Lessons from the Geotechnical Investigations of Water Resources Projects in Mirzapur and Sonbhadra Districts, Uttar Pradesh

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Abstract

Mirzapur and Sonbhadra (erstwhile Mirzapur dt.) districts depict broadly, three physiographic units namely – (1) Gangetic Plain with variable thickness of alluvium occupying northern strip of Mirzapur district; (2) The Roberts Ganj plateau area, constituting high land, covering major part of both the districts and (3) Undulating/rolling topographic unit of Son valley occupying the southern part of Sonbhadra district. The critical geotechnical assessment of 49 surface water resources development projects in these districts of Uttar Pradesh reveals that the future development of these resources in 3 different physiographic units of the districts should follow different dictum based on the experience gained in earlier investigations.

Mirzapur and Sonbhadra districts of U.P. are drought prone. Planned development of surface water resources in these districts was initiated in 1909 by making bundhis, ponds, storage schemes, barrages, lift pump water schemes through canals and earth dams to harness the irrigation potential of the area.

The paper deals at length the geotechnical setting and characteristics of each physiographic unit and proper treatment to be offered for different geo-engineering structures before seating them on foundation of complex geological terrain ranging in age from Precambrian to Recent.

Forthcoming projects in Gangetic Plain, may face the problem of bank erosion during floods and absence of bed rock at a shallow depth. This may require shifting of the site and river training and other protection works.

Robertsganj Plateau, is characteristically a combination of arenaceous and argillaceous bands dissected by three or more prominent discontinuities which have given rise to the problems of foundation leakage and dislodgement of blocks from the spillway and scouring of the softer bed rock members and sliding. Most of the bundhis located in this unit have homogeneous section, without cut-off provisions, which has allowed seepage in downstream section of the structures. Provision for grout curtain and/or blanketing of the reservoir may be necessary after evaluating the permeability of the rocks. To arrest upheaval of the rock blocks from the foundation, anchoring is to be done judiciously on the competent rock member followed by a thick concrete pad or masonry flooring spread over it.

For the projects falling in Son Valley, the solution channels in limestone country which are spread over considerably a large area and pockets of deep weathering in granitic country are to be thoroughly investigated. Dental treatment must be accorded in the weaker zones. Bundhis in this unit need key trench to minimize the foundation leakage.

Introduction

Mirzapur and Sonbhadra districts of Uttar Pradesh are drought prone. The history of planned development of surface water resources dates in these districts back to 1909 when minor and medium reservoirs namely, Sukhra (1909) on Adwa river; Ghori (1914) on Ghori river and Ahraura (1915) on Garai river were formed for irrigation. With the

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construction of Ghaghar Main Dam (Dhandraul reservoir) on Ghaghar river in 1917 and Sylhet weir on Karamnasa river in 1918, the irrigation potential of the districts was considerably increased. A network of irrigation canals/feeders was later on spread over the two districts by making pick-up weirs, bundhis, barrages, storage reservoirs and dams of multipurpose schemes.

The dams initially constructed in the districts do not appear to have involved any large scale geological investigations. However, in the course of subsequent planning for larger projects, the necessity of geological investigations was realised. Selection of suitable site for Rihand dam around 1944 laid the foundation for a close association of geotechnical studies and water resources development. Geological investigations became an integral part of nearly all the water resources projects envisaged thereafter. Most of the projects in the region are meant for irrigation and are confined to Ganga and Son river basins. They consist of minor to medium earth dams with concrete/masonry spillway and are located on small streams. In addition,

