

EFFECT OF DYNAMIC ANALYSIS METHODS ON RESPONSE OF PILES IN LIQUEFIABLE SANDY GROUNDS

Takahashi, C., FORUM8 Co., Ltd., Japan
Cai, F., Ugai, K., Gunma University, Japan

ABSTRACT: *This paper reports the results of equivalent elastic analysis, total stress nonlinear analysis, and effective stress analysis of seismic response of a ground and a piled pier under the Hyogoken-Nanbu Earthquake. Numerical results of these dynamic analyses were compared with each other. The calculated response of the total stress analyses and the equivalent elastic analyses was smaller than that of the effective stress analysis. Therefore, when applying the seismic deformation method, and when applying two-dimensional dynamic finite element analysis, the total stress methods will give the result in the dangerous side for strong earthquake such as the Hyogoken-Nanbu Earthquake.*

KEYWORDS: *liquefaction; dynamic effective stress analysis ; piles; seismic design; FEM*

1. INTRODUCTION

In the Hyogoken-Nanbu Earthquake of 1995, many serious damages induced by liquefaction of filled ground were reported. After that, many seismic design specifications have been modified in view of the disaster examples in Japan. Such seismic design specifications have adopted one-dimensional dynamic response analysis or two-dimensional dynamic FEM analysis as the liquefaction evaluation procedure. For one-dimensional dynamic response analysis, equivalent linear elastic analysis and total stress nonlinear analysis are widely used though effective stress analysis is more expected. Some seismic design specifications limit that the equivalent elastic analysis and total stress nonlinear analysis only can be used for level-one earthquake, and the effective stress analysis should be used for level-two earthquake.

Dynamic finite element analysis based on effective stress has been widely used in the research recently, and also it has gradually used in the actual seismic design, especially, in the design of embankment. However, there are few applications in the design of piles because it is of difficulties to evaluate the dynamic interaction of structure, foundation, and ground. Therefore, the seismic deformation method is often used, where one-dimensional dynamic response analysis is conducted to calculate the seismic deformation of the ground. Moreover, the dynamic analysis based on total stress is also still used well in liquefaction evaluation because of its simplicity to identify parameters of the used constitutive models of soil.

This paper performed one-dimensional dynamic response analysis of the ground of Kobe Port Island, where vertical array data was recorded in Hyogoken-Nanbu Earthquake. We compared the difference among the results of above-mentioned three dynamic response analyses. Additionally, two-dimensional dynamic finite element analysis of the pier based on both effective stress and total stress was performed to indicate the influences of these analysis methods on the bending moment of piles. All numerical analyses except the equivalent elastic analysis in this paper were conducted using a software named UWLC which can do initial stress analysis, one-dimensional and two-dimensional dynamic finite element analysis based on total and effective stress.

2. DYNAMIC FINITE ELEMENT ANALYSIS

The analysis procedure in UWLC is shown in Figure 1. All the analyses shown in Figure 1 can be finished by UWLC [1].

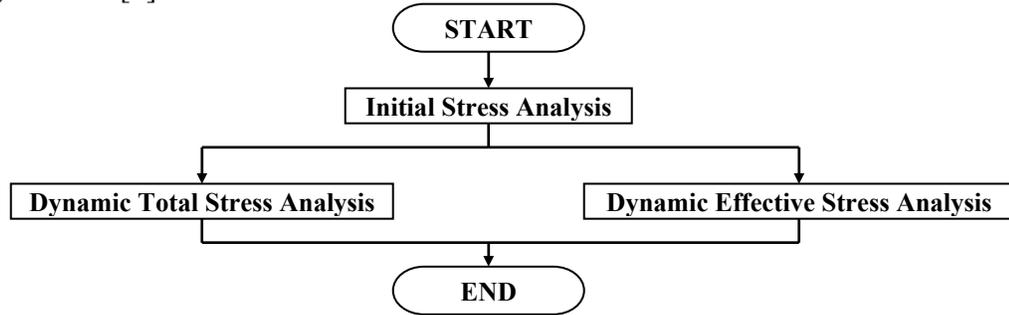


Figure 1. The flow of the analysis in UWLC

In UWLC, eight constitutive models, listed below, are available. All these constitutive models are applicable to the total stress analyses; the constitutive model (6) is recommended for liquefaction analysis. UWLC can implement fully coupled dynamic finite element analysis; thus it can consider the dissipation of excess pore water pressure during earthquake. It can also implement total stress nonlinear analysis. In UWLC, one can freely select any constitutive model coded in UWLC, and freely select whether the effective stress analysis or the total stress analysis used for any material in an analysis.

