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Study and Evaluation of Added Stresses under Foundation due to Adjacent Structure

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***Abstract*—**Added stresses due to adjacent structure should be considered in foundation design and stress control in soil under the structure. This case is considered less than other cases in design and calculation whereas stresses in implementation are greater than analytical stress.

Structure load are transmitted to earth by foundation and role of foundation is propagation of load on the continuous and half extreme soil. This act cause that, present stresses lessen to allowable strength of soil. Some researchers such as Boussinesq and westergaurd by using of some assumption studied on this issue, theorically. Target of this paper is study and evaluation of added stresses under structure due to adjacent structure. For this purpose, by using of assumption, theoric relation and numeral methods, effects of adjacent structure with 4 to 10 storeys on the main structure with 4 storeys are studied and effect of parameters and sensitivity of them are evaluated.

***Keywords*—** stress, soil, adjacent structure, foundation, loading.

I. INTRODUCTION

LOAD of structure are transmitted to earth by foundation and role of foundation is propagation of load. So we should consider that foundation of structure should be able to transfer structure load. Also soil under the structure should bear these loads. With economic development and increasing of population and for optimum using of land, foundation of structures are constructed in adjacent of together and this issue is one of the problems of designers.

Combination of stress under adjacent structure can increase stresses of soil. This stress can be greater than bearing capacity of soil. Realism determination of this stress is important in two points: 1-construction of structure in near of main structure cause that stresses are increased and this stress should be less than allowable strength of soil. 2- If clay layers are exist in depth of soil, because of little seepage of it, immediate settlement of soil is small but consolidation settlement can be big. This settlement can cause
Ununiform settlement that this is destroyer for structure [1],[2].

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In this research, for modeling of uniform load, mat foundation is considered for structures. So assumption structures are 4 to 10 storeys. In calculation of vertical stress we can use from Boussinesq and westergaurd relations.

II. THEORIC SOLUTION AND DETERMINATION OF DISPLACEMENTS AND STRESSES

Neuber-papkovich function is expression of combination of harmonic function for displacement vector ($\vec{u}$) and is in following form:

$$2G\vec{u} = \vec{A} - \vec{\nabla}\left[B + \frac{\vec{A}.\vec{X}}{4(1-\nu)}\right] \quad (1)$$

That $\vec{X}$ is a vector with x_3, x_2, x_1 term and $\vec{A}$, B and υ are vector term, numeral term and poisson ratio coefficient, respectively. With replacement of it in equilibrium relation with differential equation (eq. 2) relative to Navier equation, equation (3) is obtained:

$$(\lambda + \mu)grad(div\vec{u}) + \mu Lapl\vec{u} = 0 \quad (2)$$

$$G\nabla^2\vec{A} - (\lambda + 2G)\vec{\nabla}(\nabla^2 B) - \left(\frac{\lambda + G}{2}\right)\vec{\nabla}(\vec{X}.\nabla^2\vec{A}) = 0 \quad (3)$$

This relation is satiated if:

$$\begin{cases}\nabla^2\vec{A} = 0\\ \nabla^2 B = 0\end{cases} \quad (4)$$

So, for four harmonic arbitrary function A1 , A2 , A3 and B, when displacement vector ($\vec{u}$) are obtained from equation (1), results satiate Navier equation. $\vec{A}$ and B functions can be obtained from Galerkin vector($\vec{V}$) in following form:

$$\vec{A} = 2(1-\nu)\nabla^2\vec{V} \quad (5)$$

$$B = \vec{\nabla}.\vec{V} - \frac{\vec{A}.\vec{X}}{4(1-\nu)}$$

Top form in one of the special forms of $\vec{A}$ and B in axial symmetry problems, so we have:

$$A_z = A_z(r,z) \quad \text{and} \quad A_r = A_\theta = 0 \quad (6)$$

$$B = B(r,z) \quad (7)$$

One of the applications of these problems is in Boussinesq problem. In 1883, Boussinesq calculated stresses of soil due to point load on the ground. We assume that load is a point and intensive load and considered area is half extreme, homogeneous, elastic and isotropic. This load are presented in fig.(1). Location of P is on the ground surface and in a half extreme area.

