FIRM:Your Firm JOB NO.2009-0018 SHEET NO: 1
MADE BY:YOU DATE:05-20-2010 CHECKED BY: DATE:
TITLE:Lexington - Computing spread footing settlement

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SETTLEMENT CALCULATIONS:

Components of Settlement (*):

Total settlement is comprised of the following components:

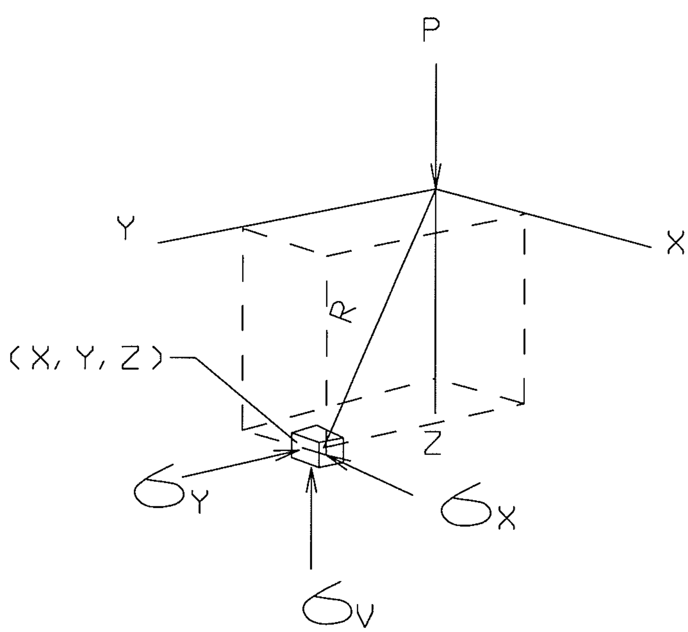
$S_t = S_e + S_c + S_s$ (AASHTO LRFD Eq. 10.6.2.4.1-1)

where,

S_e = elastic settlement
S_c = primary consolidation settlement
S_s = secondary settlement

S_e , ELASTIC SETTLEMENT:

This program computes the stresses in the soil due to surface loading by using Boussinesq's solution to the three-dimensional problem of a concentrated point load on the surface of a semi-infinite body.



$\sigma_v = \alpha * z^2$
$\sigma_x = \alpha * x^2$
$\sigma_y = \alpha * y^2$

where,

$\alpha = 3*P*z/(2*\pi *R^5)$
$R = (x^2 + y^2 + z^2)^{1/2}$

Each rectangular or circular load is divided into 100 elements (10x10), then for each element a concentrated P load is computed. Stresses in the soil due to each elemental loading are computed using the above Boussinesq equations. The total stress in a soil element is the summation of all elemental surface P loadings.

(*Refer to http://dcalc.us/Tutorials/Chapter8.pdf for a discussion)

SETTLEMENT CALCULATIONS:

S_e , ELASTIC SETTLEMENT (Cont'd):

The elastic vertical strain in each soil element is computed as,

$$\varepsilon_v = 1/E_s * (\sigma_v - \mu \sigma_x - \mu \sigma_y)$$

The elastic shortening of each soil element is,

$$\Delta S = \sum \varepsilon_v * h$$

where h=height of each element = 1 ft

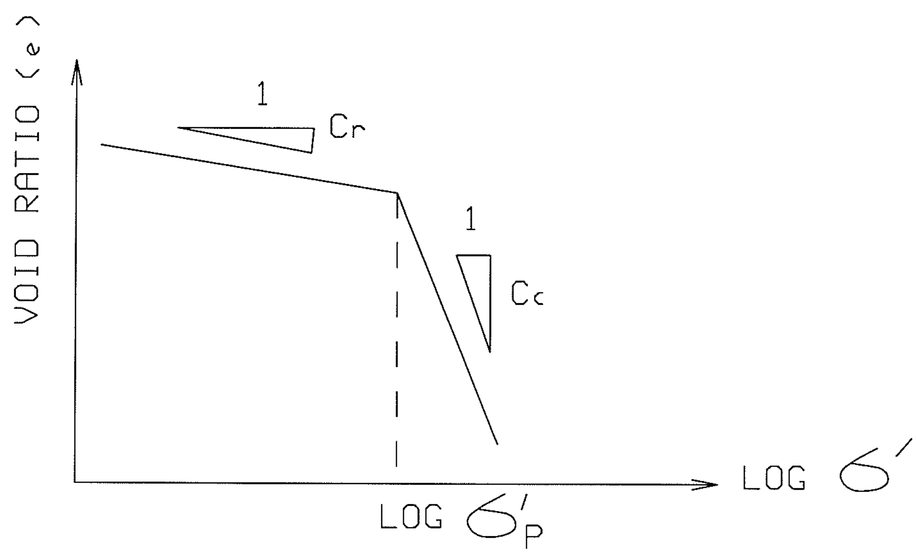
Then the total elastic settlement under a point is the summation of the shortening of all the elements located directly under the point:

