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Study on Large Diameter Steel-cased Piles Socketed in Weathered and Fresh Rocks

풍화암과 연암에 근입된 대구경 말뚝의 축하중지지 거동에 관한 연구

Nam, Moon-Seok[1] 남 문 석
Lee, Min-Hee[2] 이 민 희
Choi, Yong-Kyu[3] 최 용 규

요 지

광안대교에 설치된 두개의 대구경 말뚝(TS-1과 TS-2)에 대하여 최대 2000톤의 하중을 재하하여 정재하시험을 수행하였다. 시험 말뚝 TS-1의 경우는 연암에 근입되었고 시험 말뚝 TS-2의 경우는 풍화암에 근입되었다. 재하시험 결과에 의하면, 지지층과 상관없이 시험말뚝 TS-1과 TS-2 양쪽 경우다 대부분의 하중이 풍화암에 의해 지지되었다. 추가적으로 펜타곤3D와 ROCKET 프로그램으로 수치해석을 수행하였다. 본 연구에 의하면 풍화암이 깊게 발달되어 말뚝 시공상 어려움이 있을 경우, 풍화암도 대안의 지지층으로 고려되어질 수 있다.

Abstract

Two large diameter steel cased piles (TS-1 and TS-2) were installed and load-tested with the maximum load of 2000 ton at Kwang-An grand bridge. One of the test piles (TS-1) was socketed into the fresh rock and the other test pile (TS-2) was socketed into the weathered rock. Most loads were carried by the weathered rock layer at the maximum applied load for the test piles. In addition, numerical studies were performed using PENTAGON 3D and ROCKET. Based on this study, the weathered rock layer provided sufficient side resistances and possibility of an alternative embedded layer if weathered rocks are deeply layered over fresh rock, which caused difficulties and cost in construction.

Keywords : Fresh rock, Large diameter steel cased piles, Rock socket, Weathered rock

1. Introduction

Usages of large diameter piles with socketed in rock are being increased due to their ability for supporting large superstructures. The selected type of foundation for Kwang-An grand bridge was also a large diameter rock socketed pile. The geological formation of Kwang-An grand bridge has wide range of weathered rock over-layered fresh rock layers. The original design concept of the large diameter rock socketed pile was socketed and embedded on the fresh rock. However, the design was modified to socket and embed on the weathered rock due to difficulties of construction penetrating through deep weathered rock layer. In order to

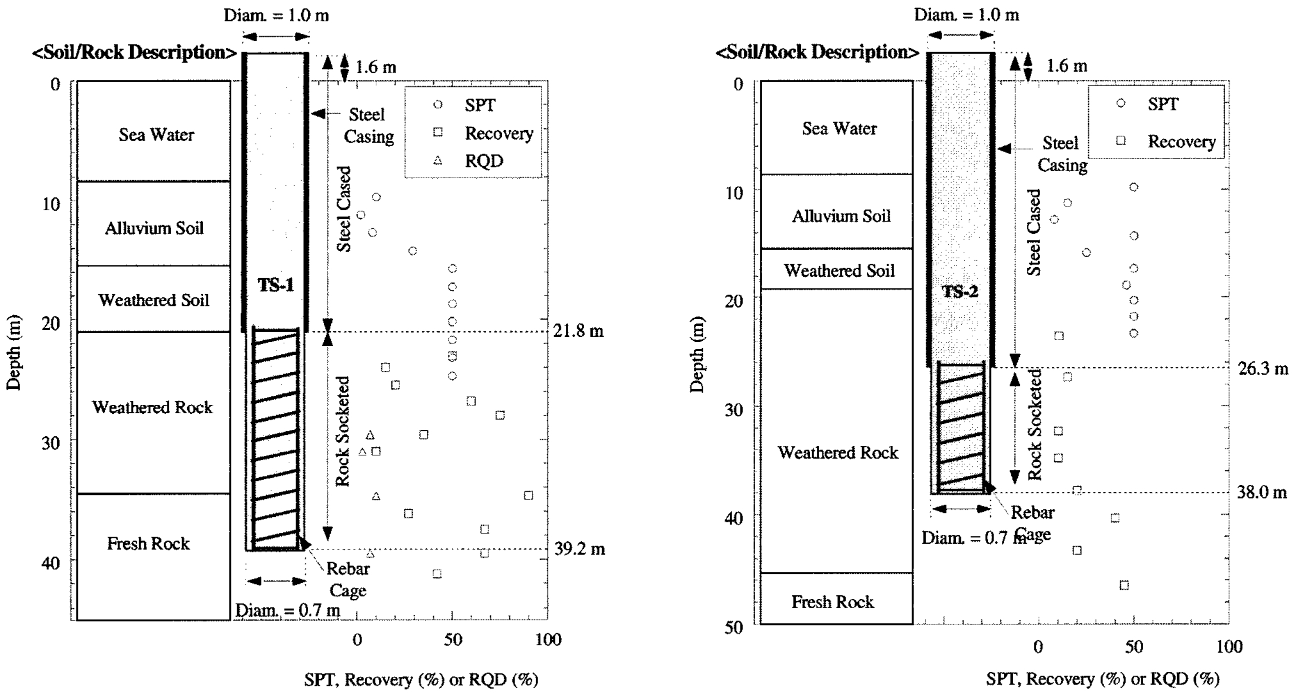
1 Post Doctor Fellow, Research Dept. of Geotechnical Engrg., Highway & Transportation Technology Institute, Korea Highway Corporation, Korea
2 Researcher, Dept. of Civil & Environmental Engrg., Kyung Sung Univ., Busan, Korea
3 Prof., Dept. of Civil & Environmental Engrg., Kyung Sung Univ., Busan, Korea

