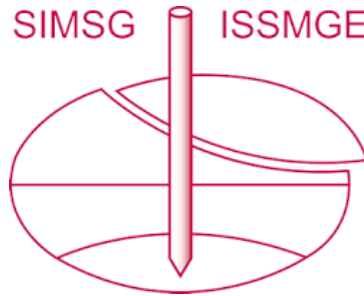


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Geotechnical study for Arctic-Circle resource development using evaluation of environmental impact and frozen soil experiment

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ABSTRACT: Construction in the extreme cold regions becomes one of the important businesses in the world. The permafrost area covers about 14percent of the world's land area and the global construction market for such area is rapidly expanded. Whereas the developed countries have already recognition of the need for research of coldest place and invested heavily in technology development, non-arctic countries are still developing and related research has rarely been performed. This paper shows the characteristics and procedures of Environmental Impact Assessment (EIA) for developing Arctic resources, and reviews how to construct a system for the systematic management of the necessary information. In addition, the laboratory chamber tests were carried out to evaluate the applicability of frozen soil behavior using the newly-produced insulated aggregate. The chamber tests were conducted to check the laboratory model surrounded by soil mixing the insulated aggregate and ordinary soil in order to prevent the damage of structures such as pipelines due to the ground being frozen. For the laboratory chamber tests, the extreme cold engineering laboratory was built in the Korea Institute of Civil Engineering and Building Technology.

KEYWORDS: Arctic-Circle, Energy, Resource, EIA, Frozen-soil

1 INTRODUCTION.

The Arctic Circle refers to the region north of 66.56° north latitude, including the Arctic Ocean. Its surface area is about 21 million km², accounting for about 6% of the earth's surface. The Arctic Ocean, which is mostly covered by ice, is the smallest ocean among the 5 major oceans and represents 3% of the world's seas. The average temperature of the Arctic coastal area ranges from -20°C to -30°C in the winter and from 4°C to 8°C in the summer. The Arctic region is in line with the timberline and the Permafrost's boundary line. Under international law, this region belongs to 8 countries, namely Russia, US, Canada, Norway, Denmark, Finland, Iceland and Sweden, but Russia, US, Canada, Norway and Denmark actually face the Arctic Ocean (Lee et al, 2010). The Arctic Circle possesses 22% of the world's total natural resources such as undiscovered oil/gas.

Currently, as global warming is in progress at a rapid pace and Arctic glaciers are melting and snow and ice are disappearing, it becomes possible to develop resources buried in this region. Global warming shortened the freezing season, increasing the period of resource exploration, development and the expansion of the geographical scope. Accordingly, the international community expresses its interest in the development of resources in the Arctic region and is having a dispute over territorial sovereignty and maritime jurisdiction (Kim, 2009). As the Arctic sea route, where earlier navigation had been difficult due to glaciers and thick ice, becomes feasible for use, there are disputes over ships' right-of-way under the international law (Yun, 2014). In addition, issues are continuously being raised over marine environmental pollution and disasters caused by resource development

organization in the Arctic and their use of the Arctic sea route.

This paper examines the different characteristics of the Environmental Impact Assessment which should be considered in promoting the Arctic resource development project and the possible ways to systematically manage and utilize the necessary information. To this end, it looked at the basic characteristics and procedures of the Arctic Environmental Impact Assessment and classified and defined the necessary data. It also suggested the concept and basic design plan of the data system required for data management and utilization.

In addition, this paper conducted a series of laboratory tests to evaluate the characteristics of frozen soil using the newly-produced insulated aggregate and analyzed the results for the construction project in extreme cold regions. It also sought ways for recycling anti-frost materials. For the laboratory chamber tests, the extreme cold engineering laboratory was built in the Korea Institute of Civil Engineering and Building Technology. The extreme cold engineering lab consists of a chamber which allows the precise control of ultralow temperatures, a full-scale chamber where the large-scale model test can be conducted, and a freezing chamber for the storage and production of frozen soil. This study also included the test on the laboratory model surrounded by soil mixing the insulated aggregate and ordinary soil in order to prevent the damage of structures such as pipelines due to the frozen ground. Based on this test, the temperature and frost susceptibility of the ground model was measured to compare them with the ground covered by ordinary soil. The study also planned to improve upon the constructability and economic feasibility through an analysis on the mixing method for soil and the insulated aggregate.

