International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 08 | Aug 2020 www.irjet.net p-ISSN: 2395-0072

Design and Construction of a Nehemiah Wall

Mohammad Zahidul Karim[1], Sheikh Rifat Iftekhar[2]

[1]Lieutenant Colonel, Corps of Engineers, Bangladesh Army, Bangladesh
[2]Major, Corps of Engineers, Bangladesh Army, Bangladesh

Abstract - *This paper focuses on the design and performance of an anchored earth wall, namely, Nehemiah wall. Expansion of Dhaka (Jatrabari intersection) to Mawa road comprised of a four-lane highway with separate lanes for slow-moving vehicles for Dhaka–Khulna (N-8) highway. A significant volume of compacted earth fill was required to raise the grade as much as 50 m to meet the level of the existing embankments. A substantial amount of compacted earth fill was required to raise the grade to as much as 50 m to meet the level of existing embankments. Wherever possible, nominal 2H: 1V fill slopes were used, but RE walls were used where fill slopes would have invaded existing ridges. Thus two-tier Nehemiah walls were built along a portion of the bridge's edge. This paper describes problems and aspects associated with Nehemiah wall design and the performance observed. Consequences show adequate RE wall performance and correlates fairly well with the results forecasted.*

Key Words: Nehemiah wall, RE wall, Design, Performance, Soil stabilization

1. INTRODUCTION

Reinforced soil retaining structure has always been a common practice in various types of bridge construction when considering cost-effectiveness compared to their counterparts [1, 2]. It is evident that, between all other revolutionary design methods, advanced construction materials and incipient advances embraced by the Roads and Highways Department (RHD), Government of Bangladesh in the development of bridges or flyovers in Bangladesh, the reinforced earth (RE) walls have demonstrated their benefits over other customary reinforced concrete (RC) retaining walls by reducing time and costs of construction. Subsequently, during the venture of "Improvement of Jatrabari Intersection to Pachchar-Bhanga through Mawa Road of Dhaka-Khulna (N-8) Highway to 4-lane with Separate Lane for Slow Moving Vehicle", twenty RE walls (Nehemiah walls) were constructed for the embankments. The north and west RE walls were instrumented for construction performance monitoring. The performance data provided additional insight into the behavior of the RE walls during and immediately after construction. This paper focuses on the construction, design and performance of the Nehemiah walls monitored.

1.1 Project Background

The nation's first-ever international standard expressway named Dhaka-Mawa-Bhanga Expressway, to open up a new era of road connectivity between the capital city Dhaka and south and southwestern parts of the country i.e. Faridpur's Bhanga upazila, with a view to reducing travel time by several hours, is jointly implemented by the RHD and the BD Army (HQ 24 Engineers Construction Brigade) [3]. The project was approved by the Executive Committee of the National Economic Council (ECNEC) in May 2016 and was scheduled to be completed by the end of June 2020. The highway is being built under a two-phase project, viz. to improve the road from Jatrabari Intersection (including Equria–Babubazar link road) to Pachchar–Bhanga in Faridpur through Mawa Road of Dhaka–Khulna (N-8) Highway into a four-lane highway with separate lanes for slow-moving vehicles. Under this project, BD Army is upgrading the 55km-long Dhaka-Khulna Highway to four-lane. There will be separate service lanes for the slow-moving vehicles on both sides from Jatrabari to Mawa (around 35km) and Pachchar to Bhanga (around 20km) as per the project documents. After completion of the project, commuters would be able to reach Bhanga from the capital (around 75km) within an hour. In this study fundamental attention will be the design and performance of Nehemiah walls built at CH.29+300 Srinagar Railway over Bridge (ROB) Approach Road to Mawa End.

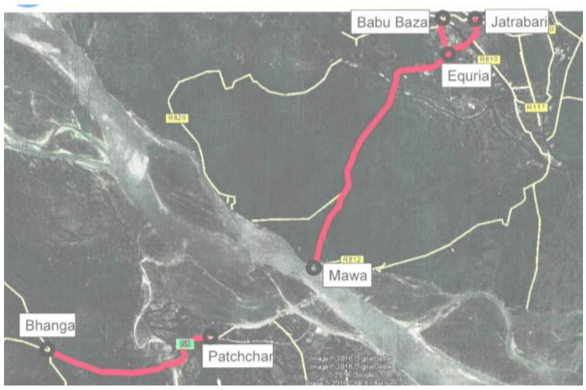


Fig -1: Project Alignment of the Dhaka-Mawa-Bhanga Expressway

1.2 Site and Subsurface Conditions

Expressway is a highway especially planned for high-speed traffic, usually having no or fewer number of intersections, limited points of access or exit, and a divider between lanes for traffic moving in opposite directions. The preconstruction topography of the project site is generally characterized by sieve analysis of back filling materials (sand) and conducting field density test using sand replacement method from Ch: L2+183.474 to Ch: 12+ 22A R/S Up#1, Mawa side.

