig.5 : Section along Umling dam axis portraing thick overburden(O), deep weathering(W), soft schist(S) in the left bank and hard gneiss(G) in the right bank with a major fault(F) in the river section.

(iv) **KARSTIC CONDITION AND CAVITIES**

Solution of limestone may result innumerable sinkholes and solution cavities or caves of various dimensions giving rise to the "karst" feature. Cavities may also be formed in some non-soluble rocks by water action or by leaching of soft material from such rocks. In the central part of India the vast terrain of Deccan basalt contains several big natural caves. Cavities present in a dam site with subsurface interconnection create problem of large-scale leakage from reservoir; but as stated under 'weak structural feature', the well-like cavity (fig 6) in North Koel dam foundation though very large in dimension but has no role in leakage as this is a 'blind' cavity without any passage for outflow of water.

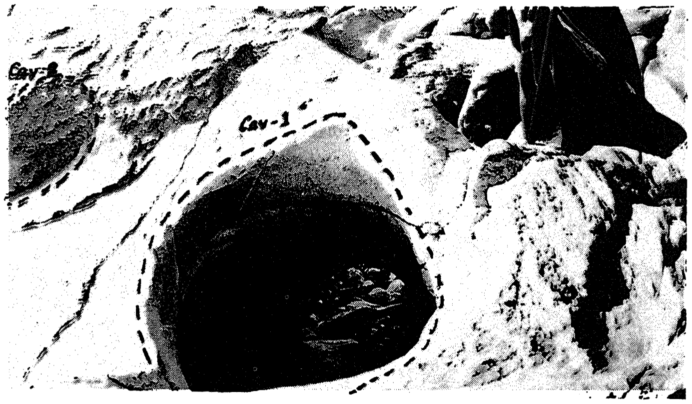

Fig.6 : Two blind cavities (larger one of 10m depth and 1.5m dia) in gneissic rock of North Koel dam foundation.

Kopili dam site

The kopili hydel project of Meghalaya/Assam is a classic example of possessing limestone with Karstic condition. In the initial project schemes of 1955-1961, a 54 m high and 1.6 Km long dam was proposed at the confluence site nearly 140m downstream of the confluence of the Kopili and Kharkai rivers. The site consists of Tertiary sand stone and limestone traversed by two faults, one at the left and another at the right banks of the river. Initially these faults were the only defective features identified at this dam site and the site was accepted with design provision for their treatments.

Subsequent investigation (Gangopadhyay, 1971) suggested that the limestone (max. thickness 35m which occurs covering a stretch of 380m in the left bank is karstic (fig 7). Five sinkholes, each of nearly 5m dia were found at the surface with subsurface ramifications. Drill holes proved the presence of a 8m (depthwise) cavity at the sub-surface. These cavities were formed by solution along the joints and bedding planes and these were like 'channels' at the subsurface region with gradient of nearly 1:20 towards downstream which threatened complete loss of reservoir water. The problem was solved by constructing the dam on granitic rock foundation by shifting the site nearly 3 km downstream with modification in the project scheme.

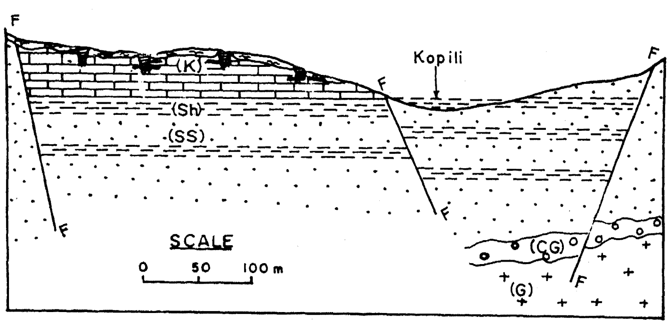

Fig.7 : A section along Kopili confluence dam axis with karstic limestone(K), soft shale(Sh), porous sandstone(SS), permeable conglomerate(CG) and gneiss(G) affected by faults(F).

Bilasi dam site

The 166m long and 20m high Bilasi dam of Bihar has unique problem at its spillway location at the left bank where several cavities are formed in quartzites. The rocks have been affected by folding, faulting and extensive shearing with some soft seams of clayey and silty material covering a large area of the left bank ridge. Leaching of the soft material has created these cavities which are slit-like or irregular in shape having cross sectional area at the surface as 20 cm x 50 cm to 60 cm x 100 cm. Tests by continuous pumping of coloured water (nearly 20,000 litres) through this cavities for six hours provided evidence of their subsurface inter-connections threatening substantial leakage under reservoir condition.

