

THE CURRENT PRACTICE OF  
LIQUEFACTION ANALYSIS IN TAIWAN

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# THE CURRENT PRACTICE OF LIQUEFACTION ANALYSIS IN TAIWAN

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**SYNOPSIS** Taiwan is located in the region with high intensity of seismic activities where numerous severe earthquake disasters have been experienced. Most the important engineering projects which are to be founded on loose sand subsoil, liquefaction potential analysis in response to a design earthquake intensity is usually carried out during the designing stage. This paper reviews the current method adopted in some of these projects. Due to insufficient of testing facilities in Taiwan, a complete study on liquefaction potential has never been performed.

## INTRODUCTION

The island of Taiwan lies on the outskirts of the Asiatic Continent and situates in the middle of the west coast of the circum-Pacific seismic zone (Fig. 1). A high frequency of seismic activities had taken place within and around the island (Fig. 2). As a result, the island had suffered considerable damages from earthquake disasters in the past years. In recent years, heavy industrialization plans and construction projects have been launched by the Government of the Republic of China to speed up the economy growth and the modernization of the nation. To prevent immensive amount of investment from earthquake damages, a seismic analysis was often carried out. For projects which are to be situated on loose sand deposits, the potential of liquefaction due to seismic load was usually evaluated.

There are two major areas in Taiwan, where many heavy industries and important constructions are located, the potential of liquefaction are of great concern. One area is

the southwest coastal region near Kaohsiung City and Tainan. The alluvial deposits in this region are generally of loose silt and sand with high water content. Fig. 3 shows a typical subsoil profile at the site of the China Steel Mill in Kaohsiung county.

The second area of concern is the Taipei Basin where a layer of loose sand exists in shallow depth. Fig. 4 indicates a representative soil profile above the gravel stratum of Taipei Basin. Overlaying the gravel stratum are sand and clay layers in alternative order. The sand layers at shallow depth are normally in loose to medium dense conditions. Owing to the fact that many structures in this area are constructed on shallow foundations, the problem of liquefaction in the sand layer is of particular importance.

Examples of liquefaction potential analyses performed for projects in Taiwan and particularly in Taipei and Kaohsiung areas are illustrated in this report.

#### PROCEDURE FOR LIQUEFACTION ANALYSIS

The procedures being used for evaluating the liquefaction potential of saturated sandy soil may be classified into three categories:

(1) Methods where both the cyclic shear stresses induced within a soil mass and the significant number of stress cycles and their distribution with time are determined by simplified procedures.

(2) Methods where the cyclic stresses induced within a soil mass are determined by means of ground response analyses. This approach was first introduced by Seed and Idriss (1967).

(3) Empirical methods based on comparison of sites where liquefaction has or has not occurred during past earthquakes. The first correlation involving an extensive number of sites was published by Seed and Peacock (1971) and this compilation has formed the most subsequent correlations.

In the first two methods, cyclic loading tests on representative soil samples are required in order to develop the cyclic stresses or significant cyclic strains which would induce liquefaction. However, in Taiwan due to the lack of suitable equipment for executing cyclic loading test the first two methods for determining liquefaction potential of soils have not been used.

An attempt of assembling a shaking table to study the settlement phenomenon of sand during earthquake has been made by Lin & Chiang (1973) at National Cheng-Kung University. Unfortunately, no further study or improvement on the equipment had been continued and the study has never been put into practical uses.

Consequently, in Taiwan the methods used for evaluating liquefaction potential for engineering design purpose were limited to the empirical methods which involve only comparison of the site conditions to the field condition where liquefaction did or did not occur during past earthquakes. The simplified method proposed by Seed & Idriss (1971) which relates the blow count number of a standard penetration test to the potential of liquefaction of a soil has been adopted. Certain significant factors affecting liquefaction analysis, such as intensity and duration of ground shaking, were established for individual project according to their locations. These data were generally obtained from the Central Weather Bureau of Taiwan.

The seismic activity in Taiwan region as recorded by the Central Weather Bureau has been extended back over a period of more than 70 years to 1900. Based on these data, a map of maximum earthquake intensities in Taiwan was sketched by Hsu (1972) and is shown in Fig. 5. The relationships between the seismic intensities scale from 0 to IV adopted by the CWB and other scales are shown in Fig. 6. The map shown in Fig. 5 was compiled on the basis of 70 years observations, and is customarily adopted as a guide in selection of design earthquake magnitude.

#### EXAMPLES

Liquefaction potential analysis performed on two sites are briefly described in the following sections:

Example 1. China American Petrochemical's complex at Lin Yuan, Kaohsiung.

The plant site is located at the southwest coast of Taiwan, between the Kaoping creek and Lin Yuan Canal. The site investigation and analysis were performed by China Technical Consultants, Inc. (CTCI) during 1976.

The mean ground surface elevation of the site is 3.4 meters above the mean sea level and with an average of 2.1 m high dredged sand fill on top. The ground water table is high, ranging from 2 to 3 meters below the existing ground

surface. The subsoil condition as shown in Fig. 8 consists of loose to medium dense fine sand down to a depth of about 20 meters (Fig. 7)

Based on a surveying of seismic data in the project region, a maximum ground surface acceleration of 0.15 g was selected by CTCI for the analysis of liquefaction potential. Liquefaction analysis was carried out by simplified method. The results of analysis are presented in Fig. 8 and 9. The conclusion drawn by the CTCI is that liquefaction is unlikely to happen for the design earthquake. However, with the consideration of significant amount of potential settlement which may be induced by the heavy super-structure loading, compaction of the upper 8 m sandy soil by using vibroflotation was recommended by the CTCI. The improvement work is underway at present.

