Journal of the Korea Academia-Industrial cooperation Society
Vol. 21, No. 6 pp. 687-695, 2020

https://doi.org/10.5762/KAIS.2020.21.6.687
ISSN 1975-4701 / eISSN 2288-4688

Horizontal Behavior Characteristics of Umbrella-Type Micropile Applied in Soft Clay Ground subjected to Seismic Motion

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연약점토지반에 적용한 우산형 마이크로파일의 지진시 수평거동 특성

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Abstract Micropile is used to improve the stability of existing structures as well as solve various geotechnical problems, such as suppressing slope activity and shearing keys of retaining walls. The existing micropile method has a significantly less capacity to resist a horizontal force than a vertical force0355 Therefore, it is necessary to develop and study an umbrella-type micropile method with excellent seismic performance that can secure seismic performance economically while minimizing structures and ground disturbance areas in the limited space of existing structures. In this study, numerical analysis was performed on the umbrella-type micropile, in which the sloped pile and vertical pile were combined, and the horizontal behavior in soft clay ground during earthquakes was analyzed. Numerical analysis showed that umbrella-type micropile suppresses horizontal displacement in soft ground, and the effect of reducing the horizontal displacement was more pronounced when the embedded depth of the slope pile was 15 m or more. The embedded depth of the micropile and horizontal displacement suppression effect was proportional. Therefore, the umbrella-type micropile has an excellent effect of suppressing horizontal displacement during earthquakes on soft clay ground.

요 약 본 논문은 한국산학기술학회 논문지 최종용 투고요령입니다. 마이크로파일은 기존 구조물의 안정성을 향상시키기 위해 사용되고 있을 뿐만 아니라 사면활동 억제, 옹벽의 전단키 등 다양한 지반 공학적 문제를 해결하기 위해 사용되고 있다. 기존 마이크로파일 공법은 연직력에 대해서는 PHC파일이나 강관파일에 비교하여 어느 정도 지지력을 확보하지만 상대적으로 작은 파일 직경으로 인해 수평력에 대해서는 연직력에 비해 현저히 낮은 지지력 양상을 보이고 있다. 이에 내진성능 향상에 우수한 우산형 마이크로파일 공법을 개발하여 기존시설물 내 국한된 협소한 장소에서 시설물의 및 지반 교란영역을 최소화하면서 경제적으로 내진성능을 확보할 수 있도록 연구해야 한다. 본 연구에서는 기존 마이크로파일의 수평지지력이 약한 단점을 보완하기 위해 사항과 연직말뚝을 일체형으로 제작한 우산형 마이크로파일에 대해 수치해석을 수행하여 연약점토 지반에서의 지진시 수평거동을 분석하였다. 수치해석 결과, 연약점토지반에서 우산형 마이크로파일은 수평변위 억제효과가 있었으며, 경사말뚝의 근입심도가 15m이상일 경우에 수평변위 저감 효과가 뚜렷했다. 마이크로파일의 근입심도와 수평변위 억제효과가 비례하였다. 이에 우산형 마이크로파일이 연약점토 지반에서 지진시 수평변위 억제효과가 우수한 것으로 판단된다.

Keywords : Umbrella-Type Micropile, Horizontal Behavior, Dynamic Analysis, Numerical Analysis, Soft Clay

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Received April 9, 2020 Revised May 11, 2020
Accepted June 5, 2020 Published June 30, 2020

