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인공섬의 계획, 조사 설계 및 시공
PLANNING, AND CONSTRUCTION OF ARTIFICIAL ISLANDS

송 병무, BYONGMU SONG

도우엔지니어즈 부사장, DOWOO ENGINEERS, SEOUL, KOREA

개 요

근래 인공섬은 그 수가 많아지고 또 그 크기도 방대해지고 있다. 이 논문은 인공섬의 완성에 앞선 각과정에 대한 제반 문제점들에 대한 지반공학적 분석결과를 포함한다. 최근 인공섬 형성 과정에 사용하는 신공법이 개발되었다. 인공섬의 형성은 단일 공법에 의한 것이 아니고 여러가지 공법의 홍용 의한다. 따라서 각 공법에 대한 완벽한 이해는 사업자체의 성공적인 완료와 경제성에 지대한 영향을 준다.

인공섬은 해성퇴적층에 위치하게 된다. 따라서 해성퇴적층의 형성과정, 환경, 퇴적 후의 변화 그리고 지반공학적인 자료가 채취되어야하고 분석되어야 한다. 해성퇴적층에 위치할 인공섬 완료에 필요한 조사, 설계 및 시공에서 반드시 고려되어야 할 과정이 실무자들이 이해하고 사용할수 있는 형식으로 제시되었다. 불완전한 자료, 또 그것에 근거한 설계 및 시공이 줄 수 있는 결과에 관해 기술했다.

INTRODUCTION

The primary purpose of this paper is to present an overview of the geotechnical aspect in the planning, design and construction of artificial islands in the Western and Southern coastal areas of Korea. Artificial islands may be categorized into two broad types: a) completely isolated and independent group; and b) closure of a baymouth, or two or more natural islands with dikes placed in between and enclosing the area to form reclaimed land for industrial, commercial and/or agricultural purposes. The latter will be treated in this paper for these types are used mainly in Korea though the principles involved are basically the same for both types.

Improvements, in a general sense, were made during the past decade and the writer's discussion will be on the utilization of these new concepts and methodologies for the planning, design and constuction of artificial islands to reduce the overall project cost, and, atleast, prevent failures during and after the constuction which are usually extremely costly.

A general concept and scope of field and laboratory exploration, design procedures and construction methodologies are presented so that practicing engineers would be able to use these directly for their tasks. Several existing construction methodologies are compared and a new closure dike construction technique is presented. practically all current projects are situated on sediments whicn were deposited subsequent to the late Wisconsin Glacial Stage, and therefore, a substantially detailed treatment is provided for the marine geology and geotechnical aspects of the sedeiments

MARINE GEOLOGY

The Korean peninsula forms a part of the Sino-Korean Platform and is underlained by Pre-Cambrian metamorphic formations (1). Sediments deposited subsequent to the Pre-Cambrian are encountered along the coastal areas (2), however, this paper will concentrate on the formations deposited subsequent to the late Wisconsin Glacial Stage for the Recent deposits present the most problems with respect to geotechnical enginnering and construction.

Glacio-Eustatic sea level changes of the Yellow Sea are presented on Figure 1, Glacio-Eustatic Sea Levels. According to Geng(3), "- - - the sea level did not rise continuously to its present position, but oscillated up and down in the range of several meters (+5 to -2m) during the past 9,000 years." It is envisaged that the surficial sediments encountered for the artificial island projects in Korea which give the greatest challenges and problems are located, in most cases, above the elevation of -30 meters. During the Pleistocene, desiccation of the surficial sediment extended to a depth of about 8 meters (4) during the glacial stages. At the peak of the Late Wisconsin Glacial Stage. the sea level reached an elevation of about -150 meters (5), and yet the thickness of the desiccated crust was on the order of 8 meters (6) indicating that capillary action or other moisture retaining phenomenon below the desiccated zone existed. Therefore, desiccation can not take place on the sediments deposited subsequent to about 9,000 B.P(Before Present). Some of the Post-Glacial sediments encountered in the Hong Kong Airport project (7), were preconsolidated with OCRs(over consolidation ratio) in the range of 1.5 to 2, and the authors attributed the high OCRs to aging.

