Indian Society of Engineering Geology Jour. Engg. Geol., Vol. XXXVI, Nos. 1-4

A Geotechnical Evaluation of Foundation Rocks of Pier and Abutments and the Unstable Slope of Bridge No.69, Londa-Vasco Line, SW Railway, Karnataka

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Abstract

The downstream slope of Bridge no-69, South Western Railway, Castlerock has been experiencing extensive bed erosion/scouring with formation of gullies due to excessive surface and sub surface water action. This resulted in deep cuts in the channel bed along with land slips in the proximity of right abutment as also removal of shoulder support to Gabion in the central part. This phenomenon has caused serious concern about the slope beds in general and the lateral support to the foundations of pier and abutments of the bridge in particular. A geotechnical evaluation of the foundation rocks at the bridge site including exploratory drilling was carried out to ascertain the stability problems of downstream slope and work out effective slope reinforcement and stabilization measures.

The bed rock at the bridge site is dominated by a multilayered sequence belonging to the Dharwar Supergroup. It comprises variegated phyllite, ferruginous phyllite with intercalation of ferruginous quartzite, ferruginous quartzite with intercalation of thin bands of phyllite and thickly bedded quartzite with intercalation of thin bands of phyllite. These litho units trend in NNW-SSE direction with 10° dip towards ENE, and are traversed by two sets of sub vertical to vertical joints trending in NW-SE and NE-SW direction.

The studies indicated a potentially unstable slope, more so because the lack of effective stabilization efforts and poor maintenance of surface drainages. The slope is assessed to deteriorate during monsoons.

Easing/grading of slope, adequate drainage arrangement and construction of retaining structures are recommended to stabilize the slope. In addition, construction of gabion walls, use of geo-textile and natural turfing over the slope are also suggested as remedial measures to stabilize the unstable mass along the stream bed downstream of the existing bridge.

Introduction

The railway girder bridge No. 69 in Karnataka on Londa-Vasco railway line, an important rail link of SW Railway to Goa, has been experiencing slope distress between Caronjol and Castle rock Railway stations near 7.16° railway curve adjacent to the entry of Tunnel-I. The 30.40 m long bridge has two spans of 12.19 m and 18.29 m.

The downstream slope of this bridge is affected by extensive bed erosion/scouring with formation of gullies/rills due to uncontrolled surface and sub surface water action. The deep cuts in the channel bed resulted in land slips near the right abutment and removed the shoulder support to the gabion walls in the central part. The deep scouring of the slope beds in general and removal of lateral support to the foundation of pier and abutments in particular threatened the stability of the bridge.

Detailed surface and subsurface geological and geotechnical studies, including drilling of exploratory borehole were deployed to assess the slope distress and to work out appropriate remedial measures.

Site Geology

The railway bridge No.69 is located across a west flowing stream on the Arabian sea facing

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mid slopes of the Western Ghat. The slope on the upstream of the bridge site is moderate but very steep on its down stream side. The valley section along the stream becomes narrow towards downstream aiding severe erosion and steep valley formation. The slope angle in this section is very steep exceeding 45°. It is associated with formation of gullies/rills in the channel bed and land slips in the proximity of right abutment and removal of shoulder support to Gabions in the central part.

The bed rock at the bridge site is dominated by a multilayered sequence belonging to the Dharwar Supergroup, comprising thick variegated phyllite, ferruginous phyllite with intercalation of ferruginous quartzite and thickly bedded quartzite with thin bands of phyllite. These rocks are weathered to various degrees at depth and are traversed by numerous fractures/ joints systems.

Thinly foliated variegated phyllite is exposed up to RL 845m, while ferruginous phyllite with intercalations of quartzite bands is exposed between RL 845m to RL 837m (i.e. up to the toe of the steep scarp/last gabion). As regards the abutment slopes ferruginous quartzite with intercalations of shale is exposed between RL 845m to 837m on the left and RL 837m to RL 832m on the right. These litho units trend in NW-SE direction with 10° to 25° dip towards NE (into the hill). The soft, thinly foliated variegated phyllite at the top is fine grained and micaceaous. It is intersected by two sets of sub vertical to vertical joints trending NW-SE and NE-SW. At the base, i.e below RL 837m, ferruginous quartzite with thin bands of ferruginous phyllite occurs. This litho unit trends NNW-SSE with 10° dip due ENE.