Location of Sample : Stack yard of 17 ECB
Description of Mat. : Sand
Purpose of Use : Reinforced earth of RE wall

Sample No. :
Sampled by : Jointly.
Date of Sample : 16.10.2019
Date of Test : 16.10.2019

SIEVE ANALYSIS
(Ref.Test Method AASHTO T- 27)

Total Weight of Dry sample : 757.7 gm

Sieve Size (mm)	Ind. Weight Retained (gm)	Cumulative Wt. Retained (gm)	Cumulative % Retained	Cumulative % Passing	Specification Limit (Grading A)	
					Lower Limit	Upper Limit
4.75	18.9	18.9	2.5	97.5	100	100
2.36	39.4	58.3	7.7	92.3		
1.18	62.1	120.5	15.9	84.1		
0.60	137.9	258.4	34.1	65.9		
0.425	122.0	380.4	50.2	49.8	0	60
0.300	85.6	466.0	61.5	38.5		
0.150	194.0	660.0	87.1	12.9		
0.075	50.8	710.7	93.8	6.2	0	15
Pan	45.7	gm				

FM : 2.09

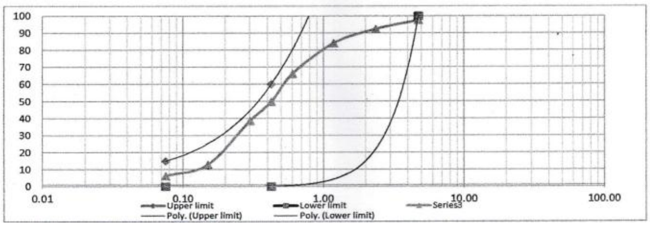


Fig -2: Back Filling Materials Testing

(Test Method AASHTO - T - 191)

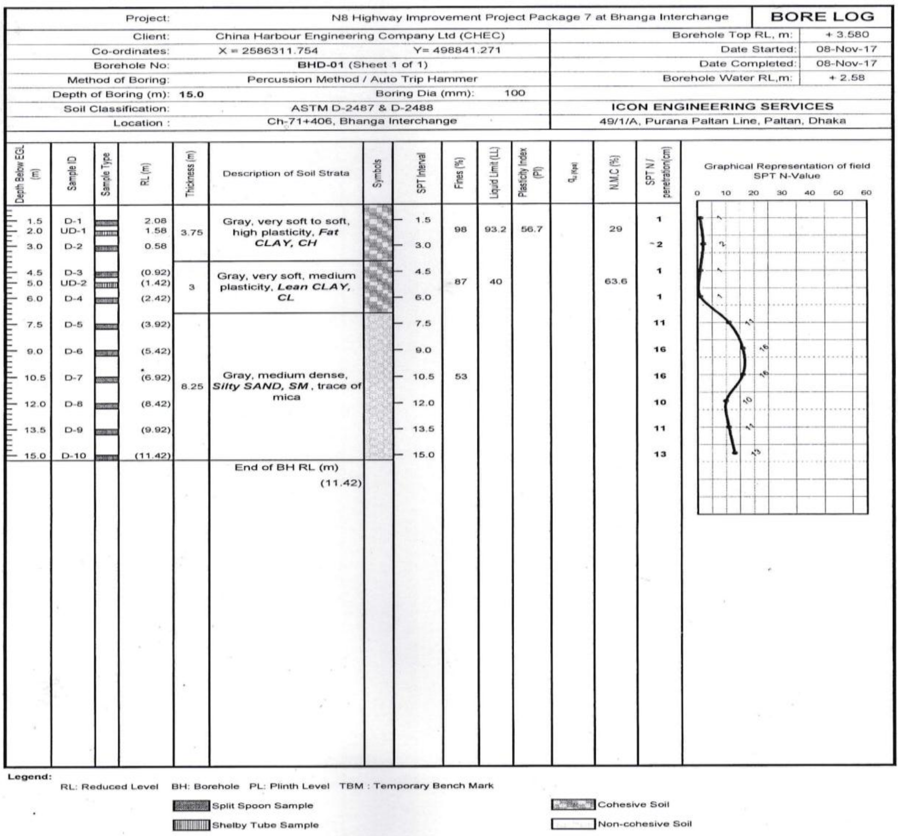
From Ch: 12 + 183.474 to Ch: 12 + 220 R/S UP#1, Mawa side.