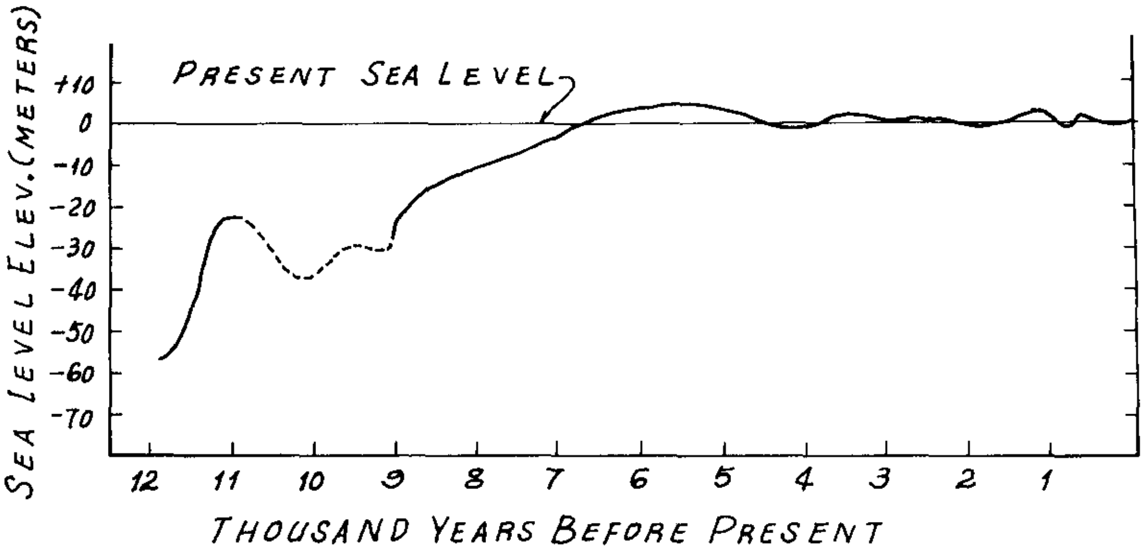

FIGURE 1. GLACIO-EUSTATIC SEA LEVELS [AFTER GENG (3)]

These sediments had moisture contents higher than the liquid limits. The final design report (8) for the New Seoul Metropolitan Airport(NSMA) project indicates that laboratory consolidation tests in some of the Recent surficial sediments with MC>LL resulted OCRs higher than one. It is not yet clear as to the general configuration of the consolidation curve for the "aged" specimen from the Post-Glacial sediments. However desiccated sediments show a distinct characteristic straight line in the region of maximum curvature of the classical laboratory recompression curve (9), Figure 2, One-Dimensional Consolidation Curve, Pleistocene Montgomery Formation. Therefore, it is apparent that desiccation in any Recent sediment along the coastal areas of Korea is not likely.

In general, the thickness of the Recent sediments in the west continental shelf of Korea ranges from about one meter to ten meters with an average of approximately five meters in the vicinity of the NSMA. The Recent sediments of this area were deposited during the post-glacial transgression, and therefore, should be in a state of under-consolidation. OCRs higher than one in these sediments are not the result of desiccation but some other causes such as "aging" and/or mineralogical bonding of some nature.

Distributions of the Recent surficial sediments in the coastal areas of Korea are Presented (2, 10, 11, and 12). For a large project, it would be useful to perform a comprehensive marine geological investigation during the planning stage for the information would very helpful for design and construction as well as post-construction evaluation of marine environmental changes.

GEOTECHNICAL INVESTIGATION

A successful completion of a large project necessitates a comprehensive geotechnical investigation. Insufficient investigations would cause costly delays and even more costly failures during and after the construction.

A comprehensive geotechnical investigation in an marine environment may be found in the paper by Koutsoftas, et al (7).

The scope of a comprehensive field and laboratory geotechnical investigation differs depending upon site conditions and project requirement. However, the following sequence of activities for a marine geotechnical exploration should be considered:

a) Definition of the site and the program. Is the investigation to be site specific or structure specific? It could be both;

