The Influence Depth of a Highway Embankment

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Abstract–*The Axle Pressure and the Consolidation Pressure decreases with the height of highway embankment and the depth of subsoil. This reduction of pressure depends on the height and width of the embankment. This depth is the significant stressed zone at which the pressure reduced to 0.2 or 20%. This significant stressed zone is defined as the influence of a Highway embankment. The axle pressure is reduced to 7% for embankment height 1-3m and to 0.7% for embankment height 4-12m at the bottom level of Highway Embankment. This observation implies that, the portion of axle pressure transferred to subsoil underlying the embankment is not significant for Equivalent Standard Axle Load (ESAL) factor up to 30.*
The 70% consolidation to be occurred after the construction of the surface layer of pavement. Considering this ratio of post construction settlement, 70% consolidation pressure ($\Delta\sigma_{70}$) is used in this analysis. The magnitude of influence depth or Significant Stressed Zone (D_s has been obtained keeping the range of crest width (at the top level of the embankment) from 5m to 50m and for the range of embankment height from 1.0m to 12.0m considering 70% of consolidation pressure ($\Delta\sigma_{70}$).
Significant stressed zones (D_S) for 70% embankment pressure ($\Delta\sigma_{70}$) are found as 2-6.2H_e for embankment top width 5-50m.

Key Words: Consolidation pressure, Equivalent Standard Axle Load (ESAL), Highway Embankment, HS 20-44, Significant Stressed Zone, Stress Distribution

1. INTRODUCTION

In Bangladesh, it is common practice to construct highway embankments on soft or very loose natural subsoil that extends to vast depths. The assessment for bearing capacity and settlement of highway embankment is subjected to the depth of stressed zone extended into the underlying poor subsoil.

The depth of subsoil (as a multiplication of embankment height) to be evaluated up to which depth the transferred stresses or pressure is significant. To obtain the significant influence depth or significant stressed zone a research study on stress distribution to subsoil below a Highway embankment has been carried out. In this study, simplified ratios of embankment height to depth or substantial stressed zone inside subsoil are determined for various depths and widths of embankment.

2. TRAFFIC LOAD ON SUBSOIL

Traffic induced stress on Highway Embankment is due to axle load of traffic vehicle. Stresses on subsoil underlying Highway embankment are transferred portion of axle load and the self-weight of embankment.

As per Bangladesh Road Master Plan [1], Standard axle loads used for calculating Equivalent Standard Axle Load (ESAL) are front (steering) axle – 65 kN; rear single axle – 80 kN; and tandem axles – 147 kN. As per traffic survey in different national highways in Bangladesh ESAL for dual tyre single axle is 33. This value is much greater than the allowable ESAL=4.8 (for heavy truck).

Equivalent Standard Axle Load,

ESAL= W_a / W_r or, W_a = ESAL (W_r) (1)

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

3. STRESS DISTRIBUTION

3.1 Distribution of Axle Load

The simplest approach of stress distribution at a depth is 2:1 (vertical to horizontal). This empirical method is used for tyre loading in this stusy (Fig- 1) [2].

Due to spreading of the same vertical load over a much larger area at depth, the unit stress reduced. Stress on the plan at depth z,

$$\Delta q = \frac{\sigma_0 BL}{(B+z)(L+z)} \quad (2)$$

According to Fig-1, pressure on tyre to pavement contact area,

$$\sigma_z = \frac{W_a}{BL} \quad (3)$$

And the concentrated load on pavement,

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

where, W_a = Axle Load and B, L=Width and Length of Tyre to pavement contact area successively.

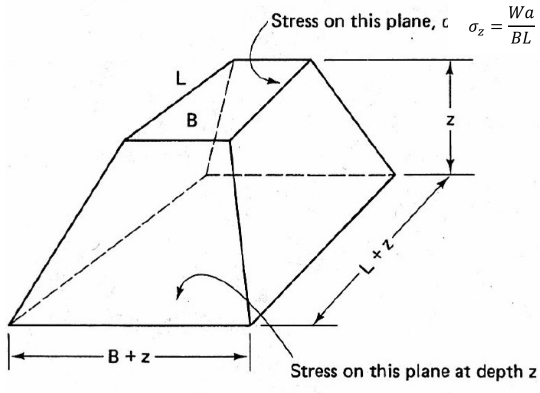

Fig- 1 The 2V:1H Method for Vertical Stress Increase as a function of soil depth below tyre [2].