Description of Layer : 37th layer of back filling of RE wall.

Unit weight of Sand: 1.288 gm/cc Date of Test: 16.10.2019

Test No.		#1	#2
General Information	Cylinder No.	#1	#2
	Spot Chainage	12+190	12+210
	Offset from Edge (m)	6.0	9.0
	Thickness of Hole (mm)	150	150
	Below from Top (mm)	--	--
DENSITY DETERMINATION			
Mass of wet sample from hole, m_w	gm	5082	5095
Mass of sand + cylinder before test, m_1	gm	8425	8343
Mass of sand + cylinder after test, m_2	gm	3850	4049
Mass of Sand in hole + Cone, $m_1 - m_2$	gm	4575	4294
Mass of Sand in Cone, m_3	gm	1255	956
Mass of Sand in hole, $m_b = (m_1 - m_2 - m_3)$	gm	3320	3338
Unit weight of Sand, Ts	gm/cc	1.288	
Volume of hole $V = m_b / T_s$	cc	2578	2592
Bulk density of sample, $P = m_w/V$	t/m^3	1.972	1.966
MOISTURE CONTENT & COMPACTION DETERMINATION			
Can No.		20	23
Mass of Can + Wet sample, P	gm	410.3	421.5
Mass of Can + Dry sample, Q	gm	360.1	370.3
Mass of Water, R=P-Q	gm	50.2	51.2
Mass of Can, C	gm	29.6	31.0
Mass of dry Soil, M_d=Q-C	gm	330.5	339.3
Water content, W=100R/M_d	%	15.2	15.1
Dry density, p_d=100p/(100+W)	t/m^3	1.711	1.708
MDD (Laboratory Value)	t/m^3	1.768	
OMC (Laboratory Value)	%	13.9	
Retain on 19mm Sieve	%	-	
Corrected MDD		-	
% Compaction, 100p_d/ MDD	%	96.8	96.6
Specified Compaction	%	95.0	

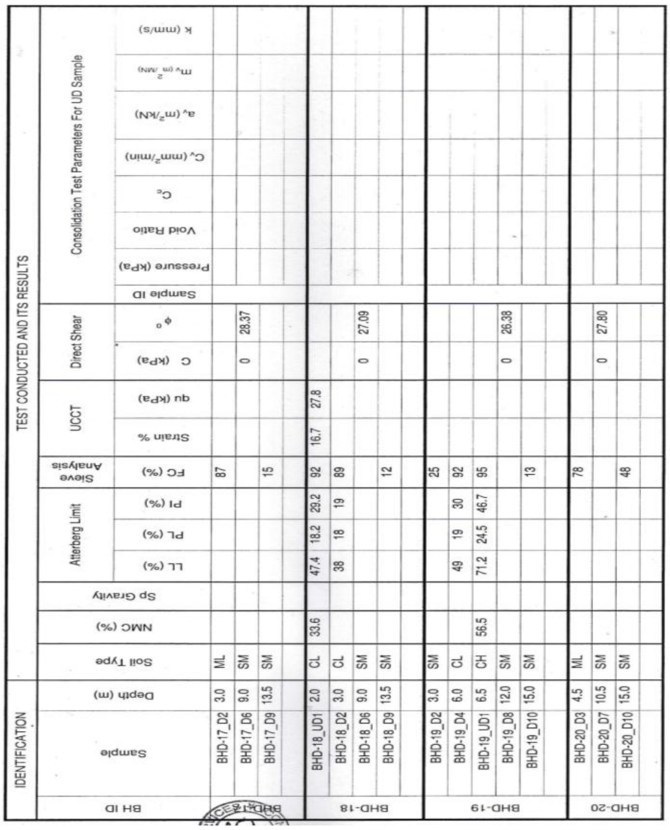
Fig -3: Field Density Testing



Project:	N8 Highway Improvement Project Package 7 at Bhanga Interchange	BORE LOG	
Client:	China Harbour Engineering Company Ltd (CHEC)	Borehole Top RL, m:	+ 3.580
Co-ordinates:	X = 2586311.754 Y= 498841.271	Date Started:	08-Nov-17
Borehole No:	BHD-01 (Sheet 1 of 1)	Date Completed:	08-Nov-17
Method of Boring:	Percussion Method / Auto Trip Hammer	Borehole Water RL,m:	+ 2.58
Depth of Boring (m):	15.0 Boring Dia (mm): 100		
Soil Classification:	ASTM D-2487 & D-2488	ICON ENGINEERING SERVICES	
Location :	Ch-71+406, Bhanga Interchange	49/1/A, Purana Paltan Line, Paltan, Dhaka	

