Height of Highway Embankment for Tolerable Residual Settlement of Loose Cohesionless Subsoil

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Abstract

Residual settlement of highway embankment is studied for different strengthof underlyingcohesionlesssubsoil. A vast volume of parametric study is carried out for different value of *ESAL factor*and for different height of embankment. The sum of elastic settlementsof cohesionless subsoil due to axle load and due to self-weight of pavement layers is considered as the residual settlement whichare to be occurred after construction of road pavement. The values of residual settlement (S_r) for different heights of road embankment (H_e) are obtained and presented graphically for different SPT Value (N_{60}) and *ESALfactor*. For rigid pavement and flexible pavementin approach to bridge or culvert,the tolerable limit of residual settlement is 0.1m. This limit is taken as 0.2m for flexible pavement in general sections of highway except approach to bridge or culvert.A comprehensive and completedesign guideline is developed for design of highway embankment underlain by very loose to loosecohesionless subsoil for limitingvalue of the residual settlement. In the current parametric studyconsidered rangesfor both of*ESALfactor*andSPT value $N_{60}$is 1-10. Theground improvement is not required if the average SPT value (N_{60}) within very loose subsoil underlying highway embankment is 5 or more for *ESALfactor*$\leq$10 and $H_e \geq$1.5m.Allowable minimum values of the embankment height are obtained to satisfy tolerable or limiting level of the residual settlement of subsoil for different N_{60} and *ESAL factor*which are termed as $H_{e,0.1}$ and $H_{e,0.2}$. Tables and charts are developed to identify $H_{e,0.1}$ and $H_{e,0.2}$ to keep the residual settlement within the mentioned tolerable limit.The developed guideline may be used to assess the necessity of ground improvement in case of cohesionless subsoil underlying highway embankment to avoid exceedance of tolerable settlement limit. The ground improvement only to be necessary when the residual settlement of subsoil is more than mentioned tolerable limit or H_e is less than $H_{e,0.1}$ or $H_{e,0.2}$ in corresponding type of road sections.

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I. INTRODUCTION

Construction of Highway Embankmentin Bangladesh often to be needed over very loose to loosecohesionless natural subsoil. Usually ground improvement is often provided to strengthen such weakcohesionlesssoil underlying the proposed embankment. However, the ground improvement notto be required when the residual settlement ofsubsoil is within tolerable limit.This research study is conducted to prepare a guideline to identify necessity of ground improvement for design of proposed highway embankment underlain by very loose to loosecohesionlesssubsoil considering not exceedancein the limiting residual settlement.

II.TRAFFIC LOAD ON SUBSOIL

The other hand, stresses on subsoil underlying Highway embankment is both of the transferred portion of reduced axleandself-weight of the embankment.According to Bangladesh Road Master Plan [1], in national highways, value ofthe *ESAL* for dual tyre single axle is found as greater than 30. This value is much more than the maximum acceptable value of *ESAL*which is4.8 [1]. Considering such kind of over loading or the future enlargement of acceptable limit, *ESALfactor* up to 10 are considered for calculation of elastic settlement of subsoil in conductingcurrent research study.

Equivalent Standard Axle Load, $ESAL = W_a / W_r$ (1)

or, $W_a = ESAL\ factor\ (W_r)$ (2)

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

III. DISTRIBUTION OF AXLE LOAD

The 2V:1H (vertical to horizontal) method of stress distribution at a depth of soil is used for axle load distribution in this study[2].

Due to 2V:1H spreading of the same wheel load ($w_a/2$) over a larger area at depth H_e from pavement level, the reduced wheelstress on the plan at subsoil level,$\sigma_z = \frac{\left(\frac{W_a}{2}\right)}{(B+H_e)(L+H_e)}$ (3)

where, 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 natural ground level including pavement layers. The pavement totyrecontact area of dual tyre single axle for HS 20-44 Truck is a single rectangle having width, B=510mm and length, L= 250mm [3][4]. These values of B and L are used in calculation of axle stress in current study.

