Geotechnical Problems Encountered in the Penstock and Powerhouse Components of Kuttiyadi Additional Extension Scheme, Kozhikode District, Kerala

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Abstract

Kuttiyadi Additional Extension Scheme (KAES) of Kerala State Electricity Board is part of Kuttiyadi Hydro Electric Project with separate intake, HRT, Surge, Penstock, and Power house to generate additional 100MW. Construction stage geotechnical assessments were made and suitable remedies were suggested for all the components of the project after geological traverses, detailed geological mapping and logging of cores. But this paper describes the geotechnical evaluation made for the penstock and power house area. The project complex is located in a country rock of Hornblende biotite gneiss and granite gneiss with enclaves of charnockite and basic granulites. The proposed penstock is to be located on the mid slope of a hill. The area is also slide prone with active and dormant slides and one slide (Konipara slide) took place even during construction. The slopes have been disturbed for penstock excavation. After the surface and subsurface study it was found that the locations of anchor block nos 13 to 17 (particularly 15 to 17) is vulnerable and made up of slide debris and highly weathered rock. Hence it was recommended to found the Anchor blocks on hard rock occurring at deeper level to transfer the load so that the stability and safety of water conductor systems is ensured. In addition, temporary slope protection measures are also to be provided during excavation. The excavated power house area is occupied by hornblende biotite gneiss with enclaves of amphibolites. Weathered seams with the thickness varying from 20cm to 70cm, intersect the rocks predominantly along the sub-horizontal joints from upstream to downstream at various levels. The weathered seams exposed on the walls of the Column pits and Machine pit areas show the differential weathering along the strike and dip direction resulting in non-uniform thickness from upstream to downstream direction. After completely assessing the rock mass condition and analyzing thoroughly the sub-surface (bore hole) and surface mapping data of the country rock/weathered seams at the surface, and sub-surface level, the various levels of founding the columns and machine pits and specific remedies such as rock anchoring, consolidation grouting etc were suggested.

1. Introduction:

Kuttiyadi Additional Extension Scheme (KAES) is proposed for enhancing the installed capacity of the existing Kuttiyadi Hydro Electric Project (125MW) at Kakkayam by 100MW (2x50MW) due to the availability of additional water supply from Karaman Thodu Reservoir of Kuttiyadi Augmentation Scheme. The KAES Scheme is implemented

by constructing an Intake in the Kakkayam reservoir, a Power House beside the existing (1x50MW) Kuttiyadi Extension Scheme, a water conductor system consisting of 684m tunnel and 2115m long penstock. The available hydraulic head is 666m. The project is located in the Kakkayam area, Kozhikode district of North Kerala.

Preliminary geotechnical investigation was carried out by GSI (Balachandran, F.S.1991-92 and 1998-99) for the KAES project and when the project was taken up for construction by KSEB, construction stage geotechnical investigation was conducted during 2004 -06. During this period apart from general geological traverses along the all components, wall mapping of Intake area, 3D geological logging of gate shaft, power tunnel and surge shaft, detailed geological traverse mapping along the penstock route cut areas, drill hole core logging for penstock anchor block location, large scale geological mapping of power house columns and machine pit and core logging of power house boreholes drilled during construction were carried out. Geotechnical notes were issued for all the site visits with suitable recommendation. However in this paper, construction stage geotechnical investigations, and the geological problems encountered in the penstock track and power house site are described.

2. Geology of Project Site:

Regionally the study area consists of Migmatite, Hornblende biotite gneiss and Quartzo feldspathic gneiss of peninsular gneissic complex. The host rock has amphibolite, pyroxenite, pyroxene granulite and charnockite as enclaves and is traversed by acid and basic intrusives. The pegmatite and aplite intrusion are common (U.S. Reddy, 1968). Pink feldspar blotches are also seen predominantly. The regional trend of foliation is NNW-SSE with a steep dip of 50° to 80° towards ENE and it swerves towards NNE-SSW with steep dip towards ESE. The Kuttiyadi project area is made up of hills with a few deep and narrow valleys. Outcrops are scarce or seen in hill tops. Near the Intake, surge, and at the middle of penstock route weathered rock outcrops are seen. Other areas are covered with thick over burden. A sub vertical dolerite dyke is seen at the penstock anchor block-3 location. The excavations made for various components have exposed the underlying rock i.e. fresh migmatitic gneiss with three to four prominent joints are common. The joints are rough, planar, tight with or without infilling. As the area receives copious rain, weathering of rock is pronounced due to which country rock is transformed in to a friable incoherent, loose material. Thick over burden and sub- horizontal weathered seams within country rock are prominent at the power house site and terminal anchor block location.

