Construction of a very high reinforced soil structure in lateritic soil: a case study on Kannur international airport

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ABSTRACT: In view of the aviation scenario, NRI population, trade potential and tourism development of Kerala, the Government has decided to build an International Airport at in Kannur district, a northern state of Kerala, India. The site at Moorkhanparambu was selected by the Airport Authority of India after the survey and recommendations with due considerations to its topographical and environmental merits. Construction of a leveled platform for airports in mountainous areas always requires huge cutting operation in uphill and filling operations in downhill. In order to support the cut slopes and to stabilize the fill slopes, high retaining structures deemed necessary. However, the selection of a suitable retention system for the runway end safety area (RESA) was challenging due to the vast stretches of laterite capped hillocks in Kannur which is having excellent geotechnical properties at dry state and very low consistency at wet state. Also, it was essential that the selected system should act a firm foundation as well as it should be able to bear the high loading of aircraft. Further, an embankment fill with total height ranging from 66 m to 87 m was constructed to support the RESA. The embankment fill consists of a relatively shallow unreinforced slope below the airport operational perimeter road and a steep top reinforced soil slope with a maximum height of 68 m using composite reinforced soil structure. Bioengineering measures has also been adopted to protect the slope surface from erosion. The design and analysis of the reinforced slopes were done by limit equilibrium method confirming to the international standards and wetted by finite element analysis. The structure is still under construction.

Keywords: laterite, reinforced soil structure

1 INTRODUCTION

Based on the travel demand, nd focus on infrastructure and tourism development the Government of Kerala has proposed to build an international airport at Kannur, a northern state of Kerala, India. Kerala offers many popular tourist destinations. Kannur is considered one of the best tourist spot in north Kerala. Kannur often known as the “crown of Kerala” because of its natural treasures is edged by the Western Ghats in the east, Kozhikode and Wayanad districts in the south, Lakshadeep Sea (Laccadive Sea) in the west and Kasargod in the north. As Sizable number of student tourists and research scholars visit the region for academic and research related work, the new Kannur International Airport will tap the vast tourism potential, aid the textile industry, and help students/research-scholars apart from 'non-resident' Indians, expatriates, business travellers, IT professionals and corporate magnates, and enhance the region's position as an international tourist destination. The site at Moorkhanparambu was selected by the Airport Authority of India after the survey and recommendations with due considerations to its topographical and environmental merits.

2 LOCATION

The Site Moorkhanparambu is situated in Kannur district which lies between latitudes 11040' to 12048' North and longitudes 74052' to 76007' East. The proposed Site covers an area of about 2000 acres of land (Figure 1 and Figure 2).

Figure 1. Google earth image of Kannur International Airport

Figure 2. (a) Google earth image of Runway End Safety Area (b) Project site before construction

3 AIRPORT MASTER PLAN AND RUNWAY DETAILS

Care has been given to site the location of the main runway in such a manner that the maximum length will be available in cutting and only areas beyond the touchdown on either side will be in filling. Care has also been given in finalizing the reduced level of runway for balancing the overall cut and fill of the operational area of the airport. The runway is designed for wide bodied aircrafts. The characteristics of the runway specification are the following, Runway length - 3400m; Runway width - 45m; Width of runway plus paved - 60m; Pavement type – Flexible; Runway strip width - 300m; Runway orientation- 07/25.

4 CLIMATE

The climate is tropical in Kannur. Rainfall is significant in most months of the year and the short dry season has little effect. The average annual temperature in Kannur is 27.2 °C. In a year, the average rainfall is 3351 mm. The precipitation varies 1023 mm between the driest month and the wettest month. Throughout the year, temperatures vary by 3.5 °C.