verify the axial behavior of rock socketed large diameter piles embedded into the weathered and fresh rocks at Kwang-An grand bridge, small scaled test piles were constructed. The objectives of this study were to investigate the axial behavior of piles socketed into weathered and fresh rocks.

2. Geological Formation and Test Piles

In order to verify that steel cased large diameter piles socketed into the weathered rocks having sufficient resistances, two test piles were installed at Kwang-An grand bridge. One of the test piles (TS-1) was socketed into the fresh rock and the other test pile (TS-2) was socketed into the weathered rock. The geological formation and engineering properties for each test pile are shown in Figure 1. For soil and rock layer description of TS-1, alluvium soils of 7.5 m (SM = 6.0 m and GM = 1.5 m) were layered over weathered soils of 5.5 m. Weathered rocks of 13 m were layered between weathered soils and fresh rock (Lee, 2002). For TS-2, alluvium soils of 7.3 m (SM) were layered over weathered soils of 3.7 m. Weathered rocks of 26.2 m were layered between weathered soils and fresh rock (Jeong, 2000).

The test pile (TS-1) with diameter of 1.0 m (including a steel casing having the length of 23.3 m) was constructed in soil layers as steel-cased piles using a RCD (Reverse Circulation Drilling) machine, and a rock socket with the diameter of 0.7 m and length of 17.5 m was constructed in fresh rocks. However, TS-2 with 1 m diameter (including a steel casing having the length of 27.3 m) was constructed in soil and weathered rock layers as steel-cased piles using the RCD machine, and a rock socket with a diameter of 0.7 m and length of 12.3 m was constructed in weathered rocks due to high cost and difficulties of construction. Steel cages were inserted



(a) TS-1 (b) TS-2

Fig. 1. Geological formation and test piles

Table 1. Summary of test piles

Test Pile	Tipped Layer	Steel Casing			Rock Socket		Total Length
		Diameter	Length	Thickness	Diameter	Length	
TS-1	Fresh Rock	1.0 m	23.4 m	18.0 mm	0.7 m	17.4 m	40.8 m
TS-2	Weathered Rock	1.0 m	27.9 m	18.0 mm	0.7 m	11.7 m	39.6 m

only in the rock sockets. Detailed information for TS-1 and TS-2 are summarized in Table 1 and Figure 1.

3. Instrumentations

In order to measure axial loads on each component (steel casing and concrete) of the test piles, several types of gages [electric resistance type gages (ER), deformable bars having full-bridged networking with electric resistance type gages (DB) and vibrating wire gages (VW)] were instrumented on the test piles. For the steel casing, ER with a full bridge networking and VW were installed at every 90° position on its surface. For the concrete and the rebar cage, DB and VW were installed at every 90° position. The details of instrumentation are shown in Figure 2.

4. Load Test

In this study, conventional static load tests using reaction piles were performed according to ASTM D1143-81-cyclic loading. The plan of load test is summarized in Table 2.

