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Stability of Suspension Bridge Anchorage System

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SYNOPSIS The lift side anchor system for a 151 m span suspension bridge over river Alaknanda in Himalayan region was unstable. The gravity type anchor block for the suspension bridge was constructed by cutting the toe of the natural slope. Walls were constructed to retaining the backfill and the anchor block. Slips along the natural slope were frequent. The site lies in an active seismic zone.

The paper presents the details of analysis of anchor block, retaining walls and the natural slopes. The analysis is carried out both under static condition and also by taking seismic coefficients. The already constructed retaining walls which were unsafe have been strengthened by designing a composite retaining wall keeping in view the requirements of the client not to demolish any of the already constructed retaining wall.

INTRODUCTION

A 151 m span suspension foot bridge was planned about 3 km upstream from Srinagar (Garhwal) over river Alaknanda. The site lies in seismic zone IV as per Indian Standards (IS:1893-1975). The left side anchor block for the bridge constructed during 1971 was founded on natural soil. The natural slope behind the anchor block formed an angle of 35° with the horizontal. The anchor block was constructed in 1971 after cutting the natural slope. Three retaining walls to protect the main anchor block were also constructed along with wind anchors and the main towers. The location of various components along with other details are given in Fig.1.

Further progress on the construction of the bridge was stopped which was restarted in 1977, after a lapse of about six years. During the period 1971-77, several slips of the natural slope behind the main anchor block were noted particularly during rains. Doubts were also raised about the stability of the main anchor block under the full applied tension and also the stability of already constructed retaining walls. It was therefore considered desirable to examine the stability of main anchor block, retaining walls and slope before taking up further construction.

The paper presents the details of stability analysis of (1) main anchor block (2) the retaining walls and (3) the natural back slope. The analysis indicates the main anchor block to be safe but the intermediate and lower retaining wall are unsafe. Strengthening measures in the form of a composite retaining wall combining the intermediate and lower retaining wall has been designed thus none of the already constructed retaining walls have been domolished. In view of the fact that the site lies in seismic zone, the analysis has been carried out taking seismic forces into account.

SOIL PROPERTIES

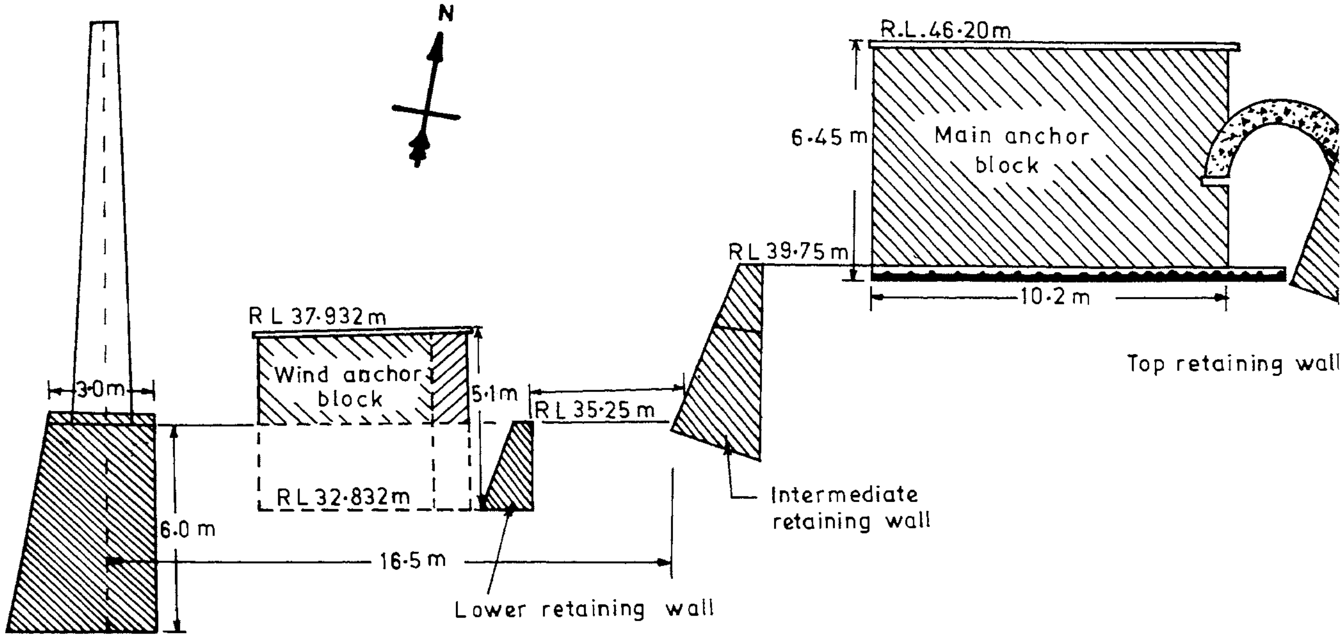
The examination of pits in front of main anchor block indicated boulders mixed with silty sand matrix. The size and percentage of boulders were noted to increase with depth.

