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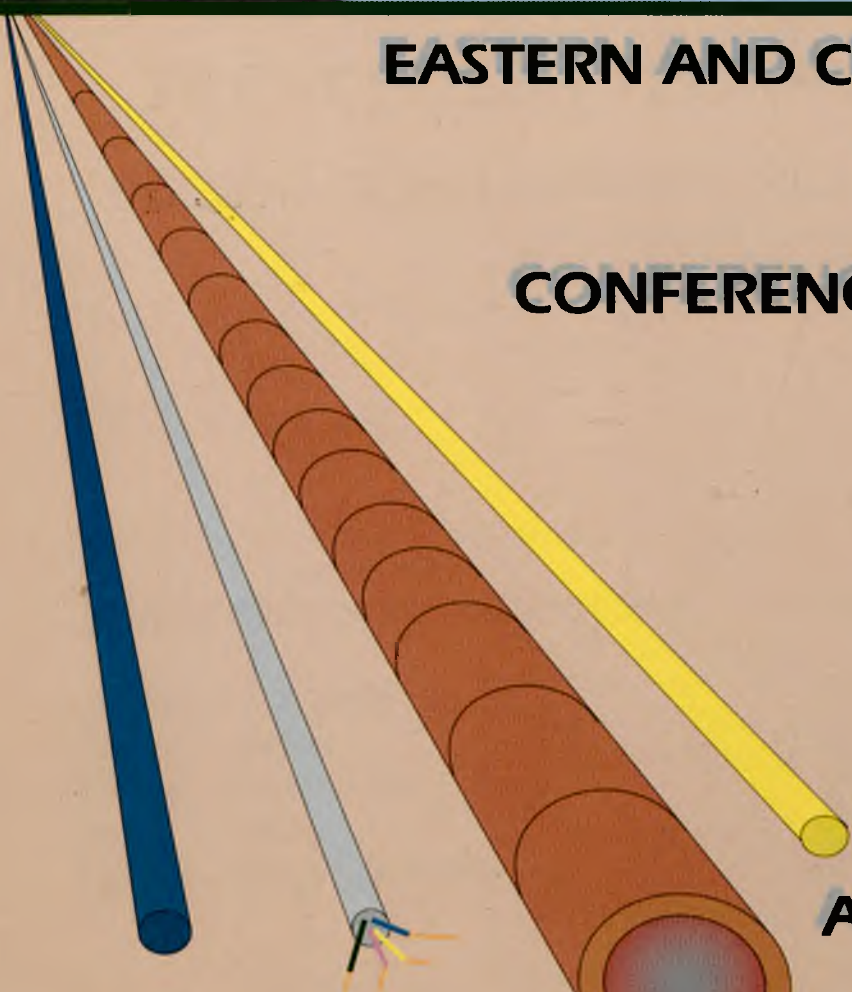

APRIL 19-20, 1995

THE WARSAW PALACE OF CULTURE AND SCIENCE

CONFERENCE PAPERS

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RESEARCH DESIGN AND REALIZATION OF ECOLOGY INFRASTRUCTURE EKOLAND Sp. z o.o.
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IN ASSOCIATION WITH

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TRENCHLESS TECH WARSAW ' 95

INTERNATIONAL CONFERENCE AND EXHIBITION

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WARSAW 19-20 APRIL 1995

CONFERENCE PROGRAMME

Wednesday 19 April 1995

0800 **Registration Desk open.**

1000 **Welcome and Introductions.**
Dr M Ways, Ekoland Sp. z o.o. (Poland).

1015 **Opening of the Conference.**
Prof. M Roman, President Polish Association of Sanitary Engineers and Technicians (Poland).

1025 **Opening Address.**
Trenchless - an Option and an Opportunity.
Dr D B Downey, Insituform Technologies Ltd. (UK).

1045 **Principal Aspects of Environmental Policy in Poland.**
A Deja, Ministry of Environment Protection (Poland).

1100 **Coffee**

1145 **Session A - Technology Transfer.**
Chairman: Prof. A Kuliczkowski
Trenchless Technology Research - Applications & Transfer.
J Cant, Water Research Centre (UK).
Application of Trenchless Technology for Hydraulic Isolation.
Prof. M Nawalany, Warsaw University of Technology (Poland).
Modernization of Underground Pipes in Towns in Poland
Dr A Kolonko & Prof. C Madryas, Technical University of Wrocław(Poland).
Microtunnelling and its Training Requirements
S Orchard, Euro Iseki Ltd (UK).
Discussion.

1300 **Refreshments.**

1430 **Session B - Trenchless Utility Installations.**
Chairman: E Holm
Microtunneling v Open-Cut - a Comparative Study.
Dr D N Chapman, University of Nottingham
S D Chapman, Leicester City Council (UK).
Connections of the Underground and Off - Shore Pipelines Using Horizontal Drilling.
Prof. B Mazurkiewicz, Gdańsk University of Technology (Poland).
Getting Wired: the Willingboro Story.
T Wilkinson, FlowMole Ltd (UK).
Long Distance Pipe Jacking in Soft Rocks.
U Sieler, LGA Grundbauinstitut (Germany).
Discussion.

1545 **Refreshments.**

1615 **Session C - Underground Detection.**
Chairman: N. Taylor
The Application of Geophysical Methods Into Locating Elements of Buried Technical Infrastructure.
Drs J Antoniuk & A Koblański, University of Mining and Metallurgy (Poland).
Magnetic Methods for Underground Recognition and Location.
Profs G Bojdys, T Grabowska & M Lemberger, University of Mining and Metallurgy (Poland).
Auto - Fault Localization in MV Cables.
Prof. E Anderson & S Maziarz, Institute of Power Engineering & Dr W Tarczyński, Opole Technical University (Poland).
Pipe & Cable Locators for NO - DIG Technology.
J P Kozłowski, Radiodetection Sp. z o.o. (Poland).
Discussion.

Thursday 20 April 1995

0800 **Registration Desk open.**
1000 **Session D - Rehabilitation.**
Chairman: Prof. C Madryas
A Method for the Renovation of Sewage Pipelines with the use of HDPE Sure Grip Relining
U Scheder, Frank Co (Germany).
Diagnostic and Renewal of Sewers.
Prof. A Kuliczkowski, R Pluta & D Zwierzchowski, Kielce University of Technology (Poland).
Renovation of Syphons under the River Elbe in the City of Dresden.
R Dilg, Insituform Brochier (Germany).
Mechanical Method of Water Supply Pipes Cleaning.
Dr J Wąsowski, Ekopig Sp. z o.o. (Poland).
Discussion.
1115 **Coffee**

1200 **Session E - Investigation and Mapping.**
Chairman: Prof. B Mazurkiewicz
Sewer Investigation & Prioritisation.
E Holm, I Krueger AS (Denmark).
Sewer Rehabilitation around Gulf of Finland.
M Ojala, Viatek Group & S Kuikka, Painehuuhtelu Oy PTV (Finland).
Robot Technology.
A Schreibelt, KATE Systems Ltd. (Switzerland).
Recent Developements in Buried Service Mapping
N Taylor, Aegis Survey Consultants Ltd (UK).
Discussion.
1315 **Refreshments.**

1445 **Session F - Trenchless Equipment and Materials.**

Chairman: S. Orchard

Trenchless technologies for laying and replacement of pipes and cables.
M Rameil, Tracto-Technik (Germany)

Modern Machines for Trenchless Technology.
D Jenne, Terra AG (Switzerland) & E Grygorcewicz BTH (Poland).

Equipment for Guided Drilling.
Dr RM Dmowski,COBRBI Hydrobudowa (Poland).

The Problem of Selecting Materials for Construction and Renovation of Water- and Sewage-Pipelines
Dr M Kwietniewski, Warsaw University of Technology (Poland).

Discussion.

1600 **Closing Summary of Proceedings.**
J E James, ISTT, (UK)

EXHIBITION CATALOGUE

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15. **Sika Poland Sp. z o.o.**
ul. Karczunkowska 89, 02-871 Warszawa, Poland.
phone: 48/2 6447824

16. **Tracto-Technik Spezialmaschinen KG**
P.O. Box 4020, 57256 Lennestadt, Germany.
phone: 49/2723 8080

17. **Vermeer International BV**
A Plesmanweg 3, 4462 GC Goes, Holland.
phone: 31/110 32232

OPENING ADDRESS: "TRENCHLESS - AN OPTION AND AN OPPORTUNITY"

Dr Declan B Downey, Insituform Technologies Ltd, UK.

SYNOPSIS

In the ten years since its inauguration, the trenchless movement has grown in stature from a special interest group to a global professional body dedicated to education and advancement of profoundly sensible engineering practise. Its aims and aspirations are of fundamental value to nations rebuilding infrastructure and are ignored at risk to growth and prosperity. The trenchless option is an opportunity for efficient use of resource. The advantages are recognised but have some way to go before any measure of universal adoption can be taken as read. The campaign for acceptance involves change in conservative industries and institutions and our efforts must be relentless. Acceptance involves an understanding of the social impact and the availability of proven and competitive trenchless options.

INTRODUCTION

It was almost exactly ten years ago that the Institution of Public Health Engineers in the UK organised the inaugural No Dig Conference in London entitled Trenchless Construction for Utilities and little more than a year later the International Society (ISTT) was launched. Today we have no less than ten national societies affiliated to the ISTT and several more trenchless organisations in embryo, perhaps 5000 engineers sharing a common goal: to advance the science and practise of trenchless technology for the public benefit. It is therefore with some pleasure and a real sense of responsibility that I embark upon this opening address at Trenchless Tech, Warsaw which is focused upon Eastern and Central European opportunities

The past five years have seen dramatic changes in the political map of Eastern Europe, these changes have created enormous challenges and opportunity for the engineers who seek to upgrade their industries and the public utilities to international standards. So too for the businessmen and financiers who will have to fund and structure the commercial deals in a situation where demand exceeds supply many times over and the legislative framework and commercial codes are at best developmental. Nonetheless the historic cities of the former Eastern bloc represent a market opportunity measured in millions of kilometres of sewer, water main and gas pipe and the development of underground power and telecommunication distribution will multiply the value of construction and maintenance work in the years ahead.

It is against this backcloth of opportunity therefore that it is essential that the cost effective merits of trenchless construction and repair be focused to play a vital role in the modernisation of infrastructure without providing the impediments to progress usually signalled by the internationally recognisable road sign "Men at Work".

OBJECTIVES

This conference brings us together for just two days of presentations in a programme brimming with interest including some of the best known technologies used in the West in the fields of detection, investigation and mapping, rehabilitation and new installation. It is encouraging that the programme contains so many contributions from the host country, perhaps an illustration of the immense technical capability of Poland and the other former Eastern bloc countries. We can therefore be optimistic that the take up of trenchless technologies will be rapid and the injection of new interpretations and novel local contributions will enrich the technology transfers which ensue to the benefit of the global trenchless movement.

I believe that we must achieve three objectives to further the aims of the international society to advance the science and practise of trenchless technologies for the public good.

We must strive for the recognition of the merits of trenchless technology - a simple enough objective in itself, but more than fifty years after the introduction of cement mortar lining, more than twenty years after the development of cured in place pipe and more than a decade after introduction of pipe bursting, directional drilling, and microtunnelling we can only estimate that 5-10% of pipe is installed or repaired by trenchless methods.

We must encourage the development of valid competition, many contractors here present, some with products developed years in advance of marketing awareness have struggled to offer sole source products. Our experience tells us beyond any doubt that the client wants a competitive bid to validate selection of a trenchless option.

We must promote quality in design and installation and intelligent exercise of choice.

I hope that in the course of the conference we shall share information, experience and opinion and in so doing will contribute to the recognition of the trenchless case, encourage healthy competitiveness and raise the expectation and delivery of quality.

RECOGNITION

In these opening remarks I want to stress the key features of the trenchless option and to make this message direct and unequivocal. In the past we have all worked very hard to show the economic benefits with as much intellectual integrity and fair play as can be applied. We have said time after time trenchless methods can be competitive and may even cost less than open cut methods of pipe installation or repair and in addition there is less disruption to the community. We have taken great care to define the circumstances of our claim so that it stands up to microscopic examination and in so doing have diluted the impact of our message. After more than ten years of offering cost effective and environmentally friendly engineering solutions to the utility authorities and their finance departments it is time to accentuate the positive.

Trenchless methods are very much better: Ted Flaxman, ISTT Chairman Emeritus, has told us at earlier conferences of the gross inefficiency of trenching, a process which often involves the removal of up to 100 volumes of soil to place one volume of underground pipe or cable — no wonder it usually costs more. Our own experience and official statistics of accident reports confirm that trenching is dangerous. We know that it is disruptive and dirty, it creates waste and promotes settlement of other pipelines, pavements and buildings and, above all, it disrupts the working of our industries and interferes with ordinary people going about their business and social lives. It should be avoided at all costs except where there is no trenchless alternative and we need legislation to promote this new philosophy. Such legislation already exists in Singapore and in Hong Kong, territories which have taken the trenchless concept wholeheartedly on board with competitive and thoroughly specified projects involving pipejacking and cured in place pipe repair.

In Japan the engineer has to canvass the support of the local community for the engineering of his pipeline repair or installation scheme and it is becoming more and more difficult to gain popular support for trenching. Japan, with its thirty years of major pipeline construction, has been one of the pioneering countries for microtunnelling, it has installed some 25000 kms of pipe by trenchless methods and in 1992 spent 45% of its construction budget on such techniques. We have come to respect Japanese innovation in engineering and its management methods, it is perhaps now time to see that its social and political consensus methods also make sense.

This acknowledgement of the trenchless arguments is not a trendy fashion, it is a soundly based practical response to the damage trenching does to the community daily life. It is a well documented fact that trenching reduces the life of our roads by a factor of three. The US Department of Transport disclosed these findings on pavement life in the mid eighties. In the UK recently Jason Consultants reported that social costs measured only as traffic delays cost as much and usually more than the direct civil engineering cost of pipelaying. This 'fact' had been brought to light some ten years earlier in a paper presented to the Institution of Civil Engineers. These examples show that the facts of the trenchless argument are not really in question it fairly obvious that trenching damages roads, existing underground services and the foundations of buildings, it is quite evident that delays interfere with business and the prosperity and happiness of the people local to a pipeline repair. Why have we been so slow to confront the issues and take up trenchless methods with more willingness? And, what basis is there for optimism that the peoples of Eastern Europe will be any faster than the rest of us?

COMPETITION

In the early years the high cost of innovation undoubtedly curbed the growth of competition between trenchless specialists. The margin between trenched and the trenchless methods was perhaps insufficient to encourage the engineer to adopt the novel method. Civil engineering involves risk and working underground with limited knowledge of the hazards involves more risk than many other construction projects, probably this has been another factor. However today there are in almost every field competitive operators offering their brands of microtunnelling, pipe bursting, slip lining or CIPP and in each category thousands of kilometres of track record existing to convince the customer that risk is understood and can be managed.

The simple practise of publication of a competitive tender may not encourage the establishment of viable competitors in the market and in the history of the trenchless business elsewhere there have been examples of positive intervention by public authorities to evaluate options and promote trenchless methods. It may be sufficient to simply set aside enough work to encourage overseas contractors to mobilise but closer interaction such as direct investment may produce better results. There are many different forms of positive involvement which act as an incentive to understanding and acceptance.

In Japan, Tokyo Metropolitan Government has involved itself in the exploitation of the SPR process, a spiral winding process similar to Ribloc or Danby with the result that this type of technology has become more successful in Japan than elsewhere in the world.

In the UK, Yorkshire Water, ARC Pipes and Decon Engineering combined to explore microtunnelling as a means of creating new urban sewers at lowest cost for the public benefit. The collaboration they formed led to a positive evaluation.

Washington Suburban Sanitary Commission has evaluated a range of trenchless renovation systems and its intervention has been important to the acceptance of trenchless methods throughout the USA.

Many others including City Authorities in Rotterdam,Stockholm, Hamburg, Berlin, Yokohama and Paris Val du Marne have taken an active role and encouraged specialist contractors. It is critically important to establish a level playing field for evaluation and provide sufficient volume of work to encourage the establishment of technologies on a local basis for the long term.

QUALITY

It is essential to establish or adopt standards at an early stage for the definition and evaluation of processes, for the management and adjudication of bids and for the continuous supervision of project work. Fortunately the International Standards Organisation (ISO), its European counterpart (CEN) and the US Bureau (ASTM) have all made substantial progress in the more established trenchless technologies. The No Dig Conferences in past years have been a forum for representation by CEN Technical Committee task group convenors, Gumbel and

Elzink, to publicise the work of their organisations and encourage participation from suppliers, contractors and customers so that we can expect over the next year or two to have a family of useful specification documents and procedures.

In addition the establishment of ISO 9000 procedures and arrangements made for independent assessment by an increasing number of contractors in the trenchless field has the potential to establish real discriminatory criteria between contractors and particularly between trenchless and trenched options. In many cases the technological demands of the trenchless processes lend themselves to the level of investment and supervision implied in total quality management. The cost saving benefits of TQM may therefore be more easily recognised and realised by the trenchless operator and the customer.

CONCLUSION

Positive thought and action by all participants in the trenchless industry, clients, consultants, suppliers and contractors is essential to the continuing growth of trenchless technologies in Eastern Europe as elsewhere. Our aim must be for a majority of the underground construction and repair to be trenchless. Achievement of this aim requires popular and political support which can only be achieved through a comprehensive recognition of the benefits to private and public enterprise taking into account all the tangible and intangible factors and by the provision of quality and economy by the supply side.

I hope that this meeting will lead to better understanding of the needs of the countries of Eastern Europe and of the contribution that trenchless technology can make to economic growth and prosperity. Most of all I hope we can make it happen, taking the experience of Western Europe, Japan and the USA and building on it for the public good.

THE PRINCIPAL ASPECTS OF ENVIRONMENTAL POLICY IN POLAND

Andrzej Deja
Department of Environmental Policy,
Ministry of Environment Protection, Natural Resources and Forestry, Poland.

INTRODUCTION

The discussion on vision of Poland's future and assumptions for perspective social, spatial and economic development has to concern the interests of future generations, for whom we have to guarantee the possibility of living in the favorable conditions of the surrounding unpolluted environment and using the natural resources of the country. The idea of sustainable development serves to ensure such living and further growth conditions for future generations.

The idea of sustainable development - constant and balanced development was passed in form of decree by Polish Parliament on May 10th, 1991 concerning the environmental policy as one of the principal aspects of formation Polish social and economic policy.

Poland pledged to put the principles of sustainable development into practice by:

- signing the Association Pact with the European Community.
  (the Article 71 paragraph 2 of Poland Association Pact with the European Community from 16th December 1991 says: "The policy of realization of Poland's economic and social growth... should be governed by the principle of constant growth. It necessary to guarantee that the needs of environment protection are from the beginning included in this policy."
- adoption of the document of United Nations Conference "Environment and Development" in that Agenda 21.
- signing or ratifying of many multilateral conventions of principal importance to the environment protection on regional and global scale. Participation in the "Environment for Europe" process, in that signing the documents of the Ministers Conference in Lucerne in 1993.

The principal assumption of the sustainable growth is to take such directions in the economy so that:

- any manufacturing activity has to be conducted at possibly lowest usage of natural resources, especially unrenewable ones (resources and energy) and with the smallest possible impact on the environment,
- the products are durable, of high quality and fulfilling the real, and not arising from irrational trends of fashion and consumptive life style, needs of individual citizens.

BASIC PRINCIPLES OF ENVIRONMENTAL POLICY

One of the basic principles of the new environmental policy is the principle of law-abidingness. This, under our conditions means the necessity of reconstruction of the legal system and the system enforcement in such a way that each regulation will be strictly abided and that no opportunities will exist for circumvention of the law for reasons of "higher necessity". In reconstruction of the legal systems there should be consistency ensured of our laws with the European Union directives and standards.

Excessive pollution is, at present, the main threat to the natural environment. The strategy for prevention of this threat shall be based on the principle of control at the source. This means that the choice of preventive measures and methods of remediation of damages, should be according to the following hierarchy:

1. avoidance of pollution generation, i.e. activities aimed at the reconstruction of manufacturing and consumption practices to reduce the burden on the environment;
2. recycling, i.e. recirculation of materials and resources; recuperation of energy, water and raw materials from sewage and waste; utilization of waste instead of its discharge into the environment;
3. neutralization of pollution, i.e. cleaning of waste water, detoxication of combustion gases and neutralisation and dumping of solid wastes.

The above means that the low priority will be given to actions within the term of "end of the pipe".

The principle of common good shall be implemented through the establishment of institutional and legal conditions to be enacted by citizens, social groups and non-governmental organisations in the whole process of environment protection and formation.

The environment protection policy will be to the maximum extent subjected to economisation principle. This means that the greatest possible advantage will be taken of market mechanisms with the necessary maintenance through the state intervention. During the initial period, market mechanisms should fully rule the production of environmental protection equipment. Gradually these instruments will be introduced into other spheres of environmental policy, for instance, the system of charges for use of the environment.

The implementation of the economisation principle shall take from of strict implementation of the "polluter pays" principle. This means placing full responsibility, including material liability, for the effects of pollution and other damages to the environment, upon the originator, i.e. subjects utilising the environmental resources.

In the reconstruction of environmental law and the system of economic instruments the principle of regionalisation shall be observed which means:

1. extension (or introduction) of rights of the territorial (local) self-government and regional governmental administration to determine regional charges, standards and other environmental requirements towards commercial enterprises,
2. the regionalisation of countrywide mechanisms and policy of environmental protection in relation to three types of areas:
   - industralised and urbanised areas,
   - areas of great natural value (with the predominance of protective, scientific and recreational functions and significant role in forestry and ecological agriculture),
   - intermediate areas (with predominance of intensive agriculture and modestly developed industry mainly food processing industry),
3. connection (coordination) of regional policy with the European regional ecosystems (e.g. the Baltic Sea and border ecosystems of neighboring countries).

Poland's substantial role in the pollution of the European environment, as well as the transboundary influx of pollutants into the Polish territory calls for the need to implement the principle of common solution by the entire international community to address European, as well as global problems of environmental devastation. The key role in that will be played by bilateral and multilateral agreements in which Poland shall participate. The significant role will be in implementation of the rules arising from international conventions such as Convention for the Assessment of Impact on the Environment in Transboundary Context in cooperation of Poland and its neighboring countries. A need also exists for the strengthening of links between regional European policy with the regional ecosystems (e.g. the Baltic Sea and border ecosystems between neighboring countries).

Due to the vast work still outstanding and the large investments required to reduce degradation and to revive the environment, the adoption of the principle of staging of long term plans with the selection of priorities for each particular stage needs to be implemented.

The achievement of significant results in environment protection requires reconstruction of those spheres of the economy which present the main source of threat to the environment i.e. energy production, industrial processes and transportation, as well as wider implementation of sustainable development in such sectors of economy (mining, agriculture, forestry, etc.), which are directly linked with the use of natural resources i.e. water, minerals, soil and other natural resources. The need of this reconstruction is further confirmed by the assessments of losses due to irrational management of natural resources. Among the main directions of the steps necessary for elimination or reducing of the threats to the environment the following can be listed:

- reorganisation of energy producing industry
- economy restructurisation
- reducing the burden of transportation
- rationalisation of use and management of water resources
- rationalisation of mining and use of minerals
- use, protection and landscaping of living natural resources.

ECOLOGICAL POLICY PRIORITIES

Taking the assessment of the environment condition and necessary activities undertaken for its improvement as the initial point and simultaneously willing to implement the rules for sustainable development in every social and economical activity in the country and in policies related to neighboring countries the priorities were chosen for implementation in three time frames, thus:

- near term priorities which implementation should be commenced immediately with attainment of results envisaged with 3-4 years, i.e. by 1994. Within this group contained are outstanding and arising threats which counteraction should not be postponed on the later date due to their direct consequences on human health and threats to the most valuable natural resources of the country,
- medium term priorities embracing systematic action aimed at protection of air, water, land and nature to counter the unfavourable trends of emmision of pollutants into the environment causing the continued degradation of the environment to reverse these tendencies and to substantially limit the pressure on the environment. The implementation of medium term goals should enable Poland to move closer to European environmental standards and allow it to join the European Union. It is envisaged that the medium term goals should gradually be raised during the implementation of the near-term priorities programme (within 3-4 years) and completed by the year 2000.
- long-term priorities which lead to full introduction of sustainable development principles into the entire economy and the attainment of such a state of environment which, according to our present criteria, could be considered desirable, ensuring safe public existence and stabilisation of thriving natural environment. The long-term goals should be achieved by the year 2020.

INTEGRATED APPROACH TO ENVIRONMENT PROTECTION ASSESSMENT OF THE IMPACT ON ENVIRONMENT

The efficacy of the state environmental policy passed on the principles of balanced development - sustainable development depends on realisation of various activities and on employment of other tools.

The conduction of spatial development policy of the country, regions and individual communities arising from the need of environment protection and landscaping has an important role, as well the rational protection and appropriate management of the natural environment in the localisational policy aided by the system for assessment of the impact on environment.

Those two means have the advantage that with their appropriate use they can allow for prevention of negative, often irreversible effects on the natural environment of activities mainly of commercial character.

Two legal decrees form the basis for management of appropriate for environmental needs spatial development of various regions and prevention of enhancing the threats to the environment and population health by proper localisation of new building, these are:

- Spatial Development Law
- Natural Environmental Protection Law

and orders and enactments being the executive acts to these two legal acts.

The Spatial Development Law came into action on 1st of January 1995, which introduced significant changes in the system of spatial planning having influence on the efficacy of this instrument in environment protection and prevention of its damage and undesirable transformations. It will probably reduce the role of plans and ideas of spatial development of the country and regions and enhance the role of local spatial development plans, and by participation of local communities - by opinion-giving councilors - in accepting the plans there will be social element in taking the decisions having the influence on shape and future condition of the environment.

The introduction of the rules of sustainable development -ecodevelopement is based, among others, on rationalisation of the spatial policies, both on the national and regional scale, as well as the local one. The elimination of threats for the environment and population health that can be caused by improper decisions on the direction of the spatial development or localistion of the particular undertaking having significant influence on the environment, often permanently degrading it and posing threat to population's health and living conditions, cultural goods, destroying the beauty of the landscape or extensively exploiting the natural resources should occur at the closest possible stage of planned activities. The important role in such actions is of the assessment of the impacts on the environment.

The importance of the institution of the assessment of the impact on environment is underlined by the mentioned above United Nations Conference "Environment and Development" in Rio de Janeiro, 1992. In rule 17 of the Declaration on Environment and Development it was written:

"The assessment of the impact on environment, as the national mean, has to be used on those planned activities, as to which it can be expected that they will have significant adverse impact on the environment and which are the subject of the decisions taken by the appropriate national authorities".

The system of assessment in operation in Poland sine 1980 has been undergoing constant improvement. Currently, mostly due to passing in Polish parliament the decrees of July 7th 1994: on spatial development and Building Law, there will be further transformations and significant modifications of this system. It can be expected that because of the tendency to harmonise our legislative acts with the European Union laws, the changes in system for assessment of environmental impact caused by the introduction of the above mentioned legislatures will only form the first step in wider changes of Environment Protection procedures in Poland.

Also, the Geological and Mining Law passed on February 4th 1994 introduced changes into existing system of assessment of the impact on environment. The compulsory requirement for provision of the assessment of the environmental impact was introduced for applications for mining concesions for:

- locating and identifying of the fossils deposits;
- mining of the fossils from deposits;
- container-free storage of substances in the rocks and storage of wastes in underground mining exploration areas;
- locating and mining of mineral resources found in waste formed after mining works and after the process of fossils enrichment.

Those assessments shall be formulated according to the legal requirements of Natural Environment Protection Law.

The experiences, so far, in application of the laws regarding the assessment of the impact on environment indicate urgent need for their modification in direction of eliminating the shortcomings or lack of precise solutions in active legislations, such as:

- lack of defining of the activities having possible adverse influence on environment condition,
- practically difficult defining of the activities, which are especially harmful to the environment and population's health,
- lack of differentiation in the scope of assessments and appropriate adoption of the range to the activities and degree of their burden to the environment.

The urgency of modification of these Laws is indicated also by the need to adjust to European standards and international conventions to which Poland is a side.

New legal solutions foreseen in the Spatial Development Law allow to start stage process of setting new legal acts modifying procedures and legislations concerning localisation of the enterprises with regard to their impact on environment.

At the first stage - in modified decree of Minister for Environment Protection, Natural Resources and Forestry of 23rd April 1990 regarding the enterprises especially harmful to the environment and population's health and conditions which should fulfill the prepared by experts assessment of the impact of the enterprises and construction objects on the environment - there will be detailed presentation and division of enterprises especially harmful to environment and population health and possibly degrading the condition of the environment. The division will depart from current classification based on the emission magnitude or influence of the enterprise in favour of precise description (enterprise categories) and parameters defining the scale of their magnitude.

In this decree there will be presented range framework and precision scale of the assessment of the impact on environment (treated as the description document) and the environment elements which changes should be included in the assessment with various degree of requirements, separately for both, above mentioned, groups of enterprises.

At the second stage, when there should be modification of the Natural Environment Protection Law of 31st January 1980 or there should be separate law devoted to the system of assessments of the impact on environment, there should be further changes introduced in e.g. requirement for forming of commissions for assessment of the environmental impact on the national or provincial level (ev. interprovincial) as the opinion- and advice-giving organs for Minister for Environment Protection, Natural Resources and Forestry and provincial authorities, respectively, and participation of community environment caretakers as the opinion-givers at the local authority level. The requirement for compulsory public debates on planned activities should also be included for given cases, as well as the possibility of increasing the participation and role of local communities in discussing the assessment of enterprises impact on the environment, among others by participation in proceedings of the commissions for assessment of the environmental impact. The changes in legal acts could possibly introduce cancelling the requirement for performing of these assessments by the experts from the list of experts of Ministry of Environmental Protection, Natural Resources and Forestry and description of the role of these experts in the procedure of assessment discussion.

The existing classification of the assessments can also be possibly changed for the assessment of the impact of enterprises on environment and the assessment of the existing objects by replacing them by environmental audit.

ASSESSMENT OF ADOPTED LOCAL SPATIAL DEVELOPMENT PLANS IN PERSPECTIVE OF ENVIRONMENT PROTECTION

The spatial development law introduced unknown, so far, in Polish law requirement of preparing and submitting prognosis of the adopted planned measures on natural environment in local spatial development plans.

To prevent taking of inappropriate decision about setting the conditions for construction works and development of the land it will be important to ensure adequate quality and precision of the prognosis of the effects of the local spatial development plans on the environment, as according to the art.43 of the law on spatial development it is impossible to reject the adopted building works and development of the area if those activities do not contravene the plan's details.

Minister for Environment Protection, Natural Resources and Forestry was empowered by the Spatial Development Law to set the conditions which should be met by the effects prognosis of the local spatial development plan on the environment. The appropriate decision should come to life really soon.

It has to be ensured that the introduced requirement to give the solutions (adopted measures) of the local plans under the assessment (prognosis) of their influence on environment is carried out in a consistent way.

Preparation of local spatial development plans and their adoption with full awareness of their effects on the environment will form rational basis for decisions allowing for undertaking of various activities, in that commercial ones.

The preparation of local plans (after their adoption they become local laws) will form the basis of localisational policy aimed at ensuring compliance with sustainable development rules and ensuring minimalisation of the effects of enterprises on the environment.

The requirement of preparation of assessment of impact on environment, according to directives being prepared by European Union, should be widened onto other plans, programmes and strategies.

OTHER ELEMENTS OF INTEGRATED APPROACH TO ENVIRONMENT PROTECTION

The important element of realisation of the ecological policy are the actions aimed at reduction of electric energy consumption, what in turn will reduce, beside the effects of protective measures in electricity generating industry the emmision of air pollutants.

The actions aimed at production of more modern and less energy-consuming articles and equipment will be supported by help in access to both national and foreign credit lines (by credit guarantees). New mechanisms of economical stimulation of introduction of technologies producing less waste will also be introduced.

The movement aimed at "cleaner production" will have important role. The introduction of management and production control changes in plants participating in the movement are aimed at reduction of waste formation and prevention of wastages in labour, raw materials and energy. Those actions following the inspection of technological operations and processes will lead by the qualitative, quantitative and cost-based identification of waste streams to describe the methods for elimination or reduction of waste burden. The technical and economical analyses carried out allow to choose the solutions that increase the usage of raw materials and energy and reduce the amount of waste polluting the environment, and in the same allow to reduce the amount of fees and fines paid by the companies for use of environment. In the final effect it enhances economical effectiveness of the companies and by that their competitiveness.

The factors aiding the realisation of economical policies and gradual introduction of the sustainable development rules are activities of proecological and consumer organisations leading to elimination of threats to the environment and helping to promote production that is environment friendly. The important role in promotion of such production and products will have introduction of product labelling with "ecological mark of quality".

TRENCHLESS TECHNOLOGY RESEARCH - APPLICATIONS AND TRANSFER

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SYNOPSIS

This paper examines various research and development projects around the World which have been carried out for trenchless technology equipment and systems. In the UK and elsewhere many organisations have been actively researching new techniques and machines for the trenchless installation of services.

Research and development is carried out by various bodies including private manufacturers, contractors, universities and research companies. Much of this R & D work can be applied to the service installation found in many parts of the world. Cities and urban areas suffer from common problems of extensive disruption and environmental damage caused by open-cut trenching work. The results of world-wide research to resolve this problem can often be readily transferred to those countries that can benefit, such as Central and Eastern European regions. In this Paper, possibilities for such a transfer of research knowledge is discussed.

INTRODUCTION

This paper gives an overview of trenchless technology research undertaken in various countries and the outputs that would be of benefit to potential users in Poland and elsewhere in Eastern Europe. It will be especially useful to those who are less familiar with trenchless technology and are seeking to use the output from research to assist the introduction of these techniques into their own countries.

This paper considers the full range of research relating to trenchless technology and for convenience divides the subject areas into technical, contractual and socio-economic subject areas. Making the most appropriate use of the available technology involves the user considering all these factors. To do this, all the relevant research that is available should be fully utilised.

TECHNICAL RESEARCH

The history of development in different countries has resulted in research being concentrated in particular areas. This is due to the demands of their respective markets. For example: in the UK much effort has been directed into pipeline renovation and on-line pipeline replacement; Japanese manufacturers have produced much equipment for first time installation, especially microtunnelling equipment. In the United States companies have developed much of the guided and directional drilling equipment.

The terminology used can vary and be confusing especially to those who are unfamiliar with the industry. For example the terms guided moling and guided drilling are used for the same types of technique by different users although they are identical. Standardising the terminology used is important and a Glossary of Terms has now been produced by the ISTT.

Tunnelling Research

There has been extensive research throughout the world into microtunnelling and pipe jacking. This is a complex area that can provide huge benefits so there is great scope for undertaking research. Much of the research has been undertaken by manufacturers in Europe, Japan and North America.

The UK Pipe Jacking Association, in association with Oxford University have undertaken extensive site monitoring of pipe jacking activities and recently published a report(1).

Directional and Guided Drilling Research

Directional Drilling research has been largely undertaken by the oil and gas industries and to meet their requirements. These techniques are fully established and their capabilities well known, the main drawback is their cost when used by other industries.

Guided drilling has great scope for use as it is a very cost effective technique and could be taken up far more widely for use by utilities in urban areas than is presently the case. The majority of guided drilling research has been undertaken in Europe and USA, most notably by contractors, and some of papers produced are: Instrumentation Systems for Guided Boring(2), Use of FlowMole GuideDril System in Europe(3), Meeting the Challenges of Trenchless Service Installation(4).

Pipe Bursting Research

This is now a well established technique and useful research has been undertaken at a number of establishments. Ruhr-Universtat at Bochum in Germany have produced papers on dynamic pipe bursting systems and British Gas in the UK have developed new systems and produced useful guides.

Guidance on pipe busting is available in the publication: Damage Control Procedure for Pipeline Construction Involving Pipe Splitting(5).

Sliplining Research

Recent research and development has been concentrated on close-fit and thin walled polyethylene sliplining systems for renovating pipelines. The close-fit techniques have the advantage over conventional sliplining of a reduced loss of pipe capacity and thin walled linings reduce the amount materials involved by employing the strength of the original pipe. There are a range of systems developed by different organisations in the UK: Swagelining™ by British Gas, Rolldown™ and Subline™ by contractor Subterra and 'U' Liner™ by contractor Avent Engineering.

Moling Research

Moling research and development has generally been undertaken by the equipment manufacturers.

Renovation Techniques Research

Extensive research effort has been directed into researching pipeline renovation techniques over the last ten years especially for rehabilitating water supply systems and sewer systems. This has involved much co-operation between the water companies and manufacturers.

Over forty different sewer renovation techniques are now marketed in the UK but the pace of newdevelopment has slowed. Techniques currently being developed in the UK include local repair techniques and spray applied lining techniques. The development is being undertaken bycontractors. Local repair techniques are short length repairs typically between 1m and 3m in length that are used as an alternative to complete manhole length repairs. The chief advantage is cost as a local repair is approximately only 10% of the cost of a full manhole length repair. The disadvantage is that they are still under development and the product is not yet fully proven. Details of all techniques marketed in the UK are available in the Sewerage Rehabilitation Manual(6).

Water mains renovation using epoxy and cement mortar linings is now fully established for use where there are water quality problems caused by old pipelines. New renovation techniques under development are generally aimed to rectify structural and leakage problems in addition to water quality problems. Thermopipe™ a flexible hose lining is being developed by Angus Fire in the UK and research is under way looking at the possibility for using structural sprayed linings.

Information on renovation is particularly relevant to older urban areas such as Krakow where services are in place and can be upgraded efficiently and with minimum disruption. In effect renovation makes use of the hole that is already in the ground.

Technique Selection

To assist the application of trenchless technology users require general information in order to select the most appropriate techniques. Few comparative research studies have been undertaken that look at the technical aspects. One that has is by the Midlands Electricity in the UK on cable installation techniques in the urban footpath(7).

Work has been undertaken at WRc that compares techniques available for rehabilitating water mains and sewers. Information is available in the Water Mains Rehabilitation Manual(8) and the Sewerage Rehabilitation Manual (SRM)(6). The SRM Volume III has also includes information on sewer renovation structural design.

The Materials Selection Manual for Water Mains(9) and the Materials Selection Manual for Sewers, Manholes and Pumping Mains(10) provide technical details on the full range of pipeline materials in use.

The UK water industry has produced a video 'The Route to Success'(11) that shows a wide range of techniques in use and illustrates the benefits of trenchless technology. This provides useful background information on techniques in use.

CONTRACTUAL RELATED RESEARCH

Users of trenchless technology are concerned to ensure that work is carried out to the standards required and to this end require the necessary information for contract documents. Trenchless technology techniques are generally more difficult to specify in contract documents than conventional trenching systems. Specifications that are based on performance criteria are suited to conventional installation techniques such as trenching whereas trenchless technology usually requires some form of method specification in a contract. Therefore the specifications and codes of practice produced by trenchless technology research usually cover aspects of installation in addition to details on materials to be used.

Research in this area can help produce the contract documentation that will give potential users more confidence in its use. This is especially the case in countries where techniques have not previously been used so there is not the local experience that can be drawn on. Research has produced documentation for contract authors that is concentrated in microtunnelling pipeline renovation systems. One reason is that special materials have been developed for these techniques.

Microtunnelling documentation

The following documents are available for microtunnelling: Code of Practice for Microtunnelling, 2nd Edition(12) . Published by Yorkshire Water plc, UK and A Draft Guideline Specification for Microtunnelling and specifications for microtunnelling pipes is published by the North American Society for Trenchless Technology in the 1994 Directory(13) .

Pipeline renovation documentation

The following documents are available for pipeline renovation: In-situ epoxy resin and cement mortar lining - operational guidelines and code of practice(14)(15) and a range of Water Industry specifications (WIS's) produced as a result of research by the UK water industry. The available WIS's cover the materials and some aspects of installation for ferrocement(16), cured-in-place linings(17) , and a number of segmental linings for man entry sewers(18) .

International standard being produced by ISO and CEN entitled: Techniques for rehabilitation of pipeline systems by the use of plastic pipes and fittings is being drafted(19) . This covers one area of trenchless technology and in future may be extended to include other types of materials.

SOCIO-ECONOMIC RESEARCH

Costs

The over-riding factor determining the take up of trenchless techniques over conventional techniques by the utilities in the UK is the cost to the companies, both short term installation costs and to a lesser extent the long term full life costs. In other industries and in other countries there is undoubtedly a similar story.

There are difficulties with determining representative unit costs for trenchless techniques as there is such a wide variance between individual schemes. A number of factors including the location and size of scheme can make a large difference to costs. It will be difficult therefore to use research into costs which has been undertaken in a different part of the World as anything more than a guide. Users will only gain reliable information through their own experience.
Research into the costs of trenchless techniques that provides useful background has been undertaken by a number of organisations. The Transport Research Laboratory in the UK have looked at costs under three categories: direct costs, indirect costs and social costs(20). Southern Water in the UK have compared the direct costs of open cut and trenchless techniques for sewerage rehabilitation.(21)

A paper by Midlands Electricity International compares the costs of techniques used for cable installation(7) . DSEA in France have shown sewer renovation to be less expensive than new construction(22) . Watson Hawksley and the Transport Research Laboratory have looked at the relationship between costs and depth when comparing trenching against tunnelling (23). Indiana State University in the United States have compared costs between traditional and trenchless techniques in which they considered direct bid costs and indirect societal costs(24).

Asset life information is often requested by users in order to calculate full life costs, Various sources of information are available which contain details including the water mains and sewers materials manuals(9)(10).

Social Costs

The social cost caused by different trenchless techniques can very enormously and it is not a meaningful comparison to group all trenchless techniques and compare them with conventional techniques. Therefore techniques need to be considered individually in relation to the social costs they will cause. Social costs research has been undertaken by the University of Manchester Institute of Science and Technology(25)(26) and the Transport Research Laboratory(20).

In addition to the social costs, utilities are concerned about the public perception of their work as a strong selling point for trenchless technology is high regard for their use by the public. Little research has been undertaken in this area, although there is evidence showing that more information is often required by the public if they are to appreciate the benefits of trenchless technology. If the public see evidence of work progressing they can be more tolerant to disruptions and are less likely to complain.

CONCLUSIONS

There is a large amount of information available from trenchless technology research that can be used by potential users in Poland and elsewhere in Eastern Europe. If trenchless technology is used effectively then its take-up should increase.

REFERENCES

1. Pipe Jacking, research results and recommendations. UK Pipe Jacking Association. 1995.
2. Pittard G, W McDonald, S Kramer. Instrumentation Systems for Guided Boring. No-Dig London Conference Papers 1989.
3. Ritchie J, Enenbach J, Kleiser K, M Steutel. Use of the FlowMole GuideDril System in Europe. No-Dig London Conference Papers 1989.
4. G Stangle, M Kern, D Keating, D Lee. Meeting the Challenges of Trenchless Service Installation. No-Dig Rotterdam Conference Papers 1990.
5. Report ERS M45, Damage Control Procedure for Pipeline Construction Involving Pipe Splitting. British Gas, WRc. 1990.
6. Sewerage Rehabilitation Manual, 3rd Edition. WRc 1994.
7. Alwyn Morgan. Technical and Economic Comparison of Cable Installation Techniques in the Urban Footpath. No-Dig Copenhagen Conference Papers. 1994.
8. Water Mains Rehabilitation Manual. WRc 1989.
9. Pipe Materials Selection Manual for Water Mains. WRc. 1988.
10. Materials Selection Manual for Sewers, Manholes and Pumping Mains. Foundation for Water Reserarch. 1993.
11. Trenchless technology video - The Route to Success. WRc. 1992.
12. Code of Practice for Microtunnelling, 2nd Edition. Published by Yorkshire Water plc, UK
13. Directory of the North American Society for Trenchless Technology. 1994.
14. In-situ epoxy resin lining - operational guidelines and code of practice. WRc 1989.
15. In-situ cement mortar lining - operational guidelines and code of practice. WRc 1990.
16. WIS 4-12-06, Precast and in situ ferrocement. WRc. 1990.
17. WIS 4-34-04, Specification for polyester Insituform sewer linings. WRc. 1986.
18. WIS 4-12-04, Glassfibre reinforced cement (GRC) sewer linings. WRc. 1986.
    WIS 4-12-05, Precast gunite sewer linings. WRc. 1986.
    WIS 4-34-02, Glassfibre reinforced plastics (GRP) sewer linings. WRc. 1986.
    WIS 4-34-05, Polyester resin concrete (PRC) sewer linings. WRc. 1986.
19. ISO Technical Report, Techniques for rehabilitation of pipeline systems by the use of plastic pipes and fittings
20. Thomson J, Sangster T, New B. The Potential for the Reduction of Social Costs Using Trenchless Technology. No-Dig Copenhagen Conference Proceedings 1994.
21. Rosbrook R, Reynolds J. Southern Water Saves Money. No-Dig London Conference Papers. 1987.
22. Legaz C. Comparison in Quality and Cost: Rehabilitation and Replacement. No-Dig Conference Papers. 1993.
23. Norgrove W, O'Reilly. Comparisons of the costs of constructing sewers by tunnelling or trenching in urban areas. No-Dig Rotterdam Conference Papers. 1990.
24. Traditional versus trenchless - a cost comparison concept. No-Dig Conference Papers. 1994.
25. Green C, Wood J. Current research into social costs of sewerage systems. No-Dig

London Conference Papers. 1987.
26. Read G, Vickridge I. The environmental impact of sewer replacement and renovation. No-Dig Rotterdam Conference Papers.

APPLICATION OF TRENCHLESS TECHNOLOGIES FOR HYDRAULIC ISOLATION

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ABSTRACT

A notion of hydraulic isolation of uncontrolled waste disposal sites (WDS) is advocated for the cases when groundwater needs to be protected and all other isolating methods are not possible. The specific type of hydraulic isolation that uses active drains is shortly described in the paper. To construct such drains underneath the waste disposal sites the trenchless technologies are clearly indispensable. The application is under research.

INTRODUCTION

An occurrence of pollution in an aquifer is a kind of the real life fact which sooner or later calls for the remediation or control action. This seems to be a trend nowadays to clean subsoil that have been polluted by unrestricted industrial activities in the past. As the consequence of these activities thousands of old uncontrolled/nonisolated dumps of industrial wastes are also reported to exist in Europe. Poorly isolated or not isolated at all they endanger groundwater through their physical contact with the underlying aquifers. Transport of pollution that follows does effect detrimentally a quality of groundwater on the local and sometimes on the regional scale. Decision makers responsible for environmental protection attempt to enforce cleaning of polluted aquifers or at least impose some control over pollution. Natural and direct reason for the decisions is that many municipal intakes or individual wells have been endangered by the pollution being transported by groundwater and therefore this convenient source of potable water may be lost soon.

When pollutants do percolate from a given waste disposal site (WDS) into groundwater some action is needed that can either annihilate the source of pollution, or isolate the source from the underlying aquifer. Accordingly, the protective actions (measures) can be categorized into two classes :

(a) **Annihilation the source.** Within this class three subclasses are possible

- (a1) removing the source physically, e.g. by relocating, recycling or utilizing the disposed waste
- (a2) "freezing" the emission, e.g. by changing harmful substances into unharmful ones, by immobilizing the pollutant within the WDS or cutting-off the recharge (roofs, impervious covers etc)
- (a3) encapsulation of the WDS.

(b) **Isolation of the source.** It is assumed within this category that the source is emitting into environment all the time however the flux of pollutants does not reach the aquifer. Examples in this category are: using drainage systems, constructing impervious liners or crack-selfsilting liners and/or operating hydraulic isolation.

Hydraulic isolation does belong to category of so called active isolation (A.I.). An obvious difference between the conventional passive type of isolation and the active isolation of WDS lies in executing technical operations only once (passive) or continuously in time (active). Hydraulic isolation is based on the principle of forming an artificial local groundwater flow system underneath the WDS. This kind of isolation does allow to control a pollution transport within the underlying aquifer by keeping the pollution confined within some predefined (possibly small) flow domain. The major advantage of the hydraulic isolation lies in leaving the waste unmoved thus avoiding logistic, technical and economic problems of the huge mass relocation. Three types of active (hydraulic) isolation can be listed:

- active isolation using (abstraction/recharging) wells
- active isolation using ditches
- active isolation using active drains.

Below the active drains are advocated for their characteristics of "strong control" of pollution plumes. This strong control results from getting physically close to the pollution beneath the WDS thanks to trenchless technologies.

ACTIVE ISOLATION TECHNOLOGY - DRAINS

Six major premises have made the idea of the A.I. - Drains (see Figure 1) isolating technology feasible, innovative and attractive:

- existing positive experience in subterrain irrigation systems used for agricultural purposes for some time (e.g. R.W. Skaggs, 1981; P.J.T. van Bakel, 1988; T.T. Walczak *et all*., 1988; D.Kirkcham, 1992);
- practical and economic feasibility of so-called "trenchless technologies" which can be possibly used to penetrate a groundwater flow domain beneath the WDS without moving the whole mass of collected wastes;
- simple realization of the zero water mass balance requirement;
- high controllability of the installation performance as well as of the subsoil environment state with simple installations;
- simple measuring procedures
- potential of combining the technology with other isolating methods.

The A.I - Drains installations should fulfil the following criteria:

- they should be located beneath and close to the bottom of the WDS;
- their range should cover the planar projection of the WDS;
- by having their water balance equal to zero they should not distort a regional groundwater flow;
- polluted water abstracted from beneath the WDS should circulate through some purification station and after being cleaned it should be returned to the aquifer.

Drains should be placed perpendicular to the longer axis of the WDS. Depth of drains should be adjusted to the natural position and variation of groundwater table in such a way that the drains are always operating within the saturated zone. This sets two special requirements for the trechless technology applied :

- horizontal drilling needs to be made in wet conditions
- shafts parallel to the longer side of the WDS are necessary to ensure proper (i.e. horizontal) drilling and allow to connect the necessary pumping equipment.

A performance of a hydraulic isolation technology consisting of abstracting-recharging drains can be analyzed with the use of the analytical vertical two-dimensional model of steady-state groundwater flow in semi-confined aquifer in a presence of drains. Simple geometry, homogeneous parameters and simple boundary conditions have been assumed for underlying aquifer to simulate the isolation performance in terms of the installation effectiveness in capturing of the WDS-born trajectories. In general case high resolution numerical models are used for purpose (e.g. Nawalany et al., 1992).

REMEDIATION

The hydraulically based isolation technique can be readily used as the remediation techniques. In particular, it can be used for cleaning the aquifer from the pollution plumes having small spatial extent. The latter limitation is the result of the tacit assumption that for creating the local flow system (crucial element of these technologies) only limited (manageable) amount of energy, so money, is needed.

If the source of groundwater pollution (WDS) is stopped the following three processes (repeated continuously) can lead ultimately to cleaning the polluted part of the aquifer:

- removal of polluted water from the soil using active drains installation;
- cleaning the water in the purification station;
- reversing the cleaned water to the aquifer.

FINAL REMARKS

(i) trenchless technologies are indispensable for the active drains based hydraulic isolation of WDS. They can be relatively easy applied for any uncontrolled/inisolated WDS for which the waste cannot be moved/relocated.

(ii) It can be concluded from the simulations (M. Nawalany et al.,1992) that for the A.I. - Drains relatively small number of hydraulic elements (drains) is needed to control the flow of polluted water beneath the WDS. This statement is again a subject of dependence on the local hydrogeological situation.

(iii) Costs of the installation described in this paper has been calculated for a number of soil and installation characteristics, (J.A.Wallis et all., 1989). Results indicate that further theoretical and experimental investigations of the A.I. - Drains should be undertaken. Especially when the arrangements of the drains different than the parallel one needs to be analyzed a very refined numerical model must be constructed and costly experiments performed.

(iv) Taking into account sources of uncertainty in the hydraulic isolation of the WDS all the modelling and designing should be subject of robustness/sensitivity evaluation.

(v) A.I. - Drains seems to be attractive alternative for its ability to control flow and transport underneath of the WDS. Also a remediation of the locally polluted aquifer can be realized using this technology.

REFERENCES

1. Kirkham, D. and Horton, R., The stream function of potential theory for dual pipe subirrigation system, WRR, Vol. 28, No. 2, pp. 373-387, February 1992.
2. Nawalany, M., Loch, J., Sinicyn, S., Active Isolation of Waste Disposal Sites by Hydraulic Means, part II, Models, Report TNO Institute of Applied Geoscience OS 91-42-C, Delft, 1992.
3. Skaggs, R.W., Water movement factors important to the design and operation of subirrigation systems, Transactions of the ASAE, pp. 1553 - 1561, 1981.
4. Van Bakel, P.I.T., Using drainage system for supplementary irrigation, Irrigation and Drainage Systems, Vol. 2, pp. 125-137, 1988.
5. Walczak, R.T., Van der Ploeg, R.R., and Kirkham, D., An algorithm for the calculation of drain spacing for layered soils, Soil Sci. Soc. Am. J., Vol. 52, pp. 336-340, 1988.
6. White, J.A., Agee, M.H., and Case, K.E., "Principles of Engineering Economic Analysis", John Wiley and Sons, N.Y., 1989.

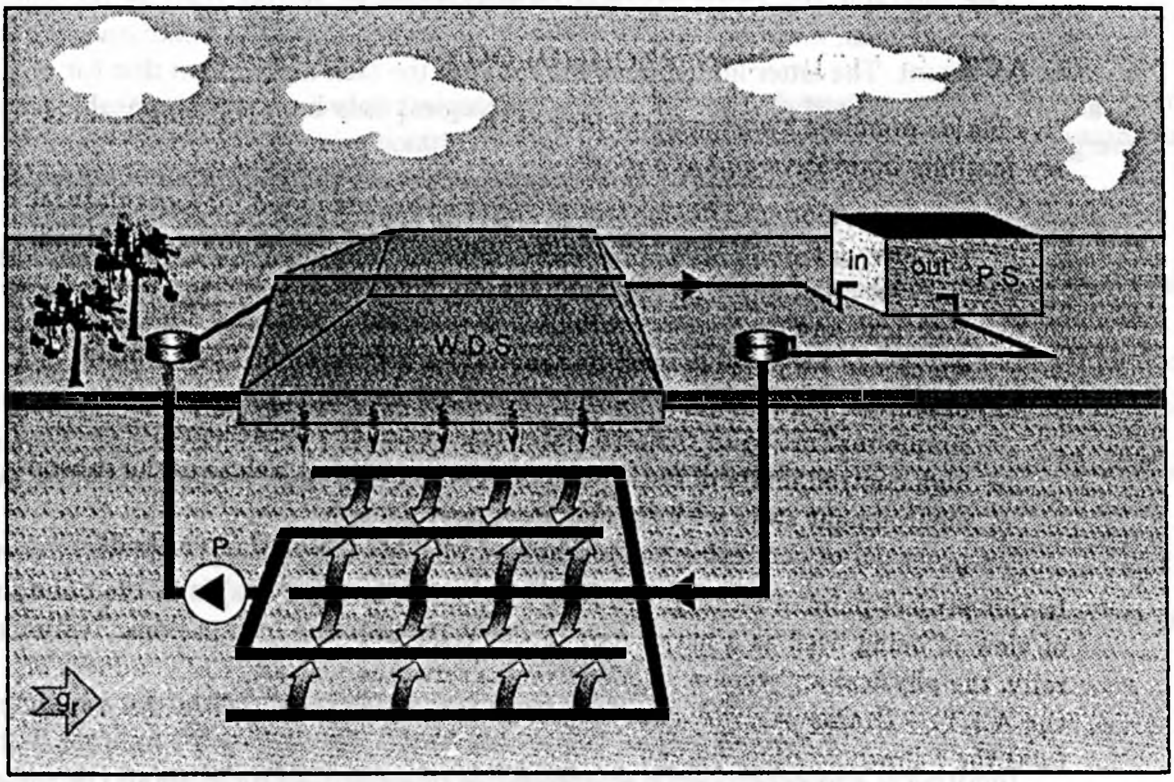

Figure 1. Configuration of the A.I. - Drains.

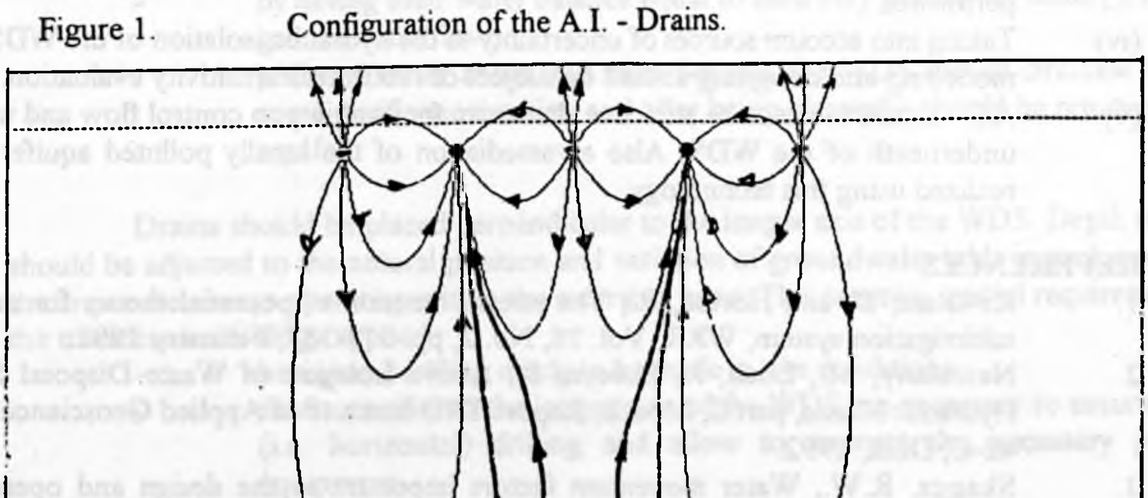

Fig. 2. Flow cells of the local system generated by the A.I.- Drains installation.

MODERNIZATION OF UNDERGROUND PIPES IN TOWNS IN POLAND

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Renovation of the existing, worn-out network infrastructure in Polish towns is one of the basic elements which make those towns conform to European standards. This problem has gained significance, especially in the light of the country's efforts to join European Union. Rehabilitation of pipes becomes necessary due to their bad technical state, poor efficiency, or such localization that collides with planned development of underground space in towns. There are discussed trenchless technologies for renovation of underground network infrastructure, starting from technologies used for single pipes to multi-conduit tunnels, as a method for complex modernization. It has been pointed to economic, technical, and legislative problems connected with the use of the solutions presented.