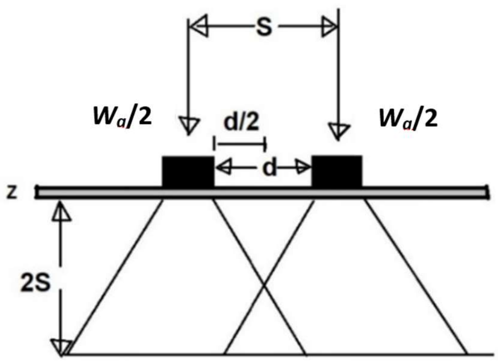

Fig- 2 The intersection of pressure interface.

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

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

Considering interface/overlap of pressure from two wheel in an axle (shown in Fig- 2),

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

where,
H_e = Height of Embankment fill above natural ground level

The ratio of stress at those two level is $\Delta q/\sigma_z$. This ratio indicates the percentage of load which transferred to H_e depth.

3.2. Distribution of Embankment Pressure

Embankment Pressure at bottom level of embankment is $q_e = \gamma_e H_e$ which is considered to be distributed as per Fig- 3 [3].

Consolidation Pressure at H_s depth below center of embankment [3],

$$\Delta\sigma_0 = \frac{q_e}{\pi}\left[\left(\frac{\frac{B_t}{2}+2H_e}{2H_e}\right)(\alpha_1+\alpha_2) - \left(\frac{\frac{B_t}{2}}{2H_e}\right)(\alpha_2)\right] \quad (7)$$

where, H_s = Depth of Subsoil underlying embankment, γ_e = Bulk Unit weight of embankment fill, B_t = Width of embankment top.

And, in equation (7) –
the distance between stressed point and end of embankment top= $B_t/2$

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

$$\alpha_2 = tan^{-1}\left(\frac{\frac{B_t}{2}}{H_s}\right)$$

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

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

$$\Delta\sigma_1 = \frac{q_e}{\pi}\alpha_1 \quad (8)$$

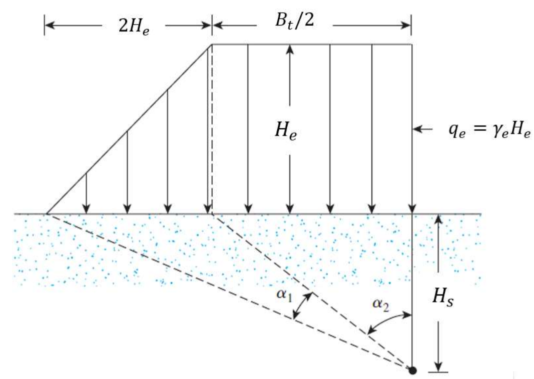

Fig- 3 Stress Reduction due to embankment loading considering 1V:2H Side slope [3]

In equation (8) –
Considering the distance between stressed point and end of embankment top= 0

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

$$\alpha_2 = 0$$

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

Average Consolidation Pressure at H_s depth below the embankment,

$$\Delta\sigma = \frac{1}{2}(\Delta\sigma_0 + \Delta\sigma_1) \quad (9)$$

where,

$\Delta\sigma_0$= Consolidation Pressure at H_s depth below center of embankment and $\Delta\sigma_1$= Consolidation Pressure at H_s depth below the end of embankment top.

In Bangladesh the range of width of carriage way is 3.0m to 22.0m [4]. The range of crest width including shoulder, verge and median is 5m to 30m. For 4 Lane and expressway the range of crest width may 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 height 1m to 12m and side slope of embankment 1V:2H are taken for analysis.

4. SIGNIFICANT STRESSED ZONE OF HIGHWAY EMBANKMENT

As recommended by [5] the depth of 20% of the foundation contact pressure is significant stressed zone for settlement analysis termed as the significant depth D_s. Terzaghi's suggestion was based on his finding that direct stresses are regarded as negligible if they account for less than 20% of the applied stress.

4.1 Significant Stressed Zone for Axle Pressure

For HS 20-44 Truck and Tandem, the design contact area of tyre for dual tyre single axle is a single rectangle of width, B= 510mm and length, L= 250mm (Fig- 4).

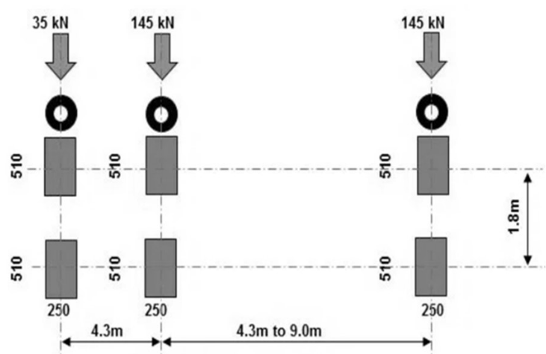

Fig- 4 Tyre contact area of HS 20-44 [6][7]

For dual tyre tandem axle is a single the design contact area is double rectangle of width, B= 510mm and length, L= 500mm. These values of B and L are used in current analysis of stress distribution.