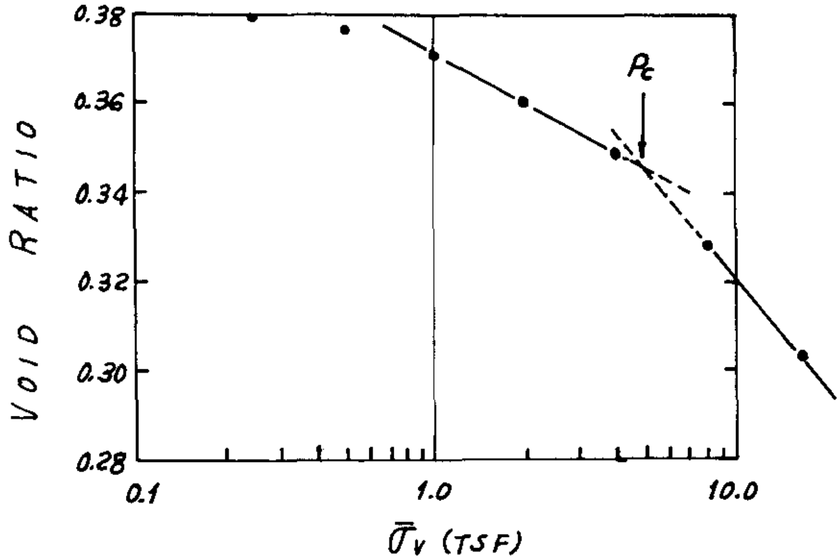

FIGURE 2. ONE-DIMENTIONAL CONSOLIDATION CURVE, PLEISTOCENE MONTGOMERY FORMATION. (1 TSF = 95.8 kPa). [AFTER MAHAR (6)]

b) Evaluation of existing geologic and geotechnical data;
c) Evaluation of the required scope of investigation as a function of the type and location of the proposed structure(facility) and of the anticipated geotechnical and environmental conditions;
d) Establisnment of a positioning system and site survey;
e) Perform a bathymetric and geophysical survey;
f) Final definition of the geotechnical investigations on the basis of the evaluation of existing conditions;
g) Perform the geotechnical investigations including sampling and in situ testing;
h) Laboratory testing of the specimen obtained during the field exploration;
i) Foundation design including the type of subsurface structure, method of construction and other related items; and
j) Installation of the instrumentation to check and monitor the behavior of the facility during and after the construction.

Often, it is necessary to perform small scale field pilot testing in order to ascertain the design assumptions.

The use of the Swedish Foil Sampler (13) and the Vibratory Corer (14) in addition to piston sampler and Shelby tube sampler in offshore investigations may be considered. It is the write's understanding that a Swedish Foil Sampler is available at the Research Institute of the Ministry of Construction of Korea. Utilization of the approprate equipment should be made. These equipment would enhance the results of the investigations, and therefore, their utilization should be encouraged.

Interesting and useful concepts concerning the geotechnical properties of marine sediments, mineralogy and other charateristics were presented by Skempton (15). Clay mineralogical contents were determined from simple identification test, and the depositional environment of the sediments was analyzed in detail. These concepts would be useful for the evaluation of post-depositional behavior of sediments.

DESIGN AND CONSTRUCTION

The most widely used design and construction method for closure dikes in marine environment in Korea currently is called "the forced displacement" method. Basically, rocks were placed from shore-line into the soft marine sediment until the settlement ceases, and the process is repeated.

Hough (16), in 1938, performed an experimental study for the Passamaquoddy Tidal Power Project in which he placed weight on soft marine sediments in order to observe the passage of the materials placed on the sediments. The results are presented on Fig, 3, Forced Displacement. As indicated in the Figure 3, the materials displaced are larger than the embankment section. In addition, the soft sediments are not replaced by the fill materials in the central area indicating additional settlement subsequent to the completion of eonstruction. This settlement should be considered as "long-term" settlement. If the owner is to pay the fill materials by volume of materials placed, a considerable waste will obviously materialize. On the other hand, if the contractor is to be paid by the length of the completed dike regardless of the volume of materials placed, he is in a loosing game. Furthermore, the completed dike is subjected to long term settlement. A docking facility constructed more than 50 years ago in Pusan, Korea is still experiencing substantial settlement requiring costly periodic remedial measures. It is understood that there were several recent cases where total failure of the complete facilities took place.

