
HEIGHT OF HIGHWAY EMBANKMENT FOR TOLERABLE RESIDUAL SETTLEMENT OF LOOSE COHESIONLESS SUBSOIL

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¹sharif.geo.2006@gmail.com**ABSTRACT**

Residual settlement of highway embankment is studied for different strength of underlying cohesionless subsoil. 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 settlements of cohesionless subsoil due to axle load and due to self-weight of pavement layers is considered as the residual settlement which are 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 ESAL factor. For rigid pavement and flexible pavement in 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 complete design guideline is developed for design of highway embankment underlain by very loose to loose cohesionless subsoil for limiting value of the residual settlement. In the current parametric study considered ranges for both of ESAL factor and SPT value N_{60} is 1-10. The ground improvement is not required if the average SPT value (N_{60}) within very loose subsoil underlying highway embankment is 5 or more for ESAL factor ≤ 10 and $H_e \geq 1.5$ m. 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.

Keywords: Axle Pressure, Elastic Settlement, Equivalent Single Axle Load (ESAL), Ground Improvement, Highway Embankment, Tolerable Residual Settlement.

I. INTRODUCTION

Construction of Highway Embankment in Bangladesh often to be needed over very loose to loose cohesionless natural subsoil. Usually ground improvement is often provided to strengthen such weak cohesionless soil underlying the proposed embankment. However, the ground improvement not to be required when the residual settlement of subsoil 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 loose cohesionless subsoil considering not exceedance in 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 axle and self-weight of the embankment. According to Bangladesh Road Master Plan [1], in national highways, value of the 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 is 4.8 [1]. Considering such kind of over loading or the future enlargement of acceptable limit, ESAL factor up to 10 are considered for calculation of elastic settlement of subsoil in conducting current research study.

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

or, $W_a = ESAL \text{ factor } (W_r)$ (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 wheel stress on the plan at subsoil level, $\sigma_z = \frac{(w_a/2)}{(B+H_e)(L+H_e)}$ (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 to tyre contact area of dual tyre single axle for HS 20-44 Truck is a single rectangle having width, $B=510\text{mm}$ and length, $L=250\text{mm}$ [3][4]. These values of B and L are used in calculation of axle stress in current study.

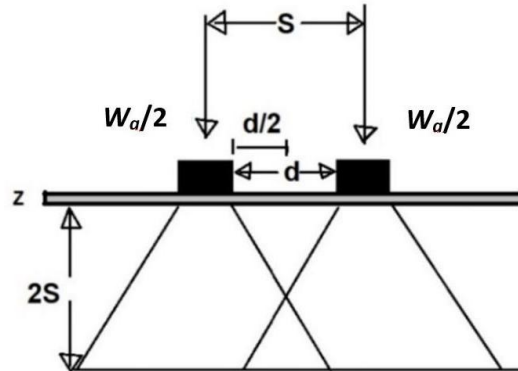


Figure:1.0 The intersection of pressure interface [5].

Pressure transferred to subsoil below road 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 cohesionless or granular subsoil due to Axle load,

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

$$\text{and } F_d = 1 + 0.33 D_f / (B+H_e) \quad (6)$$

where, H_e is height of highway embankment including thickness of pavement 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 cohesionless soil due to self-weight of pavement layers (H_p),

$$S_e \text{ (m)} = \frac{0.002 H_p \gamma_e}{N_{60} F_d} \left[\frac{(B_t+H_e-H_p)^2}{(B_t+H_e-H_p)+0.3} \right] \quad \text{for } B+H_e-H_p > 1.22\text{m} \quad (7)$$

$$\text{and } F_d = 1 + 0.33 D_f / (B_t+H_e-H_p) \quad (8)$$

where, H_e is height of highway embankment including thickness of pavement layers, H_p is thickness of pavement layers, γ_e is average unit weight of pavement layers and $B+H_e$ 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 construction or Residual Settlement. The sum of Elastic Settlement of loose subsoil layer below embankment due to reduced axle load (σ_z) and Elastic Settlement due to self-weight of embankment ($H_p \gamma_e$) is considered as Residual Settlement of cohesionless subsoil because these to be occurred after finish of pavement construction and before first maintenance of pavement.