The values of the stress transfer ratio $\Delta q/\sigma_z$ are calculated for different value of H_e and H_s. Through the values of $\Delta q/\sigma_z$ the amount of load transferred to H_s depth is assessed.

The changes of $\Delta q/\sigma_z$ with H_e for different value of $ESAL$ are presented in Chart-1 for dual tyre single axle. Similarly, the changes of $\Delta q/\sigma_z$ with H_e for different value of $ESAL$ are presented in Chart-2 for dual tyre tandem axle. $\frac{\Delta q}{\sigma_z}$ is independent of ESAL.

Simplified maximum ratios of transferred load to subsoil or the maximum values of $\Delta q/\sigma_z$ are tabulated in Table 1.0 for different range of embankment height (H_e) according to Chart-1 and Chart-2.

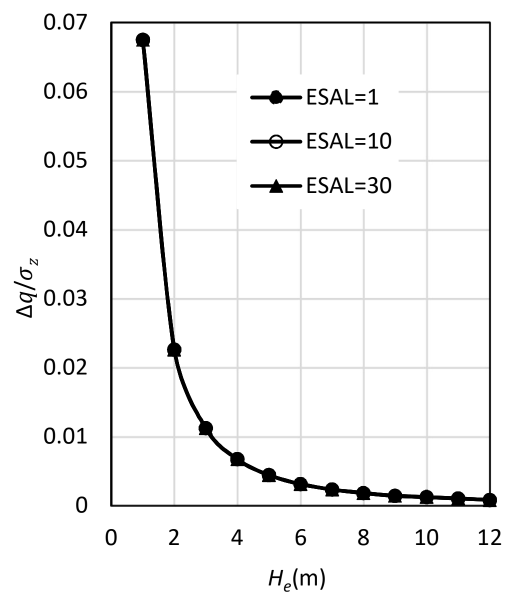

Chart-1: H_e Vs σ_z/σ_0 for H_e=1m to 12m for Dual Tyer Single Axle

Table 1 Maximum value of $\Delta q/\sigma_z$ for different range of embankment height (h_e).

Depth of Embankment, H_e (m)	1	2-3	4-5	6-7	8-9	10-11	10-12
$\Delta q/\sigma_z$ (Dual Tyre Single Axle)	7%	2.5%	0.7%	0.35%	0.2%	0.15%	≤0.08%
$\Delta q/\sigma_z$ (Dual Tyre Tandem Axle)	12%	4.5%	1.5%	0.6%	0.35%	0.25%	≤0.16%

Table 2 According to [8] the settlement and time data.

Time (Day)	10	100	730	1000	10000
Time (Year)	0.03	0.27	2.00	2.74	27.40
Considering two way drainage Consolidation Settlement (mm)	196	392	448	1288	1400
Considering one way drainage Consolidation Settlement (mm)	84	196	1000	672	1400
% of Total Consolidation Considering two way drainage	14	28	71	92	100
% of Total Consolidation Considering one way drainage	6	14	32	48	100

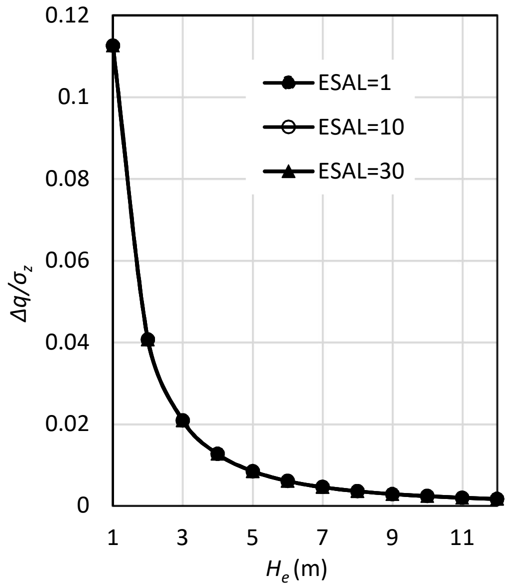

Chart-2: H_e Vs σ_z/σ_0 for H_e=1m to 12m for Dual Tandem Single Axle

As observed in Table 1, according to current study, maximum 12% of axle pressure for the range of embankment height 1-3m and maximum 1.5% of axle pressure for the range of embankment height 4-12m is to be transferred to subsoil underlying the highway embankment.

