International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Depth of Soft Cohesive Soil Underlying Highway Embankment for Limiting Residual Settlement

Sharifullah Ahmed P.Eng

Ph. D. Scholar (Geotechnical), Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka–1000, Bangladesh
Sr. Geotechnical Engineer, Soil Investigation Division, Bangladesh Road Research Laboratory (BRRL), Mirpur, Dhaka-1216, Bangladesh

Email: *sharif.geo.2006[at]gmail.com*

Abstract: ***Residual settlement of highway embankment is studied for different compressibility of cohesive subsoil. Parametric study is carried out for different height of road embankment and different depth of natural soft soil underlying the embankment. The Residual Settlement is considered as the sum of 70% of consolidation settlement and elastic settlement due to axle load only which are to be occurred after construction of pavement and before the first maintenance of road pavement. The values of residual settlement (S_r) for different depths of soft subsoil (H_s) are obtained and presented graphically for different SPT Value (N_{60}) and different Compression Ratio (CR). The tolerable limit of residual settlement is 0.100m for rigid pavement and flexible pavement in approach to bridge or culvert. For flexible pavement in general road sections this tolerable limit is taken as 0.200m. A design guideline is developed for construction of highway embankment in Bangladesh underlain by soft cohesive clayey subsoil to limit the residual settlement with in mentioned tolerable limit considering ESAL factor of 10 and for the ranges of Field SPT value, Liquid limit and Natural void ratio of 1-4, 30%-90% and 0.6-1.8 successively. Design tables, design charts and empirical equations are incorporated in this guideline. Simplified values of the ratio of embankment height (H_e) to soft subsoil depth (H_s) are obtained corresponding to satisfying tolerable or limiting level of the residual settlement. The developed guideline may be used in assessment of necessity of ground improvement to satisfy tolerable settlement limit. The ground improvement is only necessary when the residual settlement is not within tolerable limit corresponding to the soft subsoil depth.***

Keywords: Consolidation Pressure, Consolidation Time, Equivalent Standard Axle Load (*ESAL*), Ground Improvement, Highway Embankment, Tolerable Residual Settlement

1. Introduction

Highway construction in Bangladesh often to be implemented over soft cohesive natural subsoil. Usually ground improvement is often provided to strengthen the soft cohesive subsoil underlying the proposed highway embankment. However, the ground improvement not to be necessary in such a case, where the residual settlement of soft subsoil is within tolerable limit.

The current research study is conducted in aim to prepare a guideline for assessing necessity of ground improvement for highway embankment underlain by soft cohesive clayey soil considering the exceedance of the limiting value of residual settlement.

2. Loads on Subsoil

The types of stress on Highway Embankment is axle load of traffic vehicle. Stress on subsoil underlying the embankment is transferred portion of axle load and self-weight of embankment. As per Bangladesh Road Master Plan [1], standard axle loads for calculating Equivalent Standard Axle Load (*ESAL*) are front (steering) axle - 65kN, rear single axle - 80 kN, and tandem axles - 145 kN. As per traffic survey [1] according to mentioned standard axle loads in different national highways throughout the Bangladesh value of the *ESAL* for dual tyre single axle is greater than 30. This value is much higher than the maximum allowable *ESAL*=4.8 [1]. Considering this overloading *ESAL*=10 is considered for calculation of elastic settlement in current study.

$$\text{Equivalent Standard Axle Load, } ESAL = W_a / W_r \quad (1)$$

$$\text{or, } W_a = ESAL(W_r) \quad (2)$$

where, W_a is Actual Axle Load (kN) and W_r is Standard Axle Load or Reference axle load (80kN).

3. Stress Distribution

3.1 Distribution of Axle Load

The simplest approach of stress distribution at a depth of soil is the 2V:1H (vertical to horizontal). This empirical method is used for axle load distribution [2]. Due to spreading of the vertical load over larger area at a depth, the unit stress reduced. Stress on the plan at depth z,

$$\sigma_z = \frac{\sigma_0 BL}{(B+z)(L+z)} \quad (3)$$

According to [2], the concentrated load on pavement,

$$\sigma_0 BL = (W_a/2)BL = W_a/2 \quad (4)$$

where, W_a is Axle Load and *B*, *L* is width and length of tyre to pavement contact area successively.

Pressure transferred to embankment fill below pavement due to Wheel Load,

$$\sigma_z = \frac{\frac{W_a}{2}}{(B+H_e)(L+H_e)} \quad (5)$$

Considering interface or overlap of pressure from two wheel in an axle [3],

$$\sigma_z = \frac{2\frac{W_a}{2}}{(B+H_e)(L+H_e)} = \frac{W_a}{(B+H_e)(L+H_e)} \quad (6)$$

where, H_e isHeight of Embankment fill above natural ground level.

For HS 20-44 Truck and Tandem, the design contact tyre area for dual tyre single axle is a single rectangle of width, *B*= 510mm and length, *L*= 250mm [4][5]. Similarly, for dual tyre tandem axle the design contact area is a double rectangle of total width, *B*= 510mm and total length, *L*= 500mm. These values of *B* and *L* are used in current analysis of stress distribution.

3.2 Embankment Pressure Distribution

Embankment Pressure at bottom level of embankment is

$$q_e = \gamma_e H_e \tag{7}$$

where, H_e isHeight of Embankment fill excluding pavement layers above natural ground level and γ_e is Bulk Unit weight of embankment fill.

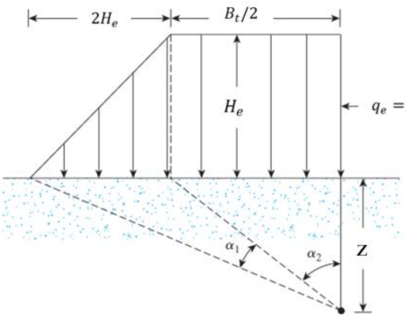

Figure 1: Stress Reduction Due to Embankment loading considering 1V:2H Side slope [6]

Embankment Pressure (q_e) is considered to be distributed as per [6].

According to mentioned distribution, the consolidation Pressure at *z* depth below center of embankment considering 1V:2H side slope of embankment (Figure :1) [6],

$$\Delta\sigma_0 = \frac{q_e}{\pi}\left[\left(\frac{\frac{B_t}{2} + 2H_e}{2H_e}\right)(\alpha_1 + \alpha_2) - \left(\frac{\frac{B_t}{2}}{2H_e}\right)(\alpha_2)\right] \tag{8}$$

where, B_t is width of embankment top.

