Drainage and reinforcement of landfill leachate using drain pile
배수파일을 이용한 매립장의 침출수 배수 및 보강

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SYNOPSIS : 매립장 내의 설치된 중간 복토층(intermediate cover)은 매립 도중 혹은 매립완료 후 종종 침출수가 하부의 침출수 집배수관으로 이동하는 것을 막아 매립장 내에 일정 침출수위를 형성시킨다. 이렇듯 중간복토층은 침출수의 원활한 순환을 막아 매립장 바닥에 형성되어야 하는 침출수위가 중간복토층 위에 형성되도록 하는데, 이는 매립장의 구조적 안정성을 깨뜨리고 주변으로 침출수 누출을 유발시키게 된다. 본 연구에서는 이처럼 중간복토층 상부에 형성된 침출수위를 저하시키기 위하여, 폐기물 매립시 중간복토층에 투수성이 뛰어나고 역학적 강도와 화학적 내구성을 갖는 배수파일(Drain Pile)을 설치할 것을 제안하였다. 배수파일은 중간복토층 상부에 형성될 수 있는 침출수를 매립장 바닥으로 배수시키고, 침출수 집배수정으로 이송이 가능하게 만든다. 또한 배수파일은 매립장 내부에 설치됨으로써 폐기물의 자체 강성을 증가시키고, 동시에 매립장의 측방유동을 막아 구조적 안정성을 확보하는 효과도 기대할 수 있다.
실내시험을 통해 배수파일 충진재로서 굴패각의 활용가능성을 확인한 결과, 산업 폐기물인 굴패각이 침출수의 pH를 중화시키고 유해물질인 NH_4^+를 제거하는데 효과적임을 확인할 수 있었다. 한편, 실제현장의 침출수 흐름을 모사하기 위해 범용 프로그램(SEEP/W)을 이용하여 매립지 내에서 배수 파일의 효과를 확인하였다.

Key words : drain pile, landfill, leachate, pH, NH_4^+, oyster shell

1. Introduction

This paper concerns with the problem which is related to high leachate level generated by low hydraulic conductivity of intermediate cover layer as pertains to the stability of landfill(Jang et. al., 1998). Low hydraulic conductivity of intermediate cover layer(less than 10^{-7}cm/sec) restrains vertical drainage and forms a puddle in several middle place. It causes a rise of leachate level. The increase of leachate level at the landfill has caused an collapse on design gradient of slope by decreasing slope stability. Moreover, declining gradient of slope which induces reduction of the amount of reclamation leads to the big financial loss eventually(Kim, 2000). To control leachate level, the development of drain pile is suggested in this research. By establishing drain piles, it is expected to facilitate the vertical drainage of leachate, prevent the landfill from lateral movement and neutralize acid leachate.

To find out the effect of intermediate cover layer of low hydraulic conductivity on the leachate flow in a landfill, laboratory tests(pH test and NH_4^+ removal test) and the numerical modeling (SEEP/W) are conducted.

2. Effect of leachate on the stability of landfill

Leachate is generated by the liquid in the waste as it arrives at the landfill and is augmented by rainwater(or snowmelt) prior to placement of the final cover over the waste mass. Using proper grading and daily cover materials, leachate can be minimized during the active filling operations. Thus, there is no "typical" leachate, and the site-specific waste mass must be considered in this regard.

At the base of an engineered landfill, there typically exists a leachate collection and removal system placed above the barrier layer. This leachate collection and removal layer should consist of a granular soil layer or geocomposite drainage layer of adequate long-term hydraulic conductivity so as to collect the leachate being transmitted through the waste mass. Thus, leachate gravitationally drains through the waste mass and eventually develops head on the base of the facility. Either leakage is accelerated due to this increased head or the head continues to build in the in the waste mass. Obviously, such situations are undesirable(Koerner and Soong, 1999).

There are five possible scenarios of leachate distribution in landfills. The five scenarios are as follows: 1) discontinuous leachate, 2) perched(or localized) leachate, 3) leachate head on the liner, 4) leachate head on the liner with gas entrapment and 5) leachate under excess pore pressure.