If Neuber-papkovich function is considered in following form:

$$A_z = 4(1-\nu)\frac{K}{\rho}$$

$$A_r = A_\theta = 0 \quad (8)$$

$$B = CLn(\rho + z) \quad (9)$$

This function satiate equation (3) and Navier relation. If equations (7) and (8) are replaced in equation (1), we have:

$$\vec{u} = \frac{4(1-\nu)}{2G}\frac{K}{\rho}\vec{k} - \frac{\vec{\nabla}}{2G}\left[CLn(\rho+z) + \frac{Kz}{\rho}\right] \quad (10)$$

That $\vec{k}$ is the univalent vector in z axial. In cylindrical coordinate, eq.(10) can be written in following form:

$$u_r = -\frac{Cr}{2G\rho(\rho+z)} + \frac{Kzr}{2G\rho^3} \quad (11)$$

$$u_\theta = 0$$

(12)

$$u_z = -\frac{(3-4y)K - C}{2G\rho} + \frac{Kz^2}{2G\rho^3} \quad (12)$$

Limit conditions of problem are: in all points on top of the half extreme area $\sigma_{rz} = 0$ and for all point expected to era of coordinate $\sigma_{zz} = 0$. From relation between strain-displacement and stress-strain, we have:

$$\sigma_{rz} = \frac{r}{\rho^3}\left[C - K(1-2\nu) - \frac{3Kz^2}{\rho^2}\right] \quad (13)$$

That from first limit condition, we can obtain relation between C and K:

$$C = K(1-2\nu) \quad (14)$$

And respectively we have:

$$\sigma_{zz} = -\frac{3Kz^3}{\rho^5} \quad (15)$$

That value of it is indefinite and zero in coordinate era and ∞. In result we have:

$$K = \frac{p}{2\pi} \quad (16)$$

That Z and L are depth of point and distance from point to load. Vertical stress relation that is assumed by Boussinesq isn't dependent to poisson ratio, unlike horizontal stress in x and y direction.

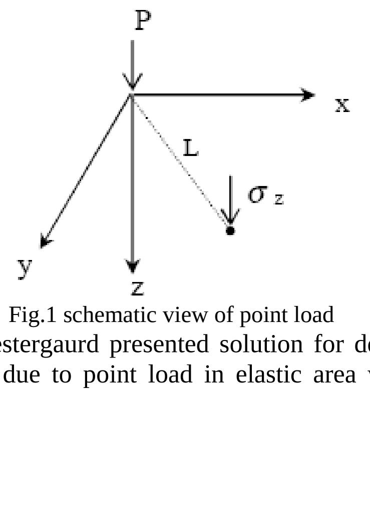

Fig.1 schematic view of point load

In 1938, westergaurd presented solution for determination vertical stress due to point load in elastic area with several layer (in interface of layers there is a rigid surface). This assumption is true for clay layers that have sand in interface of it. For such model, vertical stress due to point load in depth (z) is[5]:

$$\Delta p_z = \frac{P\eta}{2\pi^2 z^2}\left[\frac{1}{\eta^2 + \left(r/z\right)^2}\right]^{3/2} \quad (17)$$

That:

$$\eta = \sqrt{\frac{1-2\mu}{2-2\mu}}$$

And μ is poisson ratio of layer soil.

In this paper, we use Boussinesq relation, because it shows greater value than westergaurd relation. For calculation of added stress due to new structure, that load of it is uniform, it is proper that we use from integral.

III. Study of Stress in Two Adjacent Structures

Since forces are exerted on the foundation from column centralizes and it transmits to soil by foundation. Foundations extend loads to under layer and we can consider it uniform. So for determination of stress in arbitrary point such as A, we can integral on the effected area by using of Boussinesq vertical stress. With using integral from stress equation for point in the edge of a rectangular area under uniform load, fig.2, we have:

$$\Delta p = \int dp = \int_{y=0}^{by}\int_{x=0}^{bx} \frac{3pz^3}{(2\pi)(x^2+y^2+z^2)^{\frac{5}{2}}}dxdy = PI_{mn} \quad (18)$$

That:

$$I_{mn} = \frac{1}{4\pi}\left[\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2+m^2n^2+1}\left(\frac{m^2+n^2+2}{m^2+n^2+1}\right) + \tan^{-1}\left(\frac{2mn\sqrt{m^2+n^2+1}}{m^2+n^2-m^2n^2+1}\right)\right]$$

and $m = \frac{B}{z}$, $n = \frac{L}{z}$

Top relation isn't true for all values but it is proper for some of the values that on basis of m and n, values of I_{mn} are obtained. It should be mentioned that m and n are allowable only for edge of foundation, so for other points such as central point (that has major calculations) we should use superposition method. Fig.3 shows schematic plan of main structure and adjacent structure position and shows points that are studied in the tables and graphs.