In equation (8), considering $B_t/2$as the distance between stressed point and end of embankment top–

$$\alpha_1 = tan^{-1}\left(\frac{\frac{B_t}{2} + 2H_e}{z}\right) - tan^{-1}\left(\frac{\frac{B_t}{2}}{z}\right)$$

$$\alpha_2 = tan^{-1}\left(\frac{\frac{B_t}{2}}{z}\right) \text{and} \alpha_1 + \alpha_2 = tan^{-1}\left(\frac{\frac{B_t}{2}+2H_e}{z}\right).$$

Now, for Consolidation Pressure at $H_s/2$ depth below the end point of embankment top (replacing$\frac{B_t}{2}$ by 0),

$$\Delta\sigma_1 = \frac{q_e}{\pi}\alpha_1 \tag{9}$$

In equation (9), considering zero distance between stressed point and end of embankment top–

$\alpha_2 = 0$and $\alpha_1 + \alpha_2 = tan^{-1}\left(\frac{2H_e}{z}\right) = \alpha_1$.

Average Consolidation Pressure at H_s depth below the embankment,

$$\Delta\sigma = \frac{1}{2}(\Delta\sigma_0 + \Delta\sigma_1) \tag{10}$$

where, $\Delta\sigma_0$ is Consolidation Pressure at *z* depth below center of embankment and $\Delta\sigma_1$is Consolidation Pressure at *z* depth below the end of embankment top.

In Bangladesh the range of width carriage way is 3.0m to 22.0m [7]. Then range of corresponding crest width including shoulder, verge and median is 5.0m to 30.0m. For 4 Lane highway and expressway the range of crest width to be 30m to 40m. In this study, the range of crest width (at top level of embankment) is kept between 5m and 50m.The range of embankment height1m to12m and side slope of embankment 1V:2H are taken for analysis.

4. Settlement of Soft Subsoil

4.1 Elastic Settlement

Janbu et al. [8] suggested Elastic Settlement of soft undrained cohesive soil, $S_e = q_d(B_t + H_e)\frac{A_1 A_2}{E_s}$(11) For silts, sandy silt, or clayey silt, Bowles [9] suggested, Elastic Modulus, E_s=0.3*N*+1.8 (MPa) (12) where, H_e is height of highway embankment ($= D_f$), q_d is Pressure on Subsoil, A_1,A_2 are Factor for elastic settlement calculation after Christian et. al. [10], H_s is depth of soft subsoil(=*H*) and *N*is Field SPT (=N_{60}).

4.2 Consolidation Settlement

Consolidation of subsoil is to be occurred due to only fixed load. So, wheel or axle load has no contribution in consolidation pressure which are not fixed at any point. Effective Overburden Pressure at $H_s/2$ depth,

$$\sigma_0' = \gamma'\left(\frac{H_s}{2}\right) \tag{13}$$

Consolidation Settlement suggested by [11],

$$S_c = \frac{H_s}{1+e_0} c_c \log\frac{\sigma'_o + \Delta\sigma}{\sigma'_o} \tag{14}$$

where, C_c is Compression Index, e_0 is Natural Void Ratio, H_s is Depth of soft subsoil layer underlying highway embankment, γ is saturated unit weight of clay ground, σ'_0 is Effective Overburden Pressure at ($H_s/2$) depth and $\Delta\sigma$ is Consolidation Pressure at soft soil layer below the midpoint of embankment obtained from Eq.8, 9 & 10 considering $z=H_s/2$.

4.3 Secondary Compression

Secondary compression or creep settlement [11],

$$S_\alpha = \frac{H_s}{1+e_0} c_\alpha \log\frac{t}{t_p} \tag{15}$$

where, e_o is the initial void ratio, C_α is the rate of secondary compression, *t* is the elapsed time after the end of primary consolidation and t_p is the time required to reach the end of primary consolidation.

5. Residual Settlement

5.1 Definition of Residual Settlement

The portion of total settlement which to be occurred after construction of road pavement is termed as Residual or post construction settlement. The residual portion of consolidation settlement is to be considered in assessment of settlement risk. The time-settlement curve under surcharge load observed by [12] is presented in Table 1. According to that time-settlement data (Table 1), approximately 20% and 30% of total consolidation to be occurred within 1 years and 0.27 years after completion of embankment filling and before the construction of surface layers of pavement considering one way and two way drainage successively. So that, after finish of road pavement construction 80% and 70% consolidation to be occurred after filling of embankment in case of one way and two way drainage successively. This portion of consolidation is considered as residual portion of settlement for 25 years or more service life.

Therefore, the residual portion consolidation settlement to be80% and 70% of total consolidation settlement one way and two way drainage successively. However, maximum 90% consolidation settlement to be reached in case of one way drainage within 25 years. Before end of this period maintenance to be proceeded to recover 90% consolidation. Hence, for one way drainage in residual settlement is also 70% of total consolidation may be considered.

The Elastic Settlement of subsoil layer below embankment due to axle load is also included in residual settlement. Maintenance period of a newly constructed highway is 10-15 years in Bangladesh. The time to occur 90% dissipation of pore pressure or 90% consolation also not more than 15-20 years. Secondary settlement is to be occurred after 15-20 years and approximately after 5 years from recovery of the Consolidation and Elastic Settlements through first maintenance of pavement.

Finally the Residual Settlement is considered as,

$$S_r = S_e + 0.7 S_c \tag{16}$$

where, S_e is Elastic Settlement of soft subsoil below embankment due to axle load to be occurred after construction and S_c is total Consolidation settlement.

5.2 Tolerable Residual Settlement

The following criterion is found for tolerable residual or post construction settlement:

a) Hsi and Martin [13] suggested the tolerable limit of residual settlement of 0.100m-0.160m over 40 years. Long and O' Riordan (2001) suggested differential settlement should not exceed 0.050m after the operation of 25 years design life. This criteria is followed in Australia
b) According to IRC: 75-2015 [14], permissible limit of the residual settlement is 0.300m.
c) Larisch et. al. [15] suggested total post construction settlement should be less than 0.100 m and Maximum differential settlement should be 0.3% change in grade over 40 years for plain concrete (rigid) pavement.
d) According to Ministry of Transport, MOT (22TCN-262:2000), Vietnam, post construction primary consolidation settlement for expressway and highway embankment with design speed of 80 km/hr shall be smaller than 0.100 m, 0.200 m, and 0.300 m corresponding to embankment approach to bridge, near the culvert, and other areas remote from the structures, respectively [16].
e) According JKR (PWD), Malaysia total post construction settlement<0.210m&<0.250m for bridge approach and except embankment bridge approach successively [16].

