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Terrace Soil Suitability for Highway Construction: Case Study in Lesser Himalaya (CPEC Project E-35), North Pakistan

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Abstract: In this study, terrace soil investigation was carried out in project E-35 (phase-I) China-Pak Economic Corridor, Lesser Himalayas, North Pakistan. The methodology in current research is based on tests that include sieve analysis, plastic index, proctor, California Bearing Ratio, Los Angeles, sand equivalent and specific gravity. The results of these tests for different layers were compared with AASHTO and NHA specifications. The results show that the embankment, subgrade and subbase layers were composed of silt, sand and gravel, respectively while the aggregate base coarse was composed of sand, aggregate and less amount of fine clay material. The sieve analysis test shows that soil and aggregate base coarse has less clay with high silt, sandy material and index plastic to low plastic, which is appropriate for the construction. The California Bearing Ratio shows that the soil and aggregate base coarse have high load-bearing capacity. The Los Angeles abrasion reveal that the sub base and aggregate base coarse are resistive. The sand equivalent shows that aggregate base coarse has high sand material. The specific gravity illustrates that aggregate base coarse material is denser. The current study shows that terrace soil is suitable for the construction of the road in project E-35 (phase-I) China-Pak Economic Corridor.

Keywords: Terrace soil, highway construction, aggregate, sieve analysis, Haripur.

Introduction

The natural materials related to the processes of terrace formation in response to river's erosion and deposition (cut and fill) of alluvial sediments create variety of materials fluctuations (Bridgland and Westaway, 2008). These materials are reflective of the processes and are utilized for various purposes for construction and development. Testing these materials is of prime importance for the human civilization's sustainability (Young and Nanson, 1982).

Naturally, the highways are built on different geological materials having different engineering properties. The evaluation of these materials needs a variety of methods, designs and techniques. The importance of engineering geology in the construction field cannot be neglected to achieve the best use of materials. The nature and suitability of the soil plays an important role in the sustainability of road structure and design whereas the soil unsuitability may lead to structural and design failure. Thus, information about the soil profile is necessary especially for road construction (Perry and Hayes, 1985).

In the current study, the area from Jarikas to Maqsooda interchange in Haripur district (Hazara Division) is under investigation that is part of Hasanabdal-Havelian-Mansehra expressway project E-35 (phase-I) of the CPEC (Fig. 1). The China Pakistan Economic Corridor is a mega project to change the dynamics of Pak-China relations in the context of geo-economics. The main objective of CPEC is to improve the living standard of people of Pakistan and China by increasing the trading activity for regional connectivity. After completion of this project, it will become a major gateway for trading between China and many Afro-Asian countries.

The present study aims to evaluate and understand the nature and stability of terrace soil for highway construction. The main objectives are 1) To find out the geotechnical parameters of terrace soil and 2) To compare the class of terrace soil with NHA specification (1998) and AASHTO classification for the proposition of suitable material in highway construction (Fig. 2).

Tectonically, the study area lies in the Lesser Himalayas, which was formed as a collision of the Indian and Eurasian Plates in Eocene period (Khattak et al., 2017). Stratigraphically, the Hazara basin consists of Precambrian to Recent age rocks (Hussain et al., 2013). The Haripur area is having flatlands with less stratigraphically exposed surfaces as compared to other parts of the basin. It contains Quaternary deposits which are mainly stream deposits and include a system of terraces along the main rivers and larger creeks. The streams have deeply incised these deposits, forming nearly vertical gullies as much as 200 feet deep (Calkins et al., 1975; Hussain et al., 2013). The area under investigation contains the same reworked and eroded soils which are coarse to medium-sized gravels with silt and clays.

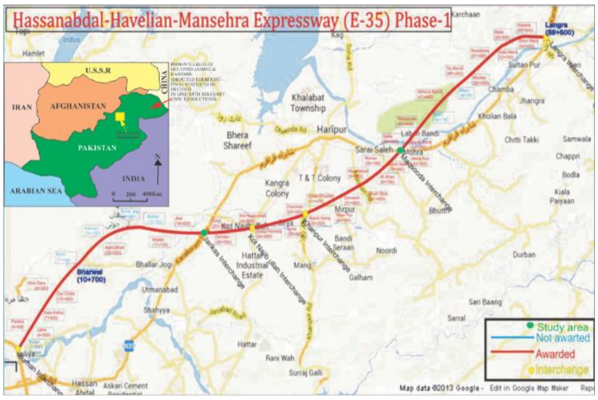


Fig. 1 Location map of study area generated from google earth. The inset shows the location of the study area in Pakistan.

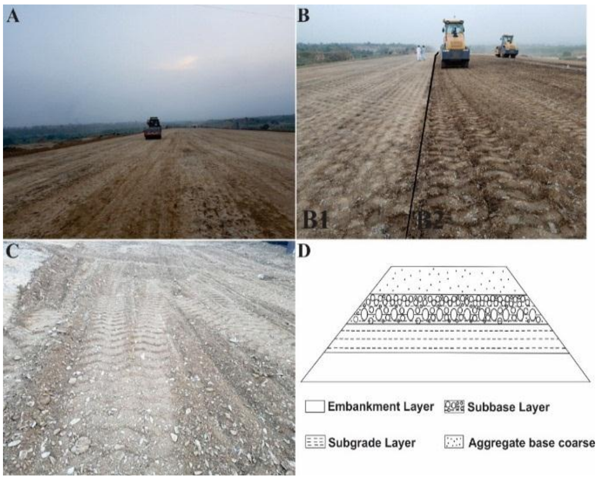


Fig. 2 (A) Showing the compacted embankment layer. (B) The glance of subgrade while (B1) compacted subgrade layer (B2) until not compacted. (C) Showing subbase layer until not compacted of project E-35 Phase-I (D) Showing embankment, subgrade, subbase, and aggregate base coarse of highways.