- (1) Elastic model
- (2) Laminating elastic model
- (3) Elastic perfectly plastic model (Mohr-Coulomb criteria for yield function and Drucker-Prager criteria for plastic potential) (MC-DP)
- (4) Modified Ramberg-Osgood model (RO)
- (5) Modified Hardin-Drnevich model (HD)
- (6) Pastor-Zienkiewicz model for sand (PZ-sand)
- (7) Pastor-Zienkiewicz model for clay (PZ-Clay)
- (8) Ugai-Wakai model (UW)

3. ONE-DIMENSIONAL DYNAMIC ANALYSIS

3.1. The conditions of examination

In this paper, the strong motion record of Kobe Port Island was back-analyzed using the following three method: (1) equivalent elastic analysis, (2) total stress nonlinear analysis, and (3) effective stress analysis. The results of those analyses were compared. In the equivalent elastic analysis, the model proposed by Public Works Research Institute (PWRI) in Japan and HD model were applied to consider the curves of shear strain versus shear modulus and damping ratio [2]. In the total stress nonlinear analysis, HD model was applied to all soil layers. In effective stress analysis, PZ-Sand model was applied to man-made fill layer and layers of gravelly sand and silt, and HD model was applied to silty clay and diluvium sand layers.

The 2E wave of the base in Kobe Port Island was used as an input motion. The observed strong motion record in the Hyogoken-Nanbu earthquake is returned to the base at GL-83m to obtain the 2E wave.

The parameters of the constitutive model in effective stress analysis were adjusted to reproduce the observed record.

The profile of the soil layers in Kobe Port Island is shown in Table 1 [3]. And the input motion is shown in Figure 2.

Table 1. Soil layer and material properties at Kobe Port Island

Soil type	Depth (GL m)	Average N-value	Unit weight (kN/m ³)	Vp (m/s)	Vs (m/s)
Man-made fill	0.0 to -5.0	5.2	17.64	330	170
Man-made fill	-5.0 to -12.6	6.5	17.64	780	210
Man-made fill	-12.6 to -16.8	6.5	17.64	1480	210
Man-made fill	-16.8 to -19.0	6.5	17.64	1180	210
Silty clay (Ma13)	-19.0 to -27.0	3.5	16.17	1180	180
Layers of gravelly sand and silt	-27.0 to -33.0	13.5	17.15	1330	245
	-33.0 to -50.0	36.5	18.13	1530	305
	-50.0 to -61.0	61.9	18.13	1610	350
Silty clay (Ma12)	-61.0 to -79.0	11.7	16.66	1610	303
Diluvium sand	-79.0 to -83.0	68.0	23.52	2000	320
Base	-83.0	—	—	—	—