The essence of all stability analysis is the formulation of a factor-of-safety(FS) value. As suggested in the following equation, its value must necessarily be greater than unity. How much greater is very subjective, but in geotechnical engineering a $FS \geq 1.5$ is a typical design goal:

$$FS = \sum \frac{\text{Resisting moments}}{\text{Driving moments}} \qquad (1)$$

Resisting moments in the above equation consist of the shear strength of the waste, soil and/or geosynthetics through which the potential failure surface extends. The driving moments are the gravitational stresses of the waste. Of course, both steep face angles and long, uninterrupted surfaces exacerbate the situation. As can be identified for the results of equation, leachate can have a significant effect on lowering the FS-value. Other factors can also have a detrimental effect such as high leachate level, surcharge loads at the top of the slope, equipment forces mobilized during waste placement, excavations at the toe of the advancing waste, vibrations due to equipment or blasting and seismically induced forces.

From cases of increasing leachate level in Kim-po metropolitan landfill in Korea, it was reported that unstable state might be developed. Actually, there had been a slope failure caused by increasing leachate level. As a result, it was required to find the way to increase the stability by lowering gradient of slope than the original plan and, in addition, lower leachate level to ensure sufficient slope stability(S.S. Kim, 2000).

3. Development and application of drain pile buffered by oyster shell in landfill

3.1 Development of drain piles

As mentioned previously, intermediate cover layer has very low hydraulic conductivity(less than 10^{-7}cm/sec). It restrains vertical drainage of leachate and forms a puddle in several middle place. Finally, it causes a rise of leachate level. The rising leachate levels give a negative influence on the stability of landfill. To control leachate level, the development of drain pile is suggested in landfill. Drain piles are expected to facilitate the vertical drainage of leachate, prevent the landfill from lateral movement and neutralize acid leachate in young landfill.

Fig.1 shows the schematic of landfill where drain piles are established . Fig.2 shows a shape of drain pile. The length of the drain pile is determined 60cm because the thickness of intermediate cover layer is usually 50cm. The drain pile may be made out of PVC and will be buffered by oyster shell.

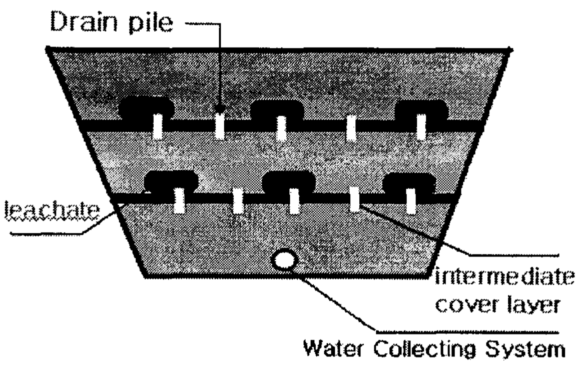


Fig.1 Schematic of landfill with drain pile

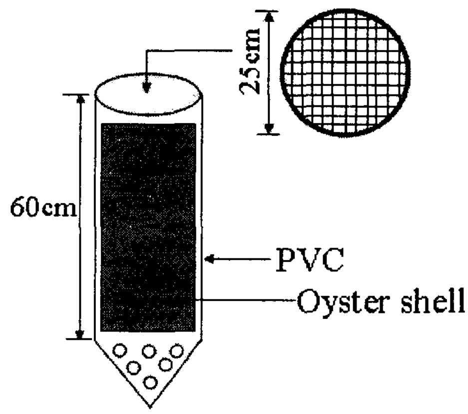


Fig.2 Schematic of drain pile

3.2 Application of drain piles

3.2.1 pH test

In the early filling periods, the leachate contains readily biodegradable organic matters. Thus, these young leachates tend to be acidic due to the presence of volatile fatty acids. The pH is typically in the range of 5 to 6 and may be lower in stressed(dry) landfills(Lee, 2001). The young leachates are drived from the processes such as the complex biodegradation of organics and simple dissolved organics.

