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MINIMUM HEIGHT OF ROAD EMBANKMENT TO SATISFY TOLERABLE RESIDUAL SETTLEMENT OF GRANULAR SUBSOIL OVERLAIN BY STRONGER SOIL STRATA

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A B S T R A C T

The Residual settlement of granular subsoil of different strength underlying Road Embankment overlain by stronger soil layer is studied. A parametric study is conducted considering variable heights of embankment and variable ESAL factors (vehicle equivalence factor). The residual settlement (S_r) is stated as sum of elastic settlements of granular subsoil due to axle induced stress and self-weight of pavement layers. Values S_r for various heights of road embankment (H_e) are obtained and delivered as a set of design charts for different values of SPT and ESAL factor. In case of rigid pavement tolerable limit of the residual settlement is 0.1m. In case of flexible pavement in bridge or culvert approach and general sections except bridge or culvert approach, tolerable limit of the residual settlement considered as 0.2m and 0.3m successfully. A comprehensive guideline is developed for design of Road Embankment underlain by Granular subsoil underlying a stronger soil strata to satisfy the tolerable limit of the residual settlement. In this research study the range of both of ESAL factor and SPT value (N_{60}) is 1-10. Through parametric study, this is observed that, no ground improvement is necessary when the thickness of overlying stronger soil strata (d) is minimum 0.45m thick in case of flexible pavement in general road section if ESAL factor≤8 and H_e ≥1.5m. For flexible pavement in bridge or culvert approach d≥1.0m required to avoid ground improvement if ESAL factor≤8 and H_e ≥1.5m. For rigid pavement d≥2.0m required to avoid ground improvement. A guideline is prepared including tables and charts to find out minimum allowable height of road embankment to keep the residual settlement within mentioned tolerable limit. Allowable minimum height of the embankment including pavement layers ($H_{e,0.1}$, $H_{e,0.2}$ or $H_{e,0.3}$) are obtained corresponding to tolerable safe level of the residual settlement of granular subsoil for different values of N_{60}, d and ESAL factor. The developed guideline is intended to be used in identification of the requirement of ground improvement in case of Granular subsoil underlying Road Embankment overlain by stronger soil strata to ensure tolerable level of the residual settlement. The ground improvement is only to be necessary when the residual settlement of subsoil is more than tolerable level or in other word if H_e is less than $H_{e,0.1}$, $H_{e,0.2}$ or $H_{e,0.3}$.

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1. INTRODUCTION

Construction of Road Embankment in Bangladesh may be proceeded over very loose to loose granular natural subsoil overlain by stronger soil strata.

Often ground improvement is being provided to strengthen the very loose to loose Granular subsoil underlying the proposed Road Embankment.

However, the ground improvement not to be mandatory when the residual settlement of subsoil is with in tolerable level. This study is executed to formulate a guideline for identification of the requirement of ground improvement for proposed Road Embankment underlain by Granular or Cohessionless or non-plastic subsoil considering limiting residual settlement.

2. AXLE LOAD ON PAVEMENT

The stress on pavement overlying Road Embankment is only axle load of transport vehicle. However, the stresses on subsoil underlying the embankment is both of the transferred portion of axle load and also the self-weight of the embankment fill and pavement layers.

According to Road Master Plan (2009), in national highways in Bangladesh, the value of the Equivalent Standard Axle Load (*ESAL*) *factor* for dual tyre single axle is found larger than 30. Considering this over loading and the future enlargement possibility of acceptable limit of *ESAL factor*, the *ESAL factor* up to 10 are considered for calculation of elastic settlement of loose subsoil in current study.

Actual Axle Load (kN), W_a = *ESAL factor* . W_r (1)

where, *ESAL factor* may be termed as the vehicle equivalence factor (Pavement Design Guide for Roads & Highways Department, 2005) or Equivalent Standard Axle Load and W_r is Standard axle load (80kN) for dual tyre single axle.

3. DISTRIBUTION OF AXLE LOAD

As per 2 vertical to 1 horizontal spreading method of stress (Holtz, R. D. et. al. 1981), a particular wheel load reduced to a larger area at lower depth. The reduced stress at a specific depth z,

$$\sigma_z = \frac{\sigma_0 BL}{(B+z)(L+z)} \tag{2}$$

In the this parametric study the concentrated load on pavement, $\sigma_0 BL = \frac{W_a}{2}$ (3)

Considering the interface or overlap of pressure comes from two wheel being in an axle (Ahmed, S., 2022),

$$\sigma_z = \frac{W_a}{(B+H_e)(L+H_e)} = \frac{2\frac{W_a}{2}}{(B+H_e)(L+H_e)} \tag{4}$$

where, W_a is actual axle load, B is width of tyre to pavement contact area, L is length of tyre to pavement contact area and H_e is total height of embankment above ground level including embankment fill and pavement.

In this case according to Equation (4), pressure on loose granular subsoil overlain by strong soil of a particular thickness due to load of two wheel in an axle,

$$\sigma_z = \frac{W_a}{(B+H_e+d)(L+H_e+d)} \tag{5}$$

where, d is the thickness of stronger soil overlying loose granular subsoil.

