# The calculation method of embankment sedimentation on the slope foundation in highway extension project

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**Abstract.** With the rapid development of Chinese economy, the phenomenon of the traffic jam is more and more serious in Chinese highway today. Therefore, in order to solve the problem of the traffic congestion, the expansion of the existing highway is thought to be an effective way. In terms of the new embankment, it can be considered as a subgrade on the slope foundation. However, the calculation method of sedimentation and the characteristics of stress distribution about the new embankment on the slope foundation are both different from the embankment on the flat ground. At present, the calculation method of embankment sedimentation on the slope foundation is mainly the basic test, and it also lacks the method of stress calculation. Thus, based on the analysis of embankment on the flat ground, this paper gets the calculation method of embankment's stress on the slope foundation, and according to the layer wise summation method, finally it obtains the calculation method of embankment sedimentation on the slope foundation.

**Keywords:** Embankment; sedimentation; calculation method; slope foundation; highway.

## 1. Introduction

With the Chinese economy sustained, healthy and rapid development, highway construction has made great achievements in China. By the end of 2012, the Chinese highway mileage has reached 96000 km, and has exceeded the America 92000 km, ranking first in the world. However, most of the Chinese highways are constructed by the construction standard of the twin four-lane, accounting for about 88% of the total mileage. With the traffic volume increases day by day, especially in the developed areas, it appears many problems of traffic congestion in the existing highway. If it constructs the new lines, it will lead to so many problems that the remove is difficult and the engineering cost is great expense. Thus, in order to solve the problem of heavy traffic ,the prospect of expanding the existing highway is considered to be a promising idea. And it can not only reduce the construction land, but also can save the project cost.

Because the consolidation process and loading degree in the new subgrade is different from the old subgrade , this will inevitably lead to appear the different embankment sedimentation between the new and the old. How to calculate their sedimentation value is very important for preventing their uneven settlement, and it is directly related to the success or failure of highway extension project. In terms of the new subgrade, because the new embankment is filled on the old roadbed slope, the old subgrade slope can be considered as a foundation of the new. However, the calculation method of sedimentation and the characteristics of stress distribution about the new embankment on the slope foundation are both different from the embankment on the flat ground. For the moment, the calculation method of embankment sedimentation on the slope foundation is mainly the basic test, and it also lacks the method of stress calculation. Therefore, it is worth researching the calculation method of embankment sedimentation on the slope foundation in highway extension project.

## 2. The analysis of embankment sedimentation on the flat ground

### 2.1 The stress analysis of flat ground

The settlement of flat ground is mainly caused by the additional stress generated by the embankment filling, and the additional stress in soil plays a decisive role to the foundation sedimentation. When calculating the sedimentation, among the loading process, the self-weight stress in soil is constant and the additional stress is only caused by the embankment. In soil mechanics, the additional stress is usually calculated by the Boussinesq's solution of elastic half space body.

Because of the successive loading process of the high embankment, the internal stress of soil is extremely complex. In order to facilitate the calculation, it makes the following two assumptions: First, the foundation deformation is calculated by the layerwise summation method. When calculating the effect of one filling soil on the foundation, this filling soil is considered as an additional load, and the original stress of foundation is the self weight stress; second, with the increase of stress, the filling soil's void ratio decreases gradually, and the compression modulus gradually improves. In addition, the stress and strain are according to the "E-P" curve. Based on the assumptions, and according to the Boussinesq's solution, we can get the calculation formula of flat foundation's additional stress.

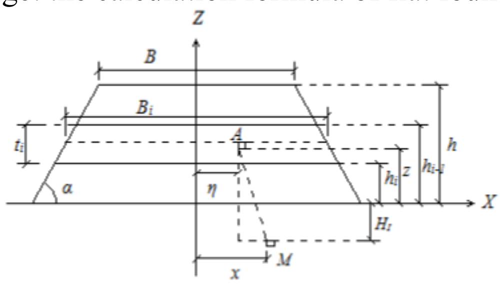


Fig.1 The stress analysis of flat ground caused by embankment

In the foundation soil, the self-weight stress can be expressed as:

$$\sigma_{H_I} = \gamma \cdot H_I \tag{1}$$

As shown in Figure 1, takes a micro surface "A" in the "i" layer filling soil, then its load can be written as $\gamma_i \cdot d\eta \cdot dz$ .