1. Introduction

Micropile is used not only to improve the stability of existing structures, but also to solve various geotechnical problems, such as suppressing slope activity and shearing keys of retaining walls. The micropile method was designed to reinforce cultural properties that were damaged by World War II in Italy in the early 1950s. It was spotlighted as an optimal method that can be reinforced while minimizing damage to existing facilities. To date, it has been developed in various forms and applied in practice [1]. As the utilization of micropiles increases, many studies related to micropiles have been conducted worldwide. Lizzi (1982)[2] suggested that, through field tests, the length of the installation of the micropile is about 10 to 30 m depending on the ground characteristics, and the installation interval of the pile is about 3 to 4 times the diameter of the pile. Han and Ye (2006)[3] conducted a study on the bearing capacity of the micropile through field tests, and Tsukada et al. (2006)[4] performed a model test to make the installation angle of the pile is 30 ° when installing the micropile. It was suggested to be effective in increasing bearing capacity. In addition, Lee and Im (2006)[5] suggested that it is effective to increase the bearing capacity of the ground only when the length of the micropile is applied at least four times the foundation width (B) by conducting a model test. Han and Ye(2011)[6] studied a field study on the behavior of single micropiles in soft clay subjected to compression or tension. Elgamal(2019)[7] performed a case study in the Nile Delta, a transported alluvuim deposit. The micropile technique used to prevent more tilting of the eleven stories building without any harmful effects on surrounding buildings. This technique seems like an effective and suitable for such constructions in town centers as no space for large drilling machine. However, most of the existing research results are for static loads

Korea, after the earthquake in 2016 (Magnitude 5.8), followed by the earthquake in Pohang (scale 5.7) in 2017, earthquakes in Japan, the United States, and Taiwan have been gradually increasing. When an earthquake occurs, the ground subsides and the superstructure is damaged, negatively affecting the safety of citizens. As a result, the need for research on micropile is also rising. The existing micropile construction method appears to secure a certain bearing capacity compared to the PHC pile or steel pipe pile for vertical force. However, due to the relatively small pile diameter, the horizontal force shows a significantly lower bearing capacity than the vertical force. Therefore, the case of applying the seismic reinforcement method to reinforce the horizontal force is low. In the case of the grouting method, which is a ground reinforcement method, there are disadvantages in that the disturbance area of the ground is wide, uncertainty in the formation of improved bulbs, and high construction cost. Therefore, it is necessary to develop and study an umbrella-type micropile method with excellent seismic performance that can secure seismic performance economically while minimizing structures and ground disturbance areas in a limited place confined to existing structures.

In this study, in order to improve the existing micropile, which has a weak horizontal bearing capacity, numerical analysis was performed on the umbrella-type micropile in which the sloped pile and the vertical pile were combined, and the horizontal behavior during earthquakes in the soft clay ground was analyzed.

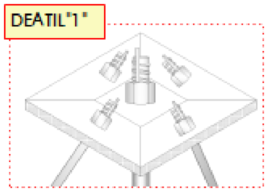
2. Umbrella-type micropile

It is effective to install the micropile inclined in response to the direction in which the horizontal force acts during an earthquake.

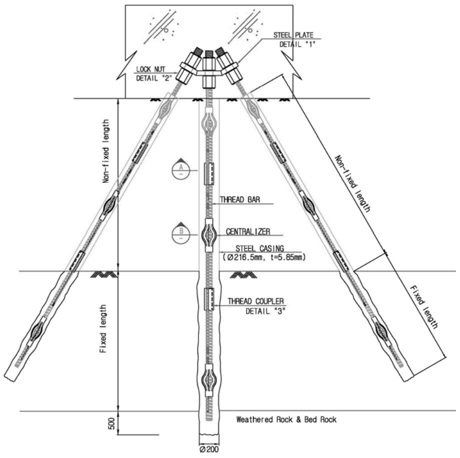
However, in order to improve the seismic performance, in the case of constructing the micropile in the conventional method, the vertical pile and the inclined pile must be respectively installed, and thus the damage to the existing facilities is inevitably increased. The behavior and support characteristics of the pile and the ground are related to the pile length ratio, which is the ratio of the pile installation length and diameter [8]. Short pile is L/d 〈 25, long pile is L/d 〉 50, and a large compressible pile or slender pile is L/d 〉 100 for piles with high compressibility or slender piles. Where, L is the installation length of the pile, and d is the diameter of the pile. The standard for the vertical or horizontal displacement of a pile is different from the standard set by each institution and proponent, but generally, the horizontal displacement of the pile is within the allowable displacement or less than 15 ~ 50mm to ensure the safety of the superstructure [9].