The programme of treatment undertaken at this site includes plugging of all the cavities by concrete followed by two rows of grouting, one along the axis and another 3m upstream of it. The grout holes were at 2m intervals and extended down to 12m. In addition thick impervious clay blanketing has been done at the reservoir fringe area close to left bank where rocks are exposed or occur under a shallow cover of soil. In the slopes of the left bank ridge berms were provided and the surface of blanketed clay was covered by boulder riprap to prevent slip during rain. The dam foundation at the river bed section has also faced the problem of leakage. This aspect has been described under the hading 'Permeable boulder deposit'.

(v) **PERMEABLE BOULDER BED**

Boulder deposit of riverine, fluvio-glacial or glacial origin when present in a dam site, excessive leakage is always expected. Unconsolidated boulders and pebbles may also occur as scree or terrace in the abutments of a dam site and create problems of foundation stability and leakage. A boulder bed of geologic age with argillaceous matrix permits substantial leakage and should be always avoided from a dam foundation.

Balason dam site

The Balason dam site of Darjeeling in West Bengal where a 160m high dam has been proposed to be constructed for power generation is likely to face serious problems of leakage through the thick terrace deposit consisting of boulders, pebbles and gravel. The site is represented by folded Darjeeling gneiss and Daling phyllite but about 90% of area is covered by boulder deposits. With the filling of the reservoir, the dam may face the danger of slide of these unconsolidated terrace material from the higher reaches in addition to excessive leakage. There is also danger of slide of huge chunks of left bank rock along the planes of an ancient slide of huge dimension. In the face of these problems, the project could not be taken up yet for construction.

Bilasi dam site

The problem of the Bilasi dam from cavity has already been described. The river section of this dam site has also got the problem of leakage through a boulder bed (3-4m thick) occuring a depth of 9-16m from the river bed level. A similar geological condition prevails in the 25m high and 597m long Murahir dam project located near Ghatsila of Bihar. There is a 1-2m thick boulders bed in the dam foundation at a depth of 7m to 10m through which substantial leakage started immediately after its construction nearly a decade back. Treatment by grouting at the post-construction period could not reduce the leakage to any significant amount. This served as a lesson in the construction of the Bilasi dam. To prevent possible leakage, the boulder bed from the dam site was removed by a deep trench-cut and refilled by impervious soil. In addition a 1.5m thick impervious soil blanket cover was provided for a distance of nearly 150m at the upstream parts to reduce the path of percolation.

Jaldhaka dam site (Old)

Initially the Jaldhaka (stage I) dam was attempted to construct in a gorge section of the Jaldhaka river where there was a thick deposit of boulder, pebbles and sand. Grouting by sodium silicate with bentonite was tried to consolidate the bouldery deposit and make it impervious for founding the dam on it. But there was no significant reduction it its permeability (1.08×10^{-3} cm/sec) even after grouting. The dam was ultimately constructed at a site 300m upstream after removing a 9m boulder deposit from the site (Sen Sharma et al, 1972).

(vi) **SOFT SEDIMENTARY ROCK**

Soft sedimentary rocks like claystone, mudstone, shale and clay-siltstone incapable of bearing load of heavy structures when exist in a dam site may give rise to the problem of plastic deformation settlement or shear failure. Smooth surface of shale or claystone occuring alternated with sandstone with low dip towards downstream may bring failure of the dam by slide.

Tigra and Kedarnala dams

The 26m high Tigra dam and 21m high Kedarnala dam of Central India were both founded on alternated beds of sandstone and shale dipping at a low angle towards downstream. The Tigra dam failed in the very first season of 1919 after reservoir filling due to uplift and sliding of the foundation rock. The Kedarnala dam also failed in 1964 by settlement and cracking of the dam body (Ramchandran et al, 1972).

Manu dam site

The site for the proposed 30m dam across the Manu river of Tripura consists of micaceous Tertiary sandstone with several soft shale beds. This sequence of soft layered rocks with 10° to 15° dip towards downstream has created a situation of dam failure by slide and settlement under reservoir condition as happened in the case of Tigra and Kedernala dams described above. To solve the problem of the Manu dam site it has been suggested to flatten the abutment slopes, strengthen the weak foundation rock and anchor the low-dipping shale sandstone beds with firm bed at depth to prevent slide.

(vii) **BURIED CHANNEL**

Such channels are deeply eroded subsurfaces in the bed rock subsequently filled up by perveous material like sand, pebbles and cobbles and as such existence of such features at a dam site endangers excessive leakage of stored water.