According to the Boussinesq's solution:

$$\sigma_z = \frac{2\bar{p}Z^3}{\pi\left[X^2 + Y^2\right]^2} \tag{2}$$

Then, the additional stress caused by the micro surface "A", can be calculated as the following formula:

$$d\sigma_Z = \frac{2\left(H_I + z\right)^3 \gamma_i}{\pi\left[\left(x-\eta\right)^2 + \left(H_I + z\right)^2\right]^2} d\eta dz \tag{3}$$

It follows from (2), that we can obtain the total additional stress in depth of "H" caused by the "i" layer filling soil:

$$\Delta\sigma_{iH_I} = \int_{h_i}^{h_{i-1}} \int_{-\frac{B_i}{2}}^{\frac{B_i}{2}} \frac{2\left(H_I + z\right)^3 \gamma_i}{\pi\left[\left(x-\eta\right)^2 + \left(H_I + z\right)^2\right]^2} d\eta dz \tag{4}$$

According to the existing research results, the additional stress has the characteristics that it is big in the middle, and it is small on both sides. So the settlement in the center line of embankment is greater than at the edge of embankment. Therefore, the result that evaluating the embankment settlement by the sedimentation value of center line is on the safe side. When only considering the sedimentation of center line, makes "x=0"into (3), then the above formula can be simplified as:

$$\Delta\sigma_{iH_I} = \int_{hi}^{h_{i-1}} \int_{-\frac{B_i}{2}}^{\frac{B_i}{2}} \frac{2\left(H_I + z\right)^3 \gamma_i}{\pi\left[\eta^2 + \left(H_I + z\right)^2\right]^2} d\eta dz \tag{5}$$

Remarks: $\frac{B_i}{2} = \frac{B}{2} + \frac{h-z}{\tan\alpha}$

## 2.2 The stress analysis of flat embankment

Because of the successive loading process of the high embankment, the internal stress of soil is extremely complex. In order to facilitate the calculation, it makes the following two assumptions: First, the embankment deformation is calculated by the layerwise summation method. When calculating the effect of one filling soil on the soil below, this filling soil is considered as an additional load, and the original stress of soil below is the self weight stress; Second, with the increase of stress, the filling soil's void ratio decreases gradually, and the compression modulus gradually improves. In addition, the stress and strain are according to the "E-P" curve. Based on the assumptions, we can obtain the calculation formula of flat embankment's additional stress.

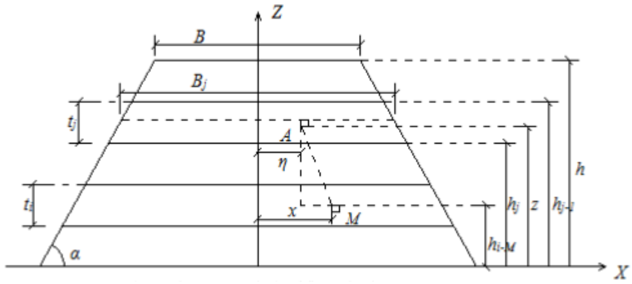

Fig.2 The stress analysis of flat embankment

In the "i" layer filling soil, the average self weight stress can be expressed as:

$$\sigma_i = \frac{\gamma_i \cdot t_i}{2} \tag{6}$$

As shown in Figure 2, just as the calculation method of flat foundation, we could get the additional stress of "i" layer filling soil in the center caused by the micro surface "A" in the "j" layer filling soil by the following formula:

$$d\sigma_z = \frac{2h_{ij}^3\gamma_j}{\pi\left[(x-\eta)^2 + h_{ij}^2\right]^2} d\eta dz \tag{7}$$

Remarks: "hij" is the altitude difference between the center of "i" layer filling soil and the center of "j" layer filling soil. Hij=z-hiM

It follows from (5), that we can have the total additional stress of "i" layer filling soil in the center caused by the "j" layer filling soil:

$$\Delta\sigma_{ij} = \int_{h_j}^{h_{j-1}} \int_{-\frac{B_j}{2}}^{\frac{B_j}{2}} \frac{2h_{ij}^3\gamma_j}{\pi\left[(x-\eta)^2 + h_{ij}^2\right]^2} d\eta dz \tag{8}$$

As the same with the flat foundation, when only considering the sedimentation of center line, makes "x=0"into (6), then the above formula can be simplified as:

$$\Delta\sigma_{ij} = \int_{h_j}^{h_{j-1}} \int_{-\frac{B_j}{2}}^{\frac{B_j}{2}} \frac{2h_{ij}^3\gamma_j}{\pi\left[\eta^2 + (z-h_{iM})^2\right]^2} d\eta dz \tag{9}$$

Remarks: $\frac{B_j}{2} = \frac{B}{2} + \frac{h-z}{\tan\alpha}$

## 3. The calculation of embankment sedimentation on the slope foundation

The calculation method of embankment's stress on the slope foundation is based on the calculation of flat embankment. As the same with the flat embankment, the settlement of slope embankment consists of two parts. One is its own settlement, and the other is the settlement of slope foundation. Calculate the sedimentation of two parts separately, and then superimpose each other. That is the total settlement of the whole embankment.

