Apr 2nd - Apr 7th

An Empirical Formula for Evaluation of Buildings Settlements Due to Earthquake Liquefaction

Huishan Liu
Central Research Institute of Building and Construction, MMI, Beijing, China

Recommended Citation

Liu, Huishan, "An Empirical Formula for Evaluation of Buildings Settlements Due to Earthquake Liquefaction" (1995). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 20.
http://scholarsmine.mst.edu/icrageesd/03icrageesd/session03/20

Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 2-7, 1995, Volume I, St. Louis, Missouri

An Empirical Formula for Evaluation of Buildings Settlements Due to Earthquake Liquefaction

Paper No. 3.39

Huishan Liu
Professor, Aseismic Dept. of Central Research Institute of Building and Construction, MMI, Beijing, China

SYNOPSIS: In this paper the liquefiable subsoils are devided into two groups: type of liquefiable supporting layer and type of liquefiable underlayer. Based on the observed subsidence data and general tendency got from finite element analysis, an empirical formula for evaluation of subsidences of type of liquefiable supporting layer is suggested. Several important factors, such as earthquake intensity, contact pressure at foundation bottom, and relative density of liquefiable soil are involved in this formula. So the formula seems credible to a certain extent.

INTRODUCTION

The earthquake investigations show that liquefaction is in the first place among the factors to cause earthquake ground damages. About 50% of foundation damages of buildings during earthquakes were caused by liquefaction. In case of no liquefaction lateral spreading at construction sites, the main danger of liquefaction is over subsidence of building and construction. Therefore, quantitative evaluation of liquefaction subsidences is a problem of significant importance for design of constructions and buildings, even if the evaluation is rough, since the people know well that so far the accuracy of settlement calculation of constructions and buildings under static loading is not satisfied too.

Until so far several methods for evaluation of liquefaction subsidence have been submitted, but most of them need available computer programs and a series of soil characteristic parameters from the construction sites. These conditions are not very often satisfied. On the other hand, most of these methods have not been checked by numerous liquefaction subsidence cases of constructions too.

The aim of this paper is summarying observed liquefaction subsidence data and submiting a simple empirical formula for rough evaluation of liquefaction subsidences, All collected subsidence data are got from some earthquakes occuring in Japan and in China. such as Nigata earthquake (1964). Heichen earthquake (1975) and Tangshan earthquake (1976), which are worldfamous due to the scale of liquefaction. Hereinafter liquefaction subsoils are devided into two groups: type of liquefiable supporting layer and type of liquefiable underlayer (Fig. 1). The mechanism of losing stability of liquefiable subsoils is shown in Fig2. The appearance of liquefied zones in both outsides of the footing leads stress redistribution in the medium zone directly underlying the footing and causes over subsidense of the footing[2].

In the case of liquefiable underlayer, the situation may be more favorable than in the case of liquefiable supporting layer, since the supporting layer still keeps its bearing capacity during the liquefaction of underlayer.

The uniformer stress distribution in liquefied underlayer than in the supporting layer is also helpful to give less value of subsidence.

However, while the unliquefiable supporting layer is very thin relatively to the width of foundation bottom, the situation is actually near the case for type of liquefiable supporting layer. In this paper it is assumed if the thickness of liquefiable supporting layer is less than $\frac{1}{4}$ width of foundation bottom, it will be treated as the type of liquefiable supporting layer.

EMPIRICAL FORMULA FOR TYPE OF SUPPORTING LAYER

The first group of data on liquefaction subsidences was got from Nigata earthquake (1964, Japan), for civil buildings (Fig. 3). In Fig. 3: S — liquefaction subsidence of structure; B — width of structure; De — liqufaction depth. The depth of liquefaction of sand layers was about 4. 5～18m during the earthquake. The relative densities of sand layers in severely liquefied regions were 0. 4～0. 5, ground surface accelaration was 159 gal, earthquake intensity was about 8° according to Chinese regulation. The second group of data was got for oil tanks located in Amori and Akita during Nihonkai Chubu earthquake (1983). The liquefiable layers in Akita were sands and liqufaction depth was ～ 7m, ground accelaration — 200gal. (about 8°). The liquefied layer in Amori was sand too. The liquefaction depth was about 4m. The maximum accelaiation of ground surface was 98 gal. (earthquake intensity 7 degree)

The liquefaction subsidence data obtained from Tangshan earthquake ($M=7.8$, 1976, China). Heichen earthquake ($M=7.3$, 1975, China) and Shintain earthquake ($M=7.2$, 1966, China) are summarized in Tab. 1 and Fig. 4. It is seen from comparison of Fig. 3 and Fig. 4, the general tendency of cirves S/De～B/De are similar, althrough the conditions in aspects of structure. subsoil and earthquake intensity are different in every case. The higher is the earthquake intensity, the greater is the liquefaction subsidence; the greater is the B/De, the less is the S/De.