INTRODUCTION

New economic principles adopted in our country and the consequent transition to market economy give new value to urban development, which is due to changes in conditions of living and labour of town inhabitants as well as to their varied expectations and demands. There is observed a growing demand for high quality services, fast and comfortable transport, parking facilities, and network services, i.e., communication, water supply, energy carriers, and sewage systems. It is also expected that those parts of towns which have been modernized will be characterized by greater utility and will conform to ecological, safety and aesthetic standards. In order to satisfy the above requirements it is necessary to intensify the use of space in towns by means of partial stereoization, that is, development of underground constructions of high degree of integration, comfort and safety, observing the principles of ecology. In Poland, matters of great urgency are rehabilitation of network infrastructure as well as development of underground communication infrastructure, which can be done either simultaneously with network rehabilitation or after its completion.

The reasons implying the necessity to renovate the network include:

- bad technical state of pipes and, resulting from it, an increased frequency of network failures,
- poor efficiency of pipes,
- such localization of pipes that renders it impossible to build other underground constructions.

Bad state of pipes is an effect of faults that are caused by errors in construction, errors in materials and technology, errors in operation, as well as environmental impacts and ageing processes. In this case, rehabilitation of pipes can be carried out with the use of open-cut or trenchless methods, without any significant changes in dimensions and localization of pipes.

Inadequate efficiency of pipes is connected with an increased demand for media and with the growing volumes of sewage, which is a consequence of setting higher standards for urban facilities. Rehabilitation of pipes, in this case, consists in increasing either the dimensions or the number of pipes, so that the modernized system should be able to supply required quantities of media or to carry off greater volumes of wastes.

It becomes necessary to change location of pipes if the existing system collides with new underground investment project. In such a situation, pipes are moved to another place usually with the use of open-cut techniques.

It follows from the above considerations that the scope of rehabilitation may be confined to either repair works (the first case) or modernization (the remaining two cases). Repairs are usually done with the use of trenchless techniques and modernization with the use of open-cut techniques (in open excavations). We can now observe apparent inten-sification of repair works using trenchless techniques, which is obviously promoted by an influx of imported technologies. We may also expect that in the nearest future the demand for modernization works will grow considerably because of the above-mentioned necessity to stereoize urban space.

TRENCHLESS TECHNOLOGIES OF REHABILITATION OF UNDERGROUND PIPELINES

Leakage of underground networks may, on the one hand, cause discomfort in daily life of inhabitants, and on the other hand, bring about an increase in the degree of environmental pollution. The term "ecological bomb" has been invented, which picturesquely describes the disastrous effects of sewage exfiltration to soil, if no end is put to it soon. Only in Germany, at present the volume of exfiltration is estimated at about 300 mln m^3 [1]. A failure of gas piping may even pose a threat to life of inhabitants. Another consequence of such a situation are economic losses stemming from uncontrolled outflow of gas if failure of pressure pipelines (water main or gas piping) occurs. In the case of leakage of sewage duct laid below the groundwater level, sewage carried off to treatment plant is diluted, which makes the operational costs increase, sometimes to a considerable degree. In speeding up the action taken to improve technical state of underground pipes, most effective appear to be legal regulations which impose tough sanctions against polluting natural environment. Introduction of such regulations in western Europe was a turning-point, leading to the development of research, elaboration of new technologies, and establishment of numerous firms offering such services.

CLASSIFICATION OF THE METHODS OF REHABILITATION OF UNDERGROUND PIPELINES

Underground utilities are, in considerable part, worn out and in bad technical state. The reason for that are long periods of operation, sometimes even more than 100 years. In Germany, as gathered from [2], the age of nearly 80% of cost-iron piping ranges from 66 to 144 years. In Poland, the percentage of old pipelines is even higher, being due to negligence as regards construction of underground infrastructure during the post-war period. It is obvious that such long periods of operating the pipelines that have not been sufficiently protected are one of the causes of their bad technical state. As indicated in [7], the most frequent causes of pipeline failures are:

- settling of the ground,
- technical and biological corrosion,
- ageing of construction material,
- inadequate load capacity of pipelines, compared to increasing traffic load of dynamic character.

The required technical state of damaged underground pipelines can be ensured through their rehabilitation. Rehabilitation can be performed using the following technical strategies:

a) Repair

Repairs apply to single, local faults. In the case of pipes the diameter of which is less than 60 cm, use is made of all sorts of robots, packers, and other similar appliances. Repairs are carried out from the outside and inside, and consist in:

- mending, - injection, - sealing.

b) Renovation

Renovation consists in reconstructing the original technical state of damaged pipeline, by applying suitable technical procedures and preserving the old construction. We can distinguish the following groups of renovation methods:

- Methods of spreading, from the inside, of special sealing coatings
  The coatings can be made from different materials and spread by means of various techniques, e.g., spraying.
- Relining methods (rigid inserts)
  They consist in introducing a PE or PVC tube, with its outer diameter being less than inside diameter, to the inside of damaged duct. This may be performed in short sections from the well (short relining), or in long sections, covering sometimes even several hundred meters, from some suitable excavation (long relining).
  If it is important that reduction of the cross-section be limited, then renovation of damaged pipeline can be carried out using one of the "close fit" techniques within the relining method.
- Relining methods (elastic inserts)
  Elastic coating, having usually a multi-layer structure, is introduced in reversible process to the inside of damaged pipe (after the letter has been previously cleaned), and then stuck to its inner surface. During the hardening of adhesive, the coating is being held tight by water-vapour, air or water pressure.
- Fitting methods
  Fitting methods consist in covering the inside surface of damaged duct by suitably formed sheets made of materials ensuring complete tightness and resistance to chemical corrosion and abrasive wear. This method is commonly used to repair damaged bottom of ducts having small diameters. In the case of ducts the diameter of which is more than 60 cm, a complete inside lining is made, using suitably formed segments of dimensions that enable their transport.

c) Replacement

Replacement consists in laying a new section of underground pipeline, which will take over the function of the old pipe, the latter being in a bad technical state or its capacity being insufficient. Replacement can be carried out by means of traditional methods in an open excavation or with the use of trenchless methods. In the latter case, the old pipe may be replaced with a new one having the same or greater diameter, and the old pipe may either be moved or its fragments may be left in the ground.

EXPERIENCE GAINED IN THE COURSE OF RENOVATION WORKS IN WROCŁAW

In recent years, modern, western technologies of trenchless renovation of underground pipeline have become available on the home market. Prior to implementation of any of those methods, an economic analysis should be made. Considering the fact that labour is still relatively cheap in Poland, it appears to be often more cost-effective to replace old pipeline with a new one, using traditional methods in open excavation than employing trenchless technologies widely applied in western countries. However, sometimes it happens that investors are compelled to use trenchless methods, especially in centres of Polish towns, for the following reasons:

- disruption to traffic organization due to underground works,
- numerous collisions with other networks of underground infrastructure,
- possibility of damaging underground infrastructure network not taken in the inventory,
- costly pavement along the pipeline route,
- the necessity to carry out works fast,
- the necessity to avoid lowering of the grundwater level.

In choosing a method, both technical and economic aspects should be taken into consideration. It is important to estimate for how long service life can be extended after renovation done with the use of particular technologies. It may appear after such an analysis that using the least costly technology is not economically feasible.

In Wrocław, the situation as far as application of trenchless technologies is concerned with respect to particular networks is the following:

A) GAS PIPING

As regards underground gas piping, there is a specific situation in Wrocław, for it is urgent that cast-iron grids be tightened. This should be made fast because of conversion to natural high-methane gas, which is both more effective as fuel and when burnt, causes least environmental pollution. A sudden increase in the number of leakage occurring in bell joints is expected after conversion to natural gas due to its unfavourable action on the sealing material. Consequent gas losses may amount to 20% [3]. Therefore, in Wrocław, priority is given to the task of sealing cast-iron sections of gas pipelines. This is done by:

- sticking of thin, polyethylene sheeting to the inside of pipe in reversive process (polyurethane glue),
- sticking of thin sheeting and needled cloth in two-stage reversive process (polyurethane glue),
- renovation by means of relining method with the use of U-linear technology (close fit),
- replacement of old, cast-iron pipes with new PE pipes in open excavations.

B) WATER MAIN

In the case of water-pipe network, it is progressive corrosion that creates major problems. It causes loss of tightness and a decrease in cross-sections of cast-iron and steel pipes due to formation of the so-called incrustation. In Wrocław, these problems are dealt with by:

- sticking of the sheeting reinforced with needled cloth to the inside of pipe in a single-step reversive process (epoxy glue),
- renovation by means of relining method with the use of U-linear (close fit) technology,
- cementation of the inside surface of pipe by spraying method (pipe diameter being less than 60 cm),
- trenchless replacement of damaged pipes with new ones using BERSTLINING method,
- open-cut replacement of damaged pipes with new ones.

C) SEWAGE SYSTEM

In the case of sewerage network, basic technical problems include, apart from leakage, also construction damage which may be caused by:

- increasing traffic load of dynamic character,
- chemical and biological corrosion,
- friction of solid particles contained in sewage against the sewer bottom,
- military operations during the war.

These problems are being solved by:

- repairs of the damaged and leaking ducts (60 cm), using mortar,
- trenchless replacement of damaged sewers with new ones, making use of BERST-LINING method,
- open-cut replacement of damaged sewers with new ones.

MODERNIZATION OF NETWORKS

Modernization of networks, the efficiency of which is inadequate, can be carried out by systematically replacing particular pipes and laying them back in the ground. This solution makes it possible to spread capital expenditure over a longer period of time. But rebuilding of the system then takes a long time, causing disruption to local traffic and deteriorating the living conditions of inhabitants. The task is difficult also in view of the fact that when modernizing pipes of one network, the latter may appear to collide with other networks. The disadvantages of operating the network thus modernized are the following:

- the possibilities of inspecting the state of pipes, current maintenance and removal of failures, without tearing up the street, are limited to tv technique and trenchless methods of renovation,
- failure rate is increased, due to their direct contact with environment.

In consequence, all this makes it difficult to perform the works and operate the network, as well as increases the costs of operation, lowering at the same time the quality of the system functioning. Taking into account the above arguments, it should become a rule to consider possibilities of replacing pipes of all networks simultaneously and laying them down in multi-conduit tunnels or technical passages, in the case where pipes of particular networks have been worn out to much the same degree, which often happens in our country. The idea of using multi-conduit tunnels and technical passages as modernization technologies [4] is also justified by the need to integrate the systems of underground infrastructure, which raises the possibility of control and, as a result, increases their reliability and safety of operation. Such a direction of activities also stems from the necessity to "compress" the network in order to save underground space for other purposes, first of all, communication.

Multi-conduit tunnels are usually made by open-cut methods as shallow underground constructions situated at various places of the cross-section of a street. Because of the construction loading, it is best to lay out the route of tunnel under the sidewalk or, if there are two traffic lanes, along the division line. An important problem is to plan connections from buildings to tunnels. Connections which are laid directly in soil constitute the most unreliable element of the whole system, as they render it impossible to control pipes on a stretch of multi-conduit tunnel building. Therefore, connections, whenever possible, should be planned as tunnels of at least 60 cm in diameter or as a bundle of circuits laid in protective linings enabling their disassembly and assembly, and avoiding this way the tearing up of a street. It is especially advantageous to locate multi-conduit tunnels in constructions used for other purposes as well (particularly, communication tunnels) or joining them with technical passages. In the latter case, there are created the multi-conduit tunnel technical passage "chains", with the length of connections being reduced to minimum, on condition that these are two separate "chains" for buildings situated on both sides of a street. In construction of a technical passage it is necessary to adapt cellars of buildings adjacent to the street, which may appear impossible to carry on in the eye of the law if property owners give no consent to driving the conduits through cellars of their premises or they state too high a rent. That is why the economic and legal matters should be settled in planning at first, so as to make it possible to carry out the project and to make it economically feasible. Putting the networks in technical passages creates optimal conditions for underground space to be used for other purpose, as it is rid of a considerable number of circuits.

Location of sewerage in tunnels may also take place when longitudinal slopes of the bottom of tunnel are suited to required slopes of sewers. The sewers are separated from other grids by laying them under the tunnel floor in a bottom plate, fitted for that purpose, or enclosing them by a tight construction that protects the tunnel against flooding with sewage and against the action of gases escaping from sewage.

Laying the network in multi-conduit tunnels implies an increase in capital costs, stemming from the costs of both construction and tunnel fittings (lighting, ventilation, communication, signalling, drainage), including also dispatcher and personnel rooms. A relation between these costs and the costs of networks laid directly in soil depends upon local conditions and technological solutions and materials used. Naturally, the investment costs are, in such a case, higher by several dozen percent than when placing the network directly in soil.

Cost-effectiveness of laying networks in multi-conduit tunnels will be revealed only if the operational costs over predicted period of tunnel amortization are included in the costs analysis. If the account is based on annual costs, considering the discount account, then the costs can be expressed by the equation

$$K_r = K_{rr} + K_e = rK_{no} + K_e, \quad (1)$$

where: K_{rr} - annual costs of extended reproduction, which consist of amortization costs K_{am} and accumulation costs K_{ak},

K_e - annual operational costs,

K_{no} - capital expenditure reduced to zero year,

r - coefficient of extended reproduction.

The annual costs method is applied in order to identify solutions which ensure maximum production effect [5]. In investigating the costs of networks, there occur the elements of decision, seemingly not connected with production sphere. They include decisions about improving technical quality of pipelines and ability to operate them, all this being done to increase operational reliability of the network. Therefore, it is necessary to extend the annual costs K_r over the costs of system unreliability K_z.

$$K_{rz} = K_r + K_z = rK_{no} + K_e + K_z, \quad (2)$$

The unreliability costs introduced to the costs account have a character of economic reproduction of the effects of unreliable network operation and equal

$$K_z = K_s + K_{rem}, \quad (3)$$

where: K_s - annual costs of recipients losses due to network unreliability,

K_{rem} - annual costs of repairs after failure, extended over losses of suppliers, caused by the fact of not levying charges for cut-off periods due to the network unreliability.

Thus, optimization reduces to the search of the set of admissible solutions, in view of minimization of their annual costs K_{rz}. If the analysed solution suggests laying pipes in multi-conduit tunnel to minimize the costs of their unreliability K_z, then this also implies changes of other components of equation (2), as the investment costs K_{no} will increase, and the operational costs K_e will probably go down. That is why optimization does not merely consist in seeking solutions of extremely high reliability, because they may appear to be economically unjustified due to too large an increase in investment costs. Then, seeking a minimum resolves itself to comparing the sums of costs of the solutions considered. In practice, we deal with a discrete model of costs, which allows formulation of differential criterion for variants being compared, for example,

I - low-cost variant, with greater unreliability (laying pipes in soil),

II - high-cost variant, with lesser unreliability (laying pipes in multi-conduit tunnel).

The more expensive solution will be cost-effective if the following condition is satisfied:

$$K_{z1} - K_{z2} \geq K_{r2} - K_{r1}. \quad (4)$$

This inequality corresponds to the assumption that the high-cost variant (II) is considered advantageous if reduction of unreliability costs covers increased annual costs caused by the rise in investment costs due to the building of a multi-conduit tunnel. Taking the difference $K_{z1} - K_{z2}$ to be a profit resulting from the improvement of reliability, implied by additional annual costs K_{r2} - K_{r1}, we can determine the effectiveness index , illustrating economic effectiveness of means earmarket for decreasing the unreliability of analysed variants

$$\epsilon = \frac{(K_{z1} - K_{z2}) - (K_{r1} - K_{r2})}{(K_{z1} - K_{z2})} \geq 0 \qquad (5)$$

The effectiveness index is mainly taken advantage of in analysis of the effectiveness of transitions between variants of increasing reliability, which consists in determining the "profitability" of means used for reliability improvement. The problem to be solved in the above costs account model is that of comparing the quantities that have been determined (annual costs) with random quantities (unreliability costs). According to the decision-making theory, such a procedure is right on condition that unreliability costs should be determined on the basis of known distributions of random variables, or some representative statistical material. Unfortunately, there are no such data from investigations available in our country that would allow any of the above-mentioned conditions to be satisfied. This causes that, for the time being, decisions can be taken merely on the basis of approximate determination of costs with the use of the strategic decision-making model. In this model, the unreliability costs should be assigned the weight $1-\alpha < 1$, where is the measure of the lack of confidence in the values K_r being introduced. For the weight thus formulated, the annual costs are expressed by the equality

$$K_n = rK_{\infty} + K_r + (1-\alpha)K_n \qquad (6)$$

and the differential criterion takes the form

$$(1-\alpha)(K_{z1} - K_{z2}) \geq K_{n} - K_{n1} \qquad (7)$$

After algebraic transformations, the effectiveness index $\epsilon_{1,2}$ of transition from a more unreliable variant (with pipes being laid in soil) to a less unreliable one (pipes being laid in a multi-conduit tunnel) is defined by the relation

$$\epsilon_{1,2} = \frac{(K_{z1} - K_{z2}) - (K_{r1} - K_{r2})}{(K_{z1} - K_{z2})} \geq \alpha \qquad (8)$$

The unreliability costs cannot be analysed without taking account of the time factor, since its functions are the changes in intensity of pipe failures and in the market prices of materials, equipment and labour. Taking into consideration the time factor requires that the mean discount values be included in the calculus, and so, equation (8) takes the form

$$\epsilon_{1,2} = \frac{a_r \sum_{i=1}^{i=T} [(1-\alpha)(K_{z1i} - K_{z2i}) - (K_{e2i} - K_{e1i})](1+p)^{T-i} - (K_{no2} - K_{no1})^r}{a_r \sum_{i=1}^{i=T} (K_{z1i} - K_{z2i})(1+p)^{T-i}} \geq \alpha \qquad (9)$$

where: a_r - coefficient of progressive amortization,
T - amortization time in years,
p accumulation rate,
i - successive years of operation.

The difficulties and limitations presented above render it impossible to carry out analysis of the real costs of multi-conduit tunnels, reducing it to comparisons of capital expenditures, the results of which are decisive in rejecting solutions of this type. As there are not many multi-conduit tunnels in our country, it is difficult to carry out research on pipeline operation in order to establish the necessary data bases, making it impossible to show technical and economic advantages of tunnels. In the face of those limiting circumstances, researchers today have at their disposal only heuristically-directed, intuitive methods.

This reluctance to use multi-conduit tunnels should also be connected with the lack of legal regulations, as far as the running of networks located in tunnels is concerned. In the case of pipes laid in soil, they are run by owners of particular networks. But if pipes are placed in a multi-conduit tunnel, there arises the question of who should run them or coordinate operation of particular network owners. The problem can be overcome by:

- establishing one-man companies in districts, the task of which would be to build tunnels and to operate pipes laid there, in return for a rent charged from particular owners,
- establishing companies that are assigned the same tasks, and whose members would be the owners of pipes laid in tunnels.

According to principles of market economy, companies cannot operate at a loss in either case. This will cause the multi-conduit tunnels to be seen as a source of potential income, and the problem of their effectiveness will have to be solved by companies undertaking the risk of building and running them, which till now has practically been nobody's problem. It seems that such enterprises might stimulate development of multi-conduit tunnels as a technology of the network infrastructure modernization in cases of considerable wear of a majority of grids, their inadequate efficiency or collision with planned development of underground space.

CONCLUSIONS

In view of the fact that technical state of pipelines is pretty bad in Poland, it becomes necessary to balance the needs and possibilities. In order to intensify technical activities, appropriate legal regulations should be set up and put into force, compelling the owners of pipelines to keep them in condition which would not create environmental and safety hazards. There are a number of firms on domestic market now, which offer various technologies of renovating underground pipelines. In order to implement them rationally, one should make thorough economic and environmental nuisance analyses, by comparison with open-cut methods.

In situation where pipe efficiency is inadequate, or the state of pipes of more than one network is bad, or else, their localization renders it impossible to carry on other underground projects, it is advisable to use multi-conduit tunnels as a technique for the network infrastructure modernization. Prior to spread of such a technique, law should be made to authorize potential owners of tunnels, for whom multi-conduit tunnels are expected to be a source of income.

LITERATURE

1. Engelmann H., Neubau oder Instandsetzung von Kanalisationen; Tiefbau Ingenieurbau Straßenbau, Heft 10 / 1990.
2. Hofer P., Planung der langfristigen Erneuerung von Wasserrohrnetzen; 3 R International, Heft 1-2 / 1994.
3. Kolonko A., Problemy techniczne przy renowacji sieci gazowej metodą PROCESS PHOENIX; GW i TS Nr 8 / 1994.
4. Kuliczkowski A., Madryas C., Tunele wieloprzewodowe, Skrypt nr 169, Politechnika Świętokrzyska, Kielce, 1989.
5. Lange O., Teoria reprodukcji i akumulacji, PWN, Warszawa, 1975.
6. Sozański J., Niezawodność zasilania urządzeń i układów elektroenergetycznych, PWN, Warszawa, 1982.
7. Stein D., Kaufman O., Shadenanalyse an Abwasserkanälen aus Beton- und Steinzeugrohren der BRD-West.

MICROTUNNELLING AND ITS TRAINING REQUIREMENTS

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INTRODUCTION

Microtunnelling is now a well established technology for the installation of pipes and ducts. It involves the sinking of two shafts and the pipejacking of a suitable pipe between the two shafts into a tunnel which is being bored by a microtunnelling machine. Microtunnelling has now been carried out for approximately 25 years, with several thousands of kilometres of pipework installed in nearly every type of ground. The variety of pipe which has been installed includes concrete, clay, GRP, steel, asbestos cement, ductile iron and no doubt others.

But we hear cries of "It's not that easy"! Indeed the process is straightforward, but its application is more complex and my subject is the training requirements so that microtunnelling is carried out effectively.

First we should identify the reasons why microtunnelling is not effective.

1. Inadequate knowledge about ground conditions.
2. Failure to sink suitable shafts.
3. Failure to choose a suitable microtunnelling machine.
4. Failure to use suitable pipes.
5. Failure to manage the operation correctly.
6. Failure to operate the machine correctly.
7. Failure to survey and install accurately.
8. Failure to maintain the mechanical and electrical equipment suitably.
9. Failure to use correct remedial measures.

We can quickly comment on the first four reasons listed above by noting that:

- it is essential for successful microtunnelling that adequate ground investigation is carried out, and the information made available to the microtunneller and its staff,
- suitable shafts must be designed and installed,
- the equipment chosen must have adequate track record and be able to demonstrate its effectiveness and
- the engineer who identifies and designs the pipes to be employed must carry out this activity correctly and effectively.

These are all absolutely vital activities. The reason why we are not spending more time on these activities is simply that they are not the direct subject of this paper. What are the training requirements for microtunnelling? Firstly it is advisable to have a training policy. This should include the following:

- A statement of objectives,
- A schedule which identifies the requirements for each person on the team,
- The documentation and information which is required to enable the training to take place,
- Equipment and a site on which the training can take place,
- Instructors who can carry out the training.

Much of the above will initially be supplied by the equipment supplier which first supplies equipment to the new microtunneller. Thereafter, the company can use its own in-house expertise to train its own employees.

MICROTUNNELLING MANAGEMENT

SITE ESTABLISHMENT AND BACK UP EQUIPMENT SELECTION

A microtunnelling site comprises a shaft, an operation station, handling and lifting equipment, pipe storage, power equipment and a means of spoil removal from the excavated tunnel. It is the nature of microtunnelling that these are often installed in congested areas where a suitable site layout can materially affect the speed of the operation.

Microtunnelling Options: The first person who needs to be trained is the supervising engineer. He needs to be able to evaluate the different microtunnelling techniques. For example, he needs to be able to decide whether to use a slurry or auger system, how long the drives might be, where are the best places to locate shafts, what is the best line for the drives and a number of other basic technique issues.

Site Layouts: Next the engineer who designs the site layout must ensure that his knowledge of the different options of layout and equipment is sufficient so that he can utilise the best arrangement to suit the requirements of a particular site.

Material handling is one of the key issues, as a project can be severely delayed if either pipe supply cannot be maintained or excavated material is not suitably removed. The material excavated can come out in different forms. Augered material is removed in skips and dumped into waiting trucks, slurry material is generally continually separated and either discharged from a separation plant into a waiting truck or dumped from settlement skips into cart away trucks at periodic intervals. Obviously if sufficient transport or suitable transport is not arranged, the entire sequence can be severely delayed.

As the environment becomes more heavily controlled it is more usual that slurry and excavated material has to be disposed of in controlled tips. If the routing and access to these tips is not properly managed it can slow the microtunnelling operation.

The separation process can also badly affect the rate of progress. It is important that the operators are familiar with the methods of separating the different types of soil. They also need to be familiar with the additives and chemicals available to assist with difficult grounds should these occur.

PLANNING AND SCHEDULING

A key part of the planning and training process is to identify a suitable sequence of shaft installation in relation to the microtunnelling activity. In order to prevent delays to the microtunnelling, it is advantageous to have shafts completed well ahead of microtunnelling. It is Iseki's recommendation that there are generally four shafts ahead of the drive shaft which is being undertaken at any one time.

The planning process should also take into account the provision of power supply, piping materials, water, electrical/mechanical fitters, surveying and the maintenance schedule as well as normal site equipment requirements.

Pipe Change Crews: The typical schedule for microtunnelling is as follows (See Attachment 1):

a) Site Establishment: This is the installation of the equipment within a prepared shaft, and the set up of the site. This can take between two and five days depending upon the size and sophistication of equipment and the experience.

b) The Time Spent Driving the Microtunnelling Machine: This is a function of the equipment, the ground condition and the skill of the operator. We have used for our example a typical 100 metre drive. This can take between 3 and 20 days depending upon skills, equipment and ground conditions.

c) The Time Spent Changing Pipes During the Microtunnelling Process: The team that carries out the pipe change is a key part of the operation. They have to be not only familiar with the operation, but skilled to ensure that the pipe change is a rapid process. An inexperienced team in a poorly established site can take up to 1 hour to change a pipe. A well experienced team might do it in as little as ten minutes.
In order to demonstrate the impact that this has on drive time, we are showing in the Attachment the difference made on a 100 metre drive where the pipejacking speed is a constant 100 mm per minute, and the pipe change time in Case 1 is 15 minutes and in Case 2 is 45 minutes.

d) The final removal of the machine from the reception shaft.

Microtunnelling is a linear process. By that I mean the whole operation is dependent upon each phase of the activity. If anything breaks down the whole operation ceases. There is very little opportunity on a microtunnelling site to usefully employ the lost time doing some other critical activity.

With microtunnelling the whole process is a critical path activity. This means that it is essential that attention is paid to detail. A single pipe connection which goes wrong - for example because a pipe packer is missing - will delay the job. Therefore, adequate detailed planning and contingency preparation is even more vital in microtunnelling than in many other types of construction project.

From this it is obvious that the training process cannot be simply targetted to the site supervision and the operator. It is also necessary that the entire microtunnelling team is trained. This will ensure that the critical activities such as pipe changes are carried out in both a speedy manner and in a way which is not likely to lead to failures.

The training of these activities is not a difficult process, it is simply one that has to addressed and not ignored. It is mainly carried out on the project through tuition provided by more experienced staff. The use of a skilled team will lead to a project being successful that will otherwise become a failure however skilled is the operator of the microtunnelling shield.

CONSUMABLES

Successful microtunnelling is heavily dependent upon correct design of lubrication and where a slurry system is being employed, the management of the slurry. This requires additional education although advice is available from specialists and even quite experienced microtunnellers may be cautious about claiming expertise in this area.

The jacking load which is applied to the microtunnelling process is principally a function of the friction which is exerted on the pipe being installed. There is a small load which arises from the face pressure on the machine being driven into the ground, but this is generally a very small component of the overall jacking load. The friction that applies to the pipe is a function of the type of ground, the depth of installation, the type of pipe material and the lubrication which is applied. There can be a very substantial change in the friction depending on these criteria. For example between 0.2 tonnes per square metre of pipe surface up to perhaps 2 tonnes or more. Therefore a suitable design of lubrication system is imperative. There are numerous different types of lubrication process and different types of lubricant, but a detailed assessment of a suitable process for each pipejacking installation is imperative.

The management of the slurry is important because the speed of installation is a function of how quickly the excavated material can be removed from the slurry. Correct training about different additives can considerably enhance the speed of the slurry handling.

This is an area where many civil engineers or mechanical engineers have little experience. Until this experience is established it is essential to take advice from experts. There are numerous experts in this type of activity either from the tunnelling industry or from the oil field industry.

CONTINGENCY PLANNING

When working in the ground, one is working within a hidden medium and there is always potential for unexpected occurrences. These require instruction in the requirements of contingent planning.

There are certain known problem areas which can be fully provided for, such as the handling of ground water. On many microtunnelling projects there is ground water. This means that in the event of any errors or complacency, the shafts, the pipe and the equipment are all liable to flooding.

One of the advantages of microtunnelling with its remote controlled activity is that it is unlikely that this will lead to safety considerations, although not impossible. However, it can materially affect the operation of the system. There must always be adequate pumping capacity and standby pumping capacity for a microtunnelling operation.

The most critical moments when a microtunnelling machine starts work is when it leaves the drive shaft and when it enters the reception shaft. At these points the machine is changing from one medium to another, and if there is ground water, particularly if it is under pressure in a loose ground, it is very easy for the operation to fail. Training is necessary in the method of proper entry and exit arrangement.

There are numerous procedures for this activity and, provided they are properly carried out, there should be no difficulty. In the event that there is a failure it is likely that several days will be lost. Once the machine is launched and is microtunnelling, the pressure is removed from this activity until it arrives at the entrance shaft when the procedure is repeated.

SYSTEM OPERATION

The operation of the microtunnelling machine is a key activity. Where training is addressed with microtunnelling, it is often the immediate focus of that training activity.

One of the purposes of this address is to identify the much wider training and educational requirement for microtunnelling to be successful. This is not intended to detract from the importance of training suitable operators, but simply to emphasise how the training process has to address the entire microtunnelling activity.

There is an obvious initial requirement that the operator knows how to operate his system. Most modern microtunnelling systems are set up so that the operator fully controls all the activities of the system. This encompasses the driving of the machine, the jacking process, the slurry handling process and the lubrication process. In addition he is the custodian of the microtunnelling records for the operation.

Operating a microtunnelling system, therefore, is a complex operation. It has been our experience that the best people to become operators are fully trained mechanical, hydraulic or electrical technicians. This is perhaps due to their understanding of the mechanical process and their sympathy for the equipment they are managing.

The initial training is a matter of learning how each of the different components of the system is operated, and how they are synchronised to ensure that the equipment works correctly. This can normally be undertaken in a 2 to 3 day period. At this stage the operator will be able to carry out a basic microtunnelling drive.

We would consider that an operator is fully trained after about 3 to 4 months of continual operation in a mixture of different ground conditions. The difference between the 2 to 3 days and the 3 to 4 months lies in the requirement for the operator to "fine tune" his knowledge of the system.

What does this fine tuning comprise? As explained, the operator is synchronising the activities of several different parts of the system. His ability to optimise the pipejacking speed against the torque of the microtunnelling crusher head and the removal of excavated material require considerable experience.

Where the operator begins to earn his money, however, is when he begins to meet a wide range of different ground conditions during a single drive. This could occur for example when in a clay and meeting boulders or any other mixture of ground conditions. In these conditions special techniques are employed to ensure that the machine does not jam, that the machine does not get deflected off line or level, or that the rate of progress does not become heavily affected.

The measures employed by the operator are partly a function of his skill in driving the machine, and partly a function his overall knowledge of the entire system. For example, when an operator finds that he is operating with a mixed face of hard ground and soft sand, the methods he employs in order to prevent the machine being driven off line by the hard material might involve a reduction in speed of advance in order to ensure that the hard material is cut, and the machine is not deflected. However, the slow down in advance could result in an over excavation of the loose material in the face of the machine. In order to overcome this the operator might increase the slurry face pressure whilst increasing the density of the slurry in order to provide a greater hold on the loose material. Thus the operator's knowledge must extend beyond simple ability to drive the machine.

An experienced operator will gain a knowledge of things which cannot be anticipated, such as an impact with some man-made object in the ground, the impact with buried timber, or penetration into voids. The recording and measuring system on modern microtunnelling machines provides the operator with sufficient indications of what is happening for him to use his judgement.

Over the last few years there has been developed a number of artificial training aids to assist operators in acquiring these skills. These take the form of a computer based simulator. However, it is generally found that nothing can beat the hands on approach which is gained from operating in the field under specialist guidance.

Automatic steering systems which have been developed can provide a trainee operator with some comfort when he is managing a system. However, they do not remove the requirement for "hands on" training.

Training by an experienced operator has the advantages also of providing the new operator with good operation technique rather than an adequate operation technique. An example is that inexperienced operators can be tempted to overcorrect when difficulties occur. If a pipe is driven 50 mm off line, an experienced operator will evaluate the reason for this and will do his best to bring the pipeline back on line in a gradual manner which does not overstress the pipe. An inexperienced operator might be tempted to try and come back on line as quickly as possible. Ironically, it is often the more experienced operator who also knows when to call for assistance due to difficulties being encountered.

SURVEYING AND SETTING OUT

However successfully a pipe is installed, if it is found to be installed in the wrong place the project is still a disaster. It cannot be emphasised enough that adequate proper surveys must be carried out. The operator will install the pipe in accordance with the instructions provided by the laser or whatever guidance system is being employed. If the surveyor has not correctly installed this laser, it is not the operator's fault. The surveyor, therefore, has to be taught how to correctly set up the laser and to monitor its accuracy during the drive.

Any competent surveyor can be trained to carry out correct setting up of the pipejack. It is simply a technique which can be learned from experienced surveyors or operators. There are guidance systems such as those with self levelling lasers which can give better protection against the laser becoming off line.

There are also alternative methods of guidance for microtunnelling such as giro compass and computer controlled laser systems. The use of these systems require specific training.

SYSTEM MAINTENANCE

The next important area is the maintenance of equipment. Microtunnelling is an activity which most amply demonstrates the maxim of "penny wise pound foolish". It is imperative that the equipment, particularly the microtunnelling machine, is suitably maintained and kept in a good state of repair.

The process of tunnelling in small diameters is very bruising for the equipment. The machine is working very very hard and, when it has successfully completed its drive, it needs to be rewarded with a very thorough investigation to ensure that it is ready for its next drive.

If any of the machine's components are suspect, it is better to carry out preventative maintenance because the cost of the early retirement of one part will always be less than the cost of resolving a problem if the machine fails in the ground. The maintenance schedule, therefore, requires that at least one person and preferably all of the technicians involved with microtunnelling have a knowledge of the machine's detailed mechanical, electrical and hydraulic fittings.

It is Iseki's normal recommendation that, in addition to checking at the end of each drive when normal wear parts such as cutter teeth and hardfacing are refurbished, a machine should be thoroughly overhauled at about every 500 metres. In this way the equipment will provide good operation.

This training is workshop based and simply involves a thorough knowledge of the equipment, its components and how they are handled. For a good workshop fitter, the main requirement is to have good technical information about the systems. With this he will be able to carry out his job.

As well as receiving the information which enables the fitter to carry out the service, it is important that he is given workshop procedures as to how to carry out the service. For example, a piece of equipment can be badly damaged if it is removed incorrectly or a piece of equipment might not work properly if it is installed in the wrong order or if the tolerances are not correctly set.

There is frequently a conflict between project progress requirements and good maintenance requirements. Project staff might be more keen to "give it a go". It is, therefore, very important that a company's senior management provides clear guidelines as to the maintenance philosophy that the company will use.

TROUBLE SHOOTING AND REMEDIAL ACTIONS

The last section under the training requirement is with regard to trouble shooting. Microtunnelling does suffer from problems, as does every form of construction. The main difference is probably the unpredictability of microtunnelling problems due to its operation in the ground in a medium which can only be partially investigated. However, when problems occur, there are generally well thought out contingent actions that can be taken and the training process should address all of these.

One of the long term benefits of good training is the confidence that it develops in the operators and the specialists. With this confidence they can both decide on the optimum method of operating the system without submitting to unreasonable pressure for performance. They can also carry out troubleshooting without fear of criticism and over time develop their own methods for overcoming the problems that do occasionally arise.

If a microtunnelling machine becomes jammed in the ground, there are a number of solutions which can be contemplated. These depend on the type of ground, the distance the machine has travelled, the depth in the ground, what is above the machine and the size of the equipment.

In principle, it is desirable to recover the machine back into either the drive or the reception shaft. If the machine has not travelled very far, it might be possible to retract it into the shaft it has left. This would be accompanied by filling the void left behind with a weak cement bentonite grout.

If the machine is close to the reception shaft, it is possible that a heading or pipe can be driven from the opposite direction in order to recover it. If the machine is a long way into the ground and recovery from above is not possible, it is possible to install a casing pipe around the installed pipe and remove the jacking pipe one pipe at a time until the machine is reached.

If the machine has to be recovered from above, it can be possible to sink a small shaft to remove an obstruction or obstacle if that is the cause of the blockage, or to install a larger shaft to remove the machine itself for remedial action. All of these techniques should be familiar to the engineers who are carrying out the microtunnelling process, and should be planned in advance. They should also be explained to the client and his representative so that in the event that they are required, there is not an unreasonable concern expressed.

CONCLUSION

Once the basic tunnelling techniques have been managed, the training can begin to address the more exotic requirements such as those for long distance pipejacking, curved pipejacking and specialist activities such as pipe roofing. All of these are achievable and form a challenging and interesting additional area in which experienced microtunnellers can become involved. However, these are subjects for another day, and I will conclude with a final comment that prevention is the best form of cure, and suitable training and preventative activities make microtunnelling successful.

Schedule (assuming 75% usable time in a day)

Schedule 1

Days 1 2 3 4 5 6 7 8
9 10 11 12 13 14 15 16

Set Up xxxxxxxxxxxx
Drive xxxxxxxxxxxxxx
100,000mm @ 100mm per min
Pipe change xxxxxxxxxxxxxxxxxxxxxxxxxxxxx
50 pipes @ 60 mins per change
Remove equipment xxxxxxxxxx

Schedule 2

Days 1 2 3 4 5 6 7 8
9 10 11 12 13 14 15 16

Set Up xxxxxxxxxxxx
Drive xxxxxxxxxxxxxx
100,000mm @ 100mm per min
Pipe change
50 pipes @ 20 mins per change xxxxxxxxxx
Remove equipment xxxxxxxxxx

Time saved is 29% of schedule xxxxxxxxxxxxxxxxxx

MICROTUNNELLING VERSUS OPEN-CUT: A COMPARATIVE STUDY

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SYNOPSIS

The choice between using an open-cut method and microtunnelling for the installation of services, such as sewers, is still very often dependent on direct cost differences and also the favouring of the perceived 'less risk' traditional approach of open-cut. Many organisations still consider open-cut methods as preferable to microtunelling even for service depths of 6m.

This paper outlines a comparative field study between a 6m deep, 600mm diameter microtunnelling operation using a ANV600 Herrenknect machine, and the equivalent open-cut method during the installation of a new sewer in Leicester, UK for Severn Trent Water Plc. The reasons behind the original choice of the methods for different sections of the work are explained. The paper also outlines the problems encountered by both techniques during the work whilst coping with the ground conditions on site. The ground conditions consisted of a boulder clay with sand lenses and a water table at 2m below ground level, which is one of the worst types of ground for microtunnelling operations in terms of risk. For the microtunnelling operation, problems included encountering boulders and a 'blow-out' of bentonite slurry at the surface necessitating lower slurry pressure and causing reduced installation rates. The open-cut operation had a problem when running sand conditions were encountered for part of the pipe installation which had an effect on the trenching method employed and subsequent progress of the work.

The conclusion made by the paper is that although the microtunnelling operation did encounter problems in the boulder clay, it proved much better overall in terms of less disruption to residents and the local environment compared to the open-cut section of the work. The microtunnelling operation also produced lower overall costs and comparable rates of installation compared to the open-cut operation, thereby diminishing the perceived 'less risk' view of open-cut methods, particularly for the depth of installation considered in this paper.

INTRODUCTION

There has been a lot of debate recently as to whether microtunnelling or open-cut operations should be used below 5m depth. This argument generally comes down to cost and the perceived risk involved.

This paper outlines a comparative study between a microtunnelling operation and an open-cut trenching operation that took place as part of the same sewer installation project. This gave an ideal opportunity to compare performance and costs of each of these operations under identical site conditions.

The project to be discussed in this paper was carried out as part of a much larger sewer upgrading programme being conducted by Leicester City Council, on behalf of Severn Trent Water Plc., in Leicester, a city approximately 100 miles north of London.

CONTRACT DETAILS

The scheme was proposed due to foul flooding incidents in the gardens of four properties in the area, and also along an alleyway running beside the houses.

The existing pumping station was unable to cope with the volume of flow reaching it and the sewer length on the main branch was undersized and had insufficient gradient to pass the flows in a 1 in 1 year, 60 minute storm (ie. a 60 minute duration storm occurring once in one year). The system was surcharging, and flooding was occurring from two low lying upstream manholes.

It was therefore proposed to construct a 375mm internal diameter relief sewer from a manhole upstream, on the existing length, through a residential housing estate and to a new pumping station with a design storage capacity of approximately $200m^3$. Figure 1 shows a plan of the area including the line of the new sewer.

SITE INVESTIGATION DETAILS

The ground investigation consisted of boreholes sunk near to the approximate positions of the manholes. Three boreholes were sunk close to Manhole 1. Only one borehole was originally commissioned in this area, but the report revealed a large area of water bearing sand, the extent of which was unknown - the sand revealed could have been a large sand pocket or a full strata. Therefore, in order to clarify this situation two additional boreholes were sunk. These boreholes showed that the main stratum was a firm to stiff boulder clay, with large sand pockets. An additional problem was found to be the high water table, which is approximately 2m below the ground level in this area.

One borehole was sunk close to Manhole 2 and one close to Manhole 3. The report showed predominantly boulder clay conditions, but did mention small sand lenses and sand pockets. A warning was given in the site investigation report regarding the random nature of the sand inclusions.

MICROTUNNELLING SECTION

This section passed from Manhole 1 to Manhole 2, a length of 44m. The reason for microtunnelling this section was due to the obstacles through which this section passed. These included a double garage structure, crossing the path of a surface water sewer at an acute angle, passing through a private garden and the possible disruption to a busy footpath. This footpath could not be closed as it provided access for the housing estate residents to a shopping centre and an industrial estate. The alternative route meant a 30 minute detour.

Heading was also considered as an alternative to microtunnelling, however the high water table did not make this method viable. Comparison of the cost for heading and microtunnelling showed them to be similar.

The original specification for the sewer on this section was a pipe of 375mm internal diameter. However, flexibility was allowed in the contract documentation for alternative sizes. The contractor had a AVN600 Herennecht microtunnelling machine available and it was agreed this would be acceptable with only minor alterations being required to the manhole designs. The alternatives available for the cutting head on this machine were a clay head or a rock head. The nature of the ground precluded the use of a rock head, however the boulder inclusions could have caused major problems for the clay head. The boulder clay ground conditions, boulders of varying size in a clay matrix, are quite common in the UK and are one of the most difficult, or high risk, grounds to tunnel through due to the extreme mixed face conditions that are possible.

The section of sewer installed by microtunnelling was 44m long and went from a depth of 5.6m below ground level at Manhole 1 to 6.1m below ground level at Manhole 2. The gradient of this length of pipeline was 1:88 running towards Manhole 1.

OPEN-CUT TRENCHING SECTION

The decision to use an open-cut method for this section of the project was solely based on cost, ie it was thought to be cheaper. Trenching would have been used on the whole project if this had been a viable option between Manholes 1 and 2. This shows that the only consideration was based on direct cost. The indirect costs of inconvenience and disruption to the local residents where not considered.

The trenching section consisted of a 50m length of sewer installation from Manholes 2 to 3. The pipe diameter was kept at 375mm internal diameter and the depth below ground level at the start was 6.1m and at the end 5.5m. The original proposal for the installation of the pipe was to use open trench sheets with hydraulic frames and walers.

PROJECT PROGRESS AND PROBLEMS ENCOUNTERED

MICROTUNNELLING

From the original ground conditions shown in the site investigation report the contractor expected that good progress would mean 4-5 pipe sections per 10 hour day (approx. 6-7.5m / day). The contractor decided that the boulder content of the clay would not be significant and hence the machine head was chosen accordingly. A rock head would have slowed the machine down considerably. The operator, however, thought that 2-3 pipes / day would be more realistic for the clay head.

Figure 2 shows the general arrangement in the jacking pit at the start of the drive. The jacking pit was 2.5m x 2.5m.

The stone content of the clay throughout the drive did prove to be significant and at one stage a large boulder was hit. This displaced the machine by approximately 20mm horizontally and 4mm vertically, but the machine managed to grind its way through the edge of the boulder. This significantly wore down the teeth on the machine and the rate of subsequent progress was reduced. A sample of slurry taken at this stage showed mainly clay, with granite and coal pieces.

A slurry blow-out occurred at one point during the drive while the machine was passing under the footpath and this caused a considerable amount of concern. The slurry had obviously found a pathway to the ground surface through some weaker material, possibly where the surface water sewer had been laid, or where some lighting cable ducts were positioned. The working pressure prior to the blow out was approximately 5 bar. This had to be reduced subsequently to 2 bar, the lowest possible level for this machine whilst still being able to progress forwards, and this inevitably reduced progress on the drive. The pressure was kept low for a short distance and was then raised slightly. However, more slurry emerged at the surface, so the pressure was reduced once more. The pressure was gradually increased after a further 3m drive to 4 bar. De Moor and Taylor (1991)[1] describe a similar slurry blow-out on a 2m diameter operation near Tilbury and also observed quite considerable heave movements both at the surface and subsurface. The issue of blow-outs is a serious one in terms of microtunnelling performance. The longer term effects of such a blow-out on the surrounding ground, and the general effect of face pressures generating heave movements, need to be looked at quite carefully.

On a more operational side, the contractor had problems emptying the slurry tank, due to the difficulty of disposing of the contents, and towards the end of the operation the excavated spoil was unable to settle out properly. This meant that the slurry became very thick and spoil removal was inefficient, again reducing progress.

Another problem occurred during a freak storm during the project. Due to this, the jacking pit was flooded and the machine in the partially completed drive became submerged. This meant that the motor became damp and had to be replaced. Although the delay caused by this replacement was only several hours, the operation was difficult and highlighted one of the basic problems with such small diameter bores, that of access to the machine. As a result of the flooding, steam was generated inside the installed pipe and this caused the laser to flicker giving potential problems in determining the accuracy of the drive.

At the breakout into Manhole 2, the machine pulled with it a large amount of sand that caused a significant amount of localised settlement in the road, which was in the region of 50mm.

The horizontal extent of this settlement was approximately 1-2m from the pit.

Notwithstanding the above problems, the pipe was installed successfully with an accuracy of approximately ± 20 mm both horizontally and vertically over the length of the drive.

OPEN-CUT SECTION

The first 5m of open-cut from Manhole 2 was completed without any problems. The general arrangement of trench support used is shown in Figure 3. Based on this the contractor decided to employ a less stringent trenching method. All seemed to going well until at approximately 8m from Manhole 2 the contractor hit running sand. The flow was such that bubbling quicksand conditions were developed. The trench very soon became unstable and work had to be stopped. The work remained at a standstill whilst discussions continued on how to proceed. This delay lasted one and a half weeks during which time an additional two boreholes were sunk. These both showed running sand conditions down to approximately the pipe invert level.

Interlocking sheet piles were the only viable option at this stage. The sheet piles had to be longer and thicker in cross-section than the originals which meant additional plant had to be brought onto site, such as a pile hammer (previously the sheet piles were pushed in using the excavator) and a mobile crane. This increased the cost and also slowed down the trenching operations. The progress actually slowed to approximately half the rate compared to the first 5m section from Manhole 2.

The subsidence damage caused to the road due to the trench collapse required extensive reconstruction of the road and could have been much more serious if it had occurred on a major road. O'Reilly and Rogers (1990)[2], and others, have shown that microtunnelling generally causes less ground movements than trenching under normal circumstances. The damage caused to road pavements caused not only by the original trench excavation, but also the movements caused by the stress relaxation of the ground around trenching operations, inevitably reduces the design life of the road. This should be an important consideration when comparing microtunnelling with open-cut operations. This is not to say that microtunnelling operations do not cause ground movements and potential damage, but the scope for movements to occur is less with a well operated machine. Even so, a current joint research project at Nottingham and Loughborough Universities is investigating the effect of microtunnelling on the surrounding ground, particularly with respect to the excavation/face support methods currently employed.

COST AND PERFORMANCE COMPARISONS

From the original tender documents, the microtunnelling was going to cost 1.5 times the cost of the open-cut operations. Due to the additional plant and labour required for the revised trenching method employed after the trench collapse, the cost for the revised open-cut operations rose to 5.5 times the original open-cut costs. This meant the open-cut operations were 3.7 times the cost of the microtunnelling operation. None of these costs include the more indirect costs associated with the inconvenience and disruption that the open-cut operation had on the local community.

The average installation rates for the microtunnelling operation throughout the pipe installation period are shown in Figure 4. These rates ranged from approximately 0.2m/hr to 0.5m/hr. As expected, the variations in the rate tend to correspond to points when problems occurred, such as the blow-out and after the boulder was encountered. The initial low point shown on the graph occurred on the 21st of the month and corresponded with the slurry blow out. The installation rate then recovered reasonably, but started to reduce once more on the 23rd, when a boulder was encountered. The rapid increase in the rate over the final couple of days was due to the machine being brought back up to reasonable working pressures, although by this stage it was apparent that the head was so worn down from its encounter with the boulder, that the efficiency of the excavation was very poor. Another factor that helped the installation rate over the final length of the drive was that more sand was encountered which helped improve the excavation rates. These rates do not include the set up time for the microtunnelling operation which was approximately 3 days and the clear up at the end of the drive, which was another 1.5 days.

The average rates for the open-cut section of the job varied between 0.1m/hr, under bad conditions, and 0.15m/hr under good conditions. These rates include the excavation down to 6m, the installation of the pipe, backfilling the trench and reinstatement. This shows that even if the rates for the microtunnelling operation had included the set up and clear away times, they would still be higher than those achieved during the open-cut operation.

CONCLUSIONS

This paper has presented case study information for a project that involved comparable microtunnelling and open-cut works. The microtunnelling operation was only considered because of the enormous problems of using open-cut operations over the initial 44m section. The microtunnelling operation was disregarded elsewhere based on cost considerations and the perceived higher risk associated with this type of work. It is true to say that microtunnelling, and indeed any form of construction where the ground conditions are 'unseen', is likely to have a higher risk of failure. However, as this paper has illustrated, open-cut operations can also be plagued with problems. This diminishes the view that open-cut is the lower risk option.

The microtunnelling operation, although slowed by various setbacks, kept going and completed the drive successfully. The microtunnelling machine did not have any problems with the running sand ground conditions, or the fact that the ground water table was only 2m below the ground surface level, due to the slurry pressure balance system which provided an effective face support. The microtunnelling operation turned out to be considerably cheaper than the open-cut operation. It also out-performed the open-cut operation in terms of creating less disruption and inconvenience to local residents.

ACKNOWLEDGEMENTS

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REFERENCES

1. De Moor E.K. and Taylor R.N., (1991), 'Ground response to construction of a sewer tunnel in very soft ground', Proceedings of the Sixth International Symposium Tunnelling '91, London, April 1991, Institution of Mining and Metallurgy, Elsevier Applied Science, pp 43-54.

2. O'Reilly M.P. and Rogers C.D.F., (1990), 'Ground Movements associated with pipejacking and trenching', Proceedings of the Fifth international Conference on Trenchless Construction for Utilities, NO-DIG'90, paper B1.

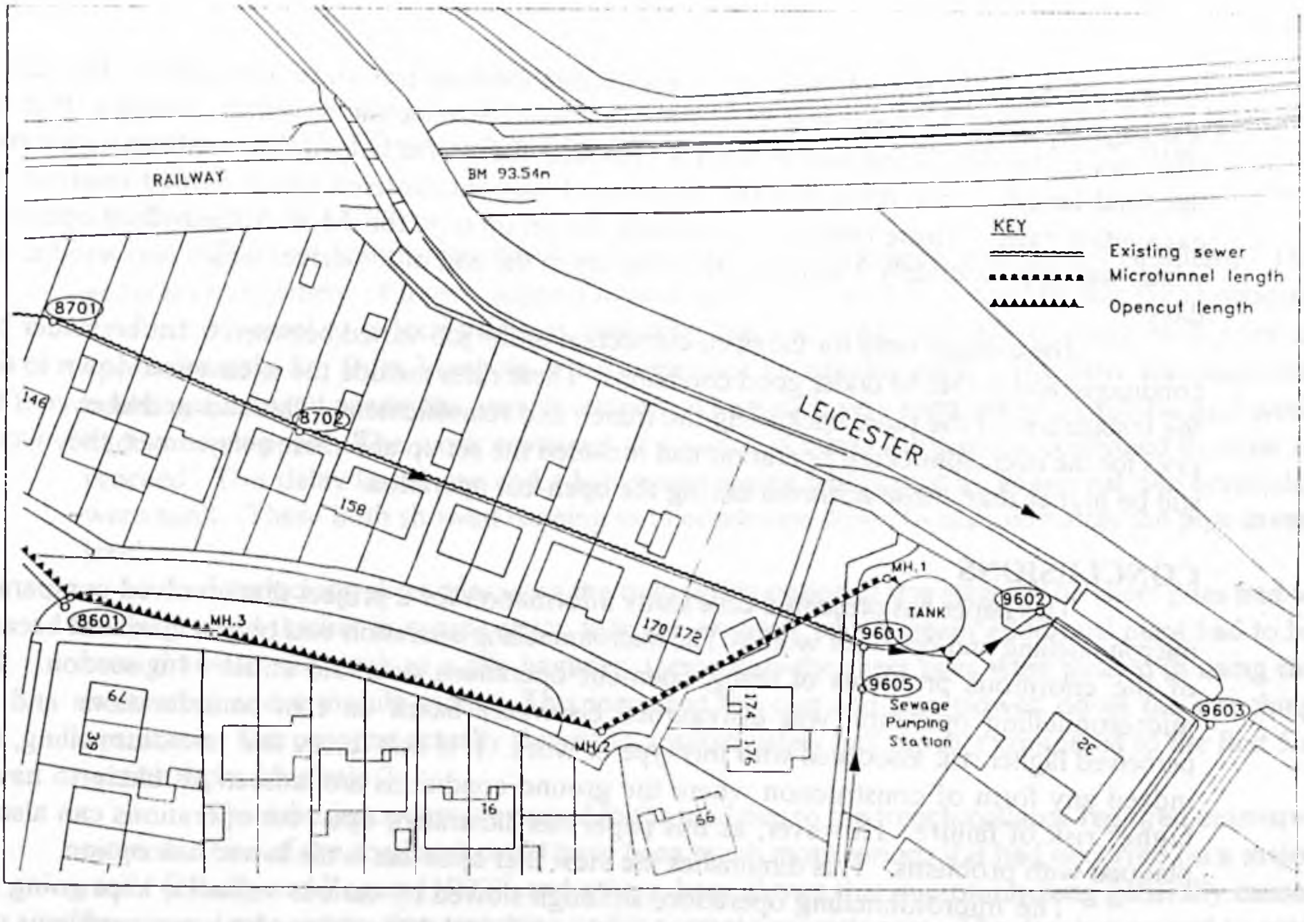

Figure 1 General arrangement plan of the microtunnelling and open-cut operations described in this paper

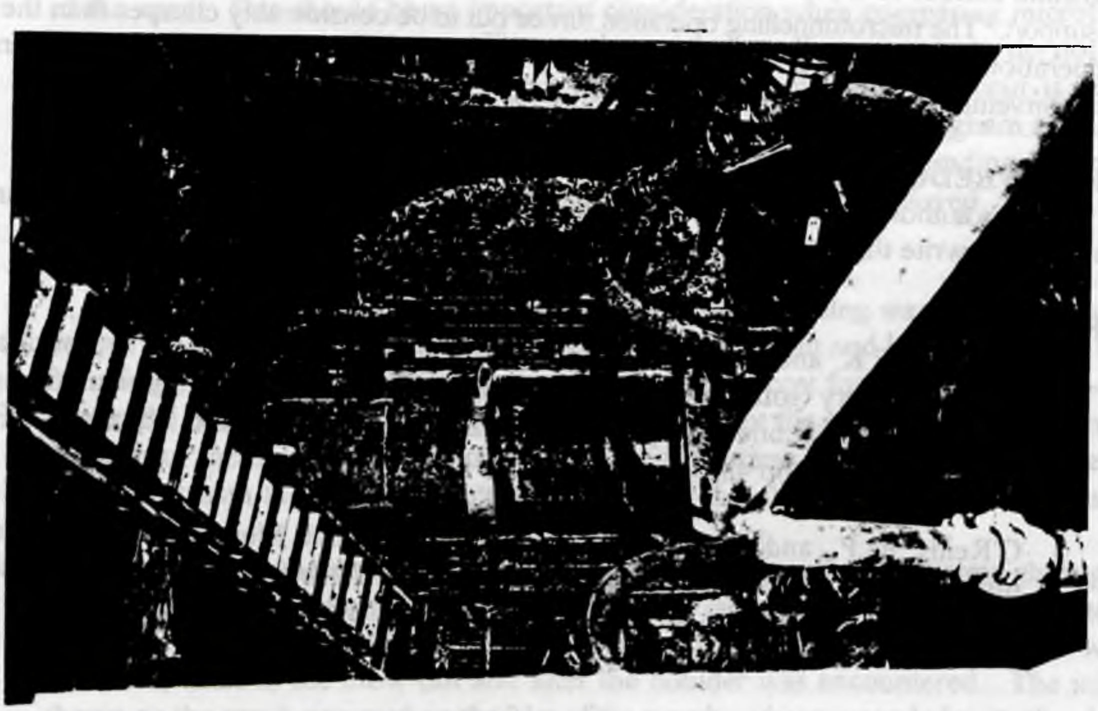

Figure 2 A view down the jacking pit

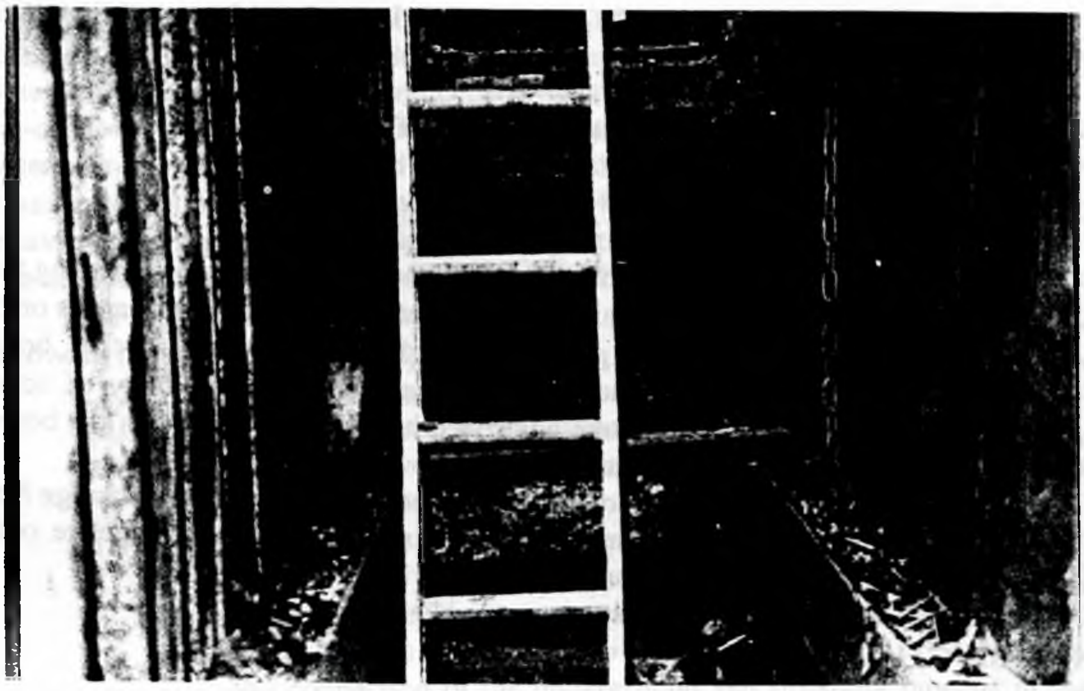

Figure 3 A view at the start of the trenching operation

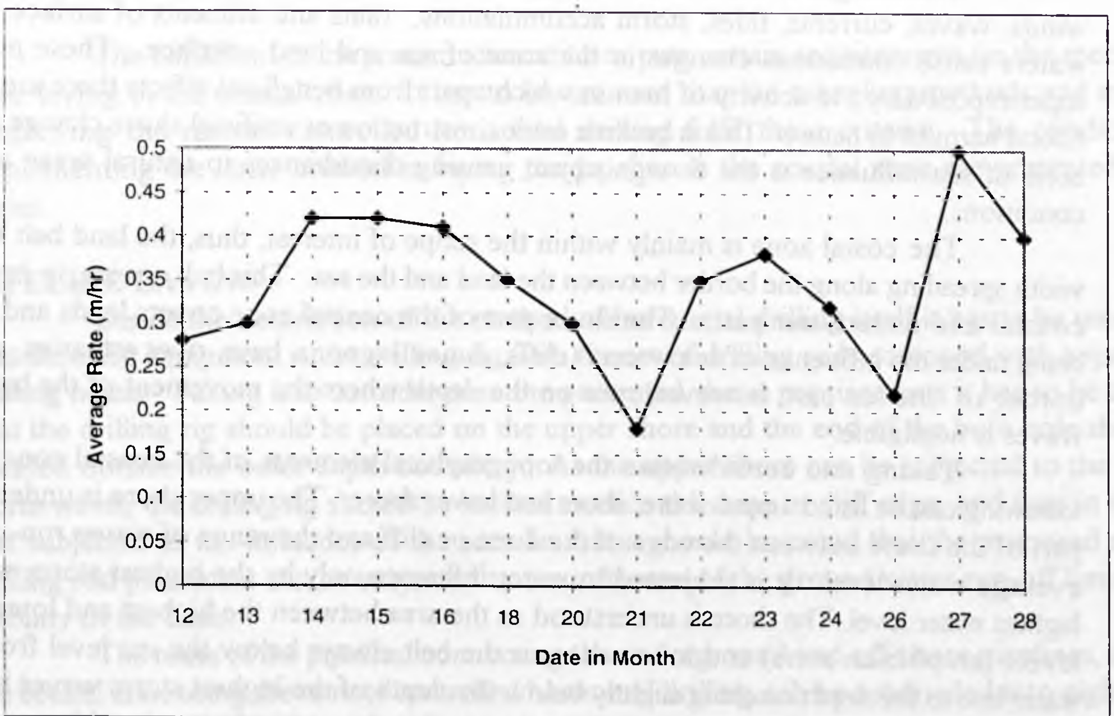

Figure 4 Graph showing the average microtunnelling rates achieved during the drive
(Note: The dates that are missing indicate when no work was carried out on the microtunnelling operation.)