Depth Below EGL (m)	Sample ID	RL (m)	Thickness (m)	Description of Soil Strata	SPT Interval	Fines (%)	Liquid Limit (LL)	Plasticity Index (PI)	q_u (Kpa)	N.M.C (%)	SPT N / penetration(cm)
1.5	D-1	2.08	3.75	Gray, very soft to soft, high plasticity, ***Fat CLAY, CH***	1.5	98	93.2	56.7		29	1
2.0	UD-1	1.58									
3.0	D-2	0.58			3.0						2
4.5	D-3	(0.92)	3	Gray, very soft, medium plasticity, ***Lean CLAY, CL***	4.5	87	40			63.6	1
5.0	UD-2	(1.42)									
6.0	D-4	(2.42)			6.0						1
7.5	D-5	(3.92)	8.25	Gray, medium dense, ***Silty SAND, SM***, trace of mica	7.5						11
9.0	D-6	(5.42)			9.0						16
10.5	D-7	(6.92)			10.5	53					16
12.0	D-8	(8.42)			12.0						10
13.5	D-9	(9.92)			13.5						11
15.0	D-10	(11.42)			15.0						13
				End of BH RL (m) (11.42)							

Fig -4: Sample Bore Log Data

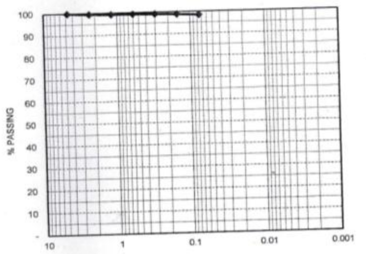


IDENTIFICATION			TEST CONDUCTED AND ITS RESULTS																			
						Atterberg Limit			Sieve Analysis	UCCT		Direct Shear		Consolidation Test Parameters For UD Sample								
BH ID	Sample	Depth (m)	Soil Type	NMC (%)	Sp Gravity	LL (%)	PL (%)	PI (%)	FC (%)	Strain %	qu (kPa)	C (kPa)	φ°	Sample ID	Pressure (kPa)	Void Ratio	C_c	C_v (mm²/min)	a_v (m²/kN)	m_v (m²/MN)	k (mm/s)
BHD-17	BHD-17_D2	3.0	ML						87												
	BHD-17_D6	9.0	SM									0	28.37								
	BHD-17_D9	13.5	SM						15												
BHD-18	BHD-18_UD1	2.0	CL	33.6		47.4	18.2	29.2	92	16.7	27.8										
	BHD-18_D2	3.0	CL			38	18	19	89												
	BHD-18_D6	9.0	SM									0	27.09								
	BHD-18_D9	13.5	SM						12												
BHD-19	BHD-19_D2	3.0	SM						25												
	BHD-19_D4	6.0	CL			49	19	30	92												
	BHD-19_UD1	6.5	CH	56.5		71.2	24.5	46.7	95												
	BHD-19_D8	12.0	SM									0	26.38								
	BHD-19_D10	15.0	SM						13												
BHD-20	BHD-20_D3	4.5	ML						78												
	BHD-20_D7	10.5	SM									0	27.80								
	BHD-20_D10	15.0	SM						48												

Fig -5: Summary of Laboratory Test Results

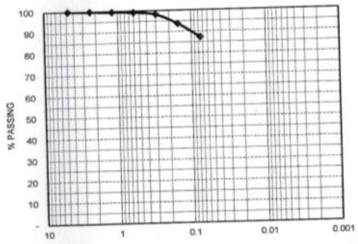
Borehole ID	BHD-1
Sample ID	UD-1
Depth, m	2
Test Data	1
Wt of can (g)	17.2
Wt of wt soil + can (g)	117.2
Wt. of dry soil (g)	100

Sieve Size (mm)	Wt Retained(g) Soil+can (g)	Wt Retained(g) Soil (g)	Passing %
4.75	17.35	0.15	99.85
2.38	17.56	0.36	99.49
1.19	17.4	0.20	99.29
0.6	17.34	0.14	99.15
0.3	17.29	0.09	99.06
0.15	17.45	0.25	98.81
0.075	17.63	0.43	98.38