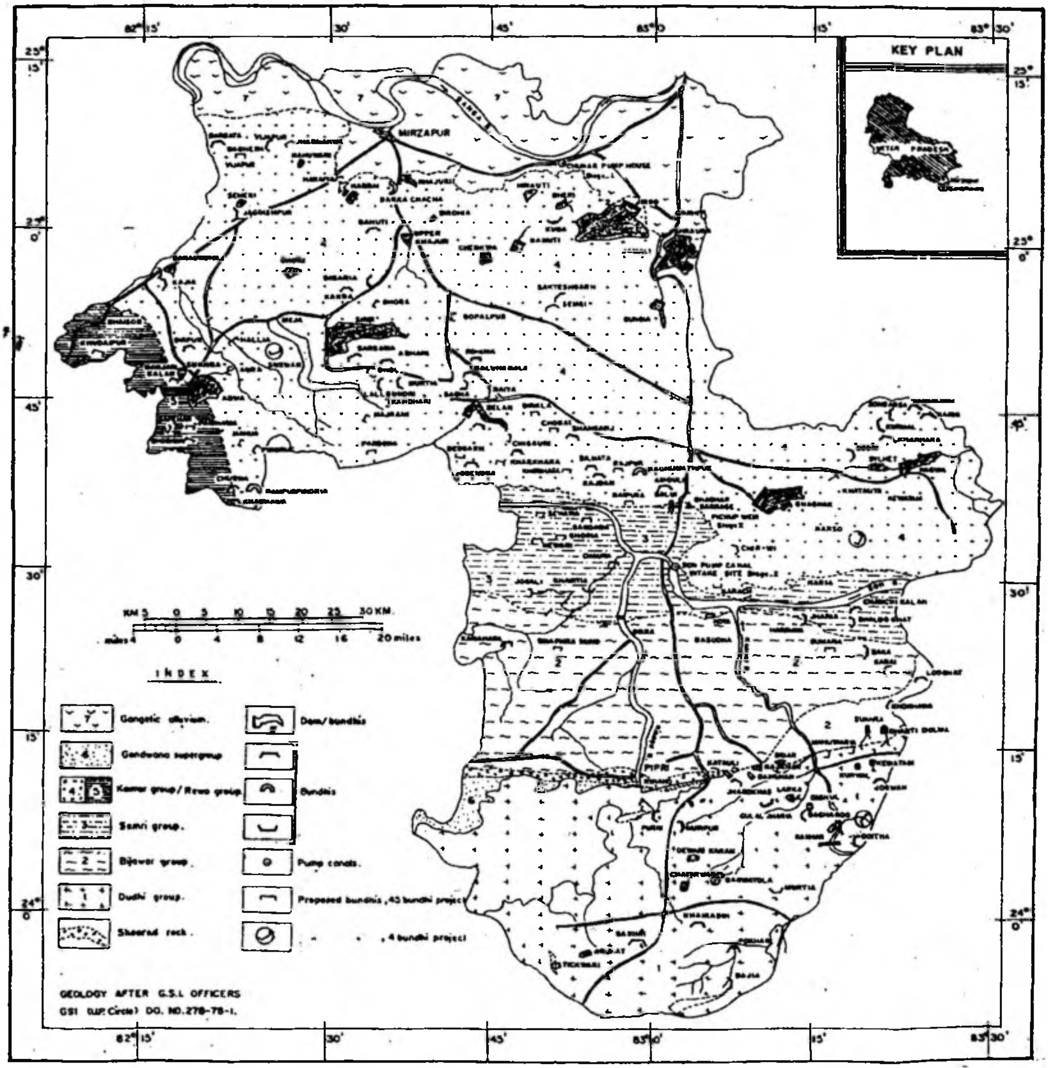

Fig.1

two major projects were executed on the Rihand river, a tributary of Son river. These include Rihand dam, a multipurpose project and the Obra dam which is a hydel project. Ghaghar barrage has been commissioned recently and a few other projects like the Kanhar irrigation scheme are under different stages of execution.

As per the data available with the authors, 18 dams ranging in height from 5 m to 93 m and 23 bundhis with height between 11 m and 20 m were constructed in diverse geological environment of Mirzapur and Sonbhadra districts (Fig.1). In addition, 21 bundhis under Drought Prone Area Project (DPAP), 3 bundhis under plan works and 34 bundhis under Bundhi Project have also been constructed.

The work on 45 bundhis proposed is in different stages of execution. The Son pump canal scheme is under operation while Chunar-Musakhand pump canal scheme is yet to be implemented.

Geomorphic setting of the area

Mirzapur and Sonbhadra districts (known as Mirzapur district before the division) are located in the southeastern extremity of Uttar Pradesh. River Ganga forms the northern boundary of Mirzapur district which extends up to Robertsganj in south. The area lying south of Robertsganj is also included in the newly formed Sonbhadra district.