The research on anti-frost materials has been steadily conducted over the years. Gandaha (1982) measured the frost heaving of the

anti-frost material layer of different materials for 20 years and proposed the thickness of anti-frost layer according to the material type (normal gravel layer, bark, light aggregate, plastic). Henry (1997) conducted a study on frost susceptibility for the 100% waste glass and 30% weight ratio waste glass with the construction aggregate. Koubaa and Snyder (2001) investigated the site freeze-thaw behavior of concrete aggregate on highways and proposed the test procedure and standards of laboratory studies. Santomi et al. (2001) carried out the uniaxial compressive tests to study the behavior of a composite material which is mixed with sandy soil and discontinuous fiber soil.

2 ENVIRONMENTAL IMPACT ASSESSMENT (EIA) FOR ARCTIC RESOURCE DEVELOPMENT PROJECT

2.1 Background of EIA for Arctic Development Project

The Arctic has a low population density, a very vulnerable ecosystem and is surrounded by sensitive social and natural environment with poor biodiversity, etc. Specifically, the unique livelihoods and local community issues of Arctic indigenous people are important factors to be considered for the approval of Arctic development projects. In the Arctic, the EIA has been settled in a diversified way by reflecting the social and environmental characteristics in the subject local areas and therefore, its systems and procedures vary depending on countries.

In 2005, the Arctic Council warned, during the Arctic Climate Impact Assessment (ACIA), that global warming in the Arctic region had been twice as fast than the world's average since 1970 (Berner, Jim, O. W. Heal., 2005). According to this report, 1) the climate in the Arctic is warming rapidly and much larger changes are expected, 2) vegetation zones are highly likely to move, causing a broad impact, 3) changes are likely to occur in the biodiversity, range and distribution of animal species, 4) the societies and facilities in many coastal areas are increasingly likely to be exposed to storm, 5) reduced sea ice is highly likely to increase the access to marine transportation and resources, 6) sea ice could destroy traffic, buildings and other infrastructure, 7) due to the dramatic climate change in the Arctic, the indigenous community faces major economic and cultural influences and 8) various influences could interact with each other, consequently increasing the impact on people and the ecosystem.

Representatives from the Arctic countries gathered in Rovaniemi, Finland in 1991 and approved the Arctic Environmental Protection Strategy (AEPS) which pursues environmental protection in the Arctic region (VanderZwaag et al., 2002). With the support of AEPS, the Arctic Environmental Impact Assessment Guideline was developed under the leadership of Finland in 1994. This guideline was approved in the process of turning the AEPS into the Arctic Council in 1997.

The purpose of the Arctic Environmental Impact Assessment is to prevent any hazardous impacts on the Arctic environment, including all flora and fauna, non-biological factors, natural resources and human health, security and well-being, etc. This guideline provides practical guidance for the environmental assessment of all parties, especially the local authority, developers and local residents. The guideline is not mandatory, but it deals with important issues unique to the Arctic region such as public participation and traditional knowledge, for example, on permafrost, those who wish to conduct a resource development project in the Arctic Circle must refer to it.

2.2 Characteristics of Arctic Environmental Impact Assessment

As the Arctic Circle is one of the regions which is the most sensitively affected by environmental pollution such as global warming, particular attention should be paid to changes occurring in the ecosystem and local community when conducting resource development projects, including oil wells or

gas. Since the Arctic region has geopolitical characteristics that it is surrounded by lands such as the Eurasian Continent, North America Continent and Greenland centering on the Arctic Ocean, there exist various standards and consultative bodies. However, there is no actual executive or binding force due to the absence of international legal values and standards.

As for the assessment of environmental pollution, a new environmental pollution impact assessment should be developed in accordance with the Arctic environment by referring to the existing assessment methodologies since currently there is only the Arctic Environmental Impact Assessment Guideline (Arctic Environmental Protection Strategy) with no mandatory provisions. Specifically, a careful and strategic approach is needed since there may be a conflict of opinions among coastal nations in the Arctic region or the sharp conflict of interests with indigenous people over development projects. In addition, as for the Arctic, once polluted, the ecosystem would be rapidly destroyed due to convection current spreading pollution rapidly, whereas the lack of infrastructure and poor climate conditions would hinder restoration. Accordingly, there have recently been cases where resource development projects for the Arctic Ocean are delayed due to environment and safety.

