Development of Backfilling Material Using Fly Ash by Application of Chemical Injection

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Summary

Lubrication can effectively reduce the needed thrust if a discrete layer of lubricant is maintained between a pipe and the excavated soil. A lower frictional force allows greater jacking lengths to be achieved. The reduction of frictional stress around the pipe strongly affects the efficiency of lubrication injection. The lubricant must be designed to form a layer in the surrounding soil, be pressurized to overcome ground water pressure and stabilize the over-cutting area. The lubricant should also fill the over-cutting area completely to minimize surface settlement. However, for a commercial lubricant to be effective, it has been suggested that ingredients such as sodium and potassium be eliminated. As a result, in order that a lubricant does not lose its function as a support against the overburden pressure of an over-cutting area and to enable a reduction in thrust, a higher quality lubricant which can overcome these problems must be developed as soon as possible. In this paper, in order to examine the characteristics and behaviour of a material developed as a lubricant and backfilling for a deeper strata excavation system such as a pipe jacking, a fundamental investigation is performed and the various results are discussed.

Keywords: lubricant; backfilling; deep strata; pipe jacking; fly ash utilization; chemical injection

Introduction

Now that long distance and narrow curve jacking techniques have been established and watertight joints for installation have been rapidly developed, the pipe jacking method can be applied to the pipe installation under the ground with overburden deeper than 20m. However, the stress release of the ground continues along with the formation of the over-cutting area. Therefore, there are many challenges to cope with for the improvement of stability in the surrounding ground [1]. While the drivage machine approaches and passes by, the stress and strain conditions change with time. Plural factors, such as the changing position of the drivage machine and surrounding friction, can often affect the ground simultaneously. In addition, a long-term ground subsidence followed by the ground deformation at the time of construction can be caused directly by the soil disturbance resulting from the ground deformation during construction. Therefore most of the ground deformations caused by the pipe jacking construction may be caused by changing stress and strain conditions over the course of construction.

The over-cutting area is the annular space between the outer surface of a pipe and the ground created during excavation by a jacking machine. Usually, the over-cutting area is set to be between 10 and 45 mm, and the lubricant should reduce the friction between the surface of the pipe and the ground as well as stabilize the ground. Lubricants injected into over-cutting areas act are used to reduce thrust, confirm the stability of the surrounding soil, and control surface settlement. In order to perform these functions, the lubricant is stabilized in the over-cutting area after its injection. Moreover, as the pipe diameter increases, so does the thickness of the over-cutting area. However, the properties of the commercial lubricants are not inadequate [2]. If enough of the over-cutting area is not adequately confirmed, unpredicted phenomena (high thrust, heavy surface settlement, etc.) can occur. That is why the discussion of appropriate lubricants and injection methods, etc. in preparation for such changes is inevitable. In this paper, in order to examine the characteristics and behaviour of a material developed as a lubricant and backfilling using fly ash for a deeper strata excavation system such as a pipe jacking, a fundamental investigation is performed and the various results are discussed.

Effect of Lubrication on Pipe Jacking

In Japan, pipe jacking has been firmly established as a special method for the construction of underground pipelines. Recent technological developments have produced successful methods for the stabilization of unstable strata by employing lubricant around the pipes. The contraction of the lubricant volume after injection into the over-cutting area needs to be reduced for slurry pipe jacking. Moreover, pressurized lubricant functions as an important support in the mitigation of overburden pressure. Moreover, during the pushing processes, lubricant is injected into the face and the over-cutting area, which is between the concrete pipe and the soil. After the lubricant fills the voids, the soil is stabilized due to the lubricant pressure during the construction work. Lubricants for pipe jacking are sold in Japan, but no research has yet been conducted in Japan concerning such topics as lubricant defects or the conditions needed for the injection of lubricants into an over-cutting area. After the construction of pipes, backfilling material such as mortar has to be injected into the over-cutting area by Japanese law. However, as a part of the injected lubricant still remained after the construction, it was recognized that many cases occurred with difficulties for backfilling material injection into the over-cutting area due to the existence of a previous injected lubricant.

Development of New Backfilling Material Using Fly Ash

Backfilling material plays an important role as a lubricant when pipe jacking is under practice and a support against overburden pressure after finishing construction. In order to overcome these issues, new backfilling material was developed by application of the principal of chemical injection. Chemical injection is defined as the improvement of weak soil by using chemical additives. A commercial injection material consists of two components: silicic acid sodium as the main component and sodium bicarbonate or heavy potassium carbonate as the additional one. The percentage of silicic acid sodium to total component can be controlled for the gelling time. From this point of view, the new backfilling material can be developed for several kinds of soil conditions. Injection forms of chemical injection materials are categorized as three types of forms [3]. The penetration injection is a form where the total volume of the injected material homogeneously penetrates from the injection hole of the grouting material into the void of the ground's soil. The splitting injection is a form where the grouting material is injected in pulses for splitting the weak part of the ground. However, the splitting injection could also happen in a case where the grouting material is injected intensively into a part of the ground which can be easily penetrated. On the other hand, the compound injection of penetration and splitting is a form where the grouting material penetrates the part where the splitting injection has partly occurred.

