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SIMPLIFIED METHODS FOR THE SURCHARGE LATERAL PRESSURE DISTRIBUTION

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ABSTRACT

A surcharge load is any load such as spoil embankments, streets or highways, construction machinery which is imposed upon the surface of the soil close enough or distance to the excavation. This load causes a lateral pressure to act on the system in addition to the basic earth pressure. One of the most famous methods is Boussinesq strip method. After many considerations on adjacent surcharge, it was found that the distribution of lateral surcharge had not accuracy, and the shape and also the magnitude of the lateral pressure were not correct.
In this paper besides considering the shape and magnitude due to the Boussinesq distribution of lateral surcharge pressure for adjacent surcharge, a combined method that is named "KZP1" and also a method based on the "KZP1" that is named "KZP2" for distance surcharge with an applied examples is presented

BOUSSINESQ METHOD

Based on the Boussinesq strip method:

$$\sigma_H = 2Q[\beta r - (\sin\beta)(\cos 2\alpha)]/\pi \qquad (1)$$

That:
σ_H = Intensity of lateral pressure at distance H from top of the excavation,
α and β = angle (Figur1),
$\beta r = \beta(\pi/180)$,
Q = Surface load.

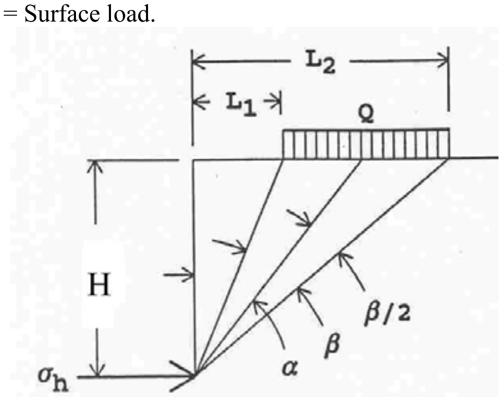


Fig. 1. Parameters for Boussinesq strip method

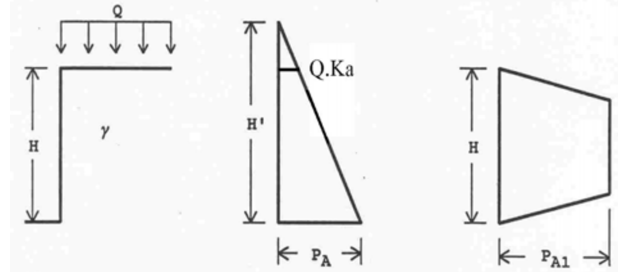
A surface load that is started from the edge of the excavation will be considered. In this case $\alpha = \beta/2$
$H = 0.0$
$L_1 = 0.0$
$\beta = \text{Arctan}(L_2/H) = 90^o$
$\beta r = \pi/2$
Therefore from eq. (1), the pressure at top of the excavation would be equal to the surcharge pressure. It means the soil acts such as water, which is not acceptable. To omit this problem the KZP1 method will be used.

Equivalent Height of the Uniform Surcharge

In this method the height of the original excavation is increased by an amount equal to the surcharge pressure divided by the density of the soil. Therefore in this method the pressure at top of the excavation would be Q.Ka.
Ka = Coefficient of active earth pressure.
The pressure at bottom of the excavation would be Pa, as shown in Figure 2.

$$Hs = Q/\gamma \qquad (2)$$
$$H' = H + Hs \qquad (3)$$
$$Kw = Ka.\gamma \qquad (4)$$
$$P_A = H'.\gamma.Ka = H'.Kw \qquad (5)$$

γ = Soil density.



Trench Section Surcharge Pressure Soil Pressure
Fig. 2. Equivalent height

From eq. (3) the equivalent height of surcharge (Hs) would be equal to H' – H.

KZP1 METHOD

Based on my considerations a combination of the uniform lateral surcharge pressure equal to (Q.Ka) and the Boussinesq method and choosing the minimum lateral surcharge pressure between those results at each height would be more acceptable.
For comparison of the results an example 1 with three methods is solved as below.

Example 1

A strutted trench with the given data is considered, Figure 3.