Table 1 KANNUR CLIMATE TABLE // HISTORICAL WEATHER DATA (https://en.climate-data.org/location/29583/)

Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation / Rainfall (mm)		3	3	7	54	245	889	1026	556	248	204	94	22
Temperature (°C)	Avg.	26.6	27.4	28.5	29.3	29	26.6	25.8	26.1	26.4	27	27	26.7
	Min.	21.7	22.9	24.4	25.7	25.6	23.9	23.4	23.6	23.6	23.8	23.2	22
	Max	31.5	31.9	32.7	33	32.5	29.4	28.2	28.6	29.2	30.2	30.9	31.4

5 INVESTIGATION

Investigation was carried out to ascertain the nature and characteristics of sub-soil below the ground level at the proposed site and to obtain the soil profile. Based on the field investigation, it was observed that the top surface of the site is rocky terrain and the topography is hilly in nature with great variation in reduced levels. The boreholes (BH) were marked along the proposed central line of runway and adjacent to it. Boring was carried out by Calyx core drill and the bore holes were made as per IS: 1892-1979. Standard Penetration tests were conducted at regular intervals (1m interval for the first 3m and then intervals of 1.5m up to 15m depth and further at 2m intervals up to 25m depth and at 3m intervals thereafter) (as per IS 2131-1981). Various laboratory investigations (Grain size analysis, Atterberg limits, Specific gravity, Direct shear tests, density, UCC tests, etc) were carried out on selected soil samples as per relevant Indian Standards.

From the investigation in general, it was observed that, the top stratum consists of very hard laterite upto a depth of 8 to 10m. Below that level the soil is mostly clayey silt with compressibility varying from low to high. As it goes down percentage sand increases and soft weathered rock or soft rock is found at 30 to 40m depth in general. The depth of weathered rock / soft rock layer varying from 4 to 14m in general and after that hard rock is encountered.

5.1 *Characteristics of Laterite soil*

Laterite occurs principally as a cap over the summits of Basaltic hills and plateaus and is the characteristic feature of tropical monsoon regions. It is best developed in the Western Ghats and in its foothills. Vast stretches of laterite-capped hillocks are characteristic features of Kannur-Kasaragod Districts of Kerala.

Geological nature of laterite was described by Francis Hamilton Buchanan, a medical officer of East India Company. He discovered a type of weathered material which was indurated clay, full of cavities and pores, containing large quantity of iron in the form of red and yellow ochre. It was soft when fresh and could be cut easily and when exposed, it became hard and resisted air and water much better than bricks. He used the term laterite to designate this material (laterite in Latin means ‘brick stone’). Laterites are the result of the sub-aerial decomposition in situ of rocks under a warm, humid and monsoonic climate. Under such conditions of climate the decomposition of the silicates, especially the aluminous silicates of crystalline rocks, goes a step further and instead of kaolin being the final product of decomposition, it is further broken up into silica and the hydrated oxide of aluminium (bauxite). The silica is removed in solution and the salts of alkalis and alkaline earths are dissolved away by the percolating water. The remaining alumina and iron oxides become more and more concentrated and become mechanically mixed with other products liberated in the process of decomposition. The vesicular or porous structure, occurs among the products left behind.

Lateritic terrain may be subjected to problem like landslide and slumping. The role of ground water in such disturbances is found to be similar to that of catalytic agent. The reason for such forms of mass wasting is due to the excess accumulation of ground water in the pores of formation. The lubricating nature of the interface between permeable and impermeable beds might be causing gravity movement of overburden in the form of land sliding and consequent slumping.

6 CONSTRUCTION OF LEVELED PLATFORM FOR RUNWAY

Construction of a leveled platform for airports in mountainous areas always requires huge cutting operation in uphill and filling operations in downhill. In order to support the cut slopes and to stabilize the fill slopes, high retaining structures deemed necessary. However, the selection of a suitable retention system for the runway end safety area (RESA) was challenging due to the vast stretches of laterite capped hillocks in Kannur which is having excellent geotechnical properties at dry state and very low consistency at wet state. Hence it was essentially required to select appropriate system which can act as a firm foundation as well as can bear high loading of aircraft. Also, conventional 1:2 slope was not possible due to the space considerations. Considering these factors, the Reinforced soil slope system has been selected for retention of Runway End Safety Area (RESA) at runway 07 side from Ch – 440 to Ch 550 (Airside Operational Road). The project site is located in hilly area and the location of proposed system before construction is shown in Figure 2(b). Figure3 (b) shows the layout plan of airport.