Example 2. Di-Hua Sewage Treatment Plant in Taipei City.

The plant is situated on the deltaic deposit of Keelung and Tamshui rivers. The site investigation program was carried out by China Engineering Consultants in 1975.

Fig. 10 shows an average subsoil condition of the site. Loose to medium dense fine sands were found at a depth of 5 to 25 m below the ground surface. Soil particles passing #200 standard sieve were generally less than 20%. Some silty clay inclusions were also present in this layer. The ground water table fluctuated between 1 and 2 m below the ground level where the ground surface elevation is only approximately 2.8 to 1 m above mean sea level.

In this project, the Shake II computer program has been adopted in association with earthquake time history recorded at the Pasadena (1952) and the State Building Park (1957) earthquake stations. The ground response analyses conducted on this site by using Shake II program were made to assist in comprehending the subsoil behavior in response to earthquake and to determine the maximum ground surface acceleration (Fig. 11). The liquefaction potential was then determined by comparing the shear stresses induced by the design earthquake with that required to cause liquefaction, both of which were determined by means of Seed and Idriss simplified method.

Fig. 11 and 12 compare the shear stresses that would be induced in an earthquake for the soils at different depth and the cyclic stresses that would cause liquefaction for the soils. It was concluded that liquefaction is likely to happen at the site when a maximum ground surface acceleration

exceeds 0.15 g. Therefore, methods of soil improvement were recommended. Thirty-five to forty-five cm diameter compaction piles with 12 to 25 m in length were installed at a spacing of 2 m c-c. The compaction work has recently been completed.

#### CONCLUSION AND RECOMMENDATION

The main objective of this report is to present the general practice of liquefaction potential analyses in Taiwan. Due to the insufficiency of testing facilities and the unawareness of the importance of liquefaction potential, a rather slow development in the practice of liquefaction potential prediction is resulted. It must be recognized that a comprehensive study may seem to be costly during the initial investigation stage, but it may help to cut down the total construction cost and/or will guarantee the safety of the design. As far as the practicing of liquefaction analysis in Taiwan is concerned, there remains much works to be done.

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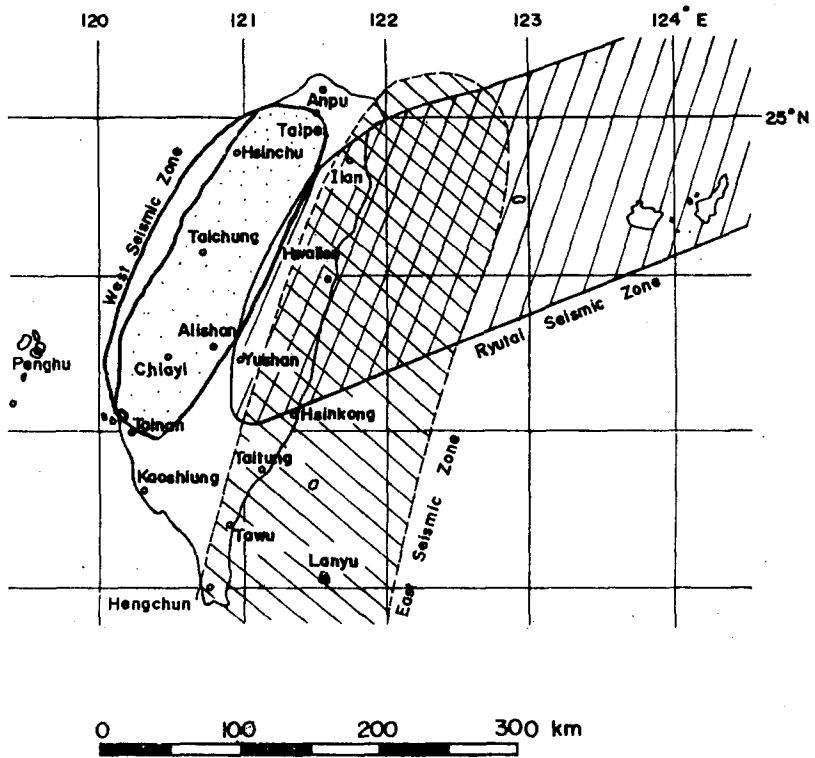


FIG. 1 Seismic Zones in Taiwan Region  
(after Hsu)