Hence, according to Terzaghi's recommendation [5] transfer of axle load to subsoil is not significant for the foundation deign of highway embankment.

4.2 Significant Stressed Zone for Embankment Pressure

Consolidation settlement of the subsoil underlying the highway embankment will take place for embankment pressure or self-weight produced pressure. Consolidation Pressure ($\Delta\sigma$) is derived from only Embankment Pressure (q_e).

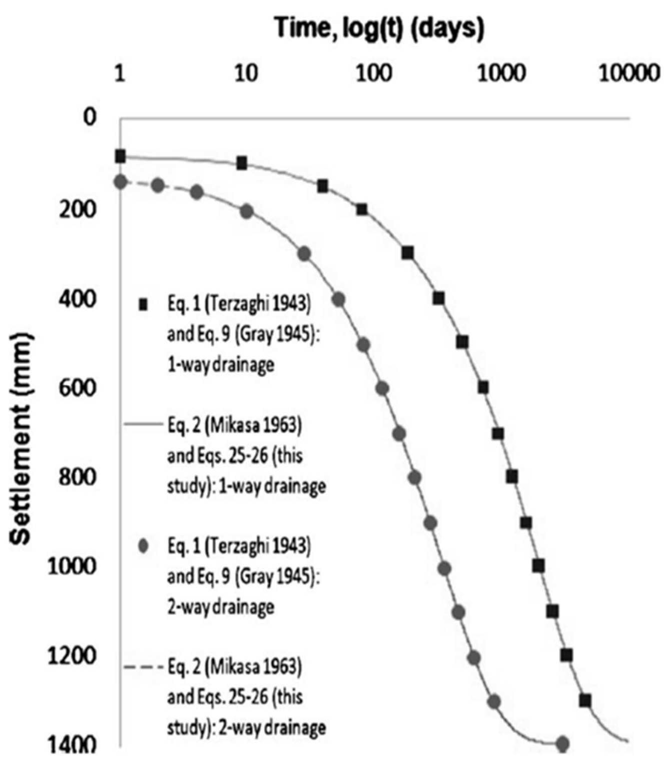

Chart-3: Settlement-time curve [8]

The transfer of embankment pressure is significant for assessment of consolidation settlement.

The residual portion of consolidation settlement is to be considering in assessment of settlement risk. According to observed time-settlement curves under surcharge load is presented in Chart-3 and in Table 2 [8].

Table 2's time-settlement data indicates that, following the completion of embankment filling, at least 30% of the total consolidation will occur during the next two years of construction.

So that, after construction 70% consolidation to be considered as residual settlement. For those two references, significant stressed zones for Highway Embankment are analyzed accounting 70% Consolidation Pressure ($\Delta\sigma_{70}$) at H_s depth due self-weight induced pressure of embankment.

Now, 70% Consolidation Pressure at H_s depth (kN/m^2),

$$\Delta\sigma_{70} = 0.7 \times \frac{1}{2}(\Delta\sigma_0 + \Delta\sigma_1) = 0.35(\Delta\sigma_0 + \Delta\sigma_1) \quad (10)$$

The values of the stress transfer ratio $\Delta\sigma_{70}/q_e$ are calculated for different value of H_e, B_t and H_s. Change of $\Delta\sigma_{70}/q_e$ for different Depth Ratio (H_s/H_e) are presented in Chart-4 to Chart-9 for range of B_t =5m to 50m and range of H_e=1m to 12m. Depth Ratio (H_s/H_e) at $\Delta\sigma_{70}/q_e$=0.20 is termed as $\left(\frac{H_s}{H_e}\right)_{0.2}$ for width of Embankment Top, B_t =5m to 50m and height of embankment, H_e=1m to 12m is presented in Table 3 and in Chart-10.

Depth Ratio (H_s/H_e) at $\Delta\sigma_{70}/q_e$=0.20 for width of Embankment Top, B_t =5m to 50m and height of embankment, H_e=1m to 12m is presented alternately in Chart-11.

According to power trend line of Chart-11, Depth Ratio (H_s/H_e) for $\Delta\sigma_{50}/q_e$ =0.20 is termed as $\left(\frac{H_s}{H_e}\right)_{0.2}$ may be expressed by equation (11.1) to (11.6) –

$$\left(\frac{H_s}{H_e}\right)_{0.2} = 3.32(H_e)^{-0.26} \text{ for } B_t\text{=5m} \quad (11.1)$$

$$\left(\frac{H_s}{H_e}\right)_{0.2} = 4.52(H_e)^{-0.347} \text{ for } B_t\text{=10m} \quad (11.2)$$

$$\left(\frac{H_s}{H_e}\right)_{0.2} = 6.11(H_e)^{-0.388} \text{ for } B_t\text{=20m} \quad (11.3)$$

$$\left(\frac{H_s}{H_e}\right)_{0.2} = 7.20(H_e)^{-0.399} \text{ for } B_t\text{=30m} \quad (11.4)$$

$$\left(\frac{H_s}{H_e}\right)_{0.2} = 8.00(H_e)^{-0.396} \text{ for } B_t\text{=40m} \quad (11.5)$$

$$\left(\frac{H_s}{H_e}\right)_{0.2} = 8.44(H_e)^{-0.375} \text{ for } B_t\text{=50m} \quad (11.6)$$