$$S_e = \sum \Delta S$$

SETTLEMENT CALCULATIONS:

S_c , PRIMARY CONSOLIDATION SETTLEMENT:

For clays, consolidation settlement is an additional form of settlement that needs to be considered.



The relationship between a soil's vertical stress and its void ratio can only be determined from a consolidation test, as shown above.

The above figure shows a kink, which occurs for overconsolidated clays at a stress σ'_p , which is the maximum past vertical effective stres in the in the soil, such as in areas that once had glaciers. In areas where clays have not experienced extremely heavy loads in the past, the clay is called normally consolidated.

CONSOLIDATION SETTLEMENT EQUATIONS (AASHTO LRFD Art. 10.6.2.4.3):

Overconsolidated $\sigma'_p > \sigma'_0$	$[h/(1+e_0)]*(C_r*\log_{10}(\sigma'_p/\sigma'_0) + C_c*\log_{10}(\sigma'_f/\sigma'_p))$
Normally consolidated $\sigma'_p = \sigma'_0$	$[h/(1+e_0)]*(C_c*\log_{10}(\sigma'_f/\sigma'_0))$
Underconsolidated $\sigma'_p < \sigma'_0$	$[h/(1+e_0)]*(C_c*\log_{10}(\sigma'_f/\sigma'_p))$

where in the above table,

C_r = recompression index
C_c = compression index
σ'_p = maximum past vertical effective stress in soil
σ'_0 = initial vertical effective stress in soil
σ'_f = final vertical effective stress in soil

SETTLEMENT CALCULATIONS:

S_s , SECONDARY SETTLEMENT:

In geotechnical analysis, the settlement that occurs in clay after primary consolidation is called secondary settlement (sometimes called creep).

The AASHTO LRFD specification provides the following equation,

$$S_s = H/(1+e_0) * C_a * \log_{10}(t/t_{90})$$ (AASHTO LRFD Eq. 10.6.2.4.3-9)

Note that the above equation does not consider stress level. This is because C_a is evaluated from time rate tests set to a void ratio corresponding to the end of primary consolidation.

Due to the complications of C_a being stress dependent, as an alternative to using the above equation, this program computes the ultimate secondary settlement as,

$$S_s = S_c * C_a / C_c$$

The ratio, C_a / C_c typically ranges from 4% to 6%, per the FHWA Publication, "Evaluation of Soil and Rock Properties", (FHWA-IF-02-034, p. 134).

The AASHTO LRFD Commentary further explains secondary settlement as follows: "Secondary settlement is most important for highly plastic clays and organic and micaceous soils. Accordingly, secondary settlement predictions should be considered as approximate estimates only."

NOTES TO DESIGNER:

1. Settlement predications are largely dependent on the choice of properties and should be considered as estimates only.
2. Designer should evaluate if elastic settlements are relevant to differential settlement studies, or if elastic settlments should be ignored.
3. Consolidation settlement occurs at a rate that is not considered by this program. The designer may need additional data from time rates determined from consolidation if this influences construction procedures or serviceabilty issues for a structure. Time rates of consolidation are typically provided from consolidation test data.