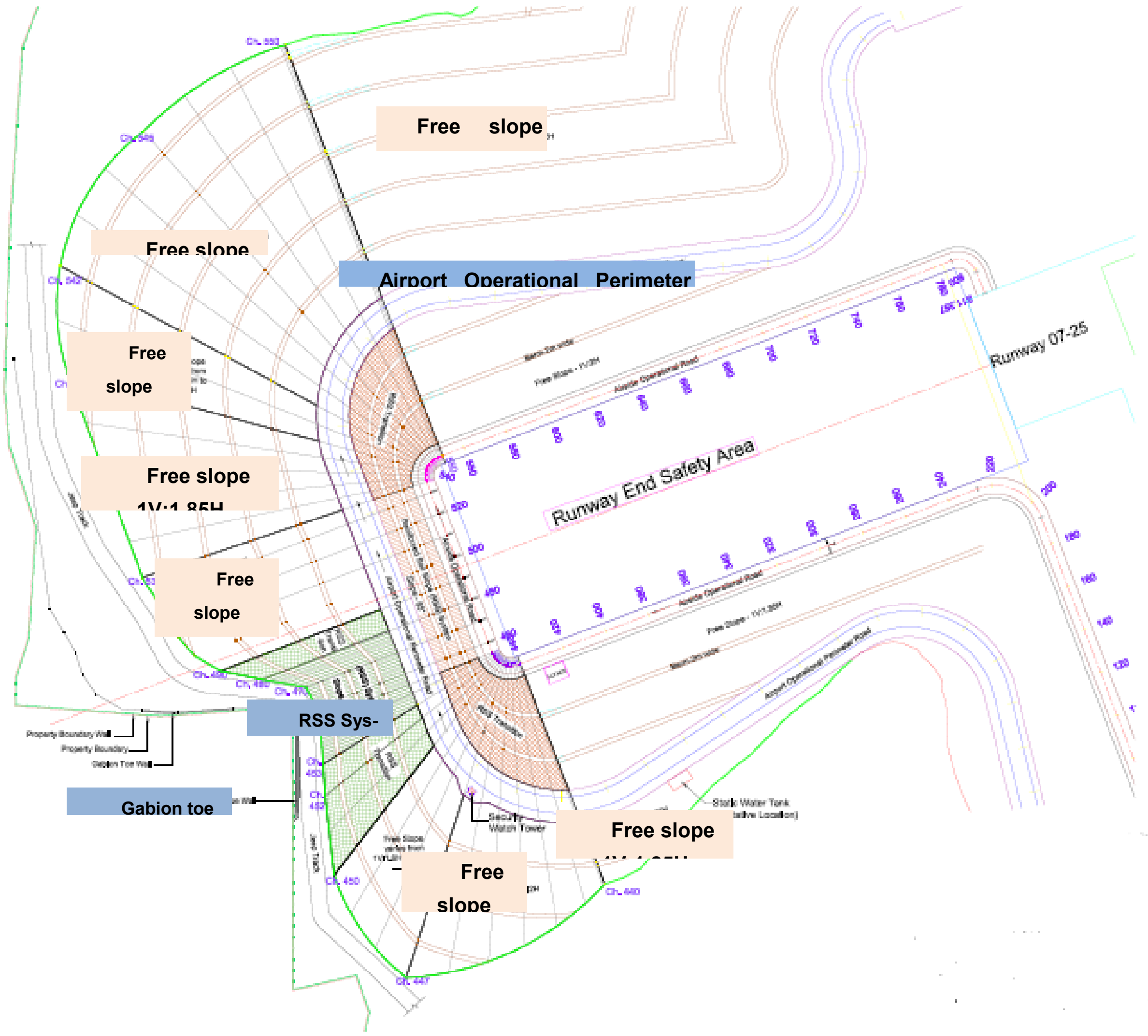

Figure 3. Layout plan for RESA area mentioning the slope

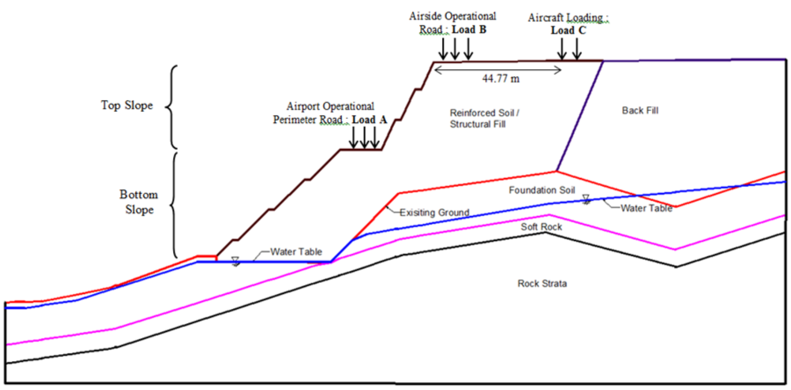

Figure 4. Details of Load Positions considered for Analysis

6.1 *Proposed system*

The proposed system of solution in depicted in Figure 3 which divides the embankment fill in to two parts, “below Airport Operational Perimeter Road” and “above Airport Operational Perimeter Road”. The top slope will be Reinforced Soil Slope of 65° and merging with unreinforced soil slope at both sides. The bottom slope will be 45° or lesser slope based on the availability of land to accommodate flatter slopes at the toe and merged with unreinforced soil slope. The slope surfaces will be protected by providing biodegradable coir mat as an erosion control mat. For assuring the steeper slope construction in the top slope of 65°, welded mesh facia unit will be used as formwork.

7 DESIGN AND CONSTRUCTION

Based on the geometry, existing ground level and the proposed Airside Operational Road & Jeep Track levels, the retention slope angle has been fixed from Ch – 440 to Ch – 550 and critical design sections have been chosen. The