The Arctic EIA should consider environmental characteristics, including low population, vulnerable ecosystem and slow recovery rate. The transboundary impact and cumulative impact among countries should be considered. In addition, it is required to consider the participation of various stakeholders having different opinions and values since there are countries claiming the territorial sovereignty and indigenous people are living in the Arctic, unlike the Antarctic.

Public consultation is very important in the Arctic EIA and includes unique provisions specific to the situation of each country. For example, there is an EIA process to consult with and embrace indigenous people in a meaningful way in northern Canada. In Greenland, Denmark, the social impact of mineral resource projects are assessed separately from EIA.

In recent years, there is a need felt for the assessment criteria which reflects the cultural values and sensitivity of each region has been raised. In the case of Denmark, for example, Greenland and the southern area, all have different EIA criterion. In Greenland, as the access road constructed as a part of the hydropower project provided an opportunity to visit to hunting sites, which was previously not available, it has been considered advantageous to the local community. In contrast, in southern Denmark, a similar project has been found to have a very harmful impact on the scenery. That is, the physical access has been considered important in Greenland with low population and the insufficient infrastructure and visual impact has not been a problem, unlike southern Denmark.

3 ESTABLISHMENT OF ARCTIC ENVIRONMENTAL IMPACT ASSESSMENT INFORMATION SYSTEM

3.1 Background and Necessity of Establishing Information System

In order to carry out an effective EIA by considering the unique characteristics of the social and natural environment in the Arctic, it is imperative to collect and analyze reliable information from the initial stage of planning and to make a decision based on such information. Currently, the information on regulations and literature, various basic materials required for the EIA of Arctic development projects is scattered, in many ways. For example, GRID Arendal provides information on the environmental pollution, ecosystem data and the distribution of indigenous people, etc. Besides, there are many Websites, including the Arctic Portal, EU Arctic Information Center and Arctic Data Explorer, where the environmental data of the Arctic could be searched and checked for. Since the categories and forms of

information provided by each Website are different from one another, however, it takes a lot of time to search and utilize the data. It is also difficult to predict the impact and risks of the project in advance to duly reflect them in the project strategy. This may hinder the smooth conducting of projects by, for example, causing difficulties in the project location selection and impact assessments and could lead to the loss of time and costs. In order to address such problems, this paper examines how to construct the information system to systematically manage and utilize all the data necessary for the EIA of Arctic development projects. The EIA information system includes both the database system managing a broad range of data and the application system reviewing the environmental impact, including data search, check and analysis.

3.2 Overview of Information System

The Arctic EIA should comply with the legal/institutional standards of the country where the development project is being conducted, while at the same time, also meeting other requirements such as related international treaties or agreements and the common guidelines of the Arctic Circle. Therefore, it is required to collect data such as a broad range of legal/institutional requirements, regional characteristics and best practices right from the initial stage of planning the Arctic resource development projects. It is also required to review sufficient data, as there is no standardized procedure or details, unlike the Antarctic, and each country has different details or criteria and different cultures.

The information system suggested in this paper includes the database in order to easily search the data necessary for the entire process right from the selection of a construction project site to planning the EIA and follow-up management for the Arctic resource development projects. It is not only linked to the data and databases of relevant organizations such as competent national organizations, research centers and international organizations regarding the Arctic EIA, but also builds the database by collecting the existing EIA cases and monitoring data, etc. In addition, this system supports effectively carrying out EIA-related procedures such as location analysis and the impact assessment of Arctic resource development projects by utilizing the database. Figure 1 shows the overview of the EIA information system.

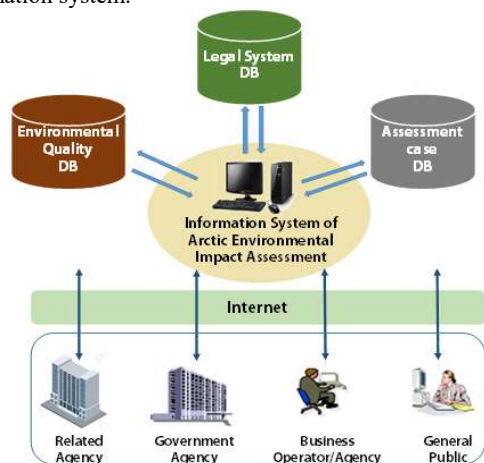


Figure. 1. Environment Impact Assessment (EIA) information system outline

4 LABORATORY TESTS ON ANT-IFROST MATERAILS

In this research, the performance of insulated aggregate using recycled vinyl was evaluated through the laboratory experiments. HDPE (High Density Polyethylene) and LDPE (Low Density Polyethylene) are mainly used in making Vinyl. While HDPE, which is hard, is used as a cover for crop farming, LDPE, which

