www.dwconst.re.kr

Daewoo Institute of Construction Technology

A New Breakwater System With Suction Piles

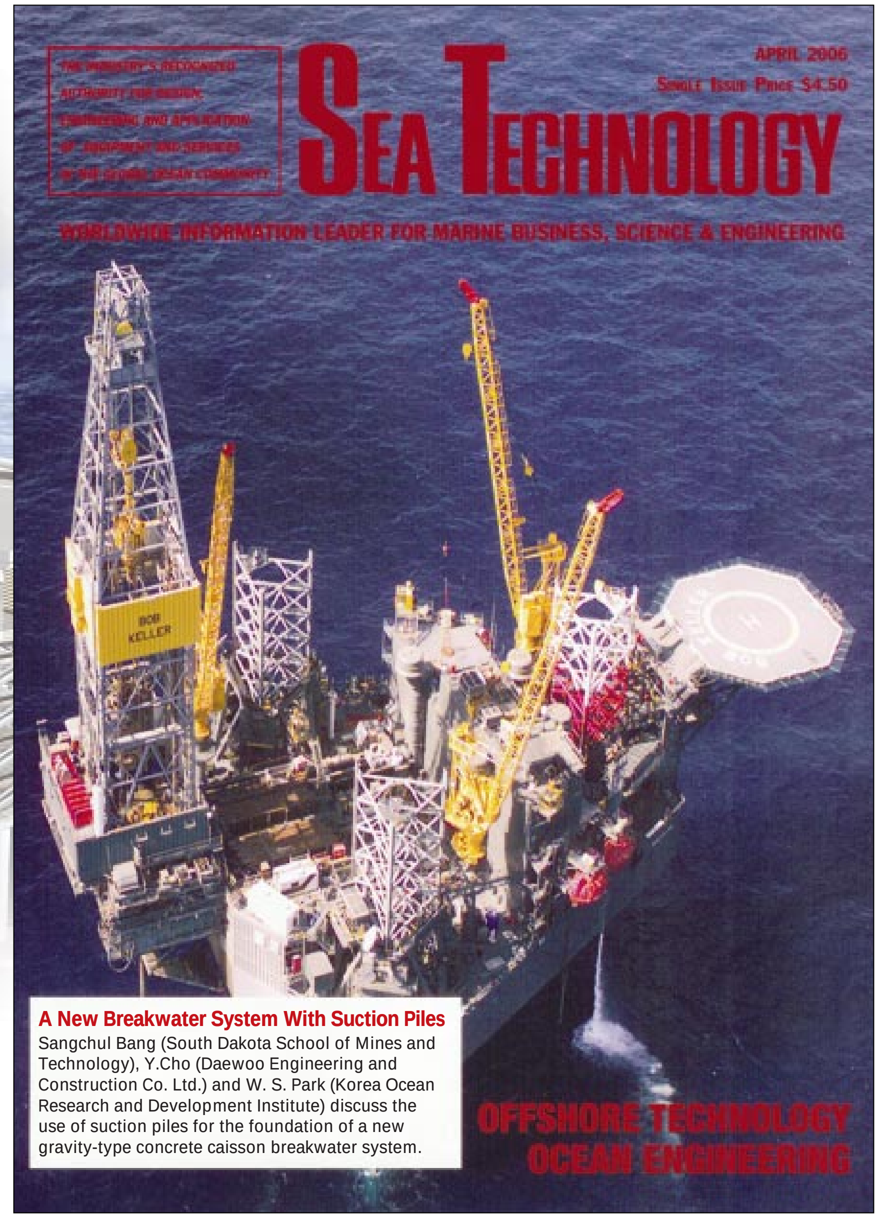
대우건설 기술연구원

440-210 경기도 수원시 장안구 송죽동 60번지
TEL.(031)250-1165 FAX.(031)250-1131

60 SONGJUK-DONG, JANGAN-GU, SUWON,
GYEONGGI-DO, 440-210 KOREA
TEL.82-31-250-1165 FAX.82-31-250-1131

석션파일을 이용한 대수심 방파제 및 연약지반 관련기술 개발

A New Breakwater System With Suction Piles



※「Sea Technology」는 미국 National Ocean Industries Association's (NOIA)에서 발행하는 저널로 해양기술에 관한 최신 정보및 동향 등을 소개하며, 전세계 100여개국에서 구독하고있음