The contact tyre area of dual tyre single axle HS 20-44 Truck is a single rectangle having width, B= 250mm and length, L= 510mm as per FHWA-IF-12-027 (2012) and AASHTO (2016) which are used in calculation of axle induced stress in current study.

4. SETTLEMENT OF LOOSE SUBSOIL

As suggested by Bowles J. E. (1977), Elastic Settlement of loose granular soil due to Axle Load (for $B + H_e >$ 1.22m),

$$S_e\,(\text{m}) = \frac{0.002\sigma_z}{N_{60}F_d}\left[\frac{(B+H_e+d)}{(B+H_e+d)+0.3}\right]^2 \tag{6}$$

$$F_d = 1+0.33(D_f+d)/(B+H_e+d) \tag{7}$$

where, H_e is the height of Road Embankment including embankment fill and thickness of pavement layers, σ_z is reduced axle pressure on subsoil , d is the depth of stronger soil overlying loose subsoil, N_{60} is SPT value at immediate top layer just below the embankment, $B+H_e$ is width of distributed wheel load at subsoil level and D_f is the depth of foundation below existing ground level (=0).

Similarly, Elastic Settlement of granular soil due to self-weight of pavement layers for $B + H_e - H_p + d >$ 1.22m,

$$S_e\,(\text{m}) = \frac{0.002H_p\gamma_e}{N_{60}F_d}\left[\frac{(B_t+H_e-H_p+d)}{(B_t+H_e-H_p+d)+0.3}\right]^2 \tag{8}$$

and $F_d = 1+0.33D_f/(B_t+H_e-H_p+d)=1$ (9)

where, H_p is thickness of pavement layers overlying embankment fill, γ_e is average unit weight of embankment materials, $H_e - H_p$ is the vertical distance of subsoil level from pavement bottom level and $H_p\gamma_e$ is self-weight of pavement layers.

5. RESIDUAL SETTLEMENT

Residual Settlement is a portion of total settlement which to be occurred after finish of embankment fill and during or after the construction of overlying pavement layers.

Hence, the Residual Settlement, $S_r = S_{e1} + S_{e2}$ (10)

where, S_{e1} is the Elastic Settlement of loose subsoil below embankment due to reduced axle pressure (σ_z) obtained from Equation (6) and S_{e2} is Elastic Settlement of granular subsoil underlying the embankment due to self-weight of pavement layers obtained from Equation (8).

As per Larisch, M. D. et. al. (2015), total post construction settlement to be smaller than 0.1 m and maximum differential settlement to be 0.3% change in grade over 40 years for plain concrete (rigid) pavement. As per IRC:75-2015, for flexible pavement tolerable limit of the residual settlement is 0.3m and maximum permissible rate of residual settlement is 25-30mm/yr.

According JKR (PWD), Malaysia total post construction settlement to be smaller than 0.21m for within 10m from bridge abutment (Long, P.V. et. al., 2013). The mentioned values or tolerable residual settlement are used in current study.

6. ANALYSIS RESULTS

Results of the current analysis and parametric study are presented in this section in forms of residual settlement charts and guideline for tolerable residual settlement.

6.1 Residual Settlement Charts

As per Geometric Design Standards Manual (2005) of Roads and Highways Department of Bangladesh, the range of width of carriage way of road in Bangladesh is 3.0m to 22.0m. Then the range of corresponding crest width to be 5.0m to 30.0m. In case 4 Lane highways and expressways the range of crest width is 30m-40m. In the current analysis, that maximum 60m crest width is considered. The range of embankment height including thickness of pavement layers is 1m to 12m and the side slope of is 1V:2H used in current analysis. Thickness of pavement layers (H_p) is taken 1.5m for analysis of residual settlement.