is soft, is used for greenhouses. Vinyl for greenhouses is easily recyclable since it rarely has foreign substances, whereas vinyl for the cover is hard to be recycled since it contains a lot of foreign substances such as soil particles. For recycled vinyl, this study used vinyl for greenhouses (LDPE) collected by the Korea Environment Corporation. Recycled vinyl used for the test contained a variety of foreign substances. In order to analyze the foreign substances contained in the recycled vinyl, the collected vinyl was divided into four pieces and then weighed. After putting the sample into a drying finance, the dry weight was measured to determine the moisture content of the vinyl. The dried vinyl was washed clean and dried again to measure the amount of soil in the vinyl. As a result, foreign substances contained in the collected vinyl was shown to be about 50% of the total weight. Of all the foreign substances, soil accounted for 60% composition, water was about 38% and others were 2%. That is, the collected vinyl consisted of 50% of pure vinyl, 30% of soil and about 20% of water.

In this study, a series of laboratory tests (specific gravity test, sieve analysis test, direct shear test, test for abrasion of coarse and aggregates with the use of the Los Angeles machine) were conducted to investigate the basic characteristics of the manufactured vinyl aggregate as anti-frost material.

4.1 Physical properties

Table 1, 2 shows the specific gravities and unit weights of the anti-frost materials using vinyl. According to the test results, insulated aggregate has a 65% of unit weight compared to the natural aggregate which were collected near the test location, Gyenggi-do, Republic of Korea. By using these characteristics, it is considered that the use of light-weight aggregate, which can reduce the weight of the structure and used as a backfill of the retaining wall, will be effective.

Table 1. Test results of specific gravities

Sample No.	No.1	No.2	No.3
Specific gravity	1.06	1.10	1.11

Table 2. Unit weights of natural aggregate and anti-frost materials using vinyl

Sample type	Anti-frost materials using vinyl			Natural aggregate (Gyenggi-do, Republic of Kore)		
Sample No	No.1	No.2	No.3	No.1	No.2	No.3
Unit weight(g/cm ³)	1.14	1.16	1.08	1.74	1.77	1.72
Average Unit weight(g/cm ³)	1.13			1.74		

Insulation aggregates were tested for abrasion in accordance with KS F 2508. The purpose of this abrasion test is that the insulation aggregate used must be stable to temperature and humidity changes and durable for freeze-thawing. If the material is an unstable and non-durable aggregate, fracture of the aggregate due to freeze-thawing occurs and affects the target structure. The equipment of LA abrasion test used in this study consists of a steel cylinder with an inner diameter of 710 mm and an inner length of 510 mm. This cylindrical mold is rotated about its axis, which is connected to the center of both sides. There is an inlet for the sample to go into the cylindrical mold, and it is completely sealed to prevent the broken powder from leaking out. The inside of the mold has a protruding dust pan which is 89 mm in width and 510 mm in length, and a rotating device is mounted on the outer right side of the cylinder. The operating method of this rotating device is a motor driving method, and the rotation speed is 30-33rpm. The diameter of the iron beads used for the test is

about 47.5mm and weight is 390-445g. The test results showed that the abrasion of vinyl-aggregate is 2.36% as shown in table 3. Considering that the abrasion of road pavement gravel is 35% or less and that of the dam concrete gravel wear is 40% or less, the abrasion of vinyl-aggregate is quite small.

Table 3. Test results of abrasion

Sample Type	Abrasion (%)
Anti-frost materials using vinyl	2.36
Aggregate of road pavement	< 35
Aggregate of Dam concrete	< 40

In addition, a direct shear test of anti-frost materials using vinyl was performed. The cohesion and internal friction of the materials are 0kg/cm² and 51.3 ° respectively

4.2 Thermal Conductivity tests

Thermal conductivity test was also carried out to evaluate the heat transfer characteristics of the insulated aggregate. Insulated aggregates were compacted at 90% of the maximum dry density in a measuring box with size 25 × 25 × 10 cm. QTM probe was placed on the sample surface, and the average value was calculated by measuring the thermal conductivity five times. In addition, thermal conductivity tests were performed on sand, clay, gravel, and rock to compare the thermal conductivity of general construction materials. Table 4 shows the test results of thermal conductivity tests.