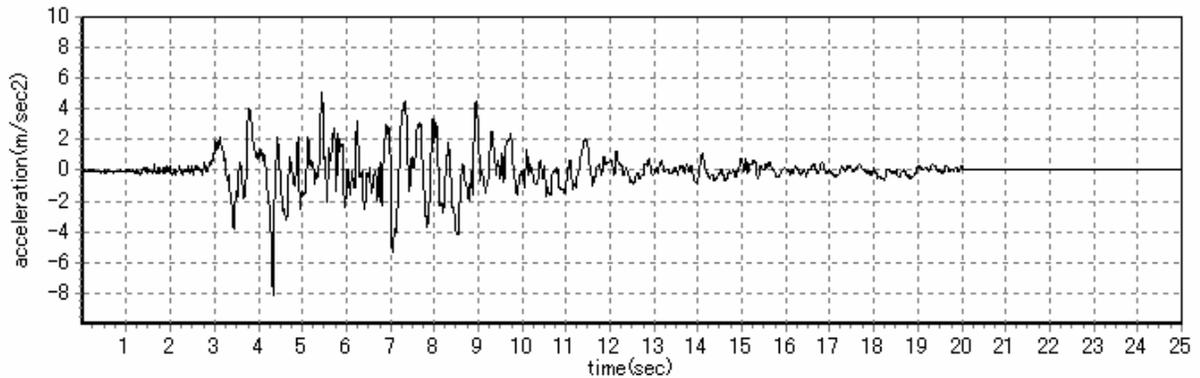


Figure 2. Base acceleration of Kobe Port Island (2E)

3.1. The results of analyses

Table 2 shows the maximum displacement and the maximum acceleration on the ground surface of each dynamic response analysis. Figure 3 shows the profiles of maximum displacement and maximum acceleration.

Table 2. The maximum displacement and the maximum acceleration on the ground surface

Case	Maximum displacement (cm)	Maximum acceleration (gal)
UWLC (PZ+HD)	38	335
UWLC (HD)	34	274
The equivalent elastic (PWRI)	24	378
The equivalent elastic (HD)	26	244
Observed	40	341

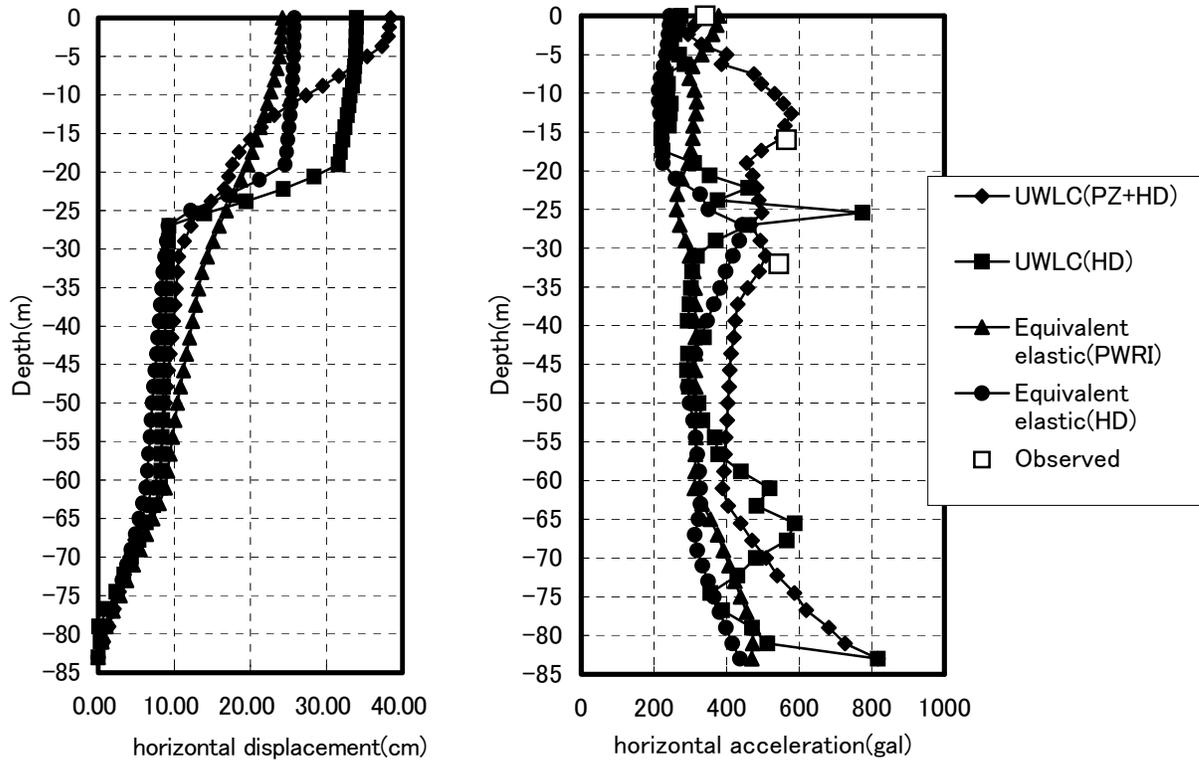


Figure 3. Comparison of each analysis method in one-dimensional dynamic response analysis