3. Geotechnical Evaluation:

3.1 Penstock:

The proposed 2144m long penstock is to be located on the side slope of a ridge since, the ridge-top is occupied by the existing penstock pipe of the Kuttiyadi hydel project. GSI conducted preliminary investigations along the proposed penstock alignment (V. Balachandran, 2001). The study indicated that along the penstock alignment weathering of the rocks remains pronounced due to which the depth of the over burden ranges from

4m to 26m. Hence GSI recommended the determination of bearing capacity of the materials for founding the anchors in overburden. The proposed alignment of penstock is to be located on the side slope of the ridge, hence stability considerations were raised by GSI, and recommended pressure shaft instead of Penstock. But, project authorities (KSEB) have preferred the surface penstock. Boreholes have been drilled on the anchor block locations and additional bore holes were also drilled in between anchor locations. The area is also slide prone (picture 1) with active and dormant slides and one slide (Konipara slide) took place even during construction and particularly the Anchor blocks 13 to 17 are located on the vulnerable slope.
The following is the geological description for the various Anchor block locations. Butterfly valve chamber (BVC) is located on a rocky hill. The location of AB1A (Anchor block no-1A) has highly to moderately weathered rock. It was observed that at AB 2 location a mafic dyke (Amphibolite) is present within the hornblende biotite gneiss with steep dip. The dyke rock is closely jointed, fractured and shattered. Corroborating the field observations, cores of the borehole in this area also reveal the presence of thin disk shaped dyke rock indicating the presence of sub horizontal and vertical joints intersecting at close spacing. Fracturing is persistent up to 10.65 m depth from the surface and below which the length of the core piece improved marginally. Hence it was recommended that the location of anchor block No.2 (AB-2) may be shifted by 20m to 25m downstream where weathered outcrops of quartzo feldspathic gneiss are seen on the surface. Alternatively, if the shifting is not possible due to design reasons, the fractured black dyke rock occurring at the proposed AB2 location can be grouted up to 5 m depth.

AB 3 location is in a small valley. For founding the pier of the bridge of the penstock, this location has in situ weathered rock. Anchor Block location AB-3A & AB- 4 has already been concreted at the time of site visit and appear to be founded on in situ weathered rock underlain by fresh rock occurring at a shallow depth. It was seen that the area of excavation between the Anchor block No. 3 and 4 is located as close as 15m to the existing pipe line and more than 13m of excavation was required to reach the fresh rock level. The entire cut section of about 10m depth is occupied by weathered gneiss and lateritic soil. A carefully designed slope cut with protection was recommended so that the existing penstock anchor block is not disturbed.

The locations of AB 4A to AB 7 is on a gentle rocky slope with thin soil and weathered rock cover. At Anchor block AB-8 location, 10.40 m of overburden comprising soil, completely weathered rock and core stone / boulder is deciphered. Hence, it is recommended that the foundation level of this anchor block may be taken up to hard rock level of 518.175 m –as per core log - (proposed foundation level is 521.02) to avoid founding on any loose core stone or boulder embedded on completely weathered rock.

The Anchor blocks 9 to 12 are proposed on a fairly steep (45° to 50°) rocky slope of the hill with thin soil cover. No slope stability problems are anticipated as the exposed rock is massive without any weak planes and all these anchor blocks will be founded on hard rock. The Anchor block 13 to 17 would be located on a moderately steep slope (30 to 35) which has old slide history and filled with slide debris etc.

3.1.1 Anchor Blocks on the Slide Zone:

The anchor blocks- 13 and 13A are proposed in the zone of accumulation of a palaeo slide. The slide debris material is unsorted comprising weathered, angular to sub angular rock blocks of varying sizes, clay, silt and sand sized particles. An erosional cave is reported to occur parallel to the direction of the slide. Though the slide is stabilised, the modification of the slope due to the construction activities may lead to instability. The depth to bed rock from the present level of excavation is about 19 m. Hence it was recommended to work out the possibility of relocating the Anchor block – 13 to the area upstream of the paleao slide, where insitu weathered rock is exposed.