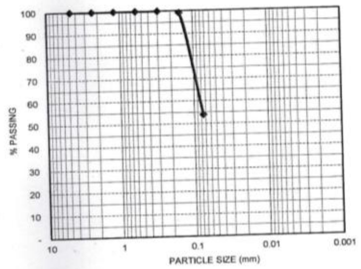
Borehole ID	BHD-1
Sample ID	UD-2
Depth, m	5.0
Test Data	2
Wt of can (g)	17.2
Wt of wt soil + can (g)	117.2
Wt. of dry soil (g)	100

Sieve Size (mm)	Wt Retained(g) Soil+can (g)	Wt Retained(g) Soil (g)	Passing %
4.75	17.2	-	100.00
2.38	17.36	0.16	99.84
1.19	17.42	0.22	99.62
0.6	17.54	0.34	99.28
0.3	18.23	1.03	98.25
0.15	21.78	4.58	93.67
0.075	23.65	6.45	87.22



Borehole ID	BHD-1
Sample ID	D-7
Depth, m	10.5
Test Data	3
Wt of can (g)	17.2
Wt of wt soil + can (g)	117.20
Wt. of dry soil (g)	100

Sieve Size (mm)	Wt Retained(g) Soil+can (g)	Wt Retained(g) Soil (g)	Passing %
4.75	17.2	-	100.00
2.38	17.2	-	100.00
1.19	17.2	-	100.00
0.6	17.2	-	100.00
0.3	17.2	-	100.00
0.15	18.14	0.94	99.06
0.075	62.43	45.23	53.83

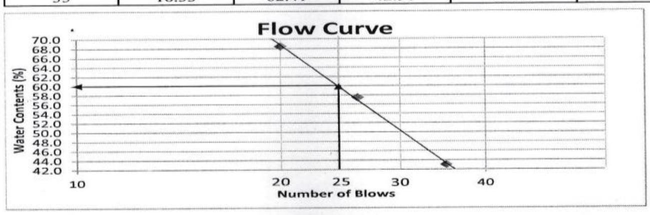


Borehole ID	Depth, m	Sample ID		Fine Content %	Particle size, mm D_{10}	D_{20}	D_{30}	D_{50}	D_{60}	Silt factor, f f=1.76*sqrtD_{50}	C_c
BHD-1	2.00	UD-1		98.38							
BHD-1	5.00	UD-2		87.22							
BHD-1	10.50	D-7		53.83							

Fig -6: Particle Size Analysis of Soils

Table for Liquid Limit Determination

No of Blows (x)	Weight of can W_1 (gm)	Wet Weight of sample W_2 (gm)	Dry weight of sample W_3 (gm)	Water content (%), $W = (W_2 - W_3) / (W_3 - W_1) \times 100$ (y)	Water content close to 25 blows
20	18.17	65.72	46.41	68.38	
26	17.45	68.71	50.00	57.48	68.38
35	16.33	62.41	42.91	43.00	



Note : Adjust its water content until the constancy requires about 25 to 35 blows of the liquid limit device to close the groove.

Table for Plastic Limit Determination

Weight of can W_1 (gm)	Wet Weight of sample W_2 (gm)	Dry weight of sample W_3 (gm)	Water content (%), $W = (W_2 - W_3) / (W_3 - W_1) \times 100$ (PLASTIC LIMIT)
52.95	53.98	53.75	28.75
61.97	63.04	62.83	24.42
48.42	49.79	49.50	26.85
Average value	26.67		

Result Summary	
Liquid Limit,LL(%) =	60.00
Plastic Limit,PL(%)=	26.67
Plasticity Index, PI (%) =	33.33

Fig -7: Determination of Atterberg Limits and Indices

The portion of the Nehemiah wall occupies an area previously serving as a seasonal drainage tributary. The walls were constructed to avoid having to relocate the creek. In general, the subsurface conditions below the footprint of the RE wall prior to construction comprised 6m of soft clay, interlayered with loose to medium dense silty sand and sandy peat, dense to very dense, slightly gravelly, silty to very silty sand. Shallow perched groundwater followed the surface of the overridden soils.