Umbrella-type micropile method is a method that is reinforced to improve the seismic performance of existing facilities. Fig. 1 is a schematic diagram of an umbrella-type micropile. The Umbrella-type micropile method is a method in which the main pillar is inserted into the weathered rock layer, and the auxiliary inclined pile is penetrated to the support layer to be integrated into one from the pile head.

Fig. 2 shows the construction order of the umbrella-type micropile. (1) Install drilling and casing. (2) After that, install the micropile. (3) Grouting. (4) After grouting, clean the head of the micropile. (5) Pour the foundation concrete and combine the vertical and inclined micropile.



(a) Top cap



(b) Overall shape

Fig. 1. Shape of umbrella-type micropile

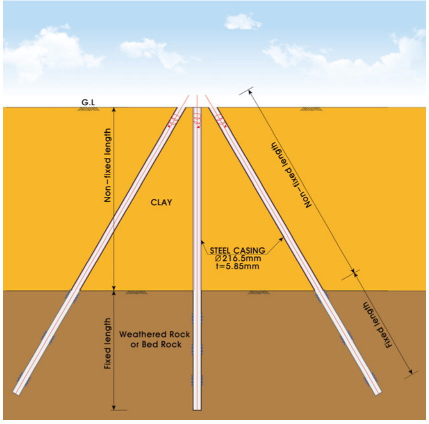
3. Numerical Modeling

3.1 Soil and micropile modeling

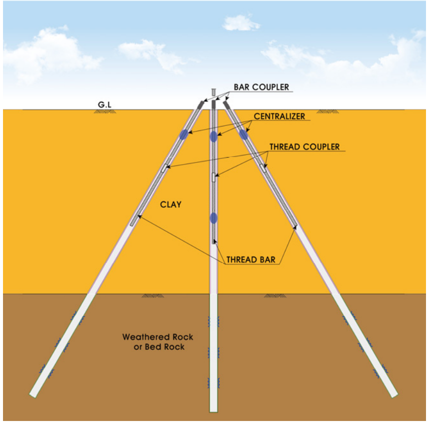
The soil deposits were classified into soft clay layer, weathered soil layer, weathered rock layer, and soft rock layer as shown in Fig. 3, and each layer thickness was applied as shown in Table 1. The slope micropile in the soil deposit was installed to maintain an angle of 30 ° to the vertical micropile. The vertical micropile and the inclined micropile were fixed by combining with a top cap made of concrete. The depth of inclination of the micro-pile was divided into 5, 10, 15, and 20 m, and numerical analysis was performed for each embedded depth.

Table 1. Case classification

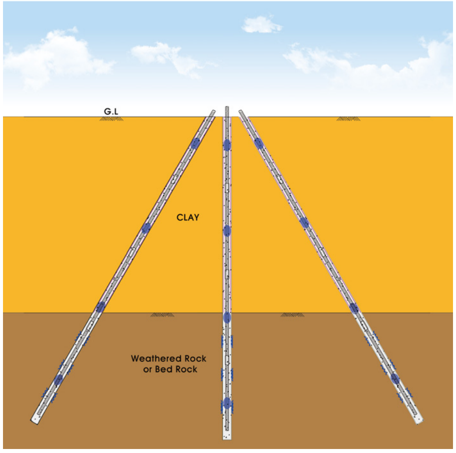
Soil deposit	Thickness (m)
Soft clay layer (N≦4)	20.0
Sedentary deposit (N=40)	5.0
Weathered rock	5.0
Soft rock	5.0
Total depth	35.0