Table 4. Test results of Thermal conductivity tests

Sample No.	Thermal conductivity (Kcal/mh °C)
No.1	0.097
No.2	0.083
No.3	0.089
No.4	0.098
No.5	0.094
Average	0.092

4.3 Environmental hazard review

The dissolution test on the insulated aggregate was performed and the pollutant content is shown in Table 5. As a result of the dissolution test, the insulated aggregate using vinyl showed 0.10ppm of copper, while Pb, As, Hg, Cr, CN, Cd, trichloroethylene, tetrachloroethylene and organophosphorus were not detected at all. Insulated aggregate using vinyl were found to be below the standard for all hazardous items and environmentally safe as general wastes.

Table 5. Test results of dissolution test

Pollution type	Acceptance criteria	Test results of dissolution test
Lead (Pb)	3.0 mg/l	ND
Cadmium (Cd)	0.3 mg/l	ND
Copper (Cu)	3.0 mg/l	0.10 mg/l
Arsenic (As)	1.5 mg/l	ND
Cyanide (CN)	1.0 mg/l	ND

Mercury (Hg)	0.0005 mg/l	ND
Trichloroethylene	0.3 mg/l	ND
Tetrachloroethylene	0.1 mg/l	ND
Oil	5 %	0.92

5 FREEZING CHAMBER TESTS

In this research, the laboratory chamber tests were carried out to evaluate the applicability of frozen soil behavior installed with the newly-produced insulated aggregate. The chamber tests were conducted to check the laboratory model surrounded by soil, mixing the insulated aggregate and ordinary soil in order to prevent damage to structures such as pipelines due to the freezing of the ground. For the laboratory chamber tests, the extreme cold engineering laboratory was built in the Korea Institute of Civil Engineering and Building Technology.

5.1 Freezing chamber

The freezing chamber with the width of 10.0 m, the length of 5.0 m and the height of 5.5 m is a test equipment produced to conduct various freezing tests under temperatures as low as 30°C within the chamber.

In the freezing chamber, four cooling motors push hot air to the air circulating duct, taking away heat from it, and then releasing the cold air inside the chamber through the duct. The temperature in the large freezing chamber is allowed to be set from the lowest temperature of -30°C to the highest temperature of 50°C. There are five thermistors in total, including the main thermistor within the chamber implemented so as to check whether the actual temperature inside is correctly set in accordance to the set temperature via real-time monitoring. The chamber temperature by this thermistor is indicated for each channel via the control box, and it is possible to check if the set temperature is maintained within the chamber via the record installed there.

The calibration chamber for the road model of the frozen ground surface has a width of 1,200 mm and a length of 1,500 mm, and largely consists of the pressurized part with overburden load, the main body part of the calibration chamber and the water tank part (supplying water). Every part of the calibration chamber is assembled with bolts and nuts, which makes it easy to dismantle the setup after completing a test. One of the calibration chamber walls has a 2 cm-thick acrylic plate on it so as to see the insides, and other side walls and the base are made of steel sheets and frame which can sufficiently withstand frost heaving during a test. Figure 2 shows the freezing chamber and chamber test equipment.



Freezing chamber



Chamber tests equipment

Figure. 2. Freezing chamber

5.2 Sample properties

The insulated aggregate used in the laboratory chamber test was in the form of pieces crushed to the diameter of 7 mm or less and used the soil sample collected from Paju, Gyeonggi-do.

The mixing ratio of the insulated aggregate and soil sample was the aggregate-based weight ratio and the test was conducted with

the ratio of i) insulated aggregate 15%: soil sample 85% and ii) insulated aggregate 50%: soil sample 50%. Table 6 shows the mixing ratio, compacted condition and water contents of the experiment samples.

Table 6. Test results of abrasion

Mixing ratio (Aggregate:soil)	g_d (g/cm ³)	g_t (g/cm ³)	Water content, w (%)
Sample A (50:50)	0.93	1.02	13.0
Sample b (15:85)	1.41	1.55	13.0

5.3 Test procedure

Four perpendicular-style earth pressure meters were installed; out of which two were 30 cm, 50 cm below the ground surface, respectively; one was on the upper part of the underground pipe; one was 15 cm horizontally away from the bottom part of the underground pipe. The sidewall types were installed both on the right and left of the underground pipe, respectively, and 12 thermistors were installed at vertical intervals of 10 cm. In order to enhance the insulation effect, the Styrofoam layer of 5 cm was installed on the wall within the chamber so that cold air in the atmosphere could only penetrate from the upper side i.e, from one dimension.

