Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

11-2-11

ESTIMATION OF EARTHQUAKE INDUCED SETTLEMENTS FOR LIFELINE ENGINEERING

Shiro TAKADA[1] and Kishiro TANABE[2]

1 Department of Civil Engineering,Kobe University,Rokkodai,Nada,Kobe,Japan
2 School of Science and Technology,Kobe University,Rokkodai,Nada,Kobe,Japan

SUMMARY

The present paper has proposed estimation formulae of ground settlement during earthquakes focused on lifeline earthquake engineering. The proposed formulae were obtained by regression analysis using 404 data of ground settlements in the past major five earthquakes in Japan. The maximum ground settlement could be expressed by the function of height of soil layer and embankment ,maximum ground surface acceleration and N-value of sandy soil layer. The proposed formulae were compared with previous research results to ensure the accuracy. They showed pretty good agreement.

INTRODUCTION

Damage investigations in recent earthquke have showed that main causes to buried pipelines are ground failure such as ground settlements, slide,liquefaction and surface fault movements as well as wave propagation during earthquakes. Current seismic design codes of buried pipelines in Japan pay little attention to these ground failures. Establishments of design procedure or countermeasures for buried pipelines subjected to ground failures are significant problems in lifeline earthquake engineering. In the present paper, an estimation formula to obtain the quantity of ground settlements during earthquakes was aimed as the first stage to design buried pipelines under the environments of ground settlements.

The methodology to estimate ground settlements during earthquakes is classified into two groups : One is a statistical way to employ many data of ground settlements in the past earthquakes to lead regression equations. (Refs.1,2). The other is an experimental way of soil tests in a laboratry to obtain a compression rate of soil specimen(Ref.3). Estimation formulae of ground settlements used for decision of input level for seismic design of buried pipelines are desirable not to include soil parameters obtained by experiments. Here, many data of ground settlements in the past earthquakes were analysed using ground parameters known by boring tests in situ.

CHARACTERISTICS OF GROUND SETTLEMENT DURING EARTHQUAKES

Table 1 shows the quality of earthquakes in which data of ground settlements were collected. Number of data of ground settlements used in the present analysis were 404. In Table 2, factors effecting ground settlements during earthquakes are listed. Two kind of maximum acceleration were used as the factor of seismic ground intensity, which were calculated by two kind of attenuation equations. Following facts were revealed by regulating the data of ground settlements.

a)Ground settlements are initiated at the maximum ground acceleration 50 gals and quantity of ground settlement has a tendency of increase according to an increase of ground acceleration(Fig.1). Fig.1 shows that ground settlements in liquefied ground are much larger than that in non-liquefied ground.

b)Ground settlements in embankment become smaller for the height more than 10 m, whereas the settlements are proportional to the height of embankment within the range of 10m. Quantity of ground settlements in embankment is considered to be influenced by natural period of the body of embankment and by the method of construction. Difference of ground settlements due to structures such as rail way, road and river embankments is few(Fig.2).

c)Ground settlements are in proportion to the depth of alluvial soil layer and to the depth of sandy soil layer. Ground settlements ,however, decrease for more depth of alluvial layer than 20 m, which will be explained by the effects of natural period of the layer as well as embankments.

d)Fig.3 shows the ground settlements related with N-value of sandy soil layer. Ground settlements are known to be inversely proportional to N-value.

e)The settlement ratio defined by the rate of ground settlements to the depth of alluvial or sandy soil layer is in the range of 1-2 % which increases depending on the quantity of ground settlements.

As shown in Figs.1-3, ground settlements cannot give a quantitative relation with each factor. Roughly speaking, an increase of seismic ground intensity, height of embankment and height of alluvial layer provides larger values of ground settlement. To the contrary, an increase of N-value in sandy layer contributes the decrease of ground settlements. In the next chapter, data of ground settlements are statistically analysed with consideration of combination of these factors.

QUANTITATIVE ANALYSIS OF GROUND SETTLEMENT

Statistical analyses were performed by classifying the data of ground settlements as data in embankment or plain site and data in liquefied ground or non-liquefied ground.

<u>Regression Analysis</u> The following expression of regression equation was employed under consideration of the general tendency of ground settlements in the previous chapter.

For embankment: $\delta = a \cdot B \cdot H \cdot A / N + b$ (1)

For plain site: $\delta = a \cdot H \cdot A / N + b$ (2)

Here, B :Height of embankment, H :Depth of sandy layer, N :N-value in sandy layer and A is the maximum ground acceleration or velocity or displacement.