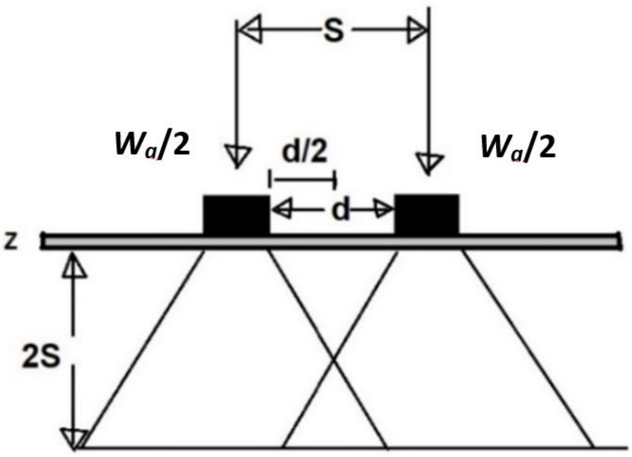

Figure:1.0 The intersection of pressure interface [5].

Pressure transferred to subsoil belowroad embankment due to Wheel Load is σ_z as per Equation (3).Considering interface or overlap of pressure from two wheel in an axle (Figure 1.0),

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

IV. SETTLEMENT OF SUBSOIL

As suggested by Bowles [6], the Elastic Settlement of cohessionless or granular subsoil due toAxle load,

$$S_e\ (\mathrm{m}) = \frac{0.002\sigma_z}{N_{60}F_d}\left[\frac{(B+H_e)}{(B+H_e)+0.3}\right]^2 \mathrm{for} B + H_e > 1.22\mathrm{m} \quad (5)$$

andF_d =1+0.33D_f/(B+H_e) (6)

where, $H_e$is height of highway embankment including thickness ofpavement layers, σ_z is reduced axle pressure on 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.

Similarly,Elastic Settlement of cohessionlesssoil due to self-weight ofpavement layers (H_p),

$$S_e\ (\text{m}) = \frac{0.002 H_p \gamma_e}{N_{60} F_d}\left[\frac{(B_t+H_e-H_p)}{(B_t+H_e-H_p)+0.3}\right]^2 \text{for} B+H_e-H_p > 1.22\text{m}$$

(7)

andF_d =1+0.33D_f/(B_t+H_e−H_p)

(8)

where, H_e is height of highway embankment including thickness ofpavement layers, H_p is thickness ofpavement layers, γ_e is averageunit weight of pavement layersand$B+H_e$is width of distributed pavement self-weight at subsoil level.

In case of highway embankment, depth of foundation below Existing ground level, D_f =0 and F_d =1.

V. RESIDUAL SETTLEMENT

The portion of total settlement which to be occurred after construction of road pavement layers overlying embankment fill is termed as post constructionor Residual Settlement.The sum of Elastic Settlement of loosesubsoil layer below embankment due to reduced axle load (σ_z)andElastic Settlement due to self-weight of embankment ($H_p\gamma_e$) is considered as Residual Settlement of cohessionless subsoil becausethese to be occurred after finish of pavement construction and before first maintenance of pavement.

Hence, the Residual Settlement is considered as,S_r=S_e+S_{ep} (9)

where, $S_e$isElastic Settlement of loosesubsoil below embankment due to reduced axle load(σ_z) obtained from Equation (5)and S_{ep}isElastic Settlement of granular subsoil below embankment due to self-weight of pavement layers ($H_p\gamma_e$) obtained from Equation (7).

For rigid pavement and flexible pavement at approach to bridge or culvert the tolerablelimit of residual settlement is 0.1m. Andfor flexible pavement in general road sections except bridge or culvert approach this is 0.2m [7].

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VI. ANALYSIS RESULT

A. RESIDUAL SETTLEMENTCHARTS

The range of width of carriage way of road is 3.0m-22.0m in Bangladesh [8]. The range of corresponding crest width (B_t) including shoulder, verge and median to be 5.0m-30.0m. For 4 Lane highways and expressways the range of crest width is 30m-40m. In this study, the range of crest width (width of road embankment at top level of pavement) is taken as 5m-50m. The range of embankment heightincluding thickness ofpavement layers is taken 1.5m to 12m along with 1V:2H side slope.Thickness ofpavement layers H_p is taken as 1.5m for analysis of residual settlement. Value of average bulk unit weight of pavement layers (γ_e) is 19.5kN/m^3 considered in analysis.

As observed through current study, thevariation of S_r with$B_t$is not significant between B_t=5m to 50m. So that, 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 $S_r$is found for the highest value of B_t=50m. Considering this, the residual settlement chart is prepared for onlyB_t=50m. However, this is also observed that, the variation of $S_r$with N_{60} is significant. Considering this variation, separate residual settlement chart is prepared for N_{60}=1, 2, 3, 4, 5 and 6.