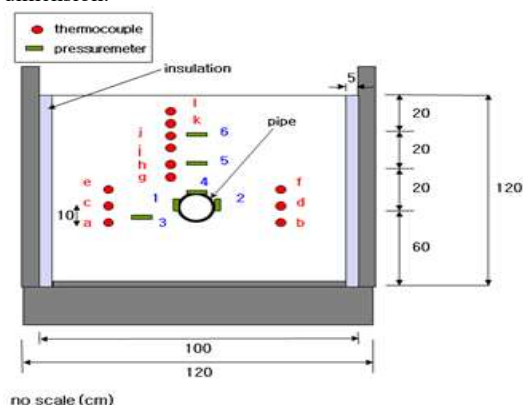


Figure 3. Layout of measuring instrument

5.4 Test results

5.4.1 Temperature distribution by location

The following is the temperature changes observed at each location of the ground mixed with the insulated aggregate where the thermistor was buried. Figure 4(a) shows that the temperature of the freezing chamber is operating at -10°C for 240 hours and -20°C for 120 hours on the condition that the mixing ratio of the insulated aggregate is 15%. The test is still ongoing. In Figure 2.5.10(a), the results measured so far show that thermistor a (-10 cm) located close to the ground surface indicated the lowest temperature of -17.2°C and thermistor j (-100 cm) indicated -12.1°C.

Figure 4(b) shows the temperature changes observed at each location when the freezing chamber is operating at -10°C for 250 hours and at -20°C for 140 hours in the condition that the mixing ratio of the insulated aggregate is 50%. For thermistors, thermistor a (-10 cm) located close to the ground surface indicated the lowest temperature of -15.8°C and thermistor k which was buried the deepest (-110 cm) among all indicated -10.3°C.

Overall, the temperature lowered as time passed and the temperature of the upper part was lower than that of the bottom part. In addition, it is shown that the higher the mixing ratio of the insulated aggregate, the larger the insulation effect.

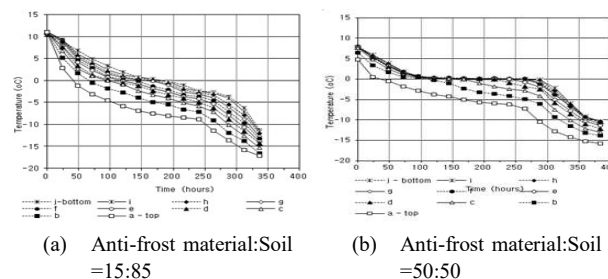


Figure 4. Temperature distribution: a) mixing ratio of Anti-frost material and soil is 15:85; b) the mixing ratio of Anti-frost material and soil is 50:50

5.4.2 Measurement of freezing earth pressure

Figure 5 shows the increase in freezing earth pressure of the soil mixed with pieces of the insulated aggregate. The increase of earth pressure at the mixing ratio of 15% was shown to be 0.58t/m² for the upper part of the underground pipe, 0.48t/m² for the bottom part, and 0.67t/m² and 0.72t/m² for the left and right, respectively.

As the insulated aggregate increased, the earth pressure decreased. Specifically, the earth pressure in the upper and bottom parts of the underground pipe became dramatically lower than that of the side parts. With a mixing ratio of 50%, it has been shown that the earth pressure increase in the side parts of the underground pipe was more than almost three times higher than that of the top and the bottom parts.