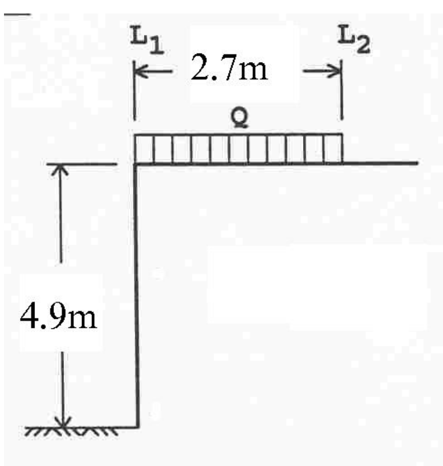
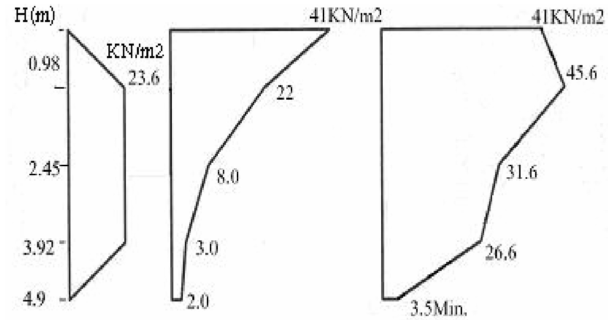


Fig. 3. Sample trench

1. Bussinesq Method

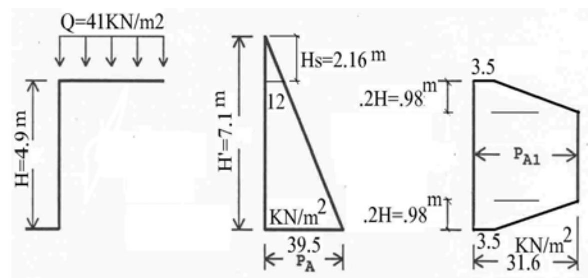
Basic trapezoid pressure would be:
PA = 0.8 Ka . γ . H = 0.8 Kw . H = (0.8)(5.6)(4.9) = 22 KN/m^2
Surcharge pressure will be calculated by Eq.(1), and for example for H=0.98m:
β = Arctan (L_2/H) = Arctan (2.7/0.98) = 70.1°
βr = 1.223 Radian
Sin(β) = 0.94
2α = β = 70.1°
Cos (2α) = 0.34
$\sigma_{0.98}$ = (2)(41)[1.223 - (0.94) (0.34)]/π = 23.6 KN/m^2
The final results are illustrated in Figure (4).



Soil Pressure Surcharge Pressure Combined Pressure
Fig. 4. Results of the Bussinesq method

2. Equivalent Height Method

Based on the assumed data and from Eq.(2) to Eq.(5),
Hs = Q/γ = 2.16 m
H' = H + Hs = 4.9 + 2.16 = 7.1 m
P_A = H'. Kw = 39.5 KN/m^2
P_{A1} = 0.8 P_A = 31.6 KN/m^2
The results are shown in Figure (5).



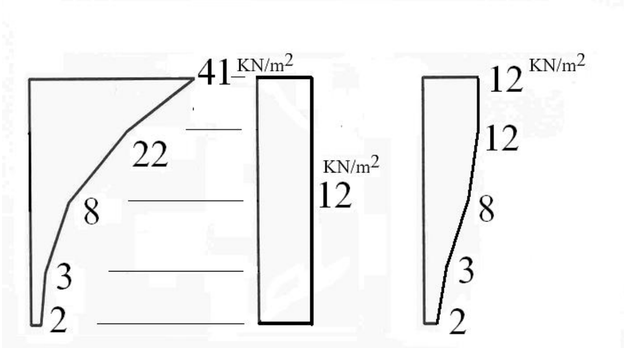
Trench Section Surcharge Pressure Soil Pressure

Ka = 0.295
γ = 19 KN/m^3
Kw = Ka . γ = 5.6 KN/m^3
Q = 41 KN/m^2
L1 = 0.0
L2 = 2.7 m

Fig. 5. Results of the equivalent method

3. KZP1 Method

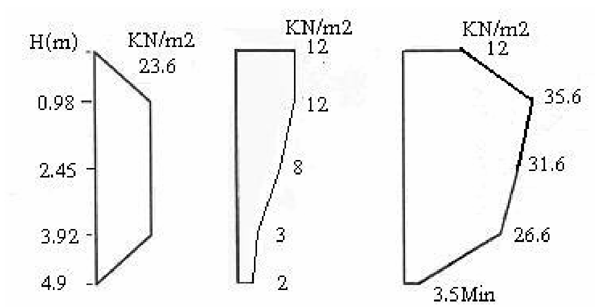
The pressure at top of the excavation in method 2 was Q.Ka =12 KN/m^2. This uniform lateral pressure shall be compared with the Bussinesq surcharge pressure (method one), and the minimum of these two at each height would be used. Final surcharge pressure of the KZP1 method is shown in Figure 6.



Bussinesq Method   Equivalent Height   KZP1 Method

Fig. 6. Lateral surcharge pressure per KZP1 method

The lateral surcharge pressure in combined method would be added to the trapezoid soil pressure that is calculated in the Bussinesq method.
The final KZP1 method results is illustrated in Figure (7).