Physiographically, the entire area can be divided into three units namely, Gangetic plain, Robertsganj plateau and Son valley. The elevation of Gangetic plain is of the order of 80 m to100 m above msl and that of of Robertsganj plateau varies from 350 to 120 m. The plateau slopes from east to west and south to north. It is because of this slope, the tributaries of Ganga flow from south to north. The westerly flowing rivers are Karamnasa and Belan which drain the eastern and central part of the plateau and ultimately join the Ganga. The Ghagar river also drains the eastern part of Robertsganj plateau but, flows southerly to become a tributary to Son river. South of Robertsganj plateau, there is an abrupt descending of 100 m to 150 m leading down to the basin of Son. The river Son flows at an average elevation of 170 m. Bijul, Kanhar and Rihand rivers are the important tributaries of Son and they flow from south to north. Son basin with occasional stretches of alluvial land on either bank also contains parallel rocky ridges of not much height.

Geological setup of the area

The geological environment of the projects in the districts presents diverse rocks such as competent granite/granite gneiss, pronouncedly jointed sandstone/quartzite, highly cavernous limestone and coal. The rock types range in age from Archaean to Permo-carboniferous. The northern part is covered with Gangetic alluvium. The eastern part bordering Bihar is the extension of Kaimur plateau while southern and south western part is the extension of Chotta Nagpur plateau. Talchir and Barakar formations of Gondwana Super Group occur along the fringes of Rihand reservoir.

The hills lying in between rocks of Vindhyan Super Group and Dudhi Granitoid Complex, south of Son river, are occupied by rocks of Mahakoshal Group (erstwhile Bijawar Group).

Geotechnical aspects of the projects

Gangetic Plain

This unit occupies a narrow strip on either bank of Ganga including the flood plain in northern part of Mirzapur district. The Alluvium can be subdivided into Older and Newer Alluviums comprising polycyclic sequence of sand, silt and clay with kankar nodules in the former and sand over silt and clay in the latter and present day flood plains. The forthcoming projects in this unit may face the problem of bank erosion during floods and absence of bed rock at shallow depths. To remedy the situation, project would require shifting of the site away from the bank and provision for river training. There is no

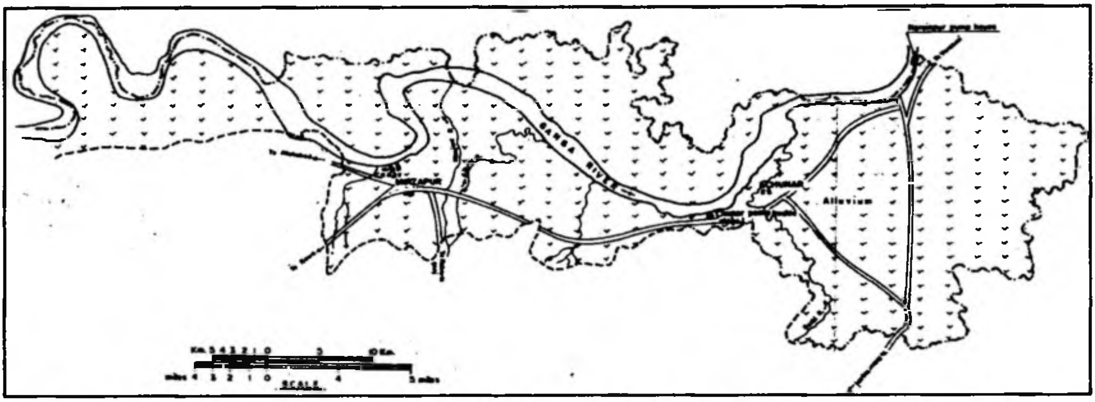

Fig. 2: Geological plan of Physiographic Unit - Gangetic Plains sowing the location of project

significant project located in this unit. However, a proposal for Chunar-Musakhand pump canal is under investigation (Fig. 2).