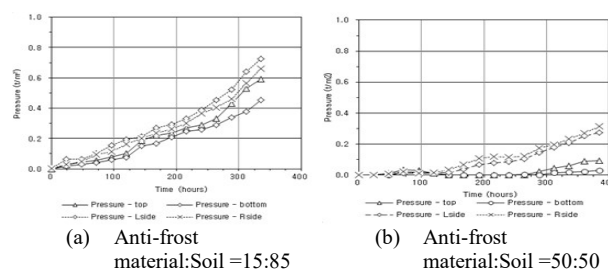


Figure 5. Earth pressure distribution: a) mixing ratio of Anti-frost material and soil is 15:85; b) the mixing ratio of Anti-frost material and soil is 50:50

6 DISCUSSION

It is well known that there are a lot of undeveloped energy resources in the Arctic Circle. As global warming enables the use of Arctic sea routes, the interest in Arctic resource development is increasing. Recently, its polar neighbors and developed countries are actively promoting construction projects in the Arctic Circle. However, the issue of environmental pollution which will be caused by Arctic resource development has been raised. Today, environmental issues have a significant impact on the success of a project as well as on the costs of Arctic development projects. Therefore, it is necessary to secure a technology related to the energy resource development and transportation aspect of the Arctic resource project. In addition, the establishment of strategy for environmental impact assessment (EIA) is important. This paper shows the characteristics and procedures of EIA for developing the Arctic resources, and reviews how to construct a system for the systematic management of the necessary information. This system consists of a database required for environmental impact

assessment and its application. The system is expected to be utilized for strategic development projects in the Arctic.

In this study, a series of laboratory experiments were performed to estimate the characteristics of newly-developed insulated aggregate using vinyl. The specific gravity test, sieve analysis test, direct shear test and test for abrasion of coarse and aggregates, with the use of the Los Angeles machine, were conducted to investigate the basic characteristic of the manufactured vinyl aggregate as an anti-frost material. In addition, the laboratory chamber tests were carried out to evaluate the performance of frozen soil behavior which is installed with the newly-produced insulated aggregate. For conducting the laboratory chamber tests, the extreme cold engineering laboratory was built. The extreme cold engineering laboratory has a freezing chamber with a width of 10.0 m, length of 5.0 m and a height of 5.5 m, is a test equipment produced to conduct various freezing tests under temperatures as low as 30°C within the chamber.

This study included the freezing chamber tests on the laboratory model surrounded by soil, mixing the insulated aggregate and ordinary soil in order to prevent damage to structures such as pipelines due to freezing of the ground surface. Based on the results of the experiments presented herein, the following conclusions can be drawn regarding the change of temperature and the earth pressure of freezing ground which is installed with the insulated aggregate using the wasted vinyl which is generally used on an anti-frost layer:

(1) Temperature distribution

In order to compare the insulation effect of the pieces of insulated aggregate, this study compared the results of temperature distribution at the installation point of the underground pipe (-60 cm) with the results of both the temperature distribution in the granite soil ground and the temperature distribution at the mixing ratio of 50%. The lowest temperature of the ground surface model including the soil mixed with the insulated aggregate (50%) was -3.3°C and that of the ground model with the ordinary soil sample was -10.5°C, showing that the temperature of the former ground sample was 7.2°C higher than the latter. Given this, it is considered that soil mixed with the insulated aggregate has a higher insulation effect than that of the ordinary soil sample.

(2) Freezing earth pressure

Looking at the increases of earth pressure at each degree of temperature on soil mixed with the insulated aggregate (50:50) and on the ordinary ground, while also observing the freezing earth pressure at each position according to time changes, it is shown that the earth pressure increase of soil mixed with the insulated aggregate was smaller than that of the ordinary ground. At a temperature of -15°C, the earth pressure increase was 1.21t/m² for ordinary ground surface and 0.056t/m² for soil mixed with insulated aggregate on the upper part of the underground pipe, while the increase was shown to be 1.202t/m² for the ordinary soil sample and 0.032t/m² for soil mixed with the insulated aggregate in the bottom part. In addition, on the right and left sides of the underground pipe the earth pressure increase was 0.55t/m² and 0.61t/m², respectively, for the ordinary soil sample, and 0.32t/m² and 0.56t/m², respectively, for soil mixed with the insulated aggregate.

As the pieces of the insulated aggregate increased, the earth pressure lowered dramatically. Specifically, in the case of soil mixed with the insulated aggregate, the earth pressure decrease in the side parts of the underground pipe was about 60% of that in the case of ordinary ground, but the earth pressure decrease in the upper and bottom parts was about 5%, indicating that the effect of the earth pressure decrease was big in the upper and bottom parts of the underground pipe.

The experimental results can be used to estimate the strength of the plant-substructure on the frozen ground. The results of the temperature distribution and freezing earth pressure can be used as basic data for evaluating and improving the running performance of fluid machinery in frozen soil in cold region.

7 ACKNOWLEDGEMENTS

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