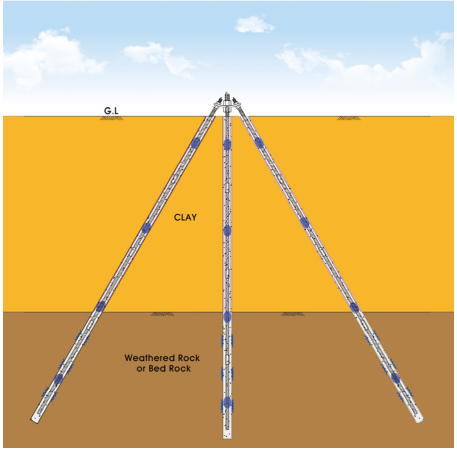
(a) Perforation of casing insllation



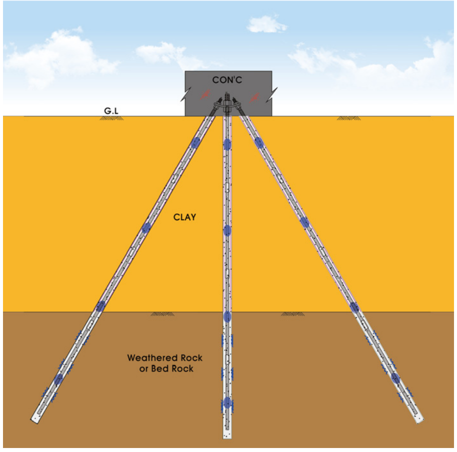
(b) Micropile Installation



(c) Grouting



(d) Micropile cap arrangement



(e) Foundation concrete pouring

Fig. 2. Construction step of umbrella-type micropile

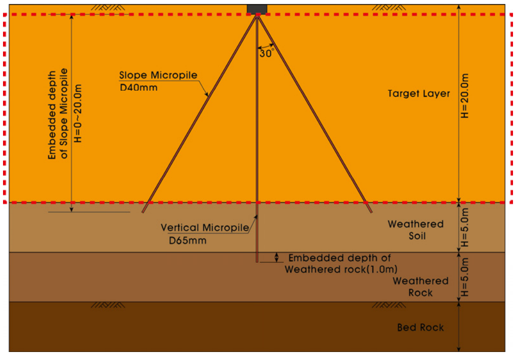


Fig. 3. Numerical modeling

Table 2. Materials of micropiles

pile type	Model type	Lateral space (m)	Cross section (mm)	Unit weight (kN/m3)	Shear modulus (GPa)	Poison ratio (ν)
slope pile	BEAM	1bon	40	78.5	200	0.3
		5m	40	157.0	400	0.3
Vertical pile	BEAM	5m	65	78.5	200	0.3

3.2 Input parameter

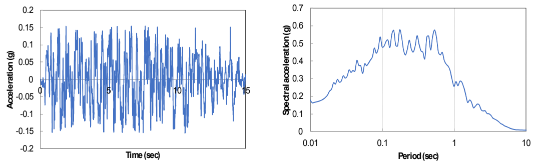
Tables 2 and 3 summarize the input parameters of the ground and micropiles. Linear elastic model for concrete, and Mohr-Coulomb model for other grounds applied. The shear wave velocity of the soft clay layer was obtained using a correlation equation with the shear wave velocity according to N value. For the correlation between N value and shear wave velocity, the formula proposed by many researchers was used, and the average value was applied to the input parameter[10-26]. The micropile was divided into an slope pile and a vertical pile, and a physically applicable thread bar was applied to input the material properties corresponding to each.