Significant stressed zone,

$$D_s = H_e\left(\frac{H_s}{H_e}\right)_{0.2} \quad (12)$$

Table 3: Values of $\left(\frac{H_s}{H_e}\right)_{0.2}$ for width of B_t =5m to 50m and H_e =1m to 12m

B_t (m)	5	10	20	30	40	50	H_e (m)
$\left(\frac{H_s}{H_e}\right)_{0.2}$	3.6	4.7	6.2	7.2	7.8	8	1
	2.7	3.6	4.7	5.5	6.2	6.8	2
	2.4	3.1	3.9	4.7	5.3	5.8	3
	2.2	2.7	3.6	4.2	4.7	5.1	4
	2.1	2.3	3.1	3.5	3.9	4.3	6
	1.9	2.2	2.7	3.1	3.6	3.8	8
	1.9	2.1	2.5	2.9	3.2	3.6	10
	1.8	2.0	2.4	2.7	3.0	3.3	12

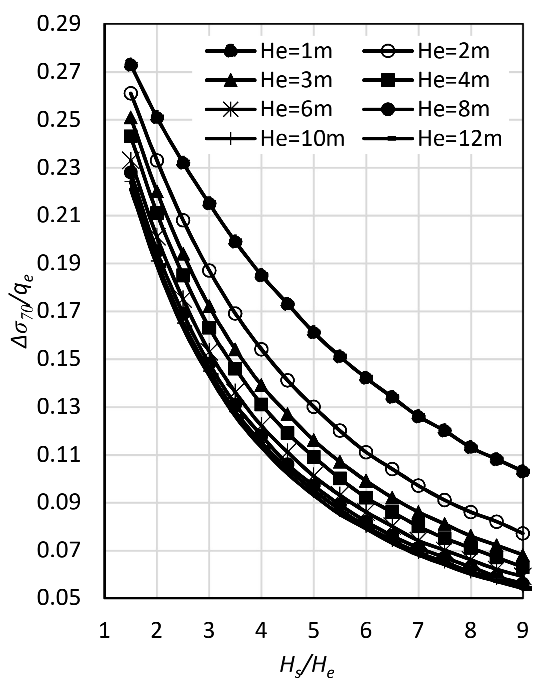

Chart-4: H_s/H_e Vs $\Delta\sigma_{70}/q_e$ for B_t=5m

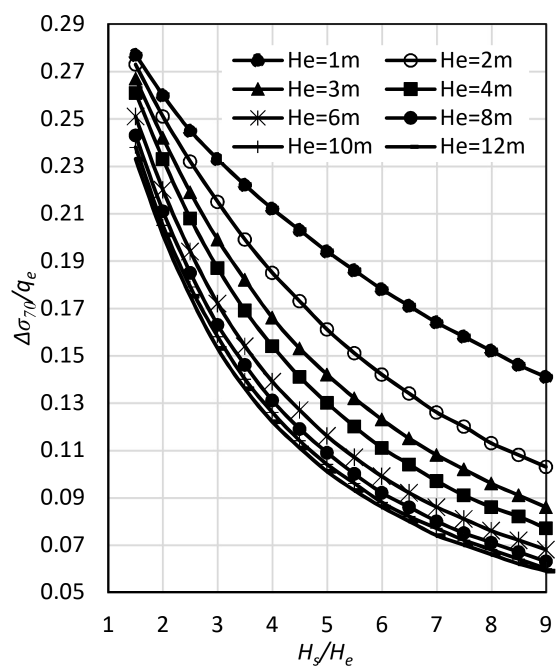

Chart-5: H_s/H_e Vs $\Delta\sigma_{70}/q_e$ for B_t=10m

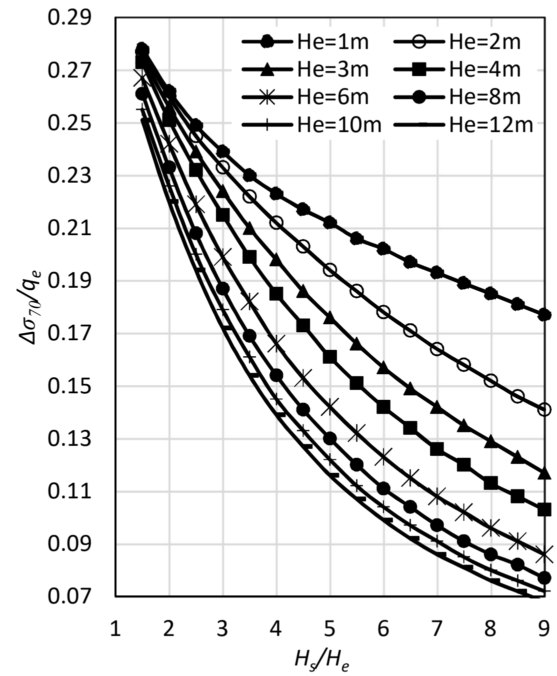

Chart-6: H_s/H_e Vs $\Delta\sigma_{70}/q_e$ for B_t=20m

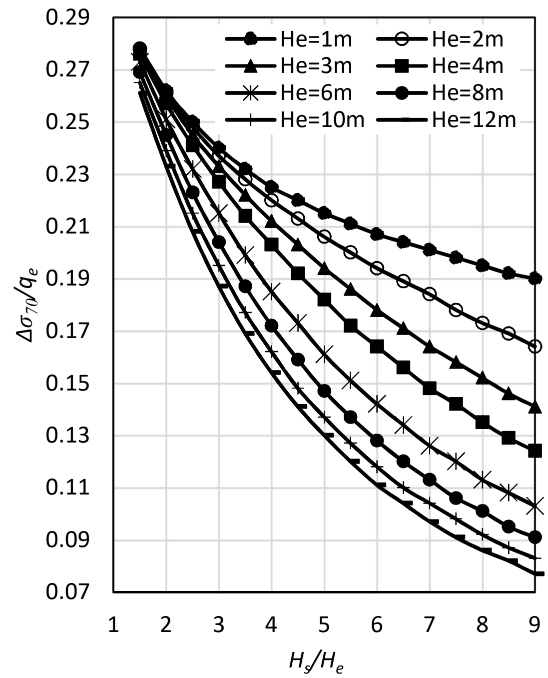

Chart-7: H_s/H_e Vs $\Delta\sigma_{70}/q_e$ for B_t=30m

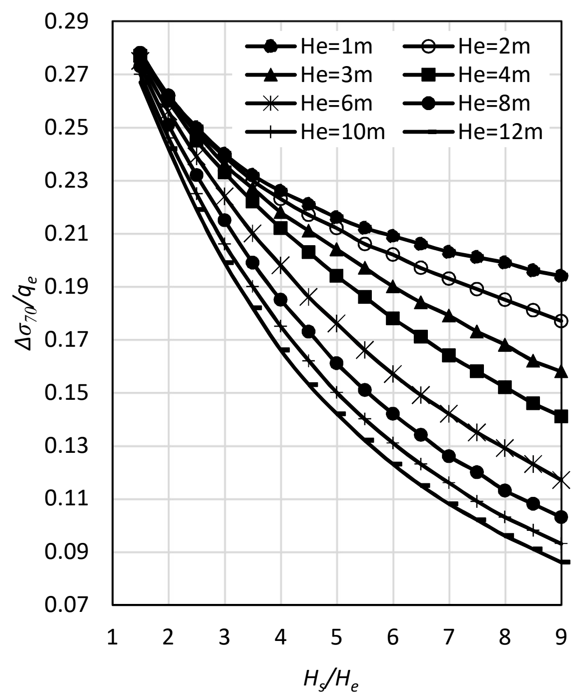

Chart-8: H_s/H_e Vs $\Delta\sigma_{70}/q_e$ for B_t=40m