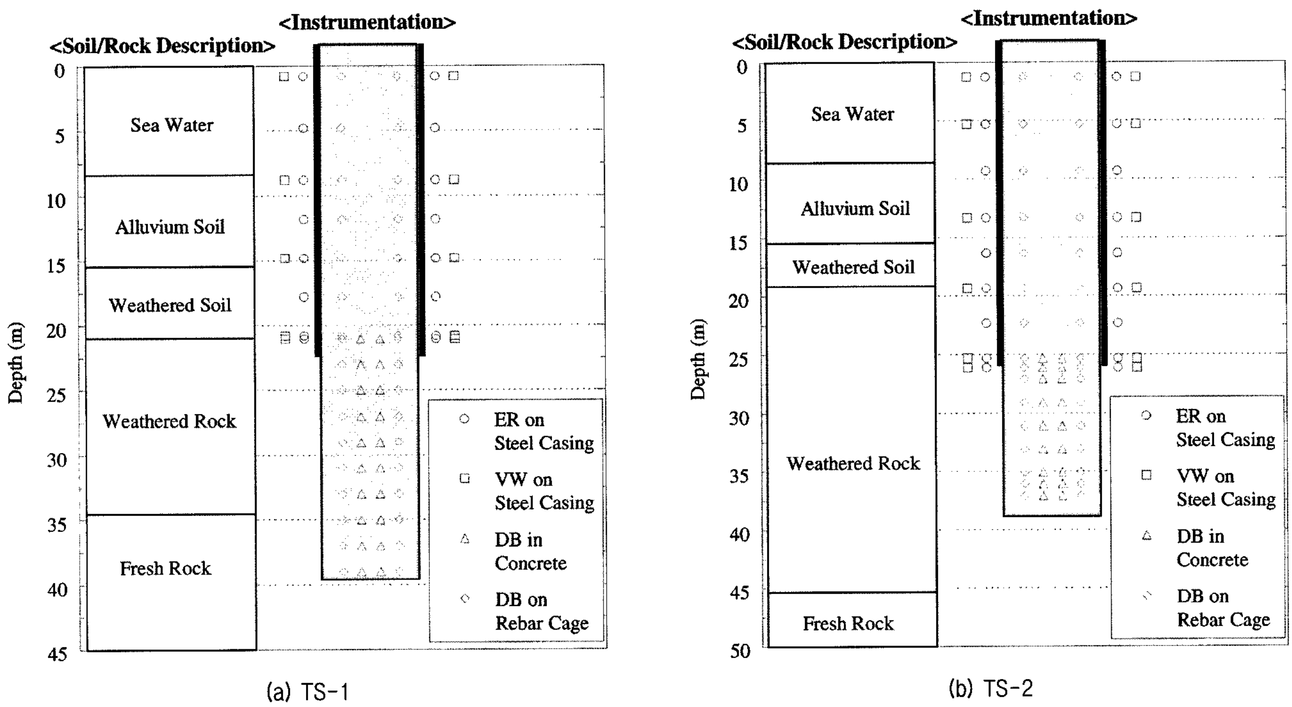


Fig. 2. Instrumentations for test piles

Table 2. Loading steps

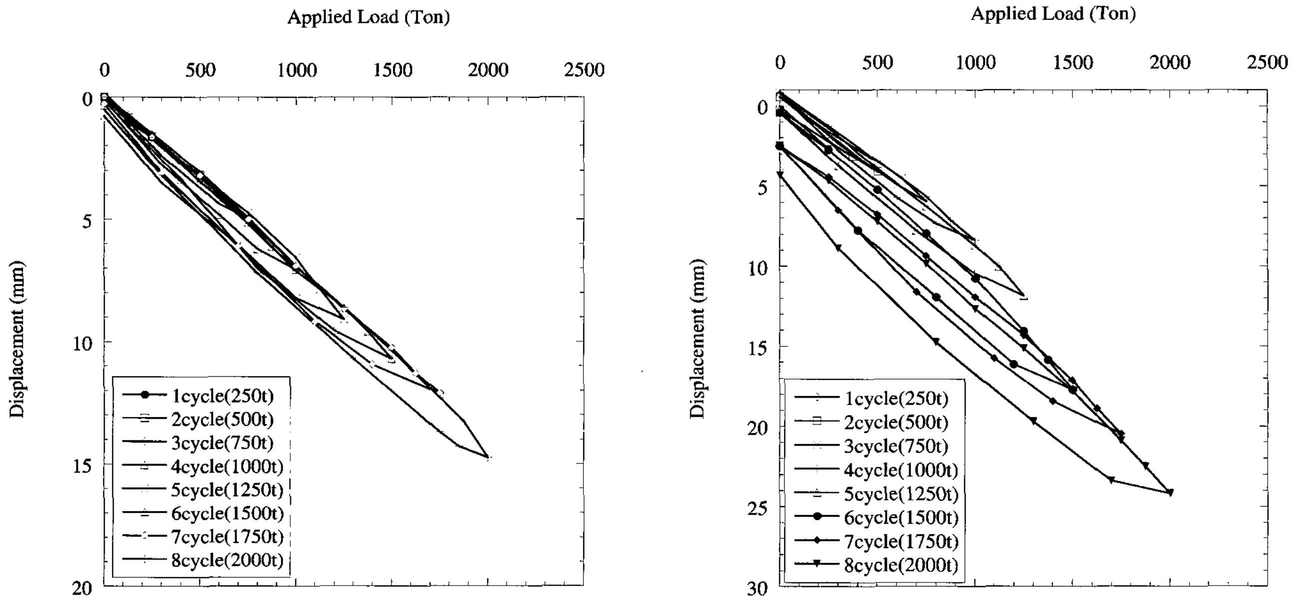
Cycle	Loading Steps (tf)	Q/QD*
①	0 → 125 → 250 → 125 → 0	0.5
②	0 → 125 → 250 → 375 → 500 → 300 → 0	1.0
③	0 → 125 → 250 → 500 → 625 → 750 → 600 → 300 → 0	1.5
④	0 → 125 → 250 → 500 → 750 → 875 → 1000 → 800 → 600 → 300 → 0	2
⑤	0 → 125 → 250 → 500 → 750 → 1000 → 1125 → 1250 → 1000 → 700 → 300 → 0	2.5
⑥	0 → 125 → 250 → 500 → 750 → 1000 → 1250 → 1375 → 1500→ 1200 → 800 → 400 → 0	3.0
⑦	0 → 125 → 250 → 500 → 750 → 1000 → 1250 → 1500 → 1625 → 1750 → 1400 → 1100 → 700 → 300 → 0	3.5
⑧	0 → 125 → 250 → 500 → 750 → 1000 → 1250 → 1500 → 1750 →1875 → 2000 → 1700 → 1300 → 800 → 300 → 0	4.0