Materials and Methods

The methodology employed in the current study includes Sieve analysis, Plastic index (PI), California bearing ratio (CBR), proctor (Moisture Density Relationship), sand equivalent, Los Angeles abrasion and specific gravity tests. The data were collected from Project E-35 (phase-I), China-Pak Economic Corridor (CPEC) (Table. 1).

Table 1 Showing the tests performed for different soil layers of Project E-35, CPEC.

S No	Layers	Sieve Analysis	PI	Proctor	CBR	Los Angeles	Sand Equivalent	Specific Gravity
1	Embankment	✓	✓	✓	✓	-	-	-
2	Subgrade	✓	✓	✓	✓	-	-	-
3	Sub base	✓	✓	✓	✓	✓	✓	-
4	Aggregate base coarse	✓	✓	✓	✓	✓	✓	✓

Samples have been collected from four layers of the Expressway. Standard methods and procedures were adopted to test the materials for the road suitability following all the QA/QC protocols (Roberts et al., 1996; Krishna and Reddy, 2002; Schaefer et al., 2008; Moaveni et al., 2013).

Results and Discussion

The data collected from different tests performed were analysed to investigate the soil and aggregate of highways (Table 2, 3).

Embankment layer

The cumulative passing percentage on sieves 1", 3/4", 3/8", No.4, No.10, No. 40 and No. 200 for embankment are 98.2, 81.5, 72.2, 50.8, 30.3, 20.7 and 18.6, respectively (Fig. 3A), compared with NHA specification (1998) shows that the material fulfils the required criteria. The test result of the plastic index is non-plastic for the embankment layer i.e.3.7 **(**Fig. 3B & C**)** and fulfils the required criteria. The result of the proctor test is that the moisture content percentage is 8.8. The maximum dry density is 2.220 gms/cc. The peak value of the graph between maximum dry density and moisture content shows that maximum dry density is 2.220 at 8.3 moisture content (Fig 3D & E). The dry density of CBR on 10 blow, 30 blow and 65 blows are 1.998, 2.109 and 2.220 for the embankment layer. The soaked CBR on 10, 30 and 65 blows are 10, 13 and 15, respectively. The moisture percentage is 8.8, on 65 blows. The CBR at 93% of max dry density 2.065. The CBR value for embankment layer is 11.5 % (Fig 4 A & B). The swell value of the material for embankment material shall not exceed five-tenths (0.5) per cent and the test swell value is 0. The result shows that the material fulfils the criteria and the material is suitable for the construction of the embankment layer.

Subgrade layer

The cumulative passing percentage on sieves 1", 3/8", No.4, No.10, No. 40 and No. 200 for subgrade are 100, 94.4, 76.5, 66.8, 42.5 and 10, respectively (Fig. 5A). The result shows that the material fulfils the required criteria and the material is A3 and suitable for the subgrade layer. The test result of the plastic index is non-plastic with a value of 11.1 (Fig. 5B & C), the material fulfils the required criteria. The result of the proctor test is that the moisture content percentage is 10.6. The dry density is 2.119 gms/cc. The peak value of the graph between maximum dry density and moisture content shows that maximum dry density is 2.119 at 10.6 moisture content (Fig. 5D & E). The dry density of CBR on 10 blow, 30 blow and 65 blows are 1.907, 2.024 and 2.100 for the subgrade layer. The soaked CBR on 10, 30 and 65 blows are 11.6, 13.3 and 15, respectively. The moisture percentage is 10.6 on 65 blows. The CBR at 93% of max dry density is 1.971. The CBR value for subgrade layer is 12.5% (Fig. 6A & B). The swell value of the material for the subgrade layer shall not exceed five-tenths (0.5) per cent and the test swell value is 0 (zero). The outcome demonstrates that the material satisfies the criteria and the material is appropriate for the development of the subgrade layer.

Subbase layer

The cumulative passing percentage on sieves 2", 1, 3/8", No.4, No.10, No. 40 and No. 200 for Subbase are 100, 75.7, 56.7, 49.9, 36.4, 12.9 and 3.4, respectively (Fig. 7A) which show that the material satisfies the criteria. The test result of the plastic index is non-plastic. The plastic index (PI= LL-PL) is 2.1 (Fig. 7B & C). The test result of the proctor is that the moisture content % is 4.8. The maximum dry density is 2.223 gms/cc. The peak value of the graph between maximum dry density and moisture content shows that maximum dry density is 2.223 at 4.8 moisture content (Fig. 7D & E). The test results show that the weight of the tested sample is 3726 gms and abrasion is 25.5 % for the subbase layer (Fig. 7F). The abrasion shows that the material is resistive and suitable, and the material fulfils the criteria of NHA specification (1998). According to NHA specification (1998), the sand equivalent for all classes shall be 25 min. The sand readings are 4.3, 4.6, 4.8 and the clay readings are 5.2, 5.5, and 5.7 for the subbase layer. The sand equivalent percentages are 82.1, 83.6, and 84.2 and the average sand equivalent percentage is 83 % (Fig. 8A). The result shows that the material fulfils the criteria. The dry density of CBR on 10, 30 and 65 blows are 2.001, 2.120 and 2.243, respectively for the subbase layer. The soaked CBR on 10, 30 and 65 blows are 30.7, 35, and 39.9, respectively. The moisture percentage is 4.8 on 65 blows. The CBR at 90% of max dry density is 2.001. The CBR value of the subbase layer is 30.7% (Fig. 8B & C). The NHA specification (1998) for the subbase layer is that the CBR material shall have a CBR value of at least 50%, determined according to AASHTO T-193. The CBR value shall be obtained at a density corresponding to ninety-eight (98) per cent of the maximum dry density determined according to AASHTO T-180. The material fulfils the NHA specification (1998) and is suitable for the construction of the subbase layer.