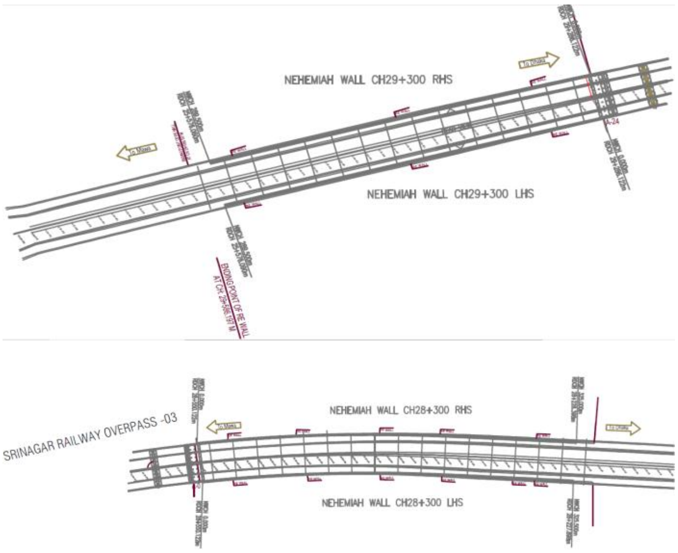


Fig -8: Layout Plan of Proposed Nehemiah Wall

1.3 Selected Aspects of Nehemiah Wall Design

Nehemiah wall is a type of reinforced soil system based on Anchored Earth concept whereby the mode of stress transfer from the back-fill to the reinforcement is by passive resistance in addition to friction. This System is reinforced by galvanized steel bars and anchored by precast concrete blocks. The facing is vertical consisting of modular hexagonal shaped concrete panels interlocked together [4].

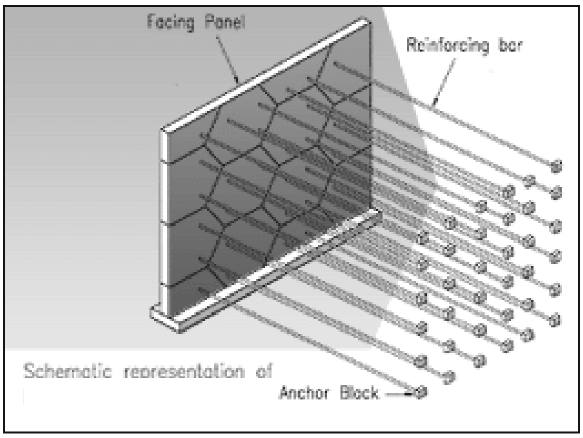


Fig -9: Schematic representation of Nehemiah wall [4]

FACING PANELS

The facing panels are constructed of precast concrete (grade 30) and are hexagonal in form. The interlock between dowel bars is of sensitive horizontal gestures and compressible material is placed in addition to facilitate vertical movement of the horizontal joints between the panels. Naturally the facing turns out to be robust and can accommodate all-encompassing differential settlement [4].

REINFORCING ELEMENTS

The reinforcement bars are constructed of carbon steels in keeping with BS 8006-1:2016 code of conduct for reinforced soils retaining structures and other fillings. The bars are galvanized with deep dips to avoid corrosion and have circular bars instead of wires so that limited surface area is exposed and hence become more resilient against corrosion. Finally, the bars are connected to the facing panels [4].

ANCHOR BLOCKS

Precast concrete anchor blocks are used where a hole is pre-formed to allow the reinforcing bar to traverse. The bar is then attached with bolts and nuts to the board. The advantage of using anchor blocks is that the reinforcing bars enhance the pull-out resistance and acts as discrete blocks. Thus it is possible to use solid frictional content as back-fill, as the device does not depend too much on friction for the tension transition [4].

BACKFILLS

In addition the backfill is constructed of granular materials and concrete gets the benefits of self-draining. This characteristic of self-draining aids in reducing hydrostatic pressure. Therefore the wall's overall stability is enhanced. Even the granular substance has improved frictional properties that further increase the wall's internal stability. Nonetheless, compact frictional fill can be recommended for use as backfill in a case where the granular content is not usable. The fill will therefore be checked and subject to other technological properties being satisfied [4].

2. DESIGN AND CONSTRUCTION OF THE RE WALL

The full scale Nehemiah wall designed as per the BS 8006:1995 [5] was built to support the approach road as part of the Dhaka-Mawa road for Jatrabari intersection. The wall was fragmented into two tiers with the upper tier being offset from the lower tier by a distance of 1.5 m. The subsoil consisted of an upper stratum of firm to stiff sandy clayey silt. The shear strength of the stratum increased with respect to depth for which the sandy clayey silt stratum was underlain by highly decomposed shale mostly.