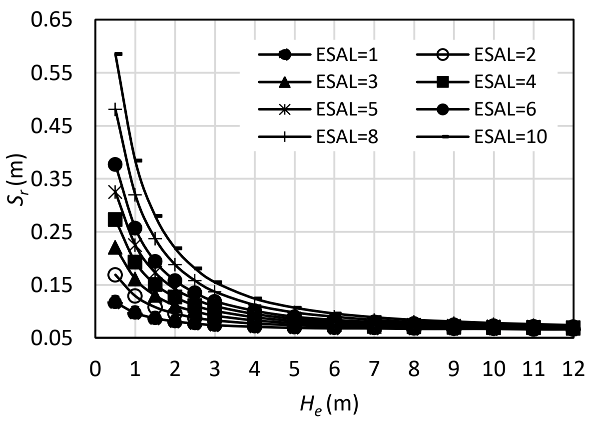

Figure 1. H_e Vs S_r for for N_{60}=1, d=0.45m

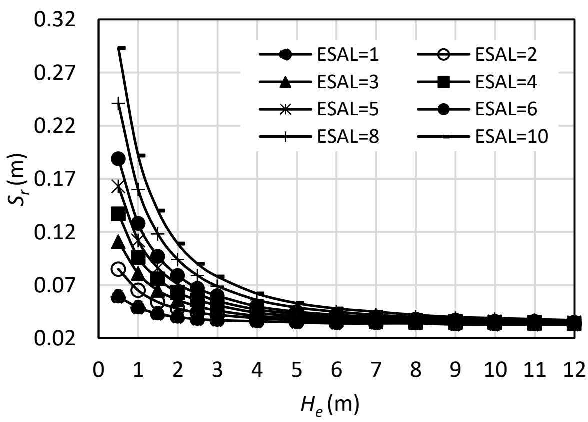

Figure 2. H_e Vs S_r for for N_{60}=2, d=0.45m

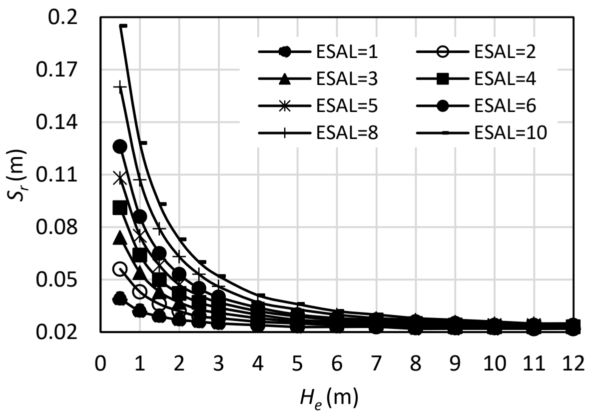

Figure 3. H_e Vs S_r for for N_{60}=3, d=0.45m

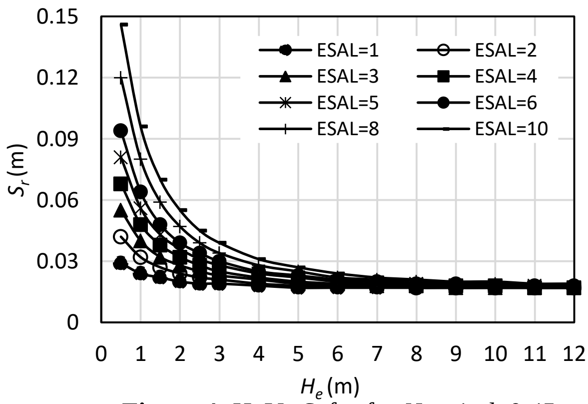

Figure 4. H_e Vs S_r for for N_{60}=4, d=0.45m

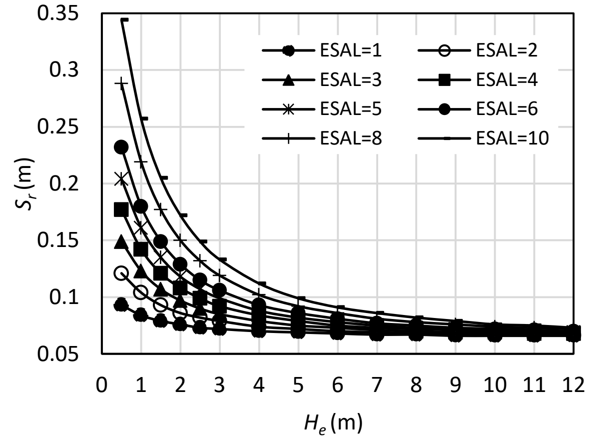

Figure 5. H_e Vs S_r for for N_{60}=1, d=1.0m

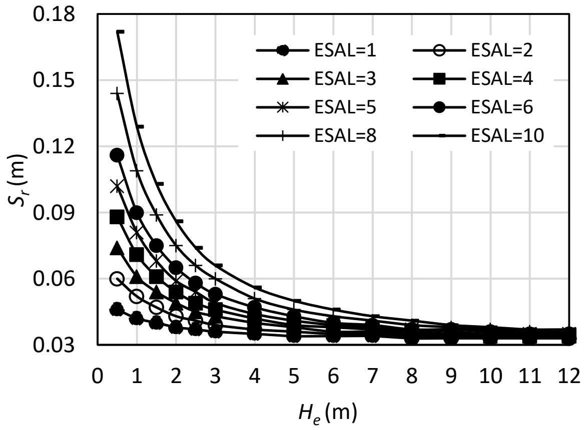

Figure 6. H_e Vs S_r for for N_{60}=2, d=1.0m

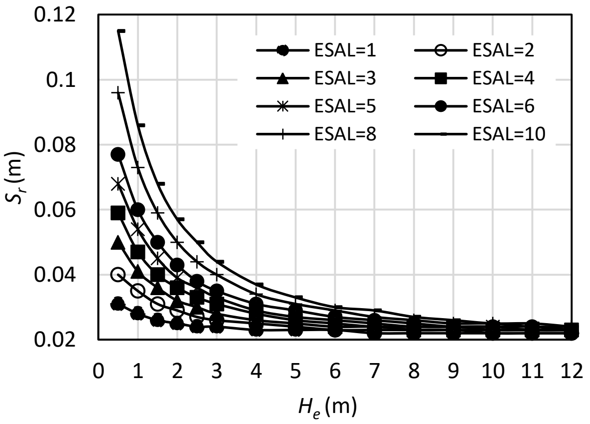

Figure 7. H_e Vs S_r for for N_{60}=3, d=1.0m

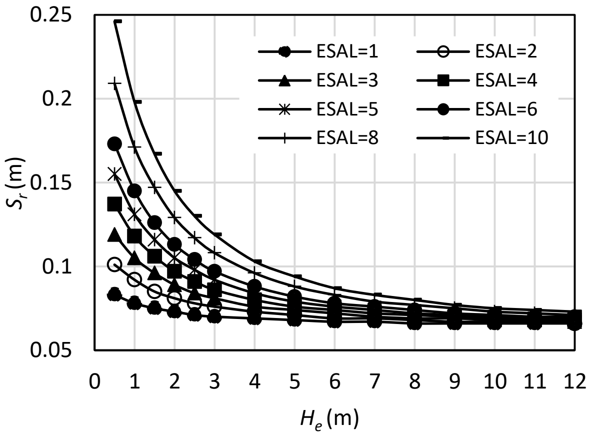

Figure 8. H_e Vs S_r for for N_{60}=1, d=1.5m

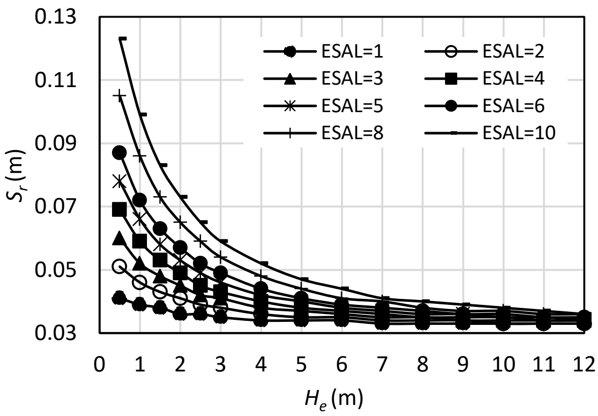

Figure 9. H_e Vs S_r for for N_{60}=2, d=1.5m

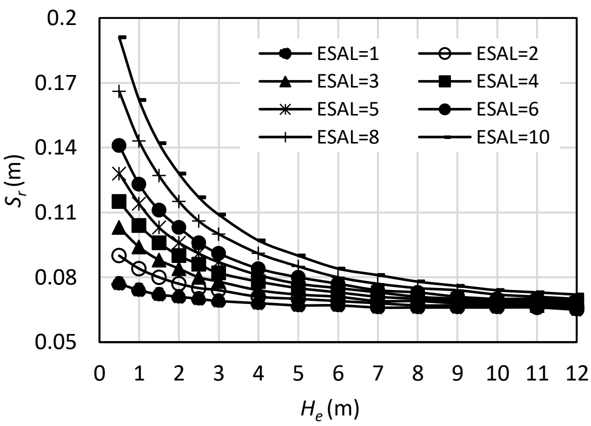

Figure 10. H_e Vs S_r for for N_{60}=1, d=2.0m

As observed through current study, the change of Residual Settlement (S_r) with change of B_t from 5m to 60m is not insignificant. Among small differences the maximum value of S_r is found for the largest value of B_t=60m. For this consideration, the residual settlement charts are prepared for B_t=60m.

However, the variation of S_r with N_{60} is quite significant. Considering this fact, separate residual settlement charts are prepared for SPT values N_{60}=1, 2, 3 and 4. The average unit weight of embankment materials, γ_e=19.5kN/m^3 considered in all cases of analysis.