CONNECTIONS OF THE UNDERGROUND AND OFF-SHORE PIPELINES USING HORIZONTAL DRILLING

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SUMMARY

The connections of the off-shore to underground pipelines requires passing through the coastal zone, where it is inadmissible, due to coastal currents layouts, disturbances or changes in the beach itself including coastal dikes e.g. to construct deep excavations, trenches, braticces, etc.

Due to the above requirement the paper presents the possibility of achieving the connection of pipelines using the remote controlled horizontal drilling with the bore-hole at a given distance from the shore or coastal dike.

The method presented can also have full implementation in water discharge from coastal sewage treatment plants into the sea requiring the positioning of the pipeline outlet at the substantial distance from the shore line.

INTRODUCTION

The activities undertaken in the seas and adjacent land areas require special attention to preserve the integrity of the natural environment. It mainly concerns the sea shore which undergoes various changes.

The changes of the shore line (e.g. its retraction) are the constant natural process. The winds, waves, currents, tides, storm accumulations, rains and affluents of surface and ground waters cause continuous changes in the zone of sea and land interface. These processes are superimposed by the activity of man in which apart from beneficial effects there are mainly side effects harmful to nature. This is because each construction or artificial shore change being in the zone of sea influence is the foreign object causing disturbances to natural wave and currents conditions.

The costal zone is mainly within the scope of interest, thus, the land belt with a given width spreading along the border between the land and the sea. This belt covers, in its width, both coastal and underwater parts. The shore part of the coastal zone covers lands and freshwaters being under the influence of sea waters (cliffs, dunes, lagoons, bays, river estuaries, straits). The border of the sea part, however, runs on the depth where the movement of the bottom due to waves is negligible.

Taking into consideration the topographical elements of the coastal zone (Fig. 1) the following can be listed: upper shore, shore and lower shore. The upper shore is understood as the part of the shore between the edge of the dune or cliff and the range of waves run-in during the average water level. It is subjected to water influence only by the highest storm waves during highest water level. The shore is understood as the area between the highest and lowest sea water levels (amphibian zone) and lower shore is the belt always below the sea level from the lower water line to the depth reaching slightly below the depth of the highest storm waves breaking, i.e. 7 - 10 m. The inner part of the lower shore lays within the zone of wave breaking and undergoes intensive sea bed reconstructions under the influence of wave movement. It has to stressed that the outer part of the lower shore is characterised by the significant stability of sea bed topography.

The basic hydro- and lithodynamic phenomena have to be taken into consideration during the analysis of the factors influencing the coastal zone (Fig. 2). The following elements can be identified here: the wave run-in zone, wave breakage zone and the zone of wave retraction and transformation. Assuming that the transport of sediments is caused by the energetic current running along the coast directly due to wave breakage, oscillatory (orbital) movement of the sea water, compensatory return currents perpendicular to the shore line, mass transport, affluent or run-off flow current caused by wave run-in, shearing currents (local flows towards the sea of the water built-up near the shore) and the gradient currents caused by local differences in water level it has to be adopted that the outer boundary where there should be no technical activity (deep excavations, pits and dikes) corresponds to depth equal to a half of the length of deep water wave. The influence of variable sea levels, as well as, the ice cover should be taken into consideration.

The phenomena presented above, in assuming undisturbed marine environment set following requirements on the pipelines running through the coastal area:

- the excavations or mining works can only take place outside the upper shore and lower shore, in that especially its inner part;
- the mining works can be carried out on the depths where the sea bottom topography is established;
- the pipeline laid down on the sea bed should be cover in such a way that the influence of dynamic wave movement on the sea bottom and on the pipeline on top of it would not cause sea bed liquefaction and increase in buoyancy and floating of the pipeline on top of the sea bed;
- the connection of the underground and off-shore pipeline in the land area should be performed considering the design depth of the off-shore part;
- the connection of the off-shore pipeline laid in coastal zone with the off-shore pipeline laid on the sea bed should occur outside the outer depth boundary ($h=L/2$).

The fulfillment of the presented conditions puts certain requirements on the methods of pipe laying in the coastal zone. It has to be assumed that the tunneling methods and methods employing the remote controlled horizontal drilling fulfil these criteria. The conditions of implementing the latter method in laying the pipeline in the coastal zone are presented in this paper.

PIPELINE LAYING

Beside the description of the method of horizontal drilling itself it has to be mentioned that the basic equipment is the drilling rig with the set of drilling rods equipped with appropriate drilling heads. Taking into consideration the presented above requirements it has to be adopted that the drilling rig should be placed on the upper shore and the end of the bore hole should be located outside the outer depth boundary. As the upper shore can be subjected to the highest storm waves, the drilling rig should be located outside the dune or cliff edge, and thus in the area not subjected to the influence of the sea. In that it should be noted that the proposed area for drilling rod placement can be subjected to the influence of the ground water run-off limiting the stability of the bank.

The route of the pipeline, connecting the underground and off-shore pipelines, through the coastal zone using the remote controlled horizontal drilling cab be subdivided into eight stages (Fig. 3). The individual stages cover:

STAGE 1

After placing the drilling rig outside the edge of the dune or shore embankment, the pilot drilling are performed in the direction of the designed pipeline axis leading to obtaining of the pilot bore. The drilling head consist of the fluid jet drill bit equipped with nozzles or the rotary hammer drill bit with drilling bezel. Slurry displacement rod equipped with drilling bezel is introduced in 80 m segments.

STAGE 2

The pilot drilling is finished. It occurs when the drilling rod and slurry displacement rod come out of the sea bed outside the outer depth boundary.

STAGE 3

The drilling rod is pulled out of the slurry displacement rod using the drilling rig. Reaming head is fixed to the end of the slurry displacement rod to which a rotary cuff connects the product pipe pushed out through the stinger from the ship or pipe-laying barge.

STAGE 4

The reaming head is pulled through the previously drilled hole by the slurry displacement rod pulled and rotated by the drilling rig. The product pipe is pulled from the ship or pipe-laying barge into the hole drilled in this way.

STAGE 5

After reaching the target the reaming head is dismantled and the product pipe is connected to trolley-mounted rig. The product pipe is connected via rotary cuff to the actual pipeline (off-shore) of required diameter and strength. Additional scraper, similar to reaming head is placed on the end of the product pipe.

STAGE 6

The drilling rig pulls the scraper and the off-shore pipeline into the drilled hole by pulling and rotating the product pipe connected on the ship or pipe-laying barge to the off-shore pipeline. Thanks to the rotary cuff the off-shore pipeline does not rotate during pulling of the scraper and product pipe. As the pipeline is covered by the earth layer the compensatory ballast generally in from of cement grout is not required in this part.

STAGE 7

The scraper is removed after pulling the pipeline on the shore. The pipeline is connected on the barge or ship to the part of the pipeline which is laid outside the outer depth boundary and shrouded with the cement layer to act as the ballast.

STAGE 8

The off-shore pipeline is digged appropriately and adopted for connection to the underground pipeline laid on the land area. The barge or ship is laying the pipeline in its off-shore part after which the pipeline is sheltered in the sea bed to protect it from influence of wave movements and damage caused by other causes (e.g. anchor dragging, trawls, etc.).

FINAL COMMENTS

The presented possibility of achieving the connection of the underground and off-shore pipelines using the remote controlled horizontal drilling allows for solution of the issue of passing the pipelines through the coastal zone, putting high requirements on the natural environment preservation. Due to that the horizontal drilling techniques can be used for pipeline segments up to 1500 m long it has to be said that there is a possibility of passing our every possible coastal zone, reaching up to the outer depth boundary using that method.

The pipelines discharging water from sewage treatment plants cause in practice significant engineering problems in passing through the coastal zone. Using remote controlled horizontal drillings it is possible to construct such discharges but also in this case the pipeline outlet in the sea should be located outside the outer depth boundary. The hydromechanical influence of the wave movement of the sea on the pipeline in its outlet segment is taken up by the special ballast construction built in form of prefabricated reinforced concrete or piling construction.

The problem of passing through the coastal zones of very substantial widths still remains unsolved. It occurs especially in the coastal zones in tidal areas where it can be as wide as 30 km. In such cases the tunnelling can be used where tunnelling can be also be performed from vertical shaft constructed at 3 km intervals.

REFERENCES

1. Mazurkiewicz B. (1986) Marine engineering encyclopedia. Wydawnictwo Morskie, Gdansk 1986
2. Basinski T., Pruszak Z., Tarnowska M,. Zeidler R (1993) Sea shore protection. Biblioteka Naukowa Hydrotechniki nr. 17 Instytut Budownictwa Wodnego PAN, Gdansk 1993

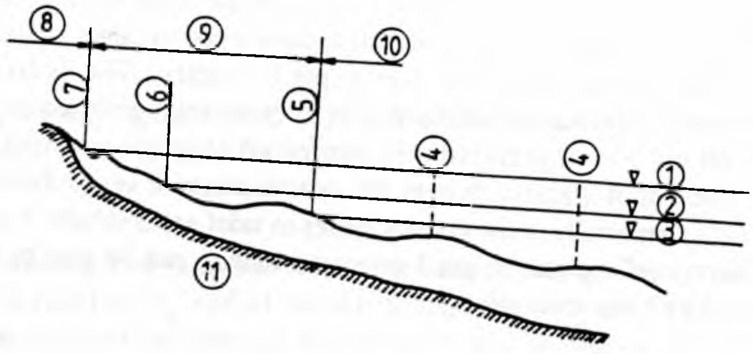


Fig. 1 Topographical elements of the sea shore: 1 - highest sea level, 2- average sea level, 3 -lowest sea level, 4 - rewa, 5 - low shore line, 6- medium shore line, 7 - top shore line, 8 - upper shore, 9 - sea shore, 10 - lower shore, 11 - abrayn platform [1].

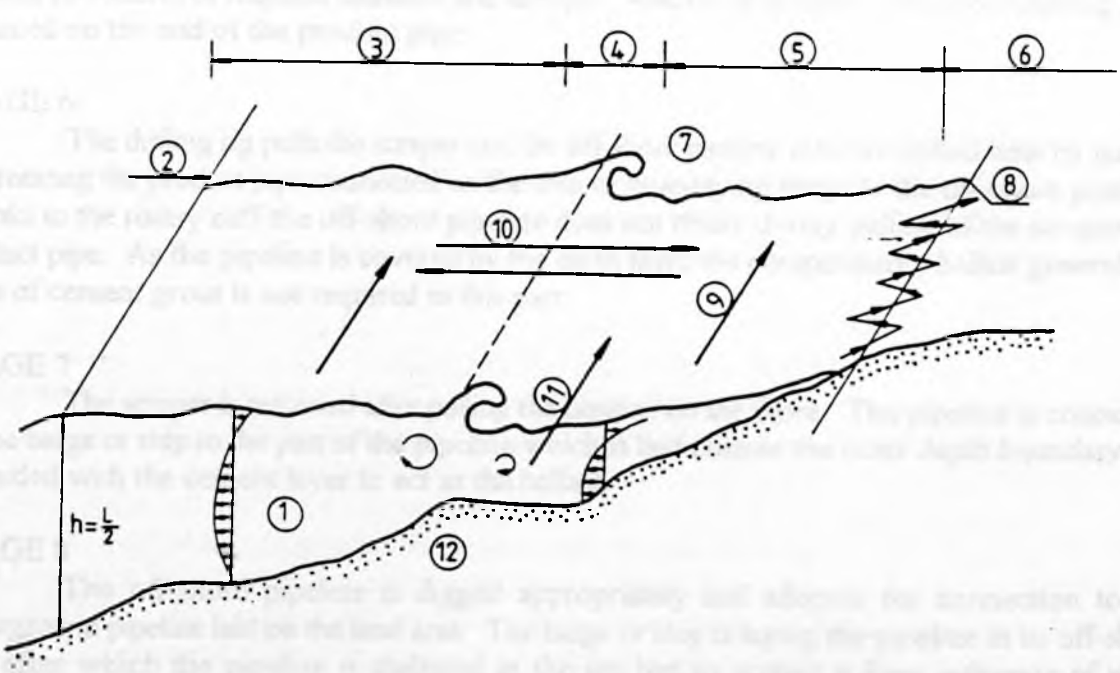
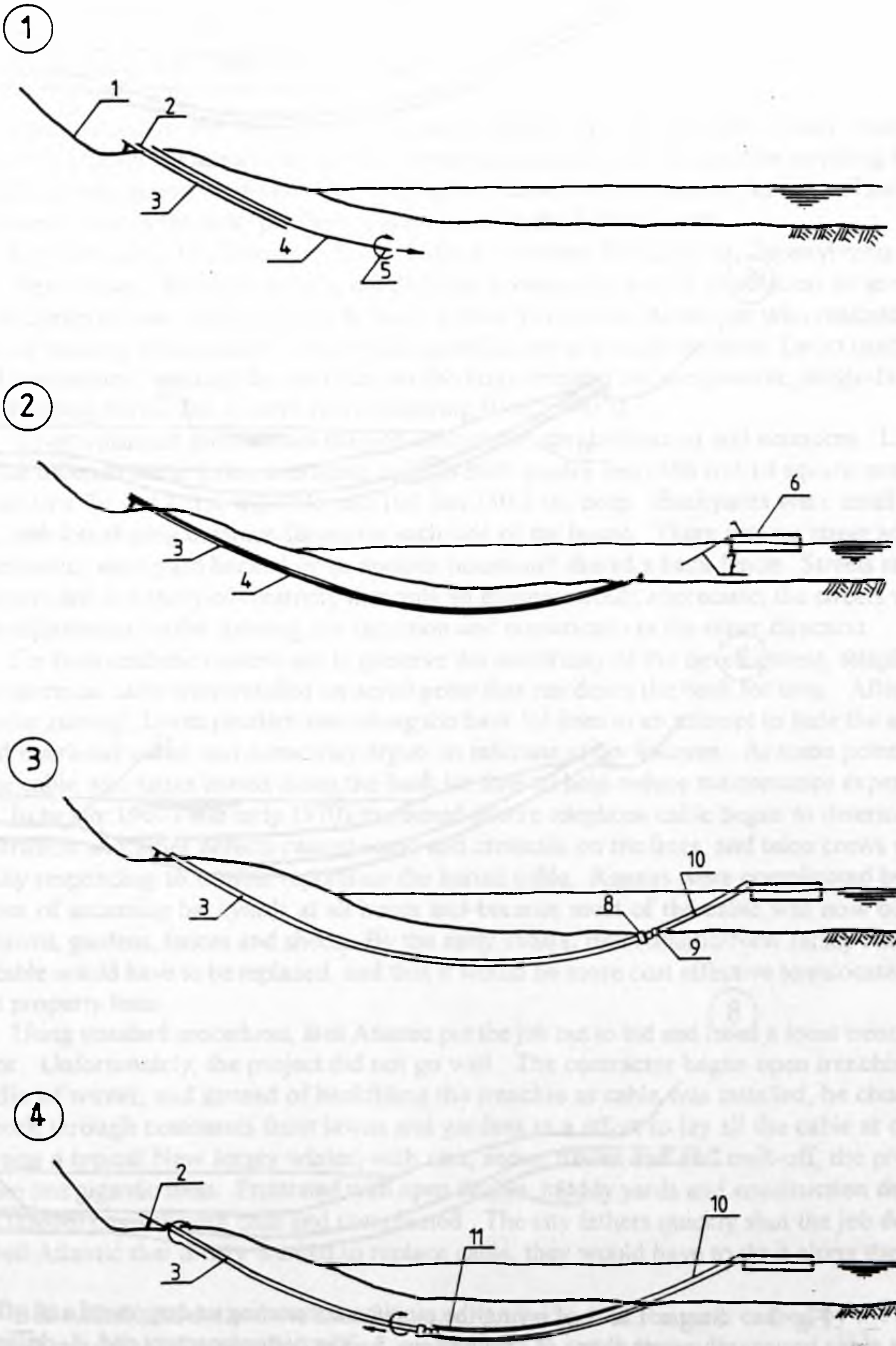


Fig. 2 Hydro- and lithomechanic phonomena of the coastal zone: 1- mass liquid transport, 2 - outer depth boundary, 3 - wave refraction and transformation zone, 4 -wave breakage zone, 5 - hitting zone, 6 - wave run-in zone, 9 - along-the-shore transport of sediments, 10 - flows in and from the shore, 11 - along-the-shore current, 12 - sea bed [2].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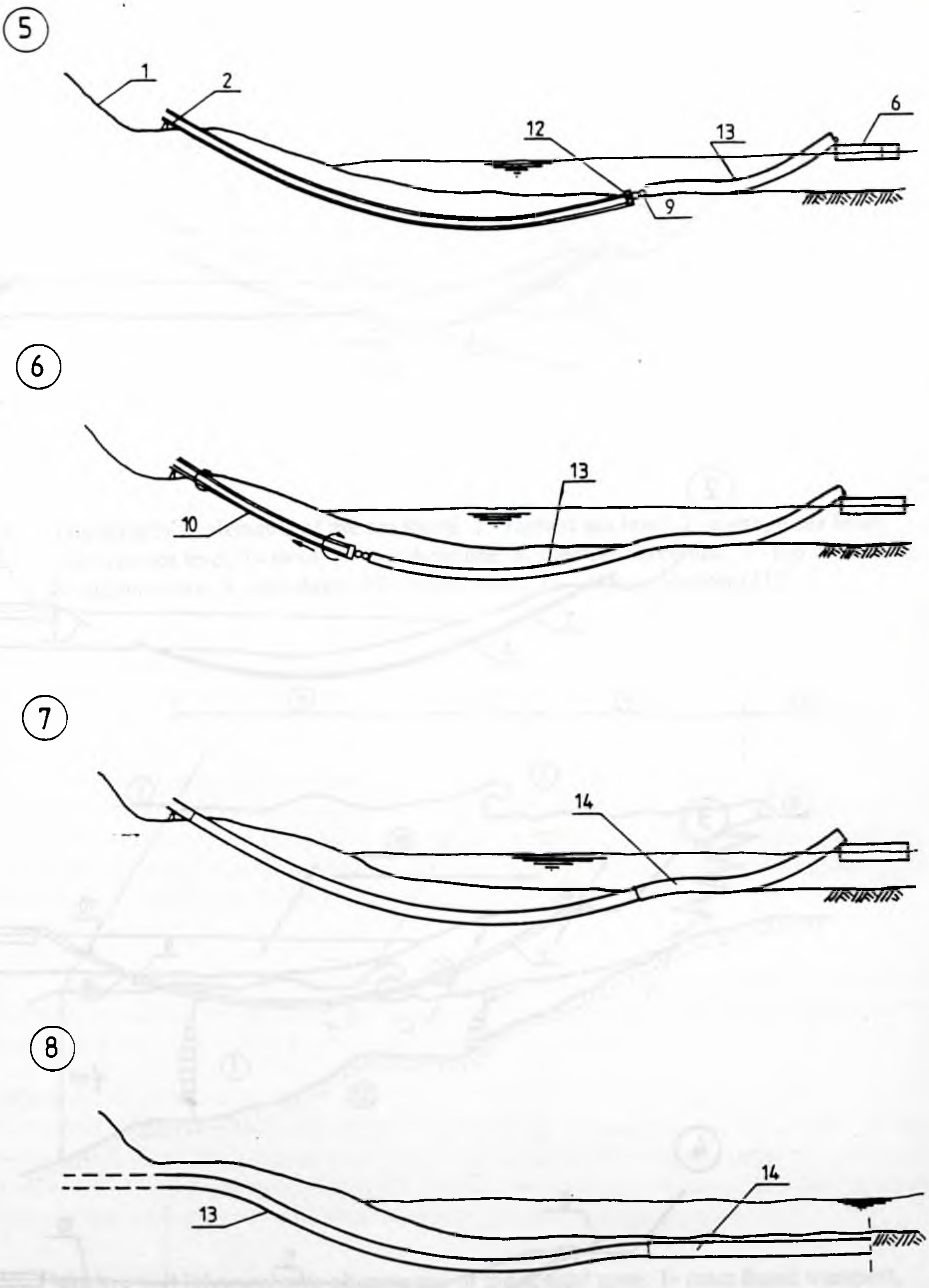

Fig. 3 Stages 1 to 1 of laying the pipeline connecting underground and off-shore pipelines: 1 - upper shore, 2 - drilling rig, 3 - slurry displacement rod, 4- drilling rod, 5 - drill bit, 6 - pipe laying ship or barge, 7 - stinger, 8 - reaming head, 9 - rotary cuff, 10 - product pipe, 11 - cement suspension, 12 - scraper, 13 - off-shore pipeline, 14 - off-shore pipeline with cement shrounding.

GETTING WIRED: THE WILLINGBORO STORY

Anthony Wilkinson, FlowMole Ltd UK.

Constructed in the late 1950's and early 1960's, the central New Jersey town of Willingboro is certainly not historic, not even by American standards which consider anything built before 1920 as, well, almost medieval. But Willingboro does have its place in American History, for it represents one of the first "planned communities" in the United States.

Located along the Delaware River, halfway between Philadelphia, Pennsylvania and Trenton, New Jersey, Willingboro is a middle-class community with a population of around 43,000. Willingboro was built by Levitt & Sons, a New York-based developer who realized the economy of building thousands of similarly-designed homes at a single location. Levitt used the "planned community" concept to capitalize on the huge demand for inexpensive, single-family detached housing during the growth years following World War II.

Levitt's planned communities stressed uniformity, standardization and economy. Levitt offered four different home styles, averaging 1600 to 2000 square feet (488 to 610 square metres) in size, on lots 70 feet (21.3 m) wide and 100 feet (30.5 m) deep. Backyards were small and compact, with lots sharing common fences on each side of the house. There was no street access to the backyards; each yard backed up to another house and shared a back fence. Streets ran in a grid pattern, and in a flurry of creativity that only an engineer could appreciate, the streets were named in alphabetical order running one direction and numerically in the other direction.

For both aesthetic reasons and to preserve the uniformity of the development, telephone cable and electrical cable were installed on aerial poles that ran down the back lot lines. After the utilities were installed, Levitt planted trees along the back lot lines in an attempt to hide the aerial poles and overhead wires, and some may argue, to infuriate utility linemen. At some point, the telephone cable was direct buried along the back lot lines to help reduce maintenance expenses.

In he late 1960's and early 1970's the buried aircore telephone cable began to deteriorate. Water intrusion and other defects caused static and crosstalk on the lines, and telco crews were continually responding to trouble reports on the buried cable. Repairs were complicated by the difficulties of accessing backyards at all hours and because most of the cable was now buried beneath lawns, gardens, fences and sheds. By the early 1980's, Bell Atlantic/New Jersey realized that the cable would have to be replaced, and that it would be more cost effective to relocate it to the front property lines.

Using standard procedures, Bell Atlantic put the job out to bid and hired a local trenching contractor. Unfortunately, the project did not go well. The contractor began open trenching in the middle of winter, and instead of backfilling the trenches as cable was installed, he chose to open trench through customers front lawns and gardens in a effort to lay all the cable at once. Since it was a typical New Jersey winter, with rain, snow, frozen soil and melt-off, the project turned into one gigantic mess. Frustrated with open ditches, muddy yards and construction debris, residents flooded city hall with calls and complained. The city fathers quickly shut the job down, telling Bell Atlantic that if they wanted to replace cable, they would have to do it along the rear lot lines.

Bell Atlantic did not want to take that route, but because of the mess caused by the open trenching, they realized they needed to find another way to install the underground cable along the rear lot lines to placate both local residents and city hall and to keep maintenance repair costs to a minimum.

As luck would have it, a new trenchless installation method was being perfected by a small company in Kent, Washington called FlowMole® (now known as UTILX® Corporation). The technology used a high pressure, fluidjet drilling technique to create stable, clay-lined tunnels up to 600 feet (183 m) long. The drilling head was remotely guided and could install underground cables without digging up peoples' lawns or open cutting driveways and city streets. This was exactly what Bell Atlantic needed!

Following a number of test projects and smaller jobs in 1987, Bell Atlantic began an ambitious 5-year plan to install over 770,000 feet (234,696 m) of cable using trenchless technology. FlowMole began work in 1989, and because of the positive response from customers and the cost-effectiveness of the trenchless method, Bell Atlantic accelerated the 5-year place to a 3-year timeline.

Following the debacle of the original open trenching project, the FlowMole installation method must have seemed almost hospital-sterile to local residents. The FlowMole crew, dressed in clean white and blue uniforms, arrived each morning looking more like a surgical team than a construction crew. Neighbours were initially notified about the work, but because the installation method was so unobtrusive, the FlowMole crews quickly became a non-event in the neighbourhood. Homeowners would frequently ask when FlowMole would be drilling in their yard, only to be told that "we drilled under your garden last week!" Turning a quick eye to her prized tomatoes, one little white-haired lady could only stare in amazement.

The FlowMole system, winner of the prestigious No-Dig 1986 award in London, is the result of years of technical innovation, engineering and excellence and exhaustive field testing. Yet when compared to the average trenching project or horizontal boring machine, the FlowMole system is surprisingly simple and compact. The system is composed of three major pieces of equipment and is typically operated by a crew of two to three technicians.

The Field Power Unit (FPU) is mounted on a truck or lorry and contains the drilling clay supply and pump, a hydraulic power unit, a pneumatic power supply and the electrical supply. The mobile drilling unit, called the GuideDril®, is towed behind the FPU and includes the drilling/thrust platform, the steering and advance controls for the drill, and the down-hole drilling heads, reamers and drill pipe. The GuideDril is self-powered and can enter backyards through standard 32-inch (80 cm) wide gates and can work up to 300 feet (90 m) from the FPU. Low pressure tyres allow the GuideDril to manoeuvre over lawns and other delicate areas with no damage.

A second truck, called the Gully Sucker, contains a vacuum system to remove the small amount of spoils generated by the fluidjet drilling process. The unit can also carry cable spools or other supplies. While the FlowMole system uses sophisticated technologies and other high tech gear, the actual set-up and installation process is very quick and efficient. The FlowMole team arrives on site with the Field Power Unit, the mobile GuideDril, and the Spoils Removal Unit. The self-powered GuideDril is easily manoeuvred through side gates to access the backyard. The drilling equipment can be set up in less than 10 minutes under ideal conditions. After notifying local residents about the day's work, the crew excavates a small access pit next to the pedestal (only necessary if connections need to be made) and positions the mobile drilling unit about 18 feet (5.5 m) from the pit.

A fluidjet drill head is configured for local soil conditions and is attached to the drill pipe. Once the drill is positioned correctly, the high-pressure fluid is activated and the drill head is inserted into the ground at a 20º angle, with forward motion provided by the thrust carriage on the drilling unit.

Small-diameter fluid jets, at very high pressure, cut through the soil with a mixture of water and bentonite clay. Since only a very small volume of fluid is needed, there is no danger of over cutting or washing out the tunnel. The clay helps stabilize the soil by impregnating the tunnel wall and providing a slippery surface for installing the cable. The sandy clay soil in Willingboro was ideal for the FlowMole technology and crews were able to drill at speeds averaging four to five seconds per foot.

As the drill head advances, new sections of drill pipe are added every 10 feet (3 m) at the drilling unit. The small amounts of excavated soil from the drilling operation are removed from the access pit by the lines connected to the Gully Sucker and disposed of under license as non-toxic, inert natural spoils.

A technician with a computerized locating devise call the FlowCator® walks along the drill path. A tiny transmitter in the drill head signals the location and depth of the drill head to the FlowCator. If the drill head strays off course, the technician relays the information via radio to the operator at the drilling unit, who makes the necessary course corrections to keep the drill head at the proper depth and direction.

During the Willingboro job, the crew manoeuvred the underground drill head around numerous obstacles, including buried utilities, tree roots, streams, and even around the plumbing system of a swimming pool. To install the telephone cable, crews typically drilled at depths of 30 to 36 inches (76 to 91 cm), with occasional deeper runs of up to 8 feet (2.4 m) to cross streams or city streets.

Utility officials and curious residents were constantly amazed that the drill head could be remotely steered on runs as long as 600 feet (183 m). One of the favourite tricks of the crew was to position a shovel hundreds of feet away, then watch the expression on peoples faces as the underground drill head know the shovel over.

At the designated exit pit, the drill head is removed and a fluidjet reamer with pulling swivel is attached. The new telephone cable is attached to the swivel and the reamer is retracted through the tunnel. The reamer expands the tunnel to the necessary size (up to 22 inches (56 cm) for certain applications) for the attached cable and the clay drilling mud provides a slippery surface to facilitate cable installation. Utility engineers were surprised that the GuideDril could pull back up to 820 feet (250 m) of cable, not contained in ducts or conduits, with no damage to the insulation or stretching of the cable itself. The system has various methods, such as fuselinks, dynamometers and over-pressure valves, to protect against overpulling the cable. Once the cable is in place, telco crews terminate the cables at the pedestals.

During the relocation of the telephone cable in Willingboro, over 770,000 feet (234,696 m) of AFMW PIC cable was installed, ranging in size from 50-pair, which required a 2-inch (50 mm) tunnel, to 1800-pair which used a 4-inch (10.16 cm) tunnel. Because of the favourable drilling conditions, crews could install an average of 600 feet (183 m) of cable per day.

With the sheer amount of cable being installed, co-ordination and staging of supplies became one of the more important activities for FlowMole's crew manager, John Petrina. While utility/contractor relations can become strained on projects this large, FlowMole and Bell Atlantic co-ordinated their activities extremely well. Bell Atlantic would give Petrina prints for the next 40,000 feet (12,192 m) of installation and Petrina would requisition the cable from Bell's supply yard. At times, Petrina had three to four crews in the field and needed several trucks just to transport the cable from Bell's yard to the job sites.

In a single day, one overly-ambitious crew installed 840 feet (256 m) of cable. According to Drew Angelozzi of Bell Atlantic, the FlowMole crews were very self sufficient and worked with a minimum of supervision. The most serious problem encountered during the project, recounts one supervisor who wishes to remain anonymous, was when the company CEO was visiting the job site and forgot to close a homeowner's gate on the way out.

In 1993, just as the relocation work for Bell Atlantic was phasing down, Public Service Electric & Gas decided taht they needed to relocate all of the overhead electrical cable in

Willingboro. The electrical cable was strung on poles that ran along the same back lot lines that FlowMole's John Petrina had become so intimately familia with during the telephone work. Having climbed over thousands of fences over the years, Petrina admits that he has prpbably met every dog in the city of Wilingboro.

According to Bernie Berkowitz, construction manager for Public Service Electric & Gas (PSE&G), the utility was responding to near constant outages in the Willingboro area, the result of ageing cable, falling tree limbs and squirrels who had difficulty differentiating between trees and 13 kV electrical lines. System wide, PSE&G's average outage time was around 30 minutes; in Willingboro, the outage time was over 2 hours. With no way to get bucket trucks into the backyards to replace poles or other equipment, PSE&G's maintenance costs skyrocketed. Having watched Bell Atlantic's success with FlowMole, PSE&G decided to take the same route, with the exception of direct burying the cables along the front lot lines.

When approaching city hall for authorization to relocate the lines to the front lots, PSE&G won the overwhelming support of the city fathers. Voters had been very please with the trenchless technology used by Bell Atlantic, and PSE&G's application sailed through the necessary approvals.

When PSE&G finally put the project out to competitive bid, they specified that the job was to be done using trenchless technology. FlowMole won the bid, which included installation of both primary and secondary cable, relocation of a number of meter box locations, and installation of cable for street lighting.

In May 1993, FlowMole began work on the first phase of the 10-year rear to front lot conversion project. Approximately 60,000 feet (18,288 m) of cable was relocated during the first phase, which was completed in August, 1994. Of a total of 8000 homes that needed to have cabling relocated, 400 homes were completed during the first phase.

What was unique about the electrical relocation project was the amount of cable being pulled through the tunnel on each run. While John Petrina and his crews pulled a high volume of cable through during the telephone job, they were pulling back only one cable per run. On the electrical relocation, up to 5 primary and secondary cables were being pulled back on a single run, using 1/0 HMWPE 175 mil, strand-blocked aluminum cable for the primaries, and #2 or 2/0 copper cable for the secondaries.

A typical day's work would include setting up the GuideDril on the lawn next to the sidewalk, and drilling parallel to the sidewalk from a pad-mounted transformer approximately 400 feet (122 m) to the next transformer. Drilling was at an average depth of 36 inches (91.4 cm). When the drill head popped out at the second transformer, the crew would install the back reamer and attach two primary cables and two secondary cables, and then begin retracting the drill rod through the tunnel. On some runs, cable for street lights was also pulled back with the primary and secondary cables. The back reamer would enlarge the original 2-inch (5 cm) tunnel to 4 to 5 inches (10.6 to 12.7 cm) to facilitate backpulling of the cable bundles.

At the first house location, a secondary cable would be pulled out of the tunnel and coiled on the ground. A separate tunnel for the service drop would be drilled later. The crew would then continue pulling the two primaries and one secondary until they reach the second house location. There, the remaining secondary cable would be pulled out of the tunnel and coiled on the ground, and the drill rod would continue pulling the two primaries. At the third house, a new secondary wire would be attached to the back reamer and the drill rod would be retracted until it reached the fourth house, where another secondary would be attached to the drill chain. Finally, the two primaries and two secondaries would be pulled to the original transformer location and connected.

To install the secondary cables (or service drops) to each house, the mobile GuideDril would be manoeuvred into position where each secondary had been dropped off. A 2-inch (5 cm) tunnel would then be drilled, approximately 20 to 40 feet (6.1 to 12.2 m) long, towards the meter location at each house. Once the drill head reached the meter location, a pulling line was attached and pulled back with the drill rod through the tunnel. The bentonite clay retained the tunnel shape, even in the sandy soil, so that the secondaries then could be back pulled to the meter locations by hand.

Based on the sheer number of cables being installed, logistics and cable handling played a much bigger role on this project than on the telephone relocation. FlowMole did the entire job turnkey, with the exception of installing the low-profile transformers which was handled by linemen from PSE&G.

Also included in the project were several major street crossings, which involved tunnelling 40 to 44 inches (101 to 112 cm) under the street and then pulling a 4-inch (10 cm) PVC conduit through the tunnel. Since the streets had just been overlaid with new asphalt, it was highly unlikely that the city would have authorized any open cutting of the streets.

For PSE&G's Bernie Berkowitz, the advantages of trenchless technology were substantial. Berkowitz calculates that the trenchless installation cost approximately 20% less than open trenching, once the restoration costs and fees to bore under all the driveways were taken into consideration. More important, out of 300 homes which were recabled in phase one, there were only three complaints. And those, said Berkowitz, "were probably just lonely people who wanted someone to talk to". Berkowitz a said that if conventional trenching had been used on this project, his phone still would be ringing off the hook with complaints about cracked sidewalks, uneven surface restoration and damaged gardens.

More difficult to measure is the restoration of public confidence in both the utility and city officials compared to the public outcry following the original open trenching job back in 1986. Residents now appreciate the efforts of both utilities to implement a technology that solved the problem of telephone and power outages without totally disrupting their daily lives. The success of the rewiring of Willingboro is perhaps best summed up in the look of appreciation from the older lady who stared in amazement at the prized tomatoes, and wondered how they got all those cables beneath them with "nary a leaf asunder".

LONG DISTANCE PIPE JACKING IN SOFT ROCKS

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ABSTRACT

In the region of Nuremberg, South East Germany, the ground predominently consists of sandstones and claystones of the Keuper formation, a part of the Triassic. These rocks vary largely in gradation and strength depending on the cementing agent. The claystones and the weak, clay cemented sandstones are especially vulnerable to weathering when exposed to air and water. They may be categorized as soft rocks. However, occasionly hard to very hard layers are encountered. Quite frequently deep quarternary erosion channels filled with waterbearing cohesionless sands are found, which then have to be crossed by pipe jacking works.

Resulting from the needs of reconstruction and enlarging the existing sewer system, a great number of canals with an internal diameter of 1600 mm to 2500 mm at depths between 5 m and 15 m below ground surface have been constructed by pipe jacking. The drive lengths vary from a few hundred to about fifteenhundred meters. Most drives are operated with roadheaderbooms. Special solutions have to be found when crossing the water bearing sands.

INTRODUCTION

Pipe jacking and widerly spoken all trenchless pipe installation techniques take place in the sub-soil which is in most cases the lessest predictable part of the system: needs -contract - pipe - installation technique - surrounding constraints - underground.

Therefore the survey and description of the underground is of vital interest for the success of a trenchless pipe installation. In the city of Nuremberg for this reason borings and other means of soil investigation are conducted for every new project in detail.

UNDERGROUND

In the region of Nuremberg the underground is dominated by the sandstones, clays and claystones of the Keuper formation of the Triassic. The region is surrounded by jurassic mountains and the old formations building the Bavarian Forest (fig. 1).

Situated near the surface these rocks are often strongly influenced by weathering. There are various scientific concepts for the classification of the degree of weathering of a soft rock. For practical purposes in the sight of pipe jacking we mainly use the heavy dynamic probing. The upper boundary of the intact rock is defined by the final depth of the dynamic probing. Over this stratum in general a layer of loamy sand as the result of residual weathering is found. The rock surface is often found quite plain but in some cases former rivers have eroded their bed some ten to twenty meters into the rock. These river beds are now filled by sands of the quarternary. The sands show a uniform gradation lacking a substantial amount of fines. Mostly they are situated below the ground-water table. If not detected in advance they can cause major problems for the stability of the cutting face of a pipe jack. For the detection dynamic probing in intervals between 15 m and 25 m is used.

The intact Keuper rocks themselves show a very varying strength as presented in figure 2. For the strength classification besides uniaxial testing the point load test is often used. Mineralogically the sand partition consist of quartz and feldspar leading to a very high abrasiveness of the rock. The clay fraction consists mainly of illite and some mixed-layer-minerals. Under the influence of air and water opened faces show a local swelling behaviour which leads to fast weathering near the surface. This can cause severe problems in the stability of a long distance boring in these soft rocks.

Classified according to the German standard DIN 18312 these rocks belong to the groups FD 1 and FD 2, meaning a uniaxial compressive strength lesser than 5 MN/m^2 (50 MN/m^2 respectively) with large distances between joints.

TRENCHLESS INSTALLATION TECHNIQUES

The first question in finding a suitabale trenchless installation technique is to decide between steerable and non-steerable techniques. In the lokal situation with sands and rocks, non-steerable techniques will successfully work for distances up to approx. 30 m. In cases where a deviation of 10 cm up to 50 cm and more is acceptable, distances up to approx. 70 m have been driven by simple devides without steering techniques.

In these cases the sandstone is cut by a conical shaped full-face-cutting head and transported by a screw auger. The pipes are steel pipes in cuts of approx. 6 m length which are connected by welding on site. In some cases for pipes with internal diameter larger than 800 mm a simple way of steering is used. The auger and the cutting device are removed, the position of the face may then be determined by measurement. Smaller corrections for the further drive are then possible by removing the rock by hand on the appropriate side of the shield.

It is of great importance for the long-time stability of the ground that the remaining slot between pipe and rock, the overbreak, is closed by injection through valves in the the pipe walls. Precautions have to be taken for these works if the internal diameter is smaller then 800 mm.

The second point is the question, whether the diameter of the pipe allows working in the pipe. In Germany we have the following restrictions:

Pipe length < 50 m	Internal Diameter > 800 mm
Pipe length > 50 m	Internal Diameter > 1000 mm
Pipe jacking under air pressure	Internal Diameter > 1600 mm

For small diameters ID 100 to 1500 mm and long driving distances directional drilling with subsequent enlarging in the counterdirection has proved to be very successful in the soft rocks. The position of the cutting head is determined by measurements of the natural or an artificially induced magnetic field. The technique is usually suitable for pressure pipes. Due to favourable experiences gained in these drives the range of applicability could be expanded. Free-flow channels with low gradients have successfully been driven in lengths of approx. 500 m with deviations from the design gradient of some centimeters.

Larger diameters are normally driven by pipe jacking techniques. The rock is cut by roadheader booms fixed in the shield. Sometimes full-fall cutting heads have been used. They were successful in homogeneous sandstones, but the clays and claystones frequently encountered in the Keuper formation will tend to aggregate in the disc cutters together with sand and so block the discs. This happens especially under the groundwater table and leads to excessive wear of the cutters.

Also for roadheader booms the wear of the cutting devices is high due to the significant quartz content of the sandstone. The cutted rock is in the most cases taken up by a band conveyor and then transported by muck haulers running directly on the bottom of the pipe.

Care has to be taken that the contact between the material and the eventual ground water is avoided as far as possible. Otherwise the rock will desaggregate to a soft clayey soil.

For the steering of the pipe jacking in rock an overbreak of about 3 cm circumferal around the shield is executed. In the case of curved drives the overbreak is concentrated on the inner side of the curve.

In many cases the overbreak remains open for the time of jacking and so the frictional resistance along the pipe is low and only related to the self-weight of the pipe. If required the friction is further reduced by injecting bentonite slurry in the overbreak.

In weaker sandstones under the groundwater table there is a danger of erosion in the inner face of the overbreak. For low water pressures up to approximately 10 m water head this can easily be overcome by a total filling of the overbreak with bentonite slurry. This is possible up to approximately 10 m before the face, otherwise the slurry will flow into the shield.

Finally the overbreak is injected with cement to guarantee long-time stability.

In case of high water pressure in connection with weak sandstones or more severe claystones with a swelling potential the overbreak can not be supported by a simple bentonite slurry because this will be washed out by the water. Special mixtures have to be designed in laboratory, which give support to the rock but do not block the jackability of the pipes. Mixtures of 1 partition cement, 4 partitions technical clay and 5 partitions water proved to be successful.

Without these precautions the rock over the pipe may weather and break down. The material in combination with water and possibly bentonite will accumulate under the pipe, leading to heave of the pipe and blocking of the jacking.

For the crossing of the described water bearing sands a possibility for keeping the shield under pressurized air has to be added. It is only used very near to and in the sands. Out of these areas the air lock is kept open an does not influence the jacking works. Only the length of the shield and additional air lock will rise from 8 m to 25 m and the air support has to be elongated for every new pipe inserted.

With the described measures pipe jackings have successfully been driven for lengths of over 1500 m. Approximately every 500 m an interjack is included. For pipe jackings near the groundwater table longer distances seem to be no technical problem. The restriction was simply imposed by the contract length.

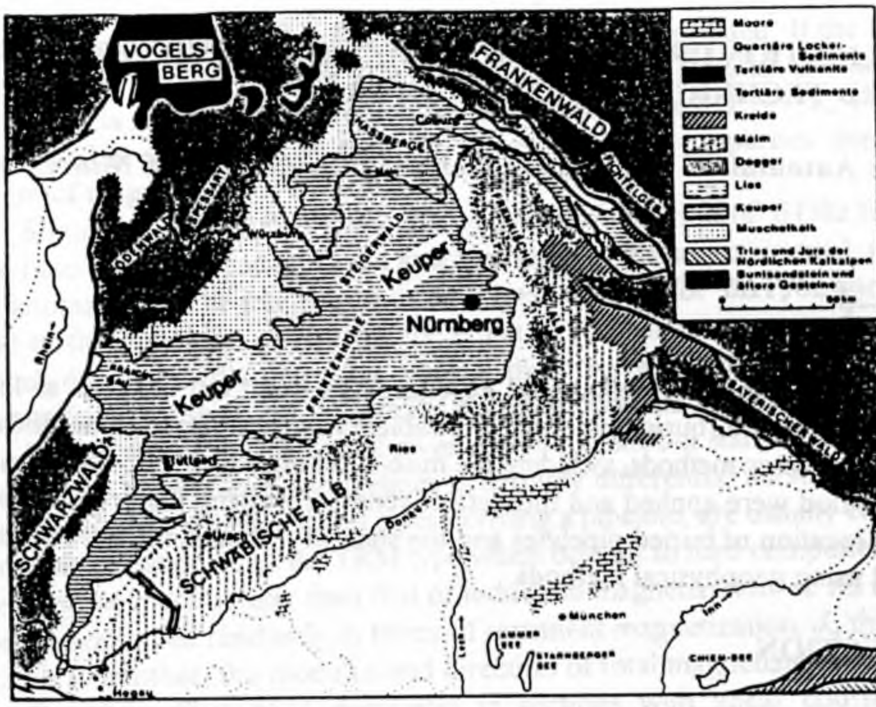
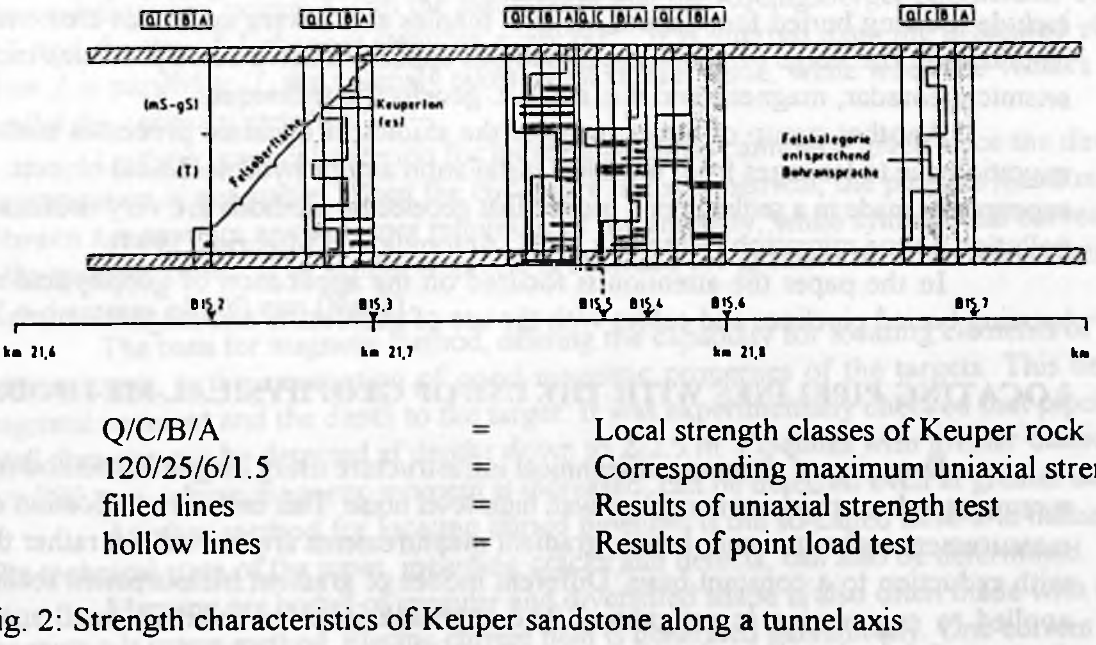


Fig. 1: Geological situation



Q/C/B/A	=	Local strength classes of Keuper rock
120/25/6/1.5	=	Corresponding maximum uniaxial strength
filled lines	=	Results of uniaxial strength test
hollow lines	=	Results of point load test

Fig. 2: Strength characteristics of Keuper sandstone along a tunnel axis

THE APPLICATION OF GEOPHYSICAL METHODS INTO LOCATING ELEMENTS OF BURIED TECHNICAL INFRASTRUCTURE

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ABSTRACT

The results of modelling and experiments carried out in order to locate elements of technical infrastructure (buried pipelines and cables) using geophysical methods are presented in the paper. Geoelectric methods, including the mise-a-la masse and VLF techniques, and magnetic gradient method were applied and their effectiveness in solving the problem was analysed. It is shown that location of buried pipelines and the state of technical infrastructure elements can be determined using geophysical methods.

INTRODUCTION

The application of geophysical methods into detection of elements of technical infrastructure is based on the assumption that physical properties of the elements are different than those of the surrounding medium. As a result of different physical properties, anomalies of geophysical field occur and reflect the features of investigated objects.

A number of engineering problems can be solved using geophysical methods. They include locating buried foundations, cellars, tunnles and sewers as well as elements of echnical installation. The range of geophysical methods applied to solve these problems include gravity, seismic, georadar, magnetic and d.c. and a.c. geoelectric techniques.

Another group of issues includes the studies of dynamic processes such as pollution migration due to leakages from technical installation and/or hydrotechnical objects. A few years' experiments made in a settling pond proved that geoelectric methods are very useful in monitoring pollution plume migration (Antoniuk 1993; Antoniuk and Miecznik 1994).

In the paper the attention is focused on the application of geophysical methods into locating buried pipelines and cables with the use of geoelectric and magnetic methods.

LOCATING PIPELINES WITH THE USE OF GEOPHYSICAL METHODS

Detection of elements of technical infrastructure using magnetic method involves measurements to be carried out in regions with high-level noise. This entails modification of a standard measurement technique and, hence, gradient measurements are carried out rather than mapping with reduction to a constant basis. Different modes of gradient measurement technique can be applied to engineering investigations. The approach involves constant small spacing of field detectors (probes) and simultaneous recording with two channels which minimize the effect of alternating field on the measurement results.The advantages of the approach include the simplicity of initial data processing and regional trend filtration, which is beneficial while mapping shallow-seated antropogenic targets. Some limitations, mostly in interpretation, are related to the fact that measurement gradient, $\Delta T/\Delta p$, in p direction is not strictly related to the derivative $\delta T/\delta p$. The parameters of the measurement system should be properly chosen so that these quantities could be compared.

Of a few techniques of gradient investigation, the measurement of vertical gradient of the modulus of total geomagnetic induction vector, T, is most popular. If the field is composed of two components, $T=T_o+T_a$, where T_o is its normal part and T_a is its anomalous part, and T_o is constant (what is satisfied in the region under discussion) and $T_a << T_o$, then vertical gradient $\Delta T/\Delta z$ could be considered as a scalar function whose properties depend on anomalous component of magnetic field, T_a (Koblański 1993).

Simulations on models show that good approximation of $\delta T/\delta z$ function are obtained when the ratio of probe spacing to the average depth to the source is smal, i.e. $\Delta z/z \leq 0.1$. Then gradient anomalies can be interpreted using the approaches for $\delta \Delta T_a/\delta z$ anomaly interpretation. Violation of this condition causes that the effect of anomalous component on records of one of the channels decreases with increasing spacing; thus, the obtained differential field, ΔT, takes the features similar to those of ΔT_a anomalies obtained using standard measurement technique.

Irrespective of the method of investigation (gradient or standard mode), the characteristic response of the targets such as pipelines is strongly differential anomaly pattern related to the target's magnetization structure. Steel pipes, forming a pipeline, are usually characteristic of strong remanent magnetization, J_r, of the TRM type which belongs to hard components of magnetization. Its value could be much greater than that of induction magnetization, J_i. As individual sections of the pipeline are joined randomly in terms of remanent magnetization, J_r, thus, when going from one section to another, the modulus and direction of total magnetization vector ($J = J_r + J_i$) can change. Rotation effect of J_r dominates in sections with linear course and it displays as differentiation in shape and intensity of anomalous field along the pipeline. This effect can be used into locating pipeline joints what is not available using other methods.

The effect of remanent magnetization on magnetic field of pipelines is illustrated with the example of computer simulation of vertical gradient, T/ z, over horizontal cylinder (Fig.1). The modelling was executed with the assumption that the Koenigsberger coefficient, Q, is equal to 1 and the dip of J_r changes stepwise every 60° . It is inferred from the presented plots that, when J_r is parallel to J_i, the anomaly takes its maximum value, while when the vectors are anti-parallel the anomaly vanishes.

Uniform practical criterion for locating pipelines cannot be given since the direction of magnetization is not stable. When the curves are not symmetrical, the pipeline location is found between a maximum and a deeper minimum of the anomaly, while symmetrical curves locate it in the anomaly center. The similar response is observed for gradient measurements over gaslines of a diameter of 200 mm (Fig.2).

The basis for magnetic method, offering the capability for locating elements of technical infrastructure, is the assumption of good magnetic properties of the targets. This depends of magnetic moment and the depth to the target. It was experimentally checked that pipelines with small diameter can be detected at depths down to 2-2.5 m. Pipelines with greater diameters, e.g. ϕ = 200 mm, whose magnetic moment is increased, can be detected even at greater depth.

Another method for locating buried pipelines is the so-called mise-a-la masse method. The technical state of the pipes, including cracks and defects, can also be determined.

Mapping ore bodies of irregular and diversified shape is also often made with the use of the mise-a-la masse method. Electric current field is generated galvanically. One current electrode is positioned in a conducting body either in outcrop or in a borehole. The other current electrode is a great distance away, usually as much as 10 to 15 times depth of burial of the first current electrode. As there is usually great resistivity contrast between good conducting ore body (electronic conductance) and the surrounding rock medium (ionic conductance), the ore bodies can be considered equipotential. Equipotential surfaces surrounding the ore body imitate its shape; then they smooth down and approach spherical shape at great distance to the body.

The mise-a-la masse method can be adopted to locate the course of a pipeline if a current source could be connected to it. The advantage of the method is its capability for locating one pipeline out of several neighbouring and parallel ones. In such a case, alternating current of small frequency is applied,so that induction effects in adjacent pipes are negligible.

Figure 3 shows the profiles of the modulus of electric field intensity over linear conductor with direct current flow. Electric field intensity was calculated along lines perpendicular to the strike of long equipotential linear conductor buried at the depth h. The intensity value over the conductor is equal to zero. On either side of the zero point two extremes occur at the abscissae $x = \pm h$. The dependence of amplitude of electric field intensity on the depth of burial of linear current source is shown in Fig.3a. In field measurements, usually for detection of pipes, a potential dipole, MN, of finite length (1-2 m) is used and the potential difference between M and N electrodes is measured. The plots of potential difference for different MN spacing, when the measurement line is perpendicular to the strike of a linear conductor, are shown in Fig.4.

The characteristic features of E or ΔV anomalies over linear electric current source presented here imply that the approach for detecting buried pipelines is rather simple and consists in finding the zero points between two extremes.

The application of geophysical methods into detecting buried pipelines will be presented in a case study from the west slope of the Parkowa Hill in Krynica. Several pipe-inlets are found inside old concrete water-basin near the Zdrój Główny spring. The course of the pipelines outside the spring was not known. Geophysical measurements using magnetic and mise-a-la masse geoelectric method were made in the neighbourhood of the basin. The pipelines were located north (125 m) and south (250 m) of the old basin. During the investigation it was revealed that a gasline of 200 mm diamater runs close to the northern old pipeline, 130 m distant from the basin. Therefore, the location of the old water pipeline could be detected using only the mise-a-la masse method. A current source was connected to the pipe-inlet in the basin.

Figure 5 presents the plots of the modulus of potential difference measured between M and N electrodes along the 27, 27b and 28 lines. The profiles shown in figures 27 and 27b are typical of electric field distribution over a linear current source. Anomalies were not recorded on line 28, 6 metres north of line 27, what implies that the pipeline ends there or is broken in the area between the lines. In order to locate the ends of the pipes going to the old basin, the measurements were made along line 45 parallel to the pipeline axis, i.e. crossing the zero points of lines 27 and 27b. The potential difference $\Delta V_{MN} \approx 0$ as long as the measurement dipole MN is over the pipe. A very sharp maximum appears when the MN dipole crosses the end of the pipe, the maximum center determines the pipe end.