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

where, S_e is Elastic Settlement of loose subsoil below embankment due to reduced axle load (σ_z) obtained from Equation (5) and S_{ep} is Elastic 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 tolerable limit of residual settlement is 0.1m. And for flexible pavement in general road sections except bridge or culvert approach this is 0.2m [7].

VI. ANALYSIS RESULT

A. RESIDUAL SETTLEMENT CHARTS

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 height including thickness of pavement layers is taken 1.5m to 12m along with 1V:2H side slope. Thickness of pavement 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/m³ considered in analysis.

As observed through current study, the variation of S_r with B_t is not significant between $B_t=5$ m 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 $B_t=50$ m. Considering this, the residual settlement chart is prepared for only $B_t=50$ m. 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.

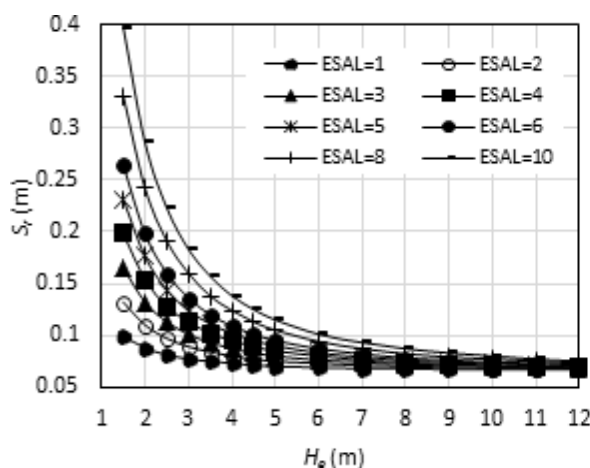


Figure 2.0: H_e Vs S_r for for $N_{60}=1$

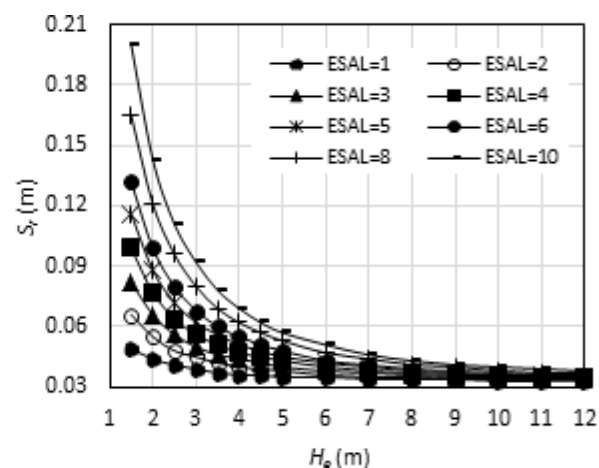


Figure 3.0: H_e Vs S_r for for $N_{60}=2$

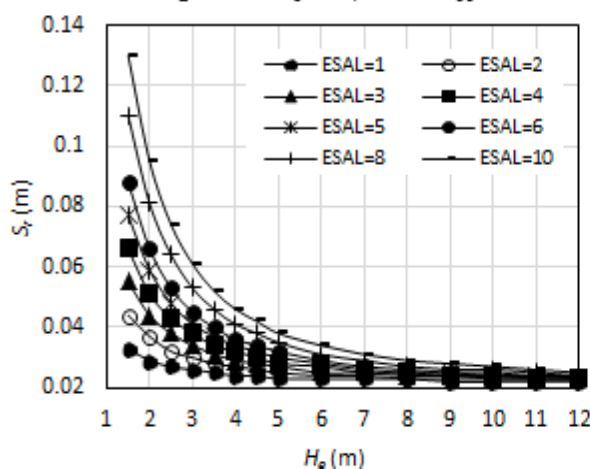


Figure 4.0: H_e Vs S_r for for $N_{60}=3$

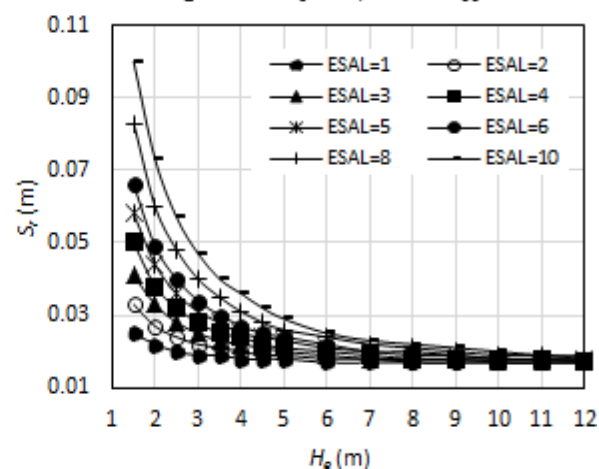
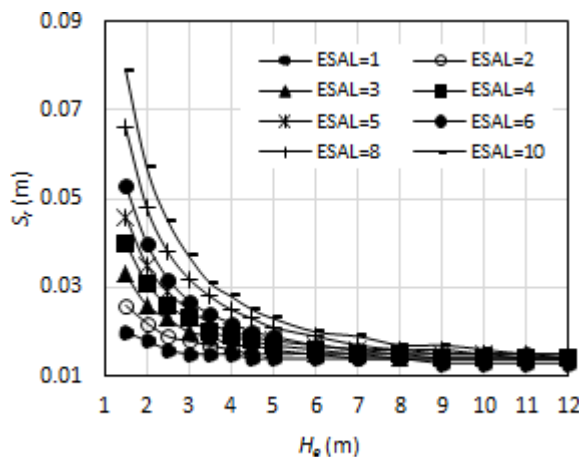