Aggregate Base Coarse

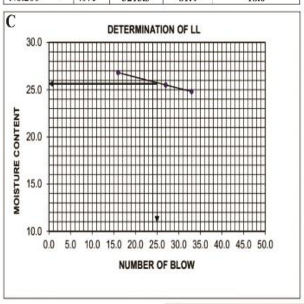
The cumulative passing percentage on sieves 2", 1", 3/4", 3/8", No.4, No.10, No. 40 and No. 200 for aggregate base coarse are 100, 78.3, 66, 41.6, 28.6, 19.2, 10.8, and 7.7, respectively (Fig. 9A) The test result of a plastic index is non-plastic where plastic index is 3. The test result of the proctor is that the moisture content percentage is 9.8. The maximum dry density is 2.245 gms/cc. The peak value of the graph shows that the maximum dry density is 2.200 at 9.8 moisture content (Fig 9D & E). The test result shows that the weight of the tested sample is 3975 gms and abrasion is 20.5 % for aggregate base coarse. The abrasion shows that the material is resistive and suitable for construction (NHA specification 1998) (Fig. 10A). The NHA specification (1998) for the sand equivalent test is that the sand equivalent determined according to AASHTO T-176 shall not be less than 45. The clay readings are 8.9, 9.0 and sand readings are 4.1 and 4.2 for aggregate base coarse. The sand equivalent percentages are 46.1, 46.7 and the average sand equivalent percentage is 46.4 %. The material fulfils the NHA specification (1998) and is suitable for the construction of aggregate base coarse layer (Fig. 10B & C). The specific gravity absorption percentage is 0.36, 0.40. The average bulk oven-dry specific gravity is 2.668, average bulk saturated specific gravity is 2.679 and average apparent is 2.696. The dry density of CBR on 10, 30 and 65 blows are 2.053, 2.170 and 2.272, respectively for aggregate base coarse. The soaked CBR on 10 blow, 30 blow and 65 blows are 81.4, 120 and 182.8. The moisture percentage is 4.5 on 65 blows. The CBR at 100% of max dry density is 2.272. The CBR value of aggregate base coarse is 182% (Fig. 11A & B). The material fulfils the criteria and is suitable for the construction of aggregate base coarse.

A — **SIEVES ANALYSIS** (AASHTO DESIGNATION T.27 - 78)

DESCRIPTION : EMBANKMENT
ORIGINAL WEIGHT OF SAMPLE: 3950 gms

sieve size Astm		MM	Cum. Wt. Retained Gms.	Cum. % Retained	Cum. % Passing
1"		25.00	71	1.8	98.2
3/4"		19.1	731	18.5	81.5
3/8"	✓	9.5	1098.1	27.8	72.2
No. 4	✓	4.75	1943.4	49.2	50.8
No.8		2.36	-	-	-
No.10	✓	2.00	2753.2	69.7	30.3
No.16		1.18	-	-	-
No.30		0.60	-	-	-
No.40	✓	.425	3132.4	79.3	20.7
No.50		.300	-	-	-
No.100		.150	-	-	-
No.200	✓	.075	3215.3	81.4	18.6

B DETERMINATION	1	2	3
LIQUID LIMIT			
NO OF BLOWS	16	27	33
CONTAINER NO.	H	G	J
WT. OF CONTAINER + WET SOIL (g)	37.57	41.40	35.60
WT. OF CONTAINER + DRY SOIL (g)	33.75	37.17	32.24
WT. OF WATER (g)	3.82	4.23	3.36
WT. OF CONTAINER (g)	19.50	20.60	18.70
WT. OF DRY SOIL (g)	14.25	16.57	13.54
MOISTURE CONTENT (%)	26.8	25.5	24.8
Liquid limit = 25.8			
PLASTIC LIMIT			
DETERMINATION	1	2	
CONTAINER NO.	A	P	
WT OF CONTAINER + WET SOIL (g)	27.66	27.57	
WT OF CONTAINER + DRY SOIL (g)	25.90	26.02	
WT OF WATER (g)	1.76	1.55	
WT OF CONTAINER (g)	18.1	18.9	
WT OF DRY SOIL (g)	7.80	7.12	
MOISTURE CONTENT (%)	22.5	21.7	
PI = (L.L - P.L) 3.7	PL = 22.1		