Further detection of the pipeline to north was not possible using the mise-a-la masse method. The pipeline was probably broken due to slope sliding or old pipes were removed while gasmains was laid. Magnetic anomalies were recorded 30 metres north of the site of the pipe break on lines 30 through 35, and their pattern refers probably to the course of the old pipeline.

DETECTION OF BURIED CABLES USING THE VLF METHOD

The VLF (Very Low Frequnecy) electromagnetic method is a passive geoelectric method for locating good conductors (including ore deposits, buried pipelines and cables) making use of EM waves emitted by military radio stations in the frequency range of 15 to 30 kHz. Infralong radio waves propagate as near surface and ionospehric waves whose extent covers the whole globe.

The VLF electromagnetic field source - vertical mast of a radio station - is a few tens to several thousand kilometres distant from the measurement station. Hence, if good conducting objects are not present in the investigated area, it can be assumed that VLF magnetic field intensity vector is horizontal and perpendicular to the radio station direction and the field is almost homogeneous. If conducting bodies do occur, then eddy currents are induced in them and their magnetic field H_s (secondary field) is superimposed on the primary field, H_p, generated by the radio station, giving the resultant field, $H = H_p + H_s$. Generally, the resultant magnetic field intensity vector is not horizontal and the field is eliptically polarized.

The VLF magnetic method version measures: (1) - amplitude of horizontal component of magnetic field, H_y (2) - in-phase vertical and horizontal component ratio, H_z^{IP}/H_y, in per cent, (3) - quadrature vertical and horizontal component ratio, H_z^{Q}/H_y, in per cent.

It should be noted that the vertical component occurs (i.e. takes the value significantly different than zero) when good conducting bodies are present in the investigated area. VLF measurements are carried out in a profiling mode exclusively. The measurement array is moved along the measurement line with a settled profiling step, and VLF magnetic field components are recorded in successive stations. The surface field distribution responses to buried conductors and magnetic field anomalies are measured. Good conductors are located and their geometrical parameters are determined on the basis of characteristic features of the anomalies.

VLF electromagnetic field anomaly, obtained over the buried cable feeding the TV relay station near Wojcieszów (the Sudetes) is shown in Fig.6. The cable was detected accidentally, as the main objective of geoelectric survey in that region was prospecting for ore veins. Using the FUO radio station transmitter of Bordeaux, broadcasting with 16.8 kHz frequency, the VLF magnetic field components were measured along the reconnaissance line No 11. The profiling interval was 5 metres, however in the portions of the line where great gradient of magnetic field changes was observed, measurements were taken every 0.5 m.

The responses shown in Fig.6 are typical of VLF profiling over very good linear conductors (cable, pipeline or vertical ore vein of small thickness) buried in relatively poor conducting medium. Two extremes, symmetrical of the point in which components are equal to zero, are clearly displayed in the responses of in-phase and quadrature vertical components. The zero point appears over the linear conductor. In the response shown in Fig.6, the zero point shows the location of the cable at 85.5 metre of the line.

When the measurement line crosses the conductor's strike at the angle $\alpha=90°$, the extremes appear at the distance $x = \pm h$ to the zero point (h - depth to the linear conductor). It should be noted that both components have their extremum at the same abscissa, however their signs are reverse. The curve of horizontal component of VLF magnetic field, H_y, differs from that of the vertical components. The former has only one extreme (the maximum over a linear conductor, Fig.6). In a case when the measurement line is not perpendicular to linear conductor ($\alpha \neq 90$), decreasing angle results in stretching anomaly on either side of the zero point (the abscissa of the extremum $x > h$), and amplitudes of anomalies decrease proportio-nally to $\sin(\alpha)$ for all components.

SUMMARY

The brief account of geophysical methods for recognition and detection of buried technical infrastructure included the techniques which are efficient and simple to operate. Only some aspects of their capabilities were discussed.

The active mode of the VLF electromagnetic method, i.e. with its own primary field source, is also applied. The mise-a-la masse method has also its magnetic version and is used when earthing is impossible (e.g. asphalt, concrete). Magnetic field of the current supplied to the target is measured rather than potential difference.

The methods disussed here can be successfully applied into engineering studies. The technical state of targets can be evaluated, and breaks in cable insulation and leakages from hydrotechnical objects can be found. Magnetic method provides a good tool for locating buried pipelines and supplementary objects. Pipeline joints can also be detected using a fine grid of measurement lines when strong remanent magnetization exists.

REFERENCES

1. Antoniuk J., 1993. Zastosowanie badań geoelektrycznych do monitorowania aureoli zanieczy-szczonych wód podziemnych wokół zbiornika osadnikowego. Zesz.Nauk. AGH, Geof. Stos. Z.13, pp. 67-81.
2. Antoniuk J., Miecznik J., 1994. Badania geoelektryczne stref migracji skażeń w wodach podziemnych na przedpolu zbiornika osadnikowego "Żelazny Most" Mat. Konf. "Ekologia w górnictwie a geofizyka" Ustroń-94, pp.7-13.
3. Koblański A., 1993. Zastosowanie gradientowej metody pomiarów magnetycznych w badaniach inżynierskich i ochronie środowiska. Zesz. Nauk. AGH, Geof. Stos. Z.13, pp.81-88.

Fig. 1. Anomalies of vertical gradient of magnetic field, T/ z, over a horizontal cylinder (computer simulation of the response of a pipeline). Probe spacing z =1m; depth to center of cylinder, z=1.5m; apparent inclination ,=65 ; curves 1-3 and 5-6 computed with the assump-tion that *J*, vector dip (,) is expressed by ,= n60 + 5 (n - number of curve), ,, = 240 . Intensity is normalized in terms of maximum of curve 1 for which induction and remanent magnetizations are consistent.

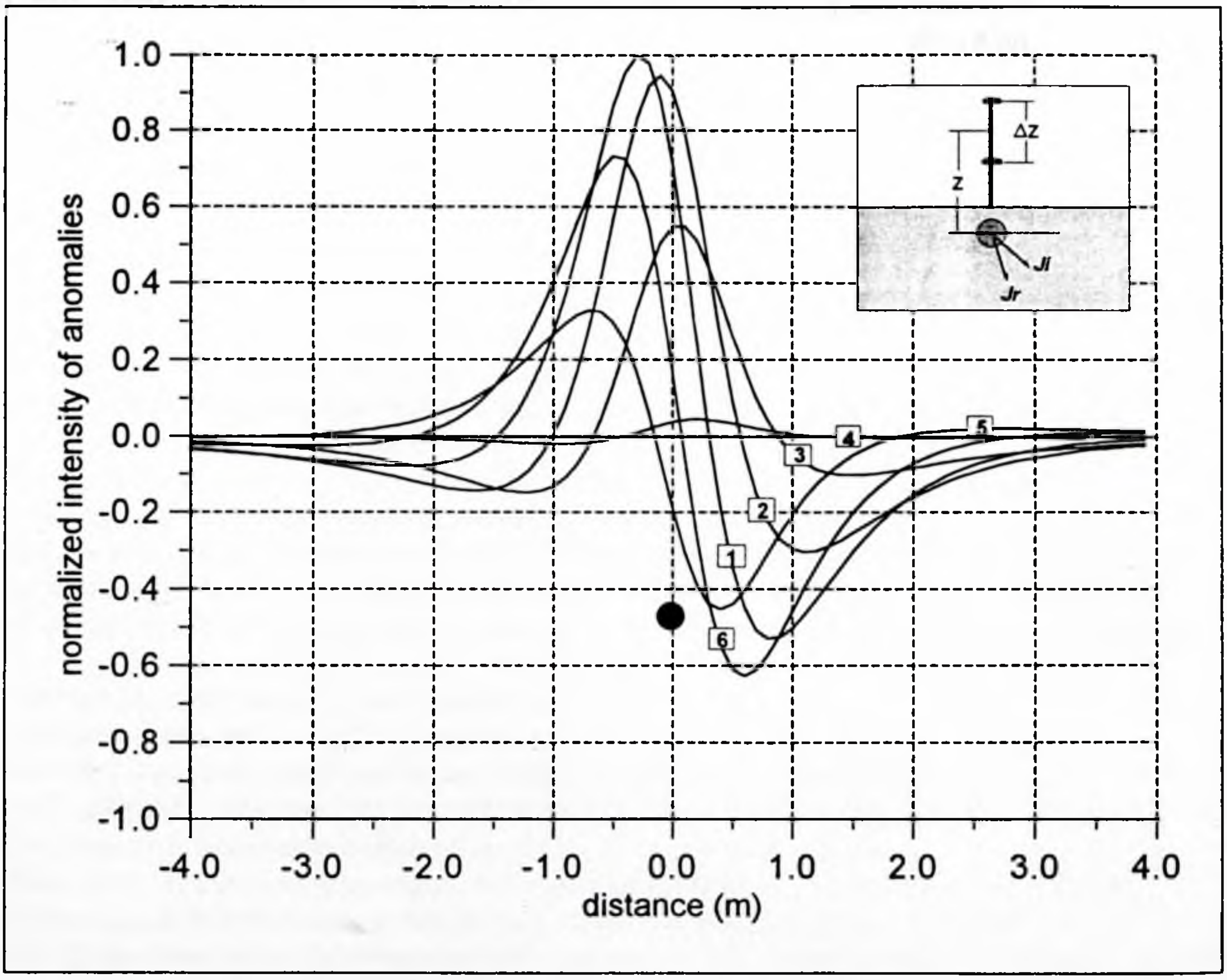


Fig.2. Vertical gradient, T/ z, anomalies over a pipeline. The pipeline (= 200 mm) is located between stations 10 and 11 m (examples of the investigation in Krynica).

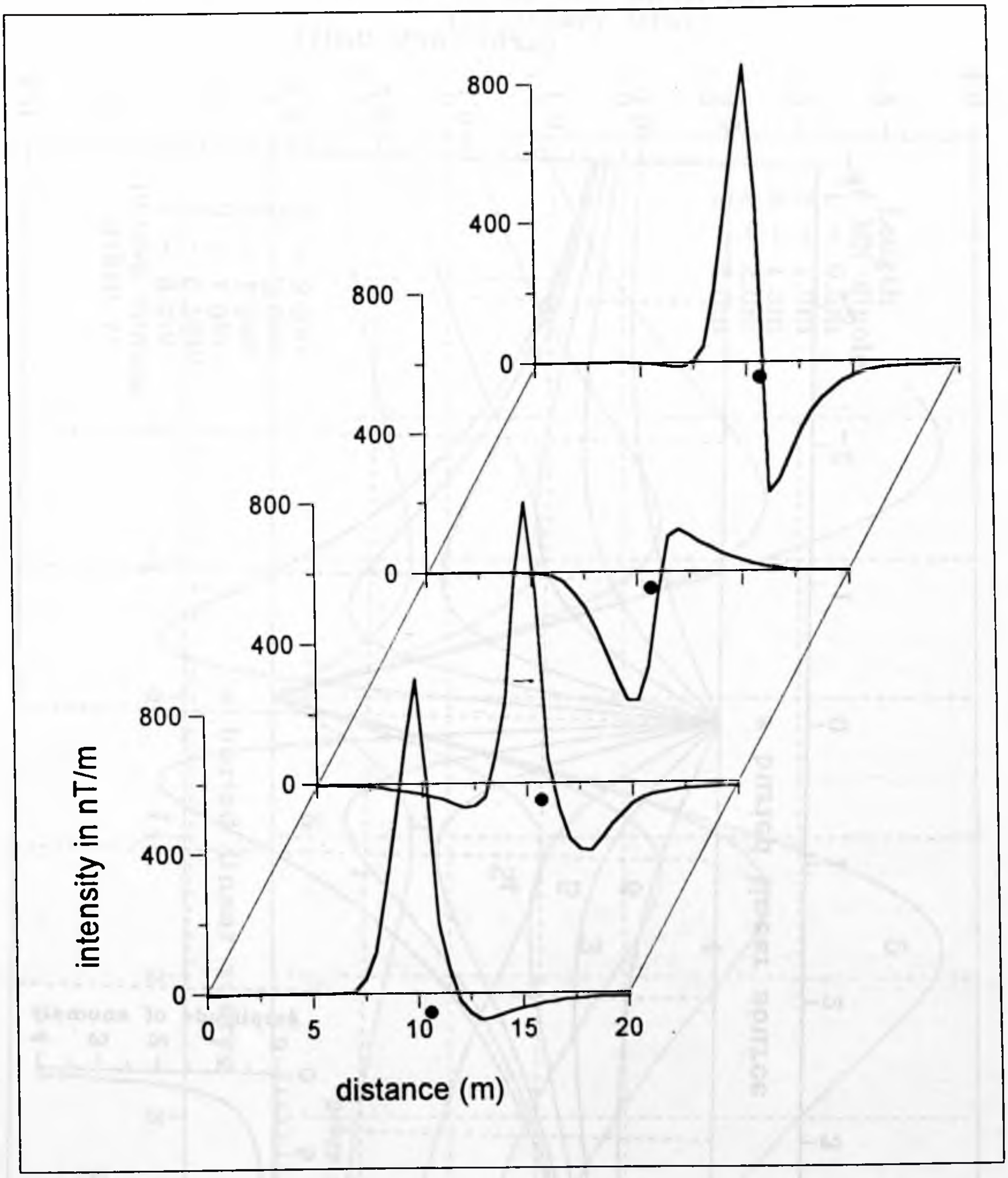


Fig.3. Plots of the modulus of electric field intensity over linear conductor with direct current; a: dependence of amplitude of electric field intensity anomaly on the depth to linear source.

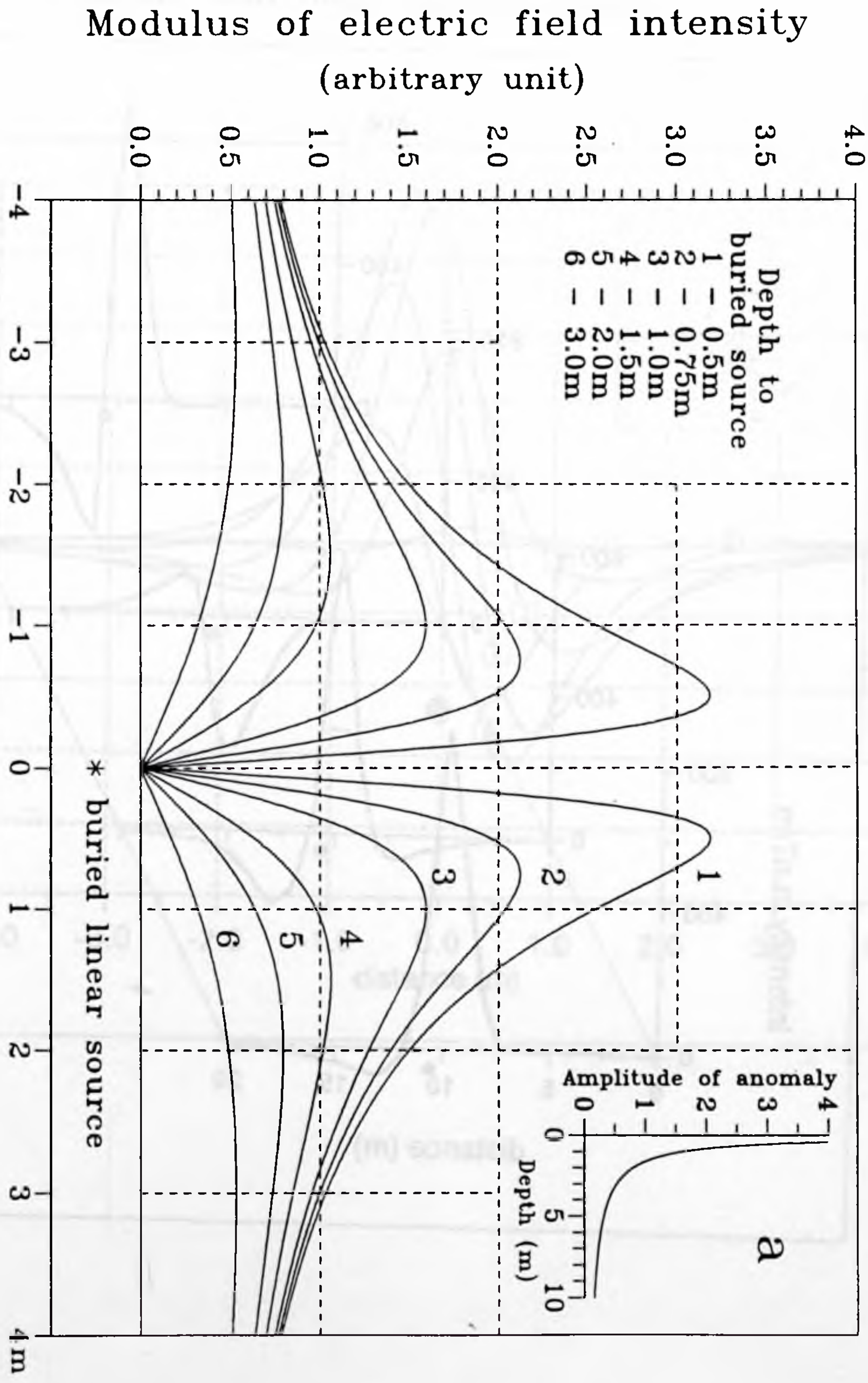


Fig.4. Plots of the modulus of electric field potential difference over lienar conductor with direct current.

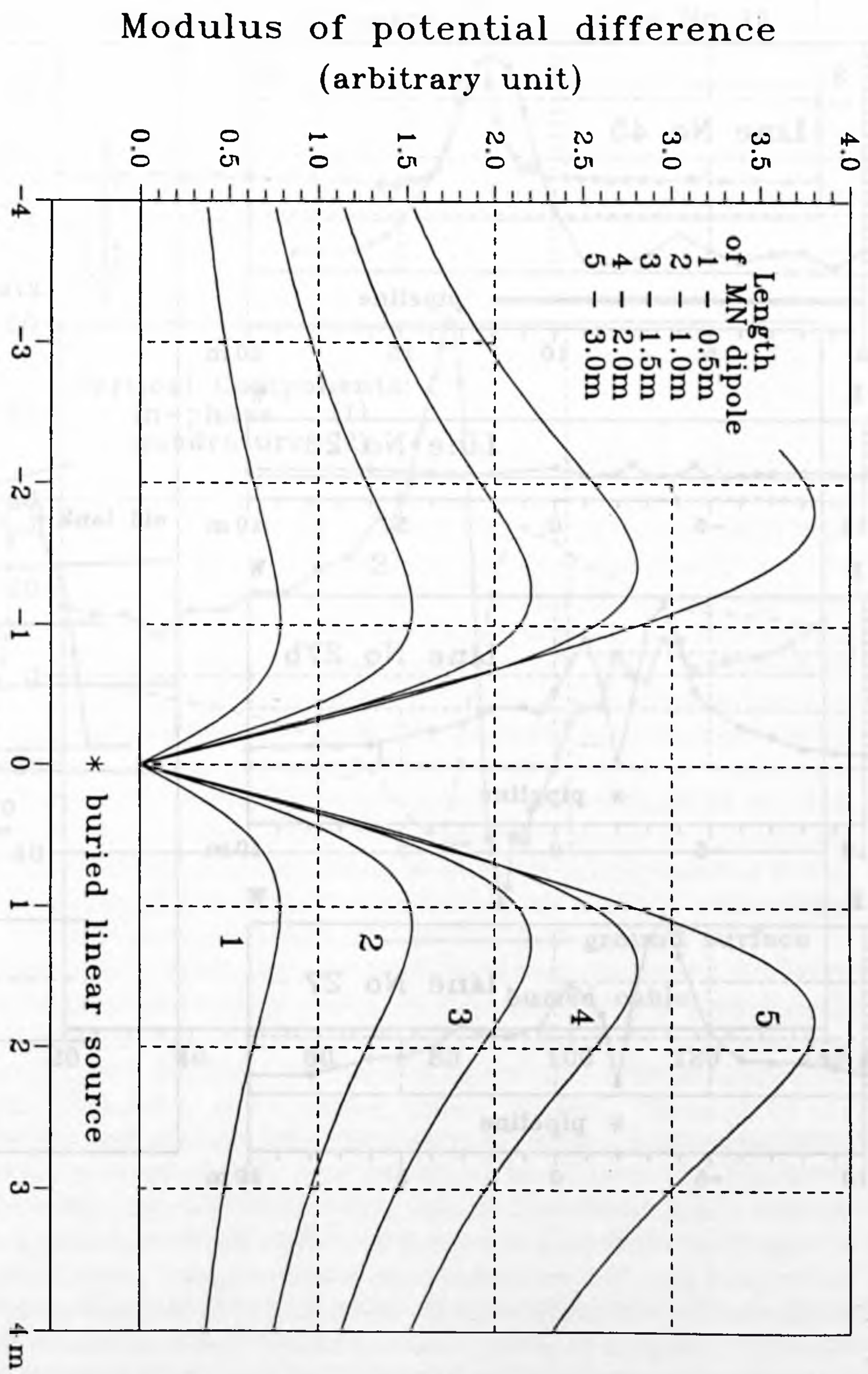


Fig.5. Results of geophysical measurements for locating old pipelines on the western slope of the Parkowa Hill in Krynica.

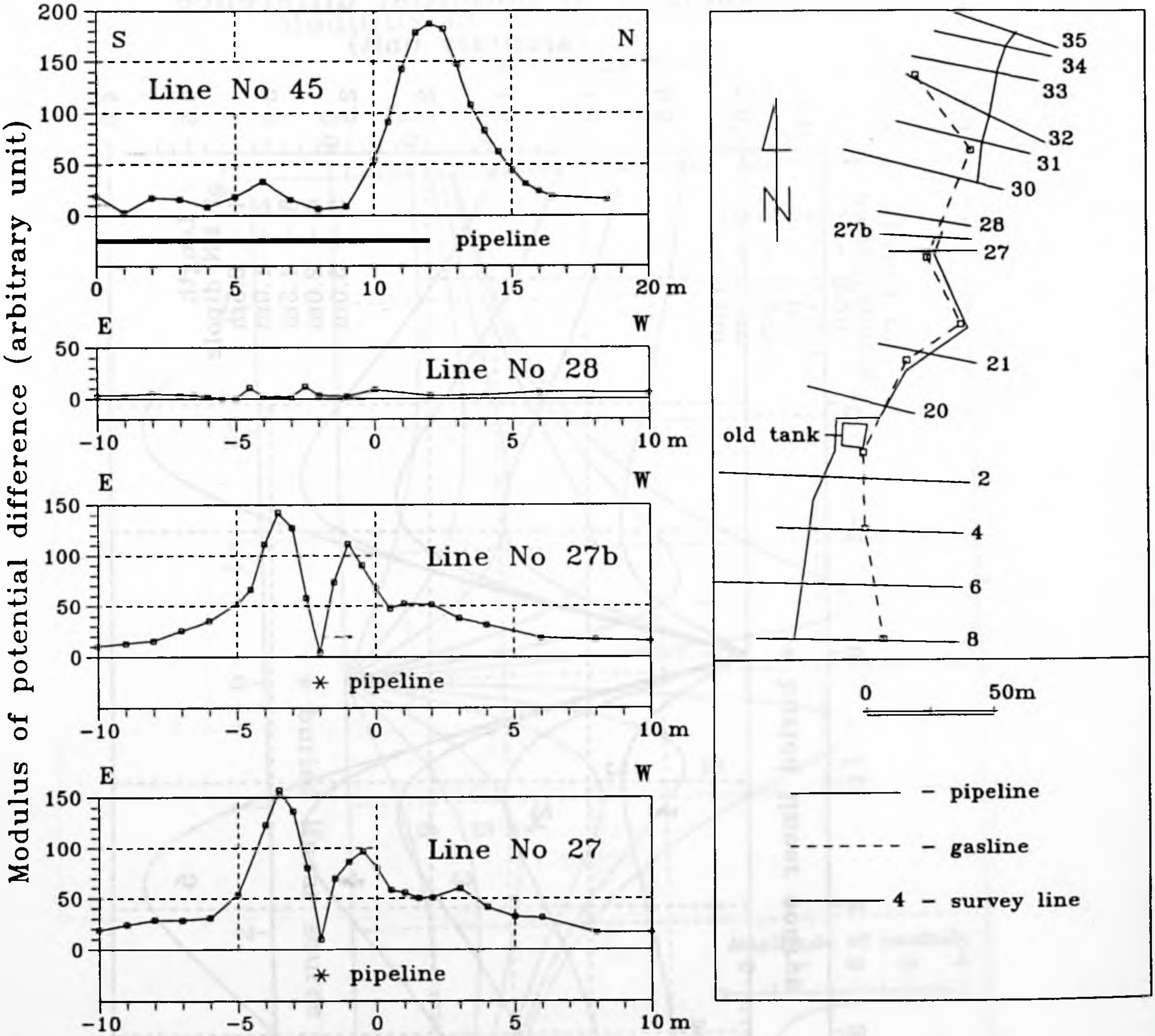
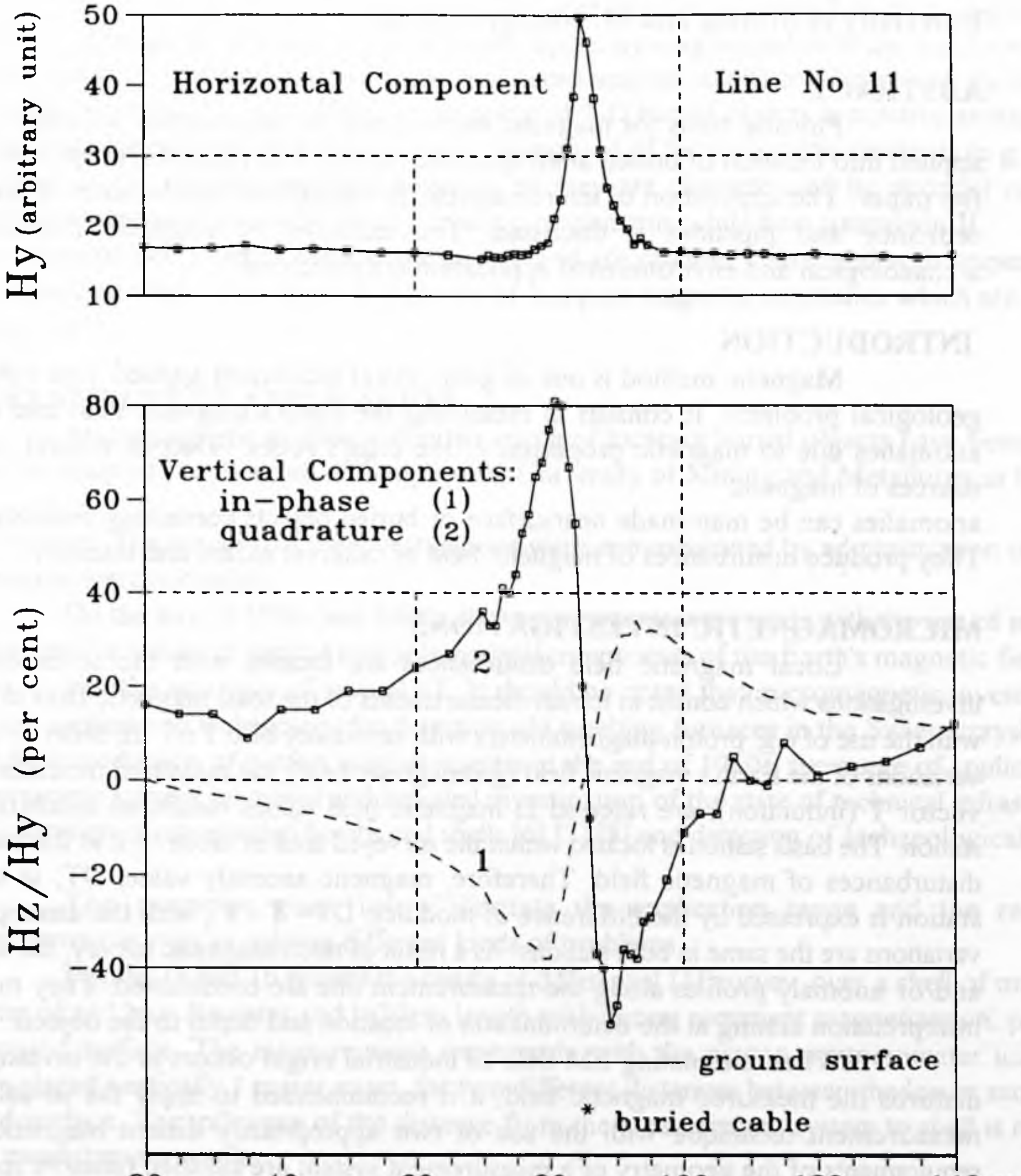


Fig.6. VLF electromagnetic field anomalies over buried cable feeding a TV relay station.



MAGNETIC METHODS FOR UNDERGROUND RECOGNITION AND LOCATION

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ABSTRACT

Physical basis for magnetic method and the peculiarities of micromagnetic survey applied into location of buried anthropogenic objects with magnetic properties are presented in the paper. The application of micromagnetic investigations into location of buried unexploded ordnance and pipelines is discussed. The examples of magnetic method capability for archaeological and environmental application are presented.

INTRODUCTION

Magnetic method is one of geophysical techniques applied into solution of different geological problems. It consists in measuring the Earth's magnetic field and determination of anomalies due to magnetic properties of the crust's rocks. Despite natural existing ones, the sources of magnetic anomalies can be man-made nearsurface or buried objects containing ferromagnetic elements. They produce disturbances of magnetic field of different extent and intensity.

MICROMAGNETIC INVESTIGATIONS

Local magnetic field disturbances are located with the so-called micromagnetic investigations which consist in terrain measurements of the total magnetic field in chosen fine-grid with the use of e.g. proton magnetometers with sensitivity of 0.1 nT. In order to eliminate diurnal variations of the Earth's magnetic field (geomagnetic field), the measured modules of the total-field vector T (induction), are referred to magnetic field values measured synchronously in a basis station. The basis station is located within the surveyed area or close to it at the site free from local disturbances of magnetic field. Therefore, magnetic anomaly value, DT, in the measurement station is expressed by the difference of modules, DT= T - T , with the assumption that diurnal variations are the same in both stations. As a result of micromagnetic survey, the DT anomaly map and/or anomaly profiles along the measurement line are constructed. They make the basis for interpretation aiming at the determination of location and depth to the objects.

When alternating EM field of industrial origin occurs in the investigated area and it disturbs the measured magnetic field, it is recommended to apply the so-called "differential" measurement technique with the use of two appropriately distant magnetic sensors. If the requirements of the geometry of a measurement system are satisfied (sensors spacing: 1/10 - 1/5 of predicted depth to the investigated object; [1]), magnetic field gradients in arbitrary direction can be measured. Generally, vertical gradient, dT/dz, is measured, rarely horizontal gradient, dT/dx, with the use of the so-called gradiometers for measuring gradients of the geomagnetic field. When applying two sensors to measure magnetic field, the resolution of the method is increased, the level of industrial noise decreases, and the Earth's magnetic field variations are eliminated as well as possible regional field which can be related to geological structure of the investigated area. The penetration depth of micromagnetic investigations depends on magnetic properties, the size and depth of the object as well as on sensitivity of measuring instrument. Usually, the depth of penetration does not exceed a few dozen metres. The penetration depth is smaller when applying gradient technique. This especially applies to locating objects with poor magnetic properties.

THE EFFECT OF MAGNETIZATION INTENSITY ON MAGNETIC ANOMALY PATTERN

The vector of magnetization intensity is the basic parameter characterizing magnetic properties of a medium. It defines the medium's capability for generating its own magnetic field in the form of magnetic anomalies. When buried objects are magnetized with the Earth's magnetic field, the direction of magnetization (called an induced magnetization) coincides with the direction of this field. Therefore, at our latitude, the response of 3-D buried objects is positive anomaly with adjoning negative northern anomaly. Objects composed of ferromagnetic elements (e.g. steal or iron) have more complex magnetic response as they are characterized by stronger remanent magnetization generated mostly during creation of elements while heat treatment. If those elements occur under the Earth's surface and are randomly arranged with respect to the Earth's magnetic field, they make the source of complex magnetic anomalies which are difficult to recognize [2].

THE EXAMPLES OF APPLICATION

Micromagnetic studies within the scope of locating buried objects have been carried out by the team of the Institute of Geophysics, University of Mining and Metallurgy in Cracow, for over 35 years. The majority of the investigations were commissioned by administration units and their results were not public.

On the turn of 1950s and 1960s, the measurements were made with the use of magnetic balance; relative values of vertical and/or horizontal components of the Earth's magnetic field were measured with the accuracy of several nT. It should be noted that micromagnetic investigations were also applied into archaeology for detection old smelting furnaces in the Swietokrzyskie Mts. [3]. After introduction of proton magnetometers at the end of 1960s, the range of application of micromagnetic surveys increased and included investigation of the state of technical infrastructure [4],[5], location of unexploded bombs and shells [6],[7],[8] ~~and~~ detection of archaeological objects [9].

The examples given below illustrate the application range and the results of micromagnetic survey in solving different kinds of problems.

Figures 1a and 1b present the results of differential DT survey over a shell of maximum diameter of a=12cm diameter and l=30cm length with strong remanent magnetization, placed at the ground surface. The measurements were made with the proton magnetometer using two sensors placed vertically 1 meter apart, for two different distances between the lower sensor and ground surface. The influence of the distance from the measurement system to shell is reflected in the measurement results.

The results of computer modelling over the shell performed using the KARO program [10], are given in figs. 2,3.

The results of micromagnetic investigations in order to locate unexploded shell at the flood terrace of the Dunajec river [8] are presented in fig.4. The pattern of DT contours implies the presence of a spherical object with strong remanent magnetization. The measurements were taken in 1 x 1 m grid; the height to the sensor was 1 m. The depth to the object's center was estimated at about 2 m.

Fig.5 presents the results of micromagnetic investigation to locate reinforced sewer pipe. The measurements were made along lines, 2m apart, perpendicular to the assumed pipe course. Measurement step was 1m. The results show different strong remanent magnetization of elements of the reinforcement.

The results of investigation over the objects and containing ferromagnetic elements located in the area of 1m are presented in fig.6. The objects were taken from the Zakrzewo burial ground of the Przeworsk culture. The height to the sensor was 1,2 m.

The application of magnetic studies into environmental protection issues should also be noted [11]. The survey involves the measurement of magnetic susceptibility with the use of special field and laboratory equipment. The in situ measurements of magnetic susceptibility of soils, river, lake and sea-bed sediments, suspended sediments and dust etc. are taken. Since industrial air pollutants contain ferromagnetic elements [12] which get into the soil and increase its magnetic properties, the pollution migration can be monitored by taking measurements of magnetic susceptibility of the soils.

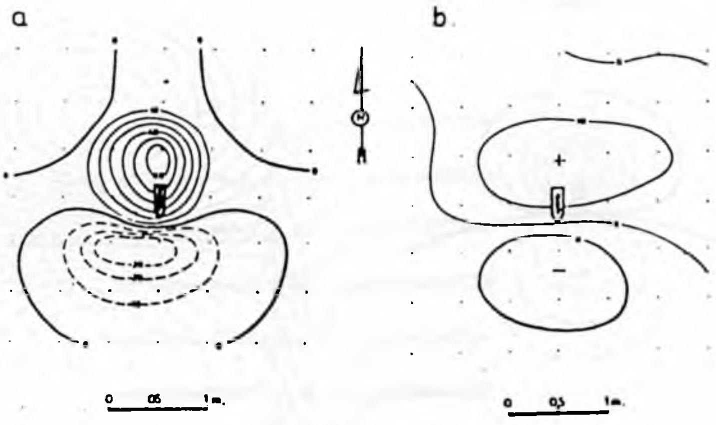

Fig.1. The results of differential field measurements of DT over a shell (according to A.Koblanski [7]).
Explanations: a) h=0,5m, isoline interval 10nT/m, b) h=1,3m, isoline interval 5nT/m.

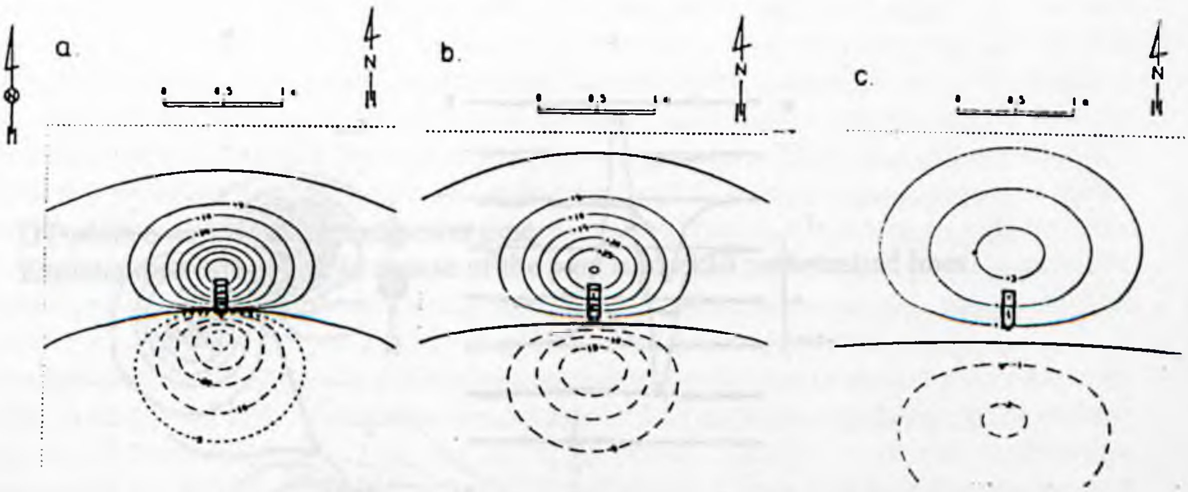

Fig.2. The results of computer modelling over a shell (differential DT, gradient of DT). Explanations: Model's parameters: dimensions of the shell as above, resultant magnetization intensity 32 A/m, the angle of magnetization i=173 , inclination of the Earth's field I=65 , a) Differential values DT, h=0,5m, Dh=1m, isoline interval 10nT/m, b) Vertical gradient of DT calculated for h=1m, isoline interval 5nT/m, c) vertical gradient of DT calculated for h=1,75m, isoline interval 1nT/m.

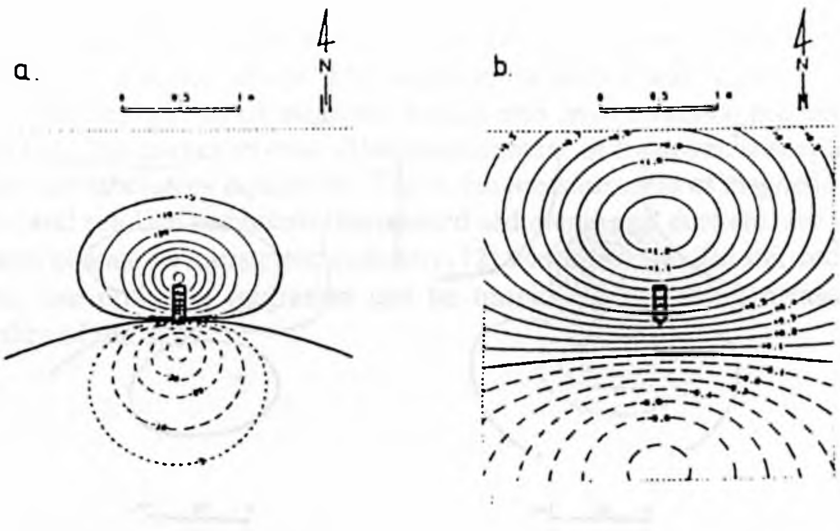

Fig.3. The results of magnetic effect, DT, modelling over a shell for different distances, h, to the sensor. Explanations: a) h=0,5m, isoline interval 10nT, b) h=2m, isoline interval 0,1nT.

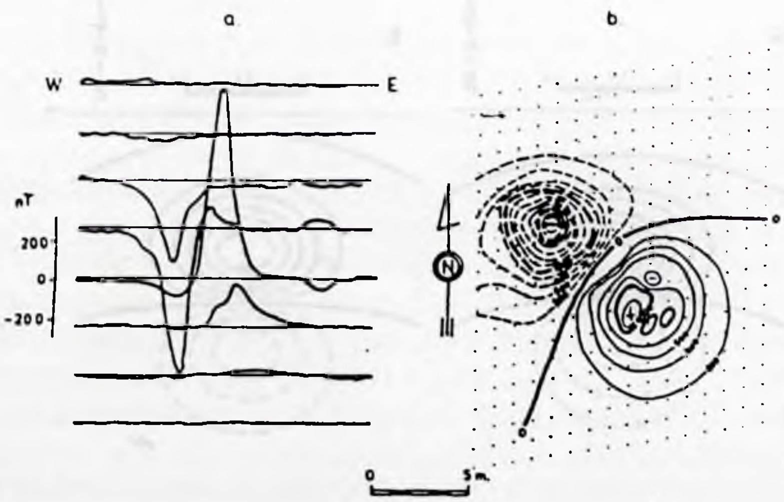

Fig.4. DT anomalies over an unexploded shell (Dunajec river area [8]).
Explanations: a) DT plots, b) map of the DT anomalies, isoline interval 200nT.

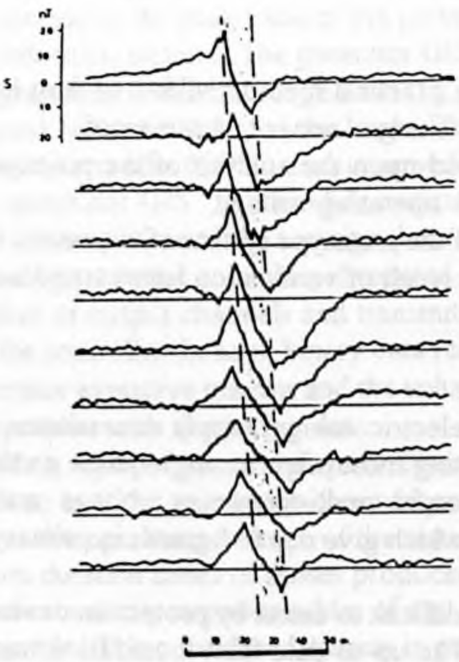

Fig.5. DT plots over the reinforced sewer pipe.
Explanations: the probable course of the pipe is marked with dashed lines.

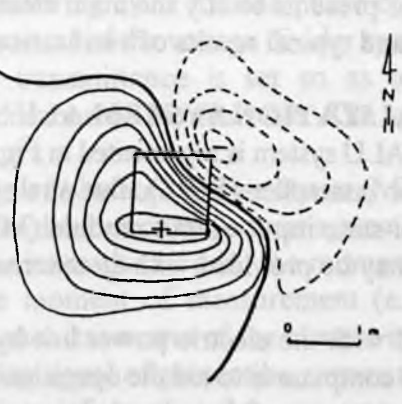

Fig.6. Measurements at the area of 1 m over the objects from a grave of the Zakrzewo burial ground, the Przemysl culture. The height to the probe was 120 cm.

AUTO-FAULT-LOCALIZATION IN MV CABLES

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SUMMARY

The realisation of a practical method MIS-1 of fault localization in medium voltage (MV) underground cable lines being in service, is presented.

This method is based upon the analysis of the propagation of single voltage pulses synchronized with the network operating voltage.

The main element of the prototype system of automatic fault localization (ALU) using the MIS-1 method as well as a result of verification tests carried out in actual MV networks, are considered.

GENERAL

The reliability of electric energy supply necessitates a rapid localization of faults appearing in MV lines, consisting most often in single-phase earth faults (about 80% of faults). These are accompanied by rapid multi-frequency voltage and current transients, causing overvoltages and overcurrents which give rise to hazards in primary as well as secondary circuits [1,2,3].

The latter faults are difficult to detect by protection devices adjusted to react to steady-state earth-fault magnitudes. The up-to-date fault localization methods require, in general, the switching-off of the line or of a fraction of the network. The preliminary as well as the precise localizations are carried out, as a rule, after the fault appearance and the flow of the short-circuit current [4,5,6,7,8].

Recently, a method as well as a computer aided system of remote automatic fault localization in underground cable lines being in normal service, without outages, has been developed [2,6]. This is a single very-short pulse method (MIS-1) which consists in analysing the propagation of suitably-shaped very-short single pulses superimposed on and synchronized with the power frequency (50 Hz) network operating voltage [1,2]. Applying the ways and means of the classic as well as digital reflectometry, the distance between the point of pulse injection and the point of fault is determined by calculating the time of pulse propagation with the use of either direct or differential measurements (Fig.1) [5,6,8].

In his report the author presents briefly the main elements of the prototype automatic fault-localization system (ALU) and typical results of verification tests.

AUTOMATIC FAULT-LOCALIZATION SYSTEM ALU

The block diagram of ALU system is represented in Fig.2. It is composed of: very-short pulse generator (GIS), generator controller (SGIS), fast analog-to-digital converter (SPA/C), microprocessor system (SµP), bi-state input-output module (MDW) and display and keyboard module. In addition, the system may be provided with an external computer of the PC class or a NOTEBOOK.

The system is coupled with the electric power line by the intermediary of a coupling system (US). The main task of the computer is to aid the operation of the ALU system. Moreover, the computer may be used for the storage of the recorded magnitudes.

The very-short pulse generator (GIS) is to produce voltage pulses of predetermined duration and peak value.

The tests carried out, as yet, show that for determining precisely the point of the fault on the line it is necessary to test the latter with pulses of different duration. The fault localization is the more precise the smaller is the width of the pulse. However, narrow pulses are not applicable for fault finding at large distances (over a few kilometers) because of their small energy. The increase of energy by increasing the peak value of the pulse is limited, however, by the capabilities of solid-states (semiconductors) systems. The generator GIS, applied in the ALU system, produces pulses of duration programmed within the range from 0.2 µs to 4.8 µs in nine steps, slope time of about 15 ns and the peak value of 400 V at the load of 30 Ω.

The generator controller (SGIS) is an intermediary circuit between the microprocessor system (SµP) and the generator GIS. This module comprises also a programmed voltage divider which is to attenuate the amplitude of the test signal on the generator output to a level at which the operation of the analog-to-digital converter is secured. Operating parameters of the generator (pulse duration, number of output channels and transmittance of the voltage divider) are loaded by the processor into the controller. In turn, binary data read by the microprocessor system (SµP) are loaded by the generator executive systems and the voltage divider into suitable registers for the purpose of their comparison with the output data.

The coupling system is a high-pass filter of LC type of amplitude/frequency characteristic adjusted so as to let pass test pulses without distortion and to isolate efficiently the measuring circuit from the operating voltage of the tested line.

At minimum duration times of pulses produced by the generator amounting to 200 ns and at a pulse propagation velocity in power cables of e.g. 180 m/µs, fault localization at distances below 20 m is impossible. The considered system is provided with a delay line giving a delay equalling at least one half of the minimum width of the pulse produced by the generator.

The analog-to-digital converter (PA/C) is the most important component of the measuring system. Its resolution and maximum conversion frequency are decisive for the applicability of the system ALU in the diagnostics of electric power lines. The minimum distance which can be determined by measuring time of pulse propagation in the line is directly proportional to the conversion frequency. The system ALU is provided with 10-bit analog-to-decimal converter with a maximum conversion frequency of 40 MHz cooperating with a buffer memory. The minimum size of the buffer memory is determined basing on the line length, the time of pulse propagation in the line and the conversion frequency. The considered system is provided with a memory, which size equals to 8 k 16-bit words. After ending measurements, the stored data are automatically transmitted to the operating memory of the microprocessor system.

The full measuring cycle for one phase of the line requires several measurements (3 pulse widths, 3 transmittances of the voltage divider system). In order to economise the processor memory, the divider transmittance is set so as to render possible a correct localization independently of the distance of the fault site. The system ALU may locate faults in lines of a length up to 25 km.

The module of bi-state inputs-outputs (MDW) serves for the communication of the locator with automation devices of the power system protection. As tests are carried out on the line at programmed time intervals (10 min) the moment of appearance of an actual line fault may fail to meet with the moment of measurement (e.g. in the case of intermittent faults). In consequence, to avoid such cases one of the bi-state inputs serves for initiating the measurement by means of the activating signal of protection automation. Moreover, one output can be used by the monitoring system to inform that the processor memory is full. All inputs and outputs are galvanically isolated from voltages of the locator.

The microprocessor system (SµP) uses an 8-bit single-circuit microprocessor provided with an additional 512 kB data memory. The processor supervises, in conformity with the provided program, the course of measurements (calculates the distance to the point of fault, stores the measuring data in memory, transmits results to the display module). The SμP stores the measuring data from five measurements. After the memory is full, the appropiated message is displayed on the screen. The processor module is provided also with a serial transmission system for communication with an external computer.

The programming of the ALU system or, in other words, the precising of output data (the time of pulse propagation in line, the generator parameters, the voltage divider transmittance, the number of measurements made on a given line, etc.) can be carried out by means of the system keyboard or by means of an external computer.

VERIFICATION TESTS

The verification tests by means of the ALU system were carried out in several cable networks: urban, electric power station auxiliary, mining and underground cable/overhead distribution network. Their configuration and kind of fault were changed. Metallic and resistance faults as well as a break in the line continuity were considered. Both the direct and the differential methods were used. The analysis of numerous reflectograms gained by oscillographic redcording and digital processing confirmed the applicability of the MIS-1 method to a remote precise detection of the considered faults. Typical reflectograms gained from network field tests, using both the direct and the differential methods, are represented in Fig.3.

The correctness of the method MIS-1 (published already in 1986 [1]) was additionally confirmed by tests concerning a locator of faults in single high-voltage overhead lines [9].

CONCLUSIONS

The ALU system applying the method MIS-1 is intended for automatic remote localization of distinct changes of local impedances, i.e. of changes which maintain permanent or quasi-permanent properties during a given time. These may cover the following disturbances or transverse and longitudinal changes of state: assymetric faults (includic the most frequent single-phase earth faults), symmetric faults of resistance and metallic nature or breaks in the continuity of connections and changes of the position of switches.

The ALU system may cooperate with very fast protection systems (automatic measurement and localization in real time) as well as fulfill the function of permanent or periodical active diagnostic of MV networks, detecting faults, e.g. at the initial stage of their development (resistance faults), and supervising the network (check of the position of switches).

Tests carried out by means of the direct method in actual network [1,2,6] as well as design works concerning the computer-aided method MIS-1 allow to conclude:

1. The direct method can be useful for a theoretical analysis of the propagation of voltage pulses in networks, while the differential one - for a precise localization of faults.
2. The developed microprocessor control/measuring system allows for an automatic analysis of the results of reflectometric measurements.
3. The applicability of the prototype system of automatic fault localization using the method MIS-1 has been verified by measurements carried out in different MV networks.

LITERATURE

1. Anderson E., Maziarz S.: Nowa metoda zdalnej lokalizacji uszkodzeń i diagnostyki stanu sieci średniego napięcia. Energetyka 1986, nr 1 (Biul. Instytutu Energetyki)
2. Anderson E. i inni: Méthode de localisation automatique et à distance des défauts et surveillance de l'état des réseaux à moyenne tension. Les annales de l'ENIT (Tunis) 1990, nr 1

3. Anderson E., Maziarz S. i inni: Badania wybranych charakterystyk elektrycznych w liniach kablowych średniego napięcia. Energetyka 1993, nr 7 (Biul. Instytutu Energetyki)
4. Cieślewicz K.: Zdalna lokalizacja zwarć w rozgałęzionych sieciach elektromagnetycznych spełniająca funkcję zabezpieczenia. Archiwum Energetyki 1987, nr 3-4
5. Hubin H.: Recherche de défauts sur câbles d'énergie. EYROLLES, Paris 1987, 2 édition
6. Maziarz S.: Zdalna automatyczna lokalizacja uszkodzeń w sieciach średnich napięć metodą impulsów szpilkowych pojedynczych. Energetyka 1994, nr 6 (Biul. Instytutu Energetyki)
7. Rijanto H., Beck R.: Fehlerortung in Mittelspannungsnetzen aus der gespeicherten Kurzschlussimpedanzgrosse von Distanzshutzeinrichtungen mit Mikrorechnern. Elektrizität swirtschaft 1988, nr 4
8. Szczerski R.: Lokalizacja uszkodzeń w sieciach elektroenergetycznych, WNT, Warszawa 1990
9. Sikorski Z., Kolenda C., Lipka S.: Mikrokomputerowy impulsowy system lokalizacji uszkodzeń napowietrznych linii elektroenergetycznych wysokiego napięcia. Energetyka 1991, nr 6

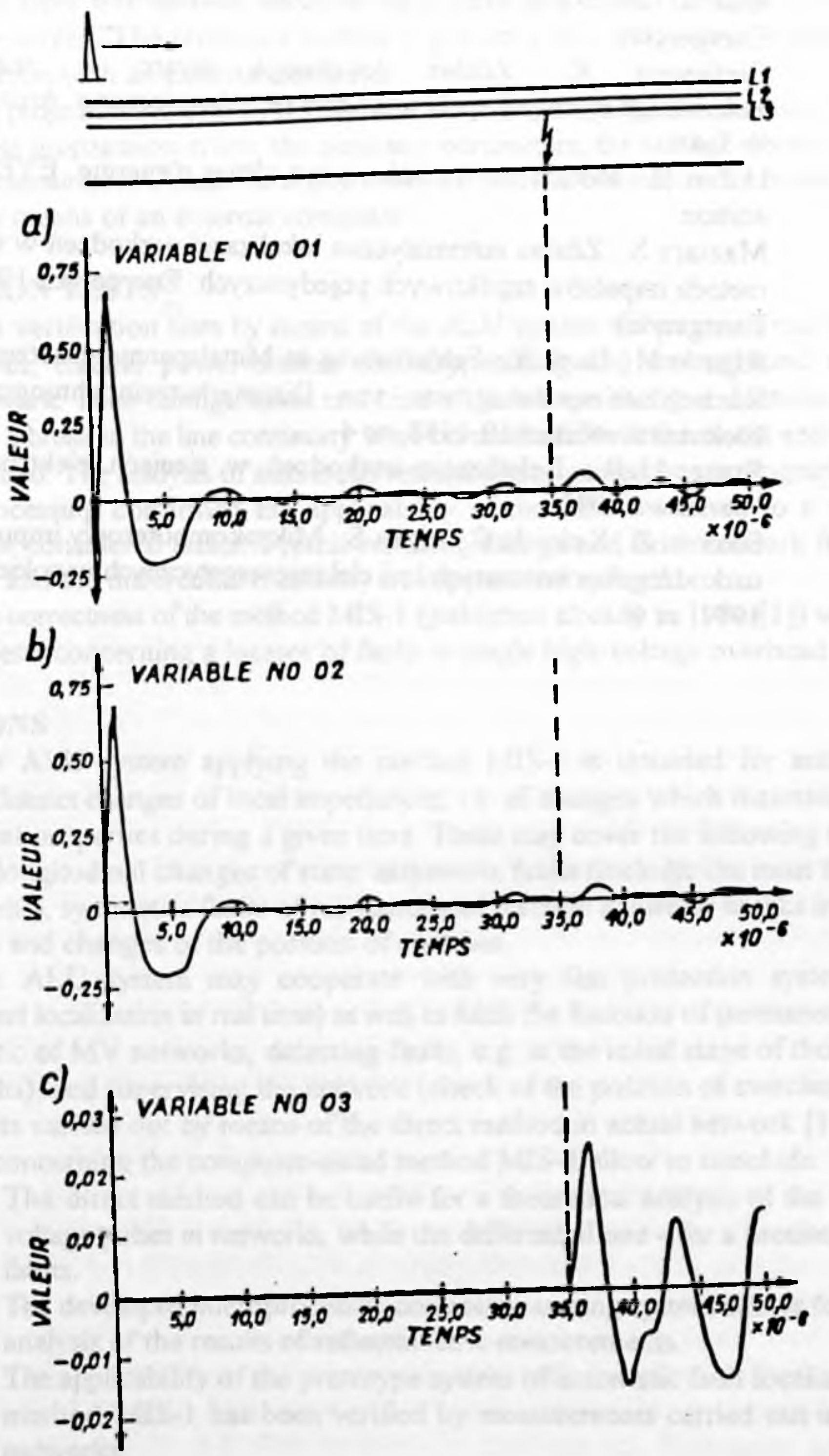
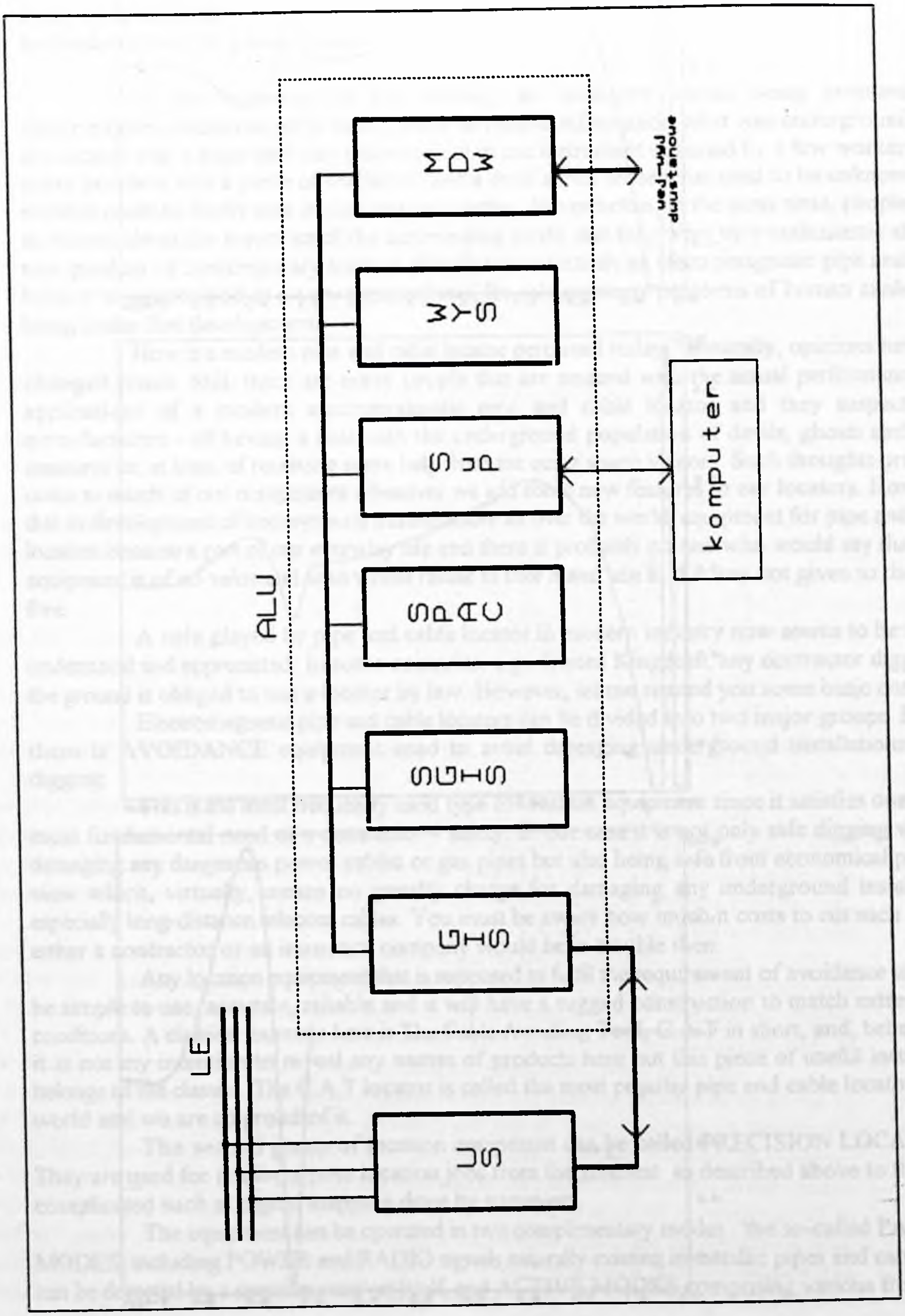
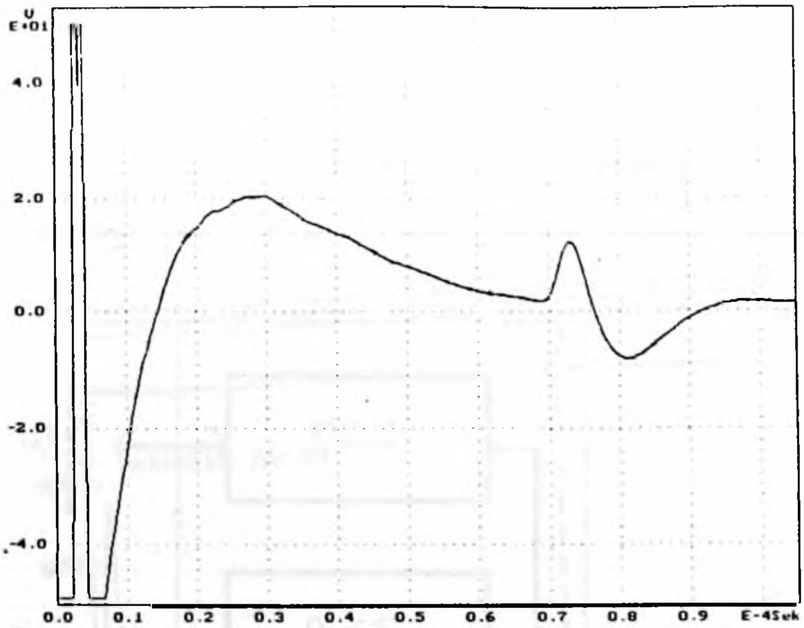


Fig. 1. Reflectometric measurements, mathematical modelling - program EMTP: a) the direct method - no fault, b) the direct method with a fault, c) differential method.