Residual settlement, S_r (m) for various values of N_{60} and d are attained from calculations and shown graphically in Figure 1 to Figure 11 for different values of Embankment Height (H_e) and *ESAL* factor or Vehicle Equivalence Factor.

Residual settlement is depends on the transfer of stresses to loose granular subsoil. For more height of

Road Embankment and more thickness of stronger layer the reduction of stresses at loose subsoil is more. For more reduction of stresses, the residual settlement is smaller. For a particular value of N_{60} the value of S_r may be obtained from corresponding chart among Figure 1 to Figure 11 for different values of Embankment height (H_e), stronger layer thickness (d) and *ESAL* factor for B_t=60m. Same value may be used for B_t < 60m.

Hereafter, basic finding of current analysis is – in residual settlement charts presented in Figure 1 to Figure 11, this is observed that, the residual settlement (S_r) is decreases with increase of H_e and d.

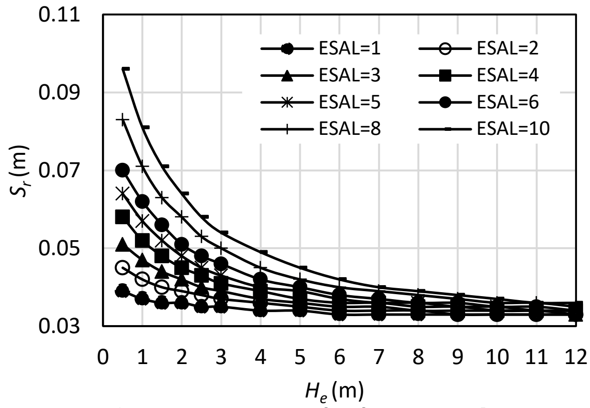

Figure 11. H_e Vs S_r for for N_{60}=2, d=2.0m

6.2 Guideline for Tolerable Residual Settlement

Minimum allowable values of embankment height (H_e) to satisfy residual settlement S_r≤0.1m, S_r≤0.2m and S_r≤0.3m are obtained from residual settlement charts presented in Figure 1 to 11.