The results of these analyses show that

- (1) The equivalent elastic analysis gave a smaller displacement than the total stress nonlinear analysis and effective stress analysis. The maximum displacement on ground surface of the equivalent elastic analysis was only about 65% that of the effective stress analysis.
- (2) The profiles of the maximum displacement of UWLC (HD) and the equivalent elastic (HD) were similar to one another; however, the maximum displacement of UWLC (HD) was 40% smaller than that of the equivalent elastic (HD).
- (3) The difference of maximum acceleration on ground surface among the used analysis methods was significantly smaller than that of the maximum displacement on ground surface.
- (4) The displacement and acceleration of effective stress analysis was consistent well with the observed record.

4. DYNAMIC FEM ANALYSIS OF THE PIER ON THE PILE FOUNDATION

4.1. The conditions of examination

The pier used in this paper is shown in Figure 4. This bridge pier was assumed to be established in the ground of Kobe Port Island. The total stress nonlinear analysis and the effective stress finite element analysis were performed to calculate its dynamic response for the strong motion shown in Figure 2. The parameters of the ground were the same as those of the one-dimensional back analyses reported in Section 3.

The dead weight of 6000kN was assigned to this pier from superstructure. The pier and the superstructure were modeled to multiple points system [4].

The piles were cast-in-place concrete piles, 32.0m long, and inserted 2.0m below into the layer of gravelly sand and silt of which upper level is GL 33.0m. And beam elements were used to model the pier and piles.

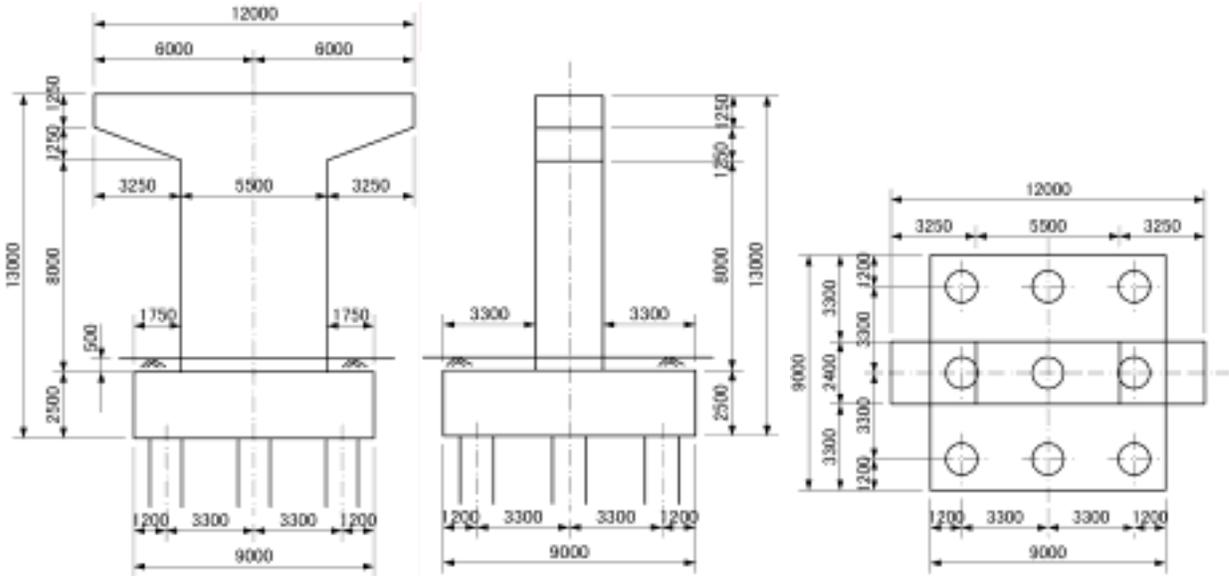


Figure 4. The model pier

The sectional constants of the pier and piles are shown in Table 3 [4]. In this paper, the elastic model was applied to the piles and the pier.