Commercial lubricants may deteriorate easily in water-saturated soil, which is problematic in terms of long-term durability [2]. As a result, the volume of a lubricant can easily contract after its injection into an over-cutting area. Moreover, its important role as a support against overburden pressure may be compromised. Accordingly, the development of a higher-quality lubricant capable of overcoming these problems is needed. To this end, the new backfilling material must have high fluidity, low friction with the concrete pipe, low bleeding, a high capacity for bearing overburden pressure, and so on. Moreover, the splitting injection and/or the compound injection are better way for the injection into the over-cutting area due to the stability after jacking.

When the commercial lubricant comes in contact with water, the additional component (sodium bicarbonate or heavy potassium carbonate) is eluted into the water. For this reason, it was decided to develop a backfilling material using fly ash as its additional component. A fundamental investigation was performed in order to examine the characteristics and behaviour of four types of backfilling material developed as backfilling materials for pipe jacking in deep strata. Tables 1 and 2 list the seven types of concentration of silicic acid sodium as Agent A and the four types of backfilling material as Agent B. The samples were mixed using the one-shot method by chemical injection. The one-shot method is a commonly used

Table 1. Seven types of concentration of Agent A of backfilling material (unit; L)

Tabela 1. Siedem rodzajów stężeń czynnika A materiału wypełniającego (jednostka; L)

Agent A	Sodium Silicate	Water
2%	10	490
3%	15	485
4%	20	480
5%	25	475
7%	35	465
9%	45	455
12%	60	440

Table 2. Contents of four types of Agent B of backfilling material (unit; g)

Tabela 2. Zawartość czterech rodzajów czynnika A materiału wypełniającego (jednostka; g)

Agent B	Sludge	Cement	Fly ash	Gypsum	Bentonite	Water
No.1	84	36	120	30	30	360
No.2	70	30	120	40	40	360
No.3	70	30	130	30	40	360
No.4	70	30	140	20	40	360

chemical injection technique to prepare the mixing of agents A and B before injection into the over-cutting area. Moreover, in order to compare the one-shot method with the two-shot method, the two shot method injection was also carried out. The volume of Agent A to Agent B was 1:1.

Bleeding Test

Suspended particles, which are fly ash and cement particles, settle in fluid at rest under the action of gravity with a velocity that is proportional to the square of the particle diameter. Coarse particles settle first, followed by finer ones, and the density of the sediment decreases with the size of the particles. Very fine particles are subject not only to the force of gravity, but also to mutually acting electrochemical forces and a Brownian motion, which appears in the suspensions of colloidal particles. Therefore, the velocity of sedimentation becomes lower than the one corresponding to Stocks' Law [4]. The stability of the fly ash and cement mixture is an important property both during and after injection. The reasons are that in the case of an unstable suspension, not only are the transport and injection pipes clogged with sediment particles, but also the effect of filling the pores is decreased due to the shrinkage of the backfill mixture volume. So, in order to evaluate the stability of the mixture of agents A and B of the backfilling material, a bleeding test was carried out [5]. Agents A and B of the backfilling material were mixed and suspended in water to yield suspension samples of the desired composition and density. The mixture material were then poured into a 1,000cm^3 laboratory jar and left to rest. At selected intervals of time, the sedimented volume of the denser suspension under clear water was recorded. In this research, the height of the interface between the clear water and denser suspension indicated the sedimented volume. The height of the laboratory jar was 30 cm [6]. Figure 1 shows the relationship between the bleeding ratio one month after beginning the test and the concentration of silicic acid sodium. No bleeding was shown in the sample of No.4. Conversely, severe bleeding was observed in the other samples. Since the other samples have few fly ash particles within a unit volume, it is easy to sediment because the restraint between particles is inferior. From this point of view, it is understood that bleeding can be controlled by the amount of fly ash. Moreover, the sample of No.4 is superior to the composition of Agent B of the backfilling material.