Fig. 2. Block diagram of the ALU system

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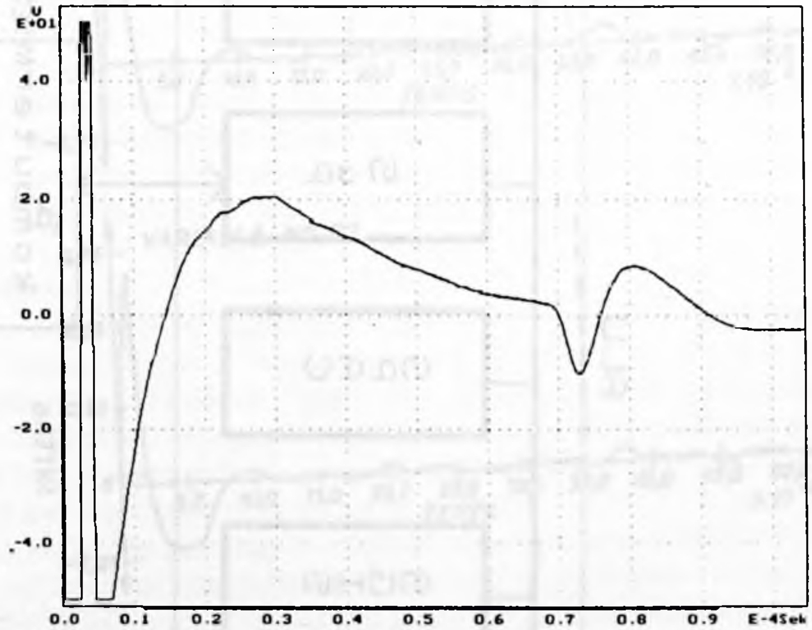
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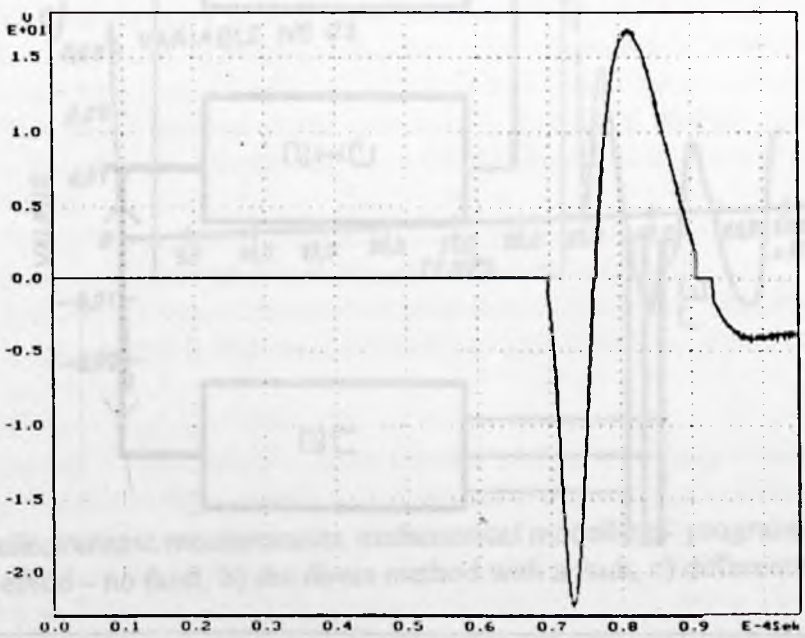
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PIPE AND CABLE LOCATORS FOR NO-DIG TECHNOLOGY

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At the beginning of this century, an intelligent human being invented first electromagnetic locator to get at least a piece of reliable information what was underground. The first locator was a huge and very inconvenient in use instrument operated by a few workers. For many people it was a piece of witchcraft and a devil's trick since what used to be unknown and invisible could be finally seen in one way or another. Nevertheless, at the same time, people were so curious about the mysteries of the surrounding world that they were very enthusiastic about a new product of contemporary science. Slowly but constantly an electromagnetic pipe and cable locator was perceived as a very practical tool for solving many problems of human civilisation being under fast development.

How is a modern pipe and cable locator perceived today ? Basically, opinions have not changed much. Still, there are many people that are amazed with the actual performance and applications of a modern electromagnetic pipe and cable locator and they suspect us - manufacturers - of having a deal with the underground population of devils, ghosts and other creatures or, at least, of receiving some help from the outer space visitors. Such thoughts probably come to minds of our competitors whenever we add some new features to our locators. However, due to development of underground infrastructure all over the world, equipment for pipe and cable location became a part of our everyday life and there is probably no one who would say that such equipment is of no value and who would refuse to take it and use it, if it was not given to them for free.

A role played by pipe and cable locator in modern industry now seems to be widely understood and appreciated. In some countries, e.g., United Kingdom, any contractor digging in the ground is obliged to use a locator by law. However, let me remind you some basic concepts.

Electromagnetic pipe and cable locators can be divided into two major groups. First of them is AVOIDANCE equipment used to avoid damaging underground installations while digging.

This is the most frequently used type of location equipment since it satisfies one of the most fundamental need of a contractor - safety. In our case it is not only safe digging without damaging any dangerous power cables or gas pipes but also being safe from economical point of view which, virtually, means no penalty charge for damaging any underground installation, especially long-distance telecom cables. You must be aware how much it costs to cut such cable - either a contractor or an insurance company would be in trouble then.

Any location equipment that is supposed to fulfil the requirement of avoidance tool will be simple to use, accurate, reliable and it will have a rugged construction to match extreme site conditions. A classical example here is The Cable Avoiding Tool, C.A.T in short, and, believe me, it is not my intention to reveal any names of products here but this piece of useful instrument belongs to the classics. The C.A.T locator is called the most popular pipe and cable locator in the world and we are so proud of it.

The second group of location equipment can be called PRECISION LOCATORS. They are used for multi-purpose location jobs from the simplest as described above to the most complicated such as digital mapping done by surveyors.

The equipment can be operated in two complimentary modes : the so-called PASSIVE MODES, including POWER and RADIO signals naturally existing in metallic pipes and cables that can be detected by a sensitive receiver itself, and ACTIVE MODES comprising various frequency signals applied to underground installations from a transmitter or a transmitting sonde. The selection of frequencies depends on a manufacturer's choice which in our case is realised in the preferred 512 Hz or 640 Hz, 8 kHz and 33 kHz.

Trenchless Technology, the primary concern of this short speech, requires a simpler but, at the same time, more precise and dedicated approach to the problem of pipe and cable location.

The simple aspect of the case is such that, in fact, it is enough for a NO-DIG contractor to use only one type of precision locator to fulfil all the requirements.

Example:

The simplest Trenchless job is probably a road crossing with the use of a non-steereable pneumatic mole. In what way can one use a pipe and cable locator then?

1. Prior to the job itself, one should be given a map of a given area with all the underground installations indicated which, in fact, requires somebody's hard work - normally this part of the job belongs to a surveyor equipped with a high quality precision locator.
2. In order to do the job safely and with no extra cost concerned with damaging any pipe or cable being on the route of a drilling machine, one should plan one's job carefully paying a lot of attention to location of both launch and receive pits as well as the route and depth of any nearby utility lines. Therefore, what one has to do is a) to use a pipe and cable locator and check the places where the pits will be located since even a simple spade-digging can make a power cable explode; and b) to use the locator for pin-pointing all the utilities and taking their precise depth measurements since it is often the case that one has to launch the pneumatic mole just between two pipes or cables being on different depths.
3. In order to monitor the progress of the mole underground, one needs to install a self-powered sonde at the head or just after the head and to take all the necessary readings of position and depth in a very simple operation. In case one loses the impact head, it is usually enough to thread a small sonde down the air hose, energise it with the locating transmitter and detect it on the surface with the use of a precision locator.

What the above example is supposed to prove is that a typical NO-DIG job requires a good quality pipe and cable locator. In fact, it is not so difficult to find an universal one that does all the job and still, it is not very expensive. If you want my advice which type of locator you need, I am at your service when I am off the stage since it is not the purpose of this presentation to advertise any particular product.

A more complex aspect of pipe and cable location for Trenchless Technology comes with steereable drilling. It is not enough to use a pipe and cable locator alone - one needs another complimentary tool - a sophisticated sonde. It is the sonde that gives the electromagnetic location another dimension - a new type of information to be carried.

Up to the point of the sonde application, we approach a situation very similar to the use of an electromagnetic locator for non-steereable impact moles - one has to use a location equipment to start and precede the job properly. However, it is the sonde that gives all the necessary information enabling actual steering of the drilling rig. Except traditional features such as accurate depth measurement, the sonde can provide us with a continuous roll angle readings of 360 Degrees in 16 steps and tilt up or down readings in 18 steps, all of them with the drilling head in continuous operation. Moreover, a temperature sensor will alarm when the temperature of the sonde exceeds 50 Degrees C and, eventually, due to danger of overheating the drilling head, it will switch the sonde off at a certain temperature level. The type of information indicated above combined with some less important messages obtainable from a locator can be immediately transmitted to an operator of the drilling rig as the core information that enables horizontal steereable drilling.

You may ask how far is the most recent steereable drilling technology from traditional electromagnetic location. One would be surprised how interrelated they are. If we consider all the examples discussed above, it seems clear that the very idea of a sonde being detected by a receiver comes from a general purpose electromagnetic location. Moreover, a good NO-DIG sonde locator providing accurate information on position and state of a drilling head - factors determining successful steereable drilling - can be an excellent pipe and cable locator at the same time.

The purpose of this short presentation was not a detailed comparison of various available methods of pipe and cable location such as using georadars vs. electromagnetic locators. Neither was it a detailed analysis of location equipment available today and their possible applications for NO-DIG technology. In fact, it was only a not very formal discussion on the present-day role of electromagnetic pipe and cable locators for any user of NO-DIG equipment. This role cannot be underestimated since, if we review any type of Trenchless job, we would find an application of a location equipment there. What is more, some of the jobs are totally dependant on the result of prior using of a locator.

The good news for NO-DIG contractors is that , since they have to use a pipe and cable locator, they will find it very easy to find one. There are a few good locators available on the market that would meet all the requirements of Trenchless Technology. The not-so good news is that what the contractors need is a precision locator. There is nothing wrong with a precision locator itself - the point is that it is a little more expensive than any present-day pipe and cable locator designed for AVOIDANCE purposes and no one wants to spend more money if it is not necessary. However, if we look at the problem from another dimension and we would say that NO-DIG business requires precision and only a precision equipment guarantees success, this sort of problem does not exist at all.

We would recommend various pieces of equipment you would be satisfied with but there is one thing that should be stressed once again : for most of NO-DIG type of jobs there is no need to search for a purpose-designed location equipment - good quality precision locators are currently available on the market. Only for some type on No-DIG jobs one requires special sondes and locators which, regardless their being HI-TECH and sophisticated pieces of equipment, use many approved and appreciated features of standard electromagnetic pipe and cable locators that have been in use for many years.

A METHOD FOR THE RENOVATION OF SEWAGE PIPELINES WITH THE USE OF HIGH-DENSITY POLYETHYLENE SURE GRIP® RELINING

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SUMMARY

There are a large number of pipelines of various age and from diverse materials in fairly poor technical condition all over the world. In the time of growing pressure for reduced costs experienced by the sewerage system maintenance firms, the expedient pipe replacement can increasingly be more difficult to finance. The situation has resulted in giving preference to the trenchless repair and rehabilitation techniques.

The methods that involve the use of fitting high-density polyethylene (PEHD) anchor-stud linings have found wide acceptance. One of such methods is the Sure Grip® Relining technique described below. Because of the system employed the Sure Grip® Relining method is a straightforward and economically sound approach to a trenchless repair of damaged sewerage pipes of just any cross section. Polyethylene, of which the lining is made, is environmentally friendly and at the same time it is featured by a high chemical resistance, mechanical strength and exhibits excellent hydraulic properties. In the method described the whole inner surface of the old pipe is repaired; in other words, after the operation no "weak points" no longer occur in the entire system, like a leak in a pipe joint which also in the case of new pipes is an element of uncertainty. In the method described the static load capacity is restored to the pipe under repair, owing to which restoration of the old pipeline can be avoided. The anchor studs of special design ensure high safety in the case of groundwater. The machines and labour required are insignificant. Hence, on numerous occasions the method is an economically sound approach.

INTRODUCTION

Pipelines undergo ageing and corrosion processes all the world over. Leaky pipe joints, cracks, etc. pose a threat to the natural environment. Whenever detected, the pipeline has to be urgently repaired or reconditioned. A significant objective for the environmental protection is the elimination of this potential hazard. Billions of cubic metres of sewage, partly highly loaded with hazardous material, make their way to groundwater each year.

As a rule renovation of municipal sewers of large diameters (above 500 mm) is associated with high costs. Additionally, the sewers run often below communication routes. For the most part these are concrete pipelines, also reinforced-concrete or brickwork ones. A threat to their proper functioning are high static loads, corrosion and incorrect structure. The data on the percentage of damaged pipelines are usually incomplete and do not reflect the actual state of affairs. The damage of the type listed below occur separately or jointly:

- Cracking and/or ruptures
- Leaks
- Obstruction to flow
- Corrosion
- Displacements
- Deformation
- Falls
- Cracks of pipeline.

The conventional trench-opening replacement of pipelines is expensive, laborious, noisy and usually connected with serious disruptions of the traffic. Because of the long cycle of the repair project, breaks in pipeline use and arduous drainage work take much time. An added problem is the removal of the material of the old sewer and its surrounding soil which, upon long service, are strongly contaminated and often have to be treated as hazardous waste. As a result, the work cycle becomes longer or a more cost-favourable variant has to be chosen, which resolves itself into indispensable repairs of the damaged spots alone. Considering the foregoing the Sure Grip® Relining technique has been developed.

THE METHOD

The trenchless renovation method with the use of PEHD anchor stud relining has been devised and worked out in recent years. One of its variants is the renovation technique described here, known as Sure Grip® Relining, which has in practice been used to advantage in renovation of large-diameter pipelines since 1988. The method has been devised by the Austrian AGRU Kunststofftechnik on the basis of year-long practical experience in the area of acid-protection and development of waste landfills. For the first time the method was implemented in France in Paris. Upon renovating first the trunk sewers in the early '90s, on the basis of the results gathered the method was extended over smaller-diameter sewers (above 250 mm). For this range the relining is factory-made for the entire section, then it is fitted in place. Thanks to the simplicity of the Sure Grip® Lining method the latter is a rapid and economically sound approach to the trenchless renovation of water supply and sewage disposal pipelines. The advantages of the trenchless rehabilitation by means of the Sure Grip® Liner are of significance not only to the users but likewise to the owners of the estate adjacent to the pipeline to be repaired, in view of the fact that excavation methods quite often represent a serious harassment to them. In general the following advantages can be pointed out:

- Essentially no excavation work
- Short time required for the work
- Cost saving
- Minimum traffic disruptions
- No noise
- Durable renovation effects
- Improved statics thanks to multiple-layer structure
- High chemical and mechanical resistance that result in prolonged service life
- Improved hydraulic properties and extended maintenance intervals thanks to the smoothness of the material surface
- Applicable to every shape of cross section.

THE MATERIAL

Sure Grip® Liner is made of polyethylene. Depending on the diameter range and the minimal wall thickness required, the liner can be made from various moulding compounds. In selecting the material, next to chemical resistance, abrasion-resistance, proper stability and permeation resistance, of signficance area also flexibility of the liner (which is temperature dependent) and deformability under internal pressure (during filling up). Routinely for diameter range from 250 to 450 mm PELD (low-density polyethylene) is used and the liner thickness of 2.5 mm, as for small cross-sections a higher flexibility is needed to ensure correct recovery of the liner shape. The Sure-Grip® Liner for the diameter range of 500 to 800 mm is made of high-density polyethylene (PEHD) with a melt flow rate (MFR) of 010 group (earlier also medium-density polyethylene PEMD was also used for the purpose); layer thickness of 3 mm. For larger diameters more rigid moulding compounds are used: PEHD, optionally polypropylene type 3 (PP-R) and greater liner thicknesses to increase self-stability of the liner. One of the major qualities of polyethylene is its excellent abrasion resistance (cf. Fig. 1), owing to which the service life of the pipeline is increased and settling of deposits is reduced. Increased durability results in reduced net costs of the project.

Lower deposits settled result in reduced number of maintenance operations (cleaning the sewers or pipelines). This is equivalent to reduced running costs of pipeline operation. Inspection tests carried out with a TV camera under the maintenance operations necessitate the liner material be possibly of a light colour, which aids in locating possible faults and damaged spots in the liner. For this reason the Sure-Grip® Liner is typically supplied in a light, yellow colour. At request the liner can be made in white colour or transparent. The transparent variety has an added advantage of possible check on how the perimeter gap has been filled.

All the liners are manufactured from the same grade moulding compounds. The high quality of the finished product is due to a permanent external and internal supervision. The quality may be documented with certificates from acceptance tests after DIN 50049 or EN 10204 3.1.

THE LINER

The anchor-stud sheets manufactured by a continuous process are made to the required liner size (its length and perimeter) at the factory. Particular attention is paid to the welding of the Sure-Grip® Liner into a sleeve and the connections carried out at the site, as the quality of the welds is a condition for tightness and durability in service. At the manufacturer's site the Sure-Grip® Liner is joined by hot wedge welding (in conformity with the DVS 2225, Part 1 recommendations) upon previous tight fitting of its edge to the pipe diameter. A significant advantage of the method is the presence of a test channel. It allows a check be made at the manufacturer's site after the DVS 2225, Part 2 recommendation (cf. Fig. 2). Results of the tests are gathered in special test certificates to be shown to the customer any time at his request. The spacing of the anchor studs and their extremely high pullout resistance (900 N/stud) and shear resistance (1800 N/stud) guarantee good anchoring in the injected grout. In a range similar to that of the ring stiffness also peak pressure strength of the pipeline increases as the result of the use of the Sure-Grip® Liner. A calculative proof of a combined effect of the entire system is rather hard to give, in view of the unknown value of the residual load-carrying capacity of the old pipeline. The residual load-carrying capacity of the pipeline is often assumed as negligibly small; hence the static loads have to be taken up exclusively by the liner and the injection grout. The foregoing approach cannot be verified in practice, as a thin grouting material also penetrates the crevices and fissures in the old pipe, whereby its improved static load capacity is achieved (cf. also Fig. 4).

Upon completion of the test the liner sleeve up to 100 m long is wound up on reels which, after their protection with protective plastic sheeting, are ready for shipment. The flexible liner, supplied on reels to the site, is introduced into the pipeline to be repaired through the existing inspection shafts by means of a winch.

INJECTION MATERIAL

The ring-shaped gap contained betwen the pipe inner surface and the Sure-Grip® Liner is filled up with a single-component cement setting grout which sets upon completion of the injecting operation. The grout used there should have a viscosity low enough (water/cement ratio of ca. 0.40) and be of a uniform composition to permit easy flow through the ring-shaped gap over a distance of up to 100 m. What is important here it is that the high liquidity be maintained during the entire time of injecting operation. The optimum performance for the case at hand (considering pump delivery, ring-shaped gap volume and the ambient temperature) can be achieved by selecting a suitable water/cement ratio. After stirring the grout is being injected under a small hydrostatic pressure (p = ca. 0.4 bar). Upon completion of the injecting operation quick setting and the resultant high strengths are required. The reaction and setting times for the grout depends, as a rule, on the temperature, so that by varying the temperature the grout properties can be modified. For instance the reaction time can be accelerated by filling up the liner sleeve with lukewarm (max. 35°C) water.

The grout on setting should neither shrink not swell excessively and should be neutral to the environment, that is, it must not pose a hazard to groundwater. When injecting the grout with groundwater present no tendency to decay of the grout mixture should occur. Otherwise, no correct filling of the ring-shape gap can be guaranteed. The prime objective of the grout is to form a tight connection between the existing sewer and the liner introduced. Leaky pipe joints, cracks and crevices in the old pipe are sealed by the grout. The washed-out sand bed or cavities formed in those areas resulting, e.g. from an outflow, can be sealed off owing to the high fluidity of the grout. The supporting effect of the grout reduces any possible displacement of the pipe caused by external factors and may aid in the statics of the entire system. The grout between the old pipe and the lining thanks to the rated strengths (depending on the grout type up to 70 N/mm²) can improve the static load capacity, or to increase static safety. The liner anchor studs in conjunction with high-strength grouts make up force-clamped joint, such as those required primarily under groundwater pressure conditions.

THE INSTALLATION

An important condition for the Sure-Grip® relining to be applicable is a preliminary inspection of the sewer. In the case of choked sewers inspection with the help of a TV camera mounted on a movable robot is indispensable. Large obstacles such as: incrustation or overgrowing roots have to be necessarily removed before the repair operation is started so as to make the liner recover its original shape. Contaminants should be removed by means of a high-pressure washing device. The sewer branches of the section under repair should be secured against penetration of the grout by means of pipe bubbles or else sealed off once open. The reel with the wound-up liner of a length matched to the pipeline section repaired is placed by the inspection shaft, then it is introduced directly through the sewer opening by means of a funnel which may be heated if lower ambient temperatures are involved. To do this, the liner end is clamped in the winch head and pulled through into the sewer pipe repaired be means of the winch (fitted on the nearest inspection chamber. The pulling rope runs on rollers or guides (cf. Fig. 3). The clamping of the liner in the head results in a decreased cross section, owing to which the pulling operation proceeds with a lower load to the material. The injecting spouts required to feed the grout into the ring-shaped gap between the liner and the old pipe are inserted at a depth of ca. 20 cm into the space from the lower-lying end of the sewer in the area of the abutment and bottom of the sewer. For oval-shaped cross sections a bigger injection spout is recommended on the bottom side. At the other end a venting pipe is inserted in the abutment area, which facilitates escape of the air from the ring-shaped gap and serves as a check on correct filling on the basis of the outflow of the grout.

The liner sleeve ends are sealed off by means of bubbles secured against slip. Subsequently, the liner sleeve is filled up with water (alternatively with lukewarm water) and placed under an overpressure up to 1.2 bar (usually ca. 0.7 bar). As a result of the pressure inside the liner sleeve, the liner recovers its original shape and, in consequence, adheres to the sewer walls. As the pressure operates inside the liner, an additional leak-proof check is made. The anchor studs situated on the outer side of the liner permit the ring-shaped gap to be of the same thickness along the perimeter. Next, the ring-shaped gap is sealed off with stop grout at both ends. The subsequent operation involves the filling of the ring-shaped gap and of the crevices in the sewer walls with the grout. The Sure-Grip® Liner anchor studs become embedded into the injection material with the formation of a new, tight, polyethylene wall inside the sewer. The grout pressure during the filling operation should be very uniform (typically ca. 0.4 bar) and always definitely lower than the water pressure inside the sleeve. Observance of this condition prevents the liner from being pressed into the grout layer. Hence, the use of an adjustable-pressure pump is recommended. The time required for the injection grout to set varies from ca. 12 to 24 hours and depends on the case in hand. Upon this time water may be let out and the pipe bubbles removed.

Upon removal of the bubbles, drying and cleaning of the liner, necessary welding work is performed after the DVS recommendations. The work is carried out by skilled welders. The surfaces to be welded are cleaned immediately before welding. The sewer should be adequately ventilated to obtain high-quality welding seams, as too high a humidity of the air adversely affects the seam (joint) quality. The extra seams are required in the inspection shaft area to achieve complete relining and elimination of weak points.

CONNECTION TO THE INSPECTION SHAFT

There are various methods of connecting the liner to the inspection shaft. In general it is advisable to line also the shaft and execution of the connection by welding. There are two methods for shaft lining, either involving the use of the Sure-Grip® protection sheets for concrete. To secure an adequate adhesion of the grout to the shaft wall, in either case the shaft wall and bottom should first be thoroughly cleaned.

Variant 1

Some lean concrete of a setting time at least 30 min is applied onto the shaft bottom and levelled out. A disk made of the concrete protection sheet (of a size of the shaft diameter) is pressed into the grout and placed under an even load until set. The factory-precut, and suitably matched to the shaft depth and diameter, Sure-Grip® sheets are recommended for the shaft lining. The ring-shaped gap between the shaft wall and the liner is ca. 2.0 cm. This can be precisely adjusted by means of the spacers placed at the bottom. Subsequently, pipe connections are cut out. At the spots the bottom sheet and shaft pipe are joined to the shaft, the liner is sealed by hot-air welding . Alternatively, a supported wooden ring with a sealant is used. To support the Sure-Grip® Liner so as to carry over the grout pressure, formwork or compressed-air devices are used. Filling the shaft with water is discouraged because of its low specific gravity (the specific gravity of injection grout is ca. 1.9 kg/l). To fill up the ring-shaped gap, a liquid grout is used, whose setting time is ca. 30 min. (the setting time should be longer than the filling time). When set, the shaft is cleaned while the spots to be jointed are extrusion welded.

Variant 2

In lining the inspection shafts of special cross sections (90° or of large diameter ones) the repair operation without additional formwork is recommended. Large-thickness, up to 12 mm, protective sheets for concrete are used and connection pieces as required. The sheets cuts to size are fixed to the shaft walls with dowels, then the ring-shaped gap is filled up. Upon setting of the grout and removal of the fixing units, the dowel holes and the piece edges are extrusion welded, then the tightness of the welds is checked.

HOUSE SERVICE PIPES

As regards house service connections, a distinction should be made between through and no-through pipes. In the case of the former type pipes, the lateral pipes, previously dimensioned and closed, upon completion of the repair, are open manually and connected to the liner by welding-in a polyethylene stub pipe. The stub is provided with an outer seal that secures a tight connection with the feed pipe that, as a rule, is made of a material other than polyethylene.

Occasionally the connection of house no-through service pipes can be made by the excavation method from the outside. If there are many service pipes alongside the pipe section under repair, the method mentioned above is useless. For that reason tests are underway to develop the best approach. One of these is the method of connecting house service pipes from the inside with the aid of the sewer robot. One of the approaches is based on the use of the HDPE "sombrero" pieces which, upon opening the service pipe, are hot-air welded with the liner. Prior to the fitting of the PE flange, the connection channel is milled to the diameter that would allow to insert the flange pipe through the connection pipe and to fit an O-ring to it.

APPLICATION RANGE

The Sure-Grip® relining is essentially suitable to damaged sewers of nominal diameter range of 250 to 1200. Larger-size sewers can be rehabilitated with the aid of sheet units and movable formwork. The method is applicable primarily whenever no substantial reduction in the cross section is involved. In the cases of more serious failures of pipes and for pipe turns usually the rehabilitation method described cannot be used, and the damaged pipe section has to be replaced by a new one.

It is often required that after the repair a high static load capacity be maintained. Extensive tests performed on rehabilitated and non-rehabilitated concrete pipes have shown the load capacity of the entire system to visibly increase upon application of the Sure-Grip® Liner.

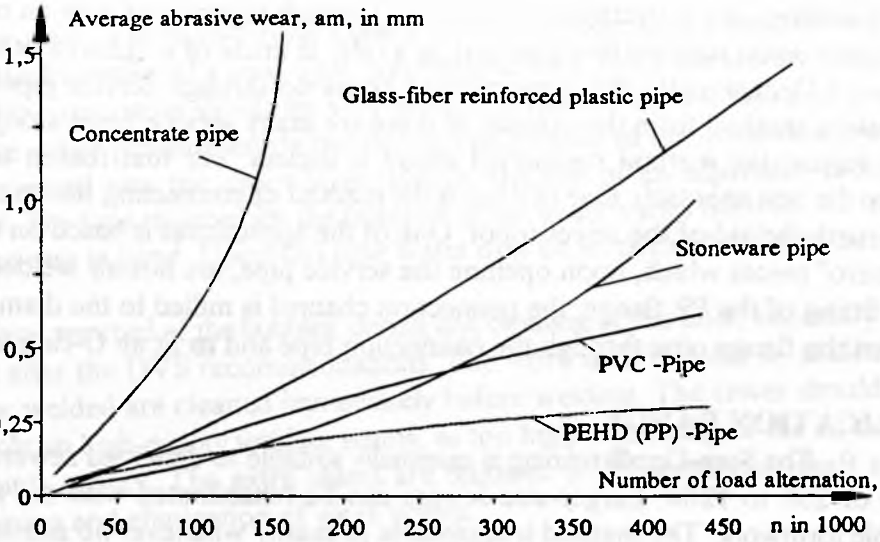

Fig. 1. Comparison of abrasion of HDPE (after the Darmstadt method) and other materials

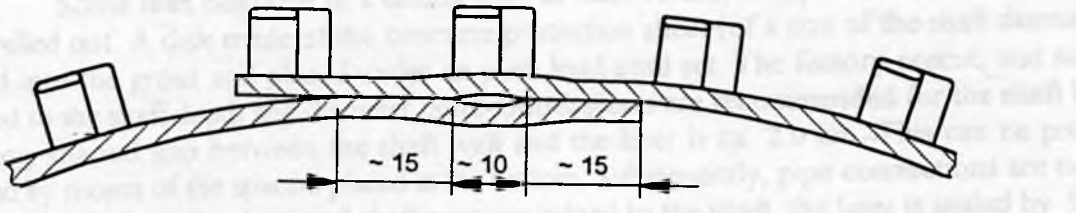

Fig. 2. A cross section through the welding seam with test channel

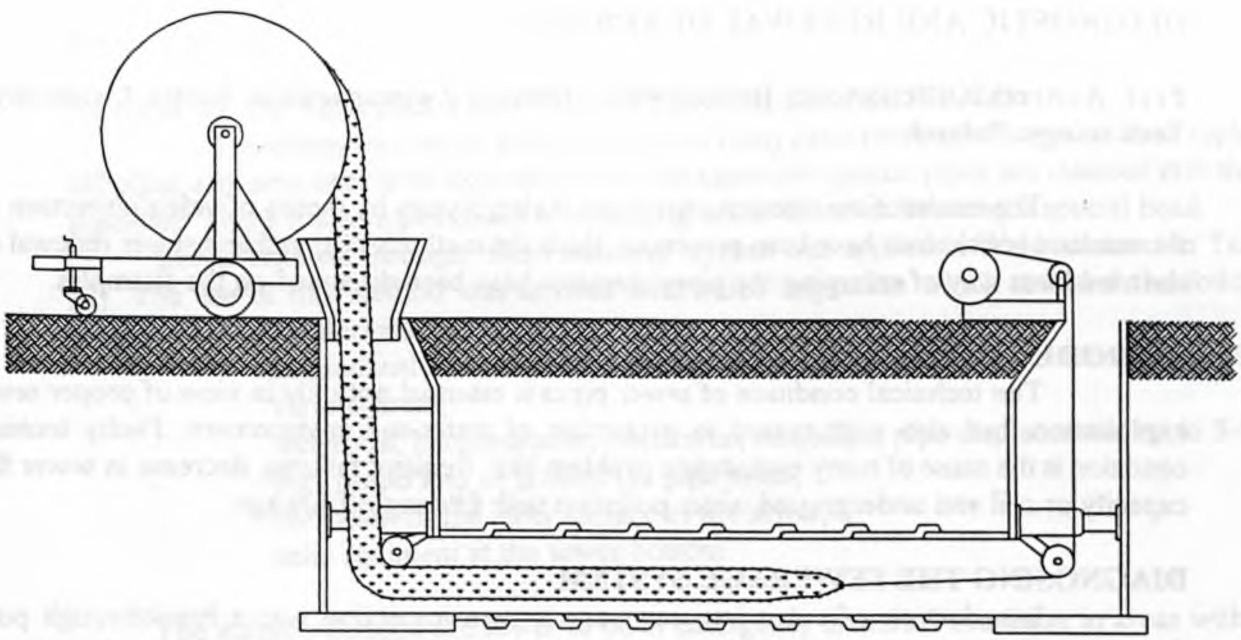

Fig. 3 A schematic diagram of the Sure-Grip® Liner introduction process.

DIAGNOSTIC AND RENEWAL OF SEWERS

Prof. Andrzej Kuliczkowski, Roman Pluta, Dariusz Zwierzchowski, Kielce University of Technology, Poland.

The results of the research carried out during 3 years by means of video inspection and the resultant conclusions have been presented. Both the methods of trenchless sewer renewal and the trenchless way of enlarging the pipes diameter have been discussed on the examples.

INTRODUCTION

The technical condition of sewer pipes is essential not only in view of proper sewers exploitation, but also with regard to protection of water-soil environment. Faulty technical condition is the cause of many exploitation problem like: frequent failures, decrease in sewer flow capacity or soil and underground water pollution with filtering off sewage.

DIAGNOSING THE SEWERAGE SYSTEM

Introduction of video into sewerage system inspection was a breakthrough point. Observation of pictures transmitted through a camera allows for a possibly thorough evaluation of the technical condition of the examined pipe without unearthing and destroying the sewer.

The television inspection is aimed at discovering and localizing the defects, faults and damages occuring in exploitation. Knowing where these iregularities occur, what type and size they are allows for determining further exploitation period or in the case of emergency state it enables preparation of data reguired for the choice of method of the sewer renewal.

Sewarage systems are diagnosed by means of video equipment at random in our country, mostly in these areas where users have exploitation problems.

The autors of this elaboration have conducted video supervisory research in most areas all over Poland since August 1991.

Until August 1991 we inspected the total of 46 km of sewa-ge pipes in over 43 towns and industrial plants. Diameters ran-ged from 100 to 1000 mm and the sewers were made of con-crete, reinforced concrete, stoneware, brick, stone and cast iron. Three year research characteristic is presented in fig. 1.

Having analysed the research results we observed that the most common defects in concrete and reinforced concrete sewers were scratches, cracks, fall of cracked pieces of the bottom leading to its complete deficiency. The damages were caused mainly by corrosion, bottom grindability as well as excessive construction overload.

Stoneware sewers were noted most frequently for mechanical damage caused by pipe overload.

Common irregularities observed in all sewer types were leaky pipe joints brought about most frequently by contractor's faults, material defects or silting up and filling the sewer with stone debris. Types of damage are presented in fig. 2.

The reasons for bad technical condition of inspected sewers are as follows: poor quality of materials, faulty contractor's work, improper sewage pipe transport or assembly, faulty exploatation of sewer.

In order to exploit sewers effectively proper actions should be taken as early as when designing and contracting them. Concrete conduits require using high-grade cement (not less than B40) and application of adeguate anticorrosive coats. Damages which occur due to faulty contractor's work can be prevented through proper pipes transport and assembly, construction of appropriate joints and the proper way of founding and consolidating the ground around the sewage pipe [1].

RENEWAL OF SEWERS THROUGH TRENCHLESS METHODS

Trenchless renewal of sewage pipes is in many cases more advantageous than replacing old pipes with new ones in an excavation. In most cases new plastic pipes are inserted into the old pipelines. There is also a possibility of enlarging sewer diameter by using a special head.

Sewer renewal through "short Relining" system was applied in Walowa street in Tarnów [2]. The use of this method was advised after video inspection which revealed the following damages and irregularities:

- longitudinal scratches and crackings in the top of sewer construction, occurring in various areas,
- reciprocal, perpendicular, horizontal, or oblique pipe displacement up to 3-5 cm,
- big compo loss all around the pipe joints,
- corrosion of the inner surface of the sewer,
- solid sediment at the sewer bottom.

The authors decided the sewer to be in emergency technical condition in areas with axial crackings and in potential emergency state in deeply corroded and scratched places. Taking into account that the same pipe assortment was used to build the sewer all along Wałowa street, we came to the conclusion that the whole section was in potential emergency. Hence the Wałowa sewer required a renewal technology that would quarantee the new coating inserted inside the old sewer to take thoroughly over the load for which sewer had been designed. The most appropriate construction material for renewing pipes in this case was polyethylene PEHD (tab.1.)

50 cm PEHD pipes (1) (fig.3.) were inserted into the old sewer (3) through wells (2) by using motor operator (4). The empty space between the old and the new sewer was filled with special joint sealing material. The material is a protection against the damaged sewer collapsing and becomes one three dimensional element with the new pipeline and the old sewer. It also fills the empty spaces outside which occur due to washing the ground into the sewer.

The sewer in Barbackiego street in Nowy Sącz [3] was sealed by using the same method of renewal. The sewer had been noted not only for its mechanical damage but also for strong underground water infiltration.

The use of "short Relining" system proves to have a lot of advantages, namely :

- increase of the sewer load capacity or taking over the load by the new inserted pipeline in the case of partial or complete defect of sewer load capacity,
- short term renovation and lower work cost when compared with excavation works,
- high durability, anticorrosive resistance and abrasion resis- tance of the renewed sewer,
- full sealing of the sewer, which prevents underground water from infiltrating into the sewer, thus the transport and sewage treament cost are not increased and the sewege does not exfiltrate into the ground and to pollute the water-soil environment,
- improvement of sewage flow conditions due to lowering the roughness factor of the sewer inner surface,
- using the old sewer for its further exploitation, which is extremely important in densely built-up areas,
- elimination of the ground works or in some case reducing them to excavating only where house sewers are connected between wells,
- no troublesome necessity of reorganization of traffic and pedestrians movements

during the construction proces,

- no environment unfriendly situations, such as flora extinction along the dig-out and storing the ground, noise or vibration while boarding.

Trenchless enlargement of sewage pipes is a new solution to the problem of hydraulically ineffcient sewerage. The method was used for the first time in Poland to enlarge a sewer from 200 mm to 315 mm in Rzeszowska street (previously E-22 international highway) in Dębica [4,5]. The reason for enlarging the sewer section was its insufficient flow capacity which frequently resulted in flooding the sewer, its work under pressure and flooding neighbouring building cellars with sewage. Enlarging sewage pipes is done through specially constructed head. The head (1) is inserted into the sewer interior (2) through the well (3) and next expanding circumferentially outwards, it destroys the old sewer (fig.4.). Then it spreads out the construction's damaged pieces towards the ground for a distance which would allow for inserting there the new sewage pipe of bigger cross-section and consisting of short segmented PEHD pipes (table.2).

The advantages of trenchless enlarging of the sewer cross -section are as follows :

- increase in sewer flow capacity due to both cross-section enlargement and the use of polyethylene pipes with roughness factor k = 007,
- noise-free and vibration-free destroying the old sewer resulting from the use of hydraulic head,
- the guarantee of full load capacity of the sewer construction due to the sewer's corrosion and abrasion resistance,
- ecologically profitable aspect due to full sealing of the new sewer,
- high economic effectiveness, especially in the case of sewer founded deeply under the street passes,
- total elimination of ground works or limitation of works to local excavation only where house drains were built between the wells,
- high rate of work,
- no problems with pedestrians movements and minimum hindrance with car traffic around the well where the pipes are lowered and broached.

CONCLUSION

The results of the research conducted show that sewer technical condition is in many cases highly unsatisfactory. The most frequently registered damages and irregularities are axial cracks and displacements, leaky joints, corrosive decrements, bottoms and stone debris.

Due to a large number of damages noted in the inspected sewers it is necessary to make use of video inspections on a larger scale in our country.

Trenchless renewal of sewers shows positive results. In many cases it helps avoid inconveniences which apocompany unearthing methods (excavations, detours) and it brings considerable economic profits as well. Hence the advisability of popularizing these methods in our country.

BIBLIOGRAPHY

1. Kuliczkowski A., Zwierzchowski D.: Influence of the technology of sewage pipes construction on the quantity of stresses and the costs of realization. GWITS, vol. 66, 1992, number 8, pp. 183-185.
2. Kuliczkowski A., Rybiński S., Dyrda R.; Renovation of sewage pipes using "short Relining" system in Tarnów. GWITS, vol. 66, 1992, number 7, pp. 162-164.
3. Kuliczkowski A., Rybiński S., Książek W.; Trenchless sealing of a sewer in Nowy Sącz. GWITS, vol. 67, 1993, number 5, pp.128-130.
4. Kuliczkowski A., Rybiński S.,Dyrda.: Trenchless enlargement of sewer pipes as exemplified in Dębica. GWITS, vol. 68, 1994, number 3, pp. 73-76.
5. Kuliczkowski A., Rybiński S., Dyrda R.: RenoRurCtrum experience concerning the renovation of sewer pipes. Materials from the Science and Technology Conference "Contemporary problems of water economics and water sewage disposal". Koszalin, 1993, vol.1, pp. 218-227.

Table 1. Type of pipes used while renovating the sewer in Wałowa street in Tarnów

Number	Sewer diameter	Total lenght	Outside diameter of PEHD pipe used in renovation
	mm	m	mm
1	500	17	450
2	400	486	355 i 315
3	300	55	250

Table 2. Possibilities of enlarging sewer cross-section

Inside diameter of the existent sewer [mm]	Possible outside diameters of the sewer enlarged cross-section with the use of PEHD pipes [mm]
100	110, 125, 180
200	225, 250, 280, 315
300	315, 355, 400, 450
400	450, 500, 560
500	560, 630

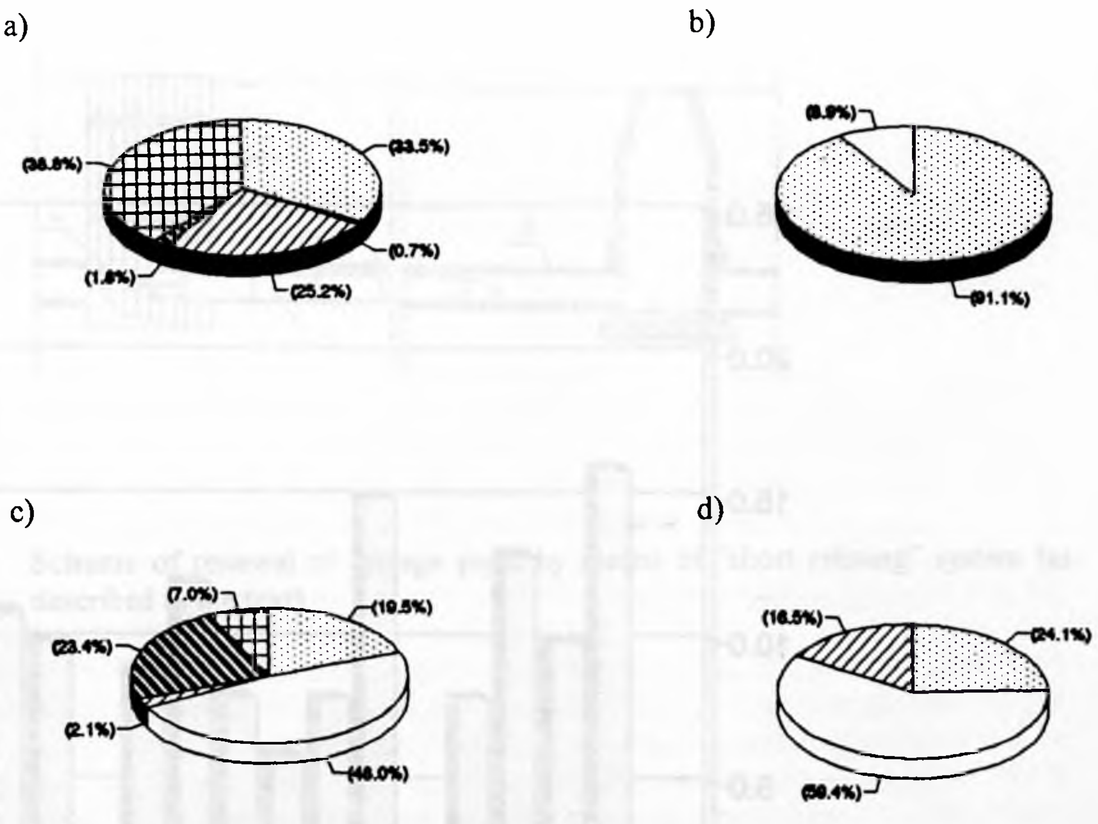

Fig. 1. Specification of parameters of the inspected sewers:
a) type of material; 1-concrete (33.5%), 2-cast iron (0.7%), 3-stoneware (25.2%) 4-brick (1.8), 5-reinforced concrete (38.8%),
b) type of section; 1-circular (91.1%), 2-oviform (8.9%),
c) type of diameter; 1-100|200 (19.5%), 2-201|400 (48.0%) 3-601|1000 (2.1%), 4-401|600 (23.4%), 5-1001|1400 (7.0%),
d) type of sewerage; 1-drain (24.1%), 2-cumulative (59.4%), 3-storm-water (16.5%).

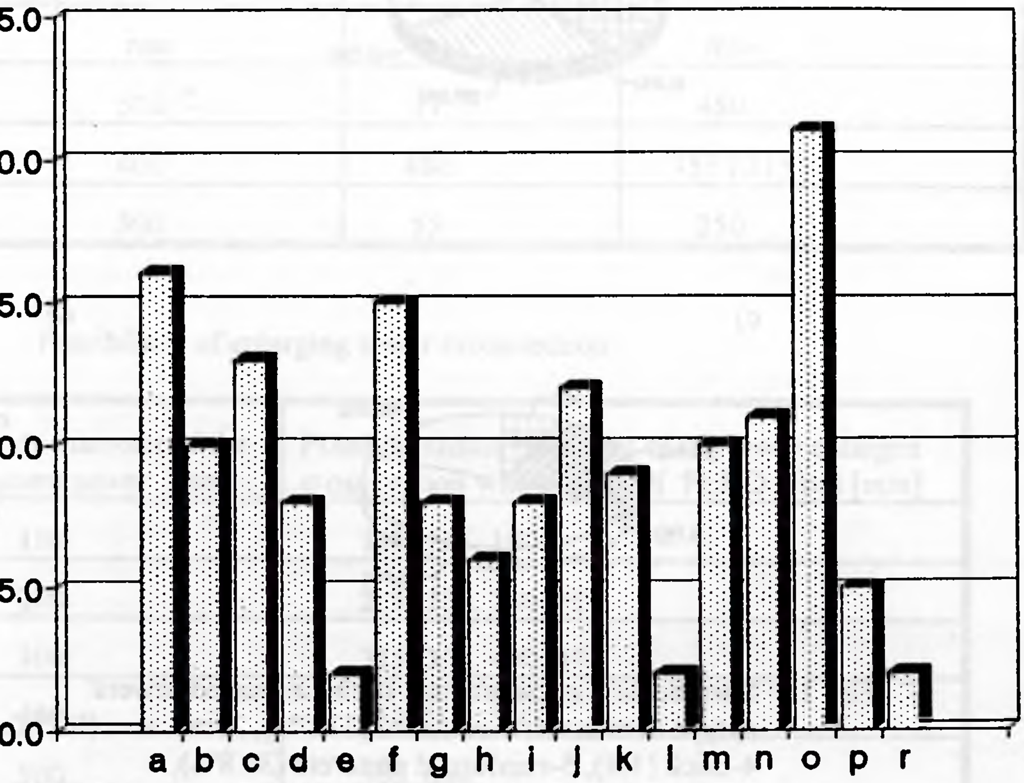

Fig. 2. Types of sewer damages registered in 41 inspections: a) longitudinal displacements b) lateral displacements, c) spalling of joints, d) lack of packing e) open concrete reinforcement f) longitudinal cracking, h) absence of the top part of the sewer, i) pitting and decrements, j) counter drops, k) infiltration, l) pipes running through the duct, m) protruding house drains, n) stone, o) silting, p) tree roots, r) goafs.

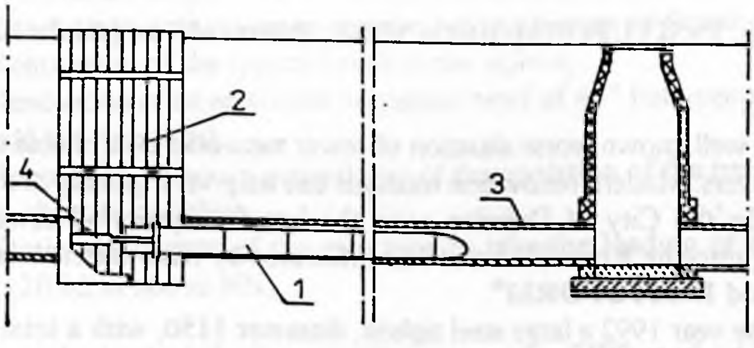

Fig. 3. Scheme of renewal of sewage pipes by means of "short relining" system (as described in the text).

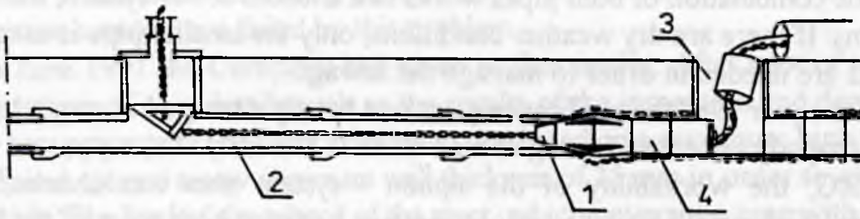

Fig. 4. Scheme of trenchless enlarging of sewage pipes (as described in the text).

RENOVATION OF SIPHONS UNDER THE RIVER ELBE IN THE CITY OF DRESDEN BY THE CIPP METHOD INSITUFORM®

Rainer Dilg, INSITUFORM-BROCHIER Rohrsanierungstechnik GmbH, Germany

SYNOPSIS

The well known worse situation of sewer networks contributes to the pollution of ground water and rivers. Modern renovation methods can help very quickly and cost saving to solve such problems. In the City of Dresden over the last four years all sewage siphons, which were exfiltrating into the River Elbe and / or infiltrated by river water, were renovated by using the CIPP method **INSITUFORM®**.

In the year 1992 a large steel siphon, diameter 1150, with a total length of 328 meter, was renovated using this method. The pipe-within-a-pipe was calculated on the Century High water of the River Elbe. The result was a minimum wall thickness for the inliner of 25 mm. After two years successful work of this siphon the Sewer Authority (WAB) tendered another double-siphon, two parallel timber-made pipes, diameter 300 and 400, with a length of 250 meter. The same CIPP method was chosen and this job was completed within less than one week - two good examples of this renovation methods.

In the year 1907 in the City of Dresden a double siphon - system was installed under the River Elbe - a technical masterpiece of these days! The siphon was made by two welded steel pipes diameter 2000 mm and 1150 mm. They had to run the whole sewage from the „Altstädter“ to the sole purification plant at the „Neustädter“ side of the river Elbe in Kaditz.

The combination of both pipes works like a mixed sewer system, using different highs of the bottoms: If there are dry weather conditions, only the smaller pipe is used, during heavy rain both pipes are needed in order to manage the sewage.

In the year 1982 the purification plant was heavily damaged during a high water and never did work properly since that. During its renovation in the early 90s, supported by the Government of the FRG, the workability of the siphon - system also was checked. As the so-called „Flügelweg“-Siphon still was the only connection between both sides of the River Elbe, this was the critical spot of the Dresden sewage - system.

In April 1990 a Diving Company from Hamburg inspected the siphons. The result was, that the bigger pipe dia 2000 was still in reasonable good condition and so could be used further without much repair. The first trial to inspect the smaller pipe dia 1150 failed, caused by masses of sludge and other sediments including stones, planks etc., which blocked the way for the diver. Therefore the siphon was cleaned again by a specialist.

In October 1990 the diver made his second trial of inspection. This time he could penetrate round about hundred meters into the pipe. The result: Considerable damages in the bottom of the pipe, caused by abrasion. The materials which were transported by the sewage such as sand, stones, granules etc. had produced grinds with a width between 10 and 20 cm. The diver could grab through holes into the subsoil of the Elbe.

Also this inspection works have to be done in „black“ sewage, i.e. at zero visibility.

The Sewage Authority (WAB Dresden) had to make up its mind, if a renovation of the siphon could be done out of technical point of view and would be acceptable out of economical reasons. Also the need of time had to be considered, because the renovated purification plant should start working again in the autumn of 1991 in order to guarantee a purification of the sewage of the City of Dresden according to the specifications.

The tendering of the Sewage Authority of Dresden (WAB) showed the result, that there was only one renovation method which could cover the different demands:

- Renovation length: 328,0 metres - Dimension: 1150 mm;
- Renovation without emptying the siphon (danger of floating);
- Renovation of the typical bends in the siphon;
- Renovation of an additional horizontal bend of 45° between the entrance chamber and the river bank;
- Renovation without a general stop of the operation of the parallel pipe and a break as short as possible;
- Static calculation of the new pipe to take the loading of a Century high-water (110.02 m above NN);

The only method, which finally was offered, was the CIPP-method **INSITUFORM®**. So the WAB decided to use this CIPP - Method, offered by the German licensee INSITUFORM-BROCHIER (IBR) in Potsdam. In the year 1990 a similar job was successfully completed in the City of Prague using the same method. This was a good reference.

Nevertheless the renovation of this siphon in Dresden was another premiere also for **INSITUFORM®**, considering the diameter and the length of 328 meter.

A special problem was caused by the construction of the double siphon. As the pipes were not anchored in the subsoil of the river, they had to be filled all the time, also during the renovation, in order to avoid a floating of the pipes. Also the operation of the pipes only could be interrupted for some hours, meanwhile the sewage must be dumped into the River Elbe - which was practised in the GDR for a long period but nowadays was not accepted further. Very nearly the renovation would have failed by this problem.

In June 1991 the Company had given its first tender. After a lot of technical discussions and presentation of new details such as the results of the inspection and demands of the client a final offer was presented. The static calculation was based on a maximum high water table (the last time 1845) and created a new minimum wall thickness of 25 mm in order to carry the load of 3.44 m water table. The load of the subsoil of the river, which covers the pipe with 1.40 m, further will be carried by the host pipe.

IBR decided to use the same „Double Inversion" technique, which successfully worked a year ago at the reference job in the City of Prague. This was the only possibility to handle the weight of the impregnated INSITU-TUBES®, which was 26.5 tons for each tube with a wall thickness of 15 mm.

Already in December 1991 the preparations for the job, such as tube manufacturing, jobside planning, provision of machinery and unit capacity started. The installation itself should be done in the beginning of February 1992, hoping that the weather conditions would be good. Two advantages were expected thereby: Permafrost should make possible to drive heavy equipment over the Elbe Meadows. Precipitation as snow instead of rain would not influence the sewage level directly.

Unfortunately St. Peter did not play along with us. After the count down run unstoppable at the end of January, general weather situation changed and mild rainy weather started and hold till the end of the job.

A second problem was the permission of stopping the flow trough of the sewage and to outlet it into the River Elbe. One Authority pushed the responsibility to the other and it had to be considered sincerely to install the tubes under operation and to open them later, when the flow trough would be less.

Originally it was planed to set up a wall in the outlet. As this was not possible under operation a provisual barrier was built by a wooden board and sand-bags.

On Tuesday, the 4th February 1992, the set-up of the jobside was finished. Two days later the siphon again was inspected, this time completely, by a diver. The inspection confirmed the results of the pre-inspection to a large extend. However the bottom of the pipe nearly over the whole length was covered by some centimetres of sludge, which could not be moved away with the existing technique. Only at the outlet of the siphon a bigger quantity could be removed in order to get an INSITU-PIPE® as smooth as possible.

On Friday morning the crew of IBR, supported by men and equipment from their Danish parent company Per Aarsleff, started the installation of the first tube. The resin impregnated tube was pulled directly from the transport truck, which had brought the tube -cooled in ice- from the impregnation plant in Denmark to the jobside, over a roller-bed to a conveyor. From there the tube was let down 7 meter into a manhole and „threaded“ by some workers into the siphon. A thick rope was pulled through the siphon and fixed at a hydraulic winch with a pulling force of 20 tons at the opposite side. Slowly the tube now was pulled under water to the other side, only using between 2 and 4 tons pulling forces. After six hours the tube reached the opposite Elbe bank.

Meanwhile the granting of the temporary letout of the sewage into the River Elbe had arrived by fax. Beside the Municipality of Dresden the Saxonian Government and the International Society for the Protection of the River Elbe had been involved therein.