### 3.1 The stress analysis of slope embankment

According to the existing research results, in terms of the new embankment on the slope foundation, the maximum settlement is at the edge of embankment. Thus, we can calculate the settlement of embankment's edge, and regard the value as the settlement of the new embankment, which is on the safe side. As shown in Figure 3, only calculate the stress of each filling soil along the line "AC".

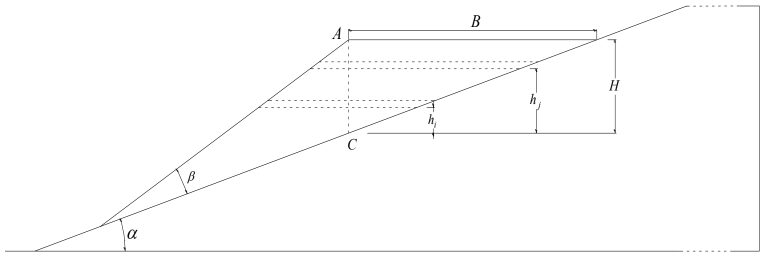


Fig.3 The stress analysis of embankment on the slope foundation

In the "i" layer filling soil, the average self weight stress can be expressed as:

$$\sigma_i = \frac{\gamma_i \cdot t_i}{2} \tag{10}$$

For the new embankment, the additional stress of point caused by the "j" layer filling soil can be written as follow, which is the intersection of "i" layer filling soil's center line and line "AC":

$$\Delta\sigma_{ij} = \int_{h_j}^{h_{j-1}} \int_{-\frac{H_j}{n}}^{\frac{h_j}{m}} \frac{2h_{ij}^{\ 3}\gamma_j}{\pi\left(\eta^2 + h_{ij}^{\ 2}\right)^2} d\eta dz \tag{11}$$

Remarks: m = tan α, n = tan θ (θ=α+β), hij=hj-hi, Hj = H-hj.

To sum up, we can obtain the additional stress of any point in the new slope embankment.

**3.2 The stress analysis of slope foundation**

First, calculate the initial stress "$\sigma_0$" of slope foundation by the semi infinite wedge theory. As shown in Figure 4, regard the part "OAFE" as a strip load. Then, calculate the stress"$\sigma_T$" of slope foundation by the elastic stress theory under the strip load. "$\sigma_0$" and "$\sigma_T$" both include the stress "$\sigma_S$" caused by the triangle load, so it must subtract the repeated stress"$\sigma_S$". Therefore, after the construction of slope embankment, the total vertical stress "$\sigma_\Gamma$" of any point in the foundation is the follow:

$$\sigma_\Gamma = \sigma_0 + \sigma_T - \sigma_S \tag{12}$$

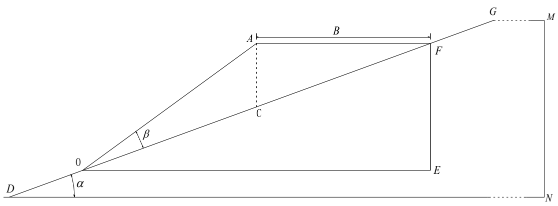


Fig.4 The stress analysis of slope foundation

(1) The calculation of "$\sigma_0$"

As shown in Figure 5, the initial stress "$\sigma_0$" can be gotten by the follow formula:

$$\sigma_z = \gamma \cdot z - \frac{\gamma}{\left(\pi - 2\alpha + \frac{1}{m}\right)\left(1+m^2\right)^2}\left\{mz\left(1+m^2\right) - \left(x+mz\right)\ln\frac{x^2+z^2}{\left(x+mz\right)^2} + \left[z\left(1-m^2\right) - mx\left(3+m^2\right)\right]\cdot \arcsin\left(\frac{z^2}{x^2+z^2}\right)^{\frac{1}{2}}\right\} \tag{13}$$