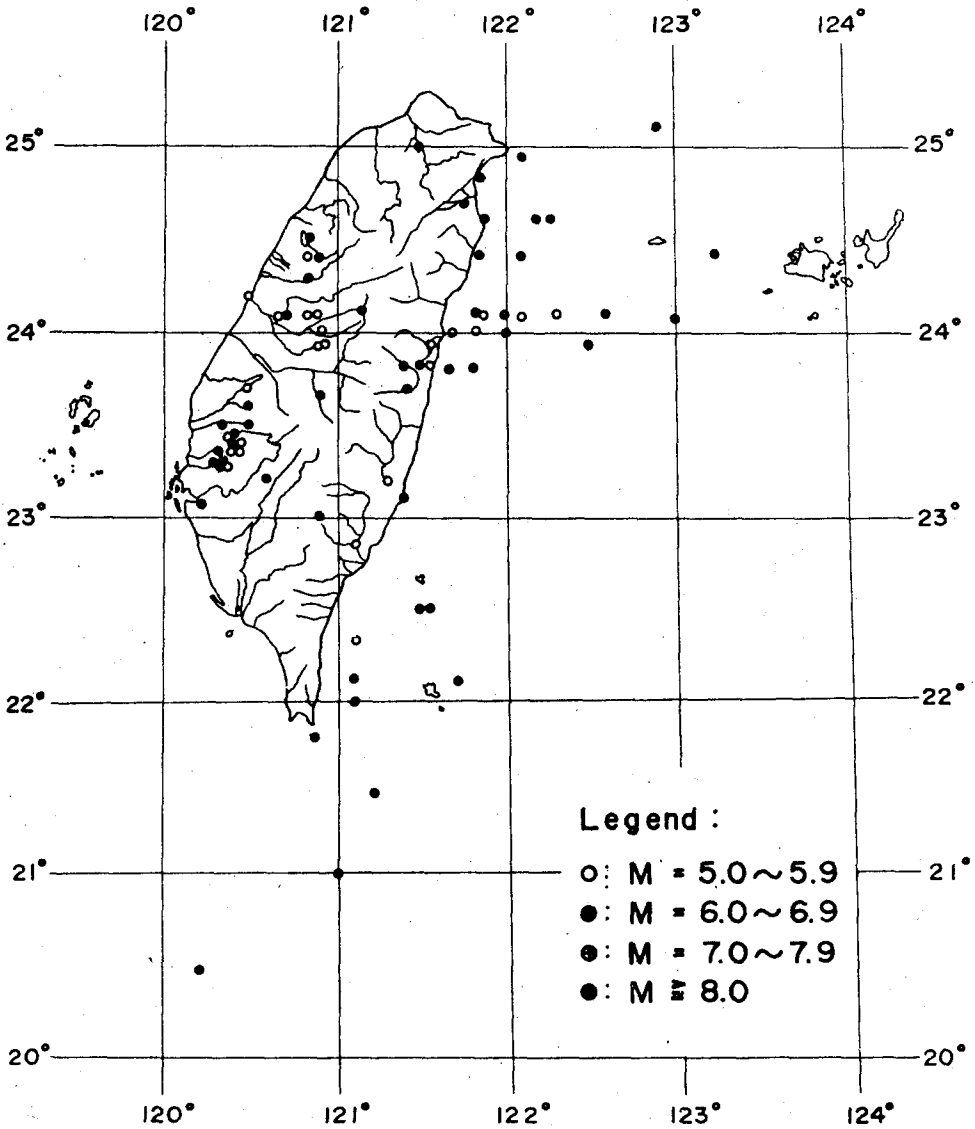


Fig.2 Epicenter's Distribution of Disastrous Earthquakes  
(after Hsu) (1900 - 1970)