Settlement limit for 40 years is considered because, road embankment is likely to be constructed for 40 years. Only pavement to be reconstructed. As mentioned above for rigid pavement and approach to bridge the tolerable limit of residual settlement is 0.100m. For flexible pavement in general road sections, this limits to be more in general technical sense. As reference Design standard and Highway authority is more reliable than publication. In this sense, (i) MOT (22TCN-262:2000), Vietnam, (ii) JKR (PWD), Malaysia and (iii) IRC:75-2015 are the most reliable references for tolerable residual settlement. As per these three references and the professional judgement the tolerable limit of residual settlement is taken as 0.200mm for flexible pavement in general road sections.

6. Analysis Result

6.1 Ranges of Parameters

The current study is limited between the ranges of Liquid limit (*LL*) of 30% to 90% and Natural void ratio (e_0) of 0.6 to 1.8 are used as presented in Table 2. The corresponding ranges of Compression Index and Compression Ratio are also derived.

As observed in Figure 2 and Figure 3 the maximum variation of residual Settlement with variation of B_t between 5m and 50m is only 4.2% which is not significant. So, the residual settlement chart need not to be prepared for small interval such as 5m, 10m, 20, 30m, 30m, 40m and 50m. Highest value of S_r found for the highest value of B_t=50m. Considering this, the residual settlement chart is prepared for only B_t=50m. However, as observed in Figure 4 and Figure 5 variation of S_r with N_{60} is significant (minimum 25.5%). Considering this variation, separate residual settlement chart is prepared for N_{60}=1, 2, 3 and 4. Average bulk unit weight of embankment fill (γ_e) and saturated unit weight of soft soil (γ) is considered 19.5kN/m^3 and 21kN/m^3 successively.

6.2 Residual Settlement Charts

Residual settlement, S_r(m) for different value of and H_s/H_s are obtained and presented graphically for value of *LL*, e_0 and N_{60} in Figure 6 to Figure 19. Residual settlement value, S_r may be obtained from those Figures for a particular value of *CR*, N_{60} and H_s/H_s for B_t=50m. Same value may be used for B_t less than 50m.

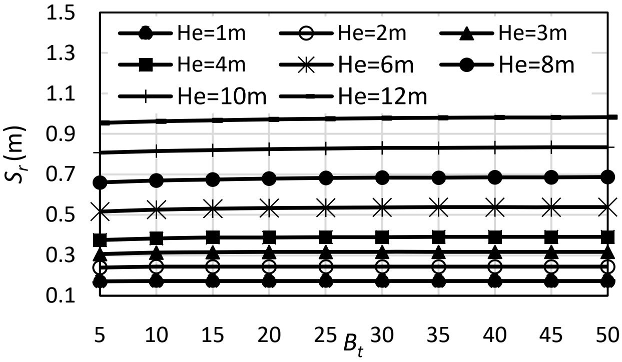

Figure 2: B_t Vs S_r for H_s/H_e=3, N_{60}=1, *CR*=0.11

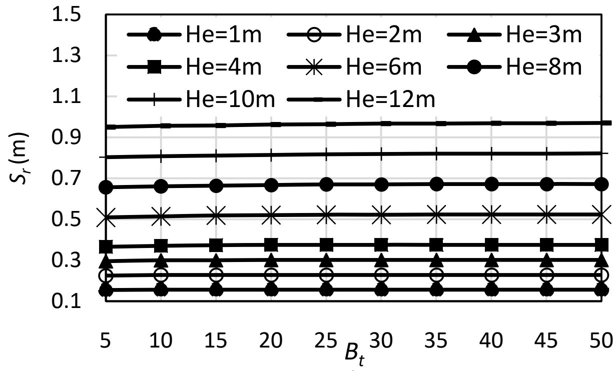

Figure 3: B_t Vs S_r for H_s/H_e=3, N_{60}=1, *CR*=0.16

6.3 Guideline for Tolerable S_r

Maximum allowable values of H_s/H_e are tabulated in Table 3 and Table 4 for B_t=50m. For a particular H_e, N_{60} and *CR* the H_s/H_e shall not be greater than the tabulated value of Table 3 and Table 4to limit the residual settlement at 0.100m and 0.200m successively. These tables may be used for crest width of highway embankment ≤50m.

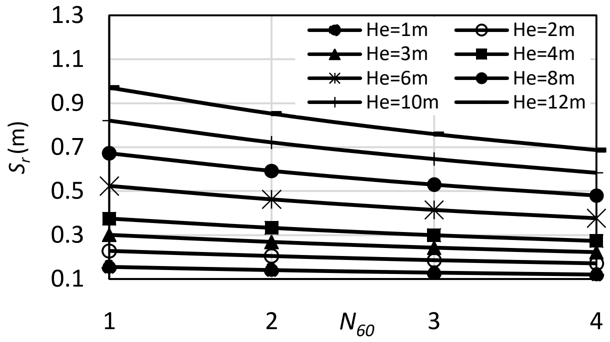

Figure 4: N_{60} Vs S_r for H_s/H_e=3, *LL*=40, e_0=0.8

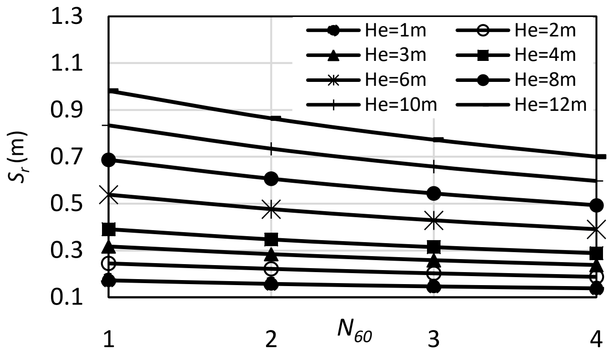

Figure 5: N_{60} Vs S_r for H_s/H_e=4, *LL*=60, e_0=1.2

Table 1: According to [12] the Consolidation settlement and time data

Time (Year)	Consolidation Settlement (mm)		% of Total Consolidation	
	Two way drainage	One way drainage	Two way drainage	One way drainage
0.05	280	110	20	8
0.27	590	240	32	17
1	700	280	50	20
2	1000	418	71	30
2.74	1390	770	99	55
25	-	1260	-	90
27.4	-	1400	-	100

Table 2: Ranges of Liquid limit (*LL*), Natural void ratio (e_0) and corresponding Compression Ratio (*CR*)

Liquid Limit, *LL (%)*	30	45	60	75	90
Void Ratio, e_0	0.6	0.9	1.2	1.5	1.8
Compression Index suggested by [17], C_c=0.0078(*LL*-14)	0.12	0.24	0.36	0.48	0.59
Compression Ratio, $CR=C_c/(1+e_0)$	0.08	0.13	0.16	0.19	0.21