River sand was used as backfill material. Resistivity test was carried out and found to range from 12500 ohm cm to 14440 ohm cm, which was considered as non-corrosive and suitable for use as backfill. The pH value of the sand was found to be 5.5. The resistivity

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 08 | Aug 2020 www.irjet.net p-ISSN: 2395-0072

and pH were measured to ensure that the backfill material was not corrosive. The shear strength parameters were obtained from direct shear test. The angle of friction was found to be 28.09 degrees at peak stress while at residue stress the angle was 23 degrees. Conservatively, an angle of friction of 26 degree at peak stress was assumed in the design. The cohesion was taken to be zero.

BH ID	Depth, m	Sample ID	Shearing Area, cm^2
BHD-1	15.0	D-10	27.144

Angle of internal friction, $\phi°$	Cohesion, c, kPa	Soil Type
28.09	0	

Normal Stress σ_n (kPa)	Proven Ring Dial Reading	Shear Stress τ (kPa)
0.000	0.0	0.000
3.247	9.0	1.530
6.494	19.5	3.567
16.673	47.0	8.901

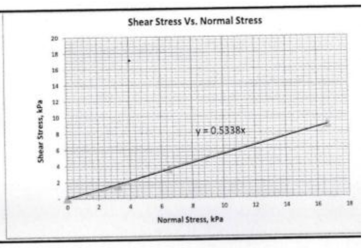
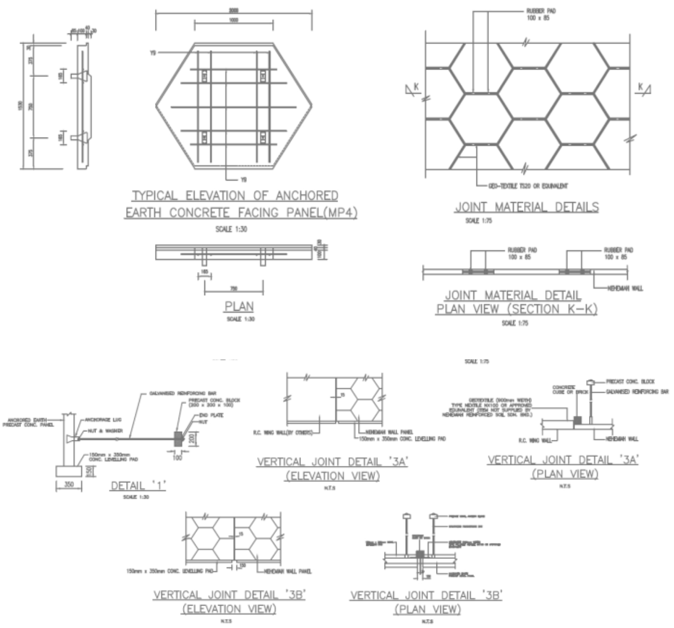


Fig -10: Results of Direct Shear Test

Prior to constructing the RE walls, the main embankment fill directly east of the wall had been in place for about 1 year. The excavation of unsuitable subgrade material and its replacement with compacted structural fill below the west RE wall occurred during September 2018. Fig. 4 shows the filling time history for the west MSE wall and at two locations approximately 43 and 73 m behind the wall. Construction of the west MSE wall began January 5, 2019, with the first, 14.6-m (48-ft) tall, tier completed 58 days later. Construction of the second, 11.7-m (38.4-ft) high, tier of the RE wall began on day 72 and took 41 days to complete.