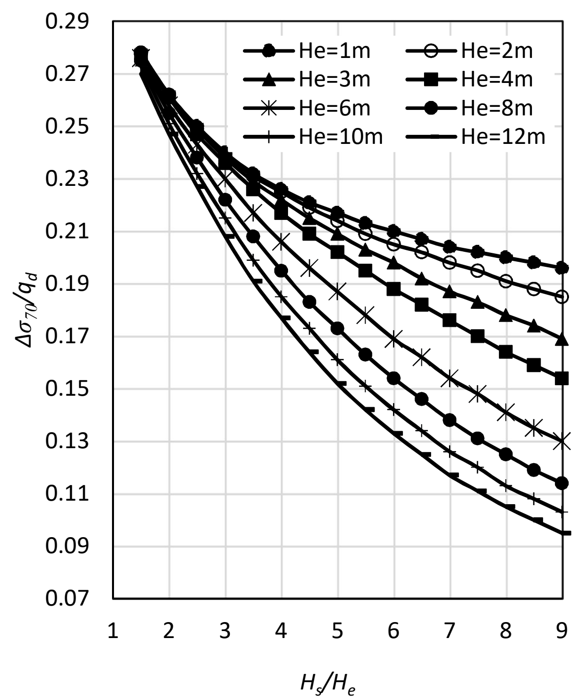

Chart-9: H_s/H_e Vs $\Delta\sigma_{70}/q_e$ for B_t=50m

Hence, the Significant stressed zone, D_s for 70% consolidation pressure may be expressed by equation (13.1) to (13.6) –

$D_s = 3.32(H_e)^{0.740}$ for B_t=5m (13.1)

$D_s = 4.52(H_e)^{0.653}$ for B_t=10m (13.2)

$D_s = 6.11(H_e)^{0.612}$ for B_t=20m (13.3)

$D_s = 7.20(H_e)^{0.601}$ for B_t=30m (13.4)

$D_s = 8.00(H_e)^{0.604}$ for B_t=40m (13.5)

$D_s = 8.44(H_e)^{0.625}$ for B_t=50m (11.6)

Approximately simplified values of D_s is given in Table 4.

Table 4: Simplified values of D_s for 70% consolidation pressure

With of Embankment Top, B_t	5-10	20-30	40-50	H_e (m)
D_s	$3H_e$	$5H_e$	$6.2\ H_e$	1-4
	$2H_e$	$2.8\ H_e$	$3.5\ H_e$	6-12

Simplified form of D_s for 70% consolidation pressure may be expressed by equation (14.1) and (14.2) –

$D_s = 4.7(H_e)^{0.67}$ for B_t=5-20m (14.1)

$D_s = 7.9(H_e)^{0.61}$ for B_t=30-50m (14.2)

5. CONCLUSION

Maximum 12% of axle pressure for embankment height 1-3m and maximum 1.5% of axle pressure for embankment height 4-12m is to be transferred to subsoil underlying the highway embankment. According to Terzaghi's recommendation for significant stressed zone, transferred portion of axle load to subsoil is not significant regardless of ESAL.

The transferred portion of consolidation is much more significant than transferred axle pressure. Considering 70% consolidation to be occurred after construction of surface layer of pavement, 70% consolidation pressure is used in this analysis. The depth was identified at which the pressure is reduced to 20% of $\Delta\sigma_{70}$ and this depth is termed as significant stressed zone (D_s).

Significant stressed zones for embankment pressure are found 2-3H_e for embankment top width 5-10m, 2.8-5H_e for embankment top width 20-30m and 3.5-6.2H_e for embankment top width 40-50m.