대우건설 기술연구원

석션파일을 이용한 대수심 방파제 및 연약지반 관련기술 개발

연구배경 및 목적

- 대형 선박출현과 항만입지 변화로 대수심 • 연약지반 입지에서 사용할 수 있는 새로운 형식의 방파제 개발 필요성 대두
- 대수심 및 연약지반에서 적용 할 수 있는 석션파일 기초 방파제의 현장 시험시공을 통한 실용화
- 대규모 해상구조물(플랜트, 해상풍력발전소 등) 개발에 필요한 핵심 기반기술 확보

연구내용

2003
- 석션파일기초 방파제 시험시공 대상지 선정
- 석션파일기초 방파제 기본설계

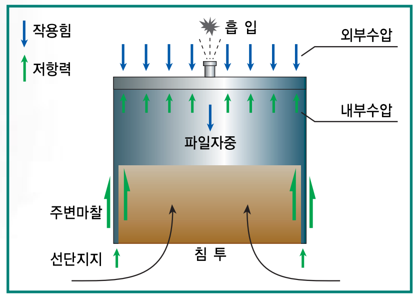
2004
- 석션파일기초 방파제 실시설계
- 석션파일기초 방파제의 안정성 평가
- 석션파일기초 25m 구간 시험시공

2005
- 석션파일기초 25m 구간 시험시공

2006
- 상부 케이슨 시공 완료
- 실시간 계측 실시
- 시험시공 결과 보고서 작성

기술적 특징

- 대수심 해양조건에서 적용성이 탁월
- 연약지반의 개량이나 치환 등의 보조공법을 사용하지 않으므로 경제적임
- 지반개량이나 준설치환이 필요 없으므로 해양환경오염 없음



• 석션파일 기술의 원리

석션파일을 이용한 방파제 시험 시공순서


• 벽체제작 / Suction Pile Manufacture


• 제작완료 / Manufactured Suction Pile


• 석션파일 예인 / Towing Suction Pile


• 석션파일 거치 / Suction Pile Placement


• 연결시공 / Connection

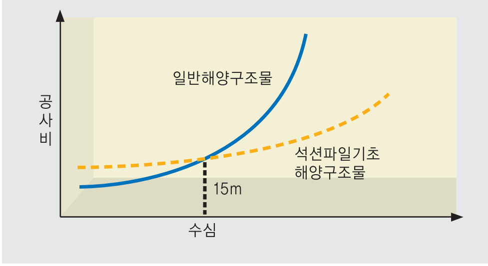

• 케이슨거치 / Caisson Placement

A New Breakwater System With Suction Piles

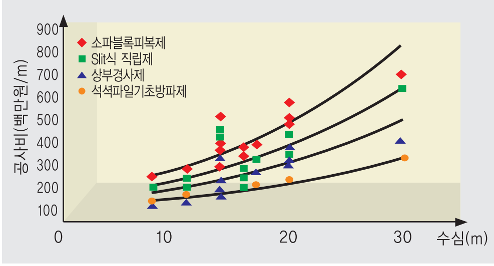
A New Breakwater System With Suction Piles

경제성 검토

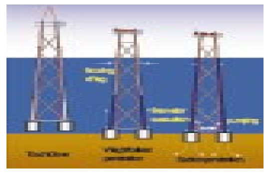
수심에 따른 공사비 비교



방파제 형식별 공사비 비교



적용분야


• 자켓구조물 기초


• 안벽 기초


• 해상공항 기초


• 풍력발전 기초

기대효과

- 대수심 해양구조물의 필요성 증가에 부응하는 최적의 기초 구조인 석션파일기초의 설계 • 시공기술의 확보

단기적
- 항만건설비용절감
효율적이고 안전한
시공보장

장기적
- 해상풍력 발전,
해양자원개발, 해상공항,
대수심 해양구조물
건설기반 기술확보

A New Breakwater System With Suction Piles

The Use of Suction Piles for the Foundation of a New Gravity-Type Concrete Caisson Breakwater System