To estimate pH change by oyster shell, the pH test was performed with the fixed-wall column containing 8 sampling ports on the wall(Fig.3). The column was compacted with oyster shell in the same manner as the flexible-wall permeameter. The reservior was filled with the acetic acid solution. The acetic acid solution was injected into the column using the peristaltic pump(Master Flex, Cole-parmer co., USA) at the flow-rate 4 mL/min. Sample from the effluent tube was periodically collected each pore volume(PV). Figure 2 shows the fixed-wall column system.

To ensure high hydraulic conductivity, oyster shell was sorted by No.4 to No.10 sieves. The specific gravity of oyster shell is 2.38.

The initial pH was 5.0 before pumping to column. After passing the column, pH of solution increases to about 7.6(Fig.4). The pH standard of discharging leachate ranges 5.8 to 8.0 in Korea. This result means oyster shell can make acid leachate into neutral material. When leachate includes many acid materials, drain piles buffered with oyster shell could neutralize those of acid materials. Following equations show the process of neutralization.

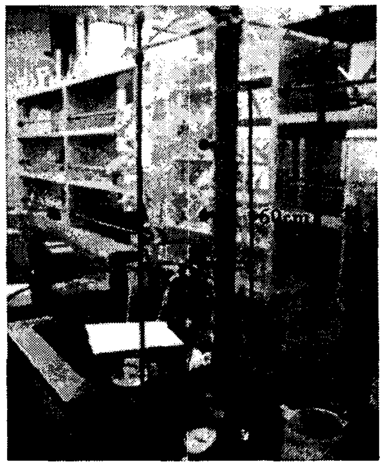


Fig.3 Fixed-wall column system

$$\text{Oyster shell}(CaCO_3) + H_2O \rightarrow \text{Oyster shell} + Ca^{2+} + CO_3^{2-} \quad (2)$$

$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^- \quad (3)$$

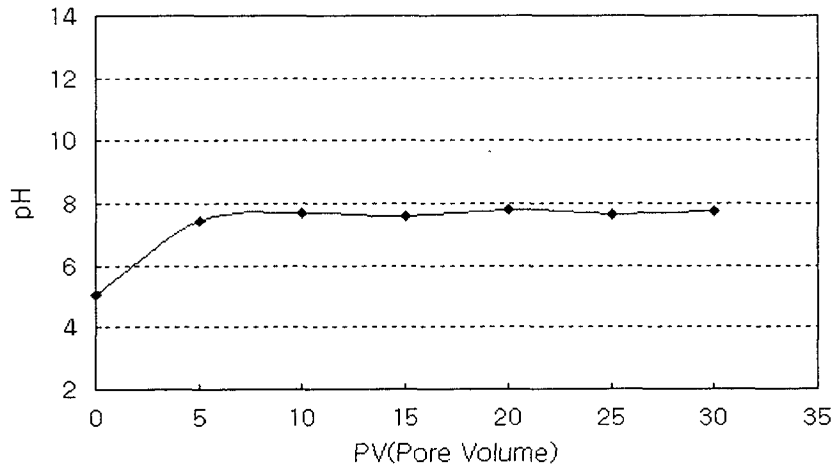


Fig.4 Result of pH test by using fixed-wall column system

3.2.2 NH_4^+ removal test

Biological management has been generally done to treat ammonia nitrogen(NH_3-N). This biological management is called as nitrification. In case of Kim-po metropolitan landfill, discharge concentration of ammonia nitrogen is 1200 mg/L to 1500 mg/L. However, when the concentration of ammonia nitrogen is more than 1000 mg/L, it is known to be very hard to maintain the biological process(Environmental management corporation and Sudokwon landfill site management corporation, 2002).

Ammonia nitrogen(NH_3-N) is the most important component to be managed in leachate because of toxicity. NH_4^+ is created by reaction of NH_3 and water. The reaction process is as follows.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^- \quad (4)$$

Tests are performed to estimate the removal efficiency of NH_4^+ by using oyster shell. First of all, NH_4Cl was dissolved in water. NH_4Cl solution and oyster shell (No.4~No.10) were mixed with blank, 1:10, 1:20, 1:50, 1:100 ratio by weight and then samples were stirred for 24hr. Vials were put into the centrifuge after stirring and samples were extracted. Finally, the concentration of ammonium in samples was analyzed with IC (Ion Chromatography, Waters 432, Waters, USA)

In this test, the initial concentration of ammonium was 2000 mg/L. Fig.5 shows the degradation of the ammonium concentration with increasing the oyster shell content. The concentration of ammonium is observed to decrease slightly with increasing oyster shell content. It means that oyster shell is effective to control the ammonium concentration.