At the same evening the installation of the second tube started. At 22:00 o' clock the flow-through of the siphon was blocked and went out of operation at its lowest level.
Now the insertion of the second tube into the first one, already installed and flat under sewage lying hose could start. By the hydrostatic pressure of 7 to 8 meter water, i.e. 0.7 - 0.8 bar, the first tube now was inflated and pressed against the wall of the host pipe. Simultaneously the sewage water was pressed forward through the outlet and pumped to the purification plant. As the pipe during the whole procedure was completely filled with water, there was no danger of floating at any time.

The duration of the inversion depended on the available quantity of water. As there were no fire hydrants with sufficient pressure at the „Altstädter“ side of the river, the water had to be transported from the other side by tank trucks and stored in two big tanks on jobside.

After a short well-deserved rest for the whole crew, the curing process of the INSITU-TUBE® started. For this four mobile Boiler-Units with a capacity of 4.5 mil kcal were needed. The process lasted from Saturday morning till Tuesday morning.

After a cooling-down period the heating hoses were pulled out and the start end and the so-called „fish“ were cut.

At Thursday the diver inspected the new INSITU-PIPE®. Now the visibility was better, so that the result could be reviewed by a video camera: a smooth Pipe-within-a-Pipe, except of some smaller wrinkles, which were caused by the sludge and tolerances in the diameter of the host pipe. Eight to ten workers on the average had created within twelve days another world record of a 328 meter long joint-less INSITU-PIPE®, dia 1100 mm, in the everlasting ranking list of **INSITUFORM®**. The total cost were less than 12 % of a new installation.

The Sewer Authority waited two years with its next tender for similar works. When after that guarantee time there were no complaints about the first siphon, they asked in autumn 1993. This time again it was a double siphon near a well-known token of Dresden, the „Blaue Wunder“, with much smaller diameters: dia 300 and 400 and a total length of 250,0 meter each. The pipe material for today is very seldom: The pipes were made by timber planks, using the same technique like coopers. As there were no plans available, the direction of the pipes was not clear. The CCTV-Inspection showed, that one of both was infiltrated by Elbe water. IBR decided to use again the „double inversion"-technique, which they had used two years ago so successfully. This time St. Peter played along, even when it was not necessary: temperatures around minus 3 - 5 ° C occurred during the installation. The rest is quickly told: This time the complete job including CCTV-Pre-Inspection, Cleaning, Installation, TV-Inspection and Pressure-Test of both pipes only endured four days.

These two Case Histories have shown, that there is no other renovation method than CIPP and within this kind **INSITUFORM®**, which are so universal and economically for the solution of a wide range of problems in sewer networks.

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MECHANICAL METHOD OF WATER SUPPLY PIPES CLEANING

Dr Jacek Wąsowski, EKOPIG Sp. z o.o., Poland.

The paper concerns the problems caused by the phenomenon of hydraulic deterioration of water supply pipes and also the ways of slowing down and elimination of burdens resulting from inlay of internal surfaces of the water pipes. The two principal methods of sediments elimination from the water supply pipes are described in detail, that is the method of hydropneumatic flushing using air and water and method of hydromechanic cleaning using special plunger (pig).

INTRODUCTION

The principal task of water supply companies is to supply the users with water in adequate quantity, at adequate pressure and in adequate quality. In practice, the realization of above task is connected with the need of water uptake and treatment and efficient and reliable water distribution. Usually large technical and technological effort and financial resources used in water uptake and treatment are made void during the transport of water to the end users, especially so when the old water supply network is used. It is caused by the fact that during the course of years chemical and biological sediments coat the inner walls of the water supply pipes intensifying the process known as hydraulic deterioration of the water supply pipes. The main factors influencing the intensity of hydraulic deterioration of pipes are [1]:

- physical, chemical and biological properties of water,
- material of water pipe,
- type of internal isolation of the water pipe,
- hydraulic parameters of flow,
- the way the network is exploited.

The negative effect resulting from the pipe inlay is the increase of walls roughness and decrease in pipe diameter, and therefore increase of pressure losses and decrease in flow capacity of the water supply pipe. The secondary pollution of transported water by corrosion products, microorganisms and their metabolites is the additional unfavorable phenomenon. Flushing and cleaning are the simplest ways of slowing down the process of hydraulic deterioration of the water supply pipes and restoring their flow capacity [2, 3, 4].

In practice there are various methods of flushing and cleaning used, which can be classified into the following categories [2, 3]:

1. hydropneumatic methods,
2. hydrodynamic methods,
3. hydromechanic methods,
4. chemical methods.

In each of the above mentioned groups, a series of methods can be named which differ in the type of equipment used, technological parameters etc. The experiences gained through many years show that due to ecological, economical reasons and due to speed, efficiency and simplicity the special attention is deserved by, in flushing operations, the hydropneumatic method using air and water; and in cleaning, the hydromechanic method using special plungers (pigs). This paper concerns the presentation of these two methods, which in many countries have been adequately tested and technically mastered.

THE METHOD OF FLUSHING WITH AIR AND WATER

The method of flushing the water supply pipes with air and water is used in prophylactic actions enabling to maintain the water supply network in state of continuous efficiency and for cleaning of pipes from soft deposits which are easy to remove. In the case of using that method in planned maintenance operations it is advisable that main and distributing pipes should be cleaned once every three years and end connections 1-2 times every year.

In general, the principle behind the method of cleaning/flushing the water supply pipes with compressed air and water relies on pumping into the pipe of appropriately conditioned air so that the turbulence and increased rate of water flow loosens and removes the sediments, sludge and live organisms which have accumulated in the pipe during its operation.

Ordinary taps or hydrants can be used as points for pumping in of the compressed air and places of inflow.

The example of flushing/cleaning of the water supply pipe is shown in Fig. 1 [4].

The course of main actions of flushing/cleaning operation devised by "EKOPIG" is similar to the typical way and is carried out in the following way:

- the slides and valves should be closed on all the branches of the cleaned segment of the pipe,
- the slides at the beginning and at the end of the cleaned segment should be closed,
- connect the compressor and equipment for conditioning of the air to the hydrant at the beginning of the cleaned part of the pipe,
- connect the stand or a special outflow to the hydrant at the end of the cleaned segment of the pipe to facilitate the discharge of flushed pollutants,
- open the slide at the beginning of the cleaned segment of the pipe and start the compressor with the water flowing in the pipe, the air should be pumped continuously or intermittently (for 10-15 s every approx. 1 min),
- adjust the slide at the beginning of the pipe in accordance with the amount of water needed,
- the operation of cleaning should be conducted until clear outflow is obtained from the hydrant installed at the end of the cleaned segment of the pipe,
- restore the normal state of operation (close hydrants, open the slides and valves, if needed flush the service pipes),
- optionally check the efficiency of the cleaning procedure by measuring the pressure loses in the cleaned segment of the pipe and comparing them with the figures obtained before the cleaning operation.

The operation of flushing/cleaning should be carried out at the following technological parameters of the process:

- the advisable water flow rate without the air should be approximately 0.4-0.5 m/s,
- the pressure of the air pumped into the pipe should be in the range of 0.3 - 0.35 MPa. The use of screw compressor with capacity of 300 Nm^3/h and maximum pressure in the range of 0.7-0.8 MPa is recommended, it should be combined with the equipment for air conditioning (the air should be cooled, free of dust and oil, cleaned on the granulated activated charcoal),
- cleaning time and length of the pipe segment being cleaned can vary depending on the pipe diameter, quantity and quality of sediments, etc. (in general cleaning time of the segment is 15-20 minutes and exemplary length of the cleaned pipe segments is: for diameters up to d=100 mm - 200 m, up to d=200 mm - 400 m),
- required number of personnel : 1 foreman and 2 workers (water supply system fitter and compressor operator).

On the basis of several years of use of the described method by our Company the following its benefits can be presented:

- technological simplicity and ease of equipping in the required equipment,
- avoidance of costly and troublesome excavations and incisions into pipes being cleaned,
- high efficiency and speed of rinsing operation,
- low costs.

CLEANING METHOD USING PLUNGERS (PIGS)

The method of cleaning the pipelines using plungers (pigs) is one of the hydromechanic water supply pipelines cleaning methods. It is mainly used for quick and effective removal of tight, hard and strongly adherent to the inner-surface of the pipe sediments. The pig is the primary cleaning element in this method, which while moving inside the pipe under the influence of water pressure supplied from hydrant removes all types sediments laid down on its inner surface [2, 3, 4].

The method using "Ekopig" pigs is one of these methods [4].

"Ekopig" pig is a cylindrical, elastic plug made of, in general, foamed polyurethane with variable density and with various types of outside coatings.

The standard pig is bullet shape i.e. it has conical front end and concave basis, that allows for obtaining maximum water thrust enabling the movement of the pig inside the cleaned pipe (Fig. 2).

For special cases, e.g. for movement of the pig in both directions, or for localisation of the pig in the cleaned pipe, special pigs are used i.e. with conical not only front end but also with conical basis, or pig with probe built-in.

In general "Ekopig" pigs used for cleaning of the water supply networks can be classified into 3 basic categories:

Group I - these are pigs of the "swabs" or "bare" types completely lacking coating or with only the basis coated with special plastic. They have the function of: inspecting, sealing and drying. They are used for assessing the patency of the cleaned pipe, sealing during passing the cleaning pigs, removing loose sediment debris and are used during disinfection of the cleaned pipe. The pigs of this type are used mainly at initial and final stages of the cleaning process.

Group II - these are pigs of "Criss-Cross" type, completely covered with plastic forming on the surface criss-crossing grooves. The pig of this type are mainly used for removing typical sediments found in the water supply networks.

Group III - these are "Scarlet Criss-Cross" type of pigs, completely covered with plastic and additionally equipped with metal brushes or spikes. These pigs are used for removing hard and very hard sediments from the water supply pipelines.

Various colours of the pig coating (yellow, blue, red) is due to different specific density of the material making the core of the pig. With increase in density of the material the pigs become less elastic, but more mechanically resistant.

The type of the pig and its diameter are chosen on the basis of the type and thickness of the sediments in the pipe being cleaned and depending on the pipe diameter (we are offering pigs with diameters from 25 mm to 1000 mm and greater).

Cleaning using the pigs takes place thanks to frictional forces occurring between the pipe wall and the pig surface. The cleaning effect significantly increases as the result of diagonal deformation of the pig under the forcing liquid on one side and the resistance of the sediments on the opposite side. Also, partial flow of liquid through the pig coating grooves causes the increase of the flow speed near the pipe wall, what further enhances sediments removal and their movement forward to the outlet of the pipe being cleaned.

The basis for pig operation are illustrated in Fig. 3 [4].

The general procedure of pipeline cleaning using "Ekopig" pigs is as follows:

- the valves at the beginning and at the end of the segment of the pipe being cleaned should be closed,
- excavations and incisions into the pipe at the beginning and at the end of the segment being cleaned should be made,
- special sleeve for introduction of the pigs should be installed at the beginning of the segment being cleaned should be installed, it is also used for water supply (it is best to supply water from the nearest hydrant),
- special outlet should be installed at the end of the segment being cleaned in order to discharge the rinsed out sediments.
- all valves at branches of the cleaned segment should be closed,
- ensure that all valves on the segment being cleaned are open,
- open the water flow from the hydrant to check the conditions of flow,
- force the bare pig of the diameter equal to the diameter of the pipe in order to establish the actual pipe lumen,
- inspect the pig after forcing, measure its diameter and select CC type pig with diameter corresponding to the actual pipe lumen. Force CC pig together with swab (swab behind the pig). The bare pig with the diameter equal to the diameter of the pipe acts as the sealant. Forcing of the pig through the pipe should be repeated several times up to complete wear of the pig.
- use CC pig with greater diameter. The cleaning procedure should be repeated. Use subsequently pigs with increasing diameter, up to the nominal diameter of the pipe. For the pipes covered with hard sediments during the last cleaning procedure the pig with metal brushes should be used,
- force through the bare pig with diameter equal to the inner diameter of the pipe in order to remove the remaining debris of loose sediments,
- rinse the segment with water (till clear outflow is obtained) and then disinfect it,
- rinse with water all segments that were cut off during cleaning procedure,
- revert to normal operational conditions.

The cleaning procedure should be carried out with the following technological parameters of the process:

- the flow rate and the pressure of water moving the pig can not exceed the typical water supply network parameters (in general v=0.5-1 m/s and p=0.15-0.4 MPa),
- speed of pig movement in the pipe should be in the range of 15-50 m/min,
- the length of the pipe segment being cleaned and cleaning time can vary depending on the diameter of the pipe and quality and thickness of the sediments (Table 1 and 2),
- required personnel: 1 foreman and 2 water supply network fitters.

In relation to other mechanical cleaning methods using various type of scrapers, brushes, heads, etc., which are most often manually moved or using the winches, the described method has following benefits:

- allows for effective and quick cleaning of longer pipe segments, what in turn maximally reduces the number of excavations and incisions into the pipes,
- significantly reduces the duration of cleaning procedure,

- allows for cleaning of the pipes with wider range of diameters,
- due to elasticity of the pig the cleaning procedure can be carried out no only on the straight segments of the pipeline but also in the pipes with variable diameter and in pipelines armoured with slides, elbows, yokes and 90° connections (Fig. 4),
- allows for simultaneous sediments loosening from the inner surface of the pipe and their rinsing out.

LITERATURE CITED:

1. Suszyński W., Szymański A.: "Operational instruction for cleaning of the water supply networks using hydropneumatic and hydrodynamic methods", Institute for Spatial and Communal Economy, Cracow branch office, Cracow 1987.
2. Dohnalik K.: "Rules for operation and controlling of the water supply and sewage disposal equipment.", Institute for Environment Formation, Cracow branch office, Cracow 1986.
3. Kwietniewski M.: "Methods of pipes cleaning", Seminars of the Institute of Water Supply and Water Constructions of Warsaw Technical University on topic of "Modern technologies and materials for construction and renewal of water supply and sewerage pipes", Warsaw 1994.
4. Reference materials of "EKOPIG" company, Warsaw.

Table 1.
Approximate maximum lengths of water supply pipe segment cleaned using the plungers.

Diameter of the pipe D (mm)	Length of the cleaned segment dependent on the thickness of the sediments layer		
	20 mm	30 mm	50 mm
100	1000 m	500 m	100-200 m
150	1200	750	400
200	1500	1000	700
250	2000	1500	1000
300	3000	2250	1500
350	4000	3000	2000
400	6000	5000	4000
450	8000	7000	5000
500	10000	8000	6000
600	15000	12000	8000
700	20000	16000	12000
800	25000	20000	15000
900	30000	25000	20000
1000	35000	30000	25000

Table 2.

Approximate time of cleaning of the water supply pipe segment using the plungers.

Diameter of the pipe D (mm)	Time of cleaning dependant on the Length of the segment (m)					
	L=200	L=1000	L=2000	L=4000	L=6000	L=10000
100	1 day	3 days	5 days	10 days	15 days	20 days
150	1	2	4	7	10	13
200	1	2	3	5	7	9
250	1	2	3	5	8	10
300	1	2	3	5	8	10
350	2	3	4	6	9	11
400	2	4	5	7	10	13
450	2	4	5	7	10	13
500	2	4	6	9	12	15
600	3	5	7	11	15	19
700	3	5	8	14	20	26
800	3	5	9	15	21	27
900	4	6	10	18	24	32
1000	5	8	11	19	25	33

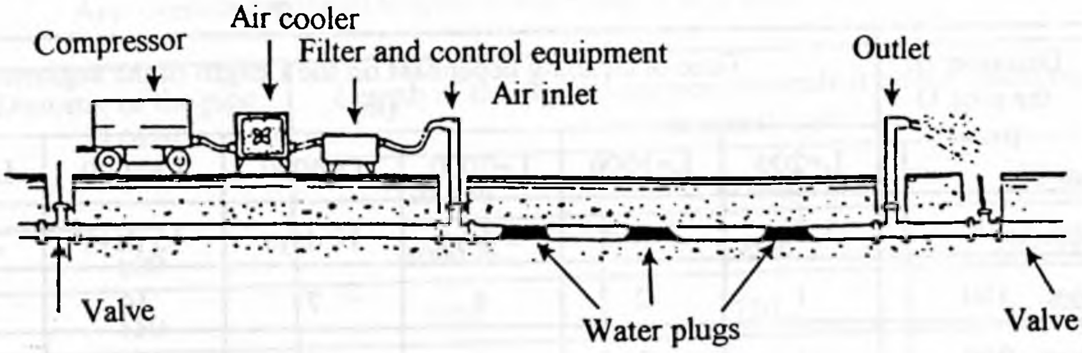

Fig. 1. Diagram of hydropneumatic method of water supply pipes cleaning.

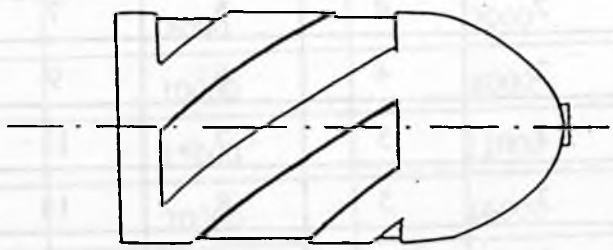

Fig. 2. Plunger (pig) for hydromechanic cleaning of water supply pipes.

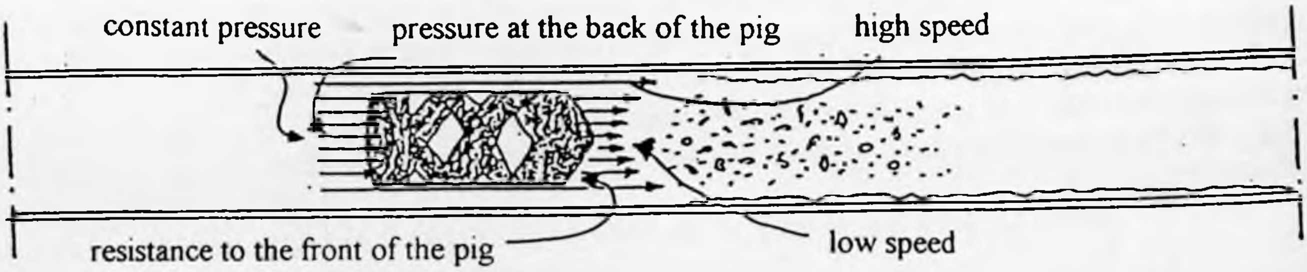

Fig. 3. Principle of plunger (pig) operation in the pipe.

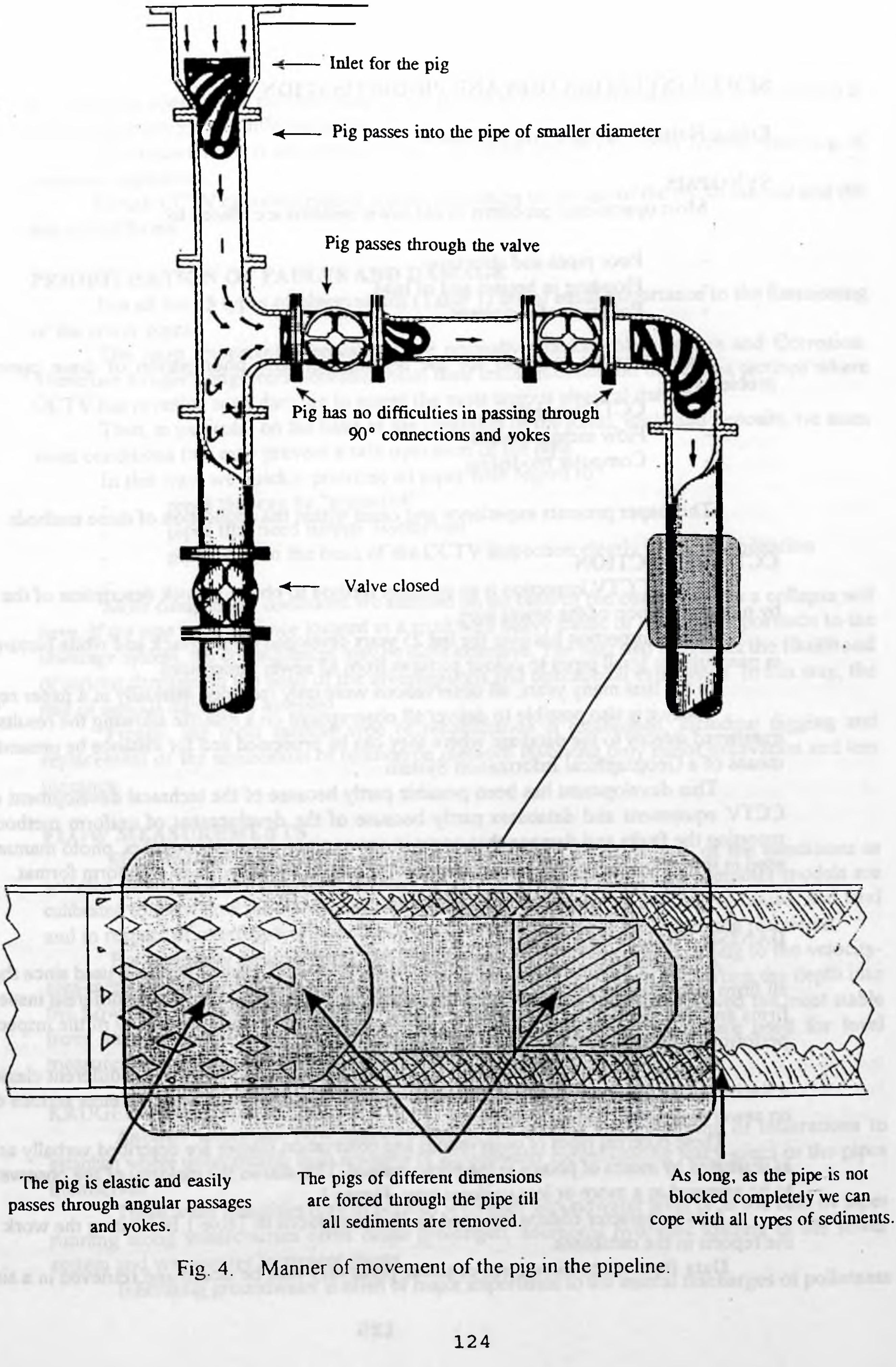

Fig. 4. Manner of movement of the pig in the pipeline.

SEWER INVESTIGATION AND PRIORITISATION

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SYNOPSIS

Most operational problems in old sewer systems are related to:

- Poor pipes and structures
- Flooding in houses and of land
- Pollution of recipients

Advantageous methods for the investigation and prioritisation of these operational problems are:

- CCTV inspection
- Flow measurements
- Computer modelling

This paper presents experience and cases within the application of these methods.

CCTV INSPECTION

Today, CCTV inspection is an excellent method to obtain a quick description of the meter by meter condition of the sewer pipe.

CCTV inspection has over the last 25 years developed from a black and white picture used in particular in small pipes to colour pictures from all sewer dimensions.

In the first many years, all observations were only recorded manually in a paper report.

Today it is also possible to deliver all observations on a diskette allowing the results to be transferred directly to the database where they can be processed and for instance be presented by means of a Geographical Information System.

This development has been possible partly because of the technical development of the CCTV equipment and databases partly because of the development of uniform methods for reporting the faults and damage that occur in sewer pipes. In most countries, photo manuals are used in the reporting so that all inspection firms submit their reports in a uniform format.

DANISH PHOTO MANUAL

A Danish photo manual was prepared in 1985. This manual has been used since then by all firms inspecting municipal sewer pipes allowing the municipalities to use different inspection firms and still get reports in a uniform format. In addition to this, the quality of the inspections performed by these firms has improved considerably.

All observations are divided into 15 types within which there are 4-5 different classes. O is the best classification (no faults) and 4 the poorest (the conditions with the most serious effect on sewer functions). Table 1.

These different types of observations and observation classes are described verbally as well as illustrated by means of photos in the photo manual. This allows the majority of the observations to be assessed in a more or less uniform way. Figure 1.

A two-character code is assigned to all observations in Table 1 facilitating the work with the reports in the databases.

Data from many kilometres of sewer pipes may thus be stored and retrieved in a simple way when the condition of the individual sewer pipe is to be assessed and when a prioritisation is to be made between the different pipes.

The report form is also standardised. The same applies to a form for the reporting of manhole inspections.

Danish CCTV operators receive regular instruction in the use of the photo manual and the associated forms.

PRIORITISATION OF FAULTS AND DAMAGE

Not all the 15 types of observations (Table 1) are of equal importance to the functioning of the sewer pipes.

The most important observations are normally Cracks/broken sewers and Corrosion. Therefore Krüger's engineers normally focus their initial attention on those pipe sections where CCTV has revealed such damage to assess the most serious physical damage.

Then, in particular on the basis of the condition of the joints, roots and deposits, we asses what conditions that may prevent a safe operation of the pipe.

In this way, we quickly prioritise all pipes with regard to

- pipes that can be "acquitted"
- pipes that need further assessment
- pipes that on the basis of the CCTV inspection clearly needs rehabilitation

More complicated conditions are assessed on the basis of the **consequences** a collapse will have. If the pipe is for instance located in a road with heavy traffic or of major importance to the sewerage system, the consequences may be quite extensive. The next step is to asses the **likelihood** of serious damage on the basis of the investigations and operational experience. In this way, the risk of serious damage is assessed.

Finally, the most suitable type of rehabilitation is established, including digging and replacement or the application of renovation methods involving only minor excavation and less nuisance.

FLOW MEASUREMENTS

Flow measurements are in particular used for the determination of the conditions in selected points in a sewer system during rain. In this way, the prepared computer models are calibrated to show how the system functions during rain in respect of flooding of houses and land and in respect of overflows of pollution from overflow structures direct into the recipients.

For these flow measurements, we primarily use meters operating according to the velocity-area-method. They are meters measuring velocity and water depth and converting the depth into the flow area and subsequently calculating the flow. These meters have proved the most stable from an operational point of view. Further to this, ultrasound meters are used for level measurements in connection with the calibration of computer models.

KRÜGER TRACING

Another important flow measurement is the tracing and measuring of infiltrations to establish where unacceptably high amounts of groundwater are infiltrating leaky joints or the pipes themselves.

These water quantities may in periods with high groundwater level or in the case of pipes running along watercourses often cause prolonged, additional hydraulic loading of the sewer system and wastewater treatment plants.

Infiltrating groundwater is often of major importance to the annual discharges of pollutants from wastewater treatment plants (WWTPs) into the recipient. This is especially true about WWTPs with high treatment efficiency where the pollution from the WWTP is in direct relation to the flow.

For the purpose of these measurements, we use tracers.

Prior to the measurement proper areas with large infiltration can be localised for instance by means of recordings of the operation of the pumps at the pumping stations or the flow into the WWTP. Figure 2.

Such simple investigations will in the majority of the situations form a good basis for the tracer measurement programme.

Tracer measurements are carried out during the night when the other wastewater flow is zero (or stable). Normally this is between 1 and 5 a.m. In one night the flow in 30-40 different manholes can be measured which means that quite a large area can be covered, as it is rarely necessary to measure in all manholes in a pipe section. Figure 3.

Upstream the selected measuring points, a tracer is dosed continuously with a specific concentration and flow. Then samples are taken at all the selected measuring points for subsequent analysis.

In this way, the dilution on the tracer and thus the flow is determined in the individual measuring points. Figure 4.

We apply a special, patented and quality assured system with tracers that ensures high accuracy and does not damage the WWTP and recipient.

COMPUTER MODELLING

Computer modelling is used for 2 purposes in particular:

- Prediction of flooding of houses and land
- Prediction of discharges of pollution into recipients.

For these purposes, we normally use the following computer models, of which most are developed by Krüger or in cooperation with Krüger:

MOUSE

Program package for calculation of runoff in sewerage systems.

PIPE MODEL: Flooding and backwater analysis, calculated on the basis of extreme rainfall events.

SAMBA: Pollution from overflow structures is calculated on the basis of many years of historical rain series and presented statistically. Design of retention basins, calculation of control strategy in connection with SCADA systems.

Krüger has participated in the MOUSE cooperation and model development work since the beginning of 1984 and is today operating Danish MOUSE Service Centre together with PH-Consult. MOUSE is sold to counties, municipalities and consultants in Denmark and abroad.

MOUSE-NAM

The NAM model is a hydrological model for calculation of surface runoff and runoff as a consequence of indirect influence from for instance infiltration from the surrounding soil. This model calculates the runoff on the basis of long rainfall time series. The use of NAM requires calibration on the basis of minimum 2 years of continuous runoff measurements. These data are often recorded at the treatment plants. By combining MOUSE-NAM and MOUSE-PILOT, all physical conditions in the sewerage system can be simulated.

MOUSE-PILOT

MOUSE-PILOT is a fully dynamic model simulating pipe flow, overflow, basins, etc. on the basis of long time series from historical rain. The model is able to carry out continuous calculations on a sewerage system with dynamic control where even complicated controls can be simulated.

By combining this model with the NAM model, the best match is obtained between reality and model.

SAMBA-STYR

Special edition of the SAMBA model used for simulation of SCADA in sewerage systems. The effect of the control is calculated and the control strategy for all the sewerage system's basins and pumping stations can be optimised.

SAMBA-RENS

Special edition of the SAMBA model which calculates the impact of rainfalls on WWTPs. The model calculates inflow statistics to be used in the design of plants, and it calculates the annual discharge of pollutants from the WWTP taking the fluctuating hydraulic loads into consideration.

SAMBA-EFOR

Linking of the SAMBA model in the MOUSE system with the EFOR model for WWTPs. With this model you can calculate the consequences of various combinations and measures in the sewerage system and at the WWTP with a view to obtaining the best possible system. This is especially relevant in the evaluation of the effect on the WWTP of changes in the sewerage system.

DOSMO

Special add-on module for SAMBA which on the basis of BOD_5 overflow pollution loads calculated by SAMBA computes the subsequent oxygen deficit in a watercourse serving as recipient for the overflows. The basins are designed to avoid fish kill as a consequence of occasional oxygen deficit following rainfalls.

CASE: CRACOW

In the period 1991-1994, we have used various computer models for computational purposes in Cracow.

Cracow's sewerage system consists of two isolated systems. Nowa Huta serving approximately 220,000 inhabitants and Cracow with approximately 500,000 inhabitants.

Nowa Huta

The combined sewer system serving Nowa Huta is generally overloaded in the sense that many of the combined sewer overflows (CSOs) start to overflow mixed wastewater and stormwater to the receiving waters at low rain intensities. On an annual basis, the pollution loads from the CSOs will be very small compared to the continuous discharge from the planned wastewater treatment plant. However, the CSOs will cause local pollution problems, especially in the River Dlubnia. Figure 5.

The construction of the planned supplementary collector sewer to the new treatment plant is an important and necessary first step in the process of upgrading the wastewater system in Nowa Huta in accordance with the water quality targets for the river.

Appropriate solutions for the planned supplementary collector have been developed and investigated using a computer model that has been set up for the main sewers in the Nowa Huta system. Pollution loads from the CSOs and the treatment plant have been computed by the model for alternative layouts of the system.

The ensuing improvement of the quality of the river has been roughly estimated on the basis of mass balance computations for various pollutants.

The civil engineering aspects of the construction of the planned supplementary collector have been evaluated and the costs of the various alternative layouts have been estimated.

The most feasible solution has been selected on the basis of an environmental, technical and financial comparison of the alternative layouts.

The outline design incorporates the provision of 3,800 m, ø2,000 mm pipe for a trunk sewer and 270 m, ø1,000 mm pipe for a connecting branch sewer.

Cracow

The sewerage system has been extended through several years around the old centre of the city. Several suburban districts have been connected to the skeleton of the system constructed in the early years of this century. The main part of the system was originally constructed to serve a smaller area and number of inhabitants than presently. Even relatively new sewer conduits (constructed in the fifties and sixties) were designed to originally serve small catchments. Figure 6.

Establishing the limits of the central sewerage system is very important for the future development of this part of the city. The capacity of the combined sewerage system determines plans concerning new construction areas as the acceptance of new connections to the central system will make it possible to avoid the construction of separate treatment plants serving new isolated sub-catchments.

The study has been performed in order to analyse present and future pollution loads caused by combined sewer overflows (CSOs) and to investigate the possibilities of additional future connections of new separate sewerage systems to the existing combined system. Hydraulic capacity problems have been examined in selected areas where flooding problems are reported.

There were three interesting problems to be investigated for the city:

- what is the present pollution load caused by CSOs?
- are there any possibilities of connecting more domestic inflows to the system? What will happen then as regards CSO pollution and the hydraulic capacity of the system (flooding)?
- are there any simple solutions to hydraulic capacity problems where flooding problems have been reported?

A mathematical model of the sewerage system has been set up covering the main sewers and structures in the Cracow system. The hydraulic capacity of selected sewer lines has been checked by a mathematical dynamic pipe flow model. Pollution loads discharged from the CSOs and the average number of CSO events per year have been calculated for a long-term series of rain events by a mathematical model for different alternatives of the population growth and proposed future extensions of the network. Calculations have been performed to assess the retention basin volumes required for different alternatives.

PRIORITISATION OF SEWER CATCHMENTS

In most of the municipalities, it is necessary to rank the sewer catchments in priority before starting extensive and expensive rehabilitations of the sewer systems. Only few municipalities have resources to carry out large rehabilitations over a limited number of years.

The following are examples of the aspects that experience has shown are relevant in most municipalities:

- The condition of the recipient and targets for an improved condition
- Flooding/hydraulic problems
- Operational problems
- Sewers in heavily trafficked roads/under buildings
- The most important sewers (main sewers)
- Areas with infiltration

The first action is therefore to take a look at the entire sewerage system of the municipality to get an overview of the locations characterised by these problems.

This overview will then allow a prioritisation of the order in which for instance CCTV inspection, flow measurements and the setting up of computer models should be made for the individual sewer catchments.

APPLICATION OF GIS

Until only a few years ago, all sewer systems were exclusively registered on drawings. It was very time-consuming to maintain these drawings and it was difficult to use data on the drawings direct together with other data, such as inspection and measurement data and results of computer modelling.

Therefore, much information - for instance from the daily operation - was not recorded systematically and stored and much useful information on renovations have consequently been lost.

The computer technology made it possible to store data in databases. In Denmark, the DAS-format is de facto standard for the exchange of data on sewerage systems. The DAS-format was developed jointly by among others the biggest Danish municipalities. This was the first step in the direction of systematising and distributing information.

Now the municipal public works department is facing increasing demands. Together with the technological development a better and more comprehensive service is required both from politicians and from citizens. The environment is playing an important part in local politics and the politicians require easily available information which can support the decision-making processes.

A Geographical information system is a computer-based system which can be used for input of data, administration, analysis and presentation of geographical data.

For many years, maps have been the medium used for geographical data. However, only a limited amount of information can be shown on one map. Therefore **thematic maps** have been produced. One map shows the network of roads, another map shows the sewerage system, others show the water pipes, the population density, the land register, the soil conditions, etc.

In GIS you also operate with **themes**. Data are stored on the basis of themes and by using GIS it is possible to analyse across the themes and even to produce new themes.

MEDINA

MEDINA is a Geographical Information System - specially designed for sewer registration. MEDINA is developed in co-operation between the two companies ALIGRAPH and KRÜGER.

Although, MEDINA is specially designed for sewerage engineering purposes, the system also allows the registration of many different other themes in the system. For the time being, themes have been developed for sewerage engineering, water supply, district heating and electricity. However, it is possible for the users to define further themes themselves. The municipalities that use MEDINA have defined themes for registration of biotopes, registration of toxic waste dumps, registration and maintenance of recreational areas, registration and maintenance of parking places, registration and administration of bottle and paper containers, registration of house owners' associations, registration of planning information, local plans, town planning regulations, etc.

The sewerage theme of MEDINA contains information on nodal points, sewer pipes, service pipes as well as results from CCTV inspections. Furthermore, the MOUSE theme contains results from MOUSE-PIPE modelling.

In MEDINA, there are facilities to search by geographical area, by values of the attributes and by combinations of the geographical area and the attributes.

You can for instance identify all sewers within a certain area with a gradient of more than x and a dimension smaller than y or all sewer pipes with hydraulic capacity problems and with dimensions of more than x.

Furthermore, MEDINA features a facility allowing production of thematic plots on basis of values in the database. E.g. you can make a plot, where the line-weight of the sewers symbolises the value of the describing element "dimension" or the colour of the sewer symbolises the value of the describing element "physical condition".

Finally, a program has been developed which can automatically generate longitudinal profiles of sewers. The sewer is selected by clicking on the nodal points in the order in which they appear on the sewer.

Data can be extracted in standard formats that can be used directly in e.g. MOUSE.

You can produce special plots by using the analysis tools, e.g. a sewerage plan where only serious damage found in a CCTV inspection is stated. Figure 7.

CASE: FARUM

The municipality of Farum covers 850 ha, has 140 km combined and separate sewerage pipes and 27,000 PE. Figure 8.

A comprehensive rehabilitation scheme has been carried out for catchment area 1 (of 3) covering the following activities: Generation of a sewer database based on the MEDINA program for the whole catchment area (including approx. 32 km of pipes and 775 manholes), CCTV inspection of 10 km sewer pipes (ø150-ø1350 mm) and 235 manholes and hydraulic analyses based on the MOUSE program. A rehabilitation plan involving the evaluation of pipe conditions, risk analysis and action plan (plan of civil works) has been carried out by means of MEDINA.

The rehabilitation project is carried out with due consideration to the recipient quality standards for the lake of Furesøen, to the planned extension of the Stavnsholt WWTP as well as to the municipal guidelines for the future operation, maintenance and extension of the sewerage system.

The first stage of the rehabilitation programme covered a preliminary overall survey of the municipality's total sewerage system. On the basis of the available information - such as complaints from citizens, operating experience and previous surveys - the most serious problems were assessed.

The registration of the pipes' conditions was concluded with a systematisation and graphic presentation of the results of the CCTV inspections by using MEDINA as well as hydraulic analyses (capacity and backwater analyses) of the performance of the system. The results were processed and presented in MEDINA as an important part of the evaluation of the physical and operational condition of the individual sewers.

After the evaluation of the condition of the individual sewer pipes and structures, a list of priorities was set up by the municipality and KRÜGER in co-operation. Special attention is paid to the points where problems will most likely arise and where the short-term effect of any malfunctioning will be most serious.

Subsequently, various overall solutions were prepared with the aim of solving physical problems, such as cracks, imminent collapse, corrosion as well as flooding and capacity problems which were detected through the hydraulic analysis (MOUSE).

The work has been summarized in the action plan proposing a list of activities ranked in priority with an estimate of the expenses, such as:

- operation routines
- manhole repairs
- sewer pipe repairs (spot repairs)
- sewer pipe rehabilitation
- further investigations

Table 1: Types of observations in the Danish photo manual

Cracks/broken sewers	1-4
Corrosion	1-4
Deformation	1-3
Joint displacement	1-4
Open joints	1-4
Protruding rubber ring	1-3
Roots	1-3
Infiltration	1-3
Encrustation	1-3
Deposits	1-3
Water	%
Obstructions/blockages	1-3
Branch pipe	0-3
Damage at side connection	0-4
Change of direction	0-3

Figure 1: Example of description and photos from the photo manual - cracks/broken sewer

2. RØRENES TILSTAND.

Revner/brud RB

<u>Definition.</u>

Rørenes bæreevne er overskredet, og der er sket brud i rørmaterialet.

<u>Klassedeling.</u>

1. <u>Fine revner.</u>

   Der er tale om fine revner, når ét eller flere af følgende forhold er til stede:

   * Fine brudlinier er synlige på rørvæggen.
   * Små udfældninger eller lignende tegn på rørvæggen, som højst sandsynligt stammer fra fine revner.
   * Små afskalninger.

2. <u>Åbne revner.</u>

   Brudlinierne har åbnet sig lidt. Rørets form er intakt, og skår af rørvæggen kan mangle.

3. <u>Brud.</u>

   Der er tale om brud, når ét eller flere af følgende forhold er til stede:

   * Brudstykker, der dækker mindre end 4 timer af røromkredsen, er forskudt i forhold til hinanden eller mangler helt.
   * Ved deformationer op til 15% af rørdiameteren (gælder kun stive rør).

6 89.09 89.09

1

2

3

Figure 2: Results from operation of a pumping station

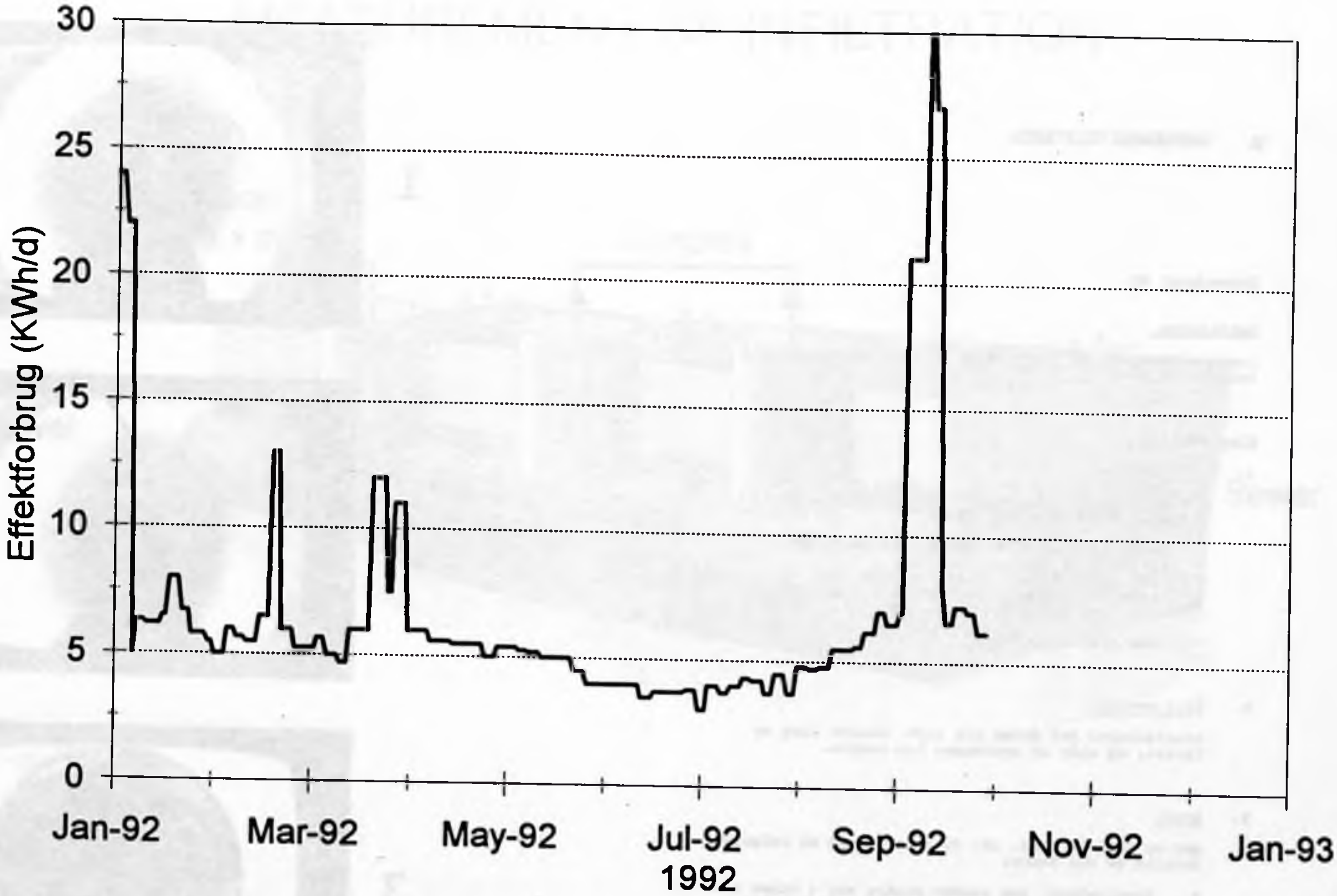


Figure 3: Illustration of Krüger tracing

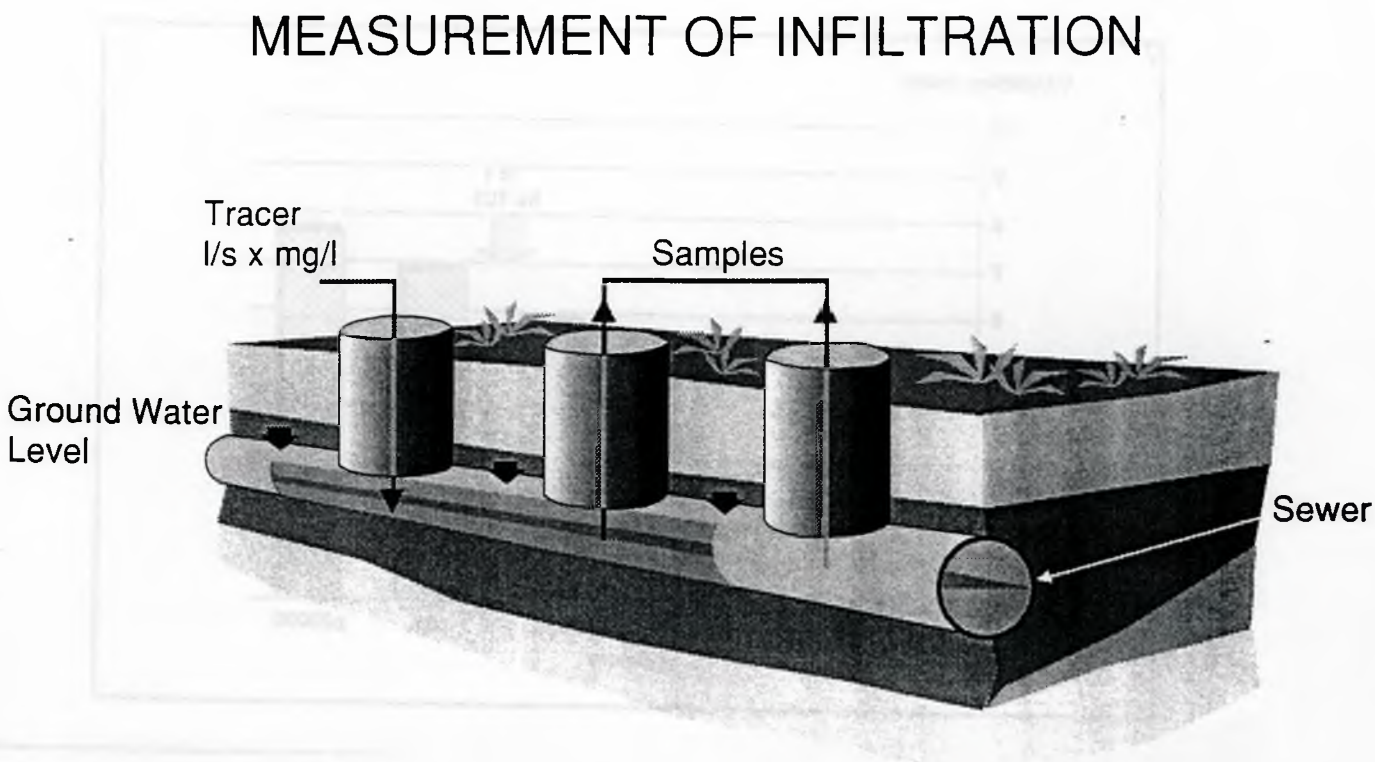


Figure 4: Results of measurements

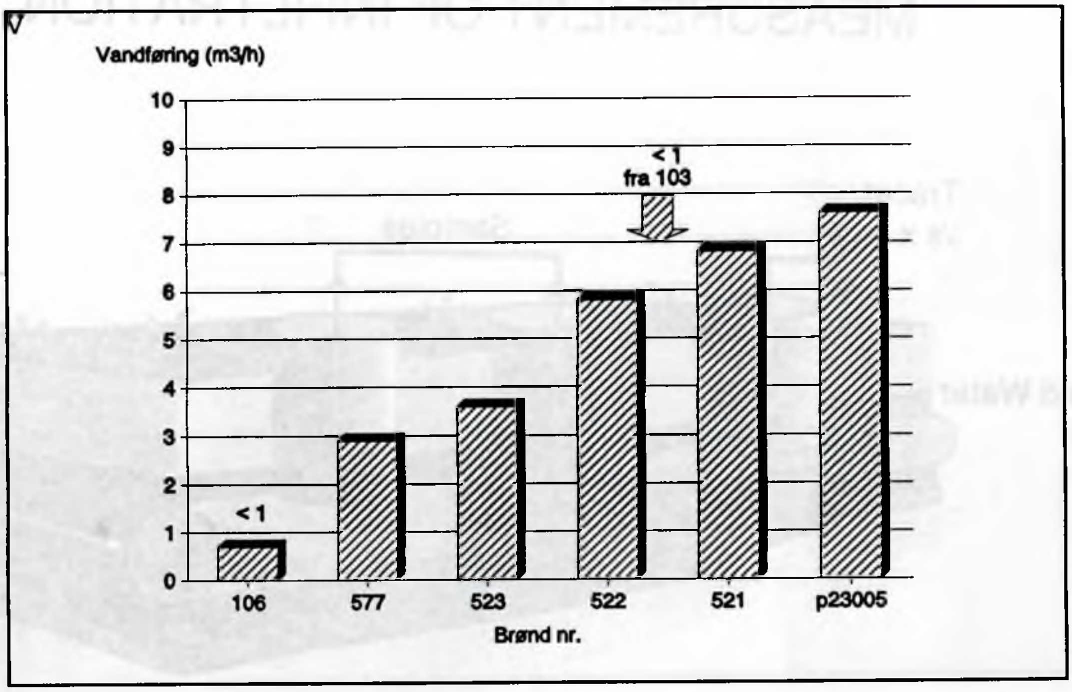


Figure 5: The Nowa Huta sewerage system

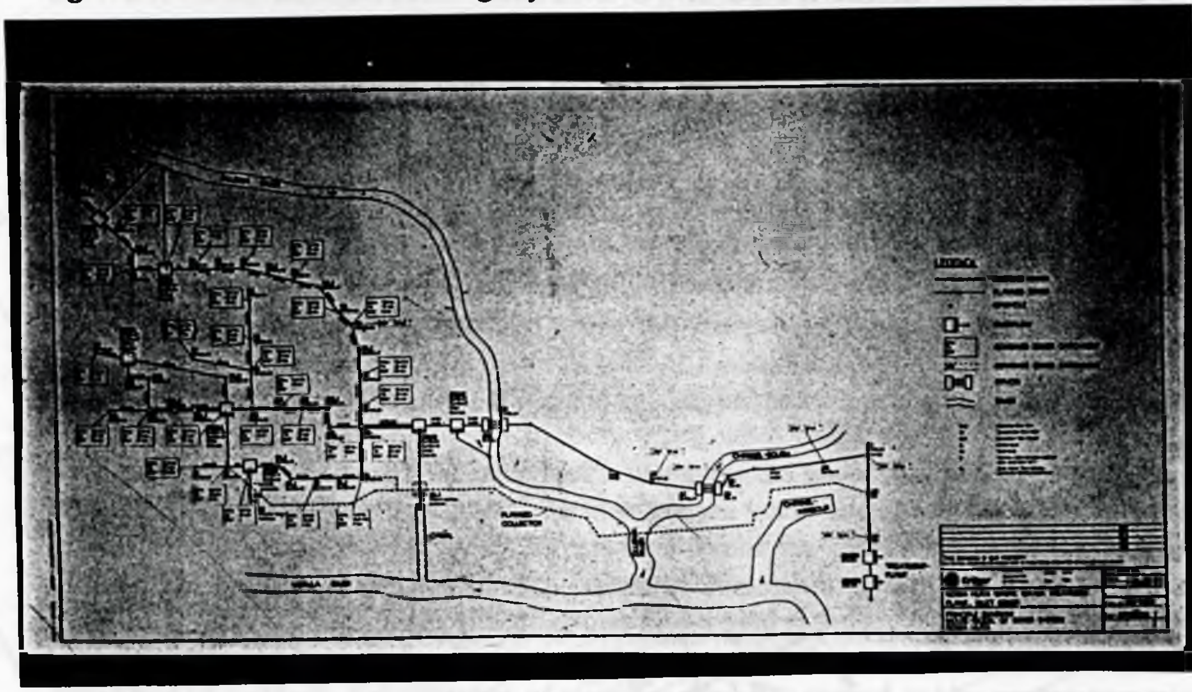
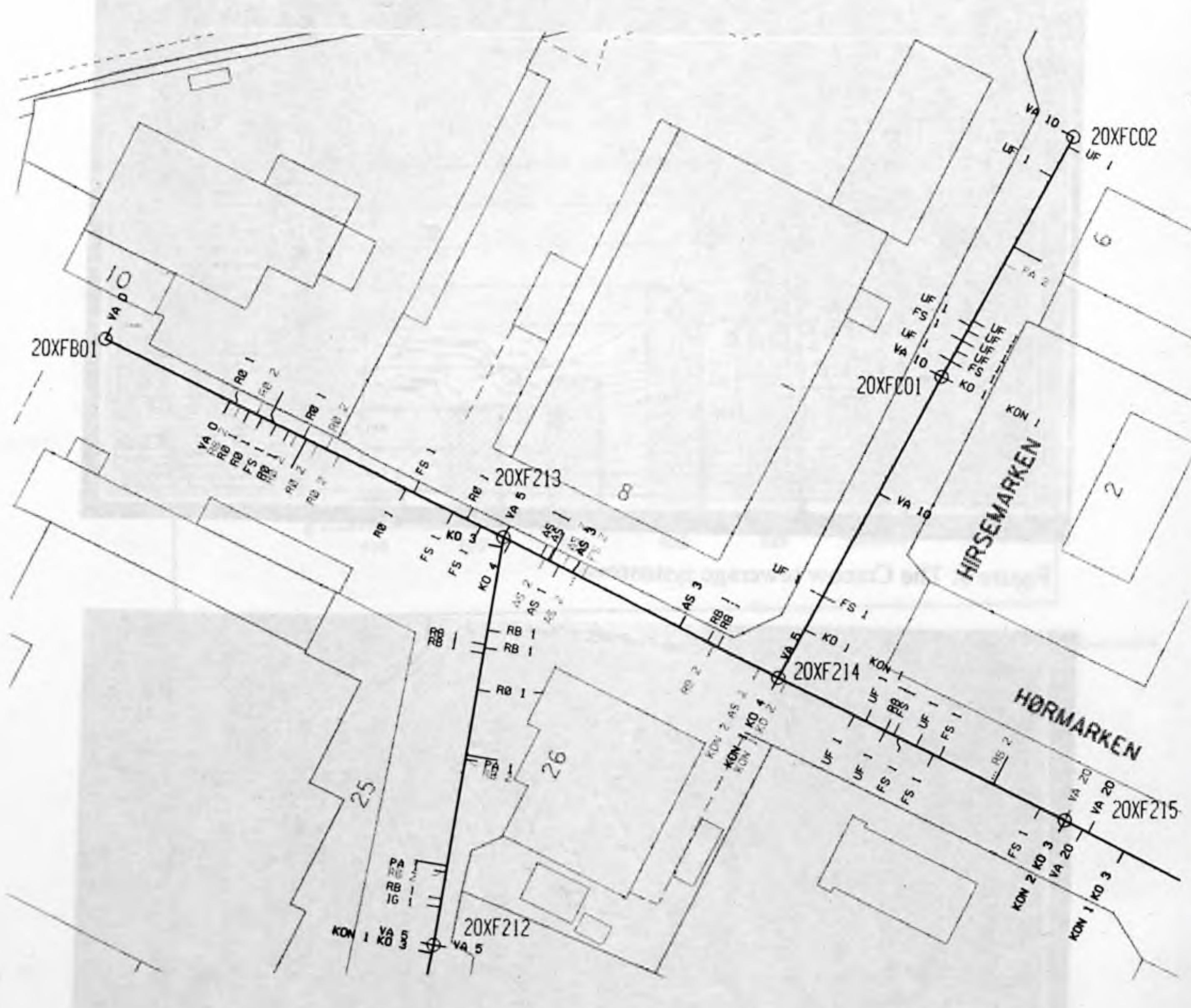


Figure 6: The Cracow sewerage system

Figure 7: A MEDINA plot with the observations from a CCTV inspection



SEWER REHABILITATION AROUND GULF OF FINLAND

Matti Ojala, Viatek Group, and Sakari Kuikka, Painehuuhtelu Oy PTV and Insituform Suomi Oy, Finland.

SUMMARY

This presentation gives an introduction to the Finnish concept for sewer rehabilitation and to the experience of Viatek Group, Painehuuhtelu Oy PTV "Pipe Wash Ltd" and Insituform Suomi Oy from several projects around the Gulf of Finland.

Based on the facts received from the Finnish National Board of Waters and the Environment concerning the state of the Gulf of Finland it is obvious that all efforts to reduce sewage originated load to the Gulf of Finland have to be made especially on Russian and Estonian side.

KureCAD-software is the main tool in managing the sewer data and in planning within our concept. With the software it is possible to measure the water and sewer networks in coordinates, prepare network maps and collect information about the pipelines for design purposes. In connection with this work the needed reference maps and existing network maps are usually scanned from original paper or plastic copies into digital format.

In the old historical cities in general the most feasible rehabilitation methods are the so called NoDig methods. Rehabilitation of pipelines is mainly carried out by contractors specialized in these kind of projects. The am companies are today cooperating also with Water and Sewage Works of St. Petersburg, Russia. The main project aims to rehabilitate the sewers of the Nevsky Prospect street at a length of 6 - 8 km.

It is possible to get grant money from various sources for sewer rehabilitation projects. Own funds of the organisation and the influence of the project to protect the environment have been taken into consideration by the Finnish Ministry of Environment when making decisions on funding.

INTRODUCTION

Viatek Group as consultant and Painehuuhtelu Oy PTV "Pipe Wash Ltd" together with Insituform Suomi Oy as contractor have been involved during last three years in several sewer rehabilitation projects around the Gulf of Finland. This presentation is a short introduction to our experiences and concept in sewer rehabilitation.

STATE OF THE GULF OF FINLAND

The state of the Gulf of Finland has been followed with great concern. To understand the willingness of the Finnish Government to support pollution protection projects e.g. sewage treatment and sewer rehabilitation also in Russia and Estonia one has to study the following figures about phosphorus and nitrogen loads to the Gulf of Finland.

Phosphorus load to Gulf of Finland, 100 tons/a:

Country	**Rivers**	**Domestic and industry**	**Sub.tot**
Finland	600	200	800
Russia	5.300	3.500	8.800
Estonia	1.700	500	2.200
Total	**7.600**	**4.200**	**11.800**

Nitrogen load to Gulf of Finland, 1.000 tons/a:

Country	**Rivers**	**Domestic and industry**	**Sub.tot**
Finland	17.000	5.000	22.000
Russia	60.000	21.000	80.000
Estonia	42.000	5.000	47.000
Total	**120.000**	**31.000**	**150.000**

Fig.1 illustrates the eutrophy of the Gulf of Finland during mid and late summer as chlorophyll content (mg/m^3).