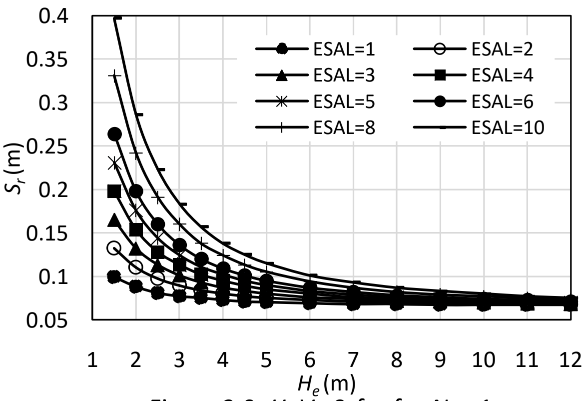

Figure 2.0: H_e Vs S_r for for N_{60}=1

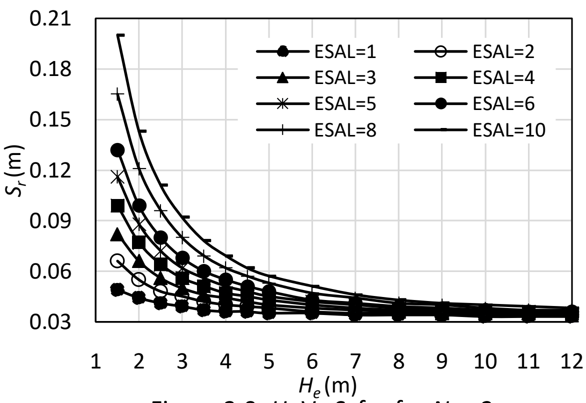

Figure 3.0: H_e Vs S_r for for N_{60}=2

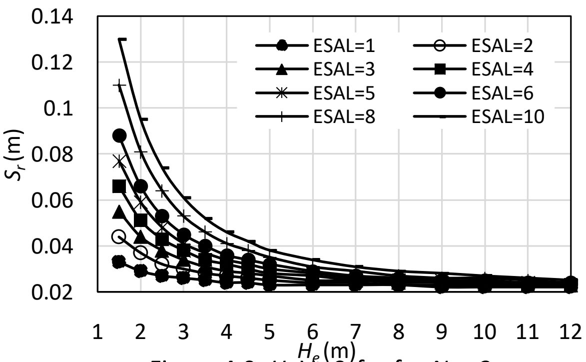

Figure 4.0: H_e Vs S_r for for N_{60}=3

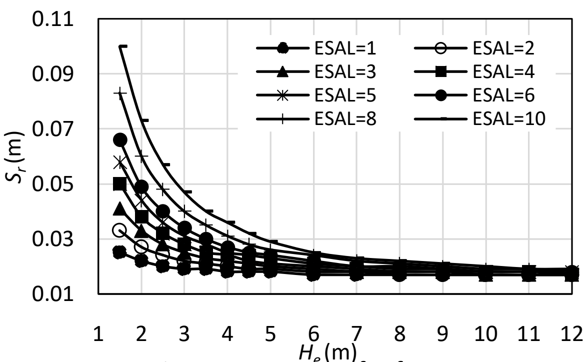

Figure 5.0: H_e Vs S_r for for N_{60}=4

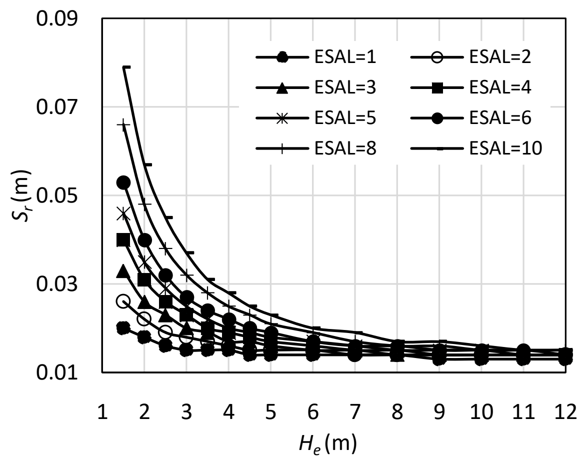

Figure 6.0: H_e Vs S_r for for N_{60}=5

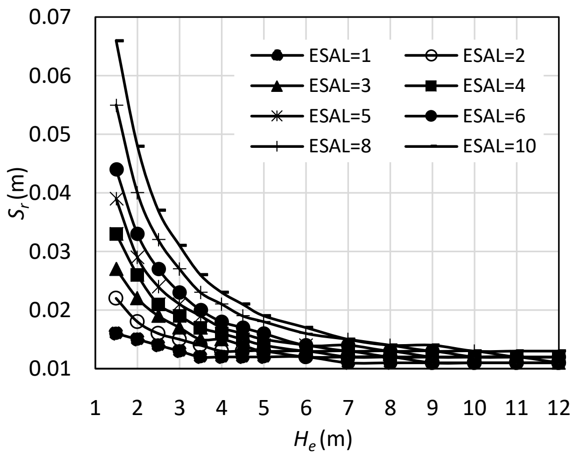

Figure 7.0: H_e Vs S_r for for N_{60}=6

Residual Settlement, S_r(m) for different values of and H_e are obtained from calculations using equation 5, 6, 7 & 8. These obtained values are presented graphically in Figure 2.0 to Figure 7.0 for different values of Embankment height (H_e), N_{60} and*ESAL* factor.

Residual settlement depends on the transferred stresses to subsoil. For more height of highway embankment the reduction of axle induced stress at subsoil level is more. For more reduction of that stress on subsoil, the residual settlement is also smaller.

Hence, in residual settlement charts presented in Figure 2.0 to Figure 7.0, this is observed that, the residual settlement (S_r) is decreases with increase of embankment height (H_e) for same *ESALFactor* and N_{60}.This is the basic finding of current research study.

For a particular value of *ESALFactor* and N_{60} the residual settlement value (S_r) may be obtained from corresponding chart among Figure 2.0 to 7.0 for different values of$H_e$for B_t=50m. Same value of S_r may be used for $B_t$less than 50m.

B. GUIDELINE TO MEET TOLERABLE S_r