* Q = Applied Load, Q_D = Design Load = 500 tf.

5. Results of Load Test

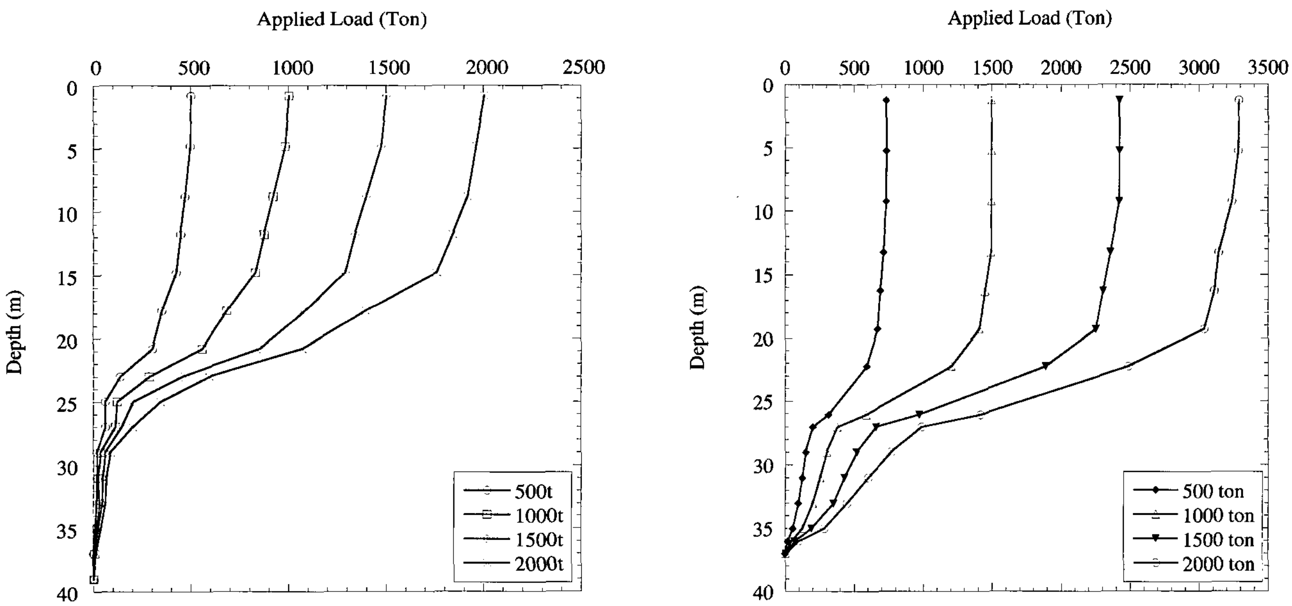
Load-displacement curves for test piles are shown in Figure 3. A maximum applied load of 2000 tf, which was about four times higher than the design load, was applied and the displacement at the maximum applied load was about 14.8 mm for TS-1. For TS-2, a maximum applied load of 2000 tf was also applied and the displacement at the maximum applied load was about 24.1 mm. However, it was not clear to define a failure load on the load-displacement curve since most displacements for the test piles were elastic displacements. Residual displacements by soil and rock were about 1 mm and 4 mm for TS-1 and TS-2, respectively.

