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Long Term Landslide Mitigation Technique Illustratedacase Study

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ABSTRACT: Landslideisthemassmovementcomprisingofrock,debrisorsoilundergravityinfluence.Themain slide triggering factors are rain and tectonic seismicity induced landslides occurring inHimalayanbeltofIndiansubcontinent.Anthropogenicactivitiesliketunnelblastingforhydroelectric projects, unplanned excavations or cuttings of side for road widening purposeactivates failure mechanism. On the other hand, continuous blasting and tunneling weakens therockjointlayers.Basedseverityofrockjointsandrocksurfaceconditions;rockstructureshavebeen characterized in to different range of GSI chart. Thorough study and analysis is requiredtocheckthelongtermstabilityforthesetypeof weakslopes withGSIrangeof10to40havingfair, poor to very poor surface conditions lying close to important and sensitive structures.Present study reveals the effectiveness of preventive measure applied to the unstable slopestretch in the vicinity of Teesta stage III hydroelectric system. Finite element modelling hasbeencarriedoutforthecriticalslidetriggeringstretchusingRocscience-Phase2v8.005.Analysishasbeencarriedoutwithoutandwithstabilitymeasures.Ithasbeenobservedthat50mvertical cladding wall having pre-stressed cable anchor with no base support survived the 2012earthquakeof 7Richtermagnitudescalewith nosigns of distress.

Keywords: Landslide;Himalayanbelt;Longtermstability;Finiteelementmodelling;Pre-stressedcable anchor;TeestastageIIIhydroelectricsystem.

I. INTRODUCTION

Constructionofdamsinseismicproneareaisa challengingtask.Thisrequirespropergeological andtopographicalanalysisinordertoevaluatestructuralbehaviourandto obtaincriticalsafetyfactors. Fig. 1 depicts factor causing the reduction in the shear strength in same strata andadjoining layer. It can be seen clearly from this figure that how rain infiltrates through thepersistent and non-persistent joints causing decrease in shear properties and consequentlycreating detachment of block in blocky rock structure and slide in highly jointed rock mass.Continuous build of pore water pressure generates flow of muck or loose mass overlying thewaterresistingstrata.

The Teesta stage III hydro project is a huge mega dam in Sikkim comprises of concrete facerock dam of 60 m height constructed across Teesta River near Chungtang village, which hasseenmulti-faceted impacts on theindigenousLepchapeople of Sikkim.

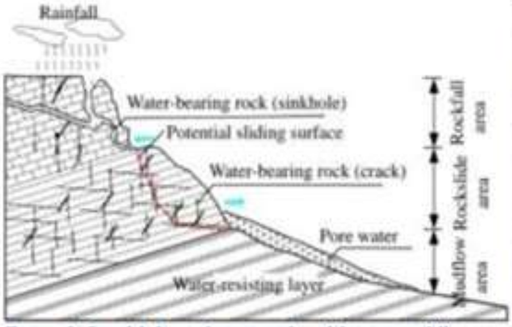

Figure 2: Landslide mechanism induced due to rainfall

Figure 1: Typical slided zone along road

Figure 3: Map showing Teesta Stage III location

Figure4.Protectionworksforunstableportion

Unstable portion was observed during construction activities at the dam site and cutting of leftabutmentwhichwassusceptibletofailure. GSIof 25showstherockstructureofdisintegrated-poorlyinterlocked,heavilybrokenrockmasswith mixtureofangular androundedrock pieces.Thisvalueof GSIsuggests a weak rock condition.

II. METHODOLOGY

1.1. Geologicalsite description

Site geology of dam site area lies in the rock formation of central crystalline; subdivided intoChungthang series, Darjeeling gneiss &Rongli series of Pre-Cambrian age. Chungthang seriescomprisesofquartz,biotitegneiss,biotiteschist,calc-silicateandthinnerbandsofargentiferous – sillimanite heavily micaceous gneissose.Rock units are highly folded; asymmetric, isoclinal innaturewithNE dips.