S. Bang
South Dakota School of Mines and Technology
Rapid City, SD
Y. Cho
Daewoo Engineering and Construction, Co., Ltd.
Seoul, Korea
W. S. Park
Korea Ocean Research and Development Institute
Ansan, Korea

INTRODUCTION

Conventional breakwater construction typically utilizes a trapezoidal-shaped rubble mound cross-section with pre-cast concrete surface elements such as tetra-pods on the seaside. Therefore, as the water depth and/or the depth to the bearing soil layer become deeper, the cross-sectional area of the breakwater increases rapidly, requiring a massive amount of rubbles. Alternatively, gravity-type concrete caissons have also been used. However, since they have to be placed directly on top of the strong bearing soil layer, it also becomes increasingly expensive, particularly when the soft seafloor soil extends to a considerable depth.

To provide more efficient and effective breakwaters, a new system has been perceived. It utilizes a gravity-type concrete caisson superstructure on top of suction piles that act as the subsurface foundation of caissons. Suction piles do not require excavation of soft seafloor soils. Instead, it penetrates into the soft seafloor soil to depths where sufficient soil bearing capacity is expected. Concrete caissons are then placed on top, which resist the lateral loads caused by the wind and wave. The details of the suction pile mechanism and applications can be found in reference [1].

This paper briefly describes the design and installation of the suction piles as well as the field site conditions. During the installation of suction piles, detailed instrumentation was made and results are summarily included.

SITE CONDITIONS

Two breakwaters, each being approximately 400-meters long, are planned to be constructed for the new Ulsan Harbor in southeastern Korea. The water depth is 20 - 21 meters at the site where the new breakwater system was to be tried ? middle of the northern breakwater site. The wave characteristics at the site call for the following design parameters: the wave height of 6.4 meters, period of 11 seconds, and length of 148.07 meters.

The seafloor soil at the test site consists of roughly 15 meters of soft silty clay underlain by medium dense silty sand. The silty clay has the water content of 56.3 ~ 95.4 %, specific gravity of 2.72 ~ 2.75, liquid limit of 91.4 ~ 94.3, plastic limit of 30.2 ~ 31.2, and undrained shear strength of 9.81 ~ 15.69 kPa measured from consolidated undrained triaxial test. The silty sand has the specific gravity of 2.65, void ratio of 0.63 ~ 0.70, water content of 23.8 ~ 26.4 %, saturated unit weight of 19.61 kN/m3, and internal friction angle of 34 degrees at the top and 38 degrees at the bottom.

If conventional rubble mound breakwater system is used, the base of the breakwater has to start from the top of the silty sand layer. Therefore, the base width of the breakwater cross-section would be over 100 meters. Instead, the new design utilizes two concrete suction piles in a row with the outer diameter of 11.0 meters and wall thickness of 55 cm. Each suction pile has a square concrete slab on top whose dimensions are 13.9 x 13.9 meters. Along the longitudinal direction on both ends, vertical flanges of 3 meters high are provided. Two-meter thick crushed rock leveling stones will be placed and compacted on top of the concrete slab and between the flanges. Concrete caisson with dimensions of 17.0 x 21.0 meter will then be placed on top of the leveling stones. This configuration utilizes four suction piles to support one concrete caisson on top. Suction piles were designed to penetrate the entire soft clay layer and 2.5 additional meters into the sand layer to provide necessary soil bearing resistance.