D — **MOISTURE DENSITY RELATIONSHIP** (AASHTO T - 180) DESCRIPTION EMBANKMENT

Wt. of Mould: 4195 gms — Vol. of Mould: 2141.9 cc

Weight of wet soil+ Mould (gms)	8873	9040	9191	9368	9338
Weight of wet soil (gms)	4678	4845	4996	5173	5143
Wet density of soil (gm/cc)	2.184	2.262	2.333	2.415	2.401
Cone No	A2	G	O	S	C
Weight of Can (gms)	62.65	62.18	64.3	63.64	67.7
Weight of wet soil+ Can (gms)	294.5	288.8	296.7	290.7	296.9
Weight of Dry soil+ Can (gms)	285.6	276.8	281.5	272.3	275.3
Weight of water	8.9	12.0	15.2	18.4	21.6
Weight of dry soil	223.0	214.6	217.2	208.7	207.6
Water content	4.0	5.6	7.0	8.8	10.4
Dry density (gm/cc)	2.100	2.142	2.180	2.220	2.175
Moisture Content (%)				8.8	

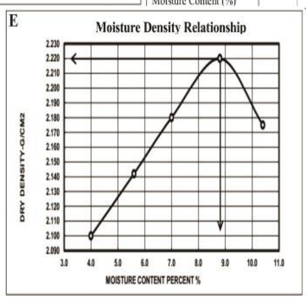


Fig. 3 A) Showing sieve analysis of embankment material, B) Showing plasticity index of embankment material, C) Showing moisture content /liquid limit on 25 blows of embankment material, D) Showing proctor test for embankment material, E) Showing moisture density relation of embankment material and peak value of graph shows that maximum dry density of embankment material is 2.220 at 8.3 moisture content.

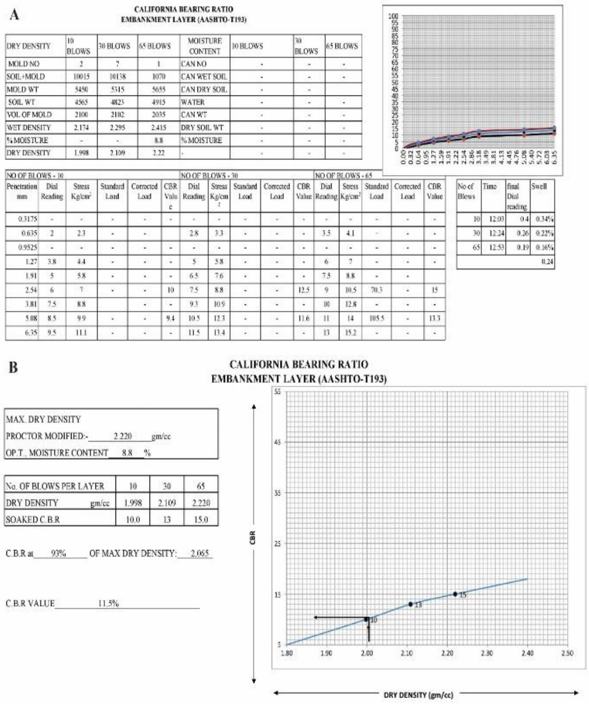


Fig. 4 A) Showing CBR test values of three moulds for embankment material and in the graph black curve shows 10 blows, the blue curve shows 30 blows and the red curve shows 65 blows, B) Showing modified proctor of CBR value and dry density for embankment layer while the graph shows the relationship between CBR and dry density for embankment layer.

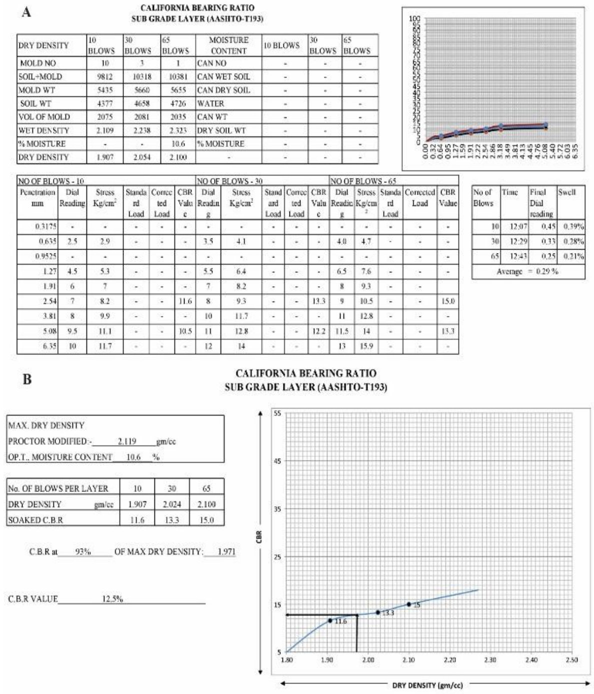


Fig. 6 A) Showing CBR test values of three moulds for subgrade material and in the graph black curve shows 10 blows, the blue curve shows 30 blows and the red curve shows 65 blows, B) Showing modified proctor of CBR value and dry density for subgrade layer while the graph shows the relationship between CBR and dry density for subgrade layer.

