July 3, 2001

Development of the World's First "Non-soil Discharge Mole Robot" to Install Conduits Without Excavation

- All "NO-DIG" Operations for Conduit Installation with the Future ACEMOLE Method Eases Traffic Congestion and Environmental Problems -

Nippon Telegraph and Telephone Corporation (NTT: Tokyo, Chiyoda-ku. President: Jun-ichiro Miyazu) has developed an entirely new trenchless method for installing underground conduits using a "mole robot (microtunneling system)". The new system eliminates the need for road excavation and does not discharge waste soil even when used in hard soils. Existing driving technologies have been revolutionized by NTT's efforts to miniaturize, reduce costs and achieve high-speed execution. Utilizing this technology to make conduit installation all NO-DIG (NO-Digging:trenchless method) will lead to a marked reduction in the problems of traffic congestion, construction noise and vibration and environmental degradation associated with conduit installation up to the present.

In order to solve the problems associated with the opencut method of conduit installation, in 1986 NTT Access Service Systems Laboratories developed and introduced the "ACEMOLE method", which uses a "mole robot" to install conduits. However, there were still a few problems to be ironed out before all NO-DIG operation could be achieved: construction costs were not always economical in comparison with the opencut method, areas suitable for construction were restricted, and driving machine operation required experience.
The future ACEMOLE method features technologies not seen in the existing ACEMOLE and comparable trenchless methods. These include world-first dynamic press-insertion driving technology in which fine vibration allows the driving machine to advance without excavation even in hard soil, pit size reduction technology utilizing new materials, robot technology for driving pipe connection works and operation system technology based on knowledge databases and optimum control theory. Use of these technologies in this latest trenchless method enables anyone, anywhere, anytime to lay conduits cleanly.

[Developmental Background]
The noise and vibration and traffic congestion caused by the long sections of road taken up by conduit installation using the opencut method negatively affect living environments and social activity, and road excavation regulations and measures for the reduction of road work are becoming more stringent. These regulations are restricting times and areas in which constructions can be conducted, reducing efficiency and increasing the amount of work conducted at night, making it impossible for the opencut method, which consists in great part of the processes associated with digging, to achieve radical cost reductions.
The increasing burden placed on individuals, society and the environment caused by opencut constructions are coming into focus as a major social problem. Traffic congestion brought about by excavation causes losses of time and energy, exhaust emissions pollute the air, large amounts of dust are created, the quarrying of earth and sand from mountains and rivers becomes necessary, etc.

The solution to these problems cannot be found in alteration and improvement of the opencut method. Only NO-DIG shows bright prospects for the future.
Against this background, it was NTT's aim to eliminate excavation from conduit installation - to make it "all NO-DIG". The "Future ACEMOLE method" is the result of bringing together NTT's leading edge technologies in the fields of public works, mechatronic, telecommunications, sensing and materials technology. This new trenchless method is certain to draw significant attention in the future from every field of enterprise concerned with the installation of conduits.

[Main Features]
1. Performance of the Future ACEMOLE Method (See Fig. 1)
The superior performance of the future ACEMOLE method stems from its use of new technologies not found in other microtunneling methods.
Constrction costs of the future ACEMOLE method are less than half those of the conventional ACEMOLE method, meaning that work can be executed at a cost equivalent to that for excavation work in provincial cities.
The speed of all aspects of driving operations has been increased, reducing the work period to less than half that required for opencut mathod. Miniaturization has solved the problem of restrictions on use, and thorough elimination of waste by adoption of the non-soil discharge configuration has greatly reduced the burden placed on the environment, both in immediate proximity to the work-site and more generally.

2. Main Features of the Future ACEMOLE Method (See Fig. 2)
1) Realization of Non-soil Discharge in Hard Soils
The adoption of dynamic press-insertion driving technology, which vibrates soil at the driving machine head face when it is advancing underground, has made possible high-speed driving underground without discharging soil, even in hard soils (N value 15-30) which previously necessitated underground excavation driving and waste soil transportation. Non-soil discharge driving is now possible in almost all soil types, other than rock mass and gravelly soil. This method can now replace the excavation driving method, in which costs were increased and driving speed retarded by excavation and soil discharge processes.
(N value: A measure expressing soil hardness. Humans can dig unaided in soils of N value 4-10.).

2) Realization of High-speed Driving Works
The speed of driving works has been considerably increased by making connection and extension work for the driving pipes and driving machine power supply hoses and control cables automatic and high-speed. In most microtunneling methods, connection of driving pipes and cables has to be performed by hand, and this takes 2-3 workforces 20-30 minutes in the pit in the conventional ACEMOLE method. In contrast, the new method uses an automated robot, requires no workforces, and takes only 4-5 minutes. Adoption of dynamic press-insertion driving technology, which is applicable to a wide range of soils, is one major reason we were enabled to use a robot for this work. Simple and inexpensive robotization was possible because the large-diameter hydraulic hoses used to supply power to the driving machine and the pipes to transport waste soil during excavation have been rendered unnecessary.