These values are tabulated in Table 1 to Table 3 for B_t=60m. Those minimum allowable value of embankment height to satisfy residual settlement, S_r≤0.1m, S_r≤0.2m and S_r≤0.3m are termed as $H_{e,0.1}$, $H_{e,0.2}$ and $H_{e,0.3}$ successively.

Table 1. Minimum allowable height of embankment to ensure S_r≤0.1m for rigid pavement underlain by loose granular soil at 0.45m-2.0m below ground surface (d=0.45m to 2.0m) for *ESAL factor*=1-10 and B_t=60m is denoted as $H_{e,0.1}$.

ESAL factor	Minimum allowable embankment height to ensure S_r≤0.1m for B_t=60m is termed as $H_{e,0.1}$							
	1	2	3	4	5	6	8	10
N_{60}=1 (d=0.45m)	0.94	1.81	2.5	3.15	3.705	4.2	5.1	5.85
N_{60}=2 (d=0.45m)	0	0	0.61	1.03	1.3	1.54	1.92	2.3
N_{60}=3 (d=0.45m)	0	0	0	0.38	0.62	0.85	1.2	1.55
N_{60}=4 (d=0.45m)	0	0	0	0	0.25	0.4	0.73	1.01
N_{60}≥5 (d=0.45m)	No ground Improvement Required							
N_{60}=1 (d=1.0m)	0.1	1.15	1.9	2.52	2.98	3.42	4.2	4.97
N_{60}=2 (d=1.0m)	0	0	0	0.3	0.55	0.8	1.2	1.55
N_{60}=3 (d=1.0m)	0	0	0	0	0	0	0.45	0.75
N_{60}≥4 (d=1.0m)	No ground Improvement Required							
N_{60}=1 (d=1.5m)	0	0.6	1.24	1.8	2.33	2.8	3.66	4.33
N_{60}=2 (d=1.5m)	0	0	0	0	0	0.2	0.62	0.9
N_{60}≥3 (d=1.5m)	No ground Improvement Required							
N_{60}=1 (d=2.0m)	0	0.3	0.73	1.23	1.7	2.2	3	3.75
N_{60}≥2 (d=2.0m)	No ground Improvement Required							

Table 2. Minimum allowable height of embankment to ensure $S_r \leq 0.2$m for flexible pavement in bridge/culvert approach underlain by loose granular soil at 0.45m-2.0m below ground surface (d=0.45m to 2.0m) for *ESAL factor*=1-10 and B_t=60m is denoted as $H_{e,0.2}$.

ESAL factor	Minimum allowable height of embankment to satisfy $S_r \leq 0.2$m for B_t=60m is termed as $H_{e,0.2}$							
	1	2	3	4	5	6	8	10
N_{60}=1 (d=0.45m)	0	0	0	0.38	0.64	0.84	1.13	1.4
N_{60}=2 (d=0.45m)	0	0	0	0	0	0	0.3	0.55
$N_{60} \geq 3$ (d=0.45m)	No ground Improvement Required							
N_{60}=1 (d=1.0m)	0	0	0	0.26	0.52	0.77	1.2	1.57
$N_{60} \geq 2$ ($d \geq 1.0$m)	No ground Improvement Required							
N_{60}=1 (d=1.5m)	0	0	0	0	0	0.22	0.63	0.98
$N_{60} \geq 2$ ($d \geq 1.5$m)	No ground Improvement Required							
$d \geq 2.0$m	No ground Improvement Required							