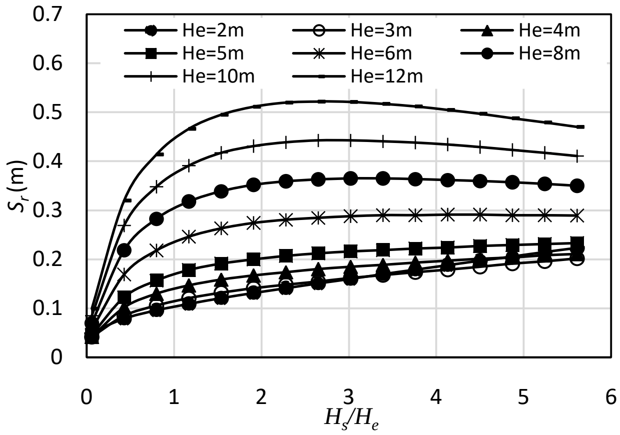

Figure 6: H_s/H_e Vs S_r for N_{60}=1, CR=0.13, B_t=50m

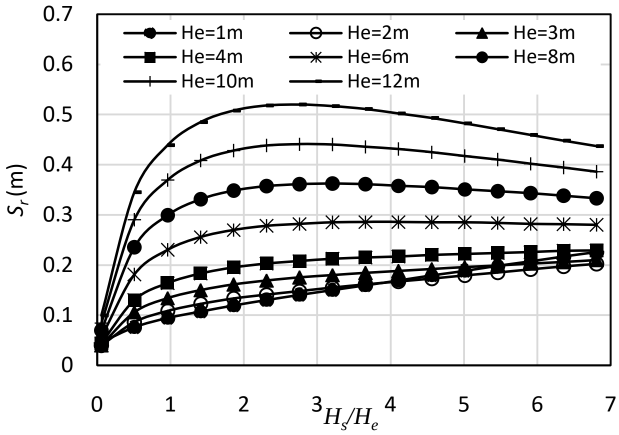

Figure 10: H_s/H_e Vs S_r for N_{60}=2, CR=0.13, B_t=50m

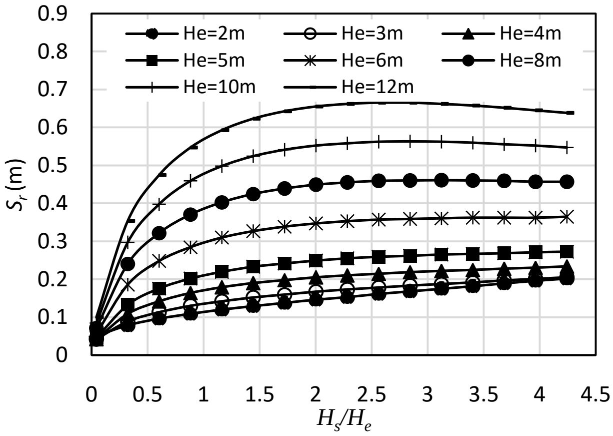

Figure 7: H_s/H_e Vs S_r for N_{60}=1, CR=0.16, B_t=50m

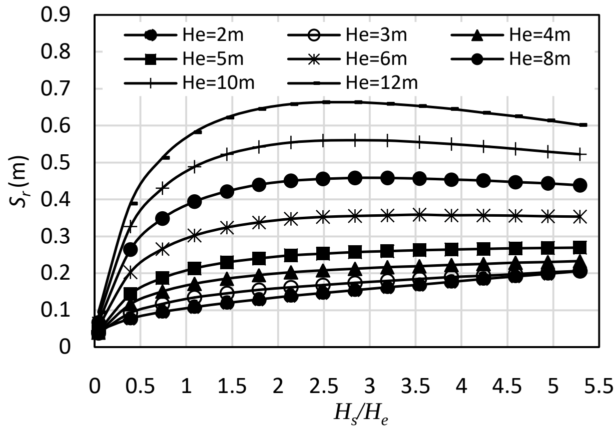

Figure 11: H_s/H_e Vs S_r for N_{60}=2, CR=0.16, B_t=50m

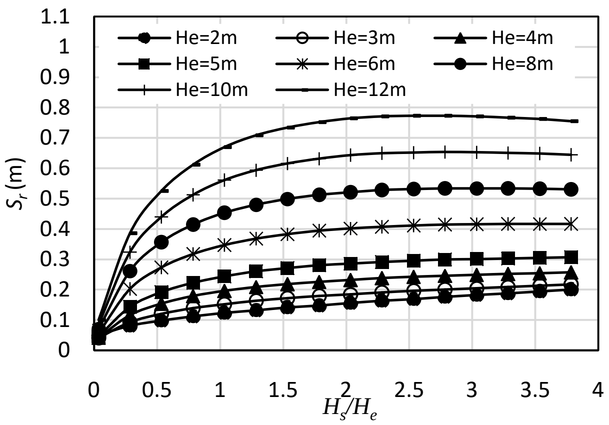

Figure 8: H_s/H_e Vs S_r for N_{60}=1, CR=0.19, B_t=50m

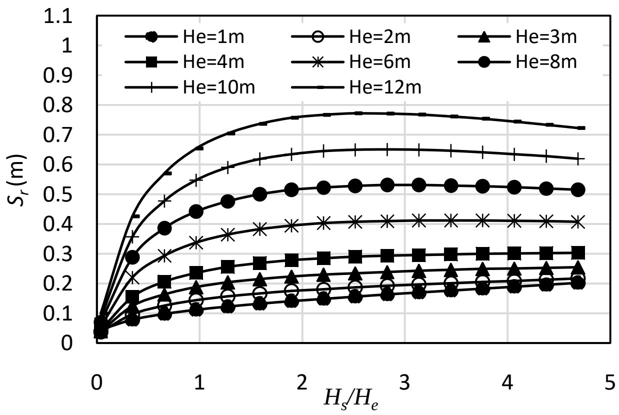

Figure 12: H_s/H_e Vs S_r for N_{60}=2, CR=0.19, B_t=50m

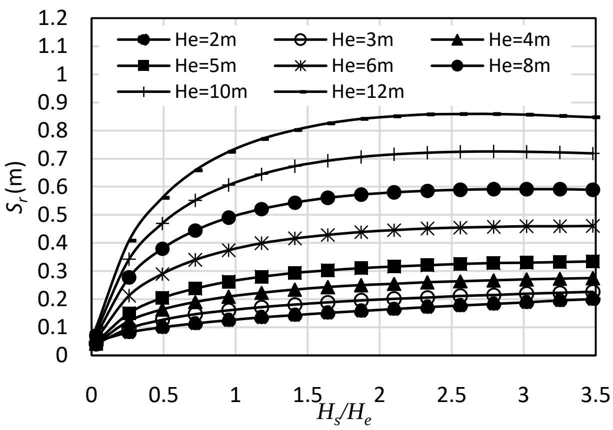

Figure 9: H_s/H_e Vs S_r for N_{60}=1, CR=0.21, B_t=50m

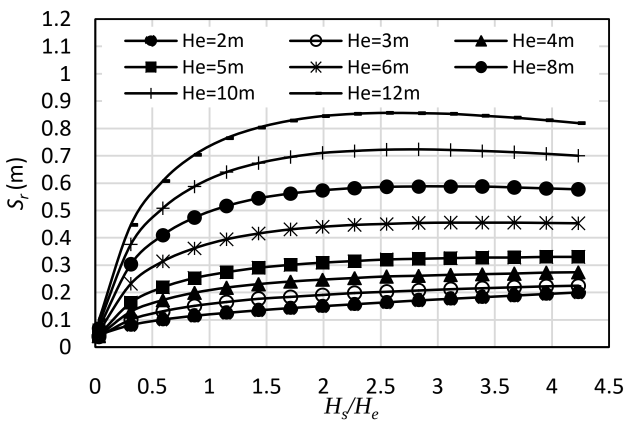

Figure 13: H_s/H_e Vs S_r for N_{60}=2, CR=0.21, B_t=50m

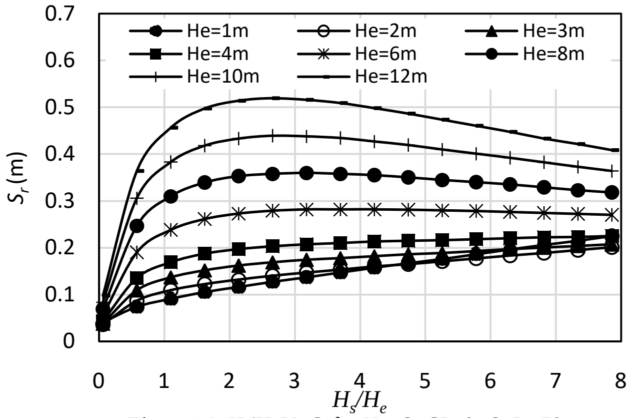

Figure 14: H_s/H_e Vs S_r for N_{60}=3, *CR*=0.13, B_t=50m