Remarks: m = tan α

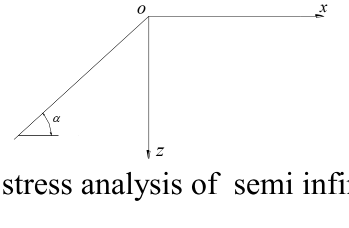


Fig.5 The stress analysis of semi infinite wedge

(2) The calculation of "$\sigma_T$"

As shown in Figure 6, the stress of any point "M" in the foundation can be calculated as the follow formula:

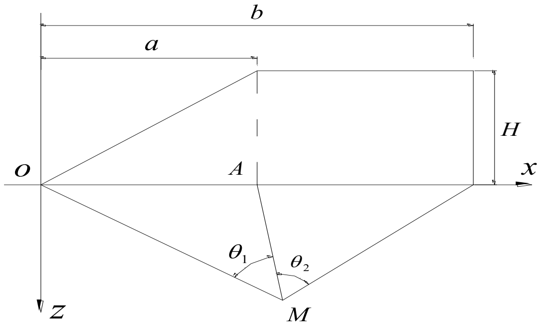


Fig.6 The stress analysis of foundation caused by the part "OAFE"

$$\sigma_z = \frac{p}{\pi}\left[\theta_2 + \frac{\theta_1 \cdot x}{a} - \frac{z}{z^2+(x-b)^2}(x-b)\right] \tag{14}$$

Remarks: $p = \bar{\gamma} \cdot H$

When calculating by the above formula, according to the position of the point, it can be divided into the following two conditions.

No.1: As shown in Figure 7, when the point is below the horizontal plane "OE", calculate the stress of "M".

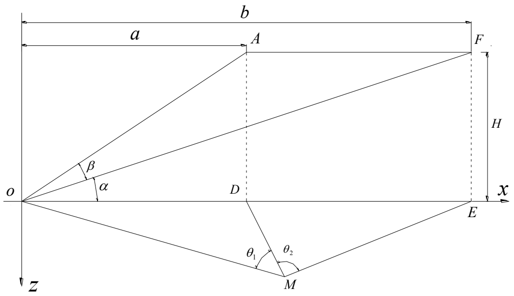


Fig.7 The analysis of stress"$\sigma_T$" ("M" is below the X axis.)

$$\begin{cases} \theta_1 = \arctan\frac{x}{z} - \arctan\frac{x-a}{z} \\ \theta_2 = \arctan\frac{x-a}{z} + \arctan\frac{b-x}{z} \end{cases} \tag{15}$$

Substituting (12) into (11), we have

$$\sigma_T = \frac{\bar{\gamma} \cdot H}{\pi}\left[\arctan\frac{x-a}{z} + \arctan\frac{b-x}{z} + \left(\arctan\frac{x}{z} - \arctan\frac{x-a}{z}\right)\frac{x}{a} - \frac{z}{z^2+(x-b)^2}(x-b)\right] \tag{16}$$

when only analyzing the stress of embankment's edge, makes "x=a", then the above formula can be simplified as:

$$\sigma_T = \frac{\bar{\gamma} \cdot H}{\pi}\left[\arctan\frac{b-a}{z} + \arctan\frac{a}{z} + \frac{z}{z^2+(x-b)^2}(b-a)\right] \tag{17}$$

No.2: As shown in Figure 8, when the point is above the horizontal plane "OE", calculate the stress of "M".

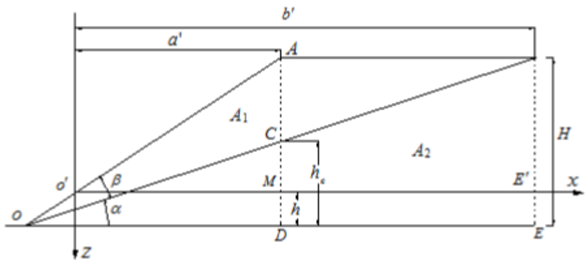


Fig.8 The analysis of stress"$\sigma_T$" ("M" is above the X axis.)

when only analyzing the stress along the line "AC", substitutes "x $=a'$ , $\theta_1=\theta_2=\frac{\pi}{2}$" into(11), then we have

$$\sigma_T=p=\bar{\gamma}'\cdot(H-h) \tag{18}$$

Remarks: $$\begin{cases} \bar{\gamma}'=\dfrac{\gamma_1\cdot A_1+\gamma_2\cdot A_2}{A_1+A_2} \\ \begin{cases} A_1=\dfrac{(H-h)^2\tan\alpha}{2} \\ A_2=\left[\left(\dfrac{1}{\tan\alpha}-\dfrac{1}{\tan(\alpha+\beta)}\right)\cdot h+B\right]\cdot\dfrac{H-h}{2} \end{cases} \\ B=b'-a' \end{cases} \tag{19}$$

(3) The calculation of "$\sigma_S$".