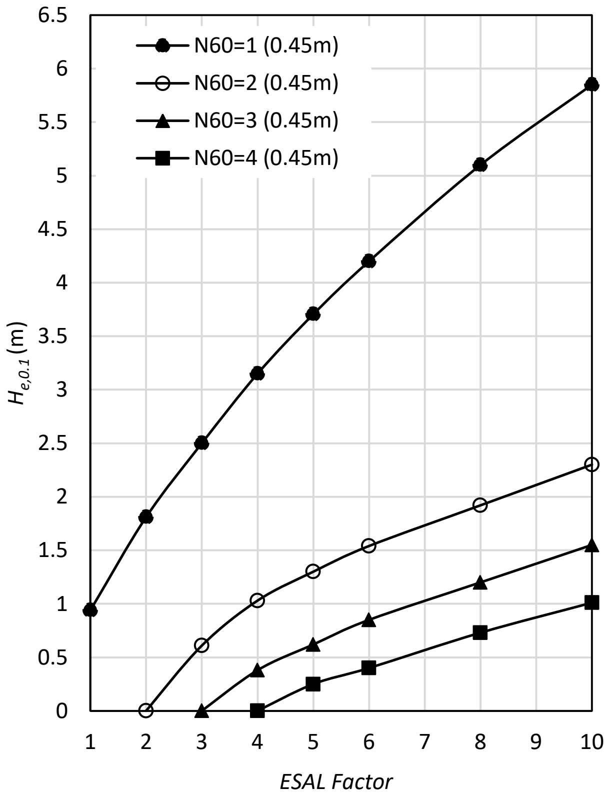

Figure 12. $H_{e,0.1}$ Vs *ESAL Factor* for d=0.45m

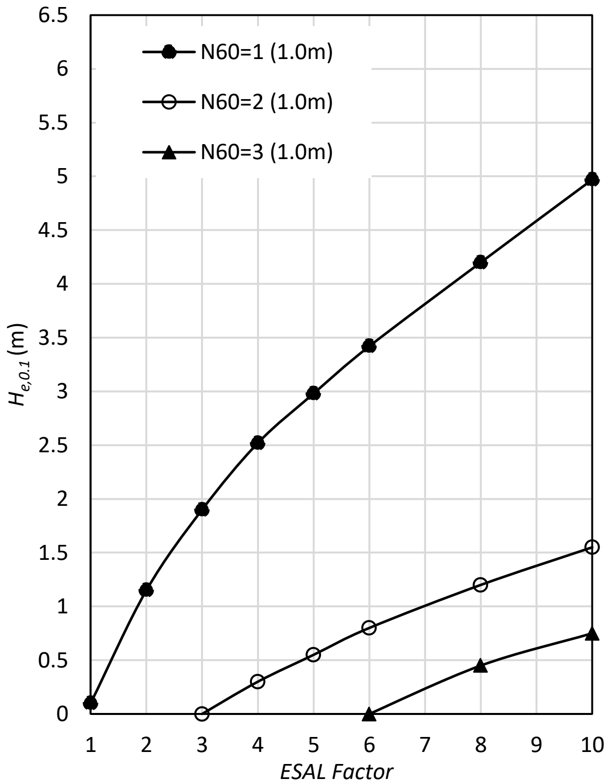

Figure 13. $H_{e,0.1}$ Vs *ESAL Factor* for d=1.0m

For a particular value of N_{60}, d and *ESAL factor* the value of H_e not to be less than the minimum value of $H_{e,0.1}$, $H_{e,0.2}$ or $H_{e,0.3}$ tabulated in Table 1, 2 and 3 to keep the residual settlement with in 0.1m, 0.2m and 0.3m. These tables may be used for crest width of Road Embankment≤60m. The same guideline is illustrated as Design Charts in Figure 12 to Figure 17 incorporating the values of $H_{e,0.1}$, $H_{e,0.2}$ and $H_{e,0.3}$ in cases of rigid pavement, flexible pavement at bridge approach and flexible pavement in general road sections for different SPT values (N_{60}).