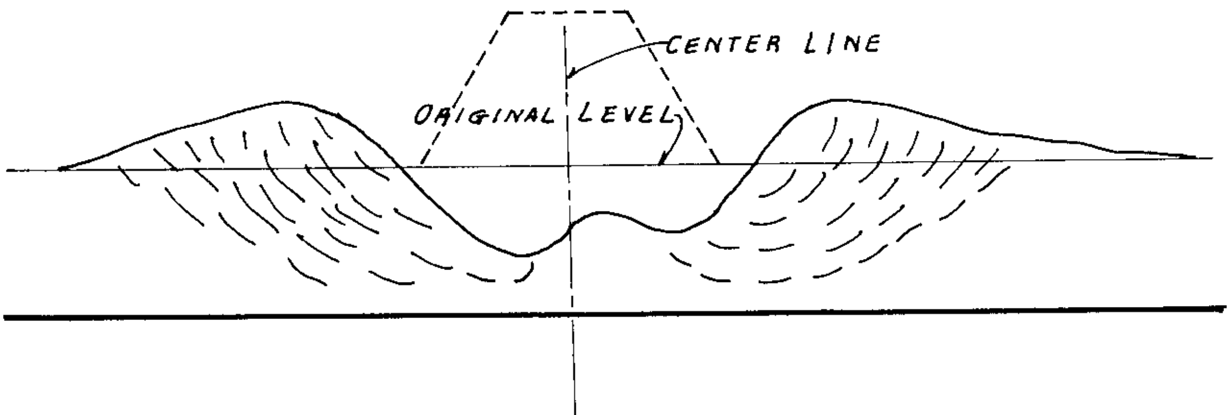

FIGURE 3. FORCED DISPLACEMENT [AFTER HOUGH (16)]

In order to accelerate the settlement within the soft sediments, several types of high permeability materials (sand columns or artificial fabrics) are inserted into the formation and surcharged. Subsequently, the surcharge materials are removed and the next phase of construction commences. Depending upon the volume of fill materials placed and length of time the fill is kept in place, reasonably good results are obtained. On the other hand, unacceptable results were also encountered. Furthermore, it often takes two years or more to complete the necessary settlement and double handing of the surcharge fill materials are also required. Also, additional settlement often takes place though it may be rather small in magnitude sometimes. Use of vertical drains to accelerate the settlement(strenghening the materials), as described above, are relatively common in Korea.

The Kansai Airport of Osaka, Japan is a good exaple where vertical drains were utilized for a very large project. The Hong Kong Airpot at Chek Lap Kok has approximately 10 meters of soft marine sediment(Upper Marine Deposits) which was dated to be younger than 8,000 years(17). Comprehensive Reports on Chek Lap Kok Airport Project are presented in the Journal of Geotechnical Engineering, Vol. 113, No. 2(7, 18 and 19), (1987).

The Phase I Report(geotechnical) for the NSMA Project in Yong-jung-do (8) evaluated and compared the following construction techniques:

a) Sand compaction pile;
b) Deep soil mixing;
c) Weight balance;
d) Stage construction;
e) Forced displacement;
f) Dredging and replacement; and
g) Fluidization and replacement.

The Trial embankments on Malaysian marine formations were constructed for a highway project during a two year period (1987 to 1989). Various construction methodologies utilized for the project(23) are shown below:

a) Electrochemical injection;
b) Well-point/vacuum;
c) Electro-osmosis;
d) Concrete piles;
e) Sand compaction piles;
f) Direct placement(no treatment);
g) Vacuum/pre-loading;
h) Georeinforcement and drains; and