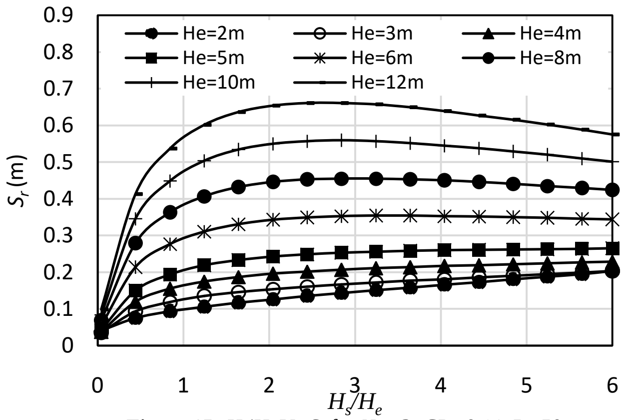

Figure 15: H_s/H_e Vs S_r for N_{60}=3, *CR=0.16*, B_t=50m

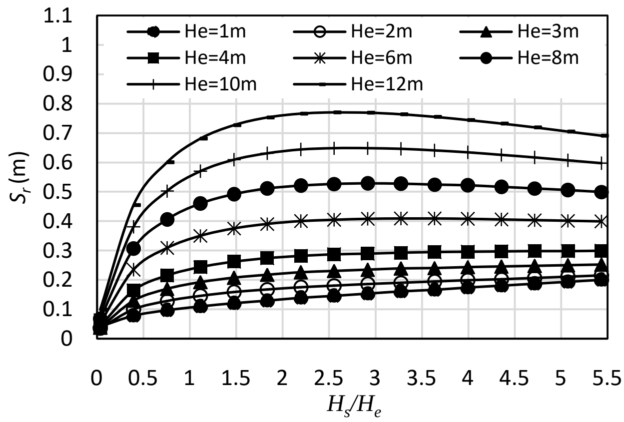

Figure 16: H_s/H_e Vs S_r for N_{60}=3, *CR=0.19*, B_t=50m

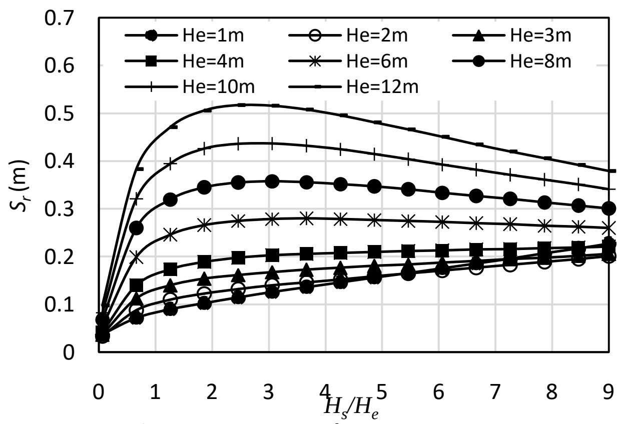

Figure 17: H_s/H_e Vs S_r for N_{60}=4, *CR*=0.21, B_t=50m

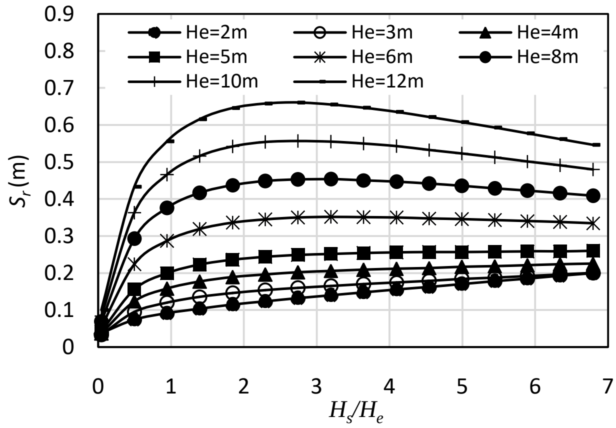

Figure 18: H_s/H_e Vs S_r for N_{60}=4, *CR*=0.16, B_t=50m

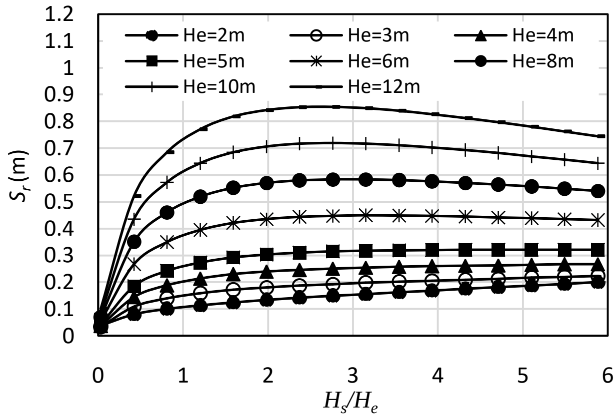

Figure 19: H_s/H_e Vs S_r for N_{60}=4, *CR*=0.21, B_t=50m

This is observed that, in case of a particular $N_{60}$the values of H_s/H_e for different values of *CR* are closer. On the other hand, in case of a particular *CR* the values of H_s/H_e for different values of N_{60} are not closer. This observation indicates little effect of *CR* on the limit value of H_s/H_e. The lowest value of H_s/H_e indicates lowest allowable depth of soft soil layer which is safer.