Robertsganj Plateau

This unit lies south of Ganga and occupies areas in both the districts. Its northern boundary with Gangetic plains is irregular. At places, it advances to the bank of Ganga, while it recedes 10 to 15 km or more from the river elsewhere. The southern extent of Robertsganj plateau is up to the base of the scarp forming the left margin of Son valley in Sonbhadra district. The entire plateau is predominantly composed of quartzite and inter-bedded shales of Dhandraul Formation of Kaimur Group. However, red to maroon coloured shale of Rewa Group are found intercalated with sandstone around Drumundganj in the western part of the district. They are sub- horizontally disposed and traversed by prominent basal joint and 2 sets of vertical joints. Besides, two more auxiliary sets of sub-vertical to vertical joints with variation in their trends are present. All the above mentioned joints are not found everywhere but, one basal and two sub-vertical to vertical sets are discernible at all

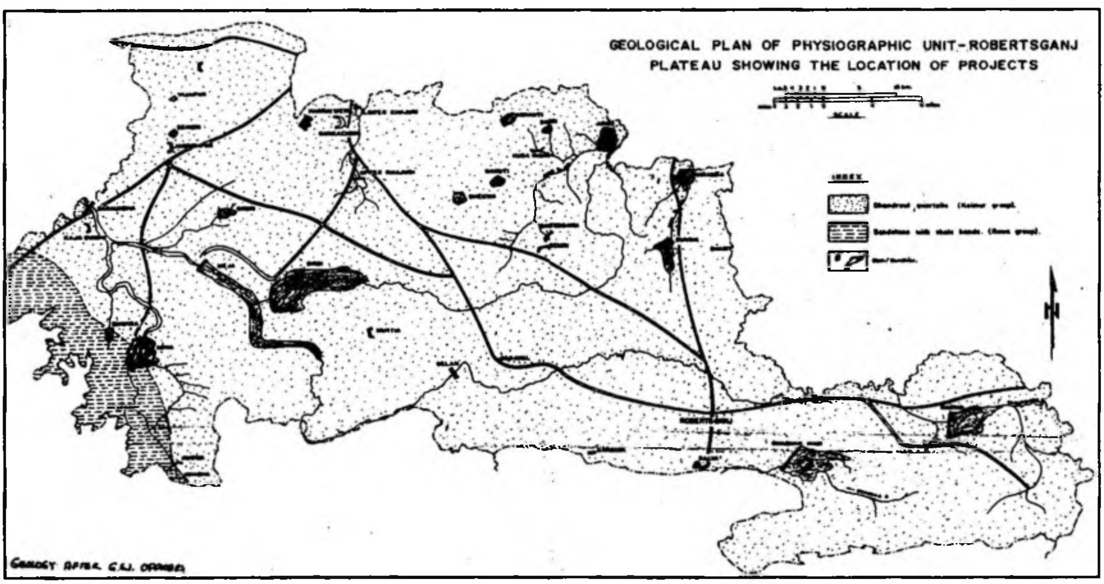

Fig. 3

the sites. It is because of the basal joints, the projects located in this unit face the problem of foundation leakage. Other problems include dislodging of blocks of rocks from the spillway, scouring of the softer bed rock members and sliding. Maximum development of irrigation potentials is seen in Robertsganj plateau. A total of 31 projects were examined in this unit (fig-3).

Foundation Leakage

The problem of foundation leakage was feared at Meja, Adwa and Pathidhari dams. Chaturvedi (1965) reported the presence of fluvio-glacial overburden down to a depth of 18 m from the ground surface at the Meja dam site. This overburden was earlier thought to be highly pervious in nature but, it was not so. Therefore, grouting of overburden material was not considered necessary. It was decided to site the dam on a partial cut-off extending to a depth of 3 m. The clay blanket was extended up to a distance of 10H from the upstream end of the filter toe and two relief wells were provided in the river section down to the bed rock level. Hukku and Jaiswar (1965) reported a similar problem at Adwa dam site. Subsequently, Verma and Srivastava (1967 and 1968) on the basis of drilling data deciphered that the existing boulder bed is due to the presence of a fault between Kaimur sandstone and Rewa shales.

Remodeling of Baraundha weir was proposed for which 6 bore holes were drilled. Bed rock was encountered at a shallow depth (1.5 m to 3.7 m depth). Presence of low dipping joint and closely spaced vertical joints have created doubt for leakage through the foundation and gliding as well. A grout curtain and anchoring of foundation rocks in the spill channel was recommended (Sinha and Srivastava, 1987).

Shaktesgar bundhi failed in 1882 due to foundation leakage and poor compaction. Clay blanket was provided subsequently in the reservoir to minimize the foundation leakage (Srivastava, 1986).