Just 25m D/S of 13A weathered rock with thin soil cover is seen. Anchor block 14 and 14A are located on rocky ridge and weathering is feeble to moderate. The slope forming material of anchor block location 15 (AB15) is made up of clayey silt, lateritic clay, micaceous and completely weathered rock (palaeo slide debris - though stabilized). Rubber plantations are there. The material has shown signs of distress and failed in the 2006 monsoon in spite of giving protection by geotextile (picture 2).

At Anchor Block 15 A location highly weathered rock is exposed on the left cut slope (where geotextile is provided for slope stability) the overburden material is clayey. The Anchor block location no.16 (AB-16) has 26 m of overburden consisting of boulder and slide debris. It is a paleo slide area (now stabilized) with assorted material which has potential for destabilization during monsoon. Already it collapsed during the 2005 monsoon and slush has flown in to powerhouse pit.

Excavation of about 15m depth made at the rear side of the proposed power house at the location of Anchor block no17 and upstream showed the presence of 8m thick litho margic clay and lateritic soil followed by moderately weathered rock of about 5 to 6m below which fresh rock is occurring. The litho margic clay when came into contact with water will become slush and induce failure of the slope on either side of penstock track. Already failure has started taking place at number of places and hence it is recommended to provide immediate support measures and berm at every 5 or 6m with slope cut of 1H and 1V at this location. The back slope of powerhouse above AB 16 A & 17 (particularly the right side) is to be eased and provided with berm as the medium is slide prone under saturated condition.

Hence in view of the above, it is recommended that at the location of the Anchor blocks 13, 15, 15A and 16 where the thickness of the overburden is high and old slide debris is predominant, it is to be ensured that the load of Anchor blocks is to be transferred to the insitu hard rock whose depth is inferred from bore hole so that the stability and safety of water conductor systems is ensured. In addition temporary slope protection measures are also to be provided during excavation.

3.2 Power House:

A 2 x 50 MW powerhouse (third powerhouse in the Kuttiyadi Scheme with the size of 32.8X17.75m) under construction has been excavated progressively in the machine pit and column foundation areas. This additional powerhouse shares the left side columns with the existing powerhouse. The powerhouse area is occupied by the hornblende biotite migmatite gneiss with tight isoclinal folds and ptygmatic folds (G. Ramalingam, 1998-99). The foliation trend in N50°W–S50°E direction with 55°dip towards N40°E direction. The sub-horizontal joints are predominant in the area with the strike of N20°E – S20°W direction with 15° to 20° dip towards N70°W direction (gentle dip towards downstream side or towards tailrace area) besides few steep dipping joints also noticed. These sub-horizontal joints are filled with weathered seams of 20cm to 70cm thickness and numbers of sub-horizontal seams transect the fresh rock which acts as sheet in the entire powerhouse area from u/s to d/s. within the hard rock intermittently at various levels.

The weathered seams exposed on the walls of the Column pits and Machine pit areas show the differential weathering along the strike and dip direction resulting in non-uniform thickness from upstream to downstream direction (picture 3)**.** The intensity of weathering also varies from place to place. Its nature varies from close spaced fracturing to completely weathered rock and clayey soil. (The seam materials were of clay, sandy clay, and sand with rock particle etc (complex nature). These multiple weak zones may act as destabilizing factor in the column foundation considering the significant design load (nearly 1000 tones per Sqm.). Hence it has become essential to ascertain the exact depth and nature of weathered seams (below the design foundation level) and thickness, fresh rock in between the sub-surface seams, etc.

After studying bore hole cores (solid rock and loose materials) discussion was held with project authorities to arrive at the founding level of various column footings considering the geological nature of various strata and the maximum possible load and pressure that is expected to come under footing of various PH columns. To know the groutability and permeability of the weak strata at the elevation of the seam tests were conducted at select places. The results indicated that most of the seams took significant grout intake and post grout permeability was also low. After analysing all the data, founding levels of columns and necessary measures to improve and strengthen the weak strata underneath, such as consolidation grouting, were decided.