3.3 Input seismic motion

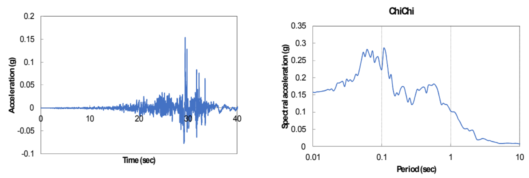
As the input seismic motion, a actual measurement seismic motion and artificial seismic wave were used. Artificial seismic waves were generated based on the 1st grade, and Chichi, Kobe, Loma

Table 3. Input parameter of soils

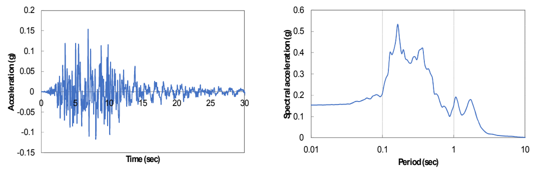
Classifiation	Unit weight (kN/m^3)	Cohension (kPa)	Internal friction angle(°)	Shear velocity (m/s)	Shear modulus (kN/m^2)	Poison ratio (ν)
Foundation Con'c	24.5	-	-	-	20,000,000	0.25
Soft clay layer (N≦4)	17.0	10	0	129.4	29,002	0.45
Sedentary deposit (N=40)	19.0	10	30	-	180,000	0.35
Weathered rock	20.0	20	32	-	1,000,000	0.30
Soft rock	23.0	100	35	-	2,000,000	0.25
Con'c filling	24.5	-	-	-	20,000,000	0.25



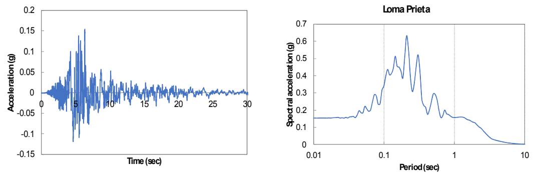
(a) Artificial earthquake wave



(b) ChiChi(Taiwan, 1999)



(c) Kobe(Japan, 1995)



(d) Loma Prieta(1989)

(e) Northridge (California, 1994)

Fig. 4. Input Seismic Motion

prieta, and Northridge seismic waves were used as the actual seismic waves. An acceleration level of 0.154 g was applied to the downtown area (I area) by applying a 1000-year return period. Figure 4 shows the acceleration time history and response spectrum of each input earthquake wave.

4. Numerical analysis results

The difference in horizontal displacement according to the embedded depth of umbrella-type micropile was analyzed. The analysis results are shown in Tables 4-5. Table 4 presents the results of horizontal displacement, and Table 5 presents the horizontal displacement ratio by dividing the maximum horizontal displacement for micropile reinforcement by the horizontal displacement for micropile vertical construction.

Table 4. Horizontal displacement

Imput Motion		Vertical installation	Slope micropile embedded depth (m)			
			5.0	10.0	15.0	20.0
Artificiality	mm	112.2	108.2	94.6	80.7	44.6
ChiChi	mm	36.2	35.5	33.2	29.2	17.6
Kobe	mm	52.4	51.4	48.9	40.2	24.6
Loma prieta	mm	71	68.8	62.1	49.8	27
Northridge	mm	41.4	39.8	36.7	32.2	26

Table 5. Horizontal displacement ratio

Imput Motion	Vertical installation	Slope micropile embedded depth (m)			
		5.0	10.0	15.0	20.0
Artificiality	1	0.96	0.84	0.72	0.40
ChiChi	1	0.98	0.92	0.81	0.49
Kobe	1	0.98	0.93	0.77	0.47
Loma prieta	1	0.97	0.87	0.70	0.38
Northridge	1	0.96	0.89	0.78	0.63

Fig. 5 presents the horizontal displacement according to embedded depth in each input seismic wave. As a result of displacement analysis, the largest displacement was observed in the artificial earthquake wave with a long period of the input wave, and the smallest displacement value in the Chichi wave with the short period of the input wave. No other trend was seen in the other three groups. As a result of analysis according to the embedded depth, it can be seen that as the embedded depth of the umbrella-type micropile increases, the horizontal displacement generated decreases. Seismic waves of Kobe, Loma prieta, and Northridge with similar periods showed almost similar values when the embedded depth was 20 m. When embedded depth is 20m, displacement was the smallest in chichi, and the largest in artificial seismic waves. As a result of comprehensive analysis of the displacement results, it can be seen that when the embedded depth exceeds a certain depth, the longer the periodic region of the input wave, the greater the occurrence of displacement. This is considered to be because the displacement of the input wave increases when the period of the input wave is long, and it affects the ground and the micropile head. That is, it can be seen that the longer the period of the input wave is, the larger the displacement occurs.