Leakage through buried channel

Presence of a buried valley was inferred at Pathidhari dam site by Hukku on the basis of geological mapping of the site carried out by Jaiswar (1967) and exploratory pits dug on the banks. Hukku felt that the gap in rock exposures at the site along the river Pathidhari represents an old course of the river (buried channel) trending oblique to the present course. He concluded that the buried channel fill in the proposed reservoir could lead to leakage.

Dhekwa dam had the problems of leakage. The overburden was initially thought to be a possible medium of leakage from the dam. However, investigations suggested that overburden material was nearly impervious in nature hence, partial cut-off was provided (Anand, 1980).

In Lali bundhi, the leakage was found through the rat holes in the earth dam and in reservoir as well. The holes were sealed and a clay blanket was proposed to be spread over the reservoir (Pant and Sushil Kumar, 1993)

Leakage through the joints

Leakage through the basal joints and 2 sets of sub-vertical joints with wide opening was reported at Chatar dam by Jaiswar (1965), Dhandraul dam by Srivastava (1961) and at Nagwa dam by Sinharoy and Sinha (1984) and Pant and Sushil Kumar (1985). Jaiswar (1965) reported that the basal joints are the most prominent source of leakage along with 4 more sets of sub-vertical joints at Chatar dam site. He further observed that some of these joints are transverse to the dam axis; hence, control of leakage may necessitate the provision of clay blanket or grout curtain below the earth dam, particularly where the bed rock is exposed.

Srivastava (1961) reported gradual increase in leakage with time through discontinuities in rock at Ghaghar main dam (Dhandraul reservoir). He mentioned that the dam gave a trouble-free performance in the initial 9 years

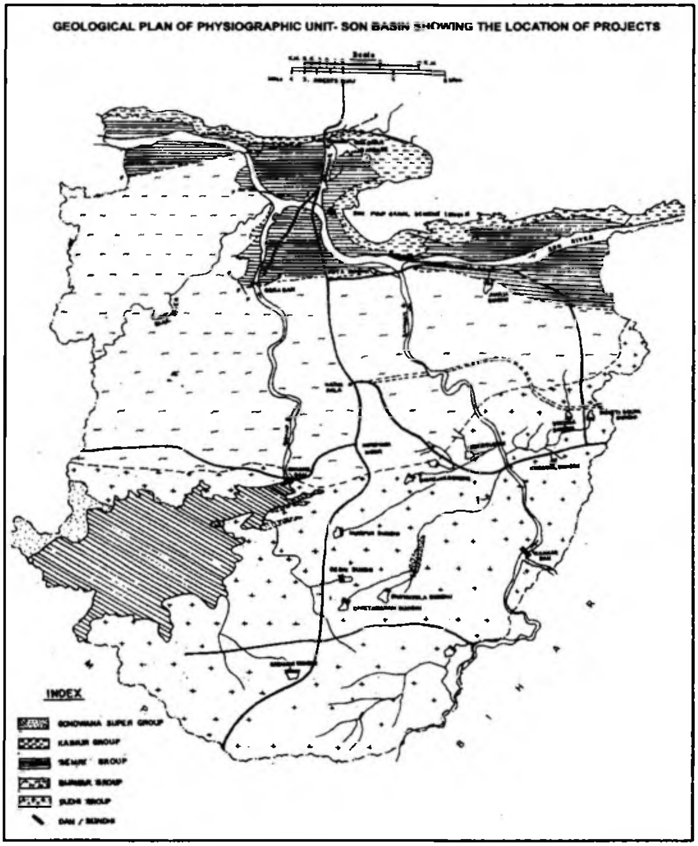

Fig. 4

from 1917. The discharge of 5 to 6 cusecs in 1926 gradually increased to 30 cusecs by 1936. Efforts to control the leakage by local blanketing gave temporary success for 4 years after that, infilling in the joints were removed by piping under a sustained hydraulic head. Curtain grouting with quick setting cement coupled with concrete back filling of open joints and cavities from the surface down to the accessible depths was recommended. Joints were sealed in 1968 and 1979 but no much success could be achieved.

While studying leakage through open joints from the quartzitic reach (which is occupying about 66% of canal length) in Marihan canal suggested caulking of open joints with cement mortar and installing gauges for measuring water level in nearby wells.