Landslideissuewasobserveddueto excessivestripping andcuttingoftheleftabutmentasshownin fig. 5. About 1 lac m^3 debris slided down the hill after the cutting work at left abutment of damsite.

Figure 5. Site condition before start of work

Figure 6: Before commencement of cable anchoring

Geological Strength Index (GSI) of slope is computed based on rock mass structure and surfacecondition of discontinuities with reference to GSI chart published by Hoek and Brown (1997).Extent of weathering, joint roughness and infilling material between the discontinuities, jointapertures were studied and analysis; based on which ratings were assigned to reach GSI value(Panditetal.,2019).GSIvalueof25wasobservedshowingrockstructureofdisintegrated-poorlyinterlocked,heavilybroken rock mass withmixtureof angular and roundedrock pieces.

1.2. Calculatingshearstrengthreductionfactors

Finite element of slope requires selection of constitutive relation between stress strain behaviour,which depends upon the material type. Equivalent continuum modelling with elastic and plasticrangesis adoptedforthesetypeofdisintegratedrock layers.

In present case study of FEM analysis, Generalizedhoek brown (Hoek et al., 2002) with materialconstants "mb, "s" and "a" have been reported and derived from GSI values (Equation 1-3) andverified from rocscienceroclab data software (Pandit et al., 2019). GHB material model adoptedforthegneissoseandsurfaceweatheredrock,whileMohr-Coulombmaterialmodelforoverburdensoil.

$$m_b = m_i * \exp\left(\frac{GSI - 100}{28 - 14D}\right)$$ (1)

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right)$$ (2)

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right)$$ (3)

The extent of problem domain of left abutment of Teesta dam site has been modelled, discretizedwith fine mesh density. Slant height of slope is 226m having average inclination angle of 62^0.Average depth of overburden massand topweatheredsurface rockisaround 24m, 12 mrespectively.Slopehasbeenmodelledwithboundary conditionshavingslopefaceasfree,verticalsidesasrollersupportallowingverticaldisplacement,baseisrestrainedfromanymoment(i.e.hingedsupport).Sixnodedtriangularwithuniformtypemeshisadoptedforthestudy asrecommendedin Rocsciencemanual (2012).