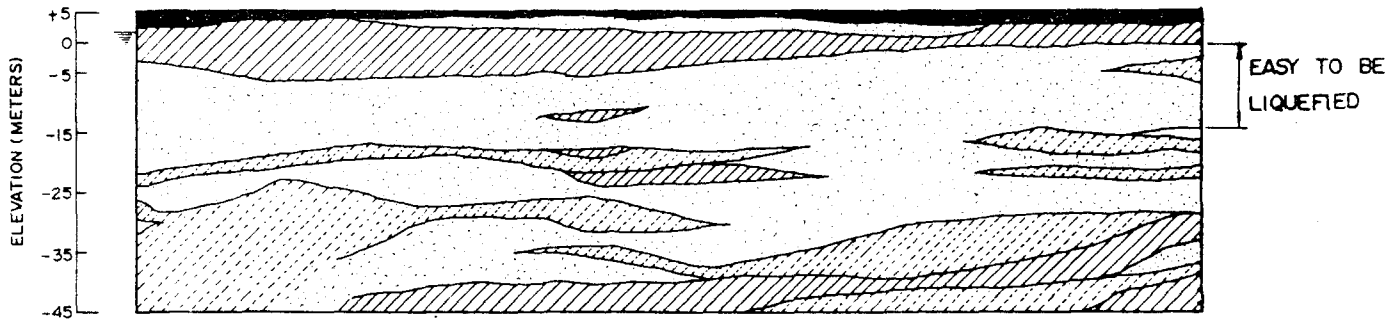


FIG. 3 TYPICAL SOIL PROFILE AT CHINA STEEL MILL, KAOHSIUNG

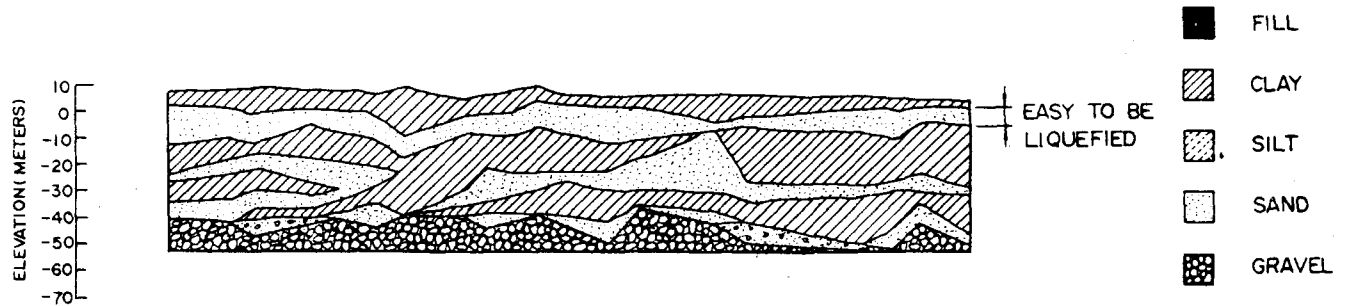


FIG. 4 TYPICAL SUBSOIL PROFILE AT TAIPEI BASIN

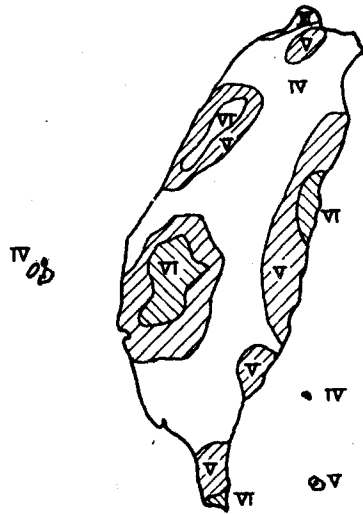


FIG.5 Map of Maximum Earthquake Intensities in Taiwan

CWB I S	JMA I S	MM I S	M.S.K I S	RATIO TO GRAVITY	ACCELERATION (GAL)
			XI XII		1000
		XII	800	0.7G	
		XI		0.8G	
		X	X	0.5G	
VI	400	432	400	0.4G	500
	VI	IX	IX	0.3G	400
250	250		202	0.2G	300
			200		200
V	V	VIII	VIII		
			94	0.1G	100
80	80	VII	VII		
			50		50
IV	IV	44	VI		40
			25		30
25	25	VI	25		
			21		20
III	III	V	V		
			12	0.01G	10
8	8	10	IV		
			5		5
II	II	5	5		4
			III		3
2.5	2.5	III	III		
			2.1		2
I	I	2.1	II		
			1.0	0.001G	1
0.8	0.8	1.0	II		
			0.8		
0	0	0.8	I		
			I		