Table 3. The sectional constants of the pier and piles

Section	A (m ²)	I (m ⁴)	E (kN/m ²)
Pier	13.20	6.34	2.35*10 ⁷
Piles (three piles)	3.39	0.31	2.50*10 ⁷

4.1. Result of analyses

The histories of bending moment at the head of piles, at the base of the pier and at the middle height of the pier are shown in Figure 5, Figure 6, and Figure 7. Here, the response values of the piles are shown for three piles. The results show that

- (1) For the bending moment and acceleration of the pier, the results of the total stress analysis were 5% to 10% smaller than those of the effective stress analysis.
- (2) The direction of the maximum bending moment and acceleration of the total stress analysis were opposite to those of the effective stress analysis.
- (3) The effective stress analysis indicates that the response of piles became smaller after liquefaction. On the other hand, this phenomenon did not show in the total stress analysis.
- (4) In comparison of the total stress analysis and the effective stress analysis, although the difference of phase was small before liquefaction, it appeared and became large after liquefaction.

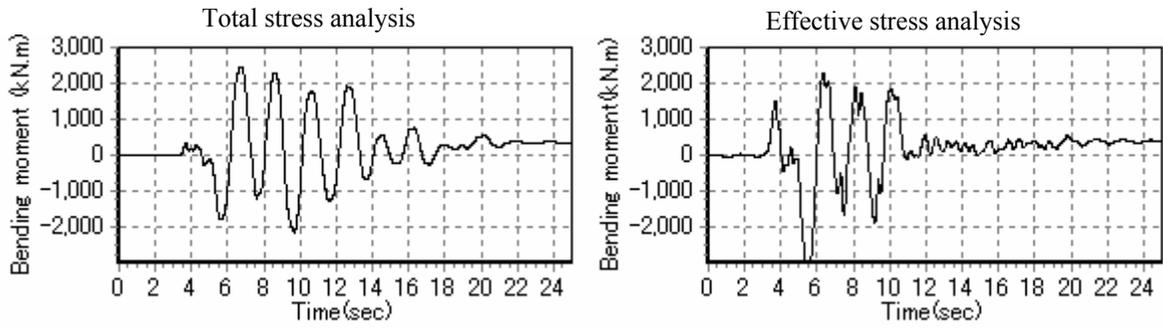


Figure 5. The bending moment at the head of piles

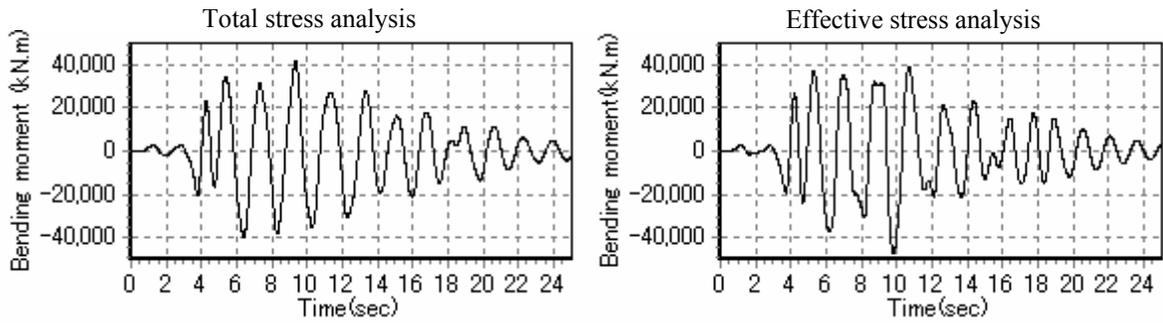


Figure 6. The bending moment at the base of the pier

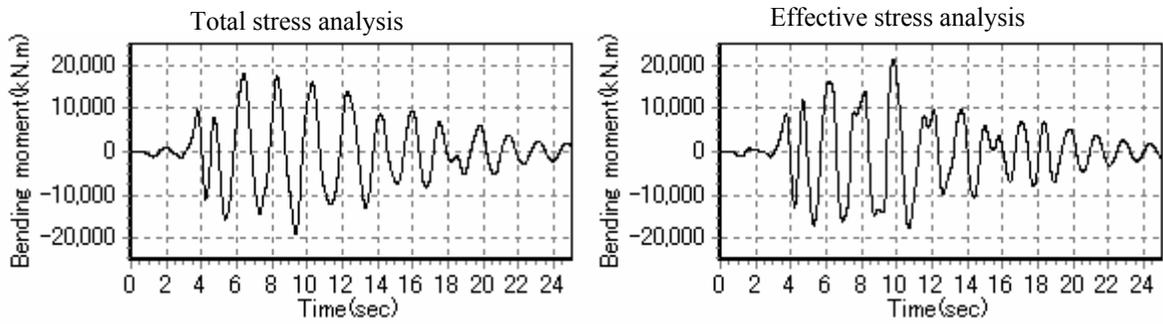


Figure 7. The bending moment at the middle height of the pier

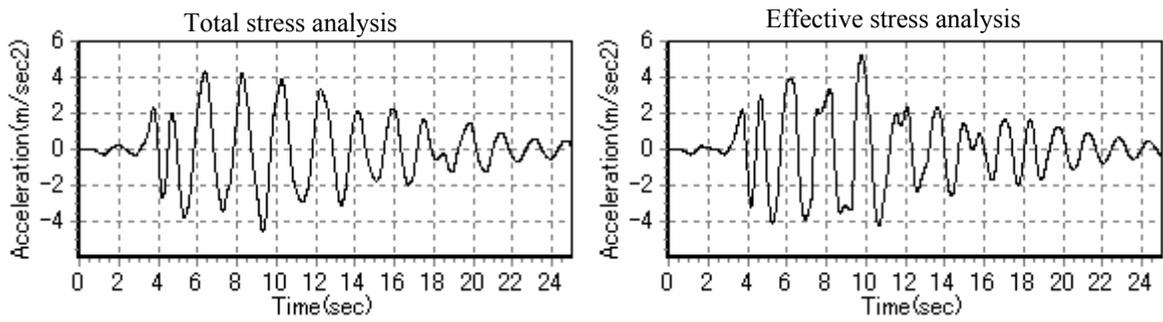