Shear Parameters

The shear parameters of the backfill were estimated from the in-situ large size (900 cm^2 and 5000 cm^2) shear tests. In case of 30 cm x 30 cm sample size test, a block 35 cm x 35 cm was left undisturbed at the desired location. The steel box frame was then put on the undisturbed block by gradually removing the soil below the steel frame. The normal load was applied by keeping sand bags. The horizontal load was applied through a remote controlled jack and proving ring taking reaction against the raft of the main anchor block. Two tests were also carried out on sample size of 5000 sq.cm. (Fig.2). The detailed procedure is discussed elsewhere (Ranjan et.al. 1978). On the basis of test results (Fig.3) value of cohesion, c of 0.06 kg/cm^2 and angle of internal friction, ϕ of 32.4° was obtained. However, for design neglecting cohesion, a value of 30° for angle of internal friction for the backfill has been adopted.

Angle of Base Friction

The angle of friction between the base of



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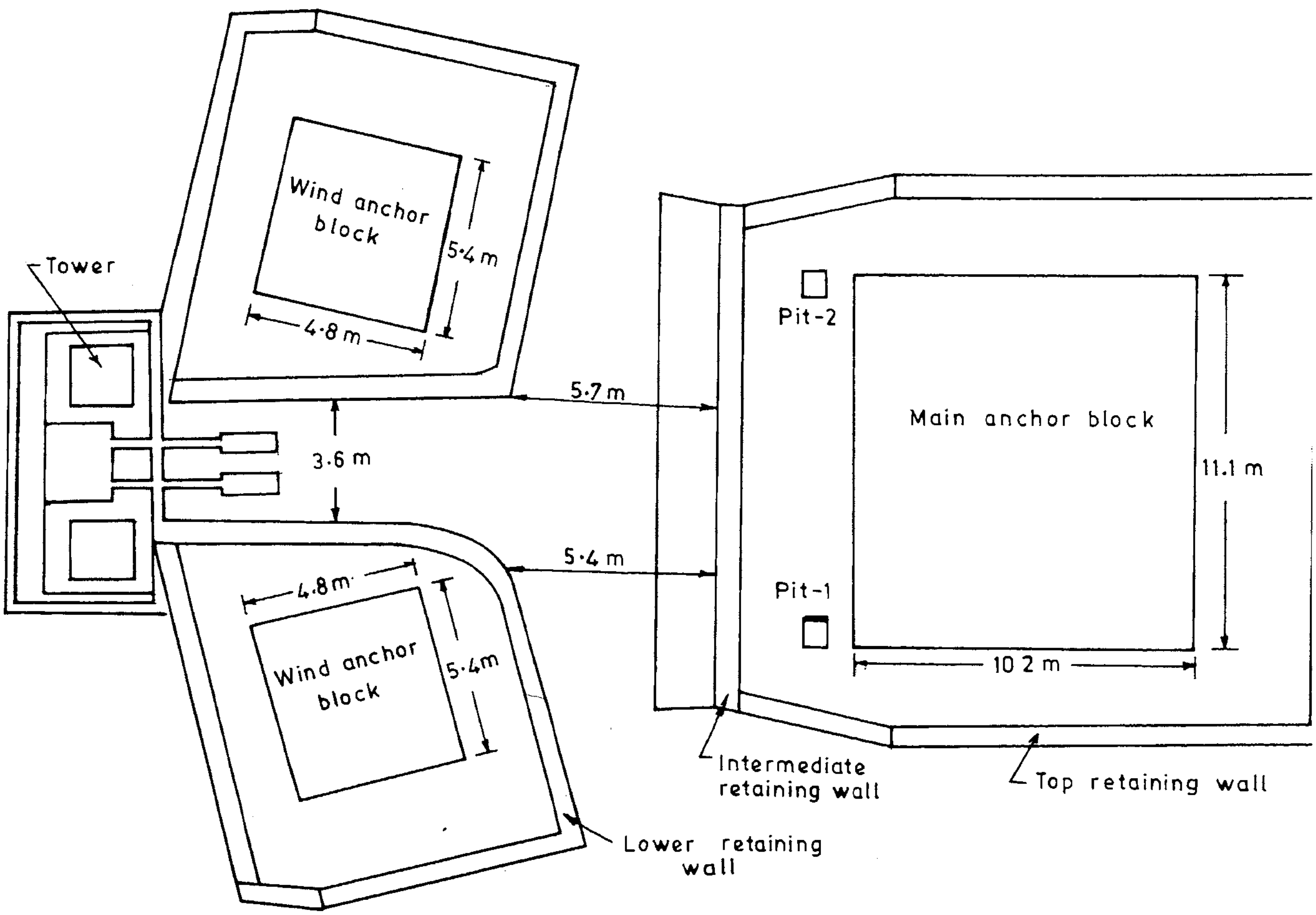