Although the ammonium concentration is decreased, it was above 1000 mg/L after completion of test. Thus, it requires careful engineering judgement to confirm the effect of oyster shell for controlling ammonium concentration.

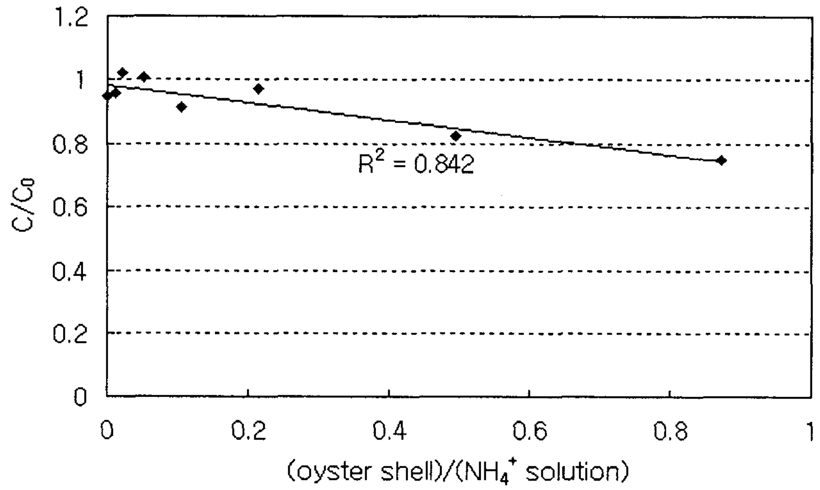
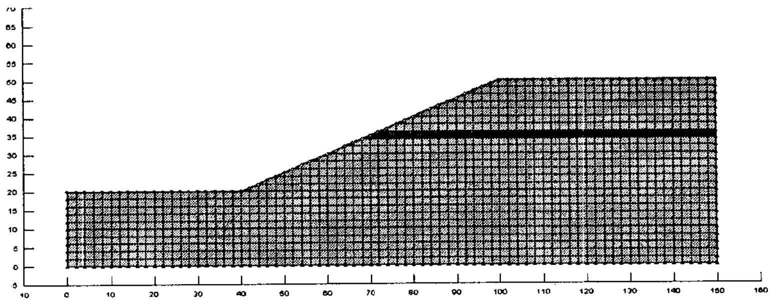


Fig.5 Variation of ammonium concentration with the oyster shell content

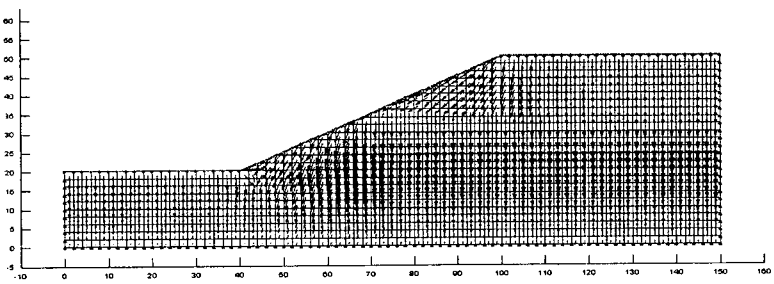
4. Numerical analysis of leachate flow using SEEP/W

4.1 Analysis on assumed landfill

Numerical analysis on landfill with one intermediate cover layer were performed. To examine the change of velocity vector due to intermediate cover layer, 2-dimensional analysis was performed. And then, plan view analysis was conducted to verify appropriate arrangement of piles. The size of landfill used in analysis was 220m in width and 30m in height. Permeability of silt and silty clay were applied to landfill and intermediate cover layer, respectively. And piles assumed to have the same permeability as sand.