Fig.6 Comparison of Various Seismic Scales

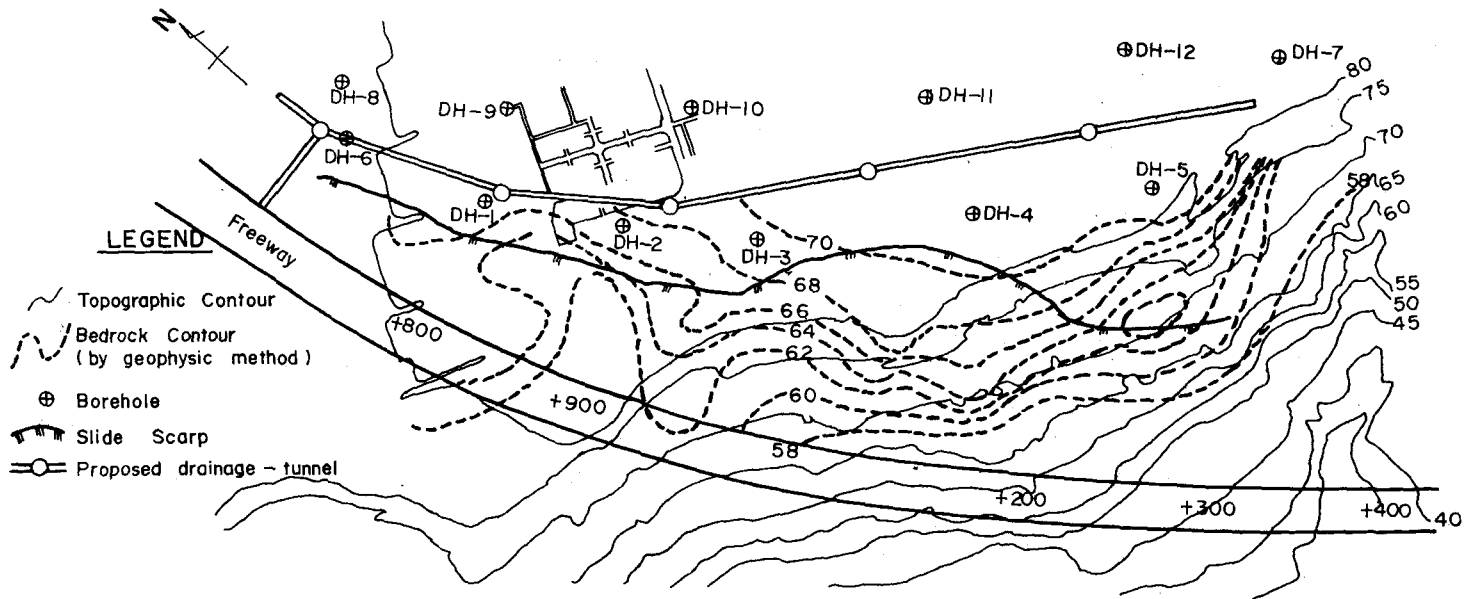


FIG. 5 SITE PLAN OF DRAINAGE TUNNEL AT 62 K OF S-N FREEWAY

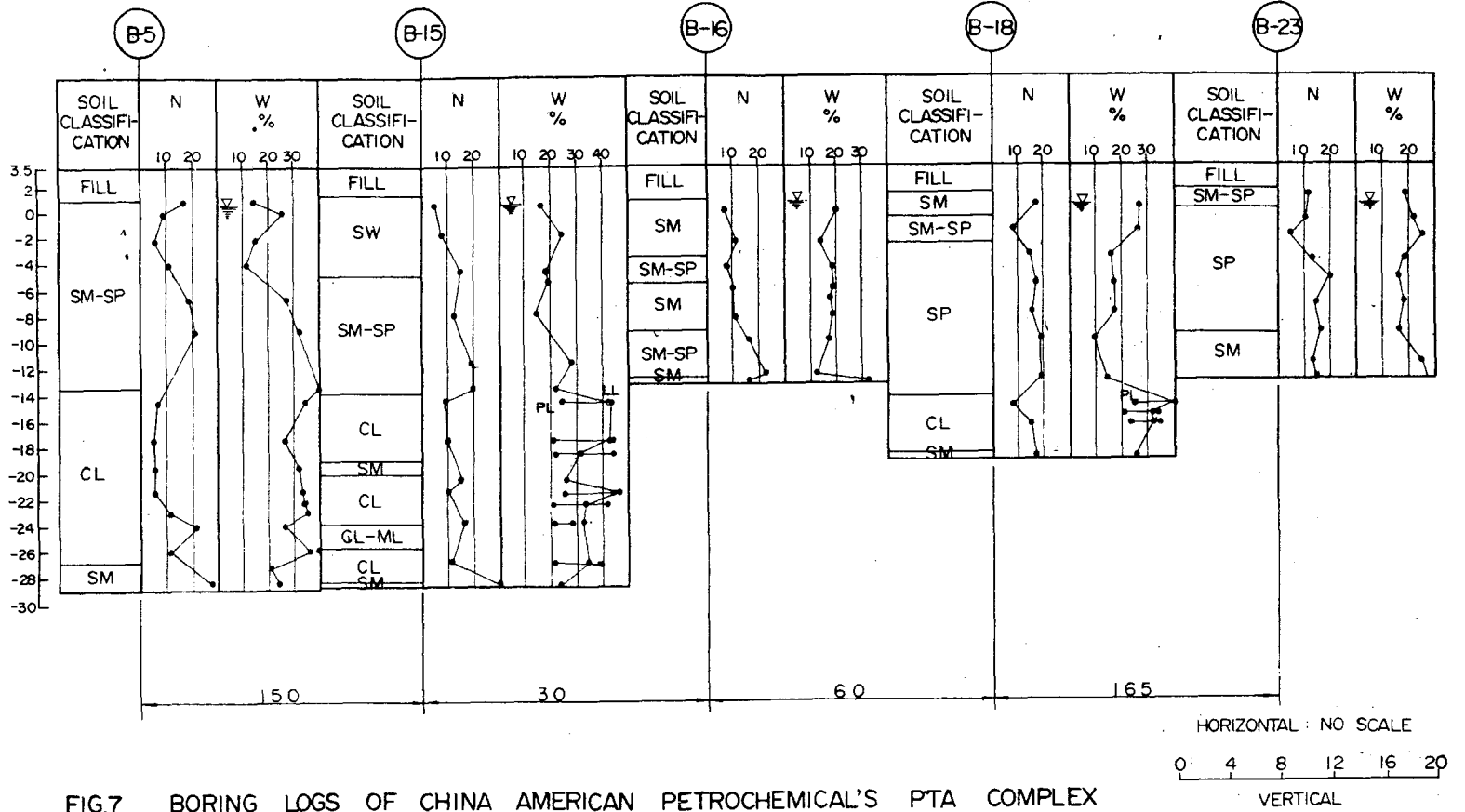


FIG.7 BORING LOGS OF CHINA AMERICAN PETROCHEMICAL'S PTA COMPLEX