Plan

Fig.1 Details of Various Components of Anchor System

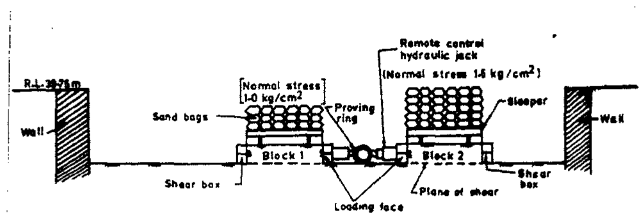

Fig.2 Shear Test with 5000 sq.cm size sample

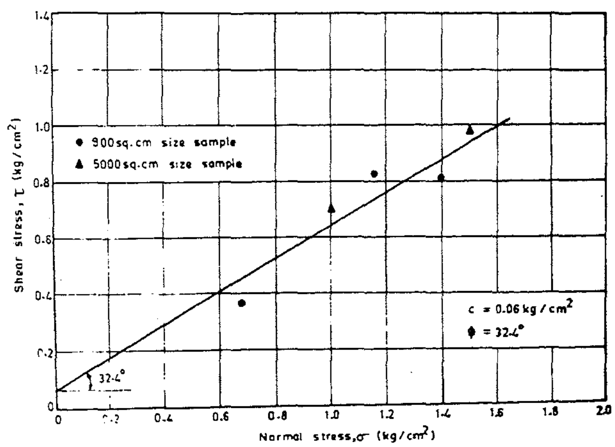

Fig.3 Normal Stress Vs Shear Stress Plot for Shear Parameter of Soil

anchor block and the soil was estimated by conducting tests on 30 cm x 30 cm size (plan dimensions) precast concrete blocks at normal loads of 1.11, 1.33 and 1.56 kg/cm^2 which correspond to the normal load due to anchor block. Analyzing the data, a value of equal to 30° is adopted for subsequent analysis.

STABILITY OF ANCHOR BLOCK

The anchor block (weighing 1430 t) was designed for a horizontal pull of 351 t exerted by the bridge cables. In the stability analysis of the block in addition to the pull by the cables, the earth pressure exerted on the block due to the back natural slope has also been considered. Factors of safety for the block in sliding and overturning have been worked out under both static condition and earthquake condition (taking horizontal seismic coefficient, $\alpha_h = 0.10$ and vertical seismic coefficient, $\alpha_v = 0.05$).

The plan dimensions of the block are 11.1 m x 10.2 m, the soil/rock on the sides shall thus provide restraints on account of friction due to active earth pressure acting on the two sides of the anchor block. Two cases are thus considered namely (1) without end restraint and (2) with end restraints.

The massive anchor block (10.2 m x 11.1 m x 6.5 m high) was noted to have very high factor of safety against overturning. Values of factor of safety against sliding are given in Table 1. The base pressures were also noted to be within limits.

TABLE 1. Factor of Safety against Sliding of Block

Condition	Value of factor of safety	
	Without end Restraints	With end Restraints
Static	1.56	1.65
Dynamic	1.13	1.20

The factor of safety without end restraints under static condition works out to 1.56 which indicates that the block is safe against sliding. If the end restraints are taken into account the factor of safety increases by about 6 percent. Further, under seismic condition the factor of safety is more than 1.0 indicating the block is safe against sliding. Thus no strengthening of the block is needed.