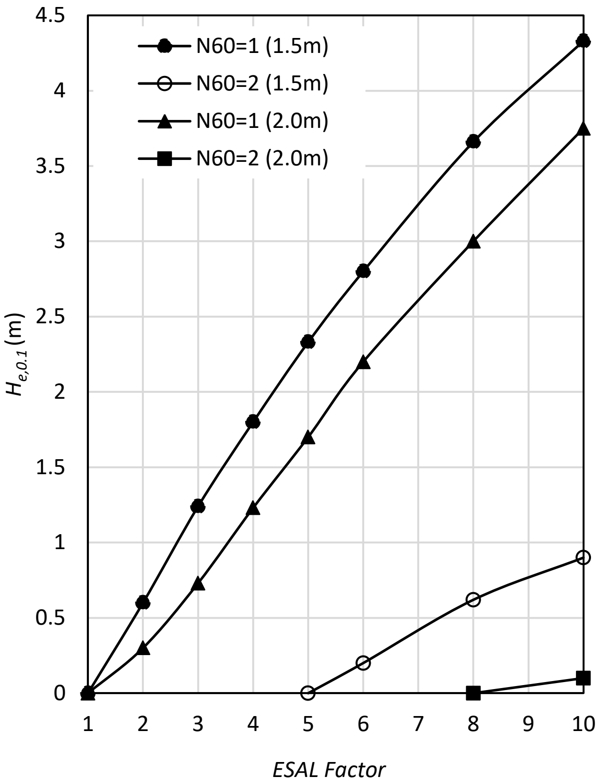

Figure 14. $H_{e,0.1}$ Vs *ESAL Factor* for *d*=1.5m and 2.0m

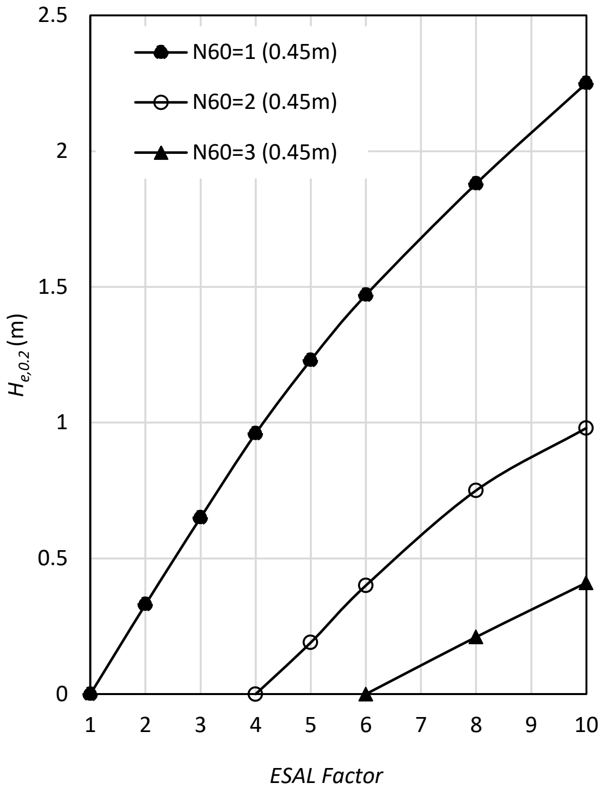

Figure 15. $H_{e,0.2}$ Vs *ESAL Factor* for *d*=0.45m

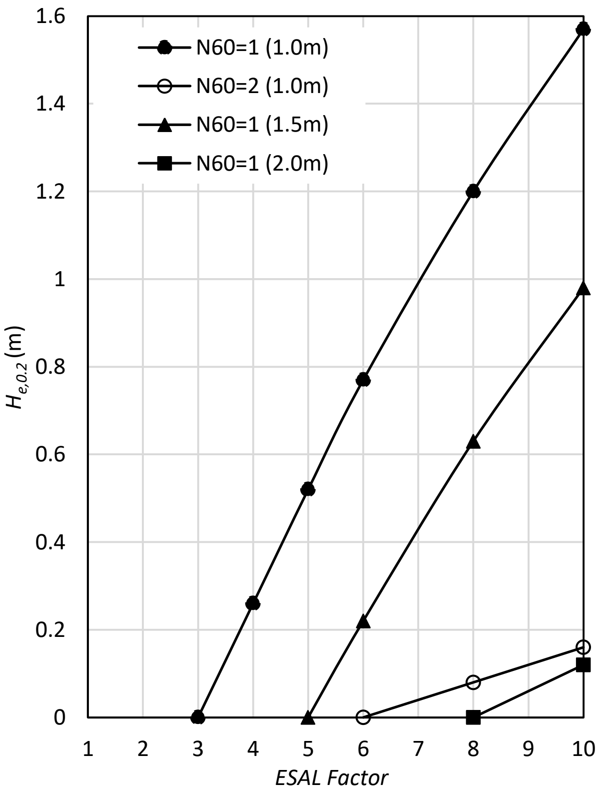

Figure 16. $H_{e,0.2}$ Vs *ESAL Factor* for *d*=1.0m, 1.5m and 2.0m

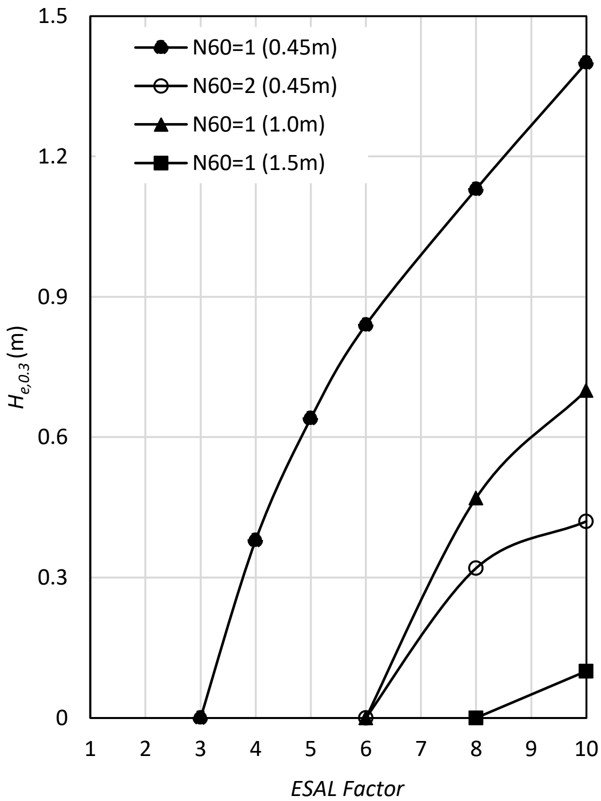

Figure 17. $H_{e,0.3}$ Vs *ESAL Factor* for *d*=0.45m, 1.0m and 1.5m

Table 3. Minimum allowable height of embankment to ensure S_r≤0.3m for flexible pavement in general section except bridge or culvert approach underlain by loose granular soil at 0.45m-1.5m below ground surface (*d*=0.45m to 1.5m) for *ESAL factor*=1-10 and B_t=60m is denoted as $H_{e,0.3}$.

ESAL factor	Minimum allowable height of embankment to satisfy S_r≤0.3m for B_t=60m is termed as $H_{e,0.3}$							
	1	*2*	*3*	*4*	*5*	*6*	*8*	*10*
N_{60}=1 (*d*=0.45m)	0	0	0	0.38	0.64	0.84	1.13	1.4
N_{60}=2 (*d*=0.45m)	0	0	0	0	0	0	0.32	0.42
N_{60}≥3 (*d*=0.45m)	No ground Improvement Required							
N_{60}=1 (*d*=1.0m)	0	0	0	0	0	0	0.47	0.7
N_{60}≥2 (*d*=1.0m)	No ground Improvement Required							
d≥1.5m	No ground Improvement Required							

Table 4. Value of correlation coefficients *a*, *b* and *c*.