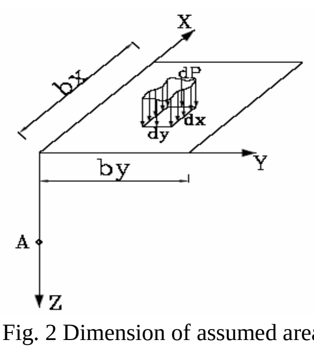

Fig. 2 Dimension of assumed area

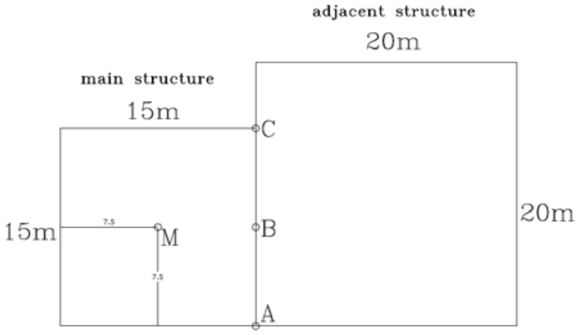

Fig.3- schematic plan adjacent structures

With attention to low allowable strength of soil, ordinary foundation of 4 storeys structure are mat, that has better condition with Boussinesq method rather other methods. Properties of structure are assumed in following: main structure, that stress of it is considered, is 4 storeys structure with $15\times15m^2$ area and weigh of each storey is 0.9 tons per square meter. Also adjacent structure is 4 to 10 storeys with $20\times20m^2$ area. In these structures, distribution of load is assumed uniform, because foundations are mat and storey weight of adjacent structure are like to main structure. Information of structures are shown in table (1).

TABLE I INFORMATION OF MAIN AND ADJACENT STRUCTURES

	Main structure	Adjacent structure						
Dimension of structure (m^2)	15*15	20*20						
Number of storey	4	4	5	6	7	8	9	10
Weight of each story (t/m^2)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Weight of total storey (t)	202.5	360	360	360	360	360	360	360
Weight of all structure (t)	1012.5	1800	2160	2520	2880	3240	3600	3960
Stress in bottom of foundation (t/m^2)	4.5	4.5	5.4	6.3	7.2	8.1	9	10

IV. NUMERAL CALCULATION AND STUDY OF RESULTS

For study of increase of stress in main structure, calculation are performed in four points A, B, C and M that calculation of point A is shown in table(2) and (3). In continue, for study of effect of storeys on added stress, stresses are shown for all adjacent structure and for all number storey in one graph that is shown in Fig. (4).

As it is shown in table (2), we can use from sum of the two structures.

In this table I1(mn) and I2(mn) are related to main structure and adjacent structure that are calculated for various depth.

TABLE II CALCULATION OF I FOR OBTAIN OF ADDED STRESS IN POINT A AND IN VARIOUS DEPTH

Z(m)	m=15/Z	n=15/Z	I_1(mn)	m=20/Z	n=20/Z	I_2(mn)
1	15.0000	15.0000	0.2499	20.0000	20.0000	0.2500
2	7.5000	7.5000	0.2496	10.0000	10.0000	0.2498
3	5.0000	5.0000	0.2486	6.6667	6.6667	0.2494
4	3.7500	3.7500	0.2467	5.0000	5.0000	0.2486
5	3.0000	3.0000	0.2439	4.0000	4.0000	0.2473
6	2.5000	2.5000	0.2401	3.3333	3.3333	0.2455
7	2.1429	2.1429	0.2352	2.8571	2.8571	0.2455
8	1.8750	1.8750	0.2295	2.5000	2.5000	0.2431
9	1.6667	1.6667	0.2229	2.2222	2.2222	0.2401
10	1.5000	1.5000	0.2157	2.0000	2.0000	0.2366
11	1.3636	1.3636	0.2080	1.8182	1.8182	0.2325
12	1.2500	1.2500	0.1999	1.6667	1.6667	0.2279
13	1.1538	1.1538	0.1917	1.5385	1.5385	0.2175
14	1.0714	1.0714	0.1834	1.4286	1.4286	0.2119
15	1.0000	1.0000	0.1752	1.3333	1.3333	0.2060
16	0.9375	0.9375	0.1671	1.2500	1.2500	0.1999
17	0.8824	0.8824	0.1592	1.1765	1.1765	0.1938
18	0.8333	0.8333	0.1516	1.1111	1.1111	0.1876
19	0.7895	0.7895	0.1443	1.0526	1.0526	0.1814
20	0.7500	0.7500	0.1372	1.0000	1.0000	0.1752
21	0.7143	0.7143	0.1305	0.9524	0.9524	0.1691
22	0.6818	0.6818	0.1241	0.9091	0.9091	0.1632
23	0.6522	0.6522	0.1181	0.8696	0.8696	0.1573
24	0.6250	0.6250	0.1123	0.8333	0.8333	0.1516
25	0.6000	0.6000	0.1069	0.8000	0.8000	0.1461
26	0.5769	0.5769	0.1018	0.7692	0.7692	0.1407
27	0.5556	0.5556	0.0969	0.7407	0.7407	0.1355
28	0.5357	0.5357	0.0924	0.7143	0.7143	0.1305
29	0.5172	0.5172	0.0881	0.6897	0.6897	0.1257
30	0.5000	0.5000	0.0840	0.6667	0.6667	0.1210
31	0.4839	0.4839	0.0802	0.6452	0.6452	0.1166
32	0.4688	0.4688	0.0766	0.6250	0.6250	0.1123