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SETTLEMENT CALCULATIONS:

SOIL BORING LOG DATA:

Boring Log:B-6
Ground Surface Elevaton=32 ft

No.	From (ft)	To (ft)	Description	UCS Type	STP N blows/ft	Qu (tsf)	Wn (%)
1	0.0	8.0	Silty Clay - trace sand, grav	ML	22	2.80	14
2	8.0	10.0	Silty Clay - trace sand, grav	ML	24	4.50	14
3	10.0	30.0	Silty Clay - trace sand & gra	CL	12	2.80	19
4	30.0	36.0	Silty Clay - trace sand & gra	CL	20	3.00	20
5	36.0	38.0	Silty Clay to Clayey Sand	SC	16		
6	38.0	44.0	Sandy Silty Clay	CL	20	1.80	12
7	44.0	50.0	Silty Clay - trace sand & gra	CL	24	7.40	15

SOIL PROPERTIES USED FOR SETTLEMENT CALCULATIONS:

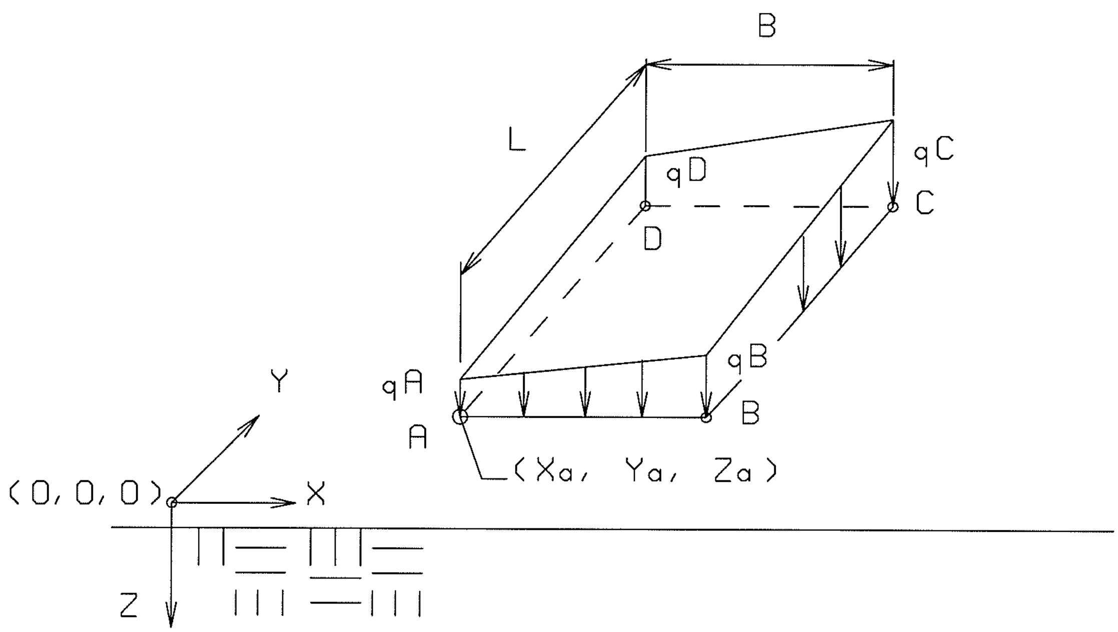
No.	Unit Wt (pcf)		Es (ksf)	Pois. Ratio	Initial Void Ratio	Normal or Preconsol-idated	Consol. Props			Max past stress (ksf)
	Dry	Sat					Cr	Cc	Ca/Cc%	
1	122.0	139.0	839	.40	.38	Preconsol.	0.03	.30	5.00	19.00
2	122.0	139.0	1350	.40	.38	Preconsol.	0.03	.30	5.00	30.00
3	111.0	132.0	839	.40	.51	Preconsol.	0.03	.30	5.00	19.00
4	109.0	131.0	900	.40	.54	Preconsol.	0.03	.30	5.00	20.00
5	119.0	136.0	310	.30						
6	127.0	142.0	539	.40	.32	Preconsol.	0.03	.30	5.00	12.00
7	120.0	138.0	2220	.40	.41	Preconsol.	0.03	.30	5.00	50.00

SETTLEMENT CALCULATIONS:

For this analysis, the water table has not been considered.

RECTANGULAR LOADINGS:

Ground Surface Elevation=32 ft.