Ramrekha dam site

A buried channel has been recorded from the Ramrekha dam site of Bihar where a 29m high and 518m long dam is under construction. Here the buried channel is 6m deep and has been formed by stream piracy. The channel-fill material is mainly loose sand and silt deposited on eroded surface of granitic rock towards the right bank of the dam site. To avoid large scale leakage, the material was replaced by imperveous clay and then the dam founded.

Teesta dam site (Stage III)

Teesta Project, Stage III proposes to construct a 30m high dam for 384 MW power. A buried channel consisting of boulder and sandy material is detected in right abutment of Teesta dam site (extreme upstream site) in Sikkim. This buried channel is presumably formed by the advance and retreat of a glacier. The present river channel however bears little or no relation to such effect of a glacier which now exists at an higher altitude away from this site. It has been proposed to extend the foundation of the dam down to the hard gneissic bed rock after removing all the bouldery deposit including the in-filled material from the buried channel.

(viii) **KAOLINISATION**

The process of a kaolinisation of felspar is associated with selective decomposition and weathering of pegmatite and coarse grained granite. Starting from surface, such zones of soft white-clayey mass generally extends downwards as irregular pockets surrounded by hard rocks. A site with zones of kaolinisation cause problem of founding concrete dam and spillway structure.

Kalo dam site

The river section of the 2.4 km long Kalo dam of Orissa where a 20m high spillway structure will be constructed consists of pegmatite, porphyritic granite and dolerite. The dolerite is partly weathered, extremely jointed and at places (specially along its contacts with granite) highly sheared. The pegmatite and granite covering an area of 120 Sq.m. (20m x 6m) in the upstream part of the dam site have been affected by weathering and kaolinisation and created problem of settlement for the spillway structure. To come over the problem the following measures were adopted : (a) The spillway axis was shifted towards the downstream by few metres to avoid the zone of kaolinisation. (b) The crushed rock of shear zones were scooped out twice the width and refilled with concrete. (c) The weathered dolerite was excavated till fresh rock was obtained and the jointed rocks of the foundation were consolidated by grouting. The dam constructed in 1978 is functioning without any trouble.

(ix) **OLD SLIDES**

An area with old slides indicate instability. In some dam sites slide scars are found at the upper reaches of the banks with slided material like soil, debris or rock chunks at the bottom parts. In the Himalayan terrain of Sikkim and Darjeeling, old slides are seen in several places. An old slide plane may be activated when construction of a dam impose new stress condition in the site.

Balason dam site

The Balason dam site as discussed earlier has the main problem due to the presence of huge terrace deposit of boulders. But it has also faced the grave problem of damage of the dam by reactivation of a huge ancient slide in the left bank.

Teesta dam site

Old slide scars are also abundantly present in areas close to the Teesta dam site in Sikkim. The dam across the Teesta (extreme upstream) is yet to be constructed after taking care of these old slides and buried channel as stated before.

Jaldhaka dam site (new)

There is a rock cum-debris slide at the right bank of the Jaldhaka dam site (stage I) of Darjeeling. The blasting done during the construction of the dam and removal of the toe support from the bank accentuated the slide by activation along the old slide planes. The slide could be stabilised by regrading the slope and supporting it by a retaining structure with weep holes for drainage purpose.

(x) RESERVOIR SILTATION

It is an indirect effect of dam construction in an area with unstable landforms all around. When a dam is constrcuted with reservoirs in slide-prone areas it may bring problem of reservoir siltation by wide-scale slides at the fringe areas of the reservoir. The problem is very acute in the reservoir areas of some dams constructed in the Himalayan terrain.

Jaldhaka dam site

The Jaldhaka (stage I) dam of the Darjeeling was built with its reservoir spread in highly slide-prone areas that gave rise to the problem of siltation. The problem of siltation became serious within one year of dam construction when there was flood in the river and large scale landslides took place in the catchment. A suspended silt content of 825 to 2517 gm/m^3 was recorded in the river water per month during the rainy season (June-July). More than 70% of these suspended particles contain minerals with hardness between 5 and 7.5 in Mohs scale of hardness (Gangopadhyay, 1980).

The enormous quantity of silt brought from the surrounding catchment area resulted : (a) reduction in the life of the dam, (b) flow of high silt content into the water conductor system causing its partial choking and (c) damage of the turbine blades by the silt containing very hard minerals. To solve the problem another dam was constructed in a tributary stream namely Bindu Khola to augment the supply by silt-free water.

CONCLUSION

Many of the dam sites of eastern India have various geological defects creating problems for the construction of the dam. Precise evaluation of these weaknesses of dam foundations at the investigation stage by engineering geological studies has helped cost-effective design and safe construction of the structures after adopting suitable corrective measures.

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