In this consideration, the simplified form of Table 3 and 4 is prepared which are Table 5 and 6 successively taking the lowest values of H_s/H_e for N_{60}=1, 2, 3 and 4.

Simplified maximum allowable value of$\frac{H_s}{H_e}$to satisfy residual settlement, S_r≤0.100m is termed as $\left(\frac{H_s}{H_e}\right)_{0.1}$. Similarly, simplified maximum allowable value of $\frac{H_s}{H_e}$to satisfy residual settlement, S_r≤0.200m is termed as $\left(\frac{H_s}{H_e}\right)_{0.2}$. For *CR* ≤0.13 and 0.13< *CR* ≤0.21 values of $\left(\frac{H_s}{H_e}\right)_{0.1}$ for rigid pavement or bridge/culvert approach and value of $\left(\frac{H_s}{H_e}\right)_{0.2}$ for flexible pavement are presented in Table 5 and 6 successively for various value of field SPT (N_{60}). These data are also represented graphically in Figure 20 to 23.

The imperial relationship for Table 5 & 6 may be expressed by equation (16) –

$$\left(\frac{H_s}{H_e}\right)_{0.1} \text{ or } \left(\frac{H_s}{H_e}\right)_{0.2} = a(H_e)^{-b} \tag{16}$$

Table 3: Maximum allowable H_s/H_e to satisfy S_r≤0.100m for rigid pavement and flexible pavement in bridge approach for B_t=50m

CR	N_{60}	Maximum allowable value of H_s/H_e to satisfy S_r≤0.100mfor B_t=50m							
		H_e=1m	H_e=2m	H_e=3m	H_e=4m	H_e=6m	H_e=8m	H_e=10m	H_e=12m
0.08	1	1.358	1.513	1.128	0.736	0.465	0.306	0.2	0.128
0.13		0.914	0.694	0.418	0.319	0.202	0.134	0.09	0.062
0.16		0.689	0.451	0.285	0.217	0.136	0.091	0.063	0.043
0.19		0.571	0.35	0.231	0.174	0.109	0.073	0.051	0.035
0.21		0.49	0.291	0.197	0.149	0.094	0.063	0.044	0.031
0.08	2	1.765	1.875	1.275	0.922	0.568	0.363	0.222	0.125
0.13		1.168	0.796	0.469	0.353	0.218	0.144	0.095	0.062
0.16		0.875	0.502	0.317	0.241	0.149	0.1	0.068	0.047
0.19		0.699	0.377	0.254	0.191	0.118	0.078	0.053	0.036
0.21		0.59	0.31	0.217	0.163	0.1	0.067	0.045	0.032
0.08	3	2.148	2.253	1.455	1.143	0.705	0.435	0.264	0.14
0.13		1.434	0.887	0.514	0.382	0.233	0.151	0.1	0.064
0.16		1.058	0.551	0.345	0.256	0.156	0.102	0.067	0.044
0.19		0.838	0.395	0.278	0.205	0.125	0.082	0.054	0.036
0.21		0.71	0.345	0.239	0.178	0.108	0.072	0.048	0.032
0.08	4	2.561	2.622	1.714	1.328	0.808	0.501	0.29	0.152
0.13		1.722	0.987	0.557	0.415	0.25	0.16	0.103	0.064
0.16		1.244	0.584	0.37	0.273	0.164	0.106	0.07	0.044
0.19		0.972	0.437	0.3	0.221	0.134	0.087	0.057	0.037
0.21		0.811	0.374	0.259	0.189	0.114	0.074	0.049	0.031

Table 4: Maximum allowable H_s/H_e to satisfy S_r≤0.200m for flexible pavement in general road section bridge or culvert approach for B_t=50m

CR	N_{60}	Maximum allowable value of H_s/H_e to satisfy S_r≤0.200m							
		H_e=1m	H_e=2m	H_e=3m	H_e=4m	H_e=6m	H_e=8m	H_e=10m	H_e=12m
0.08	1	5.32	7.53	9.034	9.87	8.57	1.234	0.7	0.545
0.13		4.623	5.487	4.408	1.91	0.664	0.383	0.291	0.229
0.16		4.15	3.893	1.803	0.861	0.386	0.255	0.195	0.153
0.19		3.785	2.785	1.112	0.6	0.282	0.204	0.155	0.122
0.21		3.48	2.062	0.841	0.473	0.242	0.174	0.133	0.105
0.08	2	6.315	8.911	10.792	12.125	15.125	1.268	0.867	0.666
0.13		5.56	6.63	5.573	2.141	0.684	0.415	0.313	0.245
0.16		5.028	4.8	2.04	0.915	0.385	0.277	0.211	0.166
0.19		4.582	3.368	1.198	0.619	0.306	0.22	0.167	0.131
0.21		4.23	2.438	0.886	0.5	0.26	0.187	0.142	0.112
0.08	3	7.335	10.309	12.593	14.645	21.12	1.421	1.064	0.817
0.13		6.508	7.773	6.82	2.4	0.688	0.443	0.333	0.259
0.16		5.893	5.743	2.31	0.939	0.408	0.293	0.22	0.172
0.19		5.435	4.085	1.283	0.649	0.325	0.233	0.176	0.137
0.21		5.017	2.886	0.932	0.519	0.28	0.201	0.152	0.118
0.08	4	8.376	11.707	14.409	17.32	25.92	1.655	1.235	0.944
0.13		7.478	8.96	8.16	2.7	0.673	0.473	0.355	0.275
0.16		6.794	6.704	2.594	0.944	0.43	0.307	0.231	0.179
0.19		6.275	4.865	1.327	0.673	0.348	0.248	0.187	0.145
0.21		5.825	3.346	0.983	0.524	0.298	0.212	0.16	0.124