STABILITY OF RETAINING WALL

The intermediate retaining wall (Fig.1) is required to support the backfill which is subjected to the surcharge due to the main anchor block. The various forces on the wall-anchor block system are shown in Fig.4. The anchor block has been considered to be acted upon by (1) seismic force, (2) anchor pull and (3) earth pressure due to slope failure. The weight has been denoted by W with the suffixes b, θ and R for anchor block, backfill wedge and retaining wall. The corresponding horizontal are vertical seismic forces are taken by multiply the respective weights with horizontal and vertical seismic coefficients respectively. Coulomb's wedge theory equation has been modified to take into account these forces. Further, the influence of main anchor block is considered by taking directly the weight of portion of the anchor block directly resting on the trial wedge (Prakash et. al. 1977).

Considering the forces, indicated above, the values of earth pressure on the wall were computed for different values of the trial wedge angle, θ (Fig.4). The magnitudes of maximum earth pressure under static and dynamic conditions are shown in Figs.5 and 6 respectively.

Having computed the earth pressure on the wall, the stability of the intermediate wall(as already constructed) is analysed and factors of safety against overturning and sliding under both static and dynamic conditions worked out. The same are shown in Table 2.

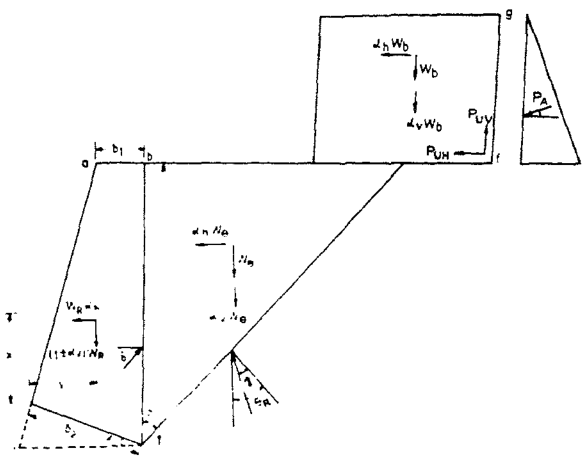

Fig.4 Diagrammatic Representation of Retaining Walls and Anchor Block

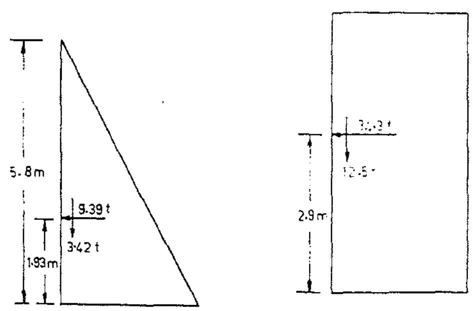

Fig.5 Earth Pressure in Static Condition

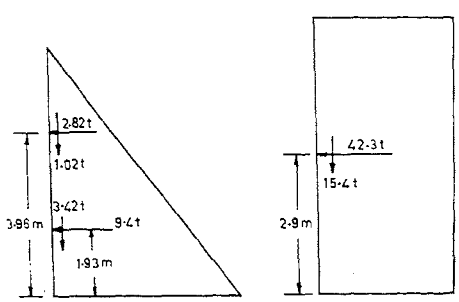

Fig.6 Earth Pressure in Earthquake Condition

TABLE 2 Factors of Safety of Existing Intermediate Retaining Wall

Condition	Factor of safety against Overturning, F_O	Sliding, F_S
Static	1.0	0.633
Dynamic	0.711	0.533

Table 2 indicates that the existing wall even under static condition has factor of safety less than one against sliding. Thus indicates that even if the dynamic forces are ignored,th existing wall under the force system will fail The strengthening of the wall is thus necessar from considerations of the safety of the ancho block and in turn the bridge.

A new retaining wall system as shown in Fig.7 has been suggested taking into account forces discussed above. The advantage of this system that the old retaining walls may be retained as they are. Their weights are useful in providing safety against sliding and overturning. The reinforced part is taking care of the excessive bending moments and horizontal shear caused due to large horizontal forces. The wal system has a factor of safety against sliding as 1.85 under earthquake condition. Factor of safety against overturning was more than 2 bot in static and earthquake condition. Maximum base pressures work out to be 23 t/m^2. These values are within safe limits.