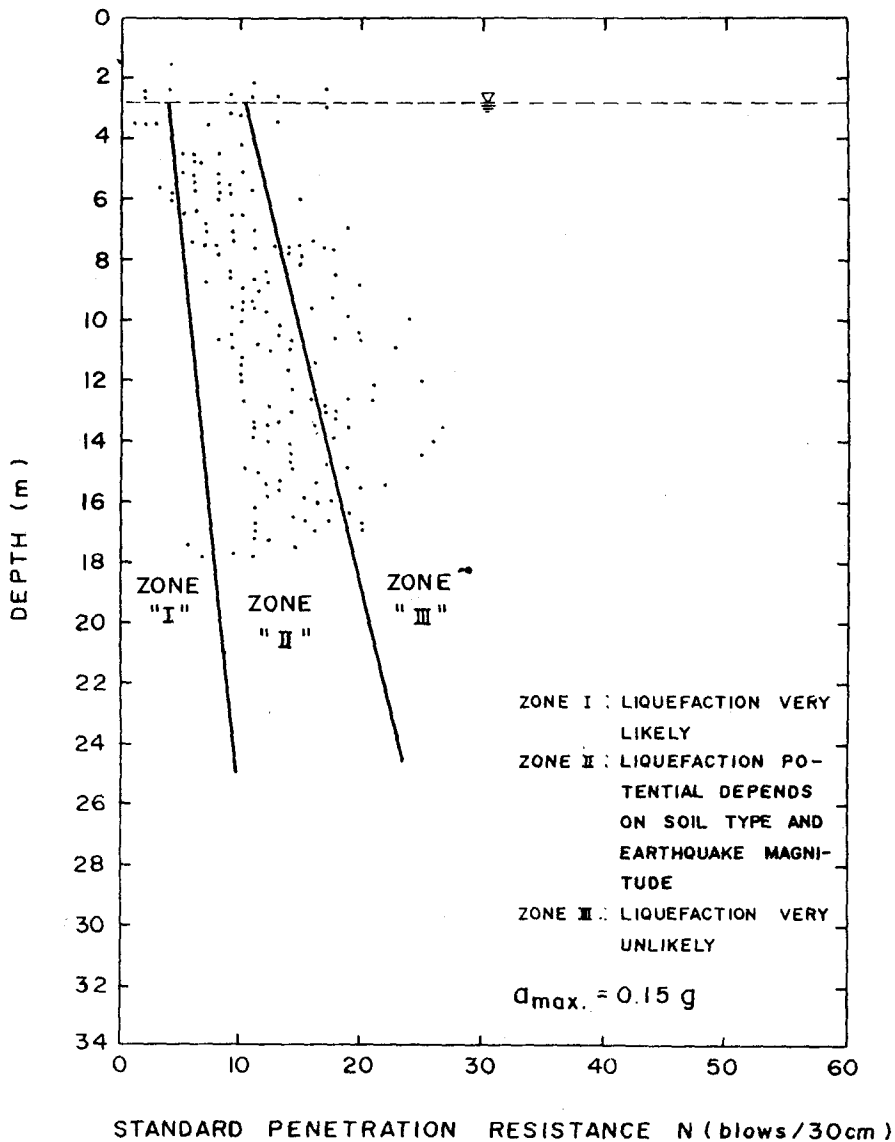


FIG.8 LIQUEFACTION POTENTIAL EVALUATION  
CHINA AMERICAN PETROCHEMICAL'S PTA COMPLEX

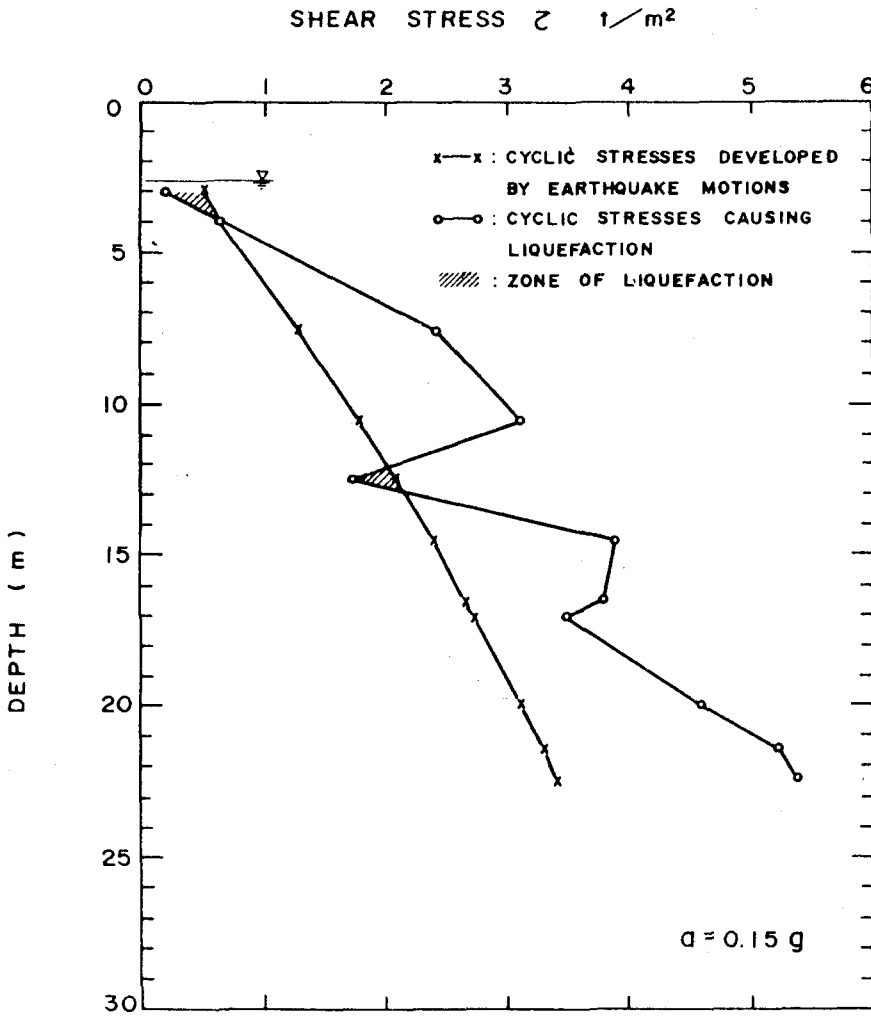


FIG.9 LIQUEFACTION POTENTIAL EVALUATION  