Based on the am facts (ref. National Board of Waters and the Environment, Finland) it is obvious that all efforts to reduce sewage originated load to the Gulf of Finland have to be made especially on Russian and Estonian side.

DATA MANAGEMENT

However reference to any product by company named should be avoided in this kind of connection, Viatek's KureCAD-software has to be mentioned and described in more details, because it is the main tool in planning sewer rehabilitation in our concept.

Present KureCAD users in connection with the Gulf of Finland are the Cities of Helsinki and Espoo in Finland, Tallinn in Estonia and recently Viatek has delivered to Water and Sewage Works of St. Petersburg, Russia, the Russian version of the software for test use and the needed hardware (workstation, scanner and takymeter with data logger).

The starting point for the development work of the system was the fact that accurate network maps are often missing and that data collection concerning water mains and sewerage network is difficult without modern tools. Even though various report forms are filled, it is still almost impossible to find and use them later when suddenly needed. Sooner or later this kind of occasional reporting results to zero-reporting.

KureCAD-software provides an efficient solution for mapping and data collection. The software makes it easier to plan all kinds of measures needed in management of networks. The software is used together with a digitized or scanned reference map. Pipelines can be mapped and fixed to coordinates. The software acts as a store for all kind of network data, which are illustrated graphically and which are saved also into the database. User can make queries from the database and see the result on the display screen.

The software is based on Oracle database and AutoCAD graphics (also available as a MicroStation version). An AutoCAD product CADOverlay ESP (or IRAS PC with MicroStation) is needed for scanned map manipulation.

MAPPING

Accurate maps are a must when sewer rehabilitation will be started. Very often happen that the existing maps are inadequate by quality and at least the z-coordinates are missing.

The network map can be created by:

- measuring the x,y,z-coordinates of each element of the network with special measuring equipment
- using existing hard copy maps and forming the digital map by scanner technique and screen digitizing
- using existing hard copy maps and forming the digital map by manual table

- digitizing
- transferring the digital map from other mapping softwares.

In any of the am cases a network map as shown in fig. 2 will be produced including the desired symbols for manholes, valves, fire hydrants etc.

INVESTIGATIONS

When the network is mapped by measuring the coordinates, also the pipe materials and diameters will be checked. In other alternatives of mapping the attributive data may be found from the existing maps.

In any case the first phase of investigation, when evaluating the state of the sewer network, is to investigate the sewer manholes. A special manhole card is developed in order to make the investigation a routine and ensure the transfer of data to KureCAD database. The material, diameter and general structure is recorded as well as the condition of the manhole. Special attention is paid to possible leaks into the sewer.

After cleaning the sewer with high pressure flushing CCTV-inspection will be carried out. A standard form is used when recording the foundings. Painehuuhtelu PTV Oy has developed a computerised recording system where the client is getting the document either as disc or a hard copy. This enables also the transfer of the data automatically into KureCAD database to be illustrated on the computer screen as symbols on correct places along the inspected sewer (see also fig. 3).

If the target is mainly to reduce the intrusion of excess waters into sewer system the investigations are often started with flow measurements in order to find the most leaking parts of the sewer system.

PLANNING

Planning, when discussing sewer rehabilitation, is mainly concentrated on evaluating the need of rehabilitation and prioritising the works. According to our concept the planning is done using the collected information and KureCAD-software and its' condition classification as a tool.

Every pipe and equipment in the system have estimated condition. Condition concept consists of three elements:

- Constructional condition
- Functional condition
- Leaks

Constructional condition estimates the strength, shape and positional status of the pipe. Functional condition estimates the ability of the element to conduct water. Leaks are estimates of the leakages from the element.

Each of these are measured with a scale from 1-4, in which 1 means a good condition and 4 a very bad condition. These estimates are judged by the maintenance or repair operations as follows:

Score	Verbal	Repairs
1	Good	No repairs
2	Satisfactory	Small problems, no actions yet
3	Bad	To be repaired in near future
4	Very bad	To be repaired immediately

Each pipe is classified also by the external factors. These factor describe how difficult the possible maintenance operation would be and the importance of the pipe for the system. These could be also called strategic importance classifications.

External factors are:
- Importance of the pipe to the system
- Clients
- Conditions above the pipe
- Conditions around the pipe

Each of these conditions are measured with scale 1-4, in which 1 means an easy situation and 4 very difficult.

Condition estimate for each pipe is based on index value 'Ojala Index' that calculated from constractual, functional and leak estimates. Also the external factors are taken into consideration. Reliability of these estimates are also in the system.

Estimates can be based on inspection, on applied knowledge, on experience or on no knowledge. Applied knowledge means that inspection results of a pipe are applied to other pipes which have similar constructional, functional and environmental features.

These factors in this calculation can be assigned different weights. Different network types have different characteristics and therefore system have a separate set of weight values for each network type. Following example will clarify the issue.

Example:

This sewer pipe is quite important for the network. There are no clients joined directly to the pipe. This sewer goes under a highway for some distance and is placed 2.5 meters deep. There has been couple of settlings and some degree of deformation reported. Functionally the sewer has worked satisfactorily. There are no leak water in the pipe.

External Factors:

	Weight			Value
Importance of the pipe	9	x	3	= 27
Clients	4	x	1	= 4
Conditions above the pipe	6	x	3	= 18
Conditions around the pipe	6	x	1	= 6
Sum	25 (constant)			55

Scale for external factors	Classification	
25-40	1	
41-60	2	(55 => class 2)
61-80	3	
81-100	4	

Condition index (CI):

	Weight			Value
Constructional condition	9	x	3	= 27
Functional condition	7	x	2	= 14
Leaks	6	x	1	= 6
External factors -	3	x	2	= 6

Sum	25 (constant)	53

The condition index of this sewer pipe is 53 (3,2,1,2). Condition index is always in the range 25-100.

In the KureCAD graphics the condition index value is displayed in the code box for each pipe. The condition index value colour is changed by its value, 25 to 49 is displayed in green, 50 to 74 in yellow and 75 to hundred in red.

CONTRACTING

Rehabilitation of pipelines is mainly carried out by contractors specialized in these kind of projects. Also the cities' own organizations have carried out rehabilitation works, although lately to a lesser degree. Implementation by a specialized contractor ensures the successful outcome of the rehabilitation work as well as the high quality of the final product, so that the rehabilitated pipeline can be used again a long period, with modern materials more than fifty years.

Guidelines and policies for pipeline rehabilitation have been prepared on different national levels, but the documents are of a different quality in different countries. The European Union has been preparing directives to unify the practices, which in turn will support in achieving a good, long-lasting and economical result.

NODIG

In the old historical cities in general the most feasible rehabilitation methods are the NoDig methods, e.g. lining with cured in place pipes, lining with continuous and discrete pipes, lining with close-fit pipes etc., which allow to achieve cost effective result taking also the environment into consideration.

Implementation of NoDig rehabilitation of pipelines begins with cleaning and CCTV-inspection before installing a new pipe. These measures secure the successful outcome of the installation as well as the best possible and effective result. If the cleaning will not be done, the condition of the rehabilitated pipeline may turn out to be even worse than the initial situation.

Our concept in sewer rehabilitation has in most cases been the Insituform method (see also fig. 4). At the work site the NoDig rehabilitation work itself is very fast. The work requires very thorough preliminary preparation in order to take into account all necessary aspects to ensure the implementation efficiently and without any problems.

With the necessary by-pass pumping the operation of the line section is secured during implementation of the rehabilitation. Flow of traffic during the work has also to be considered as well as free access to the buildings in case of emergency.

The pipe itself is taylor made in a factory according to the detailed design and e.g. Insituform Suomi Oy is using materials according to ISO 9001 quality standard.

Installation of the pipe can be started, after the above mentioned preparations have been executed and the pipe is delivered to the work site. Installation itself is done fast, taking from one to three days, depending on the diameter and the length of the pipe. Pipe connections are opened and the pipe can carry on its task for decades to come in perfect working condition.

PROJECT PRESENTATION

Following are presented some examples of our projects within the sphere of influence of the Baltic Sea.

The company represented by us and its branches operate actively in the countries surrounding the Baltic Sea: Finland, Sweden, Denmark, Germany, Poland, Latvia, Lithuania, Estonia and Russia, applying NoDig methods in rehabilitation work. We have rehabilitated some

1.000 km of pipelines in this area. The most popular among the methods used by us is the Insituform-method, which has been used for a length of more than 8.000 km in different countries in all parts of the world.

At the end of 1994 Per Aarsleff A/S from Denmark, Insituform Suomi Oy and Viatek Group from Finland, in co-operation with Water and Sewage Works of St. Petersburg (Vodokanal) have started an extensive sewer rehabilitation project in St.Petersburg in order to rehabilitate the sewers of the Nevsky Prospect street (see also fig.5) at a length of 6 - 8 km.

The project includes cleaning and inspection of the sewers as well as the delivery of the equipment required for the work, planning, design and implementation of the rehabilitation as well as training of the Russian personnel.

FINANCING

The total cost of the Nevsky Prospect project will be 12,5 million USD, including foreign currency and local costs. Vodokanal itself and the Danish and Finnish Ministries of the Environment together are financing the project. The share of Vodokanal is about 80 %.

In this kind of pilot projects the share of granted money from e.g. the Ministries of the Environment can vary from 20 to 50 %. An important aspect in obtaining support has been the fact that the project will have an effect in protection of the environment by reducing the waste load to the Gulf of Finland.

The local financing share in hard currency has also been a must in obtaining a positive decision in project aid requests.

Organizations as World Bank, EBRD and NEFKO have also granted loans and risk financing for projects improving the state of the environment.

Fig. 1. The eutrophy of the Gulf of Finland during mid and late summer as chlorophyll content (mg/m^3)

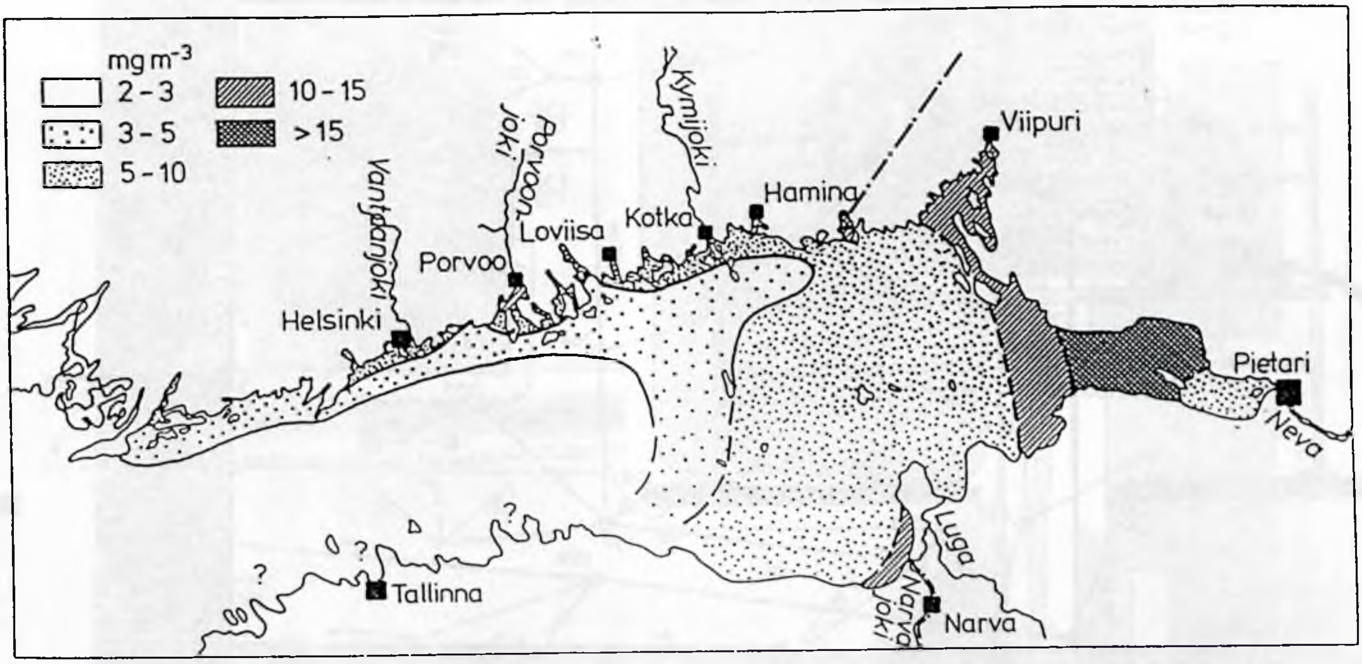


Fig. 2. Network map produced by the means of KureCAD software

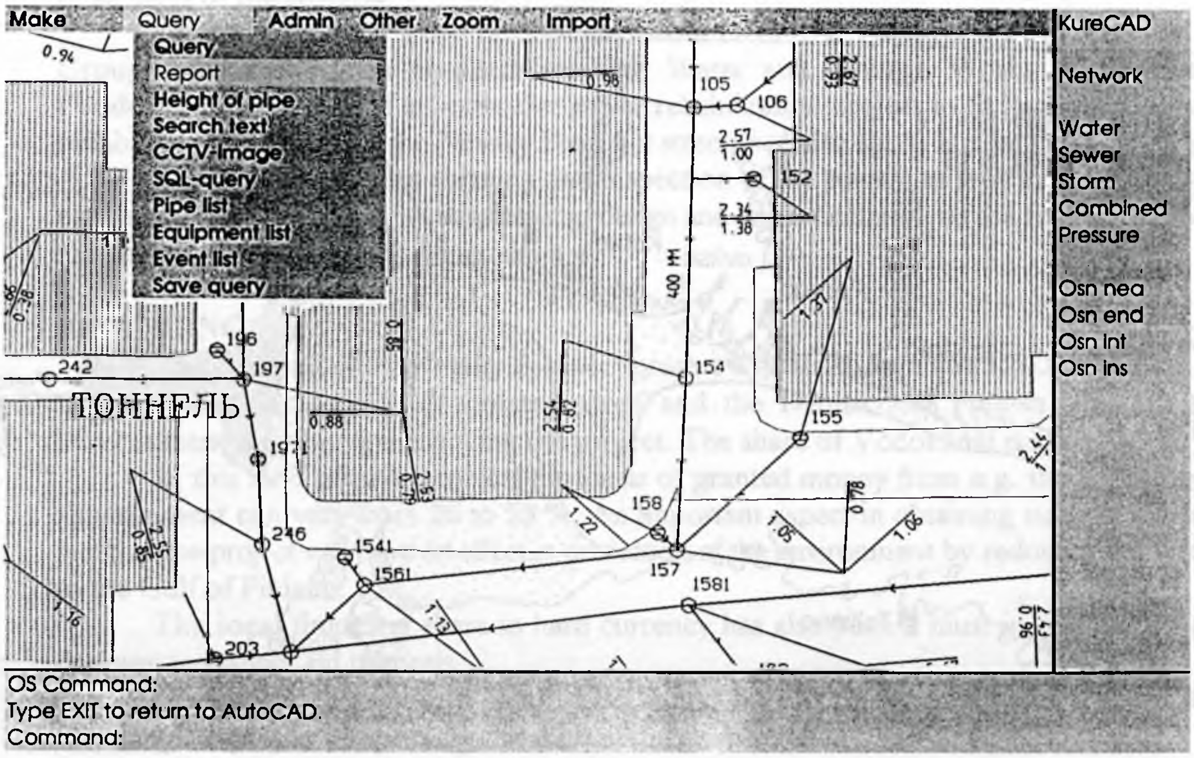


Fig. 3. Sewer data is collected and saved in the database and illustrated graphically

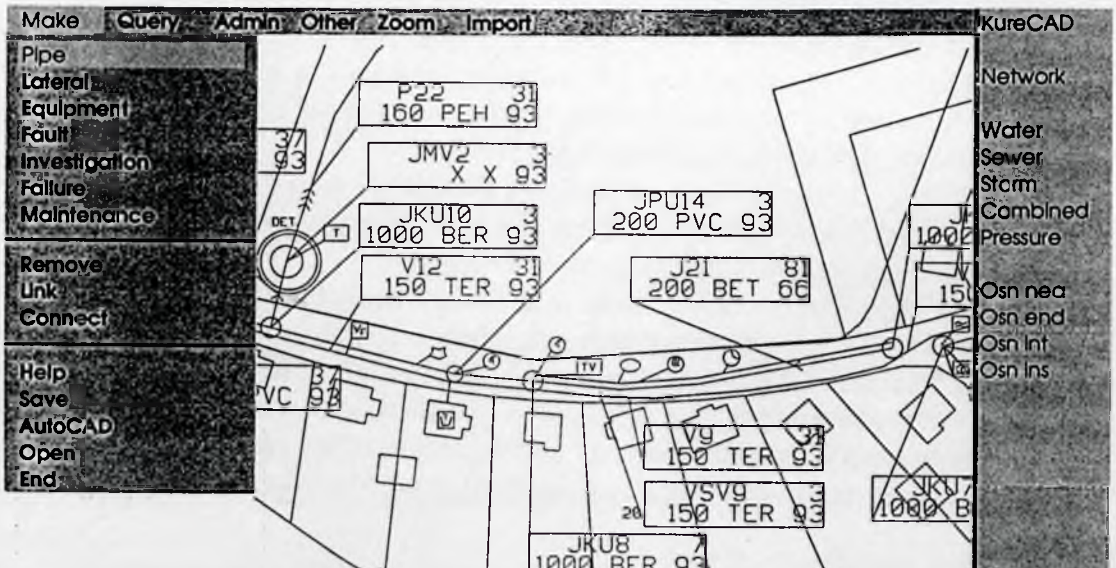


Fig. 4. NoDig method by Insituform

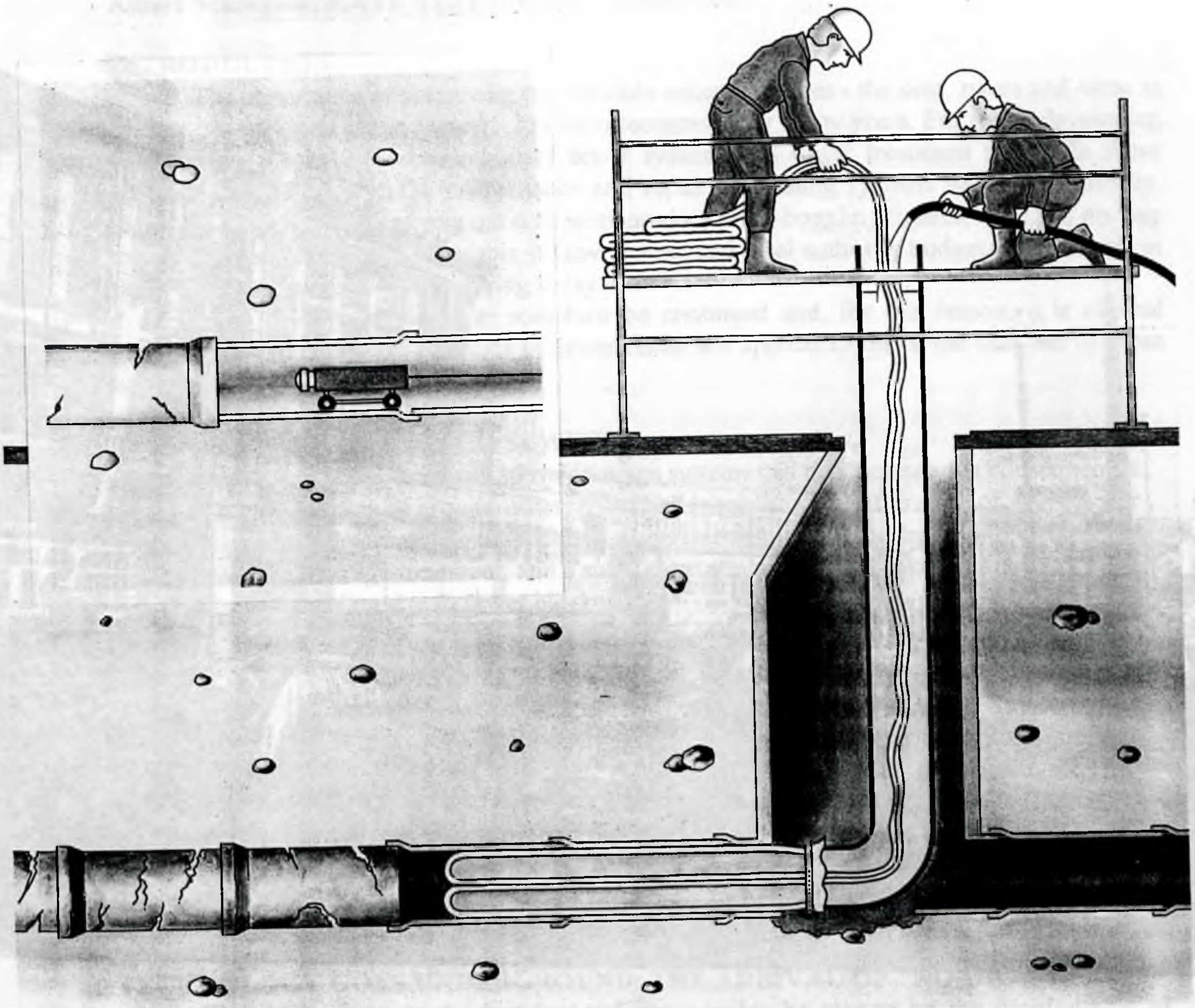


Fig. 5. Work site on Nevsky Prospect street in St. Petersburg, Russia

ROBOT TECHNOLOGY

Albert Schreibelt, KATE SYSTEMS Ltd., Switzerland

INTRODUCTION

The importance of preserving our valuable water resources - the seas, rivers and lakes as well as our precious ground water - has been recognised for many years. For many developing nations this means the construction of sewer systems and water treatment plants. In more advanced countries it is the maintenance and repair of existing systems which has priority. Estimates on the costs of carrying out such work produce mind-boggling figures, which in no way can be covered by the money available in Government and local authority budgets, particularly in times of recession, as we are suffering today.

The work must however somehow be continued and, for this reason, it is of vital importance that economic methods of sewer repair are applied to make the best use of these limited resources.

THE NECESSITY TO REPAIR SEWERS

Damage in sewer lines and storm drainage systems can produce serious consequences:

- Pollution of ground water, rivers and lakes through exfiltration of waste water
- Overloading of water treatment plants through infiltration leading to drop in levels of sewage treatment, and a subsequent strain on rivers, lakes and the sea
- Flooding due to sewer blockages
- Road and building damage following collapsed sewers
- Flow obstruction due to defect laterals and slipped joints

Whilst repair and maintenance of man-entry sewers has always been carried out, the difficulty of access to non man-entry pipes meant that this area was neclected for decades. Simple maintenance, such as the clearance of blockages, was untertaken, at the beginning by simple manual rodding and later using high pressure water jetting systems. Problems such as infiltration and exfiltration, cracking and breaking out of pipe walls could however not be solved and it was normally only when a sewer collapsed that repair work was carried out - by digging out the broken line and replacing it totally with new pipe sections.

TECHNOLOGY GOES UNDERGROUND: THE ARRIVAL OF "NO-DIG"

The appearance ot the first "robots" can possibly be said to be the development of inspection cameras used to examine the damage within non man-entry lines. Originally these were simply dragged through the sewer using a winch located at the manhole, but were gradually developed to become self-propelled and remote-controlled, and capable of recording on video all damage in the most minute detail. It was this development which alerted the authorities to the massive amounts of damage in our sewers and to the potential dangers to our environment. (Illustrations 1 - 6 show typical types of sewer damage recorded by C.C.T.V.).

In the face of this problem, over the past twenty years various innovative systems have been developed to offer "trenchless" solutions, laying the foundation for the now well established "NO-DIG" industry. Gel-injection packers appeared to tackle the problem of leaking joints; slip-lining systems and the revolutionary cured-in-place soft relining system were developed and rapidly became widely used as an alternative to dig-downs and total renewal. More recently we have seen the appearance of fold-and-form relining and cure-in-place patch systems as well as burst-lining systems as an alternative to total renewal in cases of massive structural damage.

All of these methods of pipe repair and maintenance have their valid place within the vast battery of alternatives now available to the engineer given the unenviable task of maintaining his sewer lines on a very limited, and possibly shrinking, budget. His problem is how to make best use of these limited resources, by selecting the repair method best suited the problems on hand.

The appearance in Switzerland of the first robot sewer repair system powered by hydraulic motors in the early 1980's provided a flexible solution to the vast array of sewer problems and provided the possibility of not only carrying out localized (or spot) repairs, but also of working in combination with other repair systems to provide a universal solution.

SELECTING THE MOST SUITABLE METHOD

In order for the engineer to make his choice of repair method he must first of all examine two things:

1. the extent of damage to the pipe in question
2. the suitability of the various repair methods

In examining the damage level it must be decided if the pipe still has structural strength, if it has loss of diameter, what is the possiblity of imminent collapse etc. To aid such evaluation, the WrC (Water Research Council) in Swindon, England has developed an interesting grading system for sewers from 1 (good) to 5 (collapsed or near collapse), allowing authorities to set their priorities in their sewer repair programme. Illustrations of this grading system are shown below (Illustration 8).

In his paper entitled "Localized Sewer Repairs in Northumbrian Water", presented at NO-DIG in Paris, Mr. Brian Syms of Northumbrian Water, illustrated how it could be possible to link such a grading to the method of sewer repair most suitable.

It is unfortunately however not quite so simple. Added to the evaluation of the extent of the damage, other important factors must be taken into consideration:

- depth of the pipe and type of soil
- diameter of pipe
- position (i.e. rural or urban), traffic conditions
- type of sewage (industrial, domestic)
- ease of access
- pipe material
- ground water level
- etc.

Against this damage evaluation the engineer must then appraise the suitability of each repair method. Each of the methods mentioned earlier have their strengths and special suitabilities, but it must also be said that equally each also has its weaknesses and limitations.

In the following table a strength/weakness analysis is given of each of the repair methods. This is not meant to be exhaustive but merely a general overview in the decision-making process.

FLEXIBILITY OF ROBOT REPAIRS

As well as these technical considerations, the vital questions of cost and speed of repair must be asked. It is obvious that a sewer line must be closed down for as short a time as possible and, whilst diversion pumping may be possible for the main sewer, the closure of domestic connections for any length of time can cause major problems and inconvenience. This is one of the areas where spot repair using robots without the necessity of closing laterals has proven to be a flexible and cost-effective method.

This flexibility can be demonstrated by the types of repair which can be carried out using robots. Thanks to a powerful hydraulic motor, the robot can grind back protruding laterals and remove scale quickly and cleanly. This power, achieving 4,6 horse-power, is particularly important where to a great extent the pipes, including laterals, are reinforced with steel. By their nature, sewers are also dirty and greasy and once again it is of utmost importance to grind back to clean concrete or clay before any repair work using epoxy fillers can be carried out. A selection of quick-change drill bits and grinders provides the flexibility needed to handle any type of grinding and milling work required (Illustration 9). Therefore in the case of repair to radial or lateral cracks, these must also be ground out prior to any filling. As sewer shut-downs must be avoided, the robots are also capable of working under water, the only possible restriction being impaired vision when working in cloudy water.

SPECIALLY DEVELOPED EPOXY FILLERS

The necessity to be able to work in water was also a major parameter in the development of epoxy resins suitable for robot application. In the case of the KA-TE robot system, the epoxies were developed by Master Builders and, as well as high final adhesive strength, they provide excellent initial wet adhesion, good workability and rapid hardening. To provide high and low temperature working, two different epoxies are available depending on conditions prevailing.

In the case of laterals, joints and cracks showing infiltration the robot system is also provided with a gel injection attachment (Illustration 9), allowing leaks to be sealed prior to actual repair work being carried out.

REPAIRING LATERALS

The tricky case of recessed laterals can also be handled robotically. Firstly, the area around the lateral is ground clean, following which a balloon is inflated into the connection using the filler robot. This balloon can be provided with a built-in pipe, allowing drainage from the lateral under repair throughout the entire operation (Illustrations 10 + 11).

Once the balloon is fitted, the epoxy resin is injected into the voids under pressure, filling the gap between the recessed lateral and the main sewer completely. Following hardening (approx 4 Ð 5 hours), the balloon is removed and the epoxy ground clean to provide a tight, neat connection. During hardening the robot system can of course be attending to other repair work in the same line, or even do other jobs further afield. The rapid set-up and break-down time by the two-man crew allows great mobility between job sites, meaning that the equipment is not blocked on one sewer line until that particular job is completed.

ROBOTS OR RELINING?

Such a flexible and powerful sewer repair robot system can be ideally used in sewer lines where various types of localized damage are found. As long as the extent of the damage is below a certain level, then robot repair works out also far more economical than manhole-to-manhole methods. Diagram 1 gives a general overview of cost development of robot repair versus re-lining. It can be seen that the re-lining curve is far steeper than the robotics curve, due to the fact that the cost of the re-liner itself is directly proportional to the diameter of the sewer and is a significant part of the overall cost. In the case of robotic repair, costs increase only slightly with increasing diameters, representing the extra time required as well as the slightly higher consumption of epoxy filler.

With increasing levels of damage (i.e. an increased number of individual repairs) it can be seen that the curve representing robot repair shifts upwards until a point is reached where this type of repair becomes uneconomic compared to the re-lining methods.-However, once again here, other parameters such as site location, inconvenience to local residents, number of laterals etc. still must be taken into consideration before a final decision can be made.

Diagram 2 shows a direct cost comparison robots versus cured-in-place re-lining based on market price levels in the S.E. of the USA. For the sake of this example on arbitary "mix" of damage was taken:

- 4 joints
- 2 lateral connections
- 10 feet of longitudinal cracking(all in one 300 feet of sewer line)

These prices may vary slightly from region to region depending on local conditions, but the example demonstrates the savings to be made by selecting the repair method to suit the extent of damage.

COST EFFECTIVENESS THROUGH TECHNOLOGY SELECTION

Selection of this sort can prove particularly effective in the case of large projects, where the level of damage may vary significantly from section to section. Here it may prove far more economical to renew the areas of greatest damage, re-line areas where frequent damage is found, and use localized repair with robots for the least damaged areas.

It is large projects such as the above which underline the economic significance of the robot system's flexibility. In such cases the robot can work hand-in-hand with other technologies to provide the optimum solution.

In the case of a joint project involving in-lining, the robot is used:

- to clear the sewer line rapidly of obstructions such as protruding laterals, roots, encrustation as well as smoothing out slipped joints
- to repair recessed, broken out and leaking laterals prior to the in-liner being inserted (in this way the tightness of the connection can be ensured after re-lining) (Illustrations 12 A + B).
- to re-open laterals following re-lining.

The robot's power has also been called upon on numerous occasions to cut a path clear to allow initial C.C.T.V. inspection to be carried out!

CONCLUSION

In order to stretch his limited budget as far as possible to repair and maintain his sewer lines, the municipality engineer faces a difficult choice in the face of the numerous technologies at his disposal nowadays. By carefully examining and qualifying damage levels, considering site problems, and weighing up the strengths and weaknesses of each repair method, and by doing this for each sewer section, he can however make a selection of the best methods and hence optimize cost effectiveness. The flexibility of robot repair methods offers new opportunities for cost saving, both as a stand-alone technology for localized repair as well as in combination with manhole-to-manhole solutions. Diagram 3 summarizes the positioning of the various repair and maintenance technologies.

The flexibility of robot repairs is further illustrated below

Comparison of Alternative Sewer Repair Technologies

Process	Open type	Burst lining	Soft/hard Relining	Part lining	Robot systems	Packing systems
Description	- Excavation, replacement of pipe	- Existing pipe is bursted by forcing through projectile - New pipe inserted behind	- Insertion and inflation of reinforced epoxy/PES stocking - Hard pipe insertion	- Insertion + inflation of short resin-reinforced stocking	- Local repair of pipe by remotely controlled robot	- Positioning and inflation of packer followed by gel injection
Areas of application	- General repair of complete structural damage - Pipelines close to the surface - Open areas with no obstacles	- Replacement of badly damaged sewers - Runs with few laterals	- From manhole to manhole - Medium level of damage	- Repair of holes + areas of extensive cracking	- Up to 135 m from manhole - Different types of damage within same pipe section can be repaired	- Only repair of joints
Advantages	- Completely new pipe - Longer lifetime - Modification of diameter possible - Simple and well known technology	- New pipe inserted - Limited surface disruption	- No excavation - New pipe within the pipe - Tightness very good	- No excavation - Economic compared to manhole-to-manhole - New pipe within pipe	- No excavation - Very flexible - Repair limited to area damaged - Small area occupied - Quick, economic	- No excavation - Inexpensive - Efficient
Disadvantages	- Large surface area disturbed - Risk of damaging other pipes and cables when excavating - Disturbance of traffic - Expensive - Time consuming	- Excavation required - Laterals reconnected by digging	- Reduction of pipe diameter - Pipe has to be relined in full length - Lateral connections difficult to reconnect - Bulky equipment - Limited diameter (fold + form)	- Tightness of pipe questionable - Limited application	- Specific diagnosis necessary - Skilled operator	- Only joints can be repaired - No permanent solution - No structural repair - Toxicity of gel

Illustration 1: Protruding lateral

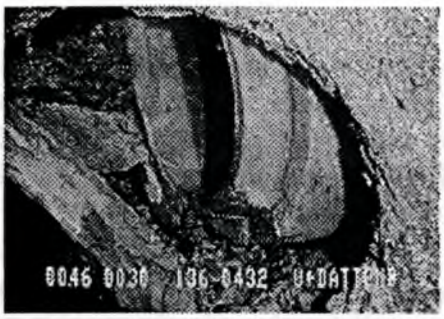


Illustration 2: Lateral broken out

Illustration 3: Slipped joint, infiltration

Illustration 4: Cracking

Illustration 5: Hole, broken out invert

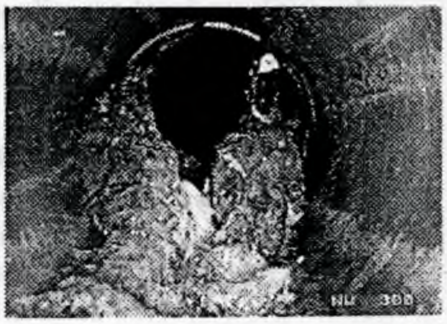


Illustration 6: Slipped joint, root ingress

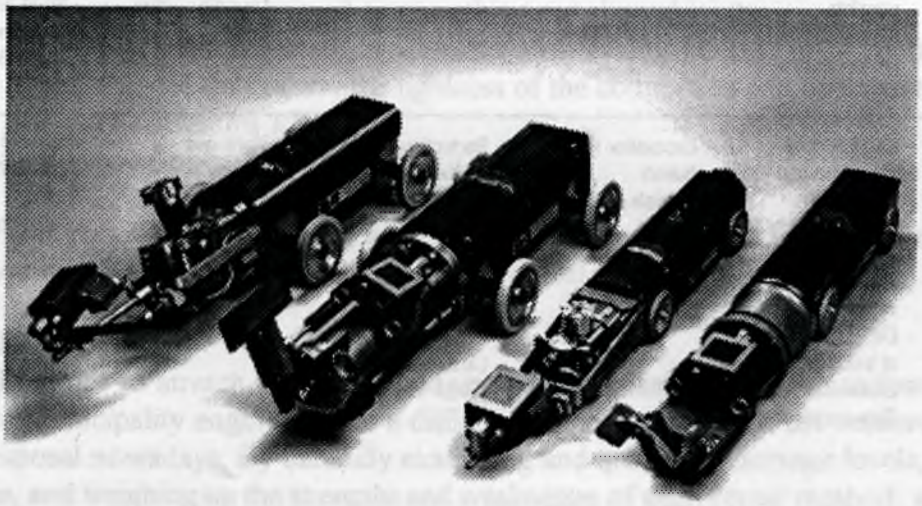
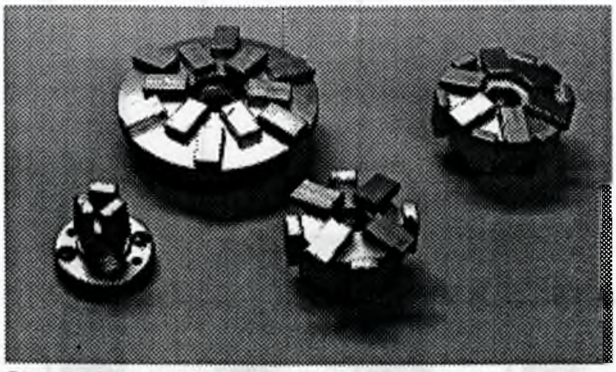
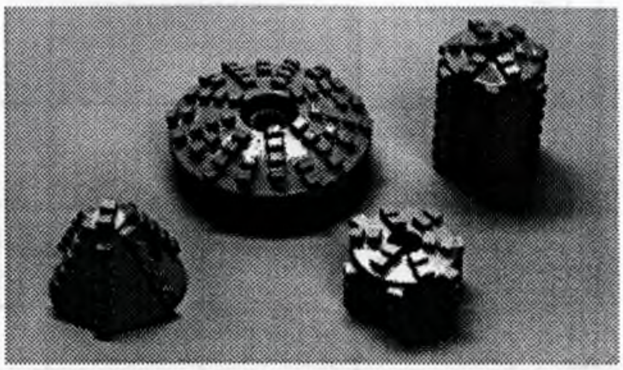


Illustration 7: KA-TE Robots for the repair of non men-entry sewers

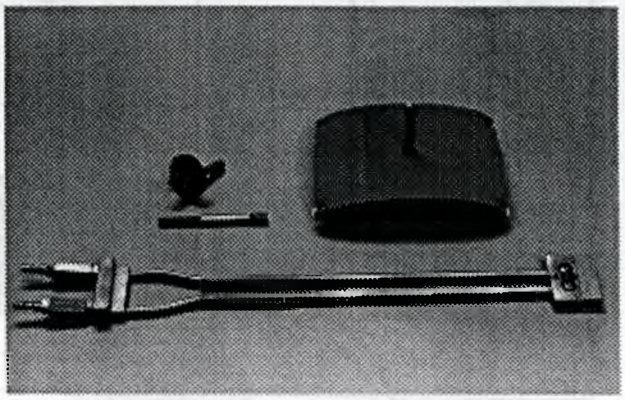


Diamond charged grinding tools



Hard metal grinding tools

Filler tools, incl. balloon, shutter, filler arms and nozzle arms



Injection attachment with injection drills

Illustration 9

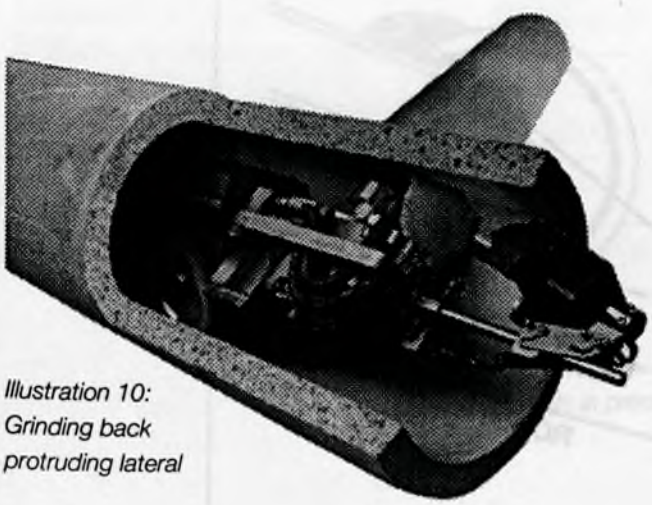


Illustration 10: Grinding back protruding lateral

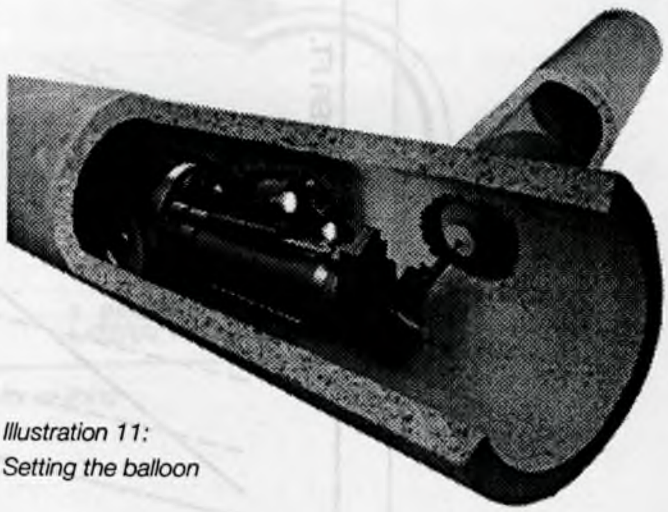


Illustration 11: Setting the balloon

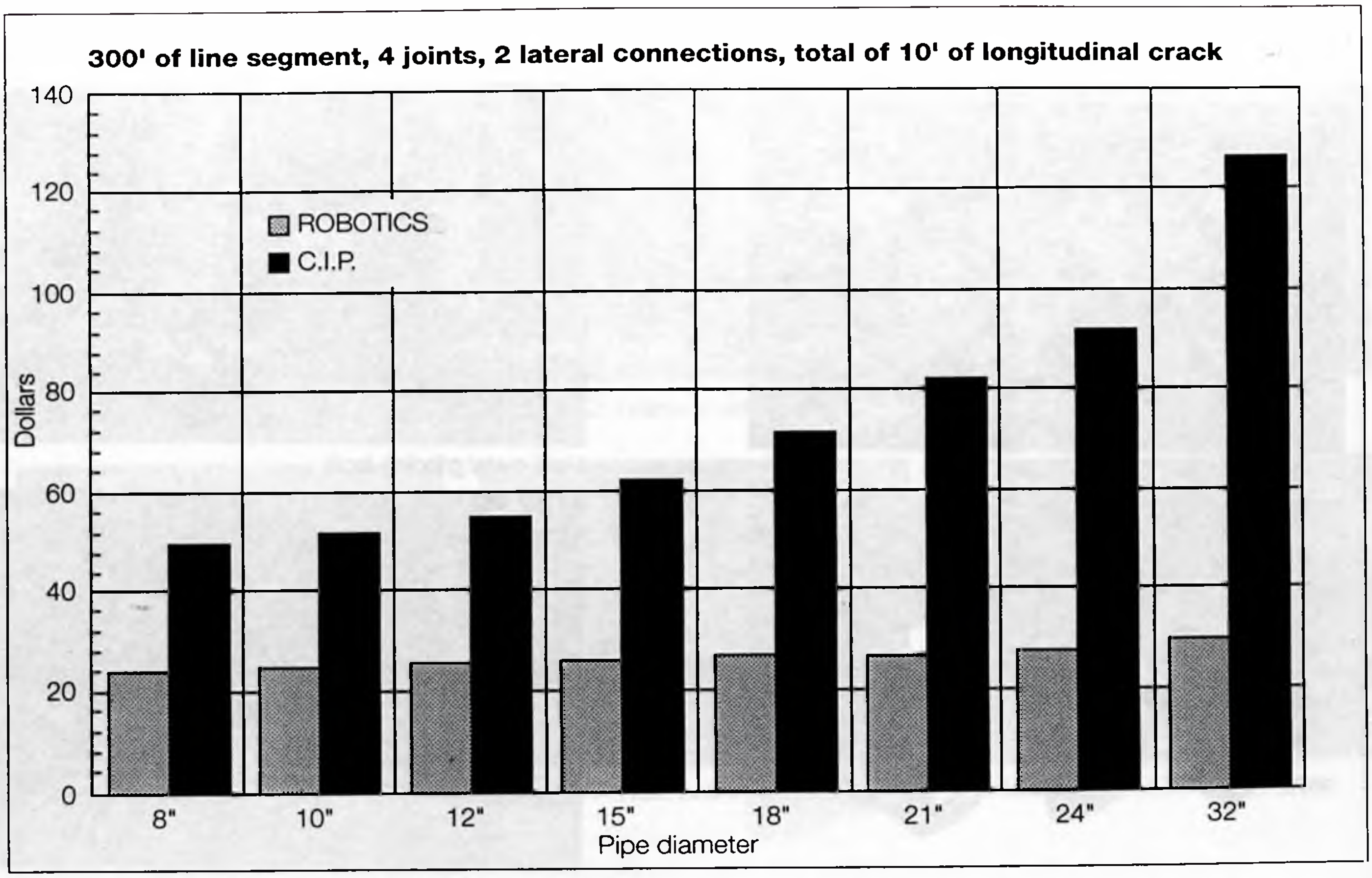


Diagram 2: Cost Comparison Robotics: C.I.P. in S.E. of U.S.

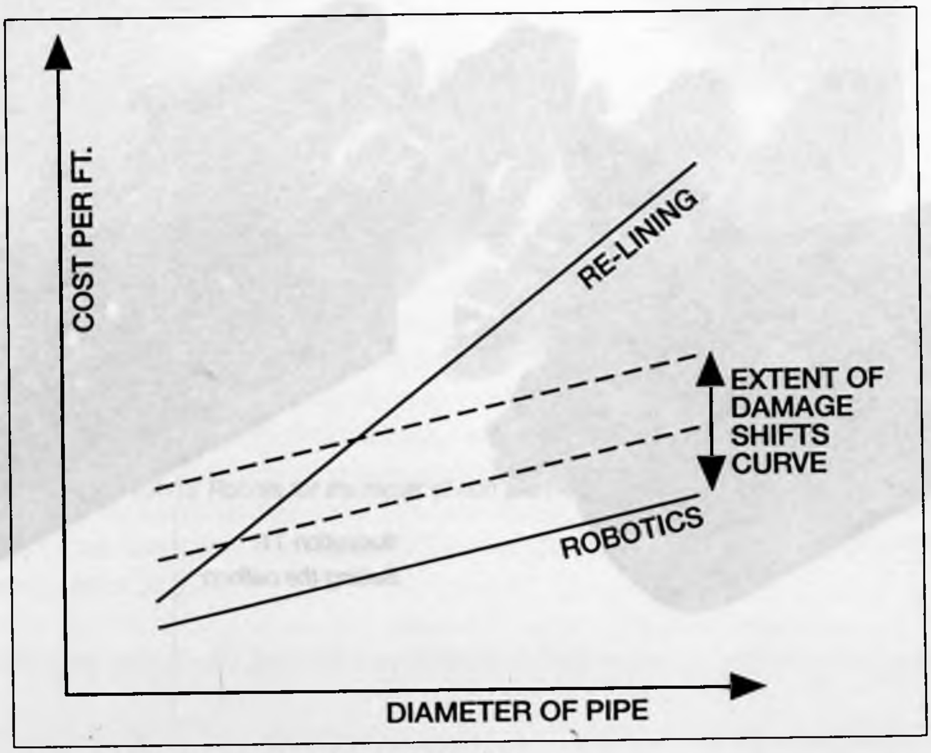


Diagram 1: Price comparison re-lining: robotics

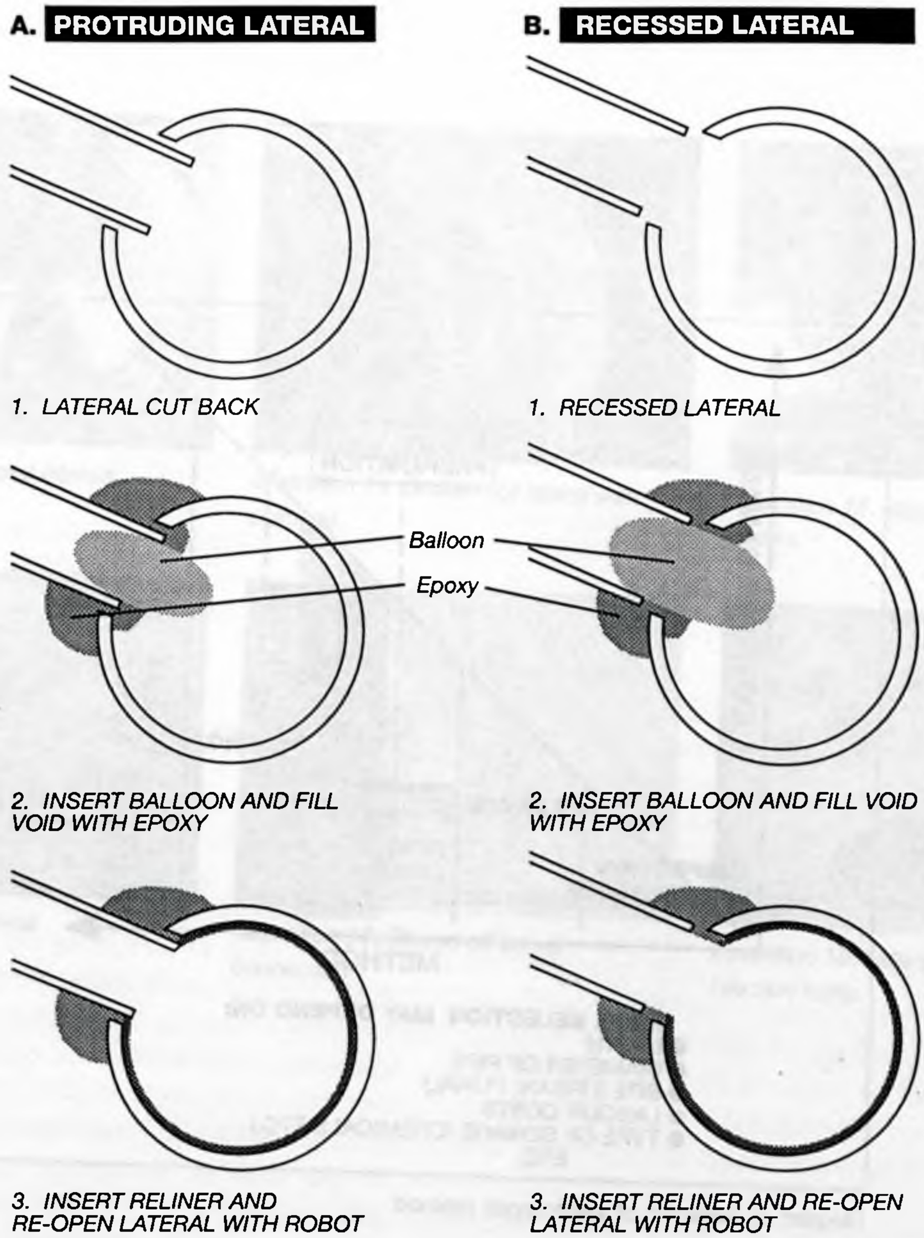


Illustration 12: Use of robots in preparation for re-lining

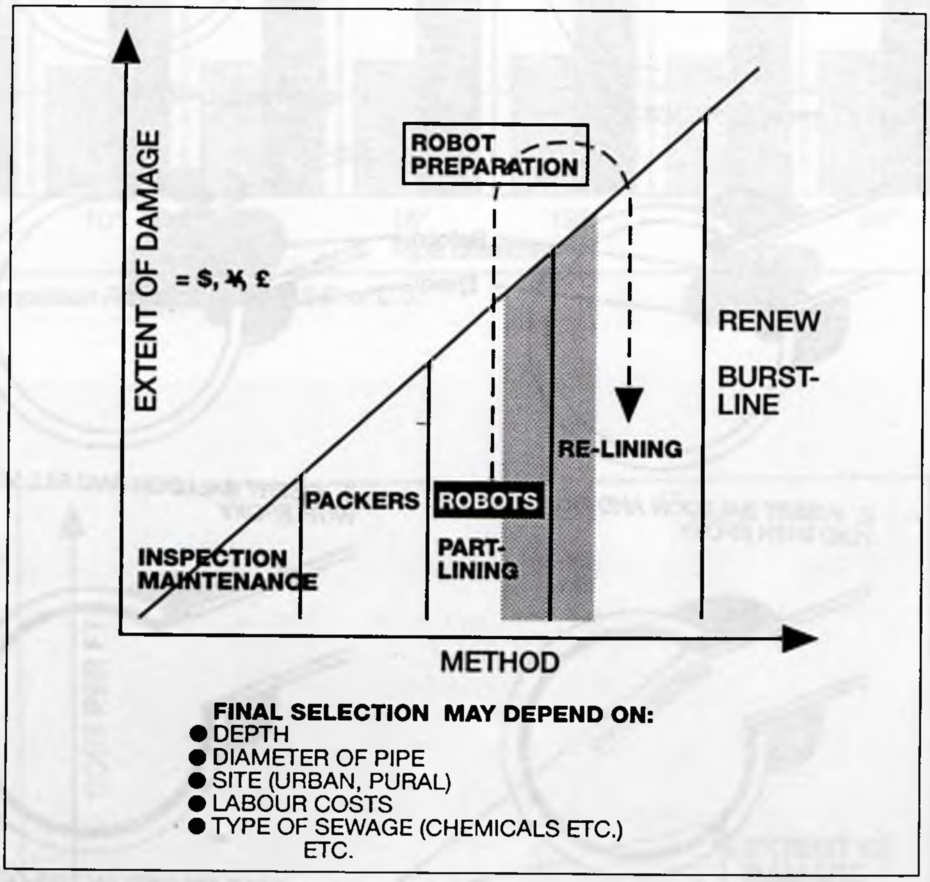


Diagram 3: Selection of sewer repair method

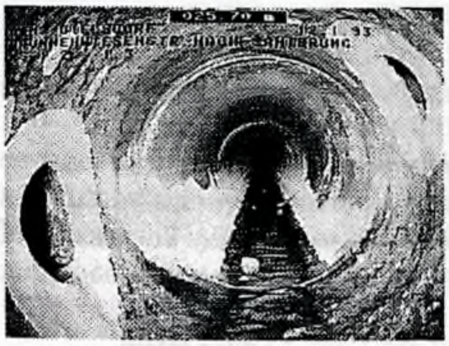


Illustration 13: Recessed laterals

Illustration 14: Broken out lateral with cracking

Illustration 15: Slipped joint + longitudinal cracks

Illustration 16: Closed hole

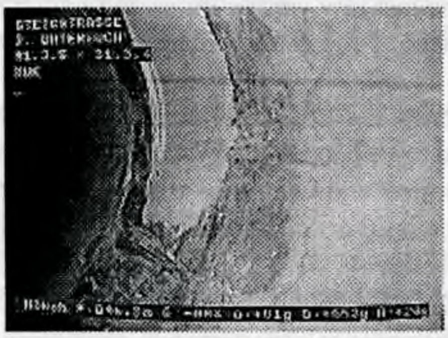


Illustration 17: Closed off lateral connection

Illustration 18: Lateral, showing injection holes

RECENT DEVELOPEMENTS IN BURIED SERVICE MAPPING

Nick Taylor, Aegis Survey Consultants Ltd., UK.

This paper is aimed at the sector concerned with the installation of new services below ground. It will endeavour to describe the recent advances in buried service mapping in the United Kingdom, the advantages gained on major projects and the benefits to pipeline management, a review of current trends in Europe.

ESTABLISHED PRINCIPLES OF KNOWLEDGE

The Water Commissioner of Rome, Italy is on record as stating with regard to the maintenance of buried services -
"These numerous and extensive works have a natural tendency to fall into decay and must be attended to before they call for large appropriations. The Water Commissioner must consult not only the builders in the employ of his office, but must seek aid from trustworthy knowledge of outsiders". How little things have changed since AD 97 when Sextus Frontinius made that comment.

RECENT RADICAL DEVELOPMENTS

With the exception of improvements in materials used in construction, things did not change that much until the last few years. Pipes and cables were laid by open cut techniques and record were kept on two dimensional medium - superimposed on base maps on paer or transparency.

Two fundaments of the provision of utilities - how new services are laid and knowing where they have been laid have been the subject of rapid advances. However, the advances in the former have been far more wide ranging than the latter - despite the fact that it would be anticipated that the two would go hand in hand.

AN ACHIEVABLE IDEAL

The ability to lay services with minimal disrupion is without doubt an achievable ideal, though currently it would seem only achievable under ideal circumstances.

Historically, the principal constraints would seem to be the prevailling ground conditions and the lack of faith. The early days of moling were beset by the presence of obstructions - deviating the mole from the intended path, often with disastrous results.

Who would contemplate a method where no one could see what was happening - what could be more straightforward than open trenching. ...How things change...

THE PROBLEM OF ROUTE SELECTION

As trenchless technology gained wider acceotance with the advent of steerable systems, the problem has become not one of where to drill string or mole is going but what needs to be done to avoid the obstacles - whether existing services or unviable ground conditions.

Services can be avoided - records should be available from the utility and show where they think they are - The obvious route lies where the pipes and cables are relatively non-existent - or can be avoided by selecting a deeper path.

A logical procedure - there is no point in deliberately making the task more difficult if you do not possess adequate information. But what of the future? Soon, in urban situations, it may not be feasible to go deeper than the existing services and if they in turn had been laid by trenchless methods ... were they accurately recorded when installed?

NO ONE CALL SYSTEM IN UK

At present, in the United Kingdom, a contractor wishing to lay new services by trenchless technology does not have the facility to approach one agency for the overall information on where existing services are laid. It is matter of collating the individual recoreds. Often, such records are woefully inadequate - comprising information digitised or scanned from paper records, with all inherent errors.

SERVICE LOCATION AND THE PROBLEM OF MAPPING

The only recourse is to use a cable and pipe locator and physically find what is there. This information is either marked on the surface or, more usefully, added to a map or survey base.

Yet here lies a further problem - depth. It is straightfroward to produce a map of buried services annotated with depths - the better locators have depth facilities and ground probing radar (GPR) can provide an interpretation of depth.

During trenchless installation of say a cable - it is vital to know the depth, not only of the mole or drill head, but the depth of other services to be avoided.

THE VITAL THIRD DIMENSION

What is of greater values, is to have depth as a data attribute, thus creating a full three dimensional map - the powerful notebook PCs now available can give this facility on site with ease is often as critical as plan location. In urban situations - where by definition the majority of utilities are laid - it is becoming increasingly problematic to lay new services - particularly by trenchless technology.

Without the vital third dimension it is not possible to generate cross-sections, long sections or visualisations.

ACQUIRING ACCURATE INFORMATION

The acquisition of data requires the effective combination of disparate techniques - principally electromagnetic location (EML) and 3D land survey and to a lesser extent GPR. It is important that services are located by the most appropriate methods.

Here EML has the advantage in that the service can be located as a continuous line with depths wherever necessary. This only applies to pipes and cables with a metal content or where a signal emittng sonde can be inserted - plastic pipes can be identified by GPR. The data is then incorporated into a 3D database.