Fig. 5～Fig. 7. present the calculated results for type of liquefiable suppoting layer[5], according for ref. [4], which offers a computer program of two dimensions and expressed in effective stress. For these figures:

the thickness of sand layer is 15m, the bedrock is its underlayer;

The input earthquake accelaration of bedrock $a_{max}=0.06 \sim 0.24g$ (g — gravity accelaration);

The relative density of sand layer $Dr=0.3 \sim 0.7$;

The contact pressure at foundation bottom, $p = 90 \sim 120$KPa;

width of bottom $B=0.8 \sim 4$m.

From Fig. 5 we get the following points:

1. curves S/De～B/De have the same characteristics just like in Fig. 3 and Fig. 4, but the values of S/De are less than the observed in general.

The differences between the calculated and observed values may be attributed to the influence of the following factors:

(1) The soil is theoretically assumed as a continuous body, so the influence of sand boiling, discontinuosness of soil skeleton and a large amount of lost pore water and soil grands is not accounted.

(2) There are some unfitness in selection of values of soil parameters, tipical soil profiles or some uncompleteness in analysis.

(3) During liquefaction occurence the subsoil is often working at the failure step of load — settlement curve (P — S curve). It is well known that in this step, a very little loading increament can cause a significant settlement increament. This may be one of the reasons to explain why many similar buildings located at one and the same construction site got very different liquefaction subsidences. But in calculations, it is very difficult to exactly reflect actual load distribution for every building, and on the other hand, simplified structure scheme used in calculation often can not reflect the actual performance of structure perfectly.

2. The curves in Fig5. have its peak values when $B/De = 0.27 \sim 0.44$, but during $B/De < 0.27$, the values S/De tend to decrease. However, from the point of practical view it is conviniant to adopt the value S/De equal to the peak value during $B/De < 0.27$, as the curves shown in Fig. 4.

It is seen from Fig. 6 and Fig. 7. that ratio S/De is increasing with the reduction of soil relative density Dr and the inereasing of contact pressure p. Such calculated results are accordant with our common concepts on liquefaction subsidence.

Based on Fig3 ～ Fig7, an empirical formula for subsidence prediction in case of type of liquefiable supporting layer is suggested:

$$\frac{S}{De} = S_0\left[\frac{0.44}{\left[\frac{B}{De}\right]}\right] \cdot (0.001p)^{0.6} \cdot \left[\frac{1-Dr}{0.5}\right]^{1.5} \qquad (1)$$

Where S — subsidence of structure due to liquefaction, m;

S_0 — basic value for calculation of subsidence, t. e. the value of S/De for the horizontal section of curves in Fig. 4, while $p=100$KPa, $Dr=0.5$, $B/De=0 \sim 0.44$. For 7, 8 or 9 earthquake intensity, $S_0=0.05$, 0.15 and 0.30 respectively;

Observed subsidences for type of liquefiable supporting layer

Tab. 1

No.	Sites & Structures	Intensity (°)	Found. depth (m)	Depth of liquefaction De (m)	Width of found. B(m)	Subsi-dence S(m)	$\frac{B}{De}$	$\frac{B}{De}$
1	Gas tank with mat foundation, Tianjing.	9	3.5	8.3	18	0.50	216	0.06
2	5-storied building with mat foundation, Tianjing	9	3.5	8.3	14.1	0.30	1.68	0.036
3	Workshop with mat foundation, Tianjing Soda Factory	8	2.0	7.5	12	0.14	1.6	0.019
4	Multi-storied building, Fonglan county, Hebei Provence	9	1.8	12.8	~8*	1.00	0.62	0.078
5	Apartment, Chang-Gui-Zhuang, Tianjing	8	1.4	3.8	~12*	0	2.31	0
6	Suntou Power Station, Hebei Prov.	7	7	13	12	0.06	0.92	0.004
7	Boiler house, 605-th Institute, Tianjing	8	3.8	9.8	27	0.05	2.75	0.005
8	Industry building, Kailuan coal mine, Hebei Prov.	9	4.0	~8	~14	0.9	1.75	0.11
9	Headframe, Kailuan coal mine	9	1.0	~8	15	0.2	1.88	0.025
10	Corridor in coaling yard, Kailuan coal mine	9	1.2	4.0	4	0.45	0.76	0.086
11	Oil tank, Kailuan coal mine	9	0	5.0	10	0.35	2	0.07
12	4-storied builing, Kailuan coal mine	9	0	5.0	12*	0.2	2.4	0.04
13	Bulldozer house, Kailuan coal mine	9	0	5.0	10*	0.7	2.0	0.14
14	3-storied substation, Kailuan coal mine	9	0	14.5	12*	0.9	0.87	0.06
15	Yinkou Hotel, Yinkou, Liaoning Prov.	7	2	6.5	~14	0	2.15	0
16	Embankment, Site A, Beijing—Shanheguan railway	9	3.5	~15	15.2	1.0	1	0.067
17	Embankment, Site B, Beijing—Shanheguan railway	9	3.2	~15	15.3	0.90	1	0.06
18	Embankment, Site C, Beijing—Shankeguan railway	9	4.1	~15	17.3	0.70	1.15	0.047