CHINA AMERICAN PETROCHEMICAL'S PTA  
COMPLEX

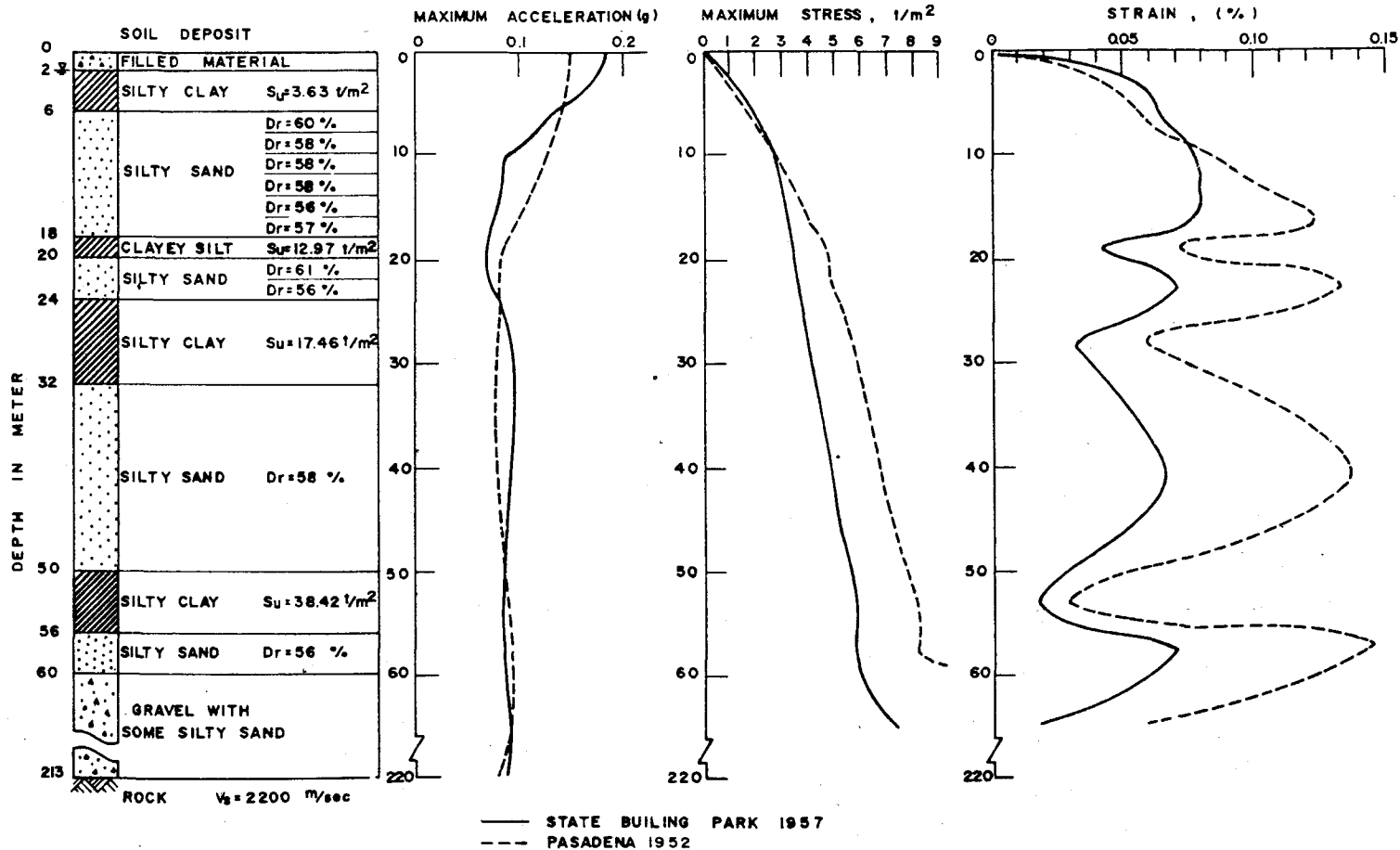


FIG.10 GROUND RESPONSE ANALYSIS  
 DIHUA SEWAGE TREATMENT PLANT SITE

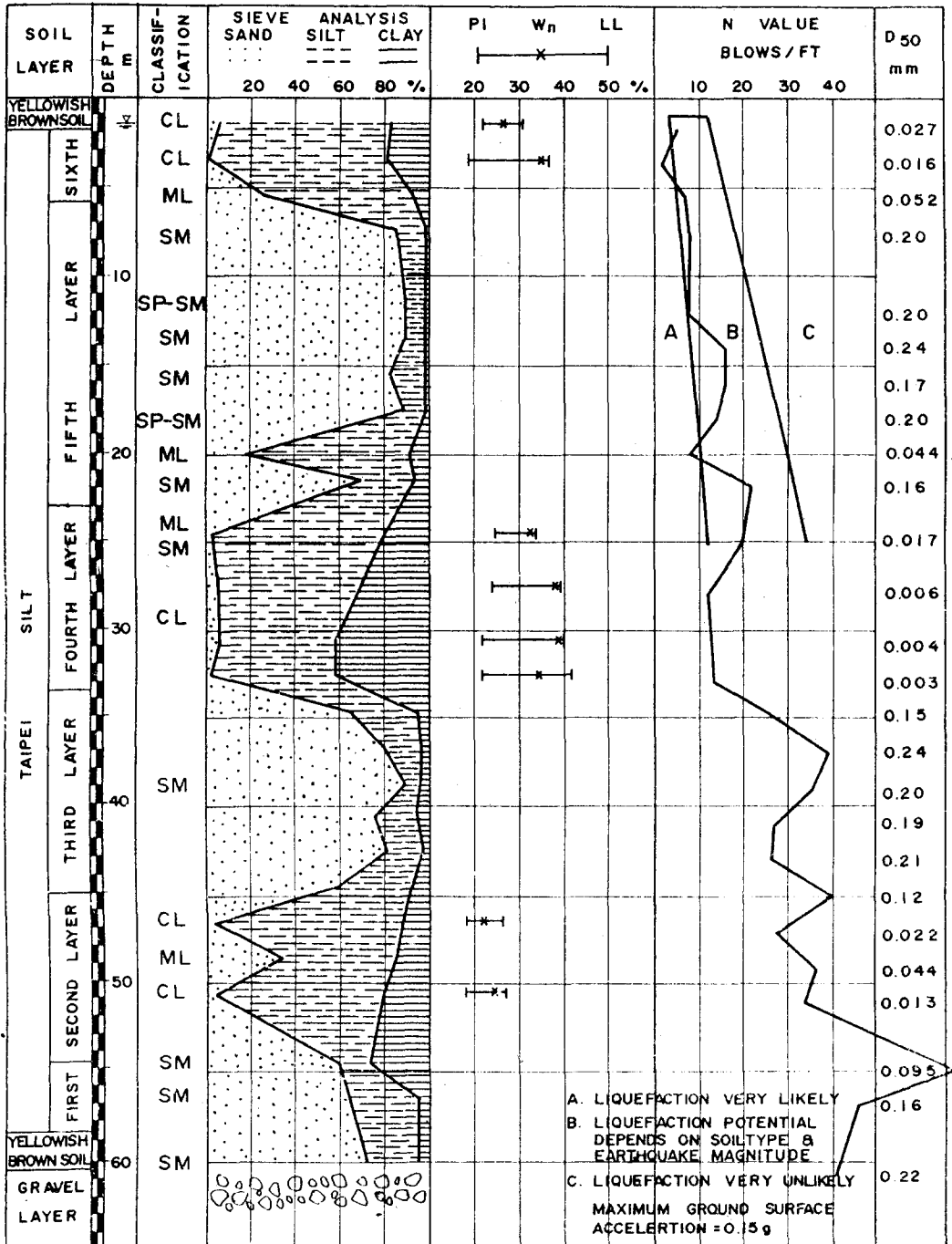