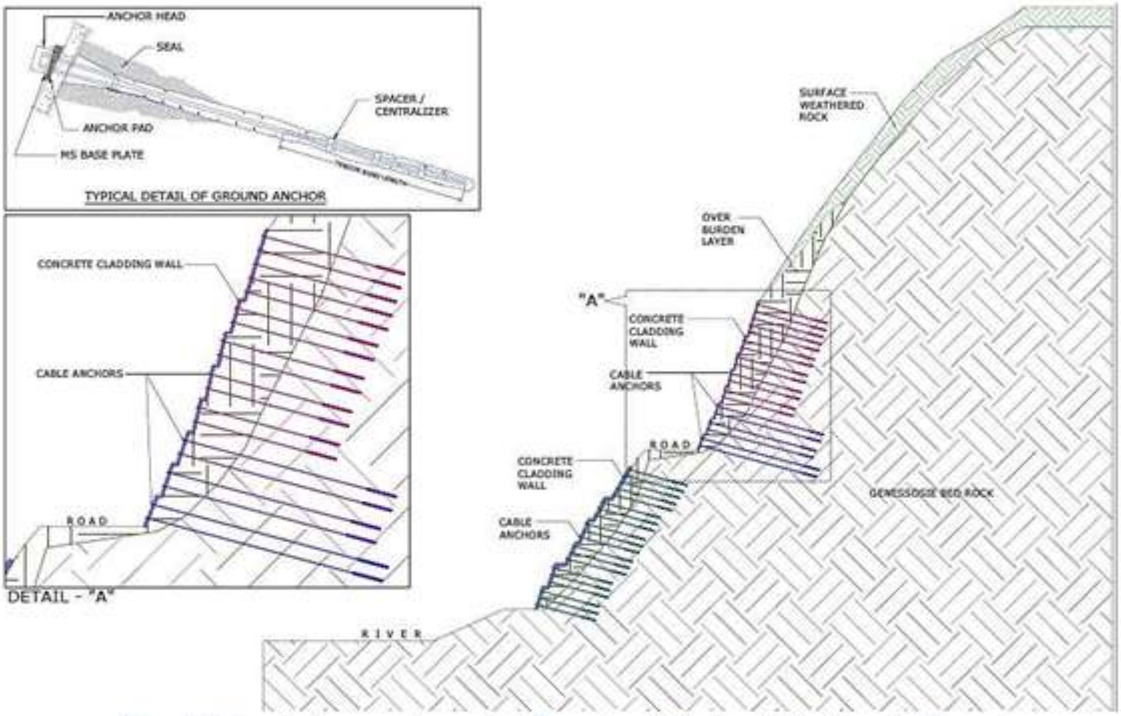

Figure 7. Schematic diagram of proposed cable anchor stabilization at left abutment of dam axis

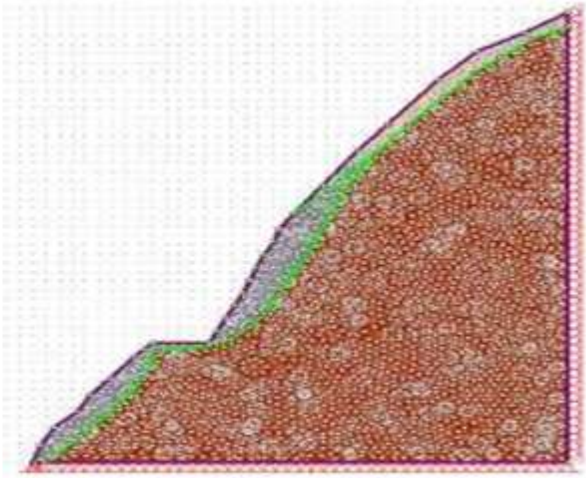

Figure 8. Typical discretized mesh of slope

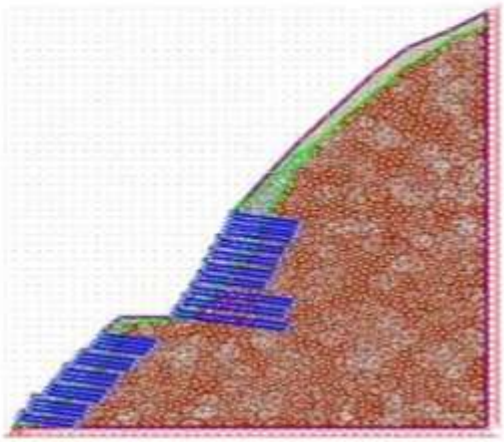

Figure 9. Discretized mesh of slope with stabilization

Once material properties are assigned and mesh discretization is done, the slope stability analysishave been performed for static and seismic analysis (Zone IV) having coefficient of horizontalseismic load as 0.15 and coefficient of vertical seismic load as 0.1 acting vertically downwardsand away from slope; which is the severe load combination. Pore water pressure with Ru as 0.25hasbeen consideredfortheanalysis.

Table.1 Propertiesofmaterials usedinFEManalysis

MaterialType	Overburden	Surfaceweatheredrock	Bedrock(Genessosie)
MaterialModel	MohrCouloumb	GeneralizedHoekBrown	Generalized Hoek Brown
Unit weight (kN/m^3)	21	22	24
Cohesion(kN/m^2)	98	215	482
Friction angle (degree)	28	17.88	19.79
mb	-	0.066	0.108
s	-	1.62e-06	3.73e-6
a	-	0.544	0.531
IntactUCS(Mpa)	-	70	120