Soil Pressure   Surcharge Pressure   Combined Pressure

Fig. 7. Final results of KZP1 method

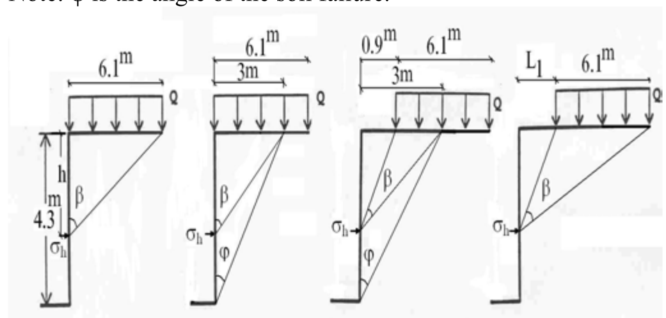
A minimum uniform lateral pressure of 3.5 KN/m^2 should be used for engineering analysis of all types of shoring systems.

Distance Surcharge and KZP2 Method

Based on the KZP1 method a new method for lateral surcharge pressure due to the distance surcharge is presented. Example 2 is shown the KZP2 method and comparison of the results with the common methods.

Example 2

A trench with adjacent and distance surcharge will be considered to find the lateral surcharge pressure based on the Bussinesq and KZP1 methods and finally find the lateral surcharge pressure based on the KZP2 method.
Assumptions for all the cases:
Building surcharge Q = 38.3 KN/m^2.
$\phi = 20^o$.
$\varphi = 45 - \phi/2 = 35^o$.
$Ka = (1-Sin\phi)/(1+Sin\phi)=.49$.
Seven cases are illustrated in Figure (8).
Case 1 : Adjacent surcharge without consideration of the soil failure wedge and based on the Bussinesq method.
Case 2 : As case 1 and with consideration of the soil failure wedge.
Case 3 : Distance surcharge with consideration of the soil failure wedge based on the Bussunesq method.
Case 4 : As case 3 and without consideration of the soil failure wedge.
Case 5 : Adjacent surcharge without consideration of the soil failure wedge based on the KZP1 method.
Case 6 : As case 4 and for D = 4.2 m.
Case 7 : As case 4 and for D = 6 m.
Note: φ is the angle of the soil failure.



Cases (1) & (5)   Case (2)   Case (3)   Cases (4),(6)&(7)

Fig. 8. Seven cases adjacent and distance surcharge

For case 1: β = Arctan (6.1/h) , $\alpha = \beta/2$
For case 2: β = Arctan (3.0/h) , $\alpha = \beta/2$
For case 3: β = Arctan (3.0/h) - Arctan (0.9/h), $\alpha = \beta/2$ + Arctan (0.9/h)
For case 4,6 and 7: β = Arctan [(L1+6.1)/h] - Arctan (L1/h), $\alpha = \beta/2$ + Arctan (L1/h)
For case 5: Q.Ka = 18.8 KN/m^2
Based on the eq. (1) and KZP1 method Table (1) is presented.

Table 1. Lateral surcharge pressures based on the KZP1 method (KN/m^2)

H (m)	Bus. Case 1	Bus. Case 2	Bus. Case 3	Bus. Case 4	KZP1 Case 5	Bus. Case 6	Bus. Case 7
0.0	38.3	38.3	0.0	0.0	18.8	0.0	0.0
0.31	35.9	33.4	10.2	13.0	18.8	2.1	1.2
0.61	33.5	28.6	15.9	21.4	18.8	4.0	2.4
1.22	28.8	20.4	16.3	26.0	18.8	7.6	4.6
1.83	24.5	14.1	12.5	24.6	18.8	10.3	6.6
2.44	20.6	9.7	9.0	21.8	18.8	12.1	8.2
3.05	17.2	6.7	6.3	19.0	17.2	13.1	9.3
3.66	14.4	4.7	4.5	16.3	14.3	13.4	10.1
4.3	12.0	3.5	3.3	14.0	12.0	13.2	10.5

The above results are plotted as 1 to 7 in Figure (9).

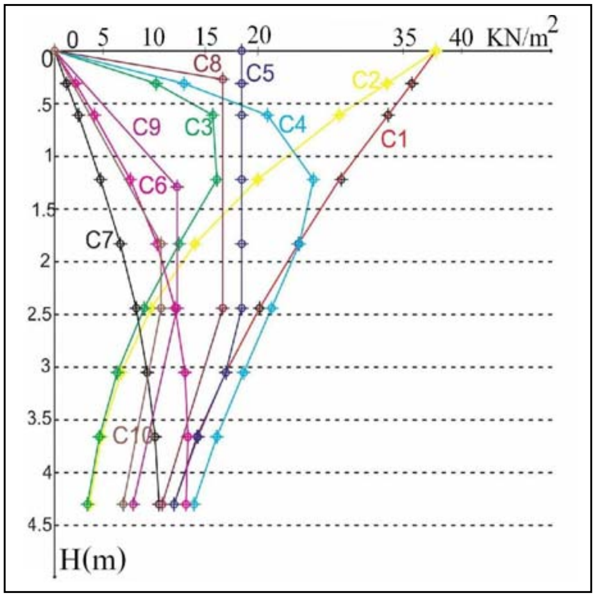


Fig. 9. Lateral pressure of the ten cases (Seven cases of Table (1) and three cases of Table (2))