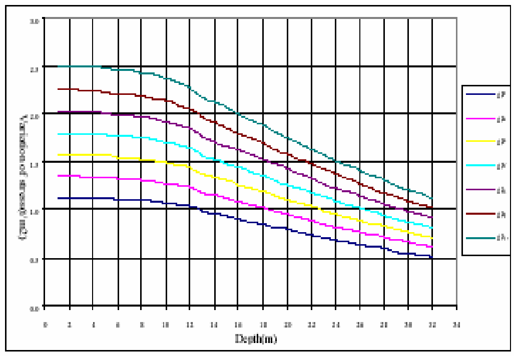

Fig. 4 Comparison of number of storeys on the adjacent structure stress in point A

TABLE III CALCULATION OF STRESS IN POINT A AND IN VARIOUS DEPTHS

POINT A								
Z(m)	ΔP_1(t/m²)	ΔP_4(t/m²)	ΔP_5(t/m²)	ΔP_6(t/m²)	ΔP_7(t/m²)	ΔP_8(t/m²)	ΔP_9(t/m²)	ΔP_{10}(t/m²)
1	1.1248	2.2496	2.4746	2.6996	2.9246	3.1496	3.3745	3.6245
2	1.1230	2.2472	2.4720	2.6969	2.9217	3.1465	3.3714	3.6212
3	1.1186	2.2408	2.4653	2.6897	2.9142	3.1386	3.3630	3.6124
4	1.1104	2.2289	2.4527	2.6764	2.9001	3.1238	3.3475	3.5961
5	1.0977	2.2105	2.4331	2.6557	2.8782	3.1008	3.3233	3.5706
6	1.0804	2.1851	2.4060	2.6269	2.8478	3.0688	3.2897	3.5352
7	1.0586	2.1632	2.3842	2.6051	2.8260	3.0469	3.2678	3.5133
8	1.0326	2.1265	2.3452	2.5640	2.7828	3.0015	3.2203	3.4634
9	1.0030	2.0835	2.2995	2.5156	2.7317	2.9478	3.1639	3.4040
10	0.9705	2.0350	2.2479	2.4608	2.6737	2.8866	3.0995	3.3360
11	0.9358	1.9819	2.1911	2.4004	2.6096	2.8188	3.0280	3.2605
12	0.8997	1.9252	2.1303	2.3354	2.5405	2.7456	2.9507	3.1786
13	0.8627	1.8416	2.0374	2.2331	2.4289	2.6247	2.8204	3.0380
14	0.8255	1.7789	1.9696	2.1603	2.3509	2.5416	2.7323	2.9442
15	0.7885	1.7154	1.9008	2.0862	2.2715	2.4569	2.6423	2.8483
16	0.7521	1.6518	1.8317	2.0117	2.1916	2.3715	2.5515	2.7514
17	0.7166	1.5886	1.7630	1.9374	2.1118	2.2862	2.4606	2.6544
18	0.6822	1.5264	1.6952	1.8640	2.0328	2.2016	2.3705	2.5580
19	0.6492	1.4654	1.6286	1.7919	1.9551	2.1184	2.2816	2.4630
20	0.6175	1.4060	1.5637	1.7214	1.8791	2.0368	2.1945	2.3697
21	0.5873	1.3484	1.5006	1.6528	1.8051	1.9573	2.1095	2.2787
22	0.5585	1.2927	1.4396	1.5864	1.7333	1.8801	2.0270	2.1901
23	0.5312	1.2391	1.3807	1.5223	1.6639	1.8055	1.9470	2.1044
24	0.5054	1.1876	1.3241	1.4605	1.5970	1.7334	1.8699	2.0215
25	0.4810	1.1383	1.2698	1.4012	1.5327	1.6641	1.7956	1.9417
26	0.4579	1.0911	1.2177	1.3443	1.4710	1.5976	1.7242	1.8649
27	0.4362	1.0460	1.1679	1.2899	1.4118	1.5338	1.6558	1.7913
28	0.4157	1.0029	1.1204	1.2378	1.3553	1.4727	1.5902	1.7207
29	0.3963	0.9619	1.0750	1.1881	1.3012	1.4143	1.5274	1.6531
30	0.3781	0.9228	1.0317	1.1407	1.2496	1.3586	1.4675	1.5885
31	0.3610	0.8856	0.9905	1.0955	1.2004	1.3053	1.4102	1.5268
32	0.3448	0.8502	0.9513	1.0524	1.1534	1.2545	1.3556	1.4679