Once all material properties and discretization has been done for static and seismic condition, theslopeisanalyzedtoassesscriticalstrengthreduction factor.Slopemodelshavebeenalsoanalyzedafterapplyingthestabilizationmeasureintheformofpre-stressedcableanchorwithRCCcladdingwall.Thecladdingwallof500mmthicknessisliftedinstagesof7to10 meters.Takingabouttheconstruction method, the slope protection using cable anchors with cladding wall is a top downconstruction process, so there is minimal stress occur at the toe of the slope. For the present casestudy,thetoeprotectionisappliedaboveandbelow slopebench.AsperIS14448-1997,thefixedanchorlengthisdesignedbasedonthethreefactorssuchasfailureofrockandgroutbond,failureof grout /anchor bond and failure of anchor. Based on these recommendations, failure criteria ofrock and gout bond observed as critical with bond stress 160 kN/m and fixed anchor length as12m.Perforateddrainagepipesareinstalledalongslopeprofile(claddingwall)torelievetheporewaterpressure.

Table.2Propertiesofstabilizedmaterialusedfor protectionsystem

MaterialType	Pre-stressedcableanchor
Anchortype	Tieback member
Diameter(mm)	150
Ultimatetensilecapacity(ton)	100
Length(m)	25 to 40 m
Outplanespacing(m)	3
Inplanespacing(m)	3
Bondstress(kN/m)	160
Pretensioningforce(ton)	120

III. RESULTS

Analysisofleftabutmentatdamaxisshowsthattheslopeisquiteunstableunderstaticandseismicconditionwith SRF0.95 and 0.81.

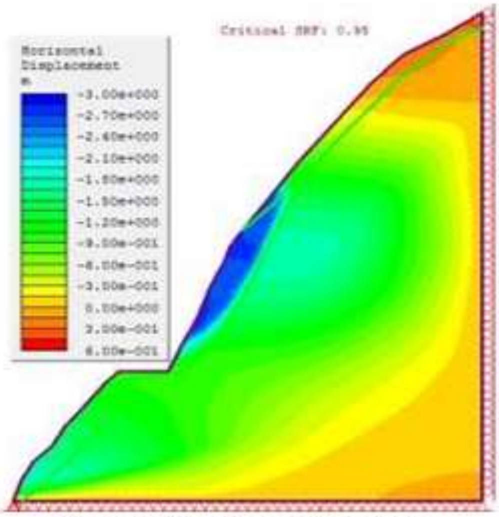

Figure 10. (a) Horizontal displacement

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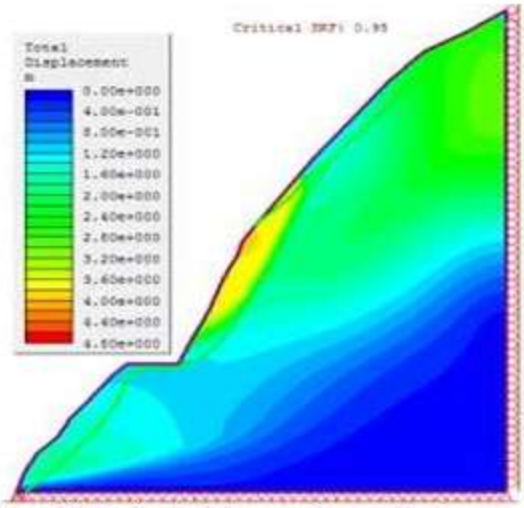