Load distribution curves along pile depth for TS-1 and TS-2 are shown in Figure 4. The side resistances took over about 100% and 99.6% of the maximum applied load (2000 tf) for TS-1 and TS-2, respectively. At the



(a) TS-1 (b) TS-2

Fig. 3. Load-displacement curve



(a) TS-1 (b) TS-2

Fig. 4. Load distribution curves

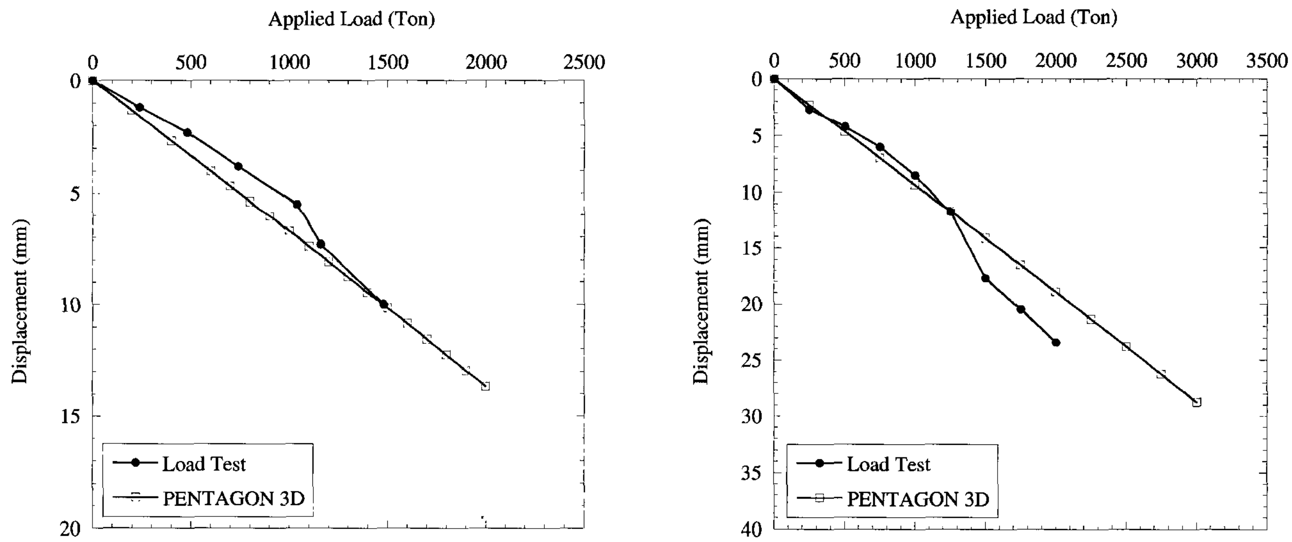
maximum applied load (2000 tf) for TS-1, alluvium soils developed the unit side resistance of 11 tf/m^2, weathered soils developed the unit side resistance of 38 tf/m^2, the upper part (22 m ~ 27 m) of the weathered rock layer developed the unit side resistance of 40 tf/m^2, and the lower part (27 m ~ 34 m) of weathered rock layer and fresh rock developed the unit side resistance of 4 tf/m^2. At the maximum applied load (2000 tf) for TS-2, alluvium soils and weathered soils developed the unit side resistance of 4 tf/m^2, the upper part (about 19 m to 26 m) of the weathered rock layer developed the unit side resistance of 45 tf/m^2, and the lower part (about 26 m to 38 m) of weathered rock layer and fresh rock developed the unit side resistance of 26 tf/m^2.