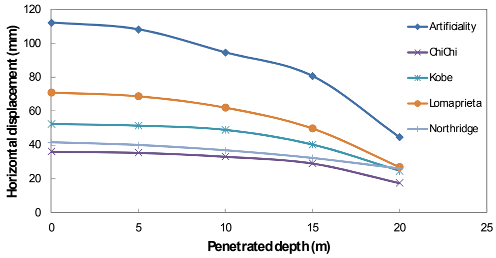


Fig. 5. Horizontal displacement according to the embedded depth

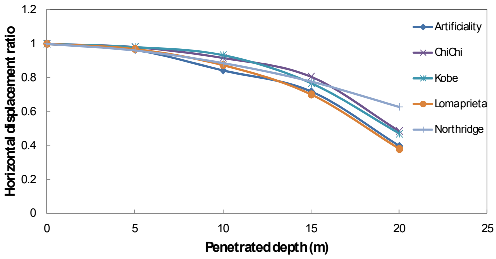


Fig. 6. Horizontal displacement ratio according to the embedded depth

Fig. 6 presents the horizontal displacement ratio according to embedded depth in each input seismic wave. According to the results, the closer the horizontal displacement ratio in Fig. 6 is to 1, the better the horizontal displacement suppression effect is compared to the vertical construction case. That is, the smaller the horizontal displacement ratio, the greater the effect of suppressing horizontal displacement. It can be seen that the horizontal displacement ratio decreases as the embedded depth of micropile increases as compared to the horizontal displacement for vertical construction of the micropile. This result shows that the Umbrella-type micropile increases the effect of suppressing the horizontal displacement as the embedded depth increases.

According to the result when the embedded depth is 20 m, the horizontal displacement ratio of existing micropile is distributed in the range of 0.4 to 0.6. It can be seen that the horizontal displacement ratio of the chichi input wave having the shortest period is about 0.63, and the horizontal displacement ratio for other input waves is 0.5 or less. In general, this result is considered to have a more horizontal displacement suppression effect than the vertical installation construction of micropile in long-period rather than short-period. Overall, as a result of analysis, it can be determined that the horizontal displacement suppression effect of the umbrella-type micropile on the soft ground is superior to that of the existing micropile.

5. Conclusion

In this study, an umbrella-type micropile was installed for the soft clay deposit, and numerical analysis was performed using the ground information of the section. Through this, the following conclusions were drawn.

(1) As a result of numerical analysis, the horizontal displacement suppression effect was slightly different according to the input earthquake wave, but the horizontal displacement suppression effect was more effective for all input earthquake waves than the existing micropile.

(2) As a result of analyzing the horizontal displacement according to the embedded depth, the horizontal displacement and the horizontal displacement ratio decreased as the embedded depth of the micropile became deeper. These results show that the embedded depth of micropile and horizontal displacement suppression effect are proportional.

(3) The horizontal displacement of the slope micropile is approximately in the range of 0.4 to 0.6. In general, it is judged that there is a more horizontal displacement suppression effect in the long period wave rather than short period.

(4) This study, the effect of suppressing the horizontal displacement of the umbrella-type micropile on the soft clay layer was analyzed. However, the ground is very varied, such as the sandy soil layer and the complex ground layer. Accordingly, the verification of the displacement suppression effect of the umbrella-type micropile for various ground conditions and the scaled model experiment are additionally being performed.

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