* Herein B is width of the building.

When formula(1) is used, attention must be payed to selection of value B. In case of oil tank or other kind of isolated footings little influenced each other, B is the diameter of the tank or width of the footing; In case of rigid structure and densely located foundations, for example, multistoried buildings, B is width of the building.

Formula (1) can be reformed as following:

$$\frac{S}{De} = S_{50} \cdot K_P \cdot K_D \qquad (2)$$

Where S_{50}—special value of $\frac{S}{De}$, while Dr=50%, p=100KPa, B/De=0.44.

$$S_{50} = S_0\left[\frac{0.44}{\left[\frac{B}{De}\right]}\right] \qquad (3)$$

K_P and K_D—revising coefficiants for factor p and Dr respectively.

$$K_P = (0.001p)^{0.6} \qquad (4)$$

$$K_D = \left[\frac{1-Dr}{0.5}\right]^{1.5} \qquad (5)$$

The relations S/De~B/De for regions of 7. 8 and 9 intensities are illustrated in Fig 8 by solid curves, while Dr=50%, p=100KPa. The shaded areas in the figure present the variation of S/De, while Dr=30~50% and p=

100KPa. It is seen that most of the observed values of subsidences are covered by the shaded areas.

CONCLUSIONS

1. The suggested formula (1) or (2) for subsidence prediction of liquefiable supporting layer is an empirical formula. It is primary and rough but convinient for practical use. Since it is got from summarization of observed subsidence data and quantitatively accordant with calculation results, it seems credible in some extent.

2. From both sides of analysis and earthquake investigations, it is shown that when $B/De \geqslant 3$, the values of liquefaction subsidences likely do not greater than 0.05 De, 0.03 De and 0.01 De for 9°, 8° and 7° respectively.

3. In order to refining liquefaction subsidence prediction it needs further enrichment on data of observed subsidences, since the collected data are very limmited.

REFRENCES

〔1〕Yoshiaki Yoshimi and Kohji Tokimatsu: Settlement of Biuldings on Saturated Sand During Earthquakes, Soils and Foundations, Vol. 17, No. 1, 1977.

〔2〕Liu, H and Qiao, T Liquefaction Potential of Saturated Sand Deposits underlying Foundation of Structure, Proc. of 8—th World Conf. on Earthquake Engineering, 1984.

〔3〕Chen, K and Liu, H, Characteristics of Subsoil Liquefaction Deformation and Failing under Structures, Proc of 4—th Conf. on Earthquake Engineering, MMI, 1986(in Chinese)

〔4〕Zhujiang Shen, An Effective Stress Method for Dynamically Coupled Liquefaction and Deformation Analysis of Sands, Water Conservancy and Hydrotranportation Sceintific Research, No. 4; 1982(in Chinese)

〔5〕Jianping Sun. Siaolu Gu and Huishan Liu, Factors Influencing Liquefaction Settlement of Buildings and Applied Formula for Settlement Evaluation, Master Thesis (in Chinese), 1993

〔6〕Huixian Liu. On Damage of Tangshan Earthquake (in Chinese), 1985.

〔7〕安田进,液状化の调查から对策工まで,1988.