Based on the results of load tests for TS-2, the ultimate load would be expected more than 2000 tf which was about four times higher than the design load, and two times higher than the general safety factor (2.0) in the allowable design. Since the weathered rock layer provided sufficient side resistances, it can be an alternative embedded layer if weathered rocks are deeply layered over fresh rock.

6. Numerical Study for Load Test

Numerical studies for the results of the load tests were performed by using PENTAGON 3D (1998) and ROCKET (2000) in this study. A finite element code, PENTAGON 3D, was used to analyze the load test. For the constitutive model of PENTAGON 3D, a Mohr-Coulomb model for soils and rock, an elastic model for concrete, and an isotropic elastic model for steel casing were applied and the parameters are summarized in Table 3.

The results of numerical studies using PENTAGON 3D



(a) TS-1 (b) TS-2

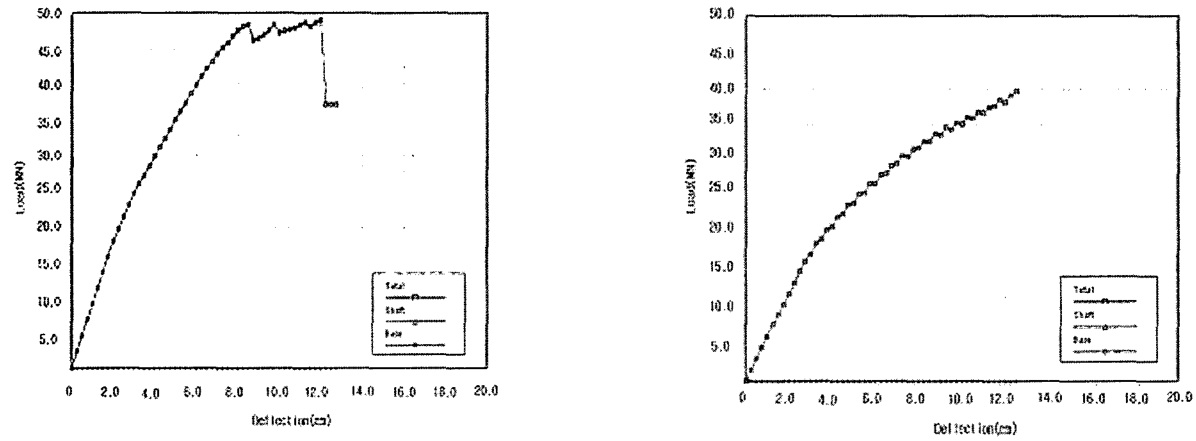
Fig. 5. Numerical study using PENTAGON 3D

Table 3. Soil and rock parameters for PENTAGON 3D

		Concrete	Steel Casing	Soils	Weathered Soil	Weathered Rock	Fresh Rock	Hard Rock
E (tf/m^2)		2323790	21000000	4000	8000	150000	300000	1000000
γ (tf/m^3)		2.4	7.9	1.9	1.9	2.3	2.5	2.7
c (tf/m^2)		-	-	2.0	4.0	50.0	100.0	350.0
ϕ (°)		-	-	32.0	35.0	36.0	40.0	45.0
K_o	K_{o-x}	1.0	-	0.5	0.5	0.5	0.5	0.5
	K_{o-y}	1.0	-	1.0	1.0	1.0	1.0	1.0
	K_{o-z}	1.0	-	0.5	0.5	0.5	0.5	0.5
ν		0.2	0.3	0.3	0.3	0.3	0.3	0.3