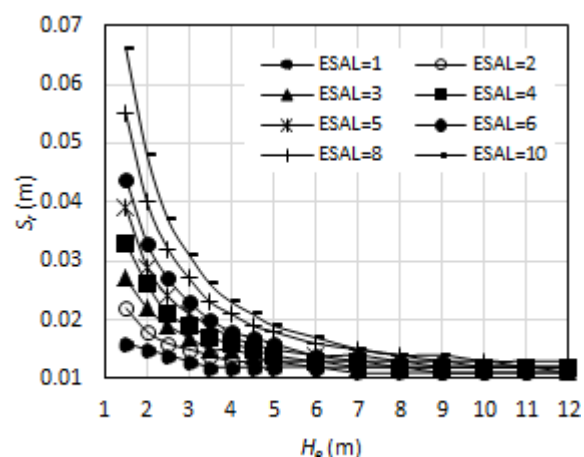


Figure 5.0: H_e Vs S_r for for $N_{60}=4$


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 $ESAL$ Factor and N_{60} . This is the basic finding of current research study.

For a particular value of $ESAL$ Factor 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 $B_t=50$ m. 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 $B_t=50$ m. Minimum allowable embankment heights 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 1 Minimum allowable embankment height to satisfy $S_r \leq 0.1$ m for rigid pavement and flexible pavement in bridge approach for loose soil at ground surface ($d=0$) for $B_t=50$ m

SPT	Minimum allowable embankment height to satisfy $S_r \leq 0.1$ m for $B_t=50$ m 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 cohesionless subsoil having $N_{60}=1-4$. If $N_{60} > 4$ no identification of Minimum allowable embankment height 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 embankment height to satisfy $S_r \leq 0.2\text{m}$ 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 $B_t=50\text{m}$

SPT	Minimum allowable embankment height to satisfy $S_r \leq 0.2\text{m}$ for $B_t=50\text{m}$ 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
$N_{60} \geq 5$	Ground Improvement not required for $H_e \geq 1.5$ and $ESAL \leq 10$							