No.	B (ft)	L (ft)	Load Elev	Xa (ft)	Ya (ft)	Za (ft)	qA (ksf)	qB (ksf)	qC (ksf)	qD (ksf)
1	2.33	50.00	28.00	0.00	0.00	4.00	2.28	2.28	2.28	2.28

SETTLEMENT CALCULATIONS:

COMPUTED SETTLEMENT (FLEXIBLE FOOTINGS ASSUMED):

Load No.	Point	X (ft)	Y (ft)	Elastic Se (in)	Primary Sc (in)	Secondary Ss (in)	Total St (in)
1	Corner A	0.00	0.00	0.047	.354	0.017	.419
1	Corner B	2.33	0.00	0.047	.354	0.017	.419
1	Corner C	2.33	50.00	0.047	.354	0.017	.419
1	Corner D	0.00	50.00	0.047	.354	0.017	.419
1	Edge 0.5AB	1.16	0.00	0.050	.384	0.019	.454
1	Edge 0.5BC	2.33	25.00	0.092	.644	0.032	.769
1	Edge 0.5CD	1.16	50.00	0.050	.384	0.019	.454
1	Edge 0.5AD	0.00	25.00	0.092	.644	0.032	.769
1	Center	1.16	25.00	0.098	.695	0.034	.828

SETTLEMENT CALCULATIONS:

COMPUTED SETTLEMENT (RIGID FOOTINGS ASSUMED):

Load No.	Point	X (ft)	Y (ft)	Elastic Se (in)	Primary Sc (in)	Secondary Ss (in)	Total St (in)
1	Corner A	0.00	0.00	0.080	.578	0.028	.688
1	Corner B	2.33	0.00	0.080	.578	0.028	.688
1	Corner C	2.33	50.00	0.080	.578	0.028	.688
1	Corner D	0.00	50.00	0.080	.578	0.028	.688
1	Edge 0.5AB	1.16	0.00	0.080	.578	0.028	.688
1	Edge 0.5BC	2.33	25.00	0.080	.578	0.028	.688
1	Edge 0.5CD	1.16	50.00	0.080	.578	0.028	.688
1	Edge 0.5AD	0.00	25.00	0.080	.578	0.028	.688
1	Center	1.16	25.00	0.080	.578	0.028	.688

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SETTLEMENT CALCULATIONS:

DETAILED CALCULATION AT LOCATION OF LOAD NO 1 AT EDGE 0.5AB:

Z (ft)	Type	Initial Stress (ksf)			Final Stress (ksf)			Settlement (inch)		
		σ_0	u_{w0}	σ'_0	σ_f	u_{wf}	σ'_f	ΔS_e	ΔS_c	ΔS_a
1	Clay	.122	0.000	.122	.122	0.000	.122	0.000	0.000	0.000
2	Clay	.244	0.000	.244	.244	0.000	.244	0.000	0.000	0.000
3	Clay	.366	0.000	.366	.366	0.000	.366	0.000	0.000	0.000
4	Clay	.488	0.000	.488	.488	0.000	.488	0.000	0.000	0.000
5	Clay	.610	0.000	.610	.688	0.000	.688	-0.002	0.016	0.000
6	Clay	.732	0.000	.732	1.008	0.000	1.008	0.000	.045	0.002
7	Clay	.854	0.000	.854	1.216	0.000	1.216	0.003	0.049	0.002
8	Clay	.976	0.000	.976	1.327	0.000	1.327	0.002	0.042	0.002
9	Clay	1.098	0.000	1.098	1.409	0.000	1.409	0.002	0.034	0.001
10	Clay	1.209	0.000	1.209	1.479	0.000	1.479	0.003	0.025	0.001
11	Clay	1.320	0.000	1.320	1.555	0.000	1.555	0.002	0.020	0.001
12	Clay	1.431	0.000	1.431	1.639	0.000	1.639	0.002	0.017	0.000
13	Clay	1.542	0.000	1.542	1.727	0.000	1.727	0.002	0.014	0.000
14	Clay	1.653	0.000	1.653	1.820	0.000	1.820	0.001	0.012	0.000
15	Clay	1.764	0.000	1.764	1.916	0.000	1.916	0.001	.011	0.000
16	Clay	1.875	0.000	1.875	2.015	0.000	2.015	0.001	0.009	0.000
17	Clay	1.986	0.000	1.986	2.115	0.000	2.115	0.001	0.008	0.000
18	Clay	2.097	0.000	2.097	2.217	0.000	2.217	.001	0.007	0.000
19	Clay	2.208	0.000	2.208	2.320	0.000	2.320	0.001	0.006	0.000
20	Clay	2.319	0.000	2.319	2.424	0.000	2.424	0.001	0.005	0.000
21	Clay	2.430	0.000	2.430	2.529	0.000	2.529	0.001	0.005	0.000
22	Clay	2.541	0.000	2.541	2.634	0.000	2.634	0.001	0.004	0.000
23	Clay	2.652	0.000	2.652	2.740	0.000	2.740	0.001	0.004	0.000
24	Clay	2.763	0.000	2.763	2.847	0.000	2.847	0.001	0.003	0.000
25	Clay	2.874	0.000	2.874	2.953	0.000	2.953	0.000	0.003	0.000
26	Clay	2.985	0.000	2.985	3.061	0.000	3.061	0.000	0.003	0.000
27	Clay	3.096	0.000	3.096	3.168	0.000	3.168	0.000	0.002	0.000
28	Clay	3.207	0.000	3.207	3.276	0.000	3.276	0.000	0.002	0.000
29	Clay	3.318	0.000	3.318	3.384	0.000	3.384	0.000	0.002	0.000
30	Clay	3.427	0.000	3.427	3.491	0.000	3.491	0.000	0.002	0.000
31	Clay	3.536	0.000	3.536	3.597	0.000	3.597	0.000	0.002	0.000
32	Clay	3.645	0.000	3.645	3.704	0.000	3.704	0.000	0.002	0.000
33	Clay	3.754	0.000	3.754	3.811	0.000	3.811	0.000	0.001	0.000
34	Clay	3.863	0.000	3.863	3.918	0.000	3.918	0.000	0.001	0.000
35	Clay	3.972	0.000	3.972	4.025	0.000	4.025	0.000	0.001	0.000

where,
σ_0 = initial total stress, σ_f = final total stress
u_{w0} = initial pore water pressure, u_{wf} = final pore water pressure
σ'_0 = initial effective stress, σ'_f = final effective stress

Note that for sand, only the total stress increase, "+σ_f ", due to footing loads is considered for elastic settlement.

SETTLEMENT CALCULATIONS:

DETAILED CALCULATION AT LOCATION OF LOAD NO 1 AT EDGE 0.5AB (Cont'd):

Z (ft)	Type	Initial Stress (ksf)			Final Stress (ksf)			Settlement (inch)		
		σ_0	u_{w0}	σ'_0	σ_f	u_{wf}	σ'_f	ΔS_e	ΔS_c	ΔS_a
36	Sand				+0.050			0.001		
37	Sand				+0.049			0.001		
38	Clay	4.337	0.000	4.337	4.384	0.000	4.384	0.000	0.001	0.000
39	Clay	4.464	0.000	4.464	4.510	0.000	4.510	0.000	0.001	0.000
40	Clay	4.591	0.000	4.591	4.636	0.000	4.636	0.000	0.001	0.000
41	Clay	4.718	0.000	4.718	4.761	0.000	4.761	0.000	0.001	0.000
42	Clay	4.845	0.000	4.845	4.887	0.000	4.887	0.000	0.001	0.000
43	Clay	4.972	0.000	4.972	5.013	0.000	5.013	0.000	0.001	0.000
44	Clay	5.092	0.000	5.092	5.131	0.000	5.131	0.000	0.001	0.000
45	Clay	5.212	0.000	5.212	5.250	0.000	5.250	0.000	0.001	0.000
46	Clay	5.332	0.000	5.332	5.369	0.000	5.369	0.000	0.000	0.000
47	Clay	5.452	0.000	5.452	5.488	0.000	5.488	0.000	0.000	0.000
48	Clay	5.572	0.000	5.572	5.607	0.000	5.607	0.000	0.000	0.000
49	Clay	5.692	0.000	5.692	5.726	0.000	5.726	0.000	0.000	0.000
50	Sand				+0.033			0.000		
							Totals=	0.050	.384	0.019