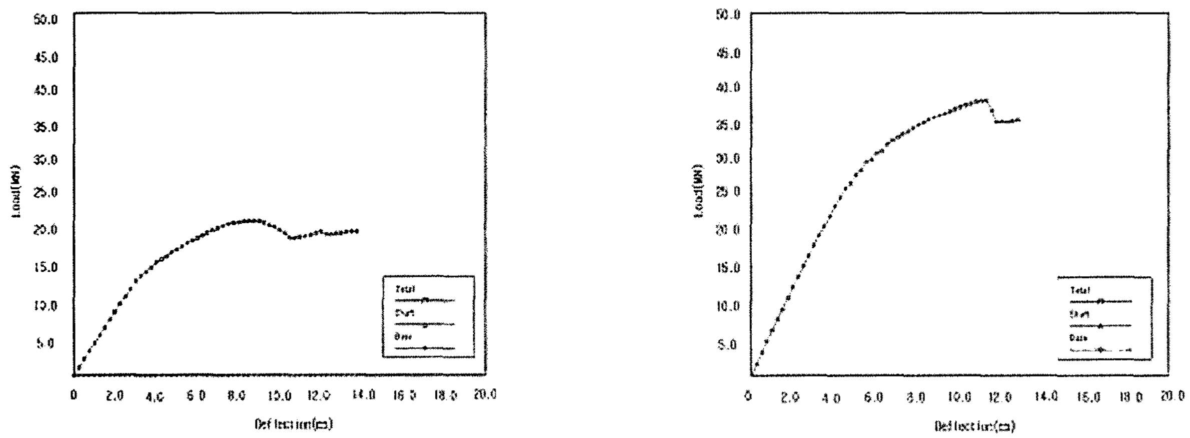
are shown in Figure 5. The results by PENTAGON 3D are in good agreements with the test results. However, ultimate loads could not be defined by PENTAGON 3D. According to the criteria of allowable displacement of 25.4 mm (KSCE, 2001), the allowable loads of 2770 ton and 2530 ton are determined for TS-1 and TS-2, respectively.

ROCKET was also used to analyze the load tests and models the interface between the concrete pile and the rock using a series of triangular asperities that may have variable sizes. Due to limitation for simulating of steel cased piles at one time, the numerical studies using ROCKET were performed by two parts. One part was the steel cased zone, and the other part was the socketed zone as shown in Figure 1. The base resistance was assumed to be zero in order to focus on the behavior of side resistances. The soil and rock parameters for the ROCKET study are summarized in Table 4 and the results are shown in Figures 6 and 7. As shown in Figures 6



(a) Steel cased aone in TS-1 (b) Rock socketed zone for TS-1

Fig. 6. ROCKET analysis for TS-1



(a) Steel cased zone in TS-2 (b) Rock socketed zone for TS-2

Fig. 7. ROCKET analysis for T-2

Table 4. Soil and rock parameters for ROCKET

	Soils	Weathered Soil	Weathered Rock	Fresh Rock	Hard Rock
E (tf/m^2)	4000	8000	150000	300000	1000000
γ (tf/m^3)	1.9	1.9	2.3	2.5	2.7
c (tf/m^2)	2.0	4.0	50.0	100.0	350.0
ϕ (°)	32.0	35.0	36.0	40.0	45.0
ν	0.3	0.3	0.3	0.3	0.3

and 7, the ultimate load was about 4580 tf for TS-1 and 5916 tf for TS-2 simply combining two ultimate loads from each zone.

7. Summary and Conclusions

Two large diameter steel cased piles (TS-1 and TS-2) were installed and tested with the maximum load of 2000 tf at Kwang-An grand bridge. TS-1 was socketed into the fresh rock and TS-2 was socketed into the weathered rock. The objectives of the current study were to verify and compare the axial behavior of the two test piles embedded into different rock layers (fresh rock for TS-1 and weathered rock for TS-2). Numerical studies were performed using PENTAGON 3D and ROCKET. Summary and conclusion are as follows:

(1) Most loads were carried by side resistances for TS-1 and TS-2.

(2) The maximum load of 2000 ton was applied to TS-1 and the axial behavior of test piles was under elastic. Most loads were carried by the weathered rock layer at the maximum load.

(3) The maximum load of 2000 ton was applied to TS-2 and the axial behavior of test piles was also under elastic. Most loads were also carried by the weathered rock layer at the maximum load.

(4) Based on the results of load tests for TS-2, the ultimate load would be expected more than 2000 tf which was about four times higher than the design load.

(5) Based on this study, the weathered rock layer can be an alternative embedded layer if weathered rocks are deeply layered over fresh rock, which caused difficulty and cost in the construction of rock socketed piles.

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