Analysed coefficient a and b are listed in Table 3. For the case of embankment, a correlation coefficient in regression equation (1) showed the highest value as 0.9158 when the displacement was used. On the other hand, the highest value of the correlation coefficient for the case of plain site was 0.8032 when the velocity was used. However, the difference of the correlation coefficient is very small being independent on the ground motions. Fig.4 shows obtained regression lines and analytical data for plain site. These figures indicate that regression equations for liquefied and non-liquefied ground do not give an efficient disagreement. Soil mechnical differences are considered to be expressed by the N-value in liquefied and non-liquefied ground.

Multi-Regression Analysis Multi-regression analysis was also performed for the same factors as in the regression analysis. Next forms of equations were assumed:

For embankment: $$\delta = 10^{a} \cdot B^{b} \cdot H^{c} \cdot A^{d} / N^{e} \qquad (3)$$

For plain site: $$\delta = 10^{a} \cdot H^{c} \cdot A^{d} / N^{e} \qquad (4)$$

Coefficients a,b,c,d and e were analysed and results are shown in Table 4. The highest multiple coefficients were acquired for the same ground motions as in the regression analysis both for the cases of embankment and plain site. Fig.5 is regression lines and data used for analyses for ground acceleration and velocity. Table 5 indicates the range of data used for analyses. Estimation formulae of ground settlement is credible under the range of paremeters shown in Table 5. Effects of the parameter of ground motions and difference of regression and multi-regression analyses are little enough, then we propose Eqs.(1) and (2) employing the parameter for the maximum ground acceleration.

COMPARISON OF RESULTS WITH PREVIOUS RESEARCHES

Present data of ground settlements are compared with data analysed in Ref.2 as shown in Fig.6. Data treated in Ref.2 were ground settlements at embankments behind rail way abutments, which include ground settlements at clay ground as well as sandy ground. Rigid line and dotted lines in the figure indicate the regression line and standard deviation lines analysed in the present study. Data in Ref.2 existing out of range of the deviation lines were revealed to be ones obtained at the ground with higher alluvial depth or very low N-values. Fig.7 is a comparison with soil experiments by Ref.3. These comparisons were carried out by converting the parameters in present analysis to physical constants such as shear stress, effective normal stress, number of cyclic loading and relative density which are treated in the experiments.

REFERENCES

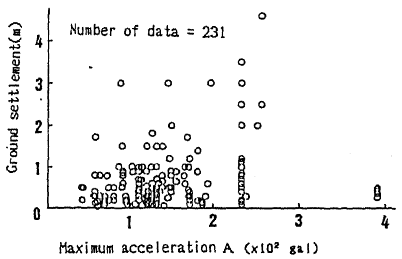
1.Okada,K., Fukushima,H. and Ogasawara,Y.:Statistical Estimation of Ground Settlements at Embankment behind Abutments, Annual Meeting,JSCE,1001,(1986).
2.Hamada,M.,Yasuda,S.,Isoyama,R. and Emoto,K. :Permanent Deformation of Ground and Damages due to Liquefaction, Proc. of JSCE, No.376,221-229,(1986).
3.Nishi,K.,Kajitani,T. and Nishi,G.: Change of Bulk Strain of Sand under Random Cyclic Loading,Annual Meeting,JSSMFE,595-598,(1985).

Table 1 Earthquakes used for analysis

Name	Date	M	Depth(km)	Number of data
Niigata	1964.6.16	7.5	40	82
Tokachi-oki	1968.6.16	7.9	20	105
Nemuro-hantho-oki	1973.6.17	7.4	40	11
Miyagiken-oki	1978.6.12	7.4	30	100
Nihonkai-chubu	1983.5.26	7.7	14	106

Table 2 Factors in regression analysis

Factor	Unit	Contents
Ground settlement	cm	Maximum value in the area
Ground condition	-	1.Plain site 2.Reclaimed ground 3.Embankment in rail way 4.Embankment in road 5.Embankment in river 6.Others
Ground kind	-	1st to 4th kind classified in Road Bridge Specification
Seismic intensity	-	Japan Meteorological Agency (JMA) intensity
Alluvial depth	m	N-value at the surface of base rock is about 50
Depth of embankment	m	
Liquefaction	-	1.Liquefied area 2.Non-liquefied area 3.Indistinstness
Epicentral distance	km	
Earthquake magnitude	-	
Ground acceleration	gal	Estimated by attenuation law
Ground velocity	kine	
Ground displacement	cm	
Depth of sandy layer	m	Total depth of sandy layers in the alluvial layer
N-value in 〃	-	Averaged N-value in sandy layers