FIG.11 LIQUEFACTION POTENTIAL EVALUATED BY N-VALUE  
DI-HUA SEWAGE TREATMENT PLANT

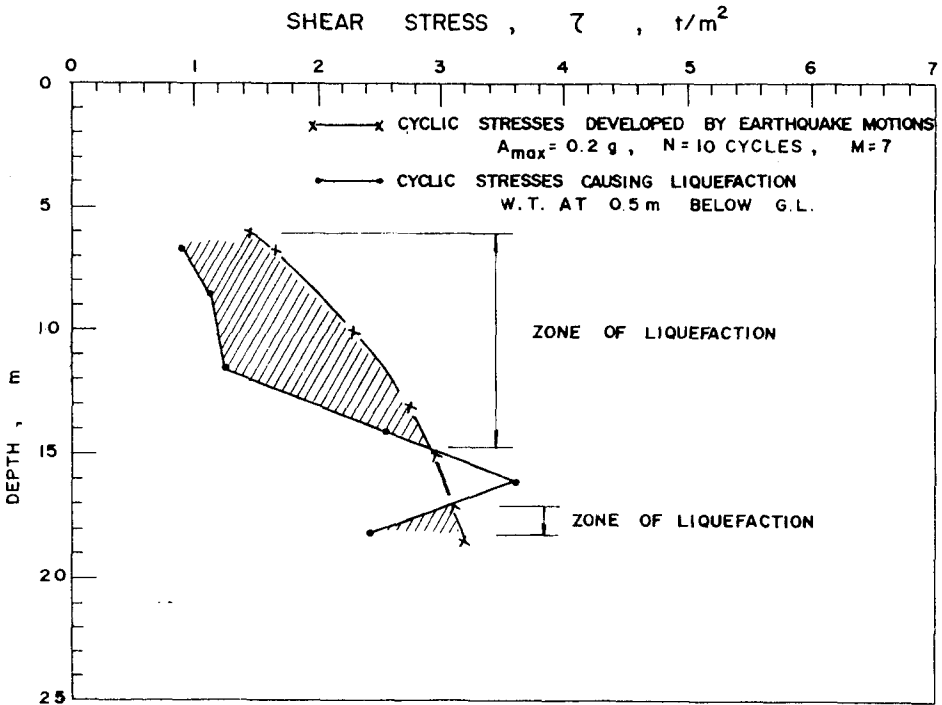
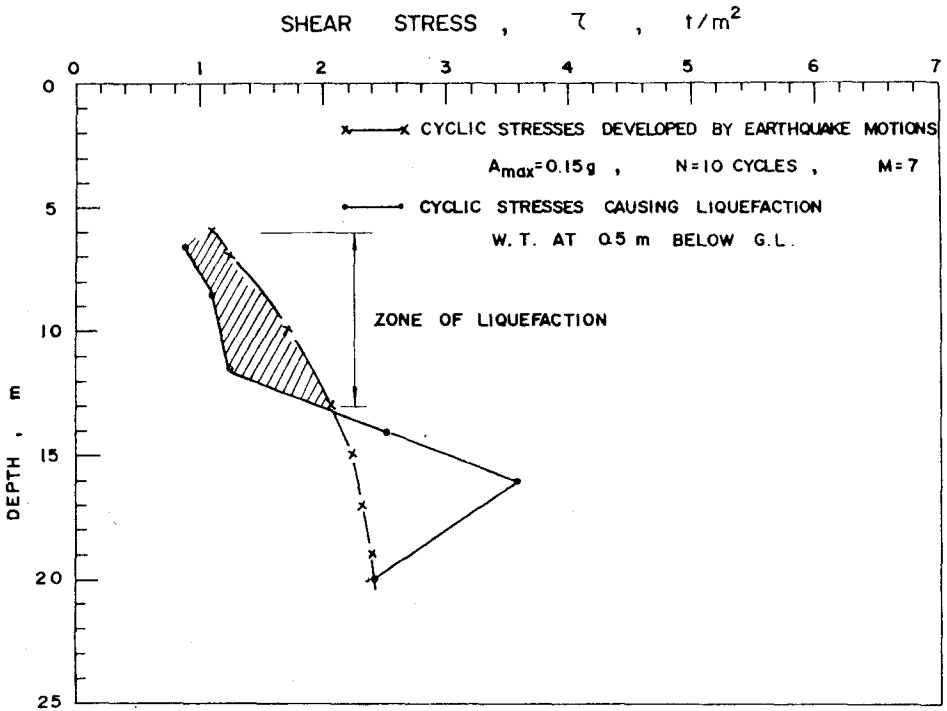


FIG 12 LIQUEFACTION POTENTIAL AT BOREHOLE T7  
DI-HUA SEWAGE TREATMENT PLANT