As shown in Figure 9, the unit weight of the triangle foundation is "$\gamma$", and the stress "$\sigma_S$" of any point "M" caused by the triangle load can be expressed as:

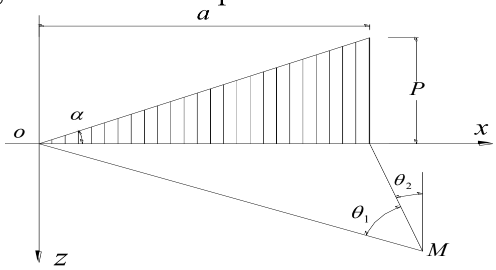


Fig.9 The stress analysis of foundation caused by the triangle load

$$\sigma_S=\frac{\gamma\cdot H}{\pi}\left[\frac{x}{a}\left(\arctan\frac{x}{z}-\arctan\frac{x-a}{z}\right)-\frac{z(x-a)}{z^2+(x-a)^2}\right] \tag{20}$$

Substituting "x=a" into (16), then the above formula can be simplified as:

$$\sigma_S=\frac{\gamma\cdot H}{\pi}\arctan\frac{a}{z} \tag{21}$$

When "M" is in the triangle part, similar with Figure 8, the stress of "M" can be expressed as:

$$\sigma_S=\frac{\gamma\cdot(H-h)\cdot\left(x-\dfrac{h}{\tan\alpha}\right)}{a-\dfrac{h}{\tan\alpha}} \tag{22}$$

Substituting "x=a" into (18), then the above formula can be simplified as:

$$\sigma_S=\gamma\cdot(H-h) \tag{23}$$

To sum up, we can obtain the additional stress of any point in the slope foundation by the follow expression:

$$\Delta\sigma=\sigma_\Gamma-\sigma_0=\sigma_T-\sigma_S \tag{24}$$

**3.3 The calculation of sedimentation.**

The total settlement of embankment consists of two parts: its own settlement and the settlement of slope foundation. After finding out the self weight stress and additional stress, we can get the sedimentation by the layerwise summation method. The layerwise summation method includes the method of "E-P" curve and compression coefficient.

According to the method of "E-P" curve, the sedimentation can be calculated as this formula:

$$S_i=\frac{e_{1i}-e_{2i}}{1+e_{1i}}t_i \tag{25}$$

Remarks: "Si" is the final sedimentation of the foundation; "e1i " is the void ratio under the self weight stress; "e2i" is the void ratio under the self weight stress and additional stress; "ti" is the thickness of the soillayer.

According to the method of compression coefficient, the sedimentation can be calculated as this formula:

$$S_i = \frac{a_{vi}}{1+e_{1i}} \Delta\sigma_i \cdot t_i \tag{26}$$

Remarks: "$\Delta\sigma_i$" is the additional stress of this soil layer; "$a_{vi}$" is its compression coefficient.

Summing all the sedimentation of foundation caused by each soillayer, then we can get the total settlement of foundation expressed as:

$$S_1 = \sum_{i=1}^{N} S_i \tag{27}$$

The calculation formula of embankment sedimentation is same with the foundation, so the settlement of "i" layer filling soil is as follow:

$$s_i = s_{ij} + \cdots \qquad \sum_{\kappa=j}^{n} s_{ik} \tag{28}$$

Summing all the sedimentation of each soillayer, then we can get the total settlement of embankment expressed as:

$$S_1 = \sum_{i=1}^{n} S_i \tag{29}$$

Then, the total sedimentation of whole embankment is as follow:

$$S = S_1 + S_2 \tag{30}$$

## 4. Summary

According to the calculation method of this paper, we can accurately calculate the settlement of the edge of embankment's top, and make it as a judgment of embankment settlement on the slope foundation. It could allow the engineers to take some measures to control the settlement ahead of time. In terms of preventing road damages caused by the uneven settlement, there is an important practical significance.

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