summary of the design sections selected based on varying heights & slopes is given in Table 1. Critical aircraft (Boeing 777-300ER) with maximum take- off weight of 353tonnes was considered for loading. Aircraft loading of 267kPa was considered in addition to the traffic load of 24kPa. Loading position can be referred in above figure 4. Seismic analysis was also done considering seismic coefficient 0.09.

Table 2 Design sections

Sr. No	Design Section	Total Height*,	Bottom Slope		Top Slope	
			Slope	Total Height of Bottom Slope	Slope Angle	Total Height of Top Slope
	Chainage	m	V:H	m	deg	m
1	447	66.42	1:2.00	38.85	43	28.25
2	450	70.23	1:1.60	40.95	56	29.23
3	452	66.60	1:1.30	37.18	62	29.60
4	453	66.56	1:1.15	36.90	64	29.71
5	470	66.53	1:1.00	36.56	65	30.00
6	480	68.53	1:1.40	38.56	65	30.00
7	490	70.54	1:1.70	40.53	65	29.97
8	535	75.41	1:1.85	45.55	65	29.89
9	540	85.40	1:1.85	55.96	53	29.25
10	542	86.78	1:2.00	58.76	44	28.53

*Refers to height of slope from top of RSS to toe of embankment. The total height will be different from summation of bottom slope height and top slope height due to presence of camber of airport operational perimeter road.