That in this table, ΔP_i are:

ΔP_1 : Stress due to main structure

ΔP_4 : Stress due to main structure plus stress due to 4 storeys adjacent structure

ΔP_5 : Stress due to main structure plus stress due to 5 storeys adjacent structure

ΔP_6 : Stress due to main structure plus stress due to 6 storeys adjacent structure

ΔP_7 : Stress due to main structure plus stress due to 7 storeys adjacent structure

ΔP_8 : Stress due to main structure plus stress due to 8 storeys adjacent structure

ΔP_9 : Stress due to main structure plus stress due to 9 storeys adjacent structure

ΔP_{10} : Stress due to main structure plus stress due to 10 storeys adjacent structure

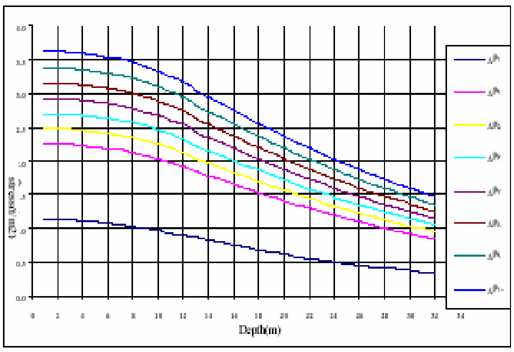

Fig. 5 Comparison of number of storeys on the variation stress of adjacent structure in point A

In Fig.(5), added stresses in point A for various storeye and in various depth are presented. In this Figure ΔP_i is added stress due to structure I in point A. For calculation of added stress due to main structure in point M, we can not sue straight method, because this point isn't in edge of uniform load. For this purpose, first area is divided to four section, as Fig.(6), and for each section calculation are performed separated and result are added together.

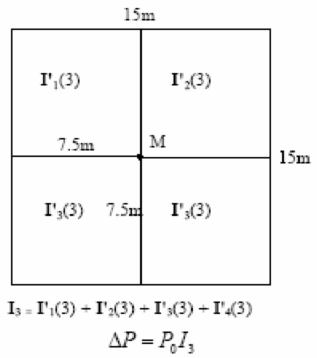

Fig. 6 manner of structure division for calculation

For calculation of stress due to adjacent structure, we can not use straight method, too. So first it is assumed that uniform load of adjacent structure is on the two area with7.5*27.5 (m) and 12.5*27.5(m) dimension. Then stress due to two area with 7.5*7.5(m) and 12.5*7.5(m) are minus to it and real stress are obtained. With attention to performed calculation according to top method, added stress for B, C and M are obtained that its results are shown in Fig. (7) to (9).