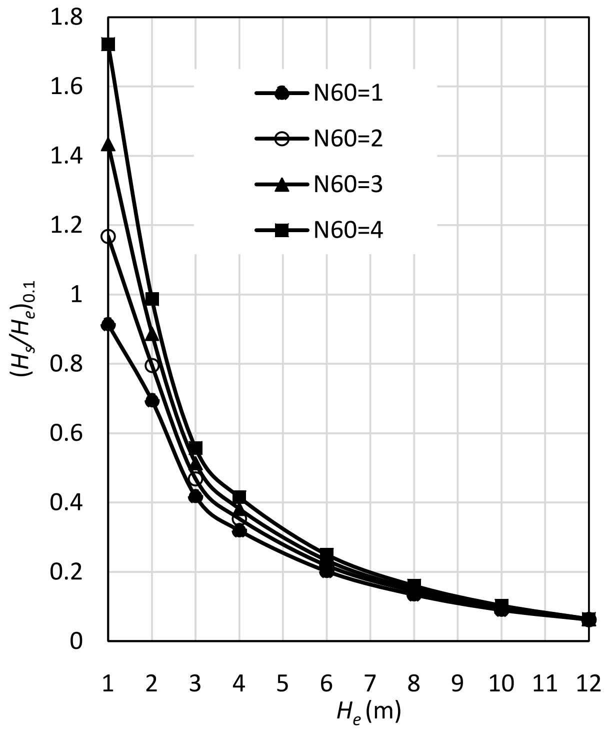

Figure 20: $(H_s/H_e)_{0.1}$ Vs H_e to satisfy S_r=0.100m for $CR \leq 0.13$ and $B_t \leq 50$m

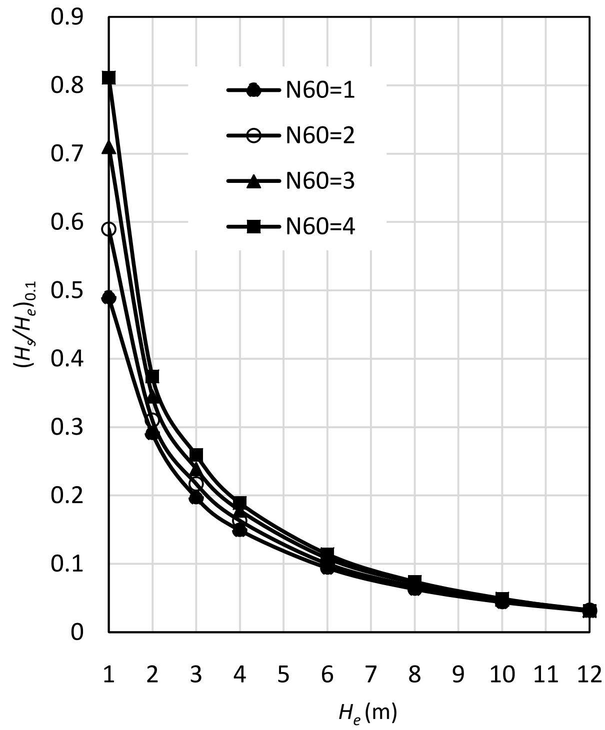

Figure 21: $(H_s/H_e)_{0.1}$ Vs H_e to satisfy S_r=0.100m for $0.13 < CR \leq 0.21$ and $B_t \leq 50$m

Table 5: Simplified Maximum allowable value of H_s/H_e to satisfy residual settlement, $S_r \leq 0.100$m for $B_t \leq 50$mfor rigid pavement and flexible pavement in bridge or culvert approach

Ranges of parameters		Maximum allowable value of H_s/H_e to satisfy $S_r \leq 0.100$m, $\left(\frac{H_s}{H_e}\right)_{0.1}$							
		H_e=1m	H_e=2m	H_e=3m	H_e=4m	H_e=6m	H_e=8m	H_e=10m	H_e=12m
$CR \leq 0.13$	N_{60}=1	0.91	0.69	0.42	0.32	0.20	0.13	0.09	0.06
	N_{60}=2	1.17	0.80	0.47	0.35	0.22	0.14	0.10	0.06
	N_{60}=3	1.43	0.89	0.51	0.38	0.23	0.15	0.10	0.06
	N_{60}=4	1.72	0.99	0.56	0.42	0.25	0.16	0.10	0.06
$0.13 < CR \leq 0.21$	N_{60}=1	0.49	0.29	0.20	0.15	0.09	0.06	0.04	0.03
	N_{60}=2	0.59	0.31	0.22	0.16	0.10	0.07	0.05	0.03
	N_{60}=3	0.71	0.35	0.24	0.18	0.11	0.07	0.05	0.03
	N_{60}=4	0.81	0.37	0.26	0.19	0.11	0.07	0.05	0.03

Table 6: Simplified maximum allowable value of H_s/H_e to satisfy residual settlement, $S_r \leq 0.200$m for $B_t \leq 50$m for flexible pavement in general road section except bridge or culvert approach

Ranges of parameter		Maximum allowable value of H_s/H_e to satisfy $S_r \leq 0.200$m, $\left(\frac{H_s}{H_e}\right)_{0.2}$							
		H_e=1m	H_e=2m	H_e=3m	H_e=4m	H_e=6m	H_e=8m	H_e=10m	H_e=12m
$CR \leq 0.13$	N_{60}=1	4.62	5.49	4.41	1.91	0.66	0.38	0.29	0.23
	N_{60}=2	5.56	6.63	5.57	2.14	0.68	0.42	0.31	0.25
	N_{60}=3	6.51	7.77	6.82	2.40	0.69	0.44	0.33	0.26
	N_{60}=4	7.48	8.96	8.16	2.70	0.67	0.47	0.36	0.28
$0.13 < CR \leq 0.21$	N_{60}=1	3.48	2.06	0.84	0.47	0.24	0.17	0.13	0.11
	N_{60}=2	4.23	2.44	0.89	0.50	0.26	0.19	0.14	0.11
	N_{60}=3	5.02	2.89	0.93	0.52	0.28	0.20	0.15	0.12
	N_{60}=4	5.83	3.35	0.98	0.52	0.30	0.21	0.16	0.12