The Machine pit area has also indicated the presence of weathered seam at El. 80.23 m to 79.43 m. The nature of the weathered seam varies from rock pellets to rock powder and clayey silt. The bore hole, drilled earlier, and the two confirmatory bore holes carried out presently, established the presence of weathered seams at different levels in the foundation medium throughout the sub surface area of machine pits. In order to consolidate the rock mass and to overcome the unequal bearing capacity of different strata at the sub-surface of machine pits the following remedial measures were suggested. For the entire machine pit area, consolidation grouting, down to the El.76.00 m from the present floor level with 3 m spacing, which are staggered evenly, is to be carried out in 3

m stages. Provision should be given for grouting by leaving pipes while laying the leveling course concrete. The foundation anchoring/bolting is to be carried out to tie up or stitch the rock mass of weathered seams sandwiched between the fresh rocks to the fresh rock at a level of 8 m from the present floor level. The anchor rods of suitable thickness may be given in staggered fashion and grouted. In the machine pit area, each row should have minimum of 3 anchors with spacing of 3 m. The anchoring has to be invariably done before pouring the leveling course concrete.

4.0 Summary and Conclusion:

By transfer of water from Karamanthodu basin to Kuttiyadi basin and by harnessing the available hydraulic head, the KAES project envisages generation of 100 MW of power with the completion of Kuttiyadi Augmentation Scheme. It is part of Kuttiyadi hydro Electric project with separate intake, HRT, Surge, Penstock, and Power house.
Construction stage geotechnical assessments were made and suitable remedies were suggested after geological traverses, detailed geological mapping and logging of cores. The project complex is located in a country rock of Hornblende biotite gneiss and granite gneiss with enclaves of charnockite and basic granulites. The country rocks have been traversed by pegmatite bodies. The foliation is trending in the direction of NNW-SSE dipping 50 to 60 towards ENE. Other than foliation joints four other joint sets are also seen. No major structural discontinuity like faults, shears etc are seen. The outcrops are scarce and as the area receives copies rain fall, weathering of rock is pronounced due to which country rock is transformed in to friable incoherent, loose sand. Part of the project area is slide prone also with dormant and active slides.

The proposed penstock is to be located on the mid slope of a hill. The study indicated that along the hill slope of the penstock alignment weathering of the rocks remains pronounced and due to which the depth of the over burden ranges from 4m to 26m along the alignment. The area is also slide prone with active and dormant slides and one slide (Konipara slide) took place even during construction. The slopes have been disturbed for penstock excavation and the penstock track excavation cut sections and cores of the bore hole drilled showed the presence of assorted material in the overburden ranging from boulder to litho magic clay and highly weathered rock.. So considering the vulnerability of the anchor block location from 13 to 17 (except 14 where rock is available). It was recommended to found the Anchor blocks 15 to 17 on hard rock to transfer the load so that the stability and safety of water conductor systems is ensured. In addition temporary slope protection measures are also to be provided during excavation.

The power house with the size of 32.8X17.75m will be housing two 50MW machines. The excavated power house area is occupied by hornblende biotite gneiss with enclaves of amphibolites. Weathered seams with the thickness varying from 20cm to 70 cm, intersect the rocks predominantly along the sub-horizontal joints from upstream to downstream at various levels. The strike of the sub-horizontal seams is, N 30^{o} E – S 30^{o} W, with average dip of 20^{o} towards N 60^{o} W direction. The weathered seams exposed on the walls of the Column pits and Machine pit areas show the differential weathering along the strike and dip direction resulting in non-uniform thickness from upstream to

downstream direction. The intensity of weathering also varies from place to place. Its nature varies from close spaced fracturing to completely weathered rock and clayey soil. After completely assessing the rock mass condition and analyzing thoroughly the sub-surface (bore hole) and surface mapping data of the country rock/weathered seams at the surface, and sub-surface level, the various levels of founding the columns and machine pits and specific remedies such as rock anchoring, consolidation grouting etc were suggested.

Over all, except the presence of deep overburden on a paleo slide area in the lower end of the penstock alignment and occurrence of sub horizontal weathered seams at various levels, no other major geological complexities are noticed in the project area.

Location Map of the Project Area

Picture 1 Excavations for Penstock track on a slide zone.

Picture 2 Failure of slope stability measures on the penstock route

Picture 3 Power house excavations exposing the subsurface weathered seams within the hard rock in the Machine bay area.

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