ReSSA software has been used for Slope Stability Analysis. It is an interactive program used to assess the rotational and translational stability of slopes. The analysis has been carried out for circular slip surface by Bishop's Method and for direct sliding along reinforcement layers by Spencer's Method. Minimum factor of safety adopted for slopes at the end of construction is 1.3 for static stability and 1.0 (as per IITK-GSDMA Guidelines) for seismic stability. The seismic analysis is carried out using the pseudo-static approach. FHWA guidelines: FHWA-NHI-10-025 has been considered for embankment design. Rotational and Translational stability analysis are performed using ReSSA software and most critical failure planes are identified. Where ever it is required to retain the jeep track at the toe of the bottom slope due to the difference in elevation between insitu ground level and the jeep track, a gabion retaining wall is proposed for some chainages where plain embankment slope cannot be provided due to shortage of space between the boundary line and the edge of the jeep track. Designs are validated with two other softwares as well i.e. Maccaferri's in-house software "Macstars W" and PLAXIS software (Figure 3).

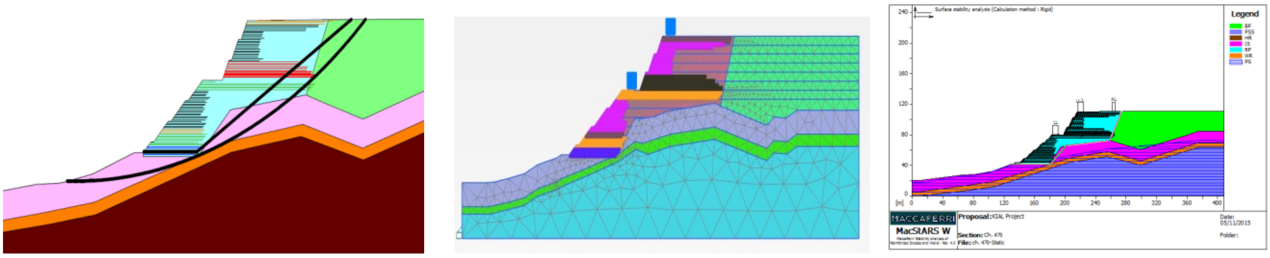

Figure 3. (a) Section modeled in RESSA software (b) Section modelled in PLAXIS software (c) Section modelled in Macstars W software

Table 3 Factor of Safety requirement (Static Analysis)

External stability	Sliding: F.S. ≥ 1.3
	Deep seated (overall stability): F.S. ≥ 1.3 Local bearing failure (lateral squeeze): F.S. ≥ 1.3
Compound failure:	F.S. ≥ 1.3
Internal slope stability:	F.S. ≥ 1.3

7.1 *Design Considerations and parameters:*

I. Live load: 24 kPa on top of Embankment and on intermediate road for 7m width.
II. Design life of RSS system : 25 years
III. Reinforced fill soil properties: Angle of internal friction, Phi= 30;Cohesion, C= 15 kPa; Density= 20 kN/m3
IV. Backfill soil properties: Angle of internal friction; Phi= 25 degree;Cohesion, C= 15 kPa; Density= 18 kN/m3
V. Foundation strata:

Two layer foundation strata have been considered for the foundation soil. Top crest consist of soil and bottom profile consist of weathered to hard Rock. The properties and depth of hard strata are considered based on the Geotechnical investigation report for Runway End Safety Area at runway 07 side (Doc No: O13202-S-AP-AS-GI-0001) provide to us.