Nagwa dam was beset with the problems of leakage through the body of the masonry spillway and foundation as well. In order to control the leakage and further augment its storage potential, the height was raised by 3.66 m and a controlled spillway was provided. Pant and Kumar (1985) recommended to provide a grout curtain down to 10 m depth in the bed rock and also covering of the upstream face of spillway by a concrete membrane founded on the bed rock and anchored to the body of the spillway structure.

Dislodging of blocks in the spillway bucket

Anchoring of the blocks of the quartzite in the spillway bucket was recommended to minimize upheaval due to buoyancy in the Nagwa spillway bucket. Pant and Kumar (1985) suggested that the slabs be pinned down at 3 to 5m c/c (staggered) along the entire length of the bucket. Similarly, remodeled Meja dam in its new spill channel needed anchoring of blocks of the rocks in the foundation to check their upheaval due to buoyancy (Kumar, 1984). Anchoring followed by a thick pad of concrete over it in Sirsi spillway was also recommended (Kumar, 1991).

Scouring of the softer bed rock members

Jirgo dam has two spillways on the left flank. To arrest the erosion of the bed rock due to inter-layering of softer shale bands, two toe walls were made on the quartzite and intervening portion of the toe walls was concreted. The foundation rock in the spill channel was tied up with the dowel bars (Verma and Srivastava, 1967).

Son Basin

Basin of Son River starts from the foot hills of Robertsganj plateau and extends for the entire length and breadth of the Sonbhadra district. It is drained by northerly flowing Bijul, Rihand and Kanhar rivers and southerly flowing Ghaghar river, all being important tributaries of Son.

The rocks of Dudhi Group, Mahakoshal Group, Semri and Kaimur Groups of Vindhyan Super Group and Talchir and Damuda Groups of Gondwana Super Group are exposed in this basin. A very large variation in rock types and structural disposition is seen.

Geotechnical problems faced by the projects located in this basin include presence of shear zones in the foundation of structures, deep weathering of granite, presence of strained quartz, leakage through sub-horizontal joints, presence of cavernous limestone, highly pervious and thick overburden in the river bed, buried deeper gorge sections and local faults. Four dams and 13 bundhis are located in this basin (Fig. 4).

Obra Dam

Obra dam is located on highly cavernous limestone of Kajrahat Formation and shales of Semri Group. Its reservoir spreads over the Kajrahat limestone and the rocks of Mahakoshal Group across the faulted contact. Leakage of water from this limestone was first postulated by Srivastava (1960, 1962). Subsequently, detailed studies were carried out by Hukku and Mathur (1963), Chaturvedi (1966), Jaiswar (1967) Varma and Srivastava (1968 b) and Chaturvedi and Jalote (1972). The geotechnical problems studied include cavernous nature of the limestone, highly pervious nature of the sand in the river bed, buried cascade and deeper gorge section along the river course downstream of the dam axis and the fault occurring along the river course and extending into spillway and the power house area (Srivastava 1969). The caverns were sealed wherever possible and a grout curtain was provided. A concrete cut-off diaphragm was also provided in the river section to prevent seepage through the overburden.

Rihand Dam

Geotechnical problems encountered in Rihand dam include deep weathering of granite gneiss on the abutments, shearing at the contacts of different rock types and open joints in the foundation. General consolidation grouting of the foundation was carried out. In addition, a grout curtain under high pressure to a depth of 30 m in the river bed and 22 m in abutments was provided. Cracks in the body of the dam and development of stress in the powerhouse cavity due to alkali-aggregate reaction have been reported.

Son pump canal scheme

The Son pump canal scheme envisages lifting of 33.98 cumecs of water from river Son (El.168 m) to Ghaghar main canal on Robertsganj plateau (El. 320 m) involving a lift of 152 m in 4 stages. A barrage has been constructed between 3rd and 4th stage on

Rohtas limestone formation of Vindhyan Super Group. The cavities have been filled up with clay. The area of limestone upstream of the barrage and bundhi has been blanketed to control the leakage .The blanket has been tied up with the afflux bundhi.

Kanhar earth dam

The Kanhar earth dam has been constructed up to El. 256 m and a positive cut-off has been provided. The masonry spillway proposed in the river bed section has not yet been taken up for construction.