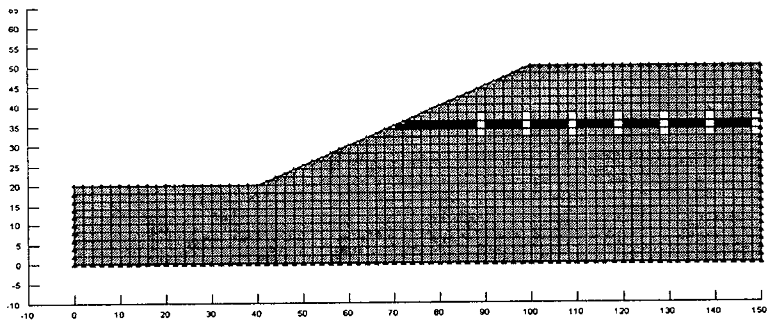


(a) finite element meshes

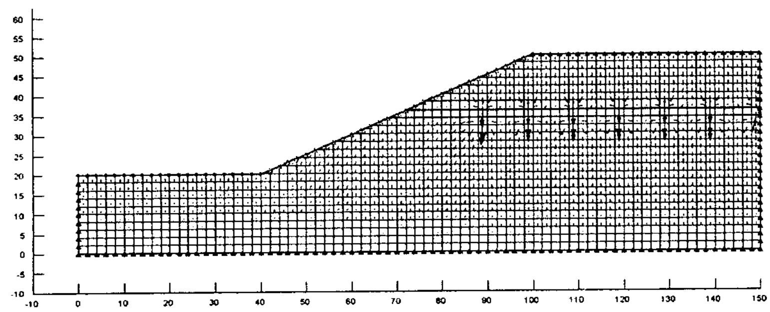


(b) velocity vector

Fig.6 Case of no drain piles in intermediate cover layer



(a) finite element meshes



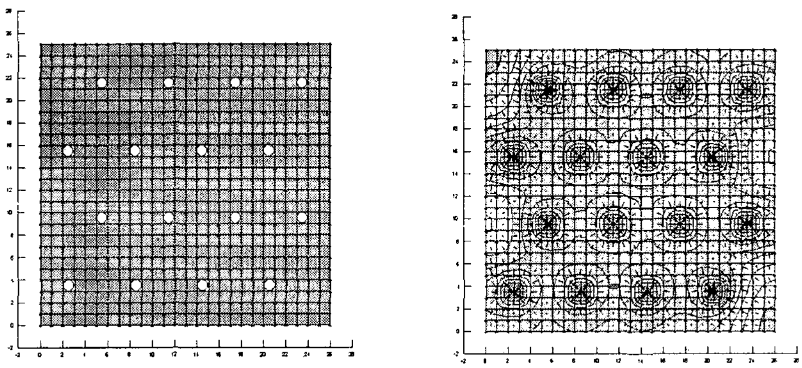
(b) velocity vector

Fig.7 Case of establishing drain piles in intermediate cover layer

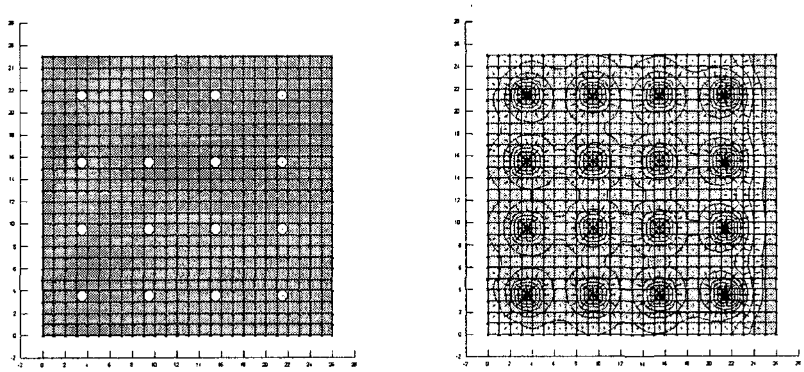
Fig.6 and 7 show the SEEP/W analysis results in consequence of drainage pile construction. From the result of 2-dimensional analysis, the drawdown of water table mounded over intermediate cover layer is confirmed.