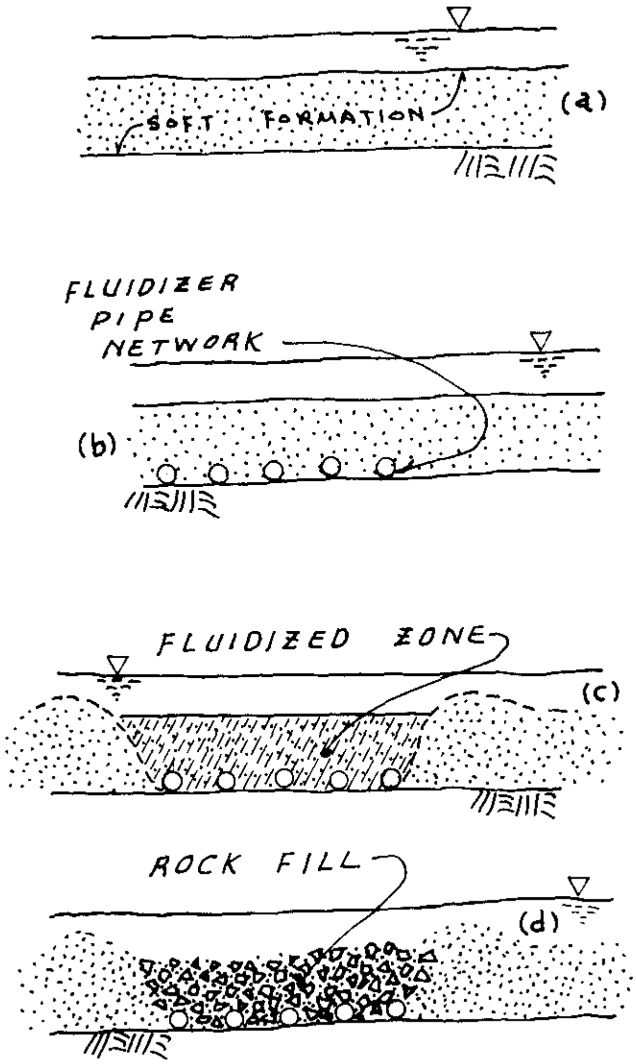

FIGURE 4. THE PROCESSES OF THE NEW TECHNIQUE.

i) Vertical drains/surcharge.

Two performance criteria were established, and they are: 1) Achievement of a method of treatment within a 15-month period; and 2) The magnitude of settlement should be less than 10 cm in 24 months after the completion. The selection and acceptance criteria were not specified for the NSMA project.

It should be understood explicitly that the basic requirement for foundation structures (piles or soft soil treatment) are their fulfillment of the design criteria with respect to the post-construction performance. The remedial measures for malfunctioning foundation systems are extremely expensive. Often, incorporation of remedial measures is not possible for a malfunctioning foundation systems, and the facility may have to be abandoned.

A new technique for soft soil improvement which eliminates the waiting period inherent to the existing methods and which also eliminates subsequent settlement has been developed recently(20).

The technique is relativel simple to implement and negligible subsequent settlement is to be anticipated. A network of perforated pipes are lowere to the bottom of the soft formation and water and/or air under pressure are supplied through the pipes until fluidization is generated within the formation above the network. Rock fragments are placed in the fluidized zone. The process is presented, in stages, on Figure.4, The Processes of the New Technique. Fluidization of fine sand formations for sediment removal purposes were used in the U.S.(21 and 22).

In general, the upper soft marine formations encountered along the coastal areas in the western portion of Korea have moisture contents in excess of the liquid limits. These sediments are very soft and their Standard Penetration Test value N is five or less in most places. The dispersivity of the materials have not yet been determined. However, judging from the low clay fraction of the materials(less than 10% passing 0.005 mm), it is believed that the dispersivity would be relatively high, In the materials with relatively high dispersivity, it would be possible to lower the fluidizer pipe network to a desired depth by supplying air under pressure through a small diameter lines attached along the bottom of the fluidizer pipes. Lowering the fluidizer pipe network by the use of high air pressure would be possible only in materials with high dipersivity. In materials with low dispersivity, methods other than the use of high air pressure such as some mechanical device, would be required.

Once lowered to a desired depth, water and/or under pressure would be supplied through the fluidization pipes and a complete fluidization of materials above the network is obtained. Fill materials(mainly rock fragments) are placed into the fluidized zone. For the fluidized zone has no bearing capacity, all fill materials placed would settle to the bottom. The process is continued until the desired volume of fill materials are in-place. The turbidity generated during the operation would be prevented from spreading to the proximity of the construction by the use of suitable membrane placed around the construction site. Fill materials thus placed would experience little or no settlement immediately following the completion of construction.

SUMMARY

An overview of the geotechical aspect in the planning, design and construction of artificial islands on the marine environment in the coastal areas of Korea is presented.

Importance of a comprehensive geotechnical investigation of marine environments and its influence on the sucessful completion of construction have been established. Also, the types of samplers which are readily available but not in use have been described. Recently developed concepts on the interpretation of desiccated materials and a new construction method were presented.

Failures during and after the completion of construction in marine environments were encountered, and the causes were often attributed to insufficient understanding of geotechnical properties and behavior of the soft sediments. Other unusual causes for failures could be due to factors of economics and time restraints receividing priority over the safety of the foundation systems. Remedial measures after the failure in marine environments are always extremely costly, and therfore, should be avoided.

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