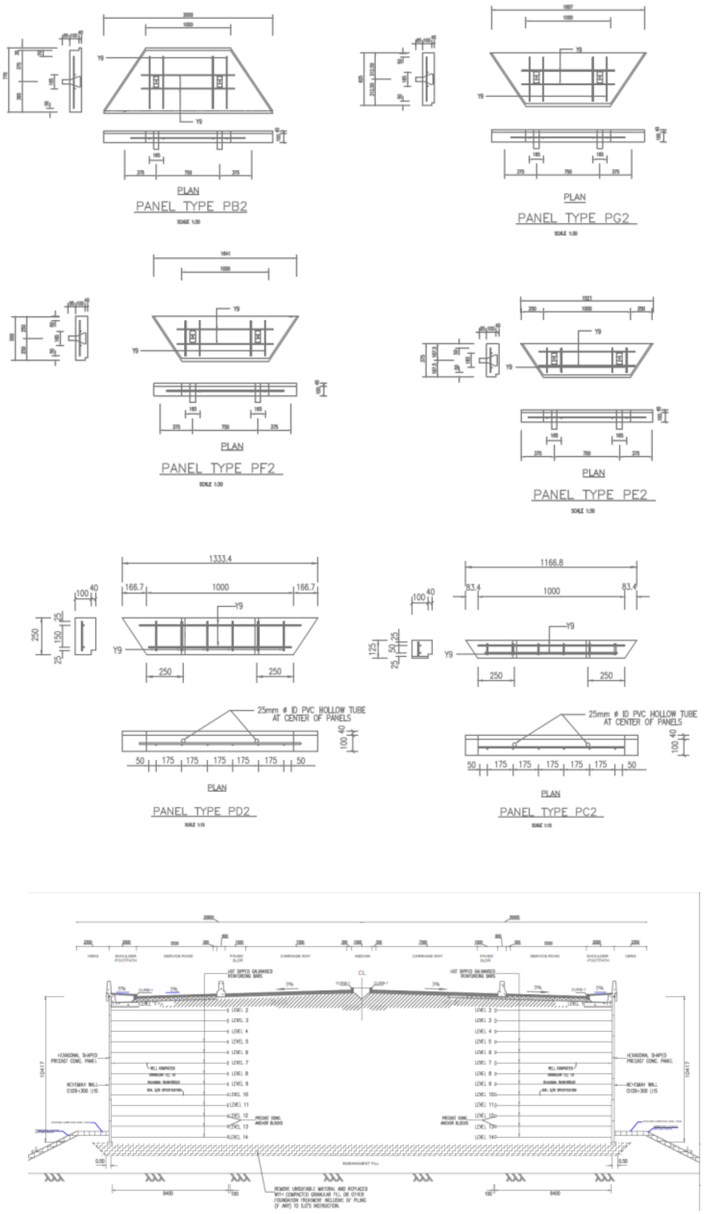


Fig -11: Plan, Elevation and Sections of RE Wall

Fig -12: Photo of Nehemiah Wall at Approach Road

Fig -13: Photo of Nehemiah Wall at Embankment

3. CONCLUSIONS

The Nehemiah wall for the Srinagar ROB from Dhaka to Mawa End was constructed to avoid stream relocation and minimize settlement impacts. The design team selected steel strip reinforced earth technology based on past successful construction of RE walls to limit the amount and extent of embankment fill. Good project team coordination between the BD Army and the RHD, with oversight by a technical review board and other peer review, contributed to the successful completion of the reinforced soil retaining structure. Geotechnical investigation included wall surveys, piezometers, and strain gages at different points on the RE wall strips by the design and construction team with the information required to verify performance of the wall relative to design as construction progressed. The full scale wall performance data provide better understanding of the behavior of such RE walls and can be used as reference data for future Nehemiah wall designers. The overall efficiency of the Nehemiah wall as measured by the geotechnical instrumentation being applied is excellent.

ACKNOWLEDGEMENT

The authors would like to acknowledge their sincere gratitude to the Headquarter 24 Engineer Construction Brigade of Bangladesh Army and the Roads and Highways Department (RHD), Bangladesh for providing all critical information pertinent to the generation of this document.

REFERENCES

[1] Singh, H., & Akhtar, S. (2015). A review on economic analysis of Reinforced Earth wall with different types of Reinforcing materials. Ultemas iv.

[2] Lee, C.H. and N.S. Nilaweera. (2002). Design and construction of a 20.5 m high innovative Nehemiah wall near Cameron Highland, Pahang. Second World Engineering Congress, Sarawak, Malaysia. pp: 117-120.

[3] Retrieved from the website: https://www.dhakatribune.com/image-gallery/2020/03/11/country-s-first-expressway-opens-thursday

[4] Retrieved from the website: https://www.nehemiah-grp.com/nh-nehemiah-wall

[5] BS 8006: 1995. Code of Practice For Strengthened /Reinforced Soils and Other Fills.

BIOGRAPHIES

Lieutenant Colonel Mohammad Zahidul Karim,Psc was commissioned in the Corps of Engineers on 12 July 2002. He completed his graduation in Civil Engineering from Military Institute of Science and Technology (Bangladesh) after joining the army. He served as Project officer (PO) in Dhaka-Khulna National Highway (N8) Improvement project which is the first access controlled express highway of Bangladesh. Presently, he is serving as Additional Director in same road construction project.

Major Sheikh Rifat Iftekhar,Engrs was commissioned in the Corps of Engineers on 25 June 2014. He completed his graduation in Civil Engineering from Ahsanullah University of Science and Technology before joining the army. He served as Assistant Project Officer (APO) in Dhaka-Khulna National Highway (N8) Improvement project which is the first access controlled express highway of Bangladesh.