4.2 Plan view analysis

To find out drain efficiency and appropriate arrangement of drain pile, drain piles were located in triangular and rectangular shape. Precipitation of 4×10^{-6}m/sec was assumed in all analyses.



(a) Case of triangular position



(b) Case of rectangular position

Fig.8 Drainage efficiency along the arrangement of drain piles

From Fig.8, circumference of drain piles appears in deep dark color. It means that the drainage efficiency is higher around drain piles. In case of triangular position of piles, deep colors appear equivalently on whole meshes. But in case of rectangular position of piles, lighter colors are shown in amid of four piles and outside of mesh. Hence, the triangular position is more efficient than the rectangular position. Therefore, it is recommended to construct piles in triangular shape at landfill area.

5. Conclusions

1) Low hydraulic conductivity of intermediate cover layer restrains vertical drainage and forms a

puddle in several middle place. It causes a rise of leachate level. The increase of leachate level at the landfill has caused an collapse on design gradient of slope by decreasing slope stability, and declining gradient of slope which induces reduction of the amount of reclamation leads to the big financial loss, eventually.

2) To control leachate level, the development of drain pile is suggested in landfill. By establishing drain piles, it is expected to facilitate the vertical drainage of leachate, prevent the landfill from lateral movement and neutralize acid leachate in young landfill.
3) Young leachates tend to be acid due to the presence of volatile fatty acids. The initial pH was 5.0 before pumping to column. After passing the column, pH of solution increases to the value of about 6.5. The pH standard of discharging leachate ranges 5.8 to 8.0 in Korea. This means drain piles buffered with oyster shell could neutralize those of acid materials.
4) Biological management has been generally done to treat ammonia nitrogen(NH_3-N). Ammonia nitrogen(NH_3-N) is the most important component to be managed in leachate because of toxicity. The concentration of ammonium is observed to decrease slightly with increasing oyster shell content. It means oyster shell is effective to control the ammonium concentration.
5) Although the ammonium concentration was decreased, it was above 1000 mg/L after completion of test. Thus, careful engineering judgement is required to confirm the effect of oyster shell for controlling ammonium concentration.
6) The SEEP/W analysis results in consequence of drain piles construction. From the result of 2-dimensional analysis, the drawdown of water table mounded over intermediate cover layer is confirmed. Also, the triangular position is found to be more efficient than the rectangular position. Therefore, it is recommended to construct drain piles in triangular shape at landfill area.

References

1. Yeon-Soo Jang, Yong-Ju Cho and Soo-Sam Kim (1998), "Flow in a municipal waste landfill with daily cover soil of low hydraulic conductivity" Environmental Geotechnics, pp. 287-292
2. Soo-Sam, Kim (1999), "Problems of leachate in municipal landfill - Case study on the Kim-po metropolitan landfill", ISSMFE, 11th Asian Regional Conference Seoul, Korea
3. Soo-Sam, Kim (2000), "Kim-po metropolitan landfill : Lessons from the large scale coastal municipal landfill" Creation of New Geo-Environment, KIGF Forum 2000, pp.41-54
4. R.M. Koerner and T.Y. Soong (1999), "Stability analysis of ten landfill failure" Proc. 2nd Austrian Geotechnical Congress, Austrian Engineering and Architects Society, Eschenbachgasse, Vienna, 99.9-50
5. R.M. Koerner and T.Y. Soong (2000), "Leachate in landfills : the stability issues" Geotextiles and Geomembranes 18, pp. 293-309
6. Y.S. Jang, Y.W. Kim and S.I. Lee (2002), "Hydraulic properties and leachate level analysis of Kimpo metropolitan landfill, Korea" Waste Management 22, pp.261-267
7. Seung-Hak, Lee (2001), "Development of nutrients and heavy metals removal technology in saturated zone using zeolite", M.D. thesis, School of Civil, Urban and Geosystem Engineering, Seoul National University
8. Sudokwon landfill site management corporation, "http://www.slc.or.kr"
9. Environmental management corporation, "http://www.emc.or.kr"