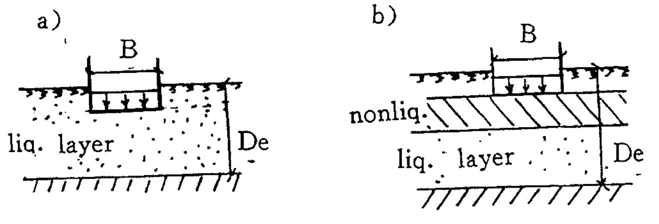

Fig. 1 Types of Subsoils: a)type of liquefiable supporting layer; b)type of liquefiable underlayer.

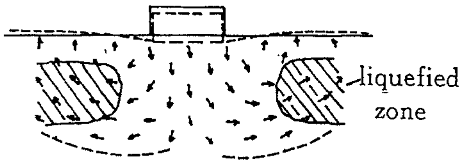

Fig. 2 Liquefied zones beneath foundation[3]

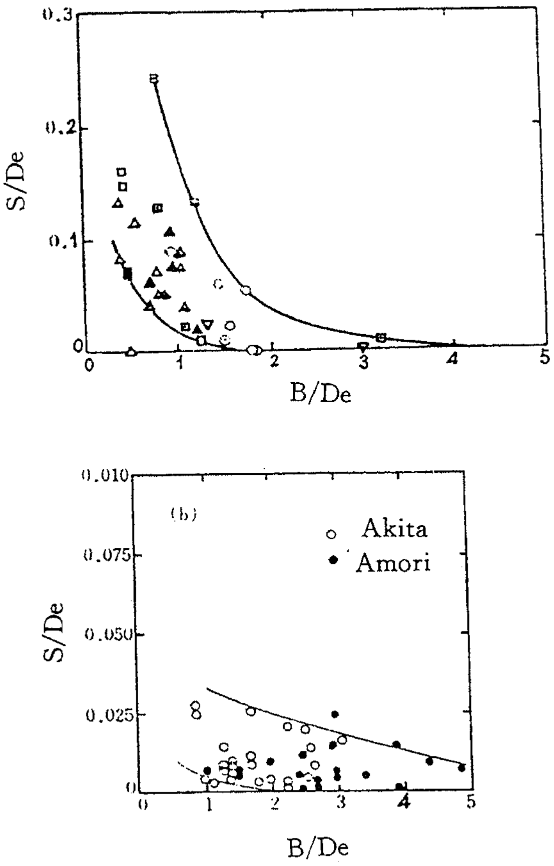

Fig. 3 Subsidences of structures[1] [7]
a)Niigata earthquake;
b)Nihonkai Chubu earthquake

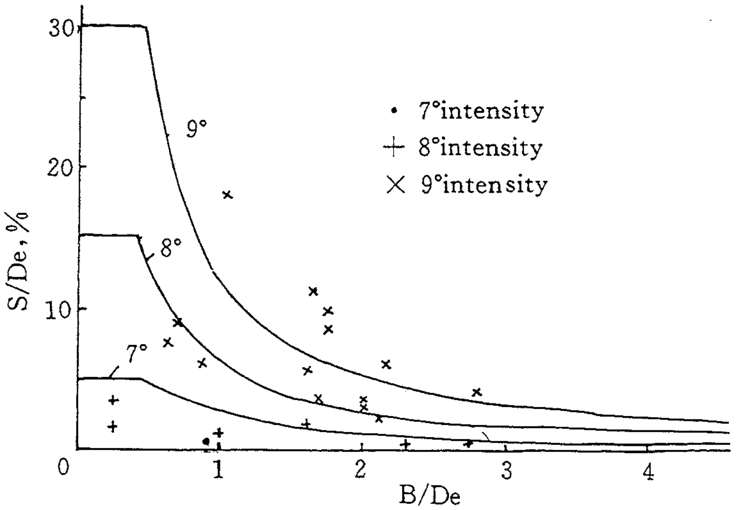

Fig. 4 Observed subsidences from China (—curves after formula (1). when p = 100KPa; Dr = 50%)