Minimum allowable values of H_e to satisfy residual settlement $S_r \leq 0.1$m and $S_r \leq 0.2$m are obtained from residual settlement charts and tabulated in Table 1 and Table 2 successively for B_t=50m. Minimum allowable embankmentheights to satisfy $S_r \leq 0.1$m and $S_r \leq 0.2$m are termed as $H_{e,0.1}$and $H_{e,0.2}$ successively.

Table 1Minimum allowable embankmentheightto satisfy $S_r \leq 0.1$m for rigid pavement and flexible pavement in bridge approachfor loose soil at ground surface (d=0) forB_t=50m

SPT	Minimum allowable embankmentheight to satisfy $S_r \leq 0.1$m for B_t=50m is termed as $H_{e,0.1}$ (m)							
	ESAL=1	*ESAL*=2	*ESAL*=3	*ESAL*=4	*ESAL*=5	*ESAL*=6	*ESAL*=8	*ESAL*=10
N_{60}=1	1.5	2.38	3.06	3.64	4.14	4.58	5.45	6.13
N_{60}=2	0.4	0.75	1.1	1.45	1.76	1.98	2.42	2.79
N_{60}=3	0.1	0.35	0.6	0.85	1.1	1.3	1.67	1.93
N_{60}=4	0.05	0.2	0.4	0.65	0.85	1	1.3	1.5
$N_{60} \geq 5$	Ground Improvement not required for $H_e \geq 1.5$ and $ESAL \leq 10$							

The same guideline as like Table 1.0 and 2.0 is represented as Design Charts in Figure 8.0 and Figure 9.0 are presented in Figure 8.0 to Figure 9.0 successively for very loose cohessionless subsoil having N_{60}=1-4. If N_{60}>4 no identification of Minimum allowable embankmentheight is required. In that case of loose to dense loose soil no ground improvement is required.

The empirical equation for minimum allowable height of Highway Embankment overlying very loose subsoil to satisfy $S_r \leq 0.1$m or $S_r \leq 0.2$m is obtained from 2 order polynomial trend line of Figure 8.0 and Figure 8.0 which is equation (10) –

$$H_{e,0.1} \text{or} H_{e,0.2} = a(ESAL)^2 + b(ESAL) + c \quad (10)$$

In equation (10) the coefficients a, b&c are to be used as presented in Table 3.