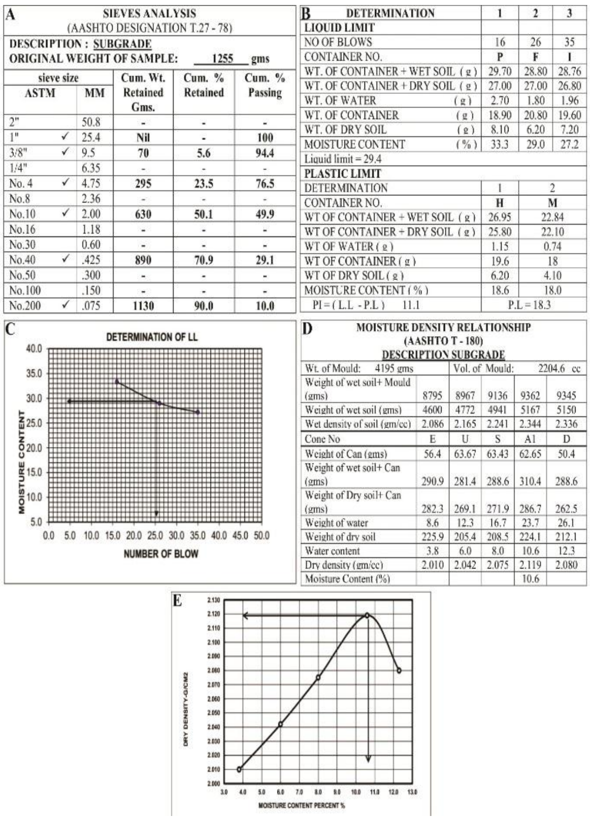


Fig. 5: A) Showing sieve analysis of subgrade material, B) Showing plasticity index of subgrade material, C) Showing moisture content /liquid limit on 25 blows of subgrade material, D) Showing proctor test for subgrade material, E) Showing moisture density relation of subgrade material and peak value of graph shows that maximum dry density of subgrade material is 2.119 at 10.6 moisture content.

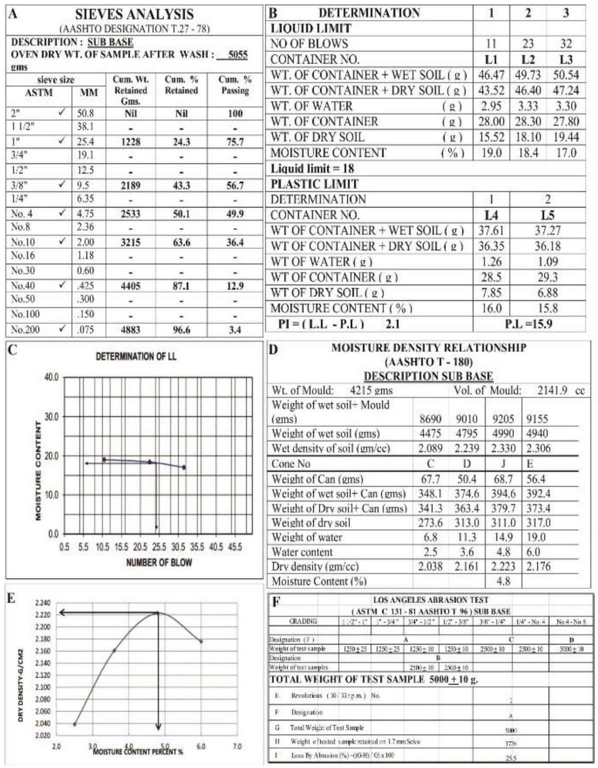


Fig. 7 A) Showing sieve analysis of subbase material, B) Showing plasticity index of subbase material, C) Showing moisture content /liquid limit on 25 blows of subbase material, D) Showing proctor test for subbase material, E) Showing moisture density relation of subbase material and peak value of graph shows that maximum dry density of subbase material is 2.223 at 4.8 moisture content, F) Showing Los Angeles abrasion test percentage calculations of subbase layer.

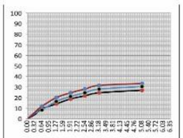
A

SAND EQUIVALENT TEST (AASHTO T-176-73)			
DESCRIPTION SUB BASE	**Determination**		
Sand Reading	4.3	4.6	4.8
Clay Reading	5.2	5.5	5.7
$Sand\ Equivalent = \frac{sand\ Reading}{clay\ Reading} x\ 100$ %	82.1	83.6	84.2
Average Sand Equivalent %	83 %		

B

CALIFORNIA BEARING RATIO
SUB BASE LAYER (AASHTO-T193)

DRY DENSITY	10 BLOWS	30 BLOWS	65 BLOWS	MOISTURE CONTENT	10 BLOWS	30 BLOWS	65 BLOWS
MOLD NO	3	10	5	CAN NO	-	-	-
SOIL+MOLD	10023	10027	10617	CAN WET SOIL	-	-	-
MOLD WT	5660	5435	5775	CAN DRY SOIL	-	-	-
SOIL WT	4363	4592	4842	WATER	-	-	-
VOL OF MOLD	2081	2075	2060	CAN WT	-	-	-
WET DENSITY	2.097	2.213	2.351	DRY SOIL WT	-	-	-
% MOISTURE	-	-	4.8	% MOISTURE	-	-	-
DRY DENSITY	2.001	2.112	2.243	-	-	-	-