Figure 8. The acceleration at superstructure of the pier

5. CONCLUSIONS

Numerical results reported in this paper indicate that the total stress analysis cannot consider sufficiently influence of liquefaction on the ground and pile response.

According to the results of one-dimensional dynamic response analyses and two-dimensional dynamic finite element analyses, generally, the calculated response of the total stress analyses and the equivalent elastic analyses was smaller than that of the effective stress analysis. Therefore, when applying the seismic deformation method, and when applying two-dimension dynamic finite element analysis, the total stress methods will give the result in the dangerous side during the liquefaction for level-two earthquake. The examination of various level of earthquake motion and various structure and ground should be performed further.

REFERENCES

1. FORUM8, Co.,Ltd, *The theoretical manual for UWLC user*, FORUM8 Co.,Ltd, Tokyo, 2004.
2. Yoshida, N., and Suetomi, I., *DYNEQ: a computer program for dynamic response analysis of level ground by equivalent linear method, Version 3.23*, 2003, pp. 12-20.
3. Zienkiewicz, O.C., Chan, A.H.C., Pasotr, M., Schlefler, B.A. and Shiomi, T., *Computational geomechanics with special reference to earthquake engineering*, John Wiley & Sons, Inc., New York, 1999, pp. 253-268.
4. Department of Civil Design, Kajima Corporation, *Seismic design - Performance-based design*, Kajima Institute Publishing Co., LTD., Tokyo, 2003, pp. 82-88.