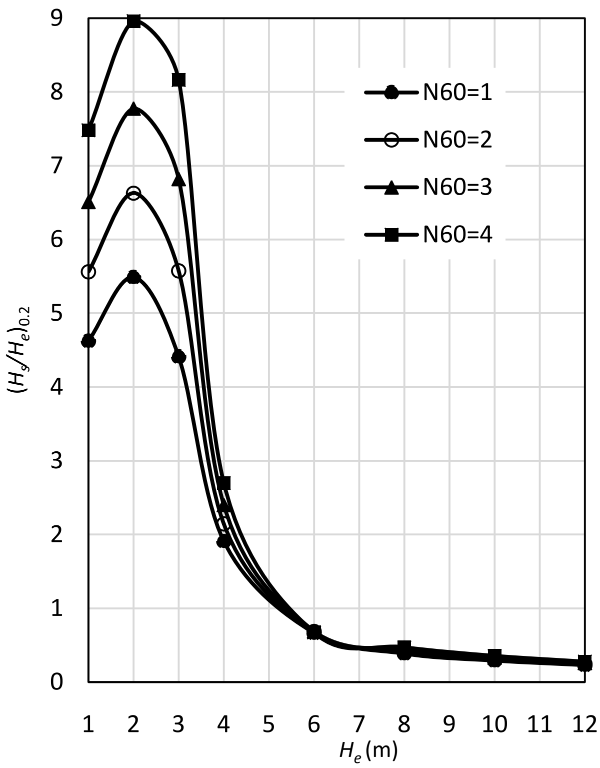

Figure 22: $(H_s/H_e)_{0.2}$ Vs H_e to satisfy S_r=0.200m for $C_c/(1+e_0) \le 0.13$ and $B_t \le 50$m

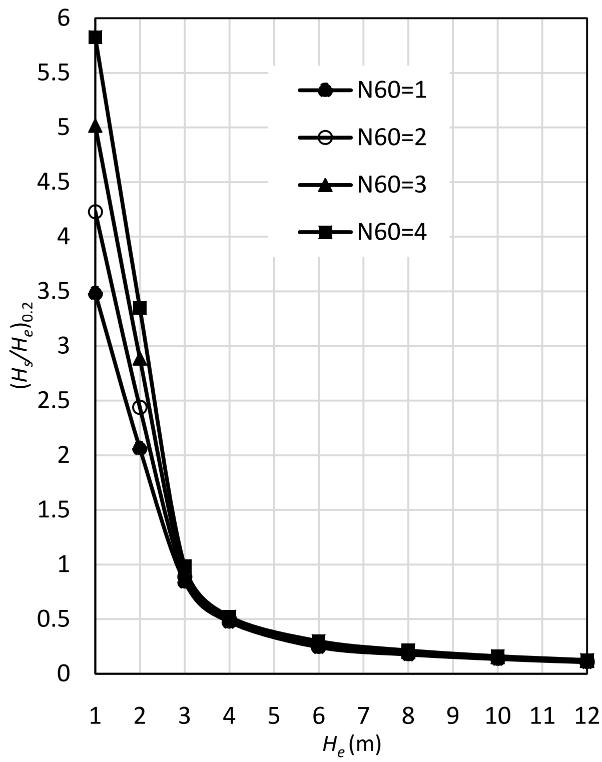

Figure 23: $(H_s/H_e)_{0.2}$ Vs H_e to satisfy S_r=0.200m for $0.13<C_c/(1+e_0) \le 0.21$ and $B_t \le 50$m

Table 7: Value of coefficients a, b & c

S_r	$\frac{H_s}{H_e}$	H_s	Ranges of parameter		a	b	Minimum R^2
≤0.100m	$\left(\frac{H_s}{H_e}\right)_{0.1}$	$(H_s)_{0.1}$	$CR \le 0.13$	N_{60}=1	2.1843	1.303	0.9576
				N_{60}=2	1.8487	1.242	
				N_{60}=3	1.5531	1.182	
				N_{60}=4	1.2468	1.101	
			$0.13< CR \le 0.21$	N_{60}=1	0.9394	1.265	0.9777
				N_{60}=2	0.8219	1.211	
				N_{60}=3	0.6946	1.155	
				N_{60}=4	0.5962	1.104	
≤0.200m	$\left(\frac{H_s}{H_e}\right)_{0.2}$	$(H_s)_{0.2}$	$CR \le 0.13$	N_{60}=1	17.955	1.629	0.8531
				N_{60}=2	15.208	1.579	
				N_{60}=3	12.590	1.521	
				N_{60}=4	10.113	1.455	
			$0.13< CR \le 0.21$	N_{60}=1	6.6088	1.646	0.9759
				N_{60}=2	5.7779	1.604	
				N_{60}=3	4.9522	1.558	
				N_{60}=4	4.1835	1.507	

The allowable depth of soft subsoil to satisfy $S_r \le 0.100$m or $S_r \le 0.200$m is expressed by equation (17) –

$$H_{s,0.1} \text{or} H_{s,0.2} = a(H_e)^{1-b} \quad (17)$$

In equation (16) and (17) the coefficients a, b & c are to be used as presented in Table 7.

7. Limitation of Study

Consolidation pressure due to full embankment weight is used in calculation of residual settlement. However, through the embankment fill excluding pavement layers full consolidation pressure not to be applied. As per this consideration maximum allowable depth of soft subsoil ($H_{s,0.1}$ or $H_{s,0.2}$) obtained from Equation (17) to be reduced by 20%. The reduced maximum allowable depth is expressed by equation (18) –

$$0.8H_{s,0.1} \text{or} 0.8H_{s,0.2} = 0.8a(H_e)^{1-b} \quad (18)$$

8. Conclusion

This research study is valid if the surface layers (aggregate base and bituminous surface) of pavement to be constructed after 1 years and 0.27 years after completion of embankment filling considering one way and two way drainage successively. This period is required to ensure occurrence of 30% consolidation before construction of the mentioned surface layers of pavement. The sums of the 70% Consolidation Settlement and Elastic Settlement due to axle load those to be occurred after construction is considered as the Residual Settlement of soft subsoil underlying the highway embankment. Secondary settlement is not included in residual settlement because that shall be occurred after 15-20 years after recovery of the primary settlements (Consolidation Settlement and Elastic Settlement) through maintenance.

Tolerable limit of the residual settlement is 0.100m for rigid and flexible pavement in approach to bridge or culvert and 0.200mm for flexible pavement in general road sections except bridge or culvert approach. The variation of Residual Settlement with change of width of embankment top (crest width)is not significant. Considering this fact, the residual settlement charts were prepared for only50m crest width and for the ranges of Field SPT value, Liquid limit and Natural void ratio of 1-4, 30%-90% and 0.6-1.8 successively. Same value of residual settlement may be used for embankment crest less than 50m.

A guideline for satisfying tolerable limit of residual settlement is prepared in form of tables, figures and empirical equations for Compression Ratio 0.08 to 0.21.In design of a proposed highway embankment the ground improvement shall be necessary if the depth of subsoil is more than $0.8H_{s,0.1}$ or $0.8H_{s,0.2}$ for rigid pavement or flexible pavement in approach to bridge or culvert and for flexible pavement in general road sections except bridge or culvert approach successively.

Acknowledgement

The author acknowledged the support of the authority and RHD personal of Bangladesh Road Research Laboratory (BRRL), Mirpur, Dhaka, Bangladesh.

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