Table 2 Minimum allowable embankmentheight to satisfy $S_r \leq 0.2$m for flexible pavement in general road section except bridge/culvert approach for loose soil at ground surface (d=0) for *ESAL* factor 1-10 and B_t=50m

SPT	Minimum allowable embankmentheight to satisfy $S_r \leq 0.2$m for B_t=50m is termed as $H_{e,0.2}$ (m)							
	ESAL=1	*ESAL*=2	*ESAL*=3	*ESAL*=4	*ESAL*=5	*ESAL*=6	*ESAL*=8	*ESAL*=10
N_{60}=1	0.5	0.9	1.2	1.5	1.76	1.98	2.41	2.79
N_{60}=2	0	0.23	0.44	0.65	0.86	1.05	1.4	1.7

N_{60}=3	0	0	0.1	0.25	0.4	0.55	0.8	1
N_{60}=4	0	0	0.03	0.13	0.23	0.35	0.55	0.7
$N_{60}\geq5$	Ground Improvement not required for $H_e\geq1.5$ and $ESAL\leq10$							

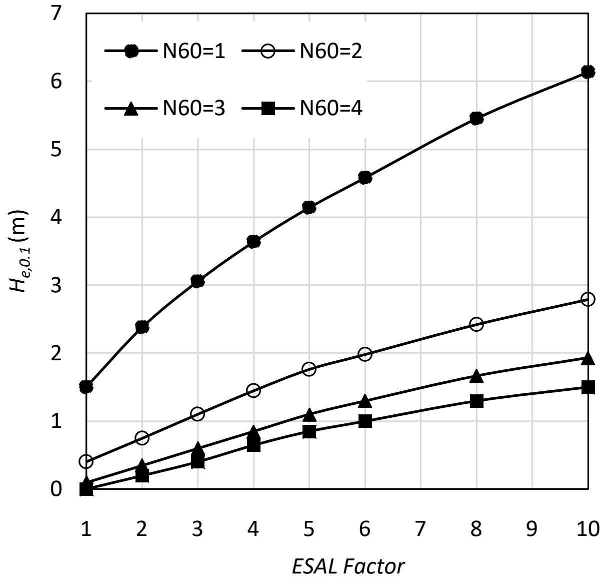

Figure 8.0: *ESAL Factor* Vs $H_{e,0.1}$ for N_{60}=1-4 and $B_t\leq50$m

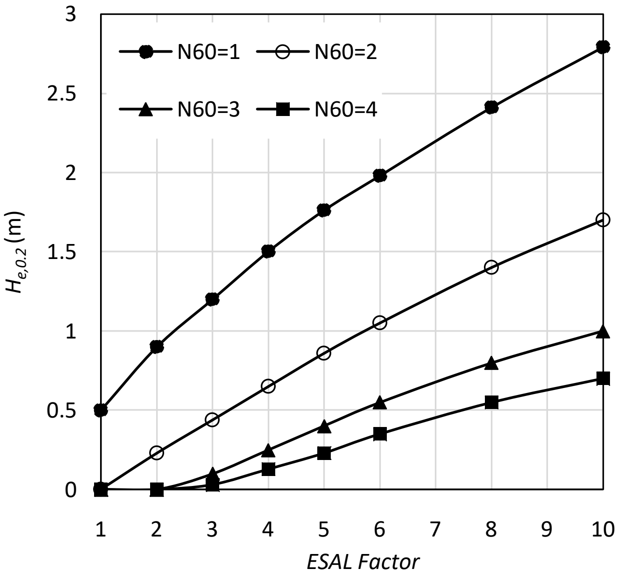

Figure 9.0: *ESAL Factor* Vs $H_{e,0.2}$ for N_{60}=1-4 and $B_t\leq50$m

Using equation (10)theminimum allowable height of Highway Embankment to be obtained for aparticular *ESAL* factor and SPT value N_{60}in the form of$H_{e,0.1}$or $H_{e,0.2}$.If the height of proposed Highway Embankment (H_e) is less than $H_{e,0.1}$in case of rigid pavement and flexible pavement inapproach to bridge or culvertthen Ground Improvement is required. Similarly, if the height of proposed Highway Embankment is less than $H_{e,0.2}$ in case offlexible pavement in general road sections except bridge or culvertthen Ground Improvement is required.