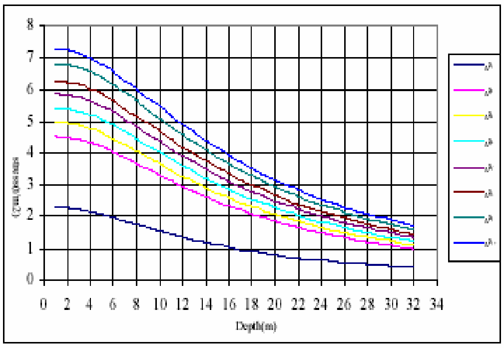

Fig.7 Comparison of number of the storey on the stress in point B

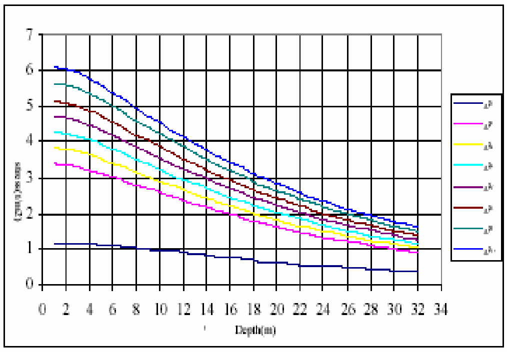

Fig. 8 Comparison of number of the storey on the stress in point C

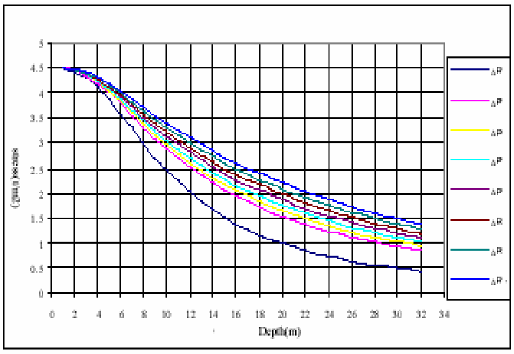

Fig. 9 Comparison of number of the storey on the stress in point M

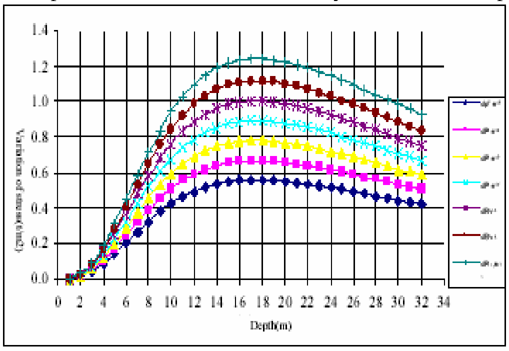

Fig. 10 Comparison of number of the storey on the added stress in point M

In Fig. (10), added stress in point M is shown that n is storey of adjacent structure. For comparison of added stress than main structure stress, it is shown for points A and M in Fig.(11) and (12) .

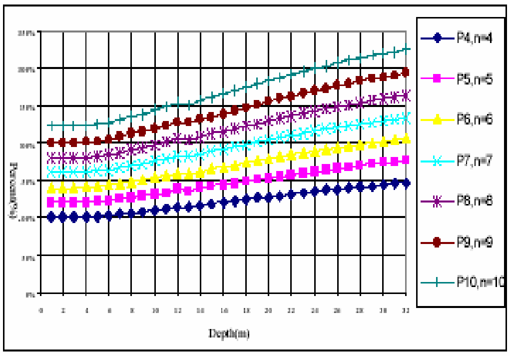

Fig. 11 added stress than main structure stress in point A

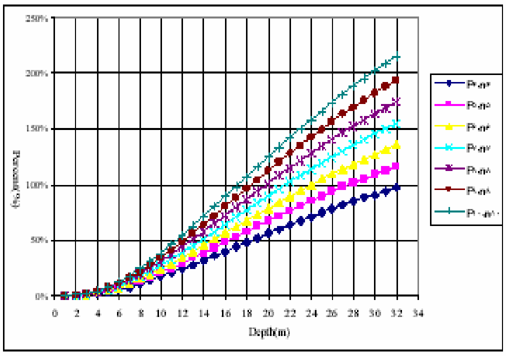

Fig.12 added stress than main structure stress in point M

V. Conclusion

According to theorical calculation and Boussinesq theory in half extreme space and homogenous and isotropic area and with assumption main structure with 4 storeys and adjacent structure with 4 to 10 storeys and study of added stresses in various points of main structure, following result are obtained:

1- With increasing of depth, added stress is decreased. 2- Added stress due to adjacent structure in main structure with increasing depth has fewer gradients. 3- Added stress in center of structure with increasing of depth, increase. But after a definite depth (near 18 m), added stress decrease. 4- For point in interface, maximum added stress is occurred in surface of ground that with increasing of depth, it decreases. 5- Percentage of added stress due to adjacent structure on the main structure, with increasing depth increase.

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