Table 4 Foundation Soil Parameters

Sr, No	Chainage section	Reference Borehole no.	Density in kN/m^3	Saturated Density	Cohesion in kN/m^2	phi in deg	Sample depth from ground
			Top Soil Parameters (based on Direct shear Test for 5hr soaking at CU Test)				
1	440 to 449	F	**18.1**	**19.6**	**29**	**28**	**0.5 m**
2		E	18.4	19.8	0	31	1.5 m
3	449 to 454	D	**17.0**	**19.0**	**5**	**32**	**1.5 m**
4		C	17.3	19.2	8	37	1.5 m
5	454 to 480	B	**17.4**	**19.2**	**15**	**33**	**1.5 m**
6		A	16.7	18.9	15	33	1.5 m
7	480 to 535	G	**17.5**	**19.3**	**8**	**31**	**1.5 m**
8		H	17.1	19.1	0	33	1.5 m
9		I	16.7	18.9	10	31	1.5 m
10	535 to 550	L	18.7	19.9	18	31	0.5 m
11		J	**18.3**	**19.7**	**5**	**32**	**1.5 m**
12		K	18.4	19.8	28	26	1.5m

Note: Highlighted values are considered in the design for the top foundation soil.

Table 5 Rock Parameters

Sr. No	Chainage section	Reference Borehole no.	Density in kN/m^3	Cohesion in kN/m^2	phi in deg	UCS in MPa	Rock depth from ground level
			Rock parameters from Rock lab software				
1	440 to 449	F	25	322	35	50	11.5 m
2		E	**25**	**351**	**37**	**63.3**	**20 m**
3	449 to 454	D	**25**	**320**	**35**	**48.9**	**10 m**
4		C	25	420	40	104.3	6 m
5	454 to 480	B	**25**	**330**	**35**	**53.2**	**13.5m**
6		A	25	330	35	53.2	12 m
7	480 to 535	G	25	352	37	63.8	15 m
8		H	25	337	36	56.3	16.6 m
9		I	**25**	**356**	**37**	**65.9**	**21 m**
10	535 to 550	L	25	306	34	43.3	12 m
11		J	**25**	**337**	**36**	**56.3**	**20 m**
12		K	25	286	33	36.2	16 m

Note: Highlighted values are considered in the design for the rock strata.

VI. Seismic coefficient

Calculation of Seismic Coefficient as per IITK-GSDMA GUIDELINES for SEISMIC DESIGN of EARTH DAMS AND EMBANKMENTS

Seismic Zone - III , Zone Factor Z = 0.16
Importance Factor (I) = 1.2
Empirical coefficient (S) = 1.5
Horizontal seismic Coefficient, Ah = 1/3*Z*I*S = 0.096
Vertical seismic Coefficient = 0

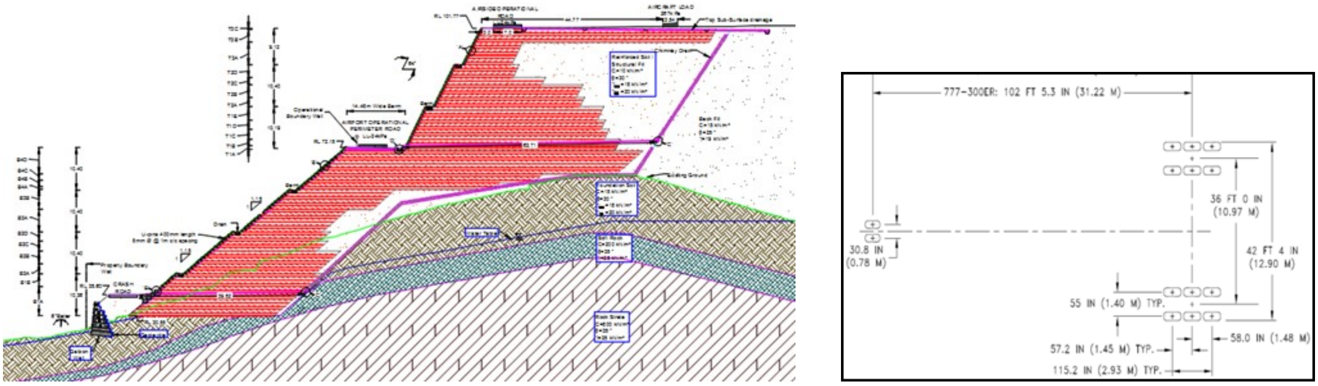

Figure 4. (a) Typical cross section for RSS system (b) Gear configuration of B 777-300ER

7.2 *Aircraft loading*

Even though the Aircraft loading does not come under the area of influence of the reinforced soil structure, the analysis has been performed for the critical design sections parallel to the runway centerline considering the impact of aircraft load. Calculations for the aircraft loading with a critical aircraft (Boeing 777-300ER) was carried out which is mentioned below.