INTELLIGENT ATTRIBUTES

The acquisition of data can be enhanced by the simultaneous capture of additional information - pipe size, construction, the number of ducts or the voltage of the cable. All of this can be readily built into a 3D model which can interrogated to access the data in a convenient and user friendly fashion. Data can be incorporated into standard CAD packages such as AutoCAD or Intergraph and GIS packages through standard transfers.

SECTIONS AND ROUTE OPTIMISATION

Once available as a 3D database. It is possible to produce cross-sections and long-sections essential for design pruposes - routes can be planned in detail.

Computer guided moling with the ability to avoid existing services is a distinct advantage - to be able to plan a route in advance even moreso. Services can be theoretically increased in size to generate a suitable safety margin such that the mole does not come within a specified distance.

Additionally, if the mole route is recorded as a three dimensional route, the path can be incorporated into the 3D map.

BENEFITS FOR MAJOR UK CONSTRUCTION PROJECTS

Three dimensional mapping of utilities is now regularly used on major infrastructure projects in UK - the benefits are being increasingly appreciated. The major transportation projects in London are routinely specifying underground mapping contracts in 3D.

London Underground use 3D mapping on the Jubilee LIne Extension and CrossRail, as do London Transport on the Tramlink project, Heathrow Airport and British Telecom. Not just for planning - the use of trial pits can be minimised - with locations chosen for maximum information with minimum disruption.

In recent proposal to re-route the services to the south of St. Paul's Cathedral, one of the Britains most famous landmark, the Consulting Civil Engineer was able to reduce the service diversion budget from £6m to £2.8m - far more than the cost of the 3D survey - with the proposal to make use of trenchless tehniques.

TRENCHLESS BOOST FROM LEGISLATION IN UK

Recent legislation in Britain has given a timely boost to NoDig technology. The New Roadworks and Streetworks Act has updated the existing laws governing excavations and reinstatements. Consequently the Utilities and Local Authorities are actively seeking ways of avoiding open cut trenching and the associated strictures. One distinc disadvantage remains - no overall composite utility system exists.

CASE STUDIES

The Netherlands

Combined information of all services is mainatined on a regional basis, commercially available to contractors, developers, engineers and the suchlike, rendering the data affordable. The data is collated by one local body, whether the municipality, a utility o suitable provate company - though only on 2D plans.

Germany

Frequent use is made of communal ducting to contain a number of services. The former East Germany instituted a system of recording all services laid, accurately in three dimensions. Unfortunately at the time of unification such record were considered top secret and subsequently destroyed.

France

A system initiated by the influential watchdog organisation Syndicat des Communes d'Ile de France pour le Gaz (SCIF) called Syncom to render streetworks less desruptive. It is operated via Minitel, the French equivalent of Ceefax or Oracle and relies on co-operation and intercommunication. Each area has its own Minitel code which allows only restriced access. With typical Gallic enthusiasm, this system is expected to spread throughout Europe.

Egypt

In a scheme funded by the UN and Finland, all buried services throughout Cairo are bieng electronically traced and mapped in 2D. One aim is to control and reduce damage by contractors excavating with scant regard for buried utilities. The contractors are obliged by law to purchase the overall service map for a fee. The incentive to follow this regulation is to be arrested by vigiliant police and summarily incarcerated.

United Kingdom

No national system exists to access composite maps of all buried utilities, nor is one officially conteplated.

A view of the future

Not without good cause have computer databases become the Fount of Knowledge. Geographic Information Systems now provide data handling and management of high sophistication and are still developing.

The systems and the information handling capacity exist - it is the data and its acquisition that is the problem ... because of its magnitude. But what is the point of spending a King's Ransom on a system when half the data is not good enough for the capability of the system. Utility systems are probably used to no more than 5% of their capabilities.

Global Positioning Systems are the much vaunted survey system of the momoent - but by definition - the most services occur in biult up areas where the problem of high buildings renders satellite GPS inoperable.

The land based GPS transmitters currently under developement will obviate this problem in urban situations and it works very well in open country - the trouble is it is only mapping system and still dependant on the location of the service being known accurately in the first place!

There are simpler and cheaper methods if all you need is to loacte the service - like using an electromagnetic locator. Furthermore GPS is not as accurate in elevation as it is in plan. Howver, is a very powerful mapping tool and very good at doing what it doeas best.

Ground Probing Radar has had vast sums of money spent on development but still highly dependent upon soil conditions and interpretation and suffers from poor position fixing. Furthermore, it doeas not trace a continuous pipe or cable but relies identifying an anomaly or "target". It can be used to lacate voids, plastic pipes and give an indication of soil structure.

Virtual reality is being explored by one national utility in UK for buried service investigation - here again such a system would rely upon highly accurate information.

WHY JUST THE 4Rs?

Roads, Runwats, Rivers and Railways - the four favoured sites for trenchless methods. Sites where open cut trenching is either prohibitively expensive - or just plan impossible.

Why is trenchless technology limited to the problem sites? Could it be that many engineers, bieng of a practical disposition would rather see what is going on? Surely trenchless is destined for greater acceptance than just "the last option".

To support the increased use of trenchless technology, accurate 3 dimensional mapping will become a necessity. Accurate, computer based records will become commonplace and commercially viable.

Computer guided moling or drilling along predetermined optimum routes through other services is no "pipe dream" ... but very, very possible.

TRENCHLESS TECHNOLOGIES FOR LAYING AND REPLACEMENT OF PIPES AND CABLES

Meinolf Rameil - TRACTO-TECHNIK, Germany.

ABSTRACT

This paper briefly reviews the development of trenchless technology and provides only a basic introduction to the range of equipment and applications, developed by TRACTO-TECHNIK.

This "window of insight" does not offer comparisons with similar equipment or alternative methods which may be promoted by competitor organisations. However the TRACTO-TECHNIK range of products is used world-wide and embraces most of the popular and more successful techniques.

INTRODUCTION

Trenchless Technology is a phrase which has only been adopted in recent years and defines the knowledge, art and practice of the underground installation or replacement of cables and pipes utilising minimal excavation and trenchless techniques.

This technology is on the ascendency and today we witness but the tip of the iceberg; the potential is unfathomable. Equipment capabilities and applications are constantly evolving.

The economical, ecological and environmental benefits are numerous but are yet to be more widely appreciated as to why pipes and cables should be installed underground using trenchless systems.

In comparison with other technologies the trenchless, no-dig activity, started late and was long overdue. In retrospect it is quite amazing that men walked on the moon before becoming serious about trenchless technology.

Particularly for the replacement of lead pipes there is presently no other solution but laying new pipes paralell to the line of the old lead pipes. In certain cases these lead pipes can be pushed out.

Therefore, let us focus on the technologies of laying the pipes parallel to existing lead pipes.

First, the mole

Correctly designated, the soil displacement hammer this is the simplest, most widely used and relatively inexpensive form of trenchless technology. Moles are self propelled and operate from compressed air. A reciprocating piston drives the percussive tool through the ground, displacing and compacting the soil to form a bore hole into which cable or pipe can be directly towed or pulled afterwards.

Diameters range from 45 mm to 180 mm. The length of bore achievable is relative to the machine size and impact, the size and type of pipe / cable to be installed and prevailing soil conditions. Small diameter moles perform well within the requirements for domestic connections - bore lengths usually no more than 15 m - and the range of larger moles install mains carrying pipes and cables at lengths of up to 30 - 50 m. Longer shots have been achieved and 70 m is not uncommon. (Articles have appeared with incorrect information for example, indicating that moles can only be used up to 10 m length bores - this may be true of some designs, it is not generally - care needs to be taken to ensure that published data retains its credibility and does not discredit the industry it seeks to serve.)

The pipe or cable outer diameter usually determines the size of the hammer to be used. However, an allowance must be made for 10 - 15 % bore hole shrinkage and to avoid friction between the pipe and bore hole surface, particularly coiled pipe lengths. Smooth surface inner and outer diameter pipes have been specially developed for moling techniques.

Displacement hammers require a minimum depth of 10 times their diameter to provide sufficient over burden to ensure directionally stable bore otherwise they will follow the natural tendency to rise to the surface.

The mole when correctly targeted, will travel on the required line and level within 1% accuracy. Often the skilled operator will hit the aiming pole in the exit trench.

Speed of bore should not be regarded as being of the essence. Speeds will fluctuate according to the soil conditions which can vary considerably in just one road crossing. However, average speeds can be anticipated at 12 m per hour.

The following schedules detail the range of popular GRUNDOMAT mole sizes, applications and operating parameters.

Model Size (mm)	Min. Depths (m)	Average Bore Length (m)	Air consumption (cbm/min)	Length (m)	Weight (kg)	Piston Strokes /min
45	0.45	8	0.45	0.90	8	550
55	0.55	8	0.60	1.11	14	500
65	0.65	9	0.70	1.29	25	450
75	0.75	12	1.00	1.41	34	400
85	0.85	12	1.10	1.47	46	450
95	0.95	20	1.20	1.69	67	330
110	1.10	20	1.60	1.89	96	280
130	1.30	25	2.70	1.73	120	350
145	1.45	25	4.0	1.85	180	300
160	1.60	20	4.2	1.95	205	320
180	1.80	20	4.5	2.15	290	275

Tab. 1: 10/94 (Special shorts versions available)

There are of course factors which limit usage. As with all trenchless technologies, ground conditions are of vital importance and must be displaceable. However, a range of head profiles and operating accessories are available to assist in variable ground types.

As moles are not surface launched they are not 100% trenchless (unless boring vertically or into embankments or other elevated surfaces) as entry and exit pits are required. Whilst these are narrow profile, they must generally be of sufficient size to accommodate the mole and its launching cradle. However, costly reinstatement can be avoided by siting these in road side verges, pavements and similar less costly surfaces.

Cohesive soils offer the opportunity to use a variety of cost effective / minimal disruption techniques. But non cohesive soils like sand and silt require a bore hole liner or product pipe to be towed in directly behind the mole not only to maintain the bore hole but provide the exhaust outlet (pneumatic hammers must always be able to exhaust to atmosphere).

Whilst there are many product and operating characteristics which ought to be included in the mole selection criteria, there are in essence two types of mole:

FIXED HEAD AND MOVING HEAD

A. The Fixed Head Mole

This type is less accurate and is very much of the same basic design as the early Russian model (body and internal piston) and has a tendency to take the line of the least resistance when encountering inclusions in the bore path. Impact is limited and not concentrated at the boring head. This type is more suitable for short shots where boring accuracy is not important as it presents a high percentage risk of bore failure, deviation and possible damage to adjacent plant and high recovery cost.

B. The Moving Head Mole

This is basically a three part machine comprising body, piston and a pre-tensioned spring loaded chisel head. It was this design which established boring accuracy and user confidence in the moling technique. The machine operates with a jack hammer action. The reciprocating chisel head independently producing a pilot bore, destroying obstacles in its path whilst the surrounding soil holds the machine body on course. The patented design ensures that almost 100 % of the impact is concentrated at the chisel head. Impact can be measured and maintained.
The diagram no 2 illustrates the basic design differences:

Reasons why Moving Head Moles are unique

- Undercut steps on multi-cuttercone for improved rock breaking ability
- Patented reciprocating chisel head assembly incorporating pre-tensioned steel spring - giving unique directional stability
- Teflon piston seals giving leak proofing, low air consumption and no metal to metal contact, hence no wear
- Main casing and piston hard chromium plated for durability
- Simple, instant reverse mechanism engaged by L turn anti-clockwise of the air hose
- Total part interchangeability plus easy to fit pulling accessories for direct installation of pipes and ducts

How the unique head action works

- Unlike conventional fixed head soil displacement hammers the GRUNDOMAT´s moving head incorporates a unique Two-Stroke-Action
- Piston impacts on rear of the chisel head assembly. This action compresses the pre-tensioned steel spring and forces the chisel head assembly forward independently of the main casing creating a small, highly accurate pilot bore-
- The expansion of the spring coupled with the inertia of the returning piston causes the main casing to follow along the bore -hole axis.

Equipment benefits

Further important contributions to the success of the moling technique includes the fitting of replaceable internal seals which ensure no direct metal to metal contact between the impacting piston and inner casing and therefore minimal wear and no costly parts replacement. More importantly, the mole can be maintained and measured throughout its life to optimal design impact - peak performance and safe / effective air consumption.

Forward / Reverse

Positive instant reversing (by a quarter turn of the air hose) ensures mole retrieval in impossible soil condition; dead end service or cable insertions, (both horizontal and vertical) minimal disruption installations and a wider scope of specialist applications, e.g. mini piling, cathodic protection, embankment drainage.

Safety

1. Non conductive air hoses: These should always be fitted and of the required torsional strength and durability for the effective operation of the forward / reverse mechanism of the mole. Operator protection in the event of a cable strike is vital.
2. Cable location equipment: All operators should be equipped with cable / pipe location equipment to ensure that the boring path and exit and entry pits (prior to excavation) are safe working areas.

Lubrication

Lubrication of the mole is essential via the lubricator unit which also provides anti-freeze when operating in low ambient temperatures.

Unguided Classification

Regardless of the accuracy and reliability of the displacement hammer, it must fall under the classification of being unguided - free flight.

Trackable Moles

This brings us to trackable moles. Advancements in electronics packaging now makes it possible to provide a transmitting sonde to the mole.

Reliable monitoring equipment now enables the mole to be tracked with pin point accuracy thus ensuring that known obstacles and existing cables etc. are avoided and confirming the progress to be on target! Thus, moles can be used particularly in restricted areas with even greater confidence, the length of bores increased and the scope of applications widened.

We now turn to other techniques.

Steel Pipe Ramming Hammers

Deep excavation and soil compaction limits the use of displacement hammers to a maximum of 200 mm diameter. For pipes above this size (and smaller than this size), a range of steel pipe ramming hammers were developed to install steel pipes up to 2,000 mm diameter.

Here the method is reversed. The hammer remains in the start trench and its impact forces used to "hammer" in steel pipe sections. This technique is restricted to steel pipes but these do not need to possess high mechanical or stress properties. It is however important to know the relationship between pipe diameter, wall thickness strength and length to be rammed.

As the soil is not compacted or displaced the open ended steel pipe cuts through the ground and therefore minimal cover is possible which eliminates the need for deep and costly entry and exit pit excavations.

The technique is relatively simple. The ramming hammer and first section of pipe are correctly aligned on parallel H-beams. No costly concrete foundations or jacking abutments are required. To avoid damage and deformation of the leading edge of the first steel pipe, an oversize steel cutting shoe is attached which also reduces internal and external soil friction on the pipe surfaces and ensures protection, when applicable, of pipe coatings. At the other end, interlocking add on ramming cones are fitted on to the front of the hammer; adapted to match the internal diameter of the steel pipe. These cones also ensure effective dynamic impact transfer and prevents flaring of the pipe ends. Patented soil removal cones assist soil removal during the ramming process which further reduces pipe surface friction and additionally , pipe sections can be internally lubricated. After the sections of pipes are rammed in, they are welded together and the ramming process repeated until the installation is complete.

Once all sections of pipe are in place, the internal soil can be removed either by using a pressure plate connected to the air compressor or by a combination of air / water jetting. With man sized entry pipes, mini-excavators can be used.

The use of this system is possible in all soil types with the exception of massive rock or very large stone / rock inclusions. A high degree of accuracy is attainable, establishing required gradients and a line and level of within 2 %. There is of course no risk of the bore hole collapsing or disturbing the surface as the pipe itself forms an immediate bore hole support. Diameters of pipes can be as low as 100 mm and up to 2,000 mm. Lengths of up to 150 m (in favourable ground conditions) have been achieved.

A schedule of the most popular sizes of hammer lists the diameters and lengths of pipe which can be installed. The largest hammer generates up to 2,000 tonne impact per stroke.

Many projects have been successfully completed world wide and the technique holds great potential and is very cost effective.

Directional Drilling Equipment (Size range from 60 mm to 350 mm)

This is the popular name by which this equipment is referred to, and is currently the most accurate form of trenchless technology. It also offers, when surface launched, a 100 % trenchless application with the capacity to install cables and pipes up to 350 mm over far longer distances than can be achieved by other methods. The larger and more powerful rigs are capable of achieving distances up to 300 metres.

The underlying benefit of this equipment is its ability to be guided over a pre-determined bore path, around identified obstructions and under motorways, rivers, railways, etc. However, bore head guidance and accuracy is dependant on the electronic detection and signalling equipment and the ability to steer is restricted to a series of gradual arcs within a minimum alloy steel rod bending radii of 30/40 m to arrive on target. No quick turns or tight corners.

This equipment is more dependant than others on the skill, experience and commitment of the operators. It is the most costly to purchase and mobilise and requires installations and contractors of the size and duration to ensure cost effective operation.

The following is a list of general observations / recommendations:

Planning is the key element for a successful guided boring project. For low cost projects, there may be a temptation not to carry out any site investigations. However, the consequences of encountering any problems could result in an increase of costs much greater than the original project budget. Site investigation is the area of large directional drilling projects where there may be a temptation to make cutbacks if the overall budget has to be reduced. However, the extend of the site investigation should be related to the size and complexity of the project.

Geological drift maps provide an efficient, rapid low cost aid to planning both low and high cost guided boring projects.

A formal guide or procedure, based on field experience, should be developed and drafted to assist the planning engineers select the steerable boring rig.

Site investigations using ground probing radar should be evaluated to complement information obtained from the geological drift maps.

The effects of changing rig operating conditions such as force, toque, rotational speed, etc. should be evaluated with the results compared to the performance records reported by the steerable boring rig manufacturers and suppliers.

Main Elements of the System

The system comprises a power source and push / pull rig which provides both the rotational torque and drill rod pushing and back reaming pulling power. The boring tool cutting head is of a variable slant angle and size to which are attached the highly flexible 1 - 3 metre section drilling rods which are built up to the required bore string length.

The basic principle of operation is similar to a hydraulic rod pusher with optional pressure ...bentonite / water / air mix to lubricate, cool and assist soil cutting during the pilot bore progress; decrease soil friction when back reaming and pulling in the product pipe or liner. Some models incorporate a displacement hammer situated at the bore head or a percussive unit is built into the main rig offering optional combinations for varying soil conditions. Pilot bores can be achieved on target utilising the slanted bore head and integrated sonde which enables the boring head to be corrected along the required path.

On arrival at the exit point, the pilot bore can be upsized with an expansion cone for harder soils, a back reamer or larger percussive hammer.

Rigs can be pit and surface launched: light weight units can be mounted on manually operated trolleys and the heavier machines are self propelled crawler / track powered. The larger fully self contained systems can be truck mounted.

The following schedule gives details of the range of guided boring systems and sizes of pipe which can be installed.

System	GRUNDOHIT	GRUNDODRILL	GRUNDOJET M15
Composition of Soil	homogenous, gravel, etc.	homogenous, gravel, etc.	homogenous with stones
Fluid assisted	partial plus impact	dual pressure plus impact	dual pressure
Surface launch	optional	yes	yes
Rod lengths	0.8 m	3 m	3 m
Drill rod diameter	48 mm	48 mm	54 mm
Dimensions: Length: Width: Height:	 1.80 m 0.60 m 0.35 m	 4.90 m 1.20 m 1.60 m	 8.30 m 2.49 m 3.70 m
Pilot drilling diameter	60 mm	60 mm	76 mm
Max. Backreaming diameter	90 mm	350 mm	450 mm
Max. PE pipe diameter	63 mm	300 mm	400 mm
Max. Drilling length	100 m	250 m	350 m
Max. Push / pull strength	1.8 t	6.5 t	15 t
Min. Curve radius	30 m	33 m	42 m

Tab. 2

We now turn from installation of new pipes and cables to the renewal and replacement of existing ones.

Pipe-cracking/Replacement Systems (sizes - 75 mm to 600 mm)

This system is extensively used for the replacement of gas and water/sewage pipes from 75 mm to 600 mm.

For 50 mm to 150 mm pipes, the equipment comprises a bladed cutting head which is fitted to the specially produced displacement hammer which is propels itself through existing cast iron, clay pipes etc., cracking and breaking them up whilst maintaining the existing line and level of the old pipe. The broken pipe fragments are displaced and pushed laterally into the surrounding soil by means of the expanded profile of the machine body which pulls in an outer sleeve carrying pipe directly behind it.

For the replacement of the larger clean and dirty water pipes (200 mm to 600 mm), the pipe ramming hammers are utilised; fitted with front end cracking displacement shrouds. All hammers are assisted by the line pull of a pre-tensioned winch which assists to maintain the line and level of existing pipes. On very large diameter pipes, hydraulic pipe pushing machines give added assistance. Usually speeds of 40 metres per hours are achieved and the distance between manholes or entry/exit pits is usually 60/80m. It can be appreciated that with the very deep sewer pipe installations, working from manhole to manhole, the financial savings are phenomenal.

With this system, it is possible to replace not just size for size but to increase the pipe carrying capacity - e.g. 100 mm to 150 mm and 250 mm to 350 mm.

Similar systems incorporate the displacement hammer fitted with an hydraulically operated bursting head and rod pushing bursting systems are available.

Further important aspects of trenchless technology training

In the majority of instance, where trenchless techniques are costly failures, or run over budget; this betrays operator ignorance and inexperience.

Training is therefore an essential but sadly neglected element of trenchless technology. The costs of training will be paid back in a very short period with lasting benefits and increased potential.

Perhaps our related Societies and Guilds can collectively seize the initiative and look at ways and means of establishing, widely recognised codes of practice and syllabuses for structured quality training to different levels of certified standards of proficiency.

Maintenance

Far too often, equipment is not maintained and is allowed to run until it stops - often in the wrong place. A false economy particularly as service and preventative maintenance ensures peak performance and maximises productivity . It is essential that equipment is serviced and tested before important and difficult projects are undertaken.

Capacity / capability

Regardless of manufacturers' built in safety and overload margins and carefully stated operating parameters, too much is expected of equipment which is subjected to abuse, overload and stress. The temptation to go faster, farther and larger results in the inevitable consequence. Consistently successful and profitable users operate within the system's capabilities and use the right equipment for the job.

Reputation and growth

The advancement of Trenchless Technology, is often set back, unfairly judged and unjustifiably criticised on failures and disappointments which arise from the lack of training, maintenance and the operation and application of equipment outside stated capacities and capabilities.

In conclusion

TRACTO-TECHNIK is at the forefront of Trenchless technology and is proud to have contributed to the formative years of the industry's history ... a boring story ... but one which is to be continued.

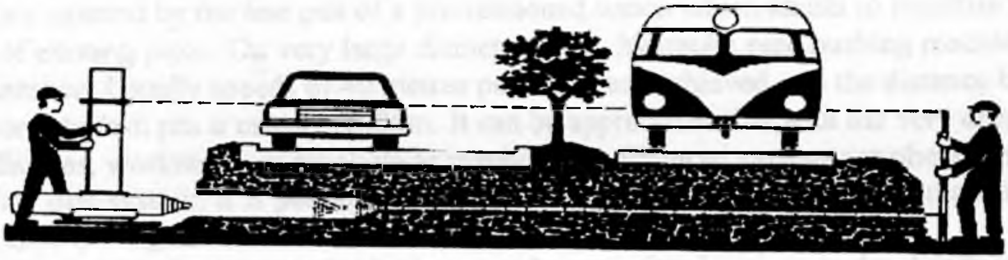


Fig. 1

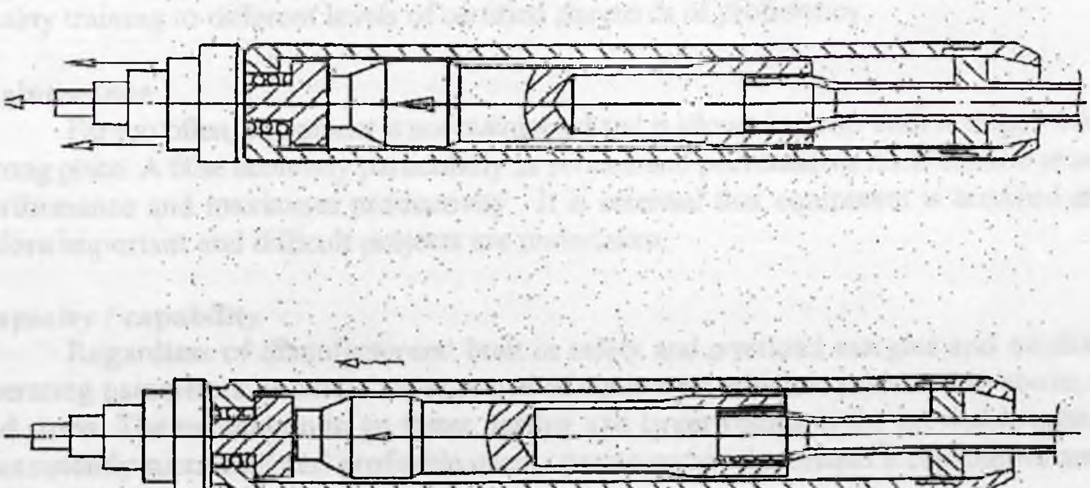


Fig. 2

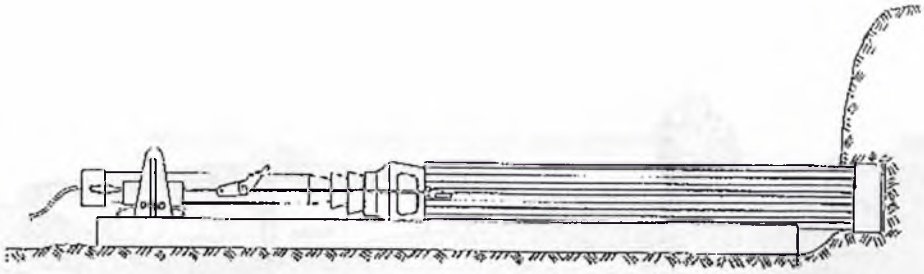
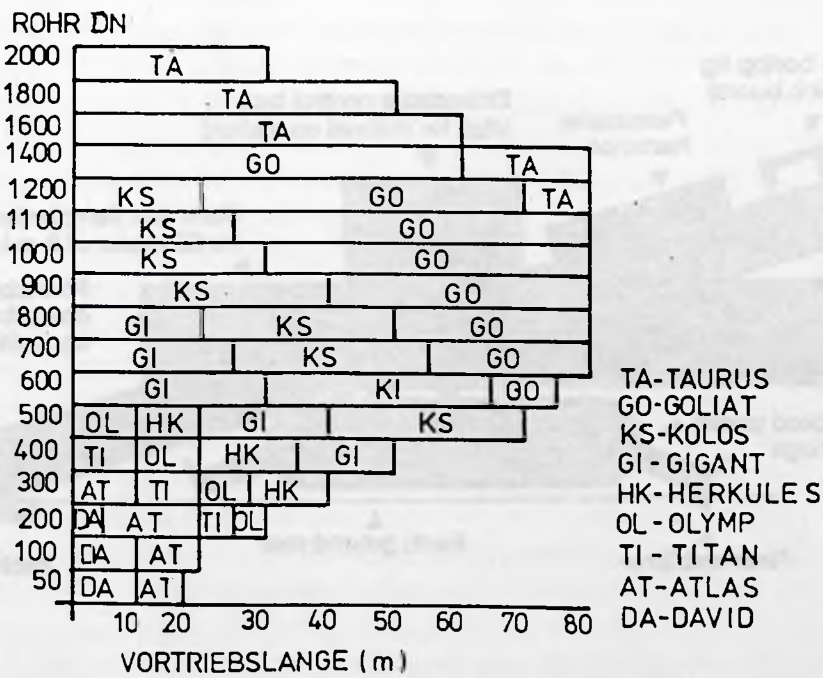


Fig. 3



ROHR DN
2000
1800
1600
1400
1200
1100
1000
900
800
700
600
500
400
300
200
100
50
TA
GO
KS
GI
KI
OL
HK
TI
AT
DA
10 20 30 40 50 60 70 80
VORTRIEBSLANGE (m)
TA-TAURUS
GO-GOLIAT
KS-KOLOS
GI-GIGANT
HK-HERKULES
OL-OLYMP
TI-TITAN
AT-ATLAS
DA-DAVID

Fig. 4

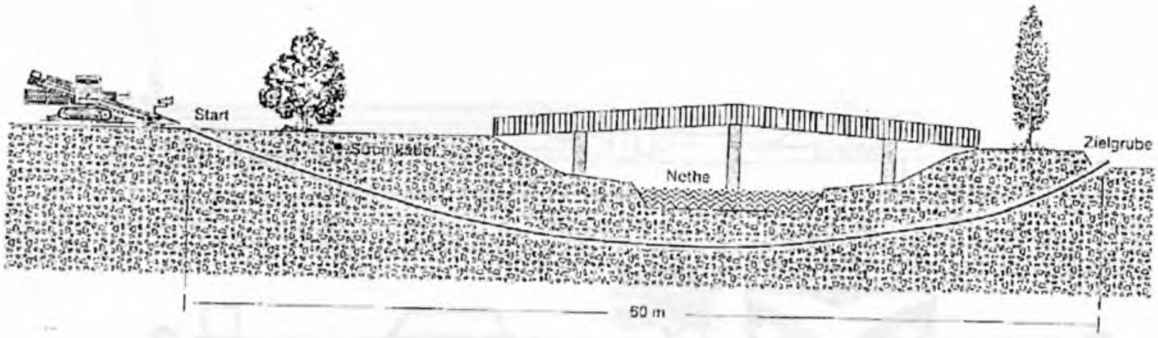


Fig. 5

Hydro-dynamic steerable boring system GRUNDODRILL

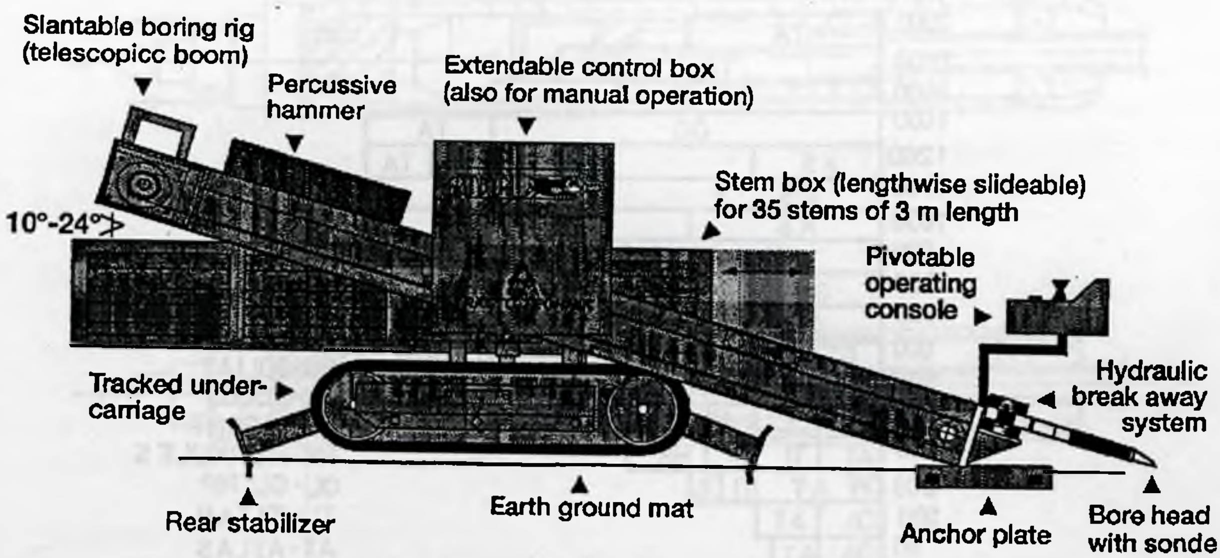


Fig. 6

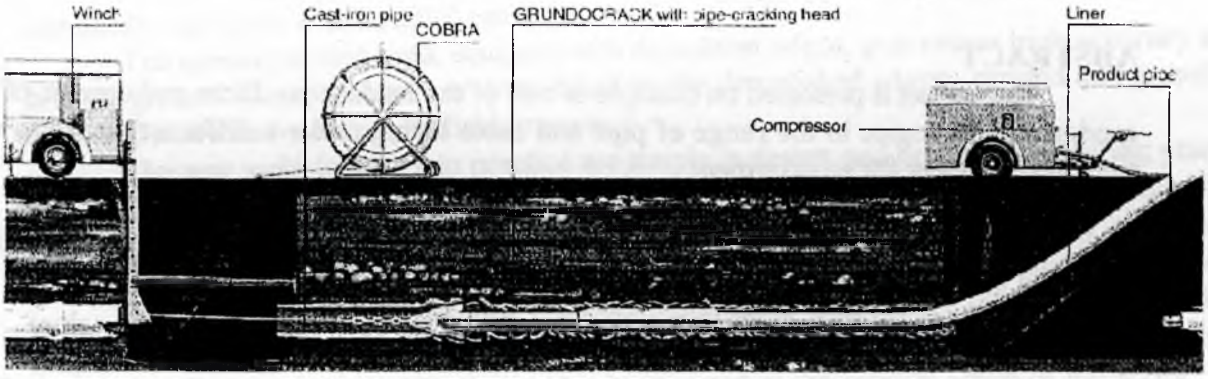

Winch
Cast-iron pipe
COBRA
GRUNDOCRACK with pipe-cracking head
Liner
Product pipe
Compressor

Fig. 7

MODERN MACHINES FOR TRENCHLESS TECHNOLOGY

Dietmar Jenne - TERRA AG, Switzerland,
Edwin Grygorcewicz - BTH, Poland.

ABSTRACT

The subject is presented on example of one of the leading producer and creator of a lot of modern technologies in the range of pipe and cable laying under a different obstacles without trenches so heavy for environment.

There are four main groups of machines and technologies:

1. Machines for underground piercing, for execution of so called minitunnels with diameter in the range of between 45 mm and 245 mm.
2. Machines for steel pipes ramming up to 2000 mm.
3. Machines for pipes bursting with maximum diameter up to 400 mm.
4. Systems for directional jet boring for pipes and cables laying with diameter up to 300 mm and lengths up to 300 m.

In above mentioned groups there are a few or a lot of types of machines with different sizes and of course with some limits as for defined diameter of pipe or cable being laid. A great advantage of such machines and systems is their universality. This is a simple possibility for adaptation to other technical applications mentioned at No 1,2 and 3 items, without any internal modifications to the basic tool. Furthermore these machines can be used for many other accessory applications such as: whell drilling, sheet ramming, posts ramming, injections in grounds and so on.

The separate group of the machines and rather the systems is the fourth group. These are the underground directional jet boring systems with usage of drilling fluid. Both machines and such technology require more trained operators, but their technical possibilities including the advance of pipe lying jobs are incomparably greater (up to 200 m of utilities to be laid daily).

Also some of the latest developments are presented in this new and very fast growing technology.

Next the advantages of application of machines and systems are shown and presented and the advantage of the leading producer of machines and systems over the other companies present on the market as well.

Trenchless construction is currently one of the most rapidly growing sectors in civil engineering world-wide. There are a lot of technics available on the market, but one of them seems to be more competitive as a cost effective and easy to fast introduction even for small construction companies. Modern underground piercing tools, popular known as a "moles" are good example for such consideration and worth more propagation. These machines are very powerful, economical, simple in construction, operation, maintenance and reliable.

Generally these machines are designed for trenchless underground pipe laying for gas, water, telephone, electricity and cable TV in diameters of 45 up to 2000 mm.

Now you can find them in most developed countries world-wide. By application of such technology underground crossings of roads, railways, rivers or any other routes can be made with up to 70 % costs savings on the open cut methods. Road surfaces are not cut and do not need repairing. Road and rail traffic continues to flow smoothly, with no interruption. House connections can also be laid at substantial savings, and they are also environmental friendly. New and modern versions of machines are still improved. Base small underground piercing tools can produce piercing bores in diameters up to 190 mm, and with special designed expanders even up to 245 mm and more. For the underground piercing the following equipment is required:

- an air compressor with a working pressure of 7 bar usually
- the lubricator as a regulating unit
- the underground piercing tool itself with the required accessories.

In the construction, each tool is manufactured from a high quality steel body and is standardly equipped with "combi" universal head.

The special piercing head, equipped with demolition edges, guarantees high accuracy even in stony ground. Boulders are easy demolished by the demolished edges, ground and gravel are displaced sidewise by its longitudinal grooves.

The new tools directed into practice are simple in design and operation, ensuring years of dependability. In the tool of this leading company it consists of even 40 % fewer parts than others. Also the main piston is 25 % heavier than other pistons, and produces extremely high impact energy. The main piston to body weight ratio is best rational indicator in this respect. Most of the tools work both directions forward and reverse (backwards). The change of direction is made by simple 1/4 turn of hose behind the tool. The latest models are equipped with remote control revers facility placed inside the special air hose and operated at the control valve of lubricator. This feature is the next one step for the new generation of machines. In the new developed construction in forward motion the main piston hits only the front. During operation, the special pneumatic locking prevents unintentional change of direction. Leading producer offers different interchangeable head adapters for different ground and applications. The replacement of head is a simple work on job site and do not need any opening of the base machine. Also the end adapters can be changed easily on site, depending on the intended use of the tool. The special air hoses are wire braided. This ensures reliability even under extremely rough conditions always found on most job sites. The function of lubricator is to add the special lubricant to the compressed air. An lubricator lubricates the tools inside and prevents freezing. The special modern lubricant is effective even up to minus 42 centigrades. It is also biodegradable and water safe. The regulation and impulse valves allow a sudden start-and-stop operation and effective regulation of the speed of each tool. The lubricators are available in several different designs and capacities depend to the size and application of the machines. Each modern machine can pull PE or PVC pipes simultaneously into the ground without any modification to the basic tool. The pipes are connected to the machine with a heavy cable clamp and a pulling cable. The special heavy cable clamp with tensioner is used for longer piercing bores. It allows additional tensioning of the pulling cable, which tightens the connection between the pipes and the machine. The special twin pulley is used in wet and loose ground. It enables active pushing of the pipe when used with a cable winch. This prevents dangerous oscillating of a piercing tool in loose ground with additional axial force. The starting procedure is made easy by special designed launchers. In this way each machine can be adjusted right on target. It is very important feature particularly for bigger and heavier models of machines. Each tool is adjusted in the starting pit with simple but very useful accessory - the aiming staff. This accessory ensures that the machine never misses the target. Another advantage is a possibility to adjust the direction of the tool even with presumed inclination. The next useful accessory is expander. With expanders a pilot bore can be increased to a larger diameter. This two or one step operation allows larger diameter bores at lower depths. The tool is slid from behind into the expander. The energy transfer is effected through the inner taper in the expander. Usually the first step for underground crossings is the excavation of starting and arrival pits. The new designed compact tools do not require big excavations. This is cost saving and important in case of limited space for job sites like in congested town conditions. In starting procedure very important is marking of pipe. This ensures easy location of the head of the tool, at any time. The working speed of modern underground piercing tools is half a meter to 120 m per hour depending on ground conditions. An approximate average in practice is 10 to 20 m per hour. Each pipes must have a 10 % smaller diameter than the piercing tool to prevent high friction. For example by an application of such machine a bore up to 125 m was accurately made in one single operation only. This is world record still unbeatable. Usual piercing lengths are from 5 to 25 m.

Some of the new designed models are equipped with traceable adapters. In connection with a suitable monitoring system, the progress of the bore can be continuously controlled and registered. Such adapter is very accurate, allowing for realisation of longer dispersible borings.

For steel pipe ramming applications such the largest machine model can drive steel pipes up to 2000 mm in diameter. When located behind the steel pipe, the ramming forces developed by the machines are transferred to the steel pipe through specially designed ram rings. The steel pipe is open at its front end. Depending on ground conditions, distances of 80 m and more are regularly achieved by the new modern machines. As soon as the first pipe section is rammed in, the new one is welded and rammed in again. On completion of pipe installation in the ground, the spoil plug within the steel pipe is cleaned out with special designed accessories. The modern machines with robust construction ensures long life. The main piston is the only moving part. The leading producer has main piston weight up to 60 % percent of the total weight of ramming machine. The main piston thus produces unequalled power. For instance the biggest ram produces ramming forces up to 2200 tons. Due to the patented design of tool, incorporating air relief channels in the main piston, the air consumption of some rams is up to 40 % less than its close competitors. In this way such advanced rams can even be driven by smaller air compressors and again saving costs of each project. Because of their unique compact design, modern rams are up to one meters shorter than other conventional rams. This also saves costs for excavating of the ramming pit at every ramming site. Here is short description of usual ramming job. First the ramming pit is excavated and in case of necessity shored (loose or wet ground). Then the special designed or any simple method of support for steel pipe and the ram is assembled and accurately aligned. Cutting rings are welded at the front pipe end to reduce friction and increase stability. The opening for steel pipe to enter the ground is cut out of the front wall of the ramming pit. The ram is lifted into the ramming pit. The lock-in ram rings and ram are assembled. The ramming process can now start. For larger distances, it is recommended to cut the driven-in steel pipe at the right angles. The next pipe section is lifted into the ramming pit. Both pipe sections are then welded. The longitudinal bars add support to the weld. Ram and ram rings can be assembled behind the steel pipe again. The ramming job continues. On completion of installation, the steel pipe is cleaned out. This can be done by one of the following methods:

- water jetting
- "pigging"
- or augering.

Water jetting is carried out with a special designed truck. Its high pressure water pump must deliver a minimum of 150 litters per minute of water at a minimum 150 bar. The water jet head loosens the spoil within the steel pipe and transport it backwards. The outcoming water and spoil is pumped out of the pit. "Pigging" occurs after completion of the installation, and is carried out from the arrival pit back into the starting ramming pit. The pipe end is prepared for the special pressure plates. The special rubber "pig" is slid into the steel pipe. Now the pressure plate can be assembled. After that the pressure plate is secured by two iron sticks. Then the steel pipe is filled with water. The spoil is pressed out of the steel pipe by combination of compressed air and water pressure or only compressed air itself depending on ground conditions. The steel pipe can be also cleaned by an auguring machines. Some of the rams are very short and can be used even in the smallest of ramming pits. These machines are also very economical for parallel steel pipe ramming of two or more pipes used for instance in one project. Another aspect is their compatibility in relation to ramming force produced. For imagination the machine with 1,5 meter and weight of

300 kilos only, is very versatile and powerful with a ramming force of approximately 370 tons. In one of the latest project a steel pipe with 1000 mm diameter was rammed in a distance of 100 m. This job was accomplished with one of the most powerful steel pipe rams in the world which produces a ramming force of 2200 tons. The successful completion of this ramming job represented another new record - pipe laying at the depth of 10 m.

It is reasonable that the ramming machines are usually designed for forward direction only. The new progressive ability is an application of remote air amplified reverse facility. This facilitates the use of ram machine in narrow launching pits as this is quite often the case in city areas. In this version the ram machine and ram rings can be detached easily from the steel pipe by simple switching of machine to reverse position.

The next method of application of underground piercing tools and rams is pipe bursting. This one is known as a "split" system for pipe bursting and simultaneous pipe renewal and is designed to burst out and replacement of old gas, water and sewer pipes. The range from 60 to 400 mm in diameter and from 30 to 100 m in length is normally achieved in practice. The old pipes are burst and the fragments are displaced sidewise. For pipe bursting the machine is located within bursting sleeve. At its front, there is a specially hardened bursting blade. The bursting sleeve is tensioned from ahead by use of a hydraulic cable winch. An essential advantage of such "split" system is the use of standard tool or ram. No any modification of them is necessary but additional accessories only. The "split" system occurs in a two stage procedure. Contrary to conventional systems, first the old pipes are split and burst by bursting blade. This system works fast and effectively, but requires more trained staff. In only one operation the old pipe is burst, the bore hole is expanded and the new pipe is pulled in. By such system one hundred meters or more utilities can be replaced daily depending on skills of operators. Short starting pits require the use of short pipes and short machines like for manhole to manhole operations. If the conditions of a bursting job site allow a long enough starting pit, one long pipe in the total length of the bursting job can be used instead of short pipes. This saves time during job site installation because the pipe bursting can continue without interruption.

Presented new modern machines are unique and have the following advantages:

- extreme power thanks to advanced engineering
- high reliability ensured by simple and robust design
- accuracy obtained through the patented special "combi" heads.

One machine can be used for three applications without any modification to the basic tool:

- for underground piercing
- for steel pipe ramming
- for pipe bursting.

Above mentioned machines are designed for straight line pipe laying jobs. For curved routes crossings there are special combine machines generally called directional boring systems. This system is known as a "JET" system and is steerable (directional), fluid assisted boring system for trenchless underground pipe and cable laying . The new and modern introduced units are designed not only for soft but for hard and stony grounds either. Ability of such combined machines are: 300 mm of diameter and lengths up to 300 m and more are reached in practice depending on ground conditions, personnel skills, models and other factors. This system exists in different models and sizes. For hard and stony grounds a combination of fluid assisted boring system with dynamic impacts of underground piercing tools previously exhausting explained is used. Small models are equipped with wheel undercarriage. This model is light and easy for manoeuvring while medium or greater with crawler undercarriage is more suitable in wet and sandy grounds. An application of special designed polymers allows elimination of spending of the time for preparation of huge volumes of bentonite solution. The new released units are fully electronically controlled or not. Also one of them are produced in extremely silent model or not. These factors reflect on the price of such complex systems, local conditions and so on. Finally an practical application of this very modern system in trenchless technology demands at least few days of training, but the technical and economical results in practice are very fruitful. The maximum pushing force is 50 kN (5 tons), while maximum back reaming force to pull the PE pipes is 100 kN (10 tons). The maximum torque is 1.600 Nm. Maximum pull back force and maximum torque are available at the same time. The detail description of the system and any aspect of this new growing technology should be a subject of separate paper.

EQUIPMENT FOR GUIDED DRILLING

Dr Ryszard M. Dmowski, COBRBI HYDROBUDOWA, Poland.

ABSTRACT

The recent decade witnessed considerable progress in applying the trenchless technology to the practice of construction and reconstruction of the various types of underground piping. Microtunnelling, directional drilling and impact moling are the trenchless techniques which cover almost the whole application field.

The equipment for monitoring the position and guiding of working head is mainly based on radiodetection, visible or laser light principle but other solutions like permanent magnet and water level have been also successfully developed. The paper gives the review of those technical solutions.

The first microtunnelling machines were developed in Japan in the 1970s, with a second generation following in Germany during the early 1980s. The history of remote guided underground jacking of pipes with impassable diameters started in Berlin in the year 1984 and thanks the favourable conditions microtunnelling has reached here substantial development, so that till the and of 1992 by means of this technology there have been completed together 96 000 m of municipal sewers with diameters DN 250 to DN 1200 and ca 23 000 m of house connections mainly with diameters DN 150.

Information on the position of boring head underground and its movement correction can be obtained by different methods: electromagnetic, magnetic, optic and ultrasound, each having specified advantages and disadvantages.

ELECTROMAGNETIC METHOD

Monitoring of boring head position underground and its movement correction is here obtained by means of radiodetection devices. Such device consists of a transmitting sonde fitted inside the boring head, very low frequency receiver and operator monitor. The sonde crystal controlled VLF radio transmitter operates on 32 kHz, since this very long radio waves are not too strong attenuated in the ground and are able to reach the receiver on the earth surface. Transmitter operation and information coding is microprocessor controlled. Both, the sonde and receiver are powered by rechargeable batteries.

The handhold receiver is shifted along the line of required piping path at the earth surface. The receiver is equipped with a liquid crystal display screen indicating position and depth of the boring head and its roll angle, in recent version of the device also the tilt angle.

Position: Bar graph indicates peak response when receiver blade is directly over and in line with the boring head. Accurate to +/- 10% at depths down to 5 m.

Depth: Digital display indicates depth in either meters or feet. Accurate to +/- 5% at depths down to 5 m.

Roll angle: 16 or 8 segments indicate 360° head roll angle throughout bore. Sonde switches of 5 minutes after last boring head movement.

Tilt angle: Boring head tilt angle up to 25° is indicated when the roll angle is within a single segment either side of 12 o'clock Arrows indicate gradient direction. These data can be transmitted and repeated on operator monitor at the spot of drilling rig. The monitor operates satisfactory at the standard maximum range 100 meters from the receiver position. Fig 1 gives the idea how Mole Monitor radiodetection device looks like.

MAGNETIC METHOD

British Gas has developed the Rotasteer detection and monitoring system (Fig.2) co-operating with the Rotamole guided, trenchless pipe and cable laying equipment. It is based on the magnetic field generated by twin flat, permanent magnets which require no power. These are held in the moling tool's head with a silicone potting compound.

The lateral position and depth of the moling tool head are determined using three magnetometers mounted on a triangular board, which is shifted on rollers along the head's route. Readings for the strength of static field at each magnetometer are taken and fed into the microcomputer which, using the trigonometric algorithm, calculates the x, y, & z coordinates relative to the mounting board.

Rotation of the drill-string also rotates magnetic field of these magnets so that it can be distinguished from other, static, magnetic influences. The detected field strength is therefore in the form of sinusoidal wave.

The peaks of this wave provide a means of checking the roll position of the tool head via a magnetometer. In the Rotasteer unit of 1990 the wave strength was indicated on a dial but now more comfortable solution for the operator is used. Rotamole is a compact, light piece of equimpment for easy transport and handling, of non-specialist operation. Installation of mains diameters 63 mm to 180 mm in spans in excess of 100 m. Accuracy of +/- 150 mm of intended route. Is capable of negotiating curves (turning radius of 20 m), correcting direction and of beeing monitored for position and depth to an accuracy of +/- 20 mm.

Information on position, depth and orientation of the angled face of the drill head is presented in digital form on the display screen, where indications for the operator to keep the bore on its planned route are given.

There is used still a very simple device for mole movement monitoring and control based on water-level principle. Its application is limited to the cases where it is enough to control mole movement only in the vertical plane and in the horizontal one the route run has some degree of freedom.

OPTICAL METHOD

Information on bore direction and its correction in microtunnelling technology is obtained by means of a laser or optical theodolite and target positioner bound up to the pipe following shield and boring head (Fig.3). For pipes with diameters up to 400 mm it is possible to achieve in the optical correction system millimetre accuracy of intended route on the distances over 35 m.

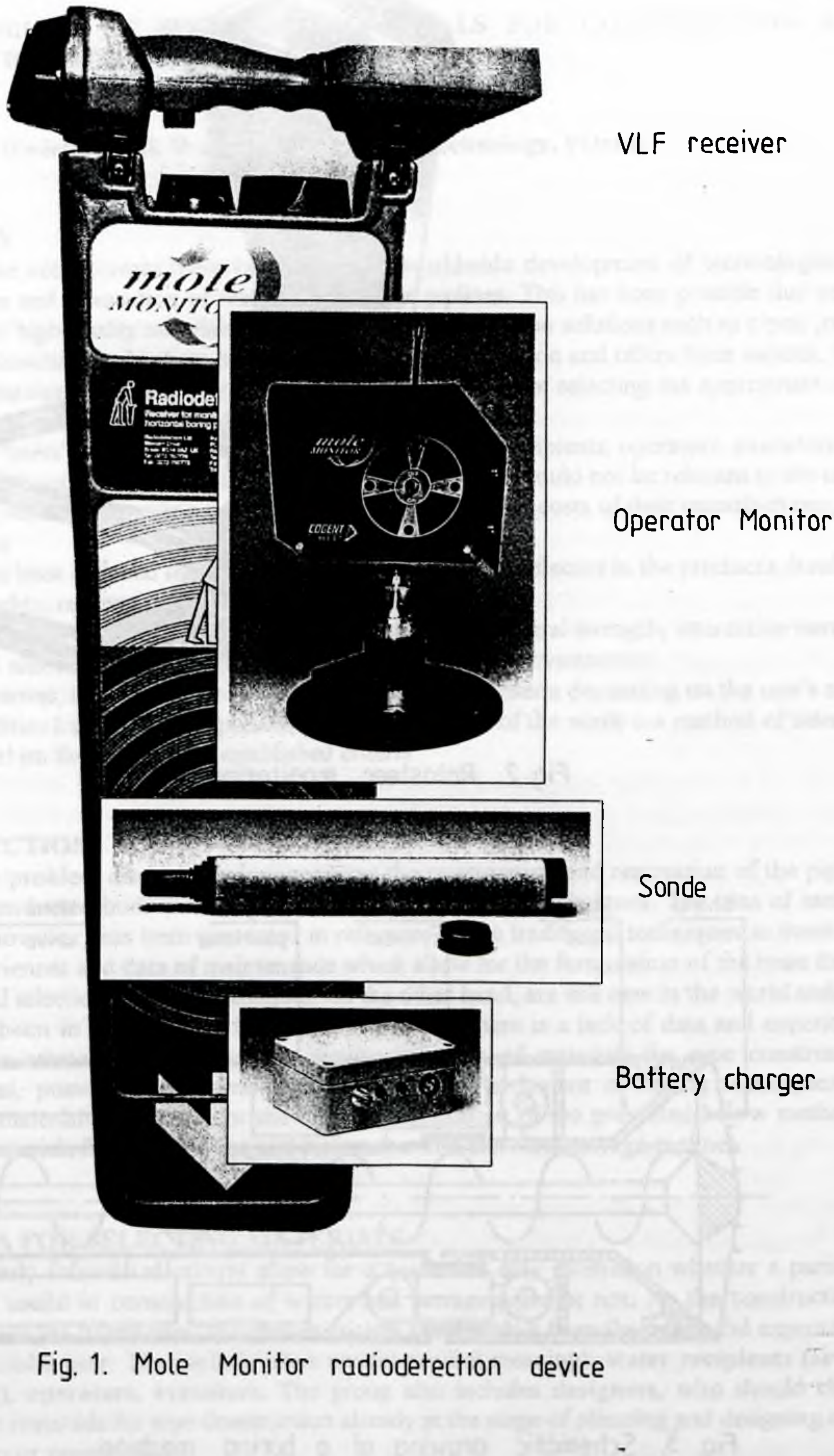


Fig. 1. Mole Monitor radiodetection device

Fig. 2. Rotasteer monitoring system

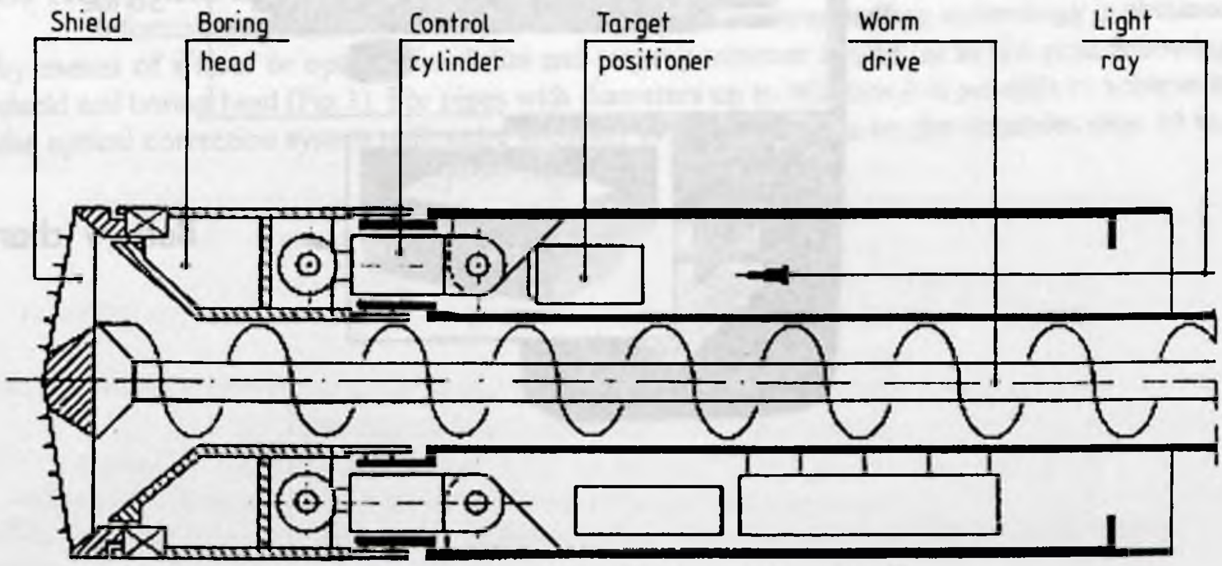


Fig. 3. Schematic drawing of a boring machine

THE PROBLEM OF SELECTING MATERIALS FOR CONSTRUCTION AND RENOVATION OF WATER- AND SEWAGE-PIPLINES

Dr Marian Kwietniewski, Warsaw University of Technology, Poland.

SUMMARY

In the recent years there has been rapid worldwide development of technologies for construction and renovation of water- and sewage piplines. This has been possible due to the application of high-quality materials and the improved construction solutions such as pipes, joints, fittings etc. Simultaneously, there has been an influx of information and offers from various, both Polish and foreign manufacturers. All this leads to a problem of selecting the appropriate offer which would meet the user's needs and expectations.

The "users", in a general understanding, can be water recipients, operators, executors and designers. Although needs of individual users can differ, this should not be relevant to the users' main target, which is providing reliable pipes at lowest possible costs of their manufacturing and maintenance.

It has been assumed that reliability of pipe elements is reflected in the product's durability and thus quality, renovation tractability and failures.

Further criteria have also been considered, such as: structural strength, interaction between the material and water (or sewage), the influence of the pipe environment.

Moreover, the importance and priority of particular criteria depending on the user's needs and possibilities have also been presented. The final effect of the work is a method of selecting pipe material on the basis of the established criteria.

INTRODUCTION

The problem discussed below concerns the construction and renovation of the piplines which is conducted both with the traditional and the no-dig techniques. The idea of material selection, however, has been presented in reference to the traditional techniques as these give many experiences and data of maintenance which allow for the formulation of the basis for the pipe material selection. No-dig techniques, on the other hand, are still new in the world and they have only been in Poland for a few years. Therefore, there is a lack of data and experiences sufficient to create full basis for a quantitive selection of materials for pipe construction. Nevertheless, possibly in the nearest future, wider development of no-dig techniques and respective materials will allow for the effective application of the presented below method of selecting materials for construction and renovation of water- and sewage-piplines.

CRITERIA FOR SELECTING MATERIALS

Clearly formulated criteria allow for a quick and easy estimation whether a particular material is useful in construction of water- and sewage-pipes or not. As the construction is conducted for the future user, the chosen criteria should result from the needs and expectations of the particular user. The piplines users are (in general meaning): **water recipients (sewage producers), operators, executors.** The group also includes **designers**, who should choose appropriate materials for pipe construction already at the stage of planning and designing of the water mains or sewer system.

Individual and particular interests of those may differ.

Water recipients,if they are not investors, would like, for example, to receive water of particular quality and pressure and at any time they wish. Material costs, durability, range of manufacturer's offer or effectiveness of assembling are of no interest to them. What is essential, though, is whether pipe material can interact with water and thus have harmful influence upon human health. In a sewer system's case, on the other hand, what counts is the capacity of pipes carrying away sewage.

Operators, would like