In the channel bed d/s of the Pier location (RL 872m) a cover of decomposed rocks consisting of layered deposits of soft, poorly cemented, ferruginous silty clay with rock fragments is present. It is underlain by soft, thin and horizontally bedded argillaceous phyllite overlying thick ferruginous quartzite with thin bands of ferruginous phyllite. The valley width narrows down considerably towards down stream side forming 2m to 3m high cascades due to the presence of hard ferruginous quartzite. Water seepage has been recorded at various points in the channel bed d/s of the Pier location.

Subsurface geological set-up at bridge site: One exploratory borehole up to a depth of 69.40m has been drilled on the upstream of bridge to ascertain the subsurface geological set-up. The drill cores were examined, logged and their data analyzed. The geological log of the bore hole is given in Fig-I.

The borehole revealed, a) depth of weathering in bed rock up to 6.5m from RL 872.00m to RL865.5m; b) the soft and friable variegated phyllite, recovered in the form of powder with fragments of quartz, upto 32.00m below the weathered phyllite, with the unit being thinly foliated and dipping sub horizontally; c) alternate layers of ferruginous phyllite with thin bands of quartzite from 55.10m (RL 816.9m) to 55.80m (RL 816.2m) & 59.15m (RL 812.85m) to 64.20m (RL 807.80m); d) ferruginous quartzite with thin bands of ferruginous phyllite from 55.80m (RL 816.2m) to 59.15m (RL 812.85m) and e) bands of hard and fractured ferruginous quartzite within the friable phyllite between 38.60m (RL 833.40m) to 42.00m (RL 830.00m) and 49.40 (RL 822.60m) to 69.40m (RL 802.60m) depth, indicating increase in percentage of quartzite with depth. Considerable water loss was recorded during drilling and core recovery varied from 50- 75% in quartzite indicating its fractured nature. The borehole has also established the ground water table at a depth of 23.00m (RL849.00m) (Fig. I).

Geotechnical assessment

The slope forming material at the top of slope comprises primarily soft and decomposed rock overlying the thinly bedded variegated phyllite. These materials are saturated and intensely fractured and have no proper bearing strength for resting of any structure over it. Many small slide scars indicating progressive slippages are seen in this material, especially where the gradient of the slope is moderately high or high. Besides, subsurface carvings are seen in this material allowing the stream water to further drain through the subsurface channels. The ground is also found sunk at a few places above these subsurface channels.

The depth of weathering in the mid slope is about 3.5m (Fig-I). As shown in Fig-2, the thinly bedded, soft, varigated phyllite occurring on the upper part of the slope, exhibits about 2.5m m thick weathered profile. The weathered part of the pink phyllite at higher levels occurs as laterite. Due to narrowing of the valley at the down slopes, the weathered part of the rock in this portion is almost eroded, thus exposing fresh rock Thickness of weathering increases considerably above the bridge level allowing luxuriant growth of vegetation. The rock mass characteristics of the various litho-units of bed rock, as observed subsurface in the downstream slope are as follows:

a. Thinly foliated variegated phyllite: It is very soft, with intense jointing. The bedding/foliation joint dips gently into the hill (Fig-I). The rock is under saturated condition and behaves like a moderately compact soil, developing surface cracks easily on drying.

b. Ferruginous Quartzite: This rock occurs as intraformational hard strata along the stream section. The joints are moderately spaced and are tight. They are found resistant and stable even at moderate slope angles.

c. Variegated phyllite with thin bands of ferruginous quartzite: This litho unit is slightly harder than the overlying varigated pink phyllite due to intercalation of quartzite. A few ground cracks are seen in the stream bed in this rock due to the day-lighting of joints that are dipping steeply towards the free face and some apparent displacement along them.

d. Ferruginous quartzite with thin intercalation of phyllite: This unit comprises quartzite (65%) with thin intercalations of phyllite (35%). It is comparatively hard and is traversed by moderately spaced joints.

e. Ferruginous Quartzite with intercalation of ferruginous phyllite: This unit consists of quartzite (75%) with thin intercalations of phyllite (25%). It is also relatively hard and is traversed by moderately spaced joints.

f. Thickly bedded quartzite with thin bands of phyllite: This is the hardest strata along the stream section in the study area. The joints are widely spaced and tight. This rock along the stream section is stable even at very steep slope angles, as at cascades/deep cuts..

