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Sand behaviour under irregular loading

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ABSTRACT: Some triaxial tests are performed under random excitations controlled by microcomputer. Different resistances to liquefaction of sand for various waves having different wave orders and frequencies are obtained. In this study undrained dynamic triaxial tests are performed by changing shock order or shock frequency in a given loading pattern. It is found that the increases of pore water pressure change for different wave order and frequency. Some conclusions about the effects of wave order and frequency on the resistance to liquefaction of sand are worked out based on the tests and theoretical calculation.

1 INTRODUCTION

The shear stresses in earthquak motions are random. Usually uniform sinusoidal loading patterns are performed in laboratories to evaluate strengths against liquefaction in laboratories, but wave order's and wave frequency's effect on strengths aren't considered. Some results of random loadings stated that resistances to liquefaction were affected by wave order in random excitations obviously. By now, somebody believed that there isn't relation between resistance and cycle frequency (from 0.05 Hz to 4 Hz) in uniform loadings, but It isn't known how the wave frequency in random loadings influences the strength of a sand.

In this paper, we perform some undrained triaxial tests of irregular loadings on a saturated sand of middle density to obtain the relations between resistance to liquefaction and wave order and between resistance to liquefaction and wave frequency.

2 TRIAXIAL TESTS FOR RANDOM EXCITATIONS

Dynamic triaxial tests are performed on a electro-liquid servo dynamic triaxial apparatus controled by microcomputer system. The specimens are 150cm in height, 75cm in diameter. Test material is a sand of medium density(d_{50}=0.32mm). After being taken shapes, specimens are of relative density of 0.63%. Specimens are consolidated isotropically to an effective confining pressure of 98KN/m² with a back pressure of 196KN/m² after being saturated.

For the dynamic triaxial apparatus, the dynamic friction force and the static friction force in it are all small and input excitations and output excitations are almost same as shown in Fig.1.

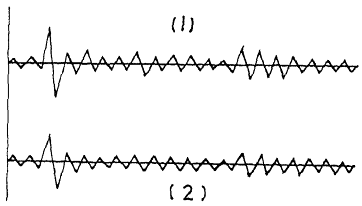

Fig.1. compareing input loading(1) and output loading(2).

In this paper, the liquefaction standard we believe is that pore water pressures in sand specimens just rise to the initial active confining pressures in them after they are actted by a entire test loading. Here, we take the maximum shear stresses(τ_{max}) in irregular loadings inducing liquefaction for the resistances to liquefaction in order to compare them each orther.

3 WAVE ORDER'S EFFECT ON LIQUEFACTION

The test loading we used have three kinds of shock irregular patterns, in which there are 20 cycles of same frequency (1HZ). The positions of the biggest pulses in the three test patterns are different as shown in Fig.2

Many irregular loadings controled by a computer act on sand specimens separately and the irregular loadings inducing liquefaction are found at last.

The test results of three irregular loading patterns are described below:

For a sand, the resistances to liquefaction

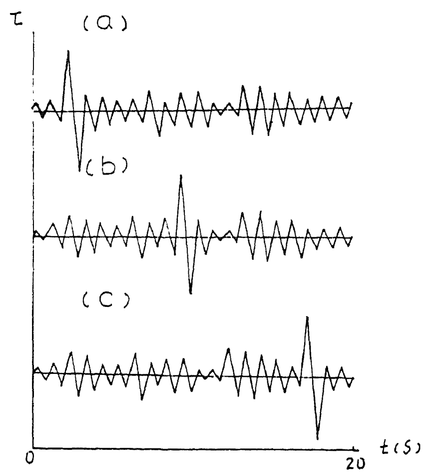

Fig.2. irregular loading patterns.

change if wave orders of loadings on it change. The later the biggest cycle in the irregular loading appears the higher the resistance to liquefaction is as shown in Fig.3.and Tab.1. The main factor that raises the pore water pressure is the biggest pulse in a test irregular loading as shown in Fig.4.

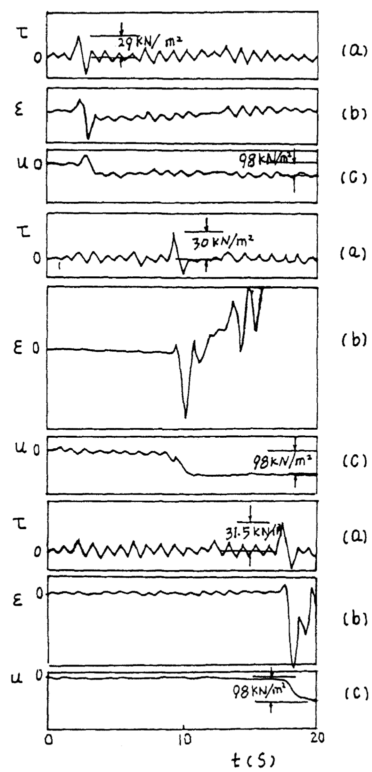

Fig.3. Typical recorded time histories of (a)shear stress (b)shear strain (c)excess pore pressure at liquefaction.