SUCTION PILE DETAILS AND INSTALLATION

The design of the suction pile diameter and length was based on the expected externally applied loads, the vertical and horizontal soil bearing capacities, and the suction pressure that can be applied safely inside the pile without causing any soil instability. Complete details of the suction pile design, considering the external loads and safe installation, are well described in references [2, 3, 4, 5].

From September through late November 2004, four suction piles were fabricated at a location adjacent to the wharf near the test site. In early December 2004, they were installed successfully near the center of the site where the northern breakwater is to be constructed. Four additional suctions piles will be installed and two concrete caissons will be placed on top of the eight suction piles in mid-2006.

Each suction pile required concrete volume of 480.6 m3, having air and underwater weights of approximately 1,200 and 700 tons, respectively. A series of water jets (diameter of 2 mm) were also installed within the pile wall. Entire water jets were activated when the pile penetration through the sand layer became difficult, whereas part of the water jets were activated when the pile started to tilt due to uneven penetration of the pile.

The suction piles were handled, transported and installed by a 1,800-ton capacity barge crane. The barge has its length of 80 m, width of 27 m, depth of 6 m, draft of 5.2 m, and displacement of 7,262 tons. The barge crane first approached the suction pile, lifted it up, moved it out to the open water, and then lowered the suction pile so that approximately half the pile length was submerged.

When the barge crane with a suction pile arrived at the installation site, it was positioned using five drag anchors located at its corners. Two global positioning system (GPS) locators were activated and utilized to pinpoint the exact position where the suction pile should be installed. Real-time trajectory of the crane barge movement was continuously monitored on a laptop computer in the control room. The suction pile was lowered until the top of the concrete slab was near the water surface. Four centrifugal type water pumps were then attached at the top of the pile. Each water pump had a capacity of 3 cubic meters per minute.

When the suction pile was correctly positioned and oriented, the crane further lowered the pile slowly until the pile penetration into the seafloor soil stopped due to its own weight. According to the analytical estimation made by the suction pile installation design method, this self-weight penetration was approximately two-third of the pile length. Field measurements by the ultrasound device and by divers confirmed that the self-weight penetration of the suction pile was very close to the predicted depth. When the penetration of the suction pile stopped, the water pumps attached at the top of the suction pile were started to apply negative water pressure (suction pressure) inside the pile.

The application of the suction pressure was continuously monitored and carefully controlled so that the soil inside the pile did not experience any instability such as boiling and/or plugging. The magnitude of the suction pressure that could be applied safely was defined by its upper and lower limits. The lower limit of the suction pressure is dictated by the soil resistance corresponding to the pile penetration. If the applied suction pressure is smaller than this value, the pile cannot penetrate any further. However, if the suction pressure is too high, the soil inside the pile becomes unstable and consequently the pile installation becomes incomplete, rendering the pile useless. This is the upper limit of the suction pressure.

The magnitudes of the lower and upper limits of the suction pressure were calculated based on the analytical solution previously developed. These limits were updated continuously as the pile penetrated into the seafloor soil deeper until full penetration. All four piles were successfully installed using the suction pressures defined by those limits.

INSTRUMENTATION

The field instrumentation included the measurements of the pore water pressures inside and outside the pile, the pile penetration depth into the seafloor soil, the elevation of the soil surface inside the pile, and the tilts of the pile. Measurements were displayed and recorded by a data logger with 0.06 second data acquisition interval.

n Suction Piles

Two piezometers were installed inside and outside, near the top of each pile at the same elevation. The difference between two piezometer readings was calculated and recorded as the suction pressure as a function of the pile penetration depth. The pile penetration depth was measured primarily by the ultrasound device and verified by the water pressure measured outside the pile. The measured suction pressures were continuously compared directly against the lower and upper limits of the suction pressure and adjustments in the water pump speed were made accordingly.

The final position and penetration depth of the suction piles were measured manually by the divers at three different locations that were 120 degrees apart along the circumference of the pile. Average of the three measurements was used as the final pile penetration depth.