	NO OF BLOWS - 10					NO OF BLOWS - 30					NO OF BLOWS - 65				
Penetration mm	Dial Reading	Stress Kg/cm²	Standard Load	Corrected Load	CBR Value	Dial Reading	Stress Kg/cm²	Standard Load	Corrected Load	CBR Value	Dial Reading	Stress Kg/cm²	Standard Load	Corrected Load	CBR Value
0.3175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.635	8	9.3	-	-	-	7	8.2	-	-	-	10	11.7	-	-	-
0.9525	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.27	12	14	-	-	-	14	16.4	-	-	-	17	19.9	-	-	-
1.91	16	18.7	-	-	-	18	21	-	-	-	21	24.5	-	-	
2.54	18.5	21.6	-	-	30.7	21	24.5	-	-	39.9	24	28	-	-	39.5
3.81	21	24.5		-	-	24	28	-	-	-	27	31.5	-	-	-
5.08	23	26.9	-	-	25.7	26	30.4	-	-	31.6	28.5	33.3	-	-	31.6
6.35	24	28	-	-	-	27	31.5	-	-	-	30	35	-	-	-

No of Blows	Time	final Dial reading	Swell
10	12:10	0.32	0.27
30	12:32	0.36	0.22
65	12:55	0.20	0.17
Average = 0.22%			

C

CALIFORNIA BEARING RATIO
SUB BASE LAYER (AASHTO-T193)

MAX. DRY DENSITY
PROCTOR MODIFIED:- 2.223 gm/cc
OP.T., MOISTURE CONTENT 4.8 %

No. OF BLOWS PER LAYER	10	30	65
DRY DENSITY gm/cc	2.001	2.120	2.243
SOAKED C.B.R	30.7	35	39.9

C.B.R at 90% OF MAX DRY DENSITY: 2.001

C.B.R VALUE 30.7%

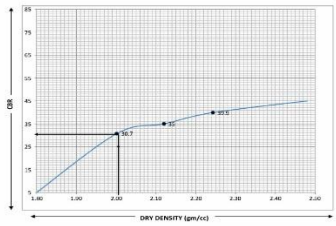


Fig. 8 A) Showing clay reading, sand reading, sand equivalent and average sand equivalent percentage of a subbase layer, B) Showing CBR test values of three moulds for subbase material and in the graph black curve shows 10 blows, the blue curve shows 30 blows and the red curve shows 65 blows, C) Showing modified proctor of CBR value and dry density for subbase layer while the graph shows the relationship between CBR and dry density for subbase layer.

A

SIEVES ANALYSIS
(AASHTO DESIGNATION T.27 - 78)

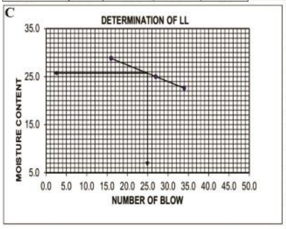
DESCRIPTION : AGGREGATE BASE COURSE
ORIGINAL WEIGHT OF SAMPLE: 5395 gms

sieve size ASTM		MM	Cum. Wt. Retained Gms.	Cum. % Retained	Cum. % Passing
2"	✓	50.8	Nil	Nil	100
1 1/2"		38.1	-	-	-
1"	✓	25.4	1171	21.7	78.3
3/4"		19.1	1834	34.0	66.0
1/2"		12.5	-	-	-
3/8"	✓	9.5	3151	58.4	41.6
1/4"		6.35	-	-	-
No. 4	✓	4.75	3852	71.4	28.6
No.8		2.36	-	-	-
No.10	✓	2.00	4359	80.8	19.2
No.16		1.18	-	-	-
No.30		0.60	-	-	-
No.40	✓	.425	4812	89.2	10.8
No.50		.300	-	-	-
No.100		.150	-	-	-
No.200	✓	.075	4980	92.3	7.7

B

DETERMINATION	1	2	3
LIQUID LIMIT			
NO OF BLOWS	16	27	34
CONTAINER NO.	5	4	6
WT. OF CONTAINER + WET SOIL (g)	34.30	36.48	38.98
WT. OF CONTAINER + DRY SOIL (g)	30.50	33.00	35.70
WT. OF WATER (g)	3.80	3.48	3.28
WT. OF CONTAINER (g)	17.30	19.10	21.20
WT. OF DRY SOIL (g)	13.20	13.90	14.50
MOISTURE CONTENT (%)	28.8	25.0	22.6
Liquid limit = 25.7			
PLASTIC LIMIT			
DETERMINATION	1	2	
CONTAINER NO.	1	K	
WT OF CONTAINER + WET SOIL (g)	27.55	28.54	
WT OF CONTAINER + DRY SOIL (g)	25.90	27.30	
WT OF WATER (g)	1.65	1.24	
WT OF CONTAINER (g)	18.7	21.8	
WT OF DRY SOIL (g)	7.20	5.50	
MOISTURE CONTENT (%)	22.9	22.5	
PI = (L.L - P.L) 3.0	P.L = 22.7		

C



D

MOISTURE DENSITY RELATIONSHIP
(AASHTO T - 180)
DESCRIPTION AGGREGATE BASE COARSE

Wt. of Mould: 4215 gms		Vol. of Mould: 2141.9 cc			
Weight of wet soil+ Mould (gms)	8368	8713	9073	9389	9273
Weight of wet soil (gms)	4153	4498	4858	5174	5058
Wet density of soil (gm/cc)	1.939	2.100	2.268	2.416	2.362
Cone No	C	M	A	L	D
Weight of Can (gms)	67.7	55.3	61.9	51.2	51.4
Weight of wet soil+ Can (gms)	286.4	286.0	285.0	296.4	290.4
Weight of Dry soil+ Can (gms)	275.6	271.9	268.5	274.5	265.9
Weight of dry soil	207.9	216.6	206.6	223.3	214.5
Weight of water	10.8	14.1	16.5	21.9	24.5
Water content	5.2	6.5	8.0	9.8	11.4
Dry density (gm/cc)	1.843	1.972	2.100	2.200	2.120
Moisture Content (%)				9.8	