Dynamic Friction Force Test

An analysis of recorded thrust data from different pipe-jacking worksites showed the predominant beneficial effects of lubrication on frictional forces. The injection of backfilling material around the pipes reduced the jacking force via two concurrent pathways: a reduction in the friction angle of the soil-pipe interface and the prevention of ground convergence around the pipes [7]. There were a wide range of backfilling compositions, which were empirically adjusted at the worksites. The selection of a particular backfilling was mainly based on the soil conditions and the technical methods to be applied. This choice is easy to make for small-diameter pipe jacking over short distances. For pipe jacking in deep strata, however, a reliable method is needed [8]. To maintain efficient lubrication and backfilling over long jacking distan-

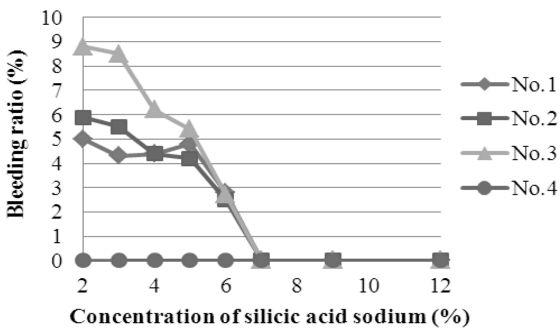

Fig. 1. Relationship between the bleeding ratio one month after setting the test and the concentration of silicic acid sodium

Rys. 1. Relacja pomiędzy czynnikiem odprowadzania miesiąc po rozpoczęciu testu oraz stężeniem krzemianu sodu ces, the lubricant must maintain its water content [9]. This means that the structure of the backfilling material must be stable as lubrication against dynamic friction at the pipe surface during jacking. Figure 2 shows the relationship between the elapsed time and the friction coefficient for seven types of concentrations of Agent A of the backfilling material. The component of Agent B was used as the sample of No.4. This figure shows that the friction factors for the soil sample were greater than that of the other samples or backfilling materials at the start of the test and slightly increased with time. From this phenomenon, it can be inferred that after the concrete surface became covered with a layer of backfilling material that increased its roughness, the friction force increased gradually over time. The friction factor for the sample of 12% of silicic acid sodium remained more or less constant over time. From the test results, it can be concluded that usage of the larger concentration of silicic acid sodium was more convenient for reduction of the friction force after injection. The average of the friction factors at the concrete-pipe interface for the soil sample was about three times greater than that of the backfilling materials. To summarize, lubricant gel stability plays an effective role in the reduction of frictional force around pipes during jacking.

Gelling Time Measurement

Each component of the backfilling materials was sent separately via a pipe from the plant, and the components were mixed just before injection into the over-cutting area. However, it was not possible to confirm whether or not the backfilling material gelled successfully because it was impossible to check its condition after injection. Therefore, gelling time was adopted as a standard check for the filling condition in the over-cutting area. Gelling time was defined as the amount of time within which the backfilling material lost fluidity after its components were mixed. In cases of low gelling time, the backfilling material hardens before it is spread uniformity within the over-cutting area. In cases of high gelling time, the backfilling material mixes with the ingredients of agents A and B which have previously been injected into the over-cutting area and kept in a liquid condition for the long-term. The gelling time measurement results are shown in Figure 3. This figure shows that the smaller the gelling time, the greater the increase in the concentration of silicic acid sodium. The gelling time of samples with 12% of silicic acid sodium was about 4 minutes. Under this gelling time, it is impossible to send backfilling material from the plant to the over-cutting area due to gelling using the one-shot method which clogged the injection pipe. Generally, a 16-hour suspension of the injection is needed for the operation shift. Namely, a gelling time of 960 minutes or more is needed for the injection. From this point of view, samples of 4% or less of silicic acid sodium showed promise of being able to behave like a liquid in the over-cutting area, due to its high gelling time. However, samples of 5% or more of silicic acid sodium have not used the one-shot method because it is impossible to confirm backfilling material injected into the over-cutting area successfully. Accordingly, if the samples of 5% or more of silicic acid sodium are adopted in the injection into the over-cutting area, it is necessary to use the two-shot method. In this case, an advantage can be obtained in that the usage of the larger concentration of silicic acid sodium is more convenient for reduction of the friction force after injection, as previously mentioned.

Mechanical Property Test

The volume contraction of a backfilling after injection into the over-cutting area needs to be reduced for pipe jacking in deep strata. Moreover, a pressurized backfilling material is important in supporting against the overburden pressure. For these reasons, an unconfined compressive strength test was carried out in order to clarify these functions.

A cylindrical mold 50 mm in diameter and 100 mm in height was used to produce the specimens. The curing

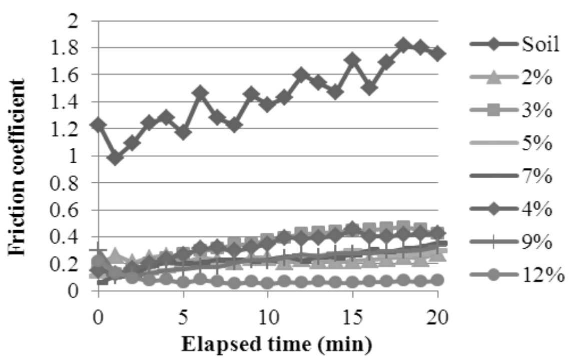

Fig. 2. Friction coefficient as a function of elapsed time

Rys. 2. Współczynnik tarcia jako funkcja upływającego czasu

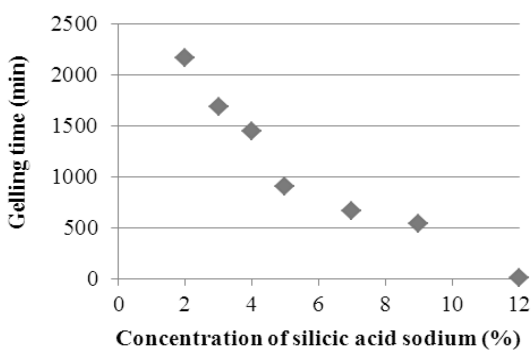

Fig. 3. Gelling time of each sample

Rys. 3. Czas żelowania każdej próbki

times for the specimens were 1, 7, 14, 28, 48 and 72 days, and an unconfined compressive strength test was performed on each specimen after its respective curing period. Each type of strength test was run on 5 to 10 specimens, and the test results were averaged to obtain the mean values for this property. From the result of the gelling time measurement, samples of 4% or less of silicic acid sodium were made by using the one-shot method, and the others were made by using the two-shot method. Figure 4 shows the results of the unconfined compressive strength test. It was observed that the strength of all samples increased with the curing period. Additionally, the strengths of the sample of 12% of silicic acid sodium were about three times as high as that of the sample of 2–4% of silicic acid sodium. Ideally, when pipes are constructed at 5m in depth, the overburden pressure becomes 90kPa. The results of the unconfined compressive strength for all samples were achieved with this value. During the pushing process, the backfilling was injected into the over-cutting area between the concrete pipe and the soil. After the soil voids were filled by the backfilling, the soil stabilized due to the pressure of the backfilling. To minimize ground deformation during the pushing process, it is necessary to maintain backfilling pressure at the same level as the overburden pressure. Thus, the uniform load of the backfilling pressure ideally always acts on the surface of the pipes. If the pressure of the backfilling cannot provide buoyancy for the pipes, the weight of the pipe will affect the bottom side of the over-cutting area. Moreover, the reaction force affects the over-cutting area in applications of curved jacking. In such situations, the over-cutting area breaks as a result of the weight of the pipe and the reaction force under the strengths of the backfilling.

Conclusion and Proposal

It was previously mentioned that backfilling material plays an important role as a lubricant when pipe jacking is under practice and as a support against overburden pressure after finishing construction. Therefore most of the underground deformations caused by the pipe jacking construction may be caused by changing stress and strain conditions over the course of construction. Moreover, lubrication can effectively reduce the needed thrust if a discrete layer of lubricant is maintained between the pipe and the excavated soil. The lower frictional force that lubrication enables allows larger jacking lengths to be achieved. That is why the discussion of appropriate lubricants and injection methods, etc. in preparation for such changes is inevitable. From this point of view, the new backfilling material can be developed for several kinds of soil conditions.

When the commercial lubricant comes in contact with water, the additional component (sodium bicarbonate or heavy potassium carbonate) is eluted into the water. For this reason, it was decided to develop a backfilling material using the chemical injection method. That is, several kinds of concentrations of silicic acid sodium as the main component and fly ash as its additional component are prepared and mixed both by the one-shot or two-shot method. It is clarified that a sample of 4% or less of silicic acid sodium mixed with the additional component by using the one-shot method showed promise of being able to behave like a liquid in the over-cutting area, due to its high gelling time. This means that it is successful for the sample of 4% or less of silicic acid sodium to inject into intact and/or strong strength rock masses. On the other hand, if the samples of 5% or more of silicic acid sodium are adopted in the injection into the over-cutting area, it is necessary to use the two-shot method. In this case, a benefit can be obtained in that the usage of the larger concentration of silicic acid sodium is more convenient for reduction of the friction force after injection, as previously mentioned. It is convenient for the sample of 5% or more of silicic acid sodium to inject into fracture dominant and/or weak rock masses. This is the reason why the sample of 5% or more of silicic acid sodium mixed with the additional component is easily and efficiently hardened using the two-shot method due

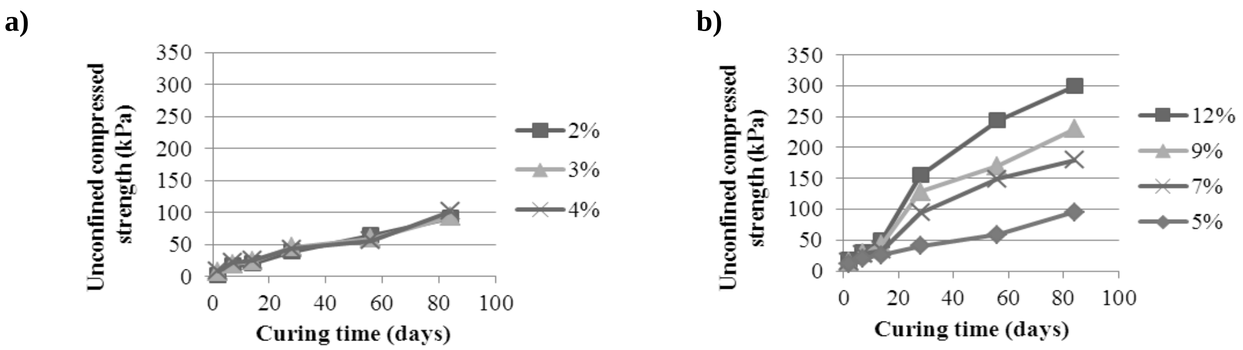

Fig. 4. Unconfined compressive strength test results
a) Samples of 4% or less by using one-shot, b) Samples of 5% or more by using two-shot

Rys. 4. Wyniki testu na wytrzymałość na ściskanie jednoosiowe
a) Próbki 4% lub mniej po jednej próbie, b) Próbki 5% i więcej po dwóch próbach

to a low gelling time. Figure 5 shows a proposal for the usage of the optimum concentration of the newly developed backfilling material against a suitable range of the soil condition.

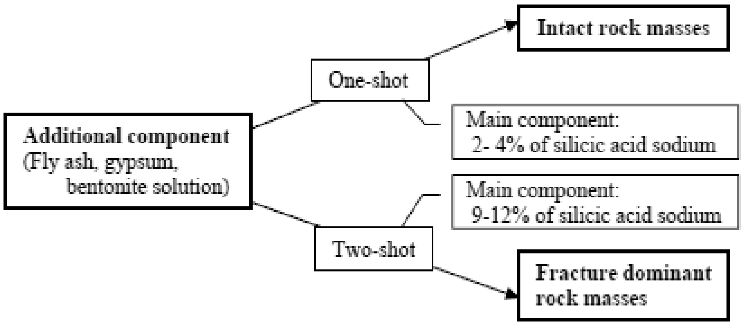

Fig. 5. Proposal for the usage of optimum concentration of the newly developed backfilling material

Rys. 5. Propozycja użycia optymalnego stężenia nowo opracowanego materiału wypełniającego

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Podawanie materiału podsadzkowego z popiołów lotnych z iniekcją chemiczną

Smarowanie może skutecznie zmniejszyć wymagany nacisk jeśli warstwa smaru jest utrzymana pomiędzy rurą a urobkiem. Niższa siła tarcia pozwala na osiągnięcie większych długości podczas mikrotunelingu. Redukcja naprężeń wokół rury silnie wpływa na efektywność wprowadzania smaru. Smar musi być zaprojektowany w taki sposób, aby tworzyć warstwę w otaczającej glebie, musi być wtłaczany pod ciśnieniem aby pokonać nacisk wód gruntowych oraz stabilizować drążoną powierzchnię. Smar powinien również wypełniać drążoną powierzchnię aby całkowicie zminimalizować osiadanie powierzchni. Jednakże, aby smar komercyjny był efektywny zdecydowano się na eliminację takich składników jak sód czy potas. W efekcie, aby smar nie stracił swojej funkcji jako wsparcie przeciw przed naciskiem nadkładu powierzchni drążonej i uaktywnić redukcję parcia, należy jak najszybciej opracować wyższej jakości smar, który poradzi sobie z wyżej wymienionymi problemami. W celu sprawdzenia charakterystyki i zachowania się materiału stanowiącego smar oraz wypełnienie dla systemu wykopu głębszych warstw jak w przypadku mikrotunelingu, przeprowadzono badania, których wyniki i omówienie znajdują się w poniższym referacie.

Słowa kluczowe: smar, podsadzka, głębokie warstwy, mocowanie rurociągu, utylizacja popiołów lotnych, iniekcja chemiczna