Conclusions and recommendations

Mirzapur and Sonbhdra districts of Uttar Pradesh are drought prone. For combating the water scarcity, planned development of water resources of these districts commenced in 1909. The area is divisible into three physiographic units viz., Gangetic plain, Robrtsganj plateau and Son basin. There is no significant project in Gangetic plain due to unfavourable topography and large scale submergence during floods. Another disadvantage with this unit is the availability of bed rock at greater depths in most of its stretch. Hence, only large scale projects on pervious foundation can be planned here. The site of Chunar-Musakhand pump canal project which is under investigation has been shifted upstream where rock is exposed or available at a shallow depth of 2 m to 3 m.

Maximum number of surface water development projects is seen in Robertsganj plateau by making bundhis, weirs, barrages and dams. A total of 15 bundhis and 16 dams/ barrages/ weirs were examined. The plateau displays rocks of Dhandraul Formation of Kaimur Group and shales and sandstone of Rewa Group, both belonging to Vindhyan Super Group. On account of rocks (shale, siltstone and sandstone/quartzite) of varying competency, the problem of differential settlement of foundation is anticipated. The existing projects have faced the problem of foundation leakage on account of open and sub-horizontal set of basal joint and two sets of vertical to near vertical joints. Other geotechnical problems such as scouring of softer shaly bands in the spillway section of Jirgo dam, upheaval of the sheets of quartzite due to buoyancy in the spill channel of Sirsi , Nagwa, Meja and Dhandraul dams and leakage of water through the body of the masonry dam at Lower Khajuri weir, Harrai weir, Nagwa and Dhandraul dam need special mention. Most of the bundhis located in this unit have homogeneous section which has allowed seepage of water. The seating of the bundhis on regolithic soil and at places partly on the sub-horizontally bedded Dhandraul quartzite has resulted in forming water pools in downstream reaches due to leakage of water through basal joints under sustained head.

The Son basin contains Maximum variation in the rock types. It has competent granite/ granite gneiss, quartzite, and pronouncedly jointed sandstone on one hand and carbonaceous shale, highly cavernous limestone and coal on the other hand. In Son basin Obra, Ghaghar and Rihand dams have been constructed and one at Kanhar is under construction. In addition, 13 bundhis were also examined from this basin. Rihand and Obra are for hydel power generation while rest is mainly for irrigation. Geotechnical problems faced in the projects located on this unit are leakage through the basal joints and cavernous limestone, differential foundation settlement, deep weathering of granite, presence of strained quartz, shear zones and thick overburden.

To obviate the above mentioned problems in the forthcoming projects in these physiographic units, following recommendations are made:

1. Detailed geological investigation with sufficient subsurface exploration is a prerequisite for all the projects irrespective of their magnitude and purpose.
2. Structures such as power/pump house in the Gangetic plain be designed on raft and proper care be taken to keep them

away from the high flood level.

3. Provision for curtain grouting and/or blanketing of reservoirs for the projects in Robertsganj plateau be made after evaluating the permeability of the rocks. To check the upheavals of the blocks of rock in the spill channel and scouring of the soft rock members, foundation must be anchored to the competent rock member and a thick concrete pad over it is to be spread or masonry flooring has to be done. Proper care must be taken to check the differential foundation settlement where quartzite and shale inter-bands are exposed in the foundation.

4. Solution channels, located in Semri Group of rocks in Son basin be evaluated by exploratory drilling and concreted. On the basis of photo interpretation map of Son valley, Srivastava and Iqbaluddin (1981) reported that about 280 sq km area in Son valley basin is covered by limestone of different Groups. Among them, the Rohtas limestone and Kajrahat limestone occupying an area of 68.5 sq km and 20 sq km respectively are reported to be cavernous and are traversed by numerous faults. These aspects have to be taken into consideration during the project formulation.

5. The pockets of deep weathering in the granitic country be identified and treated if their compressive strength is found inadequate. Dental treatment must be provided without any exception for shear zones and local faults. The aggregate to be used must be tested for alkali aggregate reaction.

6. Bundhis may be provided with key trench to minimize the foundation leakage and slopes of embankment are to be flattened to minimize the seepage of water. A rock toe must be made in all the homogeneous earth embankments to check the erosion and slope. Turfing may also help in checking the erosion and formation of gullies on the embankments. The bundhis which have been completely silted up may be excavated and the material thus obtained can be utilized in the construction of new earth embankments after testing.

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