E

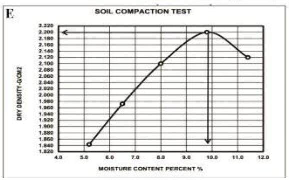


Fig.9 A) Showing sieve analysis of aggregate base coarse material, B) Showing plasticity index of aggregate base coarse material, C) Showing moisture content /liquid limit on 25 blows of aggregate base coarse material, D) Showing proctor test for aggregate base coarse material, E) Showing moisture density relation of aggregate base coarse material and peak value of graph shows that maximum dry density of aggregate base coarse material is 2.200 at 9.8 moisture content.

A

LOS ANGELES ABRASION TEST
(ASTM C 131 - 81 AASHTO T 96) AGGREGATE BASE COARSE

GRADING	1 1/2" - 1"	1" - 3/4 "	3/4" - 1/2 "	1/2" - 3/8"	3/8" - 1/4"	1/4" - No. 4	No.4 - No 8
Designation (F)		A			C		D
Weight of test sample	1250 + 25	1250 + 25	1250 + 10	1250 + 10	2500 + 10	2500 + 10	5000 + 10
Designation			B				
Weight of test samples			2500 + 10	2500 + 10			
TOTAL WEIGHT OF TEST SAMPLE 5000 + 10 g.							

		1	2
E	Revolutions (30 / 33 r.p.m.) No.	1	2
F	Designation	C	C
G	Total Weight of Test Sample	5000	5000
H	Weight of tested sample retained on 1.7 mm Seive	3890	3940
I	Loss By Abrasion (%) =((G-H) / H) x 100	22.2	21.2
		AVE= 21.7	

B

SAND EQUIVALENT TEST (AASHTO T-176-73)			
DESCRIPTION AGGREGATE BASE COARSE	Determination		
Clay Reading	8.9	9.0	
Sand Reading	4.1	4.2	
$Sand\ Equivalent = \frac{sand\ Reading}{clay\ Reading} x\ 100$ %	46.1	46.7	
Average Sand Equivalent %	46.4%		

C

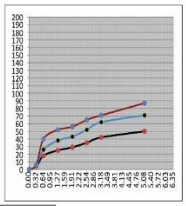
COARSE AGGREGATE			RET=3/4"	RET=3/4"	AVERAGE
Mass. Of Oven Dry Sample in Air	A	(g)	4225	4512	
Mass of S.S.D. Sample in Air	B	(g)	4240	4530	
Mass of S.S.D. Sample in Water	C	(g)	2660	2835	
Bulk Specific Gravity	A / (B-C)		2.674	2.662	2.668
Bulk S.S.D. Specific Gravity	B / (B-C)		2.684	2.673	2.679
Appearent Specific Gravity	A / (A-C)		2.700	2.691	2.696
Water Absorption	(B-A / A) x 100	%	0.36	0.40	0.38

Fig. 10 A) Showing Los Angeles abrasion test percentage calculations of an aggregate base coarse layer. B) Showing clay reading, sand reading, sand equivalent and average sand equivalent percentage of aggregate base coarse layer, C) Showing specific gravity test calculations of aggregate base coarse material.

A

CALIFORNIA BEARING RATIO
AGGREGATE BASE COARSE LAYER (AASHTO-T193)

DRY DENSITY	10 BLOWS	30 BLOWS	65 BLOWS	MOISTURE CONTENT	10 BLOWS	30 BLOWS	65 BLOWS
MOLD NO	1	10	6	CAN NO	-	-	-
SOIL+MOLD	10021	10122	10830	CAN WET SOIL	-	-	-
MOLD WT	5655	5435	5875	CAN DRY SOIL	-	-	-
SOIL WT	4366	4687	4955	WATER	-	-	-
VOL OF MOLD	2035	2070	2087	CAN WT	-	-	-
WET DENSITY	2.145	2.264	2.374	DRY SOIL WT	-	-	-
% MOISTURE	-	-	4.5	% MOISTURE	-	-	-
DRY DENSITY	2.053	2.167	2.272	-	-	-	-



	NO OF BLOWS - 10					NO OF BLOWS - 30					NO OF BLOWS - 65				
Penetration mm	Dial Reading	Stress Kg/cm²	Standard Load	Corrected Load	CBR Value	Dial Reading	Stress Kg/cm²	Standard Load	Corrected Load	CBR Value	Dial Reading	Stress Kg/cm²	Standard Load	Corrected Load	CBR Value
0.3175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.635	15	17.5	-	-	-	25	29.2	-	-	-	45	52.6	-	-	-
0.9525	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.27	30	30.35	-	-	-	45	5.6	-	-	-	75	87.6	-	-	-
1.91	40	46.7	-	-	-	60	70.1	-	-	-	95	111	-	-	
2.54	49	57.2	-	-	81.4	72	84.1	-	-	119.6	110	128.5	-	-	182.8
3.81	60	70.1		-	-	90	105.1	-	-	-	125	146	-	-	-
5.08	70	81.8	-	-	77.5	100	116.8	-	-	110.7	140	163.5	-	-	155
6.35	80	93.4	-	-	-	110	128.5	-	-	-	150	175.2	-	-	-