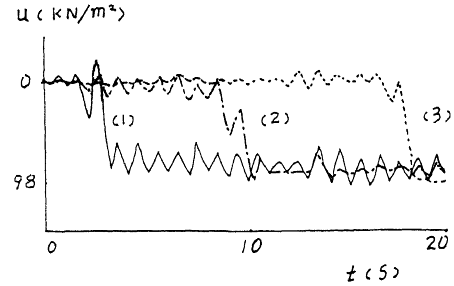

Fig.4.Time history of pore water pressure by loading(1)pattern a (2)pattern b (3)pattern c.

Tab.1.

Loading pattern	(a)	(b)	(c)
Frequency(Hz)	1	1	1
τ_{max}/σ_0'	0.290	0.300	0.315

If we make a test irregular loading into four parts as shown in Fig.5, the one(Part d) consists the biggest amplitude pulse, the others(Part e, f and g) are composed of all small amplitude pulses(the amplitudes of which are all smaller than 60% of the biggest amplitude of pulses). Between the two test irregular loadings, part e and part g are same, but the positions of part d and part f are just opposite. Here , we discuss mainly the rising of the pore water pressures by part d and part f. Some triaxial tests for the two loading patterns are performed and we obtain that on the results of tests as shown in Tab.2: the pore water pressure by the part consisting biggest pulse is much higher than that by the part consisting the small pulses(u_f/u=2.7~6.5%, and u_d/u=16.5 ~38.7), and the difference between the two pore water pressures increases when the irregular loading increases. For the same cycle amplitudes, the earlier the large pulses appear, the highier the pore water pressures rise.

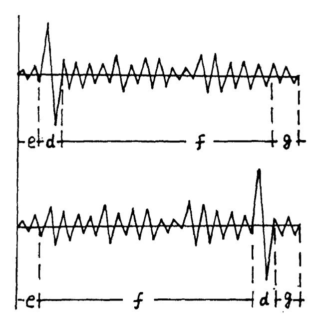

Fig.5. Separating of loading for computing pore water pressure.

Tab.2. Test Results ▲●

	$\tau max/\sigma_0'$	u(kn/m)	u_d/u(%)	u_f/u(%)
irregular	0.23	30	60.3	32.1
loading	0.27	75	68.2	32.1
pattern(a)	0.28	70	70.4	16.5
	0.29	100	59.0	38.7
irregular	0.29	47	82.8	6.5
loading	0.32	100	84.6	2.7
pattern(c)				

u-pore water pressure by test loadings.
u_d-pore water pressure by part d in test loadings.
u_f-pore water pressure by part f in test loadings.

We go further into the relations of wave orders and pore water pressures on calculating the pore water pressures in irregular loadings. In this paper, it is believed that a random excitation is composed of many uniform sinusoidal waves, the amplitudes and frequencies of which are different each other The increase of pore pressures by uniform sinusoidal waves can be calculated with the formula[proposed by Seed & Martin 1976]:

$$Ucy = \sigma_{3c}/2+\sigma_{3c}\sin^{-1}[2(N/N_L)^{1/\alpha}-1]/\pi$$

so the increase of pore water pressures by excitations can be obtained by cumulating that by uniform sinusoidal waves in the irregular excitations.

The irregular loadings we calculate are the test loadings as shown in Fig.5. Here, the initial active confining stress($\sigma_{3c}^{(i)}$) minus the pore water pressure($u_{cy}^{(i)}$) of the last sinusoidal wave is taken for the initial active confing stress($\sigma_{3c}^{(i+1)}$) of the next sinusoidal wave in a irregular loading, and N is regarded as the number of uniform sinusoidal cycles in a irregular loading. Some undrained triaxial tests of uniform loading on the saturated sand are performed and the N_L is obtained which is the number of uniform loading cycles to liquefaction as shown in Fig.6. The results of calculating show the same features as that of tests about the increase of pore water pressure by the irregular loadings as in Fig.7. and Tab.3.

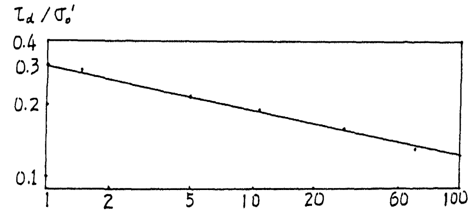

Fig.6. Relationship between ratio and number of cycles by uniform loading.

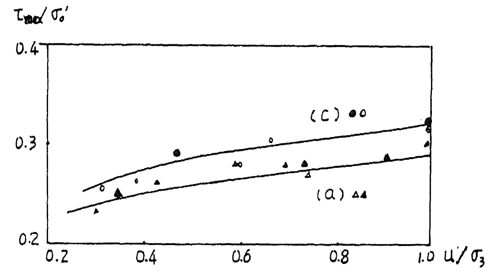

Fig.7. Relationships between maximum stress ratio and pore pressure ratio by random loading(a) & (c).