It is recommended that building, highway and similar surcharge loadings can not be limited to the width of the soil failure wedge (skew line with angle φ). Therefore the diagrams (2&3) need not be considered. The problems that can be seen in Figure (8) are:

1- Diagram (1) is started from Q = 38.3 KN/m^2 and at middle height of the excavation the lateral surcharge pressure is grater than Q.Ka = 18.8 KN/m^2.
2- Lateral pressure in diagram (4) can not be grater than adjacent surcharge, but it is grater than pressure diagram (1) from h =1.83 ^{m} to bottom of the excavation.
3- With increasing the h (from the top of the excavation) the lateral pressure distribution on a vertical line may be imagined as shown in Figure (10).

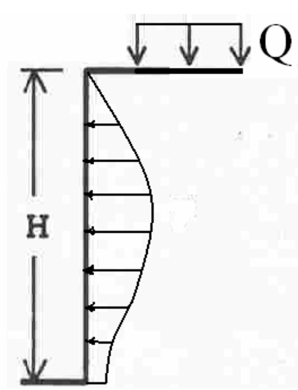


Fig. 10 Lateral pressure due to the distance strip surcharge

This kind of lateral distribution can be seen in diagram (4) but not at (6) and (7) and also at diagrams (6&7) the maximum lateral pressures are at the bottom of the excavation.

Based on the considerations on more than one hundred examples the KZP2 method is prepared, and this method can be used as below steps.

- Find the KZP1 lateral pressure distribution for adjacent surcharge (L1=0) as shown in diagram (5) of Figure (9).
- The lateral pressure will be started from (σ = 0) at the top of the excavation.
- A height of (0.3L1) from the top of the excavation will be used for the end of the first top skew line.
- The coefficient

$$Co=L/(0.75L1+L) \quad (6)$$

will be multiplied by the lateral pressure on all points in the vertical part of the diagram(5). This vertical line is started from (0.3L1).

- The bottom skew line will be started from the end point of the vertical line (same as diagram 5) and ended to the bottom lateral pressure of diagram 5 times Co.

For more considerations three cases (8,9 and 10) for various L1 will be considered as below and the Table (2) and also Figure (11) are shown the results of the KZP2 method.

For case 8: L1 = 0.9 m and from eq. (6) Co = 6.1/(.75x0.9+6.1)=0.9.

For case 9: L1 = 4.3 m and from eq. (6) Co = 6.1/(.75x4.3+6.1)=0.66.

For case 10: L1 = 6.1 m and from eq. (6) Co = 6.1/(.75x6.1+6.1)=0.57.

Table 2 Lateral surcharge pressure for distance surcharge (KZP2 method) based on the KZP1

H (m)	KZP1 (Case 5)	KZP2 (Case 8)	KZP2 (Case 9)	KZP2 (Case 10)
0.0	18.8	0.0 Start skew	0.0 Start skew	0.0 Start skew
h=0.3L1 =0.27	18.8	16.9 End skew	Skew	Skew
0.31	18.8	16.9	Skew	Skew
0.61	18.8	16.9	Skew	Skew
1.22	18.8	16.9	Skew	Skew
h=0.3L1 =1.29	18.8	16.9	12.3 End skew	Skew
h=0.3L1 =1.83	18.8	16.9	12.3	10.7 End skew
2.44	18.8 Start skew	16.9 Start skew	12.3 Start skew	10.7 Start skew
3.05	17.2	Skew	Skew	Skew
3.66	14.3	Skew	Skew	Skew
4.3	12.0 End skew	10.8 End skew	16.9 End skew	16.9 End skew

Comparison of the Results

1- KZP1

The total lateral force per unit length of the trench based on the three methods are as below.
Bussinesq method: 156.7 KN/m.
Equivalent height method: 127.3 KN/m.
KZP1 method : 129 KN/m.
The total lateral force in the last two cases are very closed, but based on the pressure distribution in Figures (5) and (7), the KZP1 distribution is more critical than the equivalent height method for the base moment.

2- KZP2

Based on the Figure (9) it could be seen that the amounts of the lateral surcharge pressure and the vertical distributions are more acceptable than the Bussinesq method.

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