The soil surface inside the pile was measured using an ultrasound device. The inclination of the suction pile during installation was measured using two tiltmeters attached at the top of the pile along perpendicular directions. Thus, the pile tilt along any direction and the maximum tilt could be estimated.

In addition to the instrumentation described above, several soil pressuremeters were installed at the tip of the suction piles to monitor the long-term variation of the soil pressures. Measurement of the soil pressures at the pile tip will begin soon.

LOAD TEST

After each suction pile was completely installed, they were load-tested by further reducing the suction pressure inside the pile. This was possible, because the necessary suction pressure for full pile penetration did not require the maximum pump capacity. Since the suction pressure could be reduced as low as negative one atmospheric pressure (101.3 kPa), the difference between the maximum suction pressure for full pile penetration and the maximum applicable suction pressure therefore could be used for the pile load test. Detailed calculation indicated that the largest suction pressure applied for the load test was approximately equivalent to 800 tons, resulting in total vertical force of approximately 1,500 ~ 1,600 tons per pile including the underwater weight of the pile. The load was held constant for a period of 30 minutes. No noticeable settlement of the suction piles was observed.

SUMMARY AND CONCLUSIONS

A new breakwater system has been designed and field-tested to provide more efficient and effective breakwaters. It utilizes gravity-type concrete caisson superstructure on top of suction piles that act as the subsurface foundation of caissons.

The full-scale field tests included detailed instrumentation. Instrumentation results indicate that all four piles were installed successfully with the maximum difference in final elevation of 0.7 meters, which can be taken care of by crushed rock leveling stones that will be placed between the piles and caissons. In addition, the piles were load tested to additional 800 tons by operating the water pumps to their full capacity after installation.

Because of fast and easy installation, environmental friendliness, and significant reduction in costs, this new breakwater system is expected to be utilized widely in near future where the seafloor consists of thick, soft soils.

ACKNOWLEDGMENTS

The analytical solutions of the suction pile installation and its loading capacities were developed with the grant from the US Department of the Navy, Office of Naval Research. The authors are grateful for the financial and technical supports provided by the Korea Ministry of Marine Affairs and Fishery, Daewoo Engineering and Construction Co. Ltd., and AdvaCT Co., Inc.

REFERENCES

[1] D. Senepere, and G.A. Auvergne, ~Suction Anchor Piles ~ A Proven Alternative to Driving or Drilling,~ Offshore Technology Conference, Paper No. 4206, 1982.

[2] S. Bang and Y. Cho, ~Ultimate Vertical Loading Capacity of Suction Piles,~ 36th Annual Symposium on Engineering Geology and Geotechnical Engineering, Las Vegas, NV, Mar., 2001, pp. 703-712.

[3] S. Bang and Y. Cho, “Ultimate Horizontal Loading Capacity of Suction Piles,” International Journal of Offshore and Polar Engineering, Vol. 12, No. 1, Mar., 2002, pp. 56-63.

[4] Y. Cho and S. Bang, ~Inclined Loading Capacity of Suction Piles,~ 12th International Offshore and Polar Engineering Conference, Paper No. 2002-PCW-01, Kitakyushu, Japan, May, 2002.

[5] Y. Cho, S. Bang, and T. Preber, “Transition of Soil Friction During Suction Pile Installation,” Canadian Geotechnical Journal, Vol. 39, No. 5, Oct. 2002, pp. 1118-1125.

To provide more efficient and effective breakwaters, a new system has been developed.

Sangchul Bang received his M.S. and Ph.D. from the University of California, Davis, in 1978 and 1979, respectively. He is currently a professor of civil engineering at the South Dakota School of Mines and Technology.

Y. Cho received his M.S. and Ph.D. from the South Dakota School of Mines and Technology in 1992 and 2001, respectively. He is currently a supervising engineer at Daewoo Engineering and Construction.

W. S. park received his M.S. and Ph.D. from the Korea Advanced Institute of Science and Technology in 1986 and 1991, respectively. He is currently a senior researcher at the Korea Ocean Research and Development Institute.