No of Blows	Time	final Dial reading	Swell
10	12:15	0.04	0.03%
30	12:24	0.02	0.02%
65	12:57	0	0.00%
Average = 0.02 %			

B

CALIFORNIA BEARING RATIO
AGGREGATE BASE COARSE LAYER (AASHTO-T193)

MAX. DRY DENSITY
PROCTOR MODIFIED:- 2.281 gm/cc
OP.T., MOISTURE CONTENT 4.5 %

No. OF BLOWS PER LAYER	10	30	65
DRY DENSITY gm/cc	2.053	2.170	2.272
SOAKED C.B.R	81.4	120	182.8

C.B.R at 100% OF MAX DRY DENSITY: 2.272

C.B.R VALUE 182%

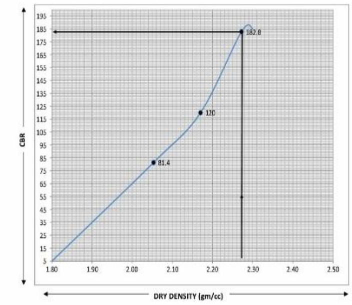


Fig. 11 A) Showing CBR test values of three moulds for aggregate base coarse material and in the graph black curve shows 10 blows, the blue curve shows 30 blows and the red curve shows 65 blows, B) Showing modified proctor of CBR value and dry density for aggregate base coarse layer while the graph shows the relationship between CBR and dry density for aggregate base coarse layer.

Table 2 Showing sieve analysis results of different layers of Project E-35, CPEC is compared with NHA specification (1998).

SIEVE ANALYSIS							
LAYERS	NHA SPECIFICATION					TEST RESULTS	
EMBANKMENT LAYER	% passing on sieve no	A1 material	A2 material	A3 material	A4 material	% passing on sieve no	
	No.10	50 max	-	-	-	No.10	30.3
	No.40	30 max	-	51 min	-	No.40	20.7
	No.200	25 max	35 max	10 max	36 min	No.200	18.6
SUBGRADE LAYER	% passing on sieve no	A1 material	A2 material	A3 material	A4 material	% passing on sieve no	
	No.10	50 max	-	-	-	No.10	49.9
	No.40	30 max	-	51 min	-	No.40	29.1
	No.200	25 max	35 max	10 max	36 min	No.200	10.0
SUB BASE LAYER	Passing percentage on sieves 2", 1", 3/8", No.4, No.10, No. 40 and No. 200 are 100, 55-85, 40-70, 30-60, 20-50, 10-30 and 5-15 respectively.					Passing percentage on sieves 2", 1", 3/8", No.4, No.10, No. 40 and No. 200 are 100, 75.7, 56.7, 49.9, 36.4, 12.9, 3.4 respectively.	
AGGREGATE BASE COARSE	Passing percentage on sieves 2", 1, 3/8", 3/4", No.4, No.10, No. 40 and No. 200 is 100, 75-95, 30-65, 25-55, 15-40, 8-20 and 2-8 respectively.					Passing percentage on sieves 2", 1", 3/8", No.4, No.10, No. 40 and No. 200 are 100, 78.3, 66.0, 41.6, 28.6, 19.2, 10.8, and 7.7 respectively.	

Table 3 Showing plastic index, proctor, CBR, Los Angeles, sand equivalent and specific gravity test results of Project E-35, CPEC are compared with NHA specification (1998) .

	LAYER																		
Tests	Embankment layer						Subgrade layer					Sub base layer					Aggregate base coarse		
	NHA specification					Test results	NHA specification				Test results	NHA specification				Test results	NHA specification		Test results
Plastic index	A1	A2	A3	A4	A5		A1	A2	A3	A4		A1	A2	A3	A4		A1	A2	
	6 max	11 min	no	10 max	10 max	3.7	6 max	11 min	no	10 max	11.1	6 max	11 min	no	10 max	2.1	6 max	11 min	3.0
Proctor	-					MDD =2.220	-				MDD =2.119	-				MDD =2.223	-		MDD=2.200
CBR	CBR value not less than 5 % Swell value not > 0.5 %					CBR value 11.5 % Swell value 0.24	CBR value not less than 7 % Swell value not > 0.5 %				CBR value 12.5 % Swell value 0.22	CBR ≤ 50 %				CBR value 33.3 % Swell value 0.29	CBR value Not less than 80 %		CBR value 90 % Swell value 0
Los angeles	-					-	-				-	LAA not more than 50%				LLA is 25.5 %	LAA not more than 40%		LLA is 21.7%
Sand equivalent	-					-	-				-	All classes shall be 25 min				83%	Shall not be less than 45		46.4%
Specific gravity	-					-	-				-	-				-	-		Apparent SG 2.696

Conclusion

It is concluded that soil and aggregate base coarse constitutes coarse grains, silt, sand, and gravel. The Atterberg limits reveal that soil is low plastic or non-plastic. The California bearing ratio shows that soil and aggregate base coarse have a high load-bearing capacity, which shows that the material has high mechanical strength. The Los Angeles abrasion test results show that the material is resistive. The sand equivalent results show that aggregate base coarse indicate high sand material. The specific gravity result shows that the material is highly dense. All the tests performed in the laboratory shows that the material is suitable for road construction of project E-35 China-Pakistan Economic Corridor.

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