Tab.3. computing Restults ▲●

	$\tau max/\sigma_0'$	u(kN/m)	u_d/u(%)	u_f/u(%)
irregular	0.25	35	82.8	17.2
loading	0.26	43	79.0	21.0
pattern(a)	0.28	74	63.8	36.2
	0.282	91	55.5	44.5
irregular	0.25	32	94.4	5.6
loading	0.26	39	94.9	5.1
pattern(c)	0.28	60	95.0	5.0
	0.30	67	95.4	4.6
	0.32	100	95.7	5.3

u-pore water pressure by calculating loadings.
u_d-pore water pressure by part d in calculating loadings.
u_f-pore water pressure by part f in calculating loadings.

4 WAVE FREQUENCY'S EFFECT ON LIQUEFACTION

The frequencies in earthquck loadings are random. In this paper, the test loading pattern we use is shown in Fig.2(c), in which the biggest pulse appears behind the small pulses. The frequency of cycles in the irregular loading used is given 0.05Hz, 0.5Hz, 1Hz, 4Hz and 6Hz respectively and the lasting time of the irregular loading used is 400s, 40s, 20s, 5s and 3.33s respetively.

On the results of tests, we find that: (1) for the given random loading pattern, the resistance to liquefaction for the sand increases with the increases of pulse frequency and this tendency is seemly obvious in the range about 0.5Hz to 4Hz of frequency as shown in Fig.8. and Tab.4.; (2) the pore water pressure decreases when the pulse frequency increases as shown in Fig.9.

Tab.4.

wave frequency (Hz)	0.05	0.5	1	4	6
lasting time for shock(s)	400	40	20	5	3.33
$\tau max/\sigma_0'$	0.21	0.24	0.32	0.36	0.38

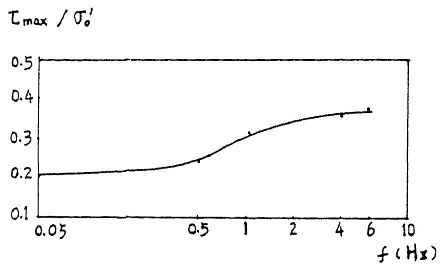

Fig.8.Relationship between maximum stress ratio and wave frequency of irregular loadings.

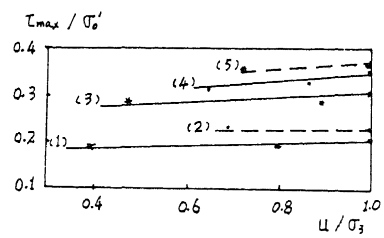

Fig.9.Relationships between maximum stress ratio and pore water pressure of irregular loadings having wave frequency of (1)0.05Hz (2)0.5Hz (3)1Hz (4)4Hz (5)6Hz.

Why have the such test results been obtained? we believe primarily that: (1) on one hand, the behavier of a sand acted by fast changing loadings should changes for the dynamic loading would approache the static loading when the wave frequency decreases a great deal and the dynamic strength of sand is different from the static strength of it;(2) on another hand, the lasting time of loadings decrease with wave frequencies'increase for same numbers of shock cycles, so the resistances to liquefaction of sand increase when the wave frequencies in the irregular loadings increase.

For the limited number of tests about wave frequency, the study in this paper is only preliminary and there would be many problems to be solved through tests in future.

5 CONCLUSTIONS

On the basis of the limited number of tests reported and approximate theoretical calculation in this paper, the followings are found:

(1).The liquefaction of a sand chiefly depends on the large amplitude pulses in random loadings for shock patterns, and the function by small amplitude pulses is relatively little.

(2).The resistance to liquefaction of a sand changes while the wave order in a random loading changes. For a given irregular loading pattern, the earlier large amplitude pulses appear in the loading pattern, the less the resistance to liquefaction would be because the pore pressures increase faster and the active confining pressures decrease rapider in sand.

(3).The resistances to liquefaction of sand change with the changing of the wave frequencies in a random loading. For a given irregular loading pattern, the resistance to liquefaction increases with increasing of pulse frequency for the acting time by the excitation decreases correspondingly.

REFRENCES

K.I shihara and s.Yasuda. 1975. Sand liquefaction under random earthquake loading condition: 5th world conference on Earthquake Engineering. Rome.

Shen Zhi-gang.1980.3. Dynamic behavier of sand under random loading. World Earthquack Enginering 1980.3.

Toshio Iwosaki.1980. Soil Liquefaction studies in Japan: soil Dynamics and Earthquake Engineering.JANARY 1986.Vo.5.

Wang Wen-shao.Some studies about liquefaction and determining method of saturated sand: Work on shock-resistance and explosion.China.