VII. CONCLUSION

The sum ofElastic Settlement due to the stress induced by reduced axle load and due toself-weight of pavement layers is Residual Settlement of loose subsoil underlying the highway embankment. ThoseSettlements to be occurred after construction of pavement layers.

For the cases of loose to dense cohessionless or granular subsoil having$N_{60}$is greater than 4, the Ground Improvement shall not be necessary if the height of embankment (H_e) is at least 1.5m and *ESALfactor* is not more than 10. However, if the subsoil is very loose having$N_{60}$is equal to 4 or less the prepared guideline to be used to identify the necessity of Ground Improvement to keep residual settlement within tolerable limits.

Tolerable limit of the residual settlement is 0.1m for rigid pavement and flexible pavement inapproach to bridge or culvertand 0.2mm for flexible pavement in general road sections except bridge or culvert. The variation of Residual Settlement with change of embankment crest width is not significant and considering this fact, the residual settlement chartswere prepared for50m crest widthonly for the ranges of SPT value and *ESALfactor* of 1-6and1-10 successively. Same value of Residual Settlementmay be used for embankment crest widthless than 50m.

A guideline forsatisfyingtolerable limit of residual settlements is also prepared in form of tables, figures and empirical equationsfor different value of SPT (N_{60}) and *ESAL factor*.In design of a proposed highway embankment the ground improvement shall be necessary if the heightof embankment (H_e) is lessthan$H_{e,0.1}$or $H_{e,0.2}$in case of rigid pavement and flexible pavement inapproach to bridge or culvert and for flexible pavement in general road sections except bridge or culvert approach successively.

Table 3 Value of coefficients *a*, *b*&*c*

S_r	H_s	Ranges of parameter		*a*	*b*	c	Minimum R^2
≤0.1m	$H_{e,0.1}$	d=0	N_{60}=1	-0.028	0.809	0.81	0.996
			N_{60}=2	-0.013	0.416	-0.012	

			N_{60}=3	-0.009	0.305	-0.216	
			N_{60}=4	-0.007	0.249	-0.235	
			$N_{60}\geq5$	Ground. Imp. Not Required			
≤0.2m	$H_{e,0.2}$	d=0	N_{60}=1	-0.011	0.373	0.17	0.998
			N_{60}=2	-0.005	0.248	-0.251	
			N_{60}=3	-0.005	0.197	-0.451	
			N_{60}=4	-0.002	0.132	-0.352	
			$N_{60}\geq5$	Gr. Imp. Not Required			

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REFERENCES

1. Road Master Plan (2009), Roads and Highways Division (RHD), Bangladesh, Ch. 3.
2. Holtz, R. D., and Kovacs, W. D. (1981), "An Introduction to Geotechnical Engineering", Prentice-Hall, Inc, Eaglewood Cliffs, New Jersey.
3. FHWA-IF-12-027 (2012), "Manual For Design, Construction, and Maintenance of Orthotropic Steel Deck Bridges", US Department of Transportation, Federal Highway Administration, P. 76.
4. AASHTO (2016), "HL-93 Vehicular Live Loading, Truck, Tandem and Design Lane Load".
5. Sherje, N. P., Agrawal, S. A., Umbarkar, A. M., Dharme, A. M., & Dhabliya, D. (2021). Experimental evaluation of mechatronics based cushioning performance in hydraulic cylinder. Materials Today: Proceedings, doi:10.1016/j.matpr.2020.12.1021
6. Sherje, N. P., Agrawal, S. A., Umbarkar, A. M., Kharche, P. P., & Dhabliya, D. (2021). Machinability study and optimization of CNC drilling process parameters for HSLA steel with coated and uncoated drill bit. Materials Today: Proceedings, doi:10.1016/j.matpr.2020.12.1070

7. Ahmed, S. (2022), “The Influence Depth of a Highway Embankment”, International Research Journal of Engineering and Technology (IRJET), Volume 9, Issue 8.
8. Bowles J. E. (1977), "Foundation Analysis and Design. 5th edition.", New York: McGraw-Hill.
9. Ahmed, S. (2022), “Depth of Soft Cohesive Soil Underlying Highway Embankment for Limiting Residual Settlement”, International Journal of Science and Research (IJSR), Volume 11, Issue 8.
10. Geometric Design Standards Manual (2005), Roads and Highways Division (RHD), Bangladesh, P. 116.