(a)Liquefied ground

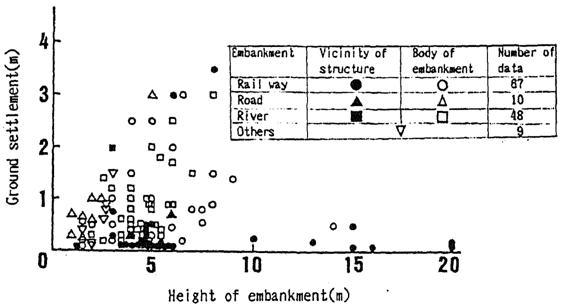
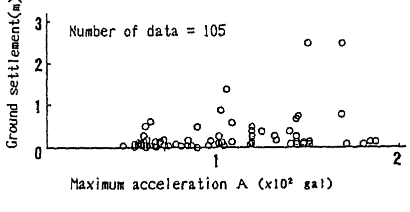


Fig.2 Ground settlement related with height of embankment



(b)Non-liquefied ground

Fig.1 Ground settlement related with ground acceleration

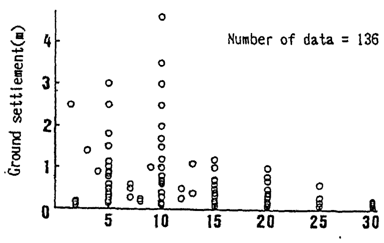


Fig.3 Ground settlement related with N-value in sandy layer

Table 3 Coefficients by regression analysis

		Maximum Ground Motion	a	b	Correlation coefficient	Standard deviation	Number of data
Embankment	Total data	Acceleration A	0.088	21.4	0.8786	44.3	42
		Acceleration A	0.118	19.9	0.8846	43.3	
		Velocity	0.919	18.5	0.9089	38.7	
		Displacement	3.570	20.0	0.9158	37.3	
	Data in liquefied ground	Acceleration A	0.092	20.0	0.8610	46.5	35
		Acceleration A	0.123	19.3	0.8790	43.6	
		Velocity	0.926	19.5	0.8941	40.9	
		Displacement	3.545	21.2	0.9024	39.4	
Plain site	Total data	Acceleration A	0.250	2.52	0.8006	16.4	43
		Acceleration A	0.332	4.86	0.8170	15.8	
		Velocity	0.237	6.10	0.8032	16.3	
		Displacement	8.580	7.91	0.7770	17.3	
	Data in liquefied ground	Acceleration A	0.261	0.28	0.7936	16.6	41
		Acceleration A	0.339	3.79	0.8087	16.1	
		Velocity	2.420	5.05	0.7935	16.6	
		Displacement	8.730	7.08	0.7646	17.6	

Table 4 Coefficients by multi-regression analysis

		Maximum Ground Motion	a	b	c	d	e	Correlation coefficient	Standard deviation
Embankment	Total data	Acceleration A	-1.648	0.560	0.493	1.523	0.626	0.8599	41.1
		Acceleration A	-0.844	0.449	0.684	1.184	0.654	0.8556	45.1
		Velocity	0.192	0.492	0.576	1.280	0.678	0.8621	41.5
		Displacement	1.044	0.525	0.547	1.168	0.692	0.8595	40.9
	Data in liquefied ground	Acceleration A	-1.734	0.556	0.426	1.515	0.423	0.8290	44.3
		Acceleration A	-0.966	0.489	0.551	1.203	0.442	0.8219	46.6
		Velocity	0.111	0.511	0.477	1.253	0.459	0.8294	44.4
		Displacement	0.929	0.531	0.452	1.163	0.464	0.8290	43.8
Plain site	Total data	Acceleration A	-0.207	-	0.591	0.737	0.427	0.7810	18.3
		Acceleration A	-0.560	-	0.642	0.971	0.490	0.8142	15.5
		Velocity	0.361	-	0.541	1.100	0.491	0.7987	16.2
		Displacement	1.004	-	0.475	0.955	0.452	0.7595	17.3
	Data in liquefied ground	Acceleration A	-0.495	-	0.961	0.820	0.708	0.8006	16.0
		Acceleration A	-0.745	-	0.777	1.033	0.574	0.8354	15.1
		Velocity	0.263	-	0.703	1.028	0.593	0.7988	15.9
		Displacement	0.924	-	0.651	0.967	0.567	0.7456	17.0