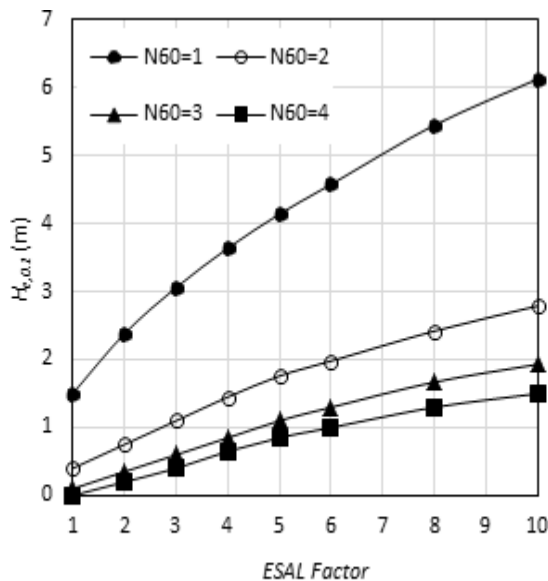


Figure 8.0: ESAL Factor Vs $H_{e,0.1}$ for $N_{60}=1-4$ and $B_t \leq 50\text{m}$

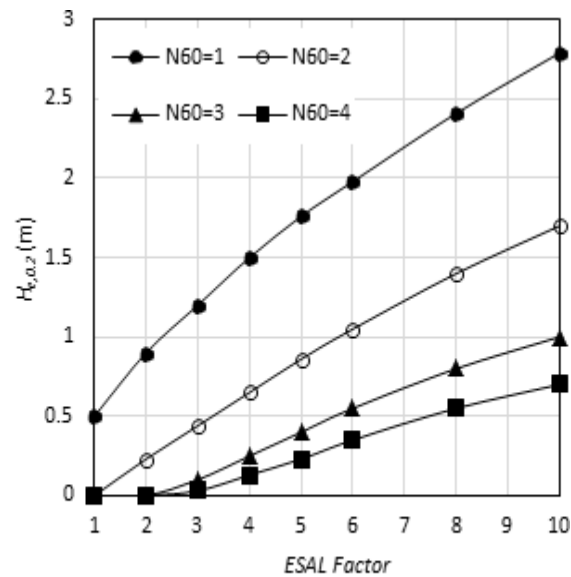


Figure 9.0: ESAL Factor Vs $H_{e,0.2}$ for $N_{60}=1-4$ and $B_t \leq 50\text{m}$

Using equation (10) the minimum allowable height of Highway Embankment to be obtained for a particular $ESAL$ 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 in approach to bridge or culvert then Ground Improvement is required. Similarly, if the height of proposed Highway Embankment is less than $H_{e,0.2}$ in case of flexible pavement in general road sections except bridge or culvert then Ground Improvement is required.

VII. CONCLUSION

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

For the cases of loose to dense cohesionless 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 $ESAL$ factor 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 in approach to bridge or culvert and 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 charts were prepared for 50m crest width only for the ranges of SPT value and $ESAL$ factor of 1-6 and 1-10 successively. Same value of Residual Settlement may be used for embankment crest width less than 50m.

A guideline for satisfying tolerable limit of residual settlements is also prepared in form of tables, figures and empirical equations for different value of SPT (N_{60}) and $ESAL$ factor. In design of a proposed highway embankment the ground improvement shall be necessary if the height of embankment (H_e) is less

than $H_{e,0.1}$ or $H_{e,0.2}$ in case of rigid pavement and flexible pavement in approach 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
$\leq 0.1\text{m}$	$H_{e,0.1}$	$d=0$	$N_{60}=1$	-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	
			$N_{60}\geq 5$	Ground. Imp. Not Required			
$\leq 0.2\text{m}$	$H_{e,0.2}$	$d=0$	$N_{60}=1$	-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	
			$N_{60}\geq 5$	Gr. Imp. Not Required			

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