Khazaei, S., Shimada, H., Kawai, T., Yotsumoto, J., Sato, I., Matsui, K., Laboratory considerations about frictional force on pipe surface when slurry machine is used.
International Symposium on the Fusion Technology of Geosystem Engineering, Rock Engineering and Geophysical Exploration
Seoul, Korea, Nov. 18-19, 2003

Laboratory considerations about frictional force on pipe surface when slurry machine is used

Saeid Khazaei[1], Hideki Shimada[1], Takashi Kawai[2],
Jyunichi Yotsumoto[2], Iwao Sato[3], Kikuo Matsui[1]
[1] Kyushu University, Fukuoka, Japan, [2]Kyowa Exeo Co., Ltd., Tokyo, Japan, [3]Telnite Co.,Ltd., Saitama, Japan

Abstract: Pipe jacking is a name for a method to excavate a tunnel by pushing pipe into the ground from an especial pit. Size of tunnels in this method is different from under 900mm (microtunneling) to more than 3,000mm. Method of excavation is also different from hand digging to use of any kind of tunnel boring machines such as slurry and earth pressure balance (EPB) machines. Slurry pipe jacking was firmly established as a special method for the non-disruptive construction of the underground tunnels in urban area. During the pipe jacking and microtunneling process, the jacking load is an important parameter, controlling the pipe wall thickness, need to and location of intermediate jacking station, selection of jacking frame and lubrication requirements. The main component of the jacking load is due to frictional resistance. In this paper the skin friction between pipe surface and surrounding condition also lubricant quality based on a few fundamental tests, were considered. During this study unconfined compressive strength test, dynamic friction measurement test and direct shear box test were raised for one of the largest diameter slurry pipe jacking project in Fujisawa city in Japan. It could be concluded that in slurry pipe jacking, prediction of frictional forces are mainly dependent on successful lubrication, its quality and lubricant strength parameters. Conclusions from this study can be used for the same experiences.

1. Introduction

Pipe jacking is a technique used to install an underground pipeline through a bore excavated by a shield type-boring machine, which is used hydraulically from an especial pit. The advantages of this method have been recognized by the entire world (Shimada, Matsui, 1997).

In Japan, slurry pipe jacking was firmly established as a special method for non-disruptive construction of the underground pipelines. Recent technological developments have led to successful methods of stabilizing unstable strata by excluding water from the excavations by means of the mud slurry around the pipes. During the pushing processes, the mud slurry is injected into the face and into the over-cutting area, which is between the concrete pipe and the soil. After, the slurry fills the soil voids; the soil stabilizes due to the created slurry cake around the pipes. After the drivage and pushing processes are finished, the mortar injection into the over-cutting area is carried out in order to maintain permanent stability of the surrounding soil and the over-cutting area (Shimada, Matsui, 1998).

During the slurry pipe jacking process, the jacking load is an important parameter, controlling the pipe wall thickness, need to and location of intermediate jacking station, selection of jacking frame and lubrication requirements. Importance of this parameter in large diameter pipe jacking is vital to prevent damages and increase expenses. Based on this point of view, some laboratory tests are needed for prediction of thrust and control the frictional forces during the jacking pipes. The number of these tests can be changed dependent on project situation. In this paper some of the needed tests for one of the largest slurry pipe jacking project in Japan were considered. Conclusions from this study can be used for the same project of mud slurry pipe jacking method as a basic knowledge.

2. Introduction of Fujisawa project

Fujisawa city is located in eastern part of Japan, near the bay of the Pacific Ocean. One of the biggest problems in this city is to control surface water in rainy season from June to August. Sometimes flood covers a big area of southern part of the city and makes trouble for traffic and living in this part. By means of gathering surface water and overcoming on these problems in Fujisawa city, a sewage system containing surface and under ground structures was designed. With considering the quantity of sewage water, it was needed to build a tunnel with inner diameter of 3,000 mm by means of the main underground vessel. Length of the tunnel is 791.97m in slop of 1.3%.

Construction period of the tunnel was from 28 April to 31 August 2003. The used pipes characteristics the machine parameters for this project respectively Tables 1 and 2 list. Soil parameters based on Figure 1 were listed in Table 3. It must be mentioned here that in this table soil was classified comparatively. Soil condition in this project is chiefly sand in different strength parameter as mentioned.

In these tables N is factor from soil penetration test (SPT), E; module of elasticity, ν; Poisson ratio, γ; natural density, C; cohesion and Φ; internal friction angle.

Table 1. Concrete pipe characteristics.

Weight (kg)	Compressive strength (MPa)	Inner diameter (m)	Outer diameter (m)	Length (m)	E (MPa)	ν	γ (MN/m^3)	C (MPa)	Φ (Deg)
15300	296.35	3	3.5	2.43	25,000	0.2	0.024	0.5	30

Table 2. Mud slurry machine characteristics.

Model	Inner diameter (mm)	Excavation diameter (mm)	Length (mm)	Weight (kg)	Maximum torque (kN.m)
HP-30.008-336	3,480	3,530	3,455	44,000	1,010

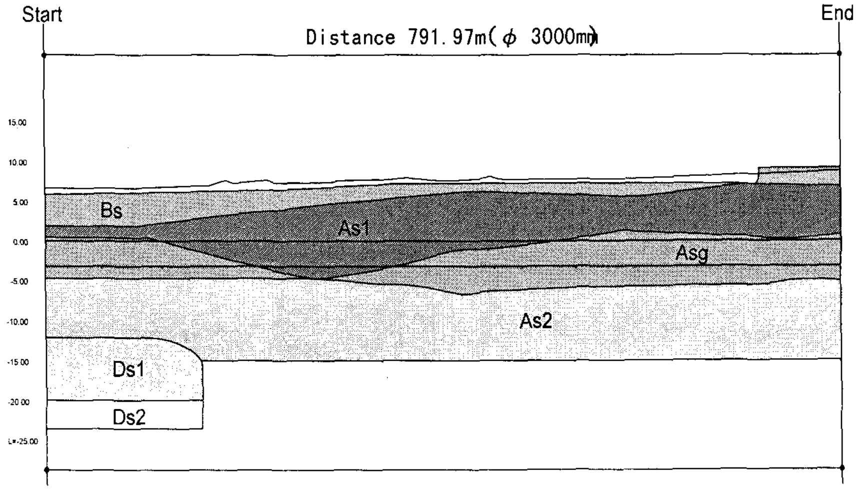


Figure 1. Soil cross section in Fujisawa project.

Table 3. Soil parameters in Fujisawa project.

Soil	N factor	E (MPa)	ν	γ (MN/m^3)	C (MPa)	Φ (Deg)
Bs	2-4	3	0.45	0.015	0.05	6
As1	50	50	0.35	0.018	0	42
Asg	50	40	0.325	0.019	0	40
As2	50	35	0.35	0.018	0	42

3. Tests for considering effect of lubrication on slurry pipe jacking method

Lubricant that was named DKIα was selected to use to reduce thrust during the jacking pipes in Fujisawa project. DKIα is compounded from two parts basically: A and B are Na_2SiO_3 and $KHCO_3$ respectively. To compensate effect of lubrication in long distance another lubricant material (DKIβ) was injected through the pipes behind the machine during the penetration. This material is compounded from a kind of resin to compensate water content of primary lubrication and polyacrylamid. In this study DKIα was considered as lubricant material to clarify contact parameters between pure lubricant-concrete and DKIβ for that of mixed lubricant with soil on concrete. Figure 2 shows schematic view of a large diameter slurry pipe jacking method.

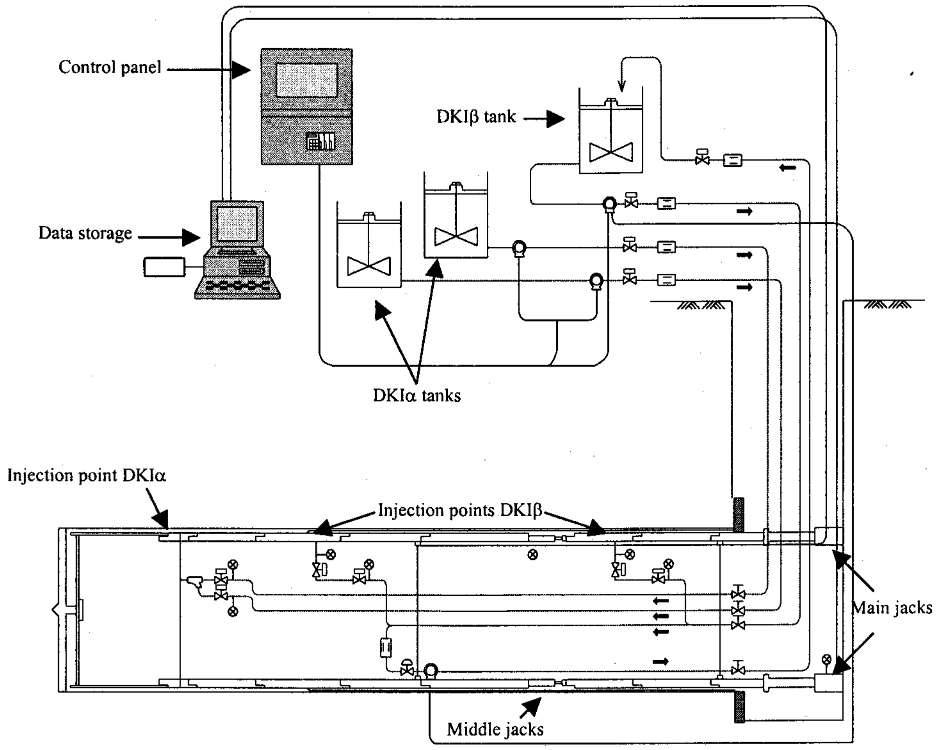


Figure 2. Schematic view of a large diameter pipe jacking method.

Compressive strength test

The main idea from this test is to consider about compressive strength of lubricant material in different conditions and also for module of elasticity. For this point of view test of a cylindrical sample in diameter 5cm and 10cm height was raised in 1, 4 and 7 days after preparing the samples. One of the noticeable phenomena that were taken from the test was to increase compressive strength between 6-10% range of strain. It can be described from molecular structure of lubricant material. Since the base of DKIα material is gel of silicate, in compression silicate structure is destroyed and clearances between molecular units are disappeared. It is necessary to say that after 7% strain; lubricant material structure was completely broken and changed into liquid. Test records do not show sensible changes in compressive strength and module of elasticity in progressive time. Table 4 lists the conclusions from the tests.

Table 4. Conclusions from unconfined compressive strength tests on lubricant material.

Parameter	Min.	Max.	Ave.
σ_c; kPa	2.591	3.997	3.519
E; MPa	0.042	0.096	0.0588

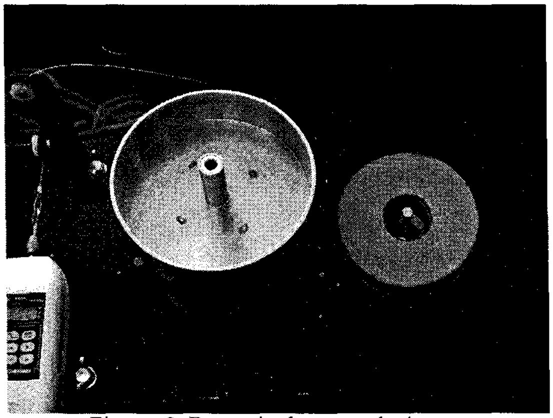
In order to consider real situation in slurry pipe jacking, a number of tests were raised for mixture of mud slurry and lubricant material. Conditions of samples in these tests were similar to that was mentioned above. Table 5 lists the recorded data for these tests. It can be understood from these tests that addition in percent of mud slurry in samples decreases compressive strength and module of elasticity. This decrease in upper than 20% of mixture is gradual. Thus as a result for this test it can be mentioned that lubricant with minimum of permeability gives better stability for surrounding soil of the pipes.

Table 5. Conclusions from samples mixed with mud slurry.

Parameter	+5% Mud	+20% Mud	+30% Mud	+40% Mud	+50% Mud
σ_c; kPa	3.173	2.121	2.172	2.184	2.013
E; MPa	0.066	0.036	0.035	0.038	0.024

Consideration about interface dynamic friction

By this test dynamic shear strength between lubricant material and concrete was checked. Figures 3 and 4 show test devices and method of using these devices. In this test real situation of interface between soil, lubricant and concrete pipe was simulated. As the figures show, there are two parts for the device. In this case lower part was filled with fine sand in the bottom and lubricant material on it. In upper part, concrete with surface roughness same the concrete pipe was placed and put on the lower part. Then connection wire was connected and test started with rate of 1 round rotation per 6 minutes. This test was done with two kinds of lubricant sample with different gel strengths. Sample 2 in this test had more gel strength than Sample 1. Situation Test results for each sample were shown in Figures 5 and 6.


Figures 3. Dynamic shear test devices.

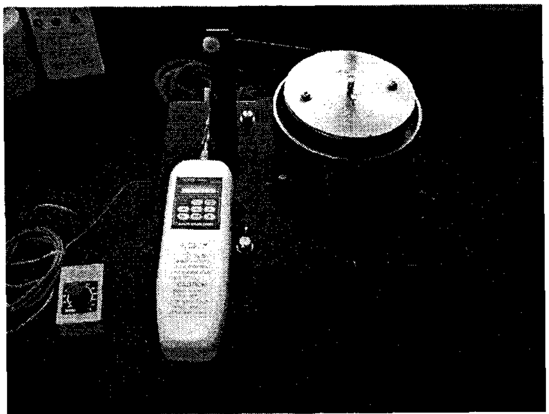


Figure 4. Method of using test devices.

Figure 5 shows that the lubricant was sheared through itself. It means that cohesion between concrete and lubricant was higher than that of lubricant. For Sample 2, shear happened through the interface between concrete and lubricant. In this case as the graph shows that shear strength raised down in progressing of time. It could be concluded from these tests that lubricant strength and interface cohesion were two major parameters, increasing the thrust during slurry pipe jacking method effectively. Also stability of lubricant during pushing process can cover effect of pipe surface roughness. Figure 7 shows comparison between friction factors for samples in progressing of time. In this graph friction factor was taken for T/W that T is wire tension and W is weight of the upper part plus concrete. The graph shows that frictional resistant in Sample 1 raised up a little in progressing of time but Sample 2 was sheared through the interface with concrete, coming down in the same state.

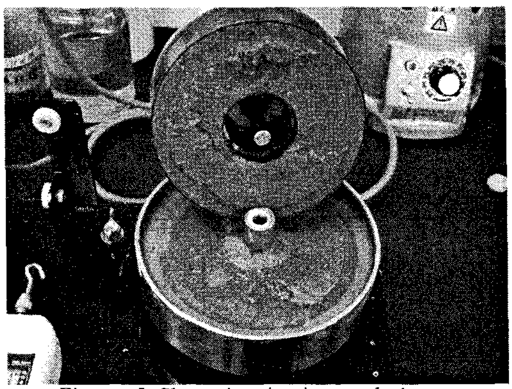

Figures 5. Shear situation in sample 1.


Figure 6. Shear situation in sample 2.

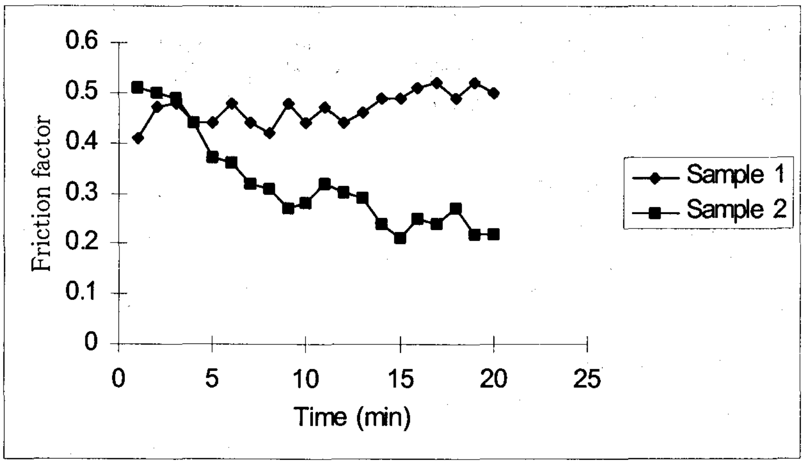
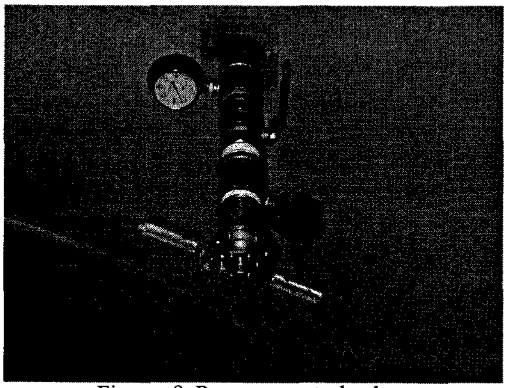


Figure 7. Comparison between friction factor for two kinds of sample in progressing of time.

Direct shear box test for measuring interface parameters

For this test two conditions of contact between pure lubricant and concrete as well as real sample from soil mixed with lubricant and concrete were considered. Kind of lubricant material during the first test was DKIα that was injected through the over-cutting area from behind the machine and for the second test DKIβ that was injected the pipes behind during the jacking process. Mixed samples from lubricant and soil were taken from different parts of the tunnel and sampled by a special device. This device was made by stainless steel with a particular isolated part for sampling in front of its head. With this device, 20cm length in 2cm diameter sample could be taken. Also for avoiding rush of lubricant through the tunnel during sampling, a special valve was added to the device. Figures 8 and 9 show pressure control valve and method of sampling with this device, respectively.



Figures 8. Pressure control valve.

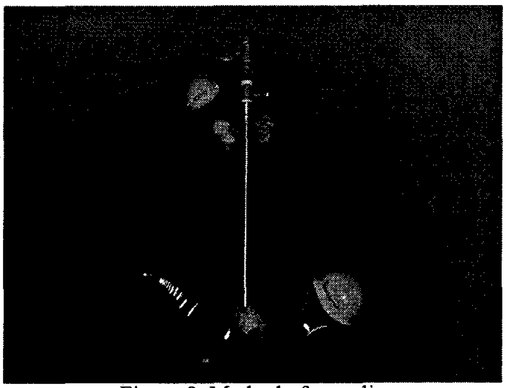


Figure 9. Method of sampling.

To draw Mohr-Coulomb graph for interface between pure lubricant and concrete, direct shear test was raised in four different normal pressures. Measured pressure behind the concrete pipes in Fujisawa project had a range between 40-90 kPa. This pressure increased near the cutter head to the maximum value. Figures 10 and 11 show the samples after test for 30 and 70 kPa normal stress respectively. As the figures show in the case of pure lubricant test, shear happened through the lubricant material instead of in the interface with concrete. It means in this case, shear resistance of interface was greater than that of lubricant material. Also cohesion between lubricant and concrete surface, because of concrete surface roughness, is larger than that of lubricant. Figure 12 displays the concluded graph of the test. As the graph shows in this case, friction angel and cohesion for interface can be taken 9.89 degree and 2.66 kPa respectively.

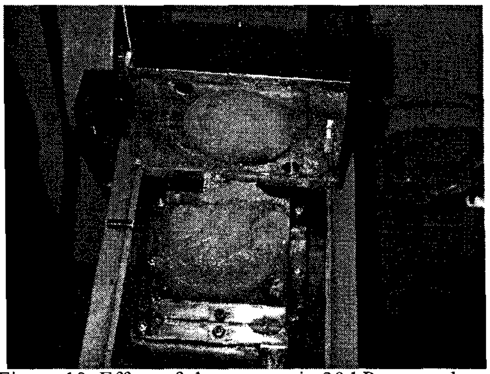


Figure 10. Effect of shear stress in 30 kPa normal stress.

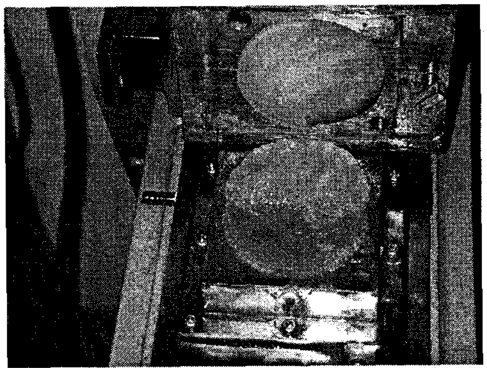


Figure 11. Effect of shear stress in 70 kPa normal stress.

As mentioned in interface dynamic friction test, comparatively it can be chiefly concluded that to increase the effect of lubrication and decrease frictional force around the pipes, it is needed to enhance strength parameters of DKIα material.

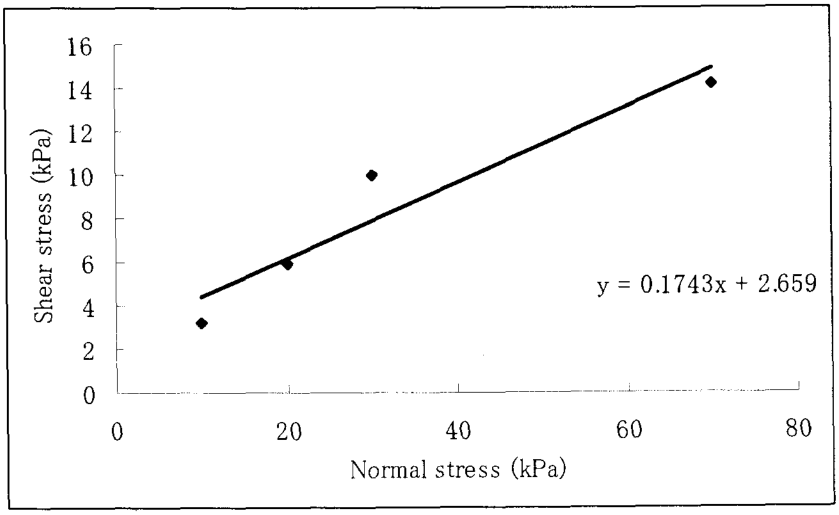


Figure 12. The test graph for pure lubricant on concrete.

To clarify the effect of real condition of contact with pipe surface, in the second part of the tests real samples were used to considerer about interface in situation of contact between mixed soil and lubricant on concrete surface. As mentioned above, to reduce frictional forces around the pipeline during jacking process in Fujisawa project DKIβ was used for lubrication. This material was better in stability against the underground water and pressure than DKIα. In this case real samples were kept in contact with concrete in shear box of the test machine. Based on the recorded pressures behind the pipes, test was raised in three normal pressures 50, 70 and 90 kPa. In each test, because of state of sample as saturated sand, a stable state in shear force was not recognized. Shear stress changed during the tests in a range between 4-5 kPa and increasing in normal stress could not affect on increasing of shear stress. In this case correct cohesion and friction angle, because of scattered results of the tests, cannot be concluded. From these tests for shear strength a range between 4-5 kPa and for friction angle zero in the state of tunneling in sandy soils can be suggested. Figure 13 shows the range of changes in shear strength under 70 kPa normal stress in the case of real sample test. It can be say here as a conclusion that successful lubrication around the pipes has a great effect on decreasing of thrust after making mixture with sandy soil around the pipes in slurry pipe jacking method.

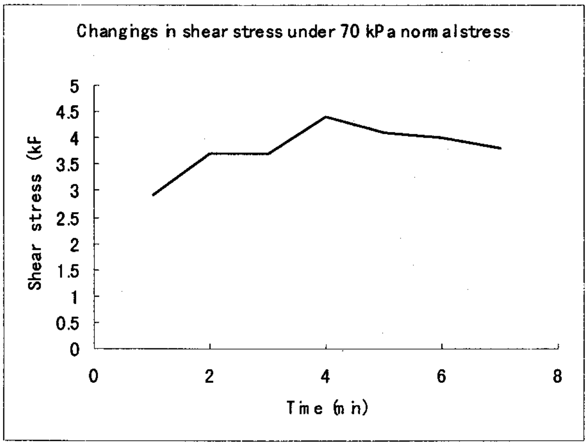


Figure 13. Shear stress changes under 70 kPa normal stress.

4. Conclusions

During the construction work with large diameter slurry pipe jacking, the most important parameters to stability of surrounding soil of pipes and reduction of thrust during jacking process, is lubrication and quality of lubricant. These parameters have significant role in construction successes and reduction of project risks. Lubricant material is injected into the over-cutting area around the pipes and keeps the pipe surface away from contact to soil. This function of lubricant material is impressive to reduction of frictional forces around the pipeline and stability of surrounding soil. From this investigation, methods of quality control for lubricant material and finding of important parameters that are used to design and control slurry pipe jacking, during a case study of large diameter slurry pipe jacking in sandy soil condition, were considered.

From this investigation the following results can be inferred:

a. Lubricant compressive strength: from this test compressive strength and module of elasticity of lubricant material under different conditions of lubricant material were investigated. These parameters are important to make numerical modeling of slurry pipe jacking. Also from these tests it can be taken that increasing in percent of mud slurry in mixture with lubricant reduces strength parameters of lubricant and low permeable lubricant gives higher strength parameters.

b. Dynamic friction of interface: from this test, dynamic frictional resistance of concrete surface in contact with lubricant material in different qualities of lubricant was investigated. From this test it can be understood that minimum dynamic friction happens in interface between lubricant and concrete and not in lubricant material. In the case of dynamic shear strength decreases in progressing of time.

c. Direct shear box test: two kinds of test were selected for direct shear box test, the first test for pure lubricant on concrete sample and the second for real mixed sandy soil-lubricant sample. In the first state all of the samples were sheared through the lubricant material under different normal stresses. It can be inferred here that this state was related to roughness of concrete surface and cohesion for interface that was greater than that of the lubricant material. In this case cohesion and friction angle for sheared surface were concluded from Mohr-Coulomb criteria 2.66 kPa and 9.89 degree respectively. In the second state of the test behavior of sample was similar to saturated sand. In this case stable shear strength was not concluded for all of the tests. Shear strength and friction angle for the state of sandy soil from this test were suggested between 4-5 kPa and zero respectively.

Acknowledgement

With special thanks to Fujisawa city municipality and Tobishima Co. Ltd. to give permission for this research. Also with thanks to Telnite Co. Ltd. and especially Mr. Tetsuya Ito for tests and kindly assistance of Mr. Kazumichi Kagawa from Kyowa Exeo Co. Ltd. It must be appreciate here also to Mr. Yasuhiro Yoshida from Sankyo Material Co. Ltd. for his assistance during the research period.

References

Shimada H. & Matsui K., 1998, A new method for the construction of small diameter tunnels using pipe jacking, proc. of regional symposium on sedimentary rock engineering, 234-239.

Shimada H. & Matsui K., 1997, Effect of mud slurry on surrounding soil in using pipe jacking, proc. of the 1st Asian rock mechanics symposium, Vol. 1, 221-226.