Figure 10. (b): Total displacement for unstable slope under static condition

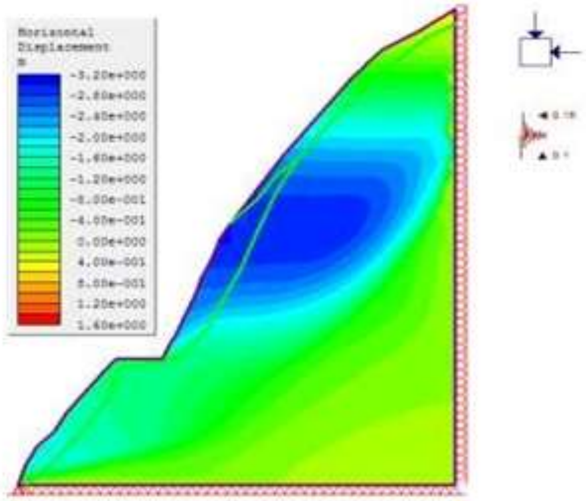

Figure 11. (a) Horizontal displacement seismic condition

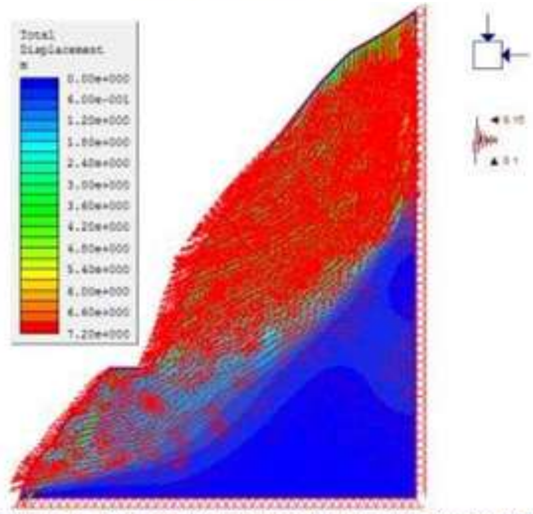

Figure 11. (b) Total displacement for unstable slope under seismic condition

Following results depicts effect of inclusion of pre-stressed cable anchors in reducing horizontaldisplacement, total displacement. Critical SRF value of 1.65 with 41 mm displacement for thestaticcase(fig.10to14)and1.32criticalSRFwith47 mmdisplacementhasbeenobservedunderseismiccase (fig.15 to 17).

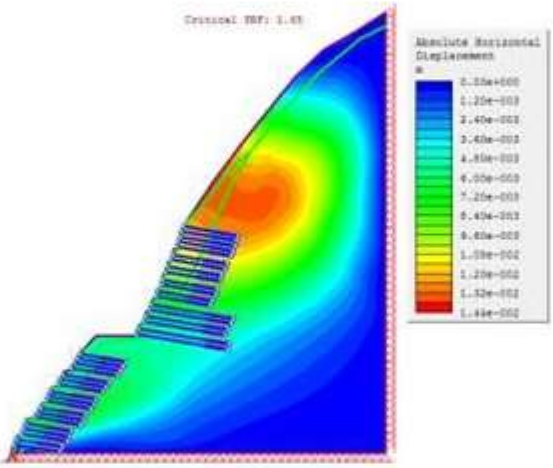

Figure 12. (a): Horizontal displacement (Left side)