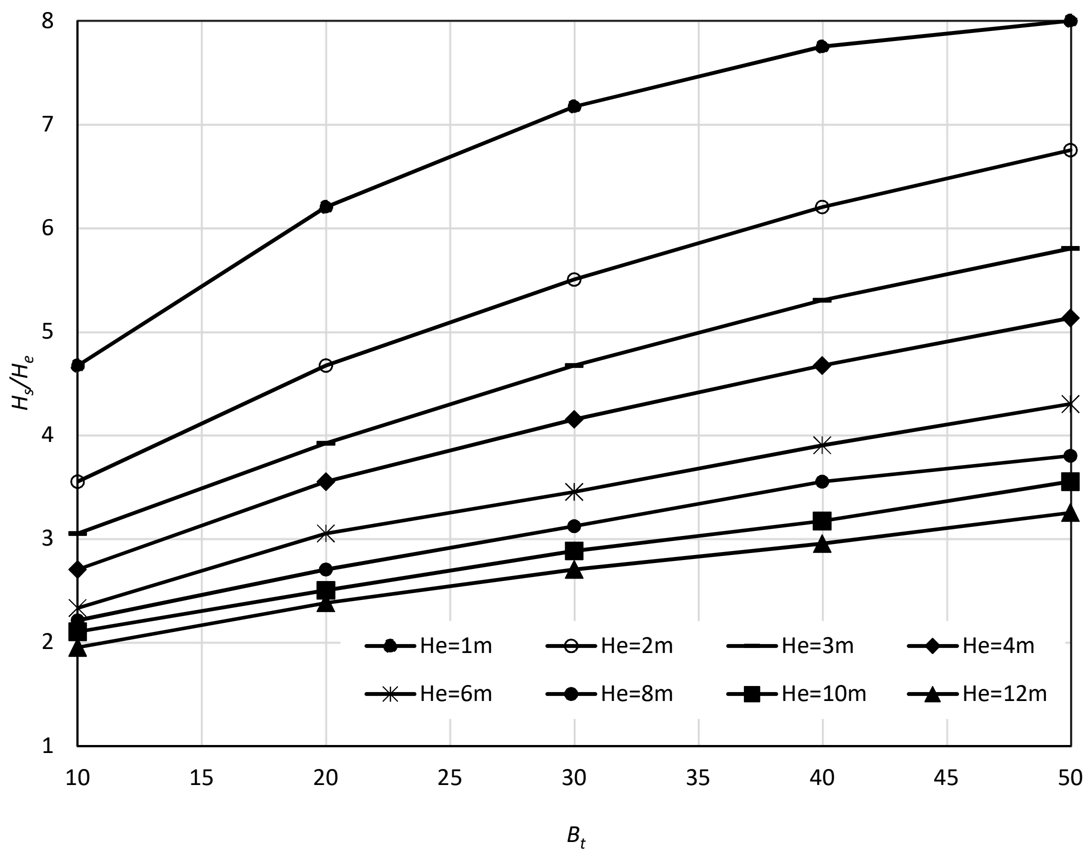

Chart-10: H_s/H_e Vs B_t for $(\Delta\sigma_{70})/q_e$ =0.20

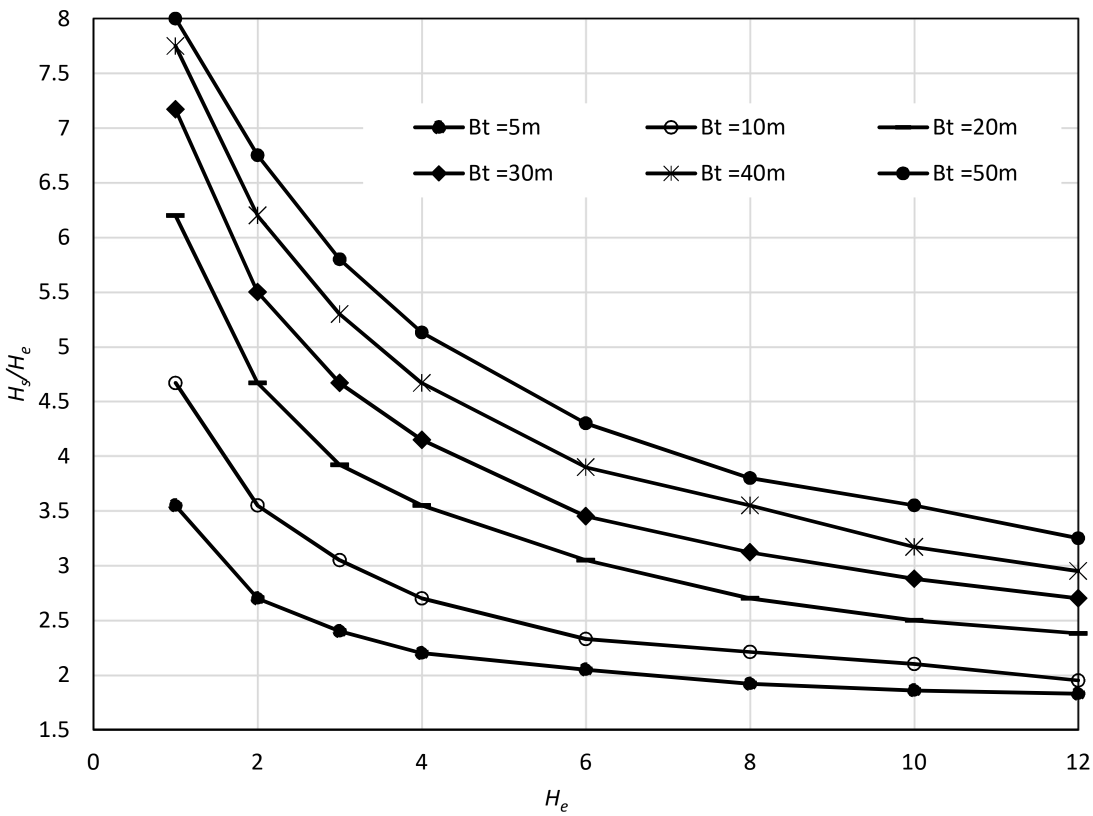

Chart-11: H_s/H_e Vs H_e for $(\Delta\sigma_{70})/q_e$ =0.20

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DECLARATION

This is my own research work. This is not copy of any research.

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