Table 5 Range of data used in regression analysis

	Ground settlement(cm)	Height of embankment(m)	Depth of sandy layer(m)	N-value in sandy layer	Maximum acceleration(gal)
Embankment	10-350	1-9	0.7-23	2-25	92-258
Plain site	10-150		2-22	2-30	42-392

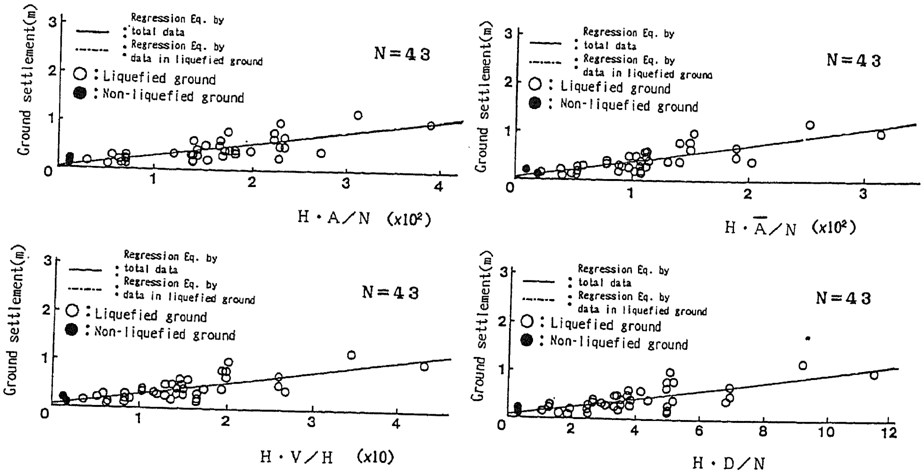


Fig.4 Estimated ground settlement by regression analysis (Plain site)

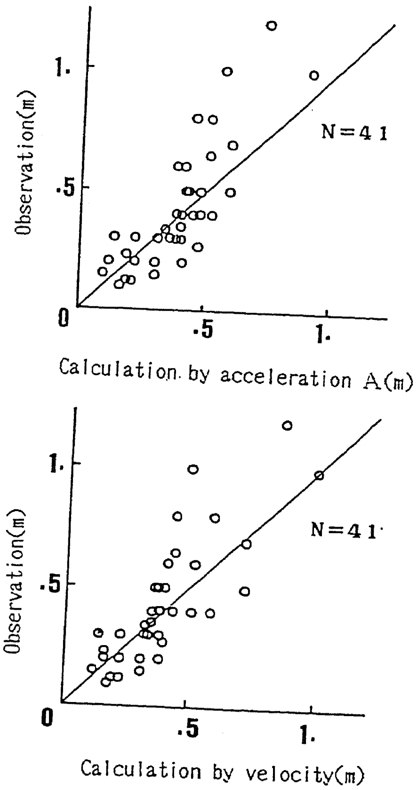


Fig.5 Estimated ground settlement by multi-regression analysis(Plain site)

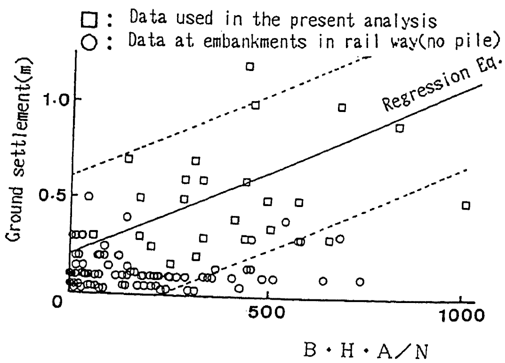


Fig.6 Comparison of present results with others

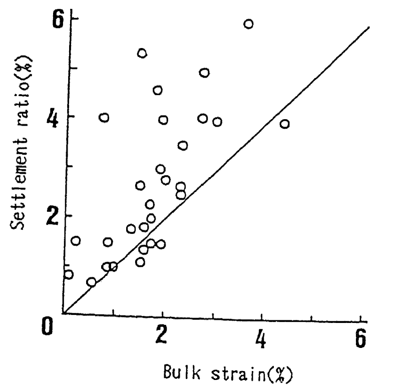


Fig.7 Relationship between settlement ratio and bulk strain