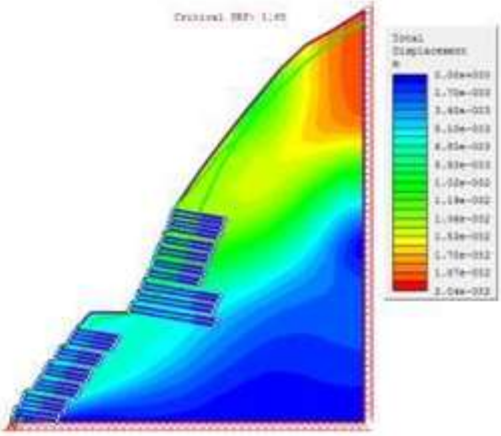

Figure 12. (b): Total displacement for stabilized slope under static condition

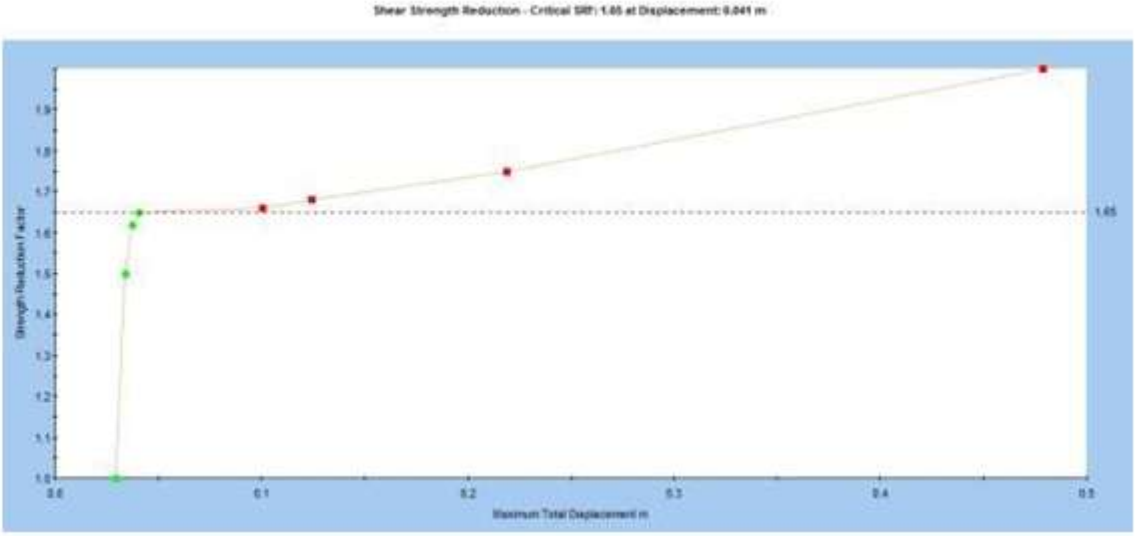

Figure 13. Variation of strength reduction factor with maximum total displacement for static case (with stabilization)

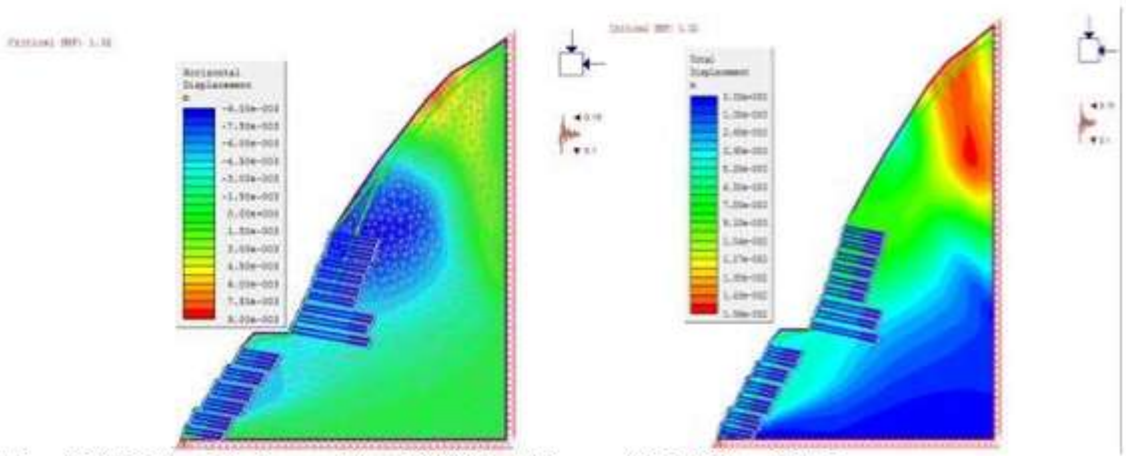

Figure14.(a) HorizontaldisplacementFigure 14. (b): Totaldisplacement(Rightside)forstabilized slope under seismic condition