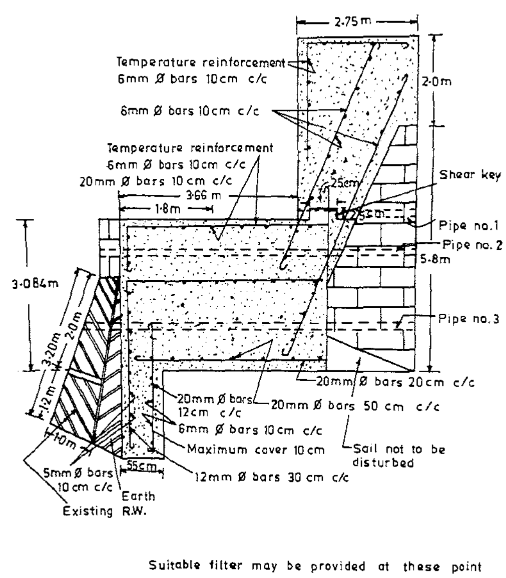

Fig.7 New Retaining Wall Section

STABILITY OF NATURAL SLOPE

Rock Surface

The exposed rocks at the site were noted to be very weak and thinly laminated schist. These were highly weathered and dipping towards the hill side with 40° dip. The rock profile is therefore, likely to rise gradually towards the hill side. No firm rock was observed in 4-6 m deep pits dug along the intermediate wall. The average depth of bed rock was therefore assumed to be 4 m below the lowest retaining wall(Fig.8).

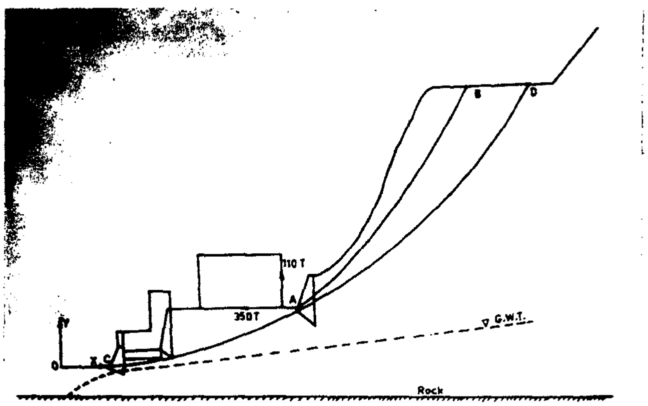

Fig.8 Stability Cut, Block and Retaining Wall

Ground Water

Heavy rains had occurred during May 1977. About two days after the rains during the site visit pits were examined and level of water noted. On the basis of ground water observations, the ground water profile is plotted (Fig.8) assuming a parabolic shape.

Soil Parameters

As indicated earlier, the soils were classified as cohesionless boulders/gravel with silty sand matrix. Further, the size of boulders was noted to increase with depth. Also, it was reported that several slips of the natural slope had taken place. The soil parameters were estimated from back analysis of natural hill slope (Prakash et. al. 1977). Several slip circles taking various combinations of shear parameters (based on soil type) were tried. The analysis was carried out modifying Bishop(1955) equation to account for seismic force. A value of 40° for angle of internal friction for the soil was adopted for subsequent analysis.

Stability of Cut above Block and Overall Stability of Cut Block and Retaining Wall

Modifying Bishop's (equation) to account for seismic force, the minimum factor of safety of the cut and also the overall stability are computed. In analysing the stability of slope horizontal and verticaly seismic coefficients of 0.10 and 0.05 are taken. The pull on the block including the seismic forces on the block are also considered.

TABLE 5. Factors of Safety of Cut and Overall Stability

Condition	Factor of Safety	Critical circle
Stability of Cut:		
Without earthquake force	0.81	AB(Fig.8)
With earthquake (α_h=0.10, α_v=0.05)	0.67	
Overall Stability:		
Without earthquake force	1.41	CD(Fig.8)
With earthquake (α_h=0.10, α_v=0.05)	1.15	

Uplift forces due to ground water profile have been neglected as the water table is too deep and is not likely to influence the analysis. However, the soil is assumed saturated. The minimum values of safety factors for different cases are presented in Table 5.

As the factor of safety of the cut even without earthquake forces is less than one, the cut is unstable and the slip is likely to take place AB. However, the block and retaining wall are safe, factor of safety being greater than 1.0.

Further, it may be noted that the shearing resistance on vertical sides of slip surface which have been neglected in the analysis are likely to improve the factor of safety by about 10%. It is probably on account of these end effects that the cut is standing. However, it is unlikely that the cut may remain stable for long. It is suggested that cut may be covered with vegetation to avoid eroding of ground surface due to rain water.

CONCLUSIONS

The main anchor block of the suspension bridge analysed for the force system indicates that the block is safe. However, the retaining walls and the cut are unstable. The retaining walls have been strengthened by a new properly designed walls. The new retaining wall has already been constructed which has resulted in a significant saving. The construction of bridge has been completed and the same has been opened for traffic.

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