S_r	H_e	Ranges of parameters		*a*	*b*	c	Minimum R^2
≤0.1m	$H_{e,0.1}$	*d*=0.45	N_{60}=1	-0.028	0.845	0.184	0.979
			N_{60}=2	-0.025	0.577	-0.958	
			N_{60}=3	-0.014	0.397	-1.026	
			N_{60}=4	-0.008	0.276	-0.963	
			N_{60}≥5	No ground Improvement Required			
		d=1.0m	N_{60}=1	-0.034	0.893	-0.595	0.994
			N_{60}=2	-0.01	0.357	-0.969	
			N_{60}=3	-0.018	0.487	-2.25	
			N_{60}≥4	No ground Improvement Required			
		d=1.5m	N_{60}=1	-0.02	0.706	-0.703	0.997
			N_{60}=2	-0.003	0.464	-0.553	
			N_{60}≥3	No ground Improvement Required			
		d=2.0m	N_{60}=1	-0.011	0.355	-1.5	0.998
			N_{60}≥2	No ground Improvement Required			
		d≥2.5m	No ground Improvement Required				
≤0.2m	$H_{e,0.2}$	*d*=0.45	N_{60}=1	-0.011	0.373	-0.363	0.999
			N_{60}=2	-0.01	0.311	-1.09	
			N_{60}≥3	No ground Improvement Required			
		d=1.0m	N_{60}=1	-0.007	0.326	-0.915	0.999
			N_{60}≥2	No ground Improvement Required			
		d=1.5m	N_{60}=1	-0.006	0.298	-1.322	0.997
			N_{60}≥2	No ground Improvement Required			
		d≥2.0m	No ground Improvement Required				
≤0.3m	$H_{e,0.3}$	*d*=0.45	N_{60}=1	-0.018	0.437	-1.103	0.994
			N_{60}≥2	No ground Improvement Required			
		d=1.0m	N_{60}=1	-0.03	0.655	-2.85	1.000
			N_{60}≥2	No ground Improvement Required			
		d≥1.5m	No ground Improvement Required				

The empirical relationship for minimum allowable height of Road Embankment overlying cohessionless or granular subsoil to satisfy S_r≤0.1m, S_r≤0.2m or S_r≤0.3m is obtained from 2 order polynomial trend line of Figure 12 to Figure 17. These empirical relationships are expressed by single equation (11) –

$$H_{e,0.1} \text{ or } H_{e,0.2} \text{ or } H_{e,0.3} = a(ESAL)^2 + b(ESAL) + c \quad (11)$$

In equation (11) the correlation coefficients *a*, *b* & *c* are presented in Table 4. Using equation (11) the minimum allowable height of Road Embankment to be obtained for a particular *ESAL factor* and SPT value (N_{60}).

If the height of proposed Road Embankment is less than $H_{e,0.1}$ in case of rigid pavement then Ground Improvement shall be required. Similarly, if the height of proposed Road Embankment is less than $H_{e,0.2}$ or $H_{e,0.3}$ in case of flexible pavement in bridge/culvert approach or in general road sections successively then the Ground Improvement shall be required.

7. CONCLUSION

The sum of Elastic Settlement due to the stress induced by reduced axle pressure and due to self-weight of pavement layers is considered as the Residual Settlement of Granular subsoil underlying the Road Embankment.

The change of Residual Settlement with variation of crest width is not significant and in view of this insignificancy, the residual settlement charts and guideline for tolerable Residual Settlement is prepared only for 60m crest width.

Those charts and tabular guideline prepared for the range of SPT value (N_{60}) of 1-5 and *ESAL Factor* of 1-10. Same value of Residual Settlement may be considered for crest width smaller than 60m. The proposed guideline is valid if the height of embankment (H_e) is at least 0.5m.

In case of stronger layer thickness, *d*=0.45m, 1.0m, 1.5m and 2.0m no Ground Improvement to be necessary for N_{60} greater than 4, 3, 2 and 1 successively, if *ESAL factor* is not more than 10 for rigid pavement. In case of stronger layer thickness, *d*=0.45m, 1.0m, 1.5m and 2.0m no Ground Improvement to be necessary for N_{60} greater than 2, 1, 1 and 0 successively, if *ESAL factor* is not more than 10 for flexible pavement in bridge or culvert approach. In case of stronger layer thickness, *d*=0.45m, 1.0m, 1.5m and 2.0m no Ground Improvement to be necessary for N_{60} greater than 2, 1, 0 and 0 successively, if *ESAL factor* is not more than 10 for flexible pavement in general road section except bridge or culvert approach. If N_{60} is not greater than the mentioned values in corresponding case then the prepared guideline to be used to identify the necessity of Ground Improvement to keep residual settlement within tolerable limit.

A guideline is prepared in the forms of tables, figures and empirical equations for different values of stronger layer thickness (*d*), SPT Value (N_{60}) and *ESAL factor* for limiting the residual settlement with in tolerable level. In design or assessment of Road Embankment the ground improvement to be necessary when the height of embankment (H_e) is less than $H_{e,0.1}$ in case of rigid pavement, less than $H_{e,0.2}$ in case of flexible pavement in bridge or culvert approach or less than $H_{e,0.3}$ for flexible pavement in general road sections except bridge or culvert approach.

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