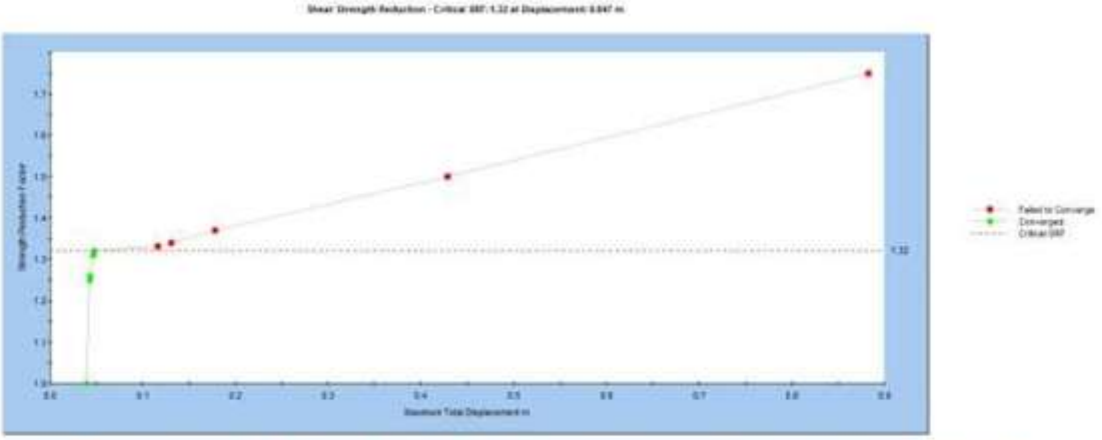

Figure 15. Variation of strength reduction factor with maximum total displacement for seismic case (with stabilization)

ThechartsshowstherelativeincreaseincriticalSRFvaluesforstabilizedandunstabilizedconditionsunderstaticand seismiccase.

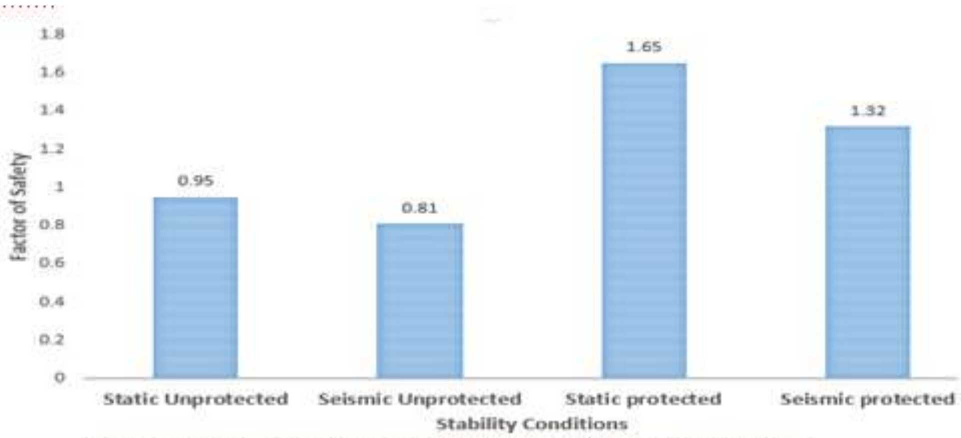

Figure 16. Variation of strength reduction factor under different stability conditions

Figure 17: Condition of stabilized slope with pre-stressed anchor after 2012 earthquake (Magnitude 7)

IV.DISCUSSION

Stabilization of poor class rock in seismic and region of high pore pressure is very vital. Use ofpre-stressedcableanchorprovideseffectiveandlongtermsolution.Itisclearfromtheabovefiniteelementanalysisresultsthatthereissignificantimprovementinthecriticalsafetyfactorresults.Ithas been observed that there is 73.68% and 62.96% improvement in safety factor values understaticandseismicconditionsrespectivelyafterinclusionofpre-stressedcableanchors.Displacement is also a critical criteria for the slope stability. In present case, displacementsrestrainedwith in thenominal limitsforstaticcaseand seismic case.

The mechanism behind the stabilization is due to increase in the shear strength along the failuresurface, as pre-tensioned cable anchor increases the active resistance resulting from the stage ofmobilizationofsheared mass alongslip line.

V. CONCLUSIONS

Presentanalysisshowsthatthereissignificant improvementinthesafetyfactorresults.Thecurrentstatusoftheprojectsiteisthatthe50mverticalcladdingwall havingpre-stressedcableanchorwithno base support survived the 2012 earthquake of 7 Richter magnitude scale with no signs ofdistress.

VI.ACKNOWLEDGEMENT

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