Causes of slope instability

Gradient of the slope/ stream bed, type and nature of the slope forming material and the hydrological condition are the prime factors controlling the stability of slope. The gradient along the stream is high and the adjoining hill slope is steep (>45°) in the study area. The slope forming material comprises primarily decomposed soft rock (Fig-2), and the bed rock is dominated by very soft thinly bedded variegated phyllite. The interface between weathered soft rock and hard rock provides the plane along which the distressed slope material slides progressively, whenever the active stresses exceed the shear resistance.

The steep joints/ interconnected fractures dipping towards the free face (down slope) allow the surface water to seep through them easily and reduce the shear resistance of the media. During the rainy season the rain water percolates through these open joints/ interconnected fractures and also flows over the loose scree making it to behave like a flowing ground.

Similarly, the pore pressures developed during rainy season in this distressed slope exert enormous internal pressure eroding the shear resistance of the slope forming material under the existing slope conditions.

Regular removal of the toe support at the base of the slip plane around RL 837 m, excessive pore pressure in the slope forming material and the active stresses from the top, including the ground vibrations generated by the passing trains, especially during rainy season when the slope material looses its strength considerably, causes instability of slope.

Conclusions and Recommendations

Geotechnical evaluation of the foundation media and stability problems of downstream slope of Bridge no-69 was carried out, which involved, inter-alia, core drilling, for working out effective slope reinforcement and stabilization measures.

The borehole drilled at the upstream of bridge established, a) the depth of weathering in bed rock is 6.5m (RL865.5m); b) a 32 m thick soft and friable variegated phyllite, which is thinly foliated – dipping subhorizontally exists below the weathered phyllite; c) alternate layers of ferruginous phyllite with thin bands of quartzite occur from 55.10m to 55.80m and from 59.15m to 64.20m; d) ferruginous quartzite with thin bands of ferruginous phyllite occurs from 55.80m to 59.15m and e) bands of hard and fractured ferruginous quartzite occur within the friable phyllite from 38.60m to 42.00m and from 49.40 to 69.40m depth, indicating increase in percentage of quartzite with depth. These rocks are in varying states of weathering and are traversed by fractures/joints systems.

Alternative stability measures for downstream slope were analyzed and the most appropriate methods suited to site conditions are worked out based on the studies carried out. Following is a brief account of the recommendations made:

Surface water Drainage

a. Rain water debouches straight into the bridge site from uphill. The water entering into the stream from above must be effectively conducted away from the bridge site by constructing and maintaining 1 or 2 contour drainage channels at the upstream. These diversion channels must be of sufficient capacity to drain the run off from the heaviest possible spell of rain. Maintenance of drains is also essential to keep them clear and functional.

Effective slope protection work

a. Slope easening by back filling of erosion scars/ gullies/rill areas is needed.

b. Stabilization of soil/weak strata constituting the slope media through sub surface drainages. The hydrostatic pressure erodes shear strength of the slope media. Effective subsurface drainage arrests movement of soil from below the gabions. Hence, provision of sub horizontal drains through perforated or slotted pipes driven deep in to the slope face at frequent intervals, is recommended.

c. Concrete apron over the slope with drainage holes: The area between crest level (1^{st} stage gabion) and the toe of the bridge is recommended to be graded and the surface of the graded slope provided with a concrete apron, in order to protect the channel bed from seepage pressure exerted by percolating water.

d. Gabions: In order to dissipate the impact of rushing water and reduce the path of percolation, provision of continuous gabions of dimensions 2m x 1m x 1m, along with existing ones, from crest to toe of the slope are recommended to be placed over concrete apron/padding.

Inclined piles at mid slope

a. The basic aim of inclined piles is to resist the stresses induced by train movements as also to decrease the mobility of gabions. Two rows each of anchored piles/bored piles staggered with beam caps are recommended (Fig-II) along the toe part of the 1st and 2nd stage gabion walls, as also along the toe line of the bridge foundation. These piles are to be anchored to the fresh bed rock existing below the weathered rock.

Anchored retaining wall at toe region

a. Construction of a 7 m high anchored retaining wall between RL-842.5m to835.5m with adequate weep holes and filters is recommended at toe area in order to confine and support the upstream slope including bridge.

Monitoring

a. Recommendation is also made for consistent field monitoring to check the efficacy of various remedial measures adopted.

Acknowledgements

The authors extend their sincere thanks to Dy. Director General, Op. Karnataka & Goa, GSI, Bangalore for giving permission to publish this paper. Shri M.M. Swamy, the then Director, Engineering Geology Division, Op: Karnataka & Goa, GSI, Bangalore is also thanked for his technical guidance.