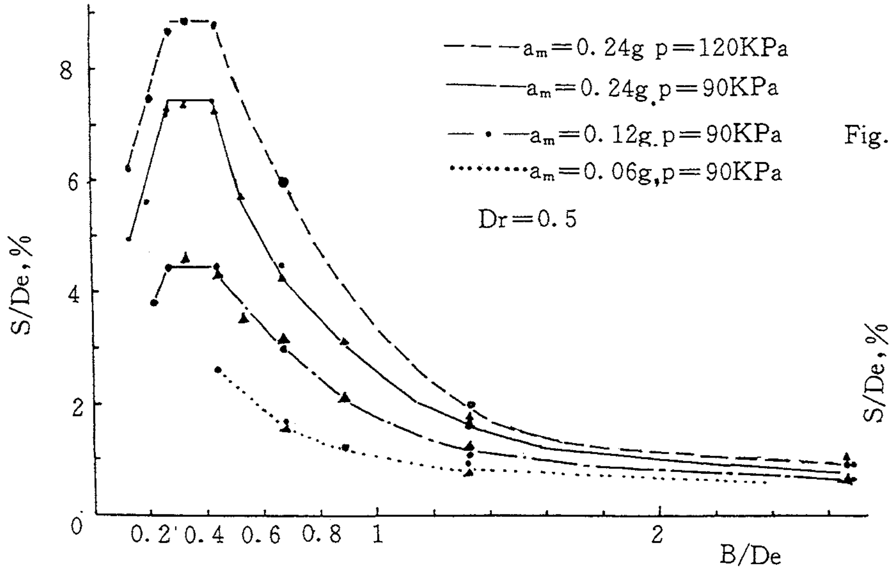

Fig. 5 Calculated relations between S/De and B/De[5]

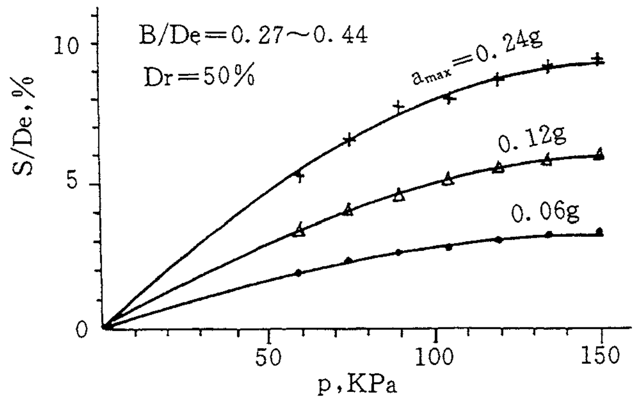

Fig. 6 Influence of contact pressures on liquefaction subsidence [5]

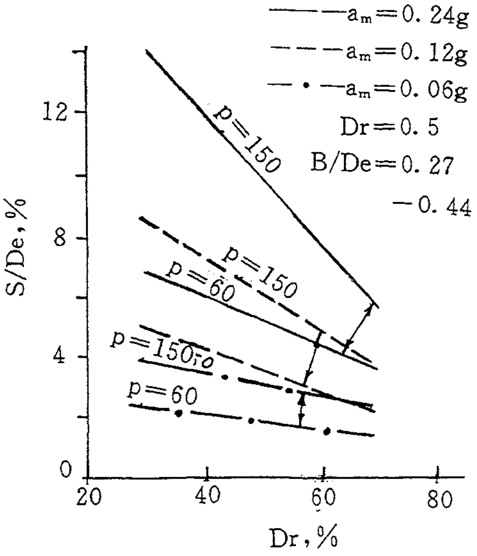

Fig. 7 Influence of relative density on liquefaction subsidence[5]

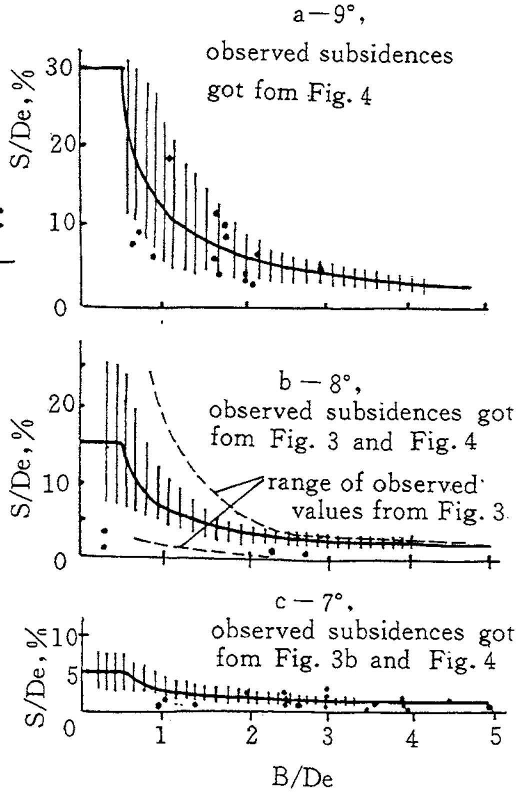

Fig. 8 Comparison between observed values and calculated by For(1) when p=100KPa Dr=50%