Maximum take – off weight = 353 tonnes
Considering 95% load on each main gear on rear side = 95% x 3530 / 2 = 1676.75 kN
Tyre contact dimensions of each wheel = 378.8 mm x 606.1 mm

As shown in Figure 4 (b), dimensions considered for each main gear – rear side to calculate the aircraft loading:

Length = 3.54
Width = 1.78 m
Aircraft loading = 1676.75 / (3.54 x 1.78) = 267 kPa

Considering the critical position of aircraft nose wheel at Runway End Safety Area end, the distance of aircraft loading from the edge of embankment shall be 44.77 m. Based on the above, an aircraft loading of 267 kPa for a width of 3.54 m acting at 44.77m from the edge of embankment has been considered in the designs.

7.2.1 *Load Combination*

The RSS system has been designed for external live load as shown in Figure

Load A = 24kPa at Airport perimeter Road; Load B = 24kPa at Airside operational Road; Load C = 267 kPa for Aircraft loading

Plaxis static analysis has been carried out for seven different combinations viz., (1) Load A alone; (2) Load B alone; (3) Load C alone; (4) Load A + Load B; (5) Load B + Load C; (6) Load C + Load A; (7) Load A + Load B + Load C

The proposed RSS has been designed for Targeted factor of safety of 1.30 with reference to clause 9.2.1.b of FHWA-NHI-10-025 "Design & Construction of MSEW and RS Slopes - Vol II" for Load combination A, B & AB. The RSS system design has also been checked for Load C and associated combinations (BC, CA, and ABC) for critical sections along the runway centerline. However, it must be recognized that the independent loading case C (the heaviest aircraft in the fleet mix; B777-300ER, carrying full payload in an aborted Take-off case (though the runway length caters for this case), over shoots into the RESA till the RESA end) or combinations of other loads with load C has the rarest of rare probability of occurrence. Therefore a FOS of 1.1 has been considered as well adequate for such cases, which is even higher than FOS of 1.0 considered for an Earthquake analysis. The minimum Factor of safety achieved for such loading cases is 1.17 as against 1.1 considered.

7.2.2 *Factor of safety at interface of fill and virgin ground*

The Plaxis and ReSSA analysis computes the factor of safety for the overall defined search range and the output presented is for the most critical surface within the defined zone. In order to analyze the factor of safety exactly at the interface between fill and virgin ground, the design sections have been checked in MacStARS software by Janbu method of analysis and the factor of safety at the interface of the fill and virgin ground has been calculated.

7.3 *Construction*

Construction is under progress. Few photos of construction are shown in Figure 5and Figure 6.

Figure 5. (a)Geogrid Laying (b) Welded mesh facia with coir mat (c) Erosion control measures

Figure 6. (a) Overall view of the slope (b) Reinforced soil slope

8 CONCLUSION

Hybrid reinforced soil structure combines high strength geogrid as primary soil reinforcement and heavily galvanized and PVC coated steel wire mesh panels as secondary reinforcement. The stability to potential slip circles are provided by main primary geogrid reinforcement whereas secondary reinforcement contributes to necessary face stability. Experience from the presented case histories and many others, show that hybrid reinforced soil structures are apt for higher loading (aircraft), poor ground conditions & difficult climatic conditions. Also there is a considerable potential for cost effectiveness that can be exploited in high reinforced soil walls, as the height of structures crosses certain limit. Thus, Hybrid reinforced soil structures are technically sound, truly environment friendly and economical as well.