3) Realization of High-precision Long-distance Curved Route Driving
Long-distance curved route driving is a major technological capability of the conventional ACEMOLE method. This is made possible by driving machine position detection technology using electromagnetism. During measurement, the driving machine is stopped, and an electromagnetic field from the driving machine is measured above ground. Position detection is possible over both straight and curved routes, but measurements are discontinuous over distances of several meters. Fiber-optic gyroscopes have been applied to position detection in

fast-moving objects such as airplanes. We have realized their use for a driving machine moving at low speed underground (several tens of cm per minute), allowing continuous, high-precision position measurement in real time. This has made possible high-precision control of the driving machine over long-distance curved routes.

4) Realization of Reduced Pit Size and High-resistance Structure
The pit is the base for constructions, and we have reduced pit size in order to minimize traffic disruptions caused by roadwork and avoid as much as possible restrictions on areas in which underground conduit installations can be carried out.
The newly designed pit configuration minimizes space by altering the existing manhole cable housing method, and using that space as the pit. NTT has developed an original high-strength resin mortar as the structural material, realizing a structure capable of resisting the enormous driving pressures placed on the pit.
This method divides the structure into small blocks which can be quickly laid and connected underground, and when driving is completed the structure can be used as a manhole without alteration. This method markedly reduces the cost and the period required for execution, and minimizes both the amount of waste soil produced and disruption of the passage of traffic and pedestrians.

5) Elimination of Driving Trouble / Spread of the Technology
The development of a cyber control system which includes the accumulated skills of experienced operators for driving machine control, together with an auto navigation system which sequentially displays direction control and estimates of driving trajectory, has made it simple for anyone to operate the driving machine. A long-distance support system using public access communications systems allows on-site operator support, and trouble can be either avoided in advance or rapidly normalized when it occurs.
Most conventional driving methods rely on the skills of operators, and time and money is required to upgrade these skills and train more operators. In addition, human errors in judgment or operation often result in an increase in the amount of time and money required for execution. This method has solved the majority of these problems, a fact which will lead to rapid and far-reaching diffusion of the technology.

[Technological Details]
The future ACEMOLE method incorporates numerous new technologies (See Fig. 2). At the core of these are dynamic press-insertion driving technology, which enables non-soil discharge driving in hard soil, pit construction technology realized through high-strength resin materials, and operation system technology composed of cyber control, auto navigation and long distance support systems, which makes it possible for anyone to easily operate the driving machine.

1) Dynamic Press-insertion Driving Technology
The press-insertion driving which uses pressure applied by a jacking machine placed in the pit to push the driving machine is one method currently available for advancing the driving machine underground without excavating or discharging soil. However, conventional press-insertion which relies on static penatration (static press-insertion) is incapable of driving through hard soil. The future ACEMOLE method uses world first dynamic press-insertion driving technology which vibrates the tip of the driving machine while pressing and inserting, realizing press-insertion driving in hard soils (N value 15-30) up to now impossible. This technology applies the optimum vibration acceleration for the soil type, locally liquefying the soil particles at the driving machine head face and opening an aperture for the driving machine to penetrate. To put it another way, it resembles a very tiny earthquake which liquefies only one section of soil.
Dynamic press-insertion driving technology reduces the soil resistance at the driving machine head face by 30% in comparison with static press-insertion. This means that soil with an N

value of 30 has an equivalent resistance for the dynamic press-insertion method as soil with an N value of 15 has for static press-insertion.

2) Pit Construction Technology Using High-strength Resin Materials
The pit used when driving must have a wall structure capable of resisting enormous driving pressures. NTT has made this possible using high-strength resin materials. These materials are 1.5 times stronger than ordinary resin materials (bending and tensile strength), and because the resin mortar is integrated with reinforcing steelbar when it hardens it has a strength greater than the breaking strength of steel materials, and its performance goes beyond the limit strength of reinforced concrete. Furthermore, because the resin materials have high mutual adhesiveness, a pit wall composed of small blocks has the same properties as a one-piece wall, and because driving pressure can be resisted over a wide area of the wall surface, resistance is increased twofold over reinforced concrete structures even in small pits, and long distance driving is possible in the same way as for the existing ACEMOLE method.

3) Operation System Technology Incorporating Knowledge Database and Optimum Control Theory
This technology consists of two elements: 1) A cyber control system which uses a knowledge database accumulating the skills of trained operators with superior driving know how to judge the validity of control operations, and if abnormalities are detected, which displays the optimum control method for normalization to the operator before trouble occurs; and 2) An auto navigation system with a self-learning function for results of control of the driving machine, which displays the optimum amount of direction control and position estimates based on this to the operator in real time. The support provided by these systems makes it possible for anyone to simply and accurately operate the driving machine. In addition, the Technological Support Center (provisional name) will be able to provide real time support for the on-site operator using public access communications lines, including consultation while sharing data and images and driving machine control via the long distance support system. These systems offer total support previously unavailable in small-diameter conduit driving systems, and will make possible the elimination of work execution trouble and the smooth and rapid spread of the technology.

[Future Plans]
The future ACEMOLE method is scheduled to be used for NTT-related operations from around fall 2001.
NTT Access Service Systems Laboratories intends to proceed with research and development in future, in order to expand application of this technology to a broad range of fields, including other lifeline facilities such as drainage systems.

- Figure 1 Performance of the Future ACEMOLE Method
- Figure 2 Main Features of Future ACEMOLE Method

For inquiries related to this matter:
NTT Information Sharing Laboratory Group
Planning Department, Public Relations: Kurashima, Sano, Ikeda
TEL: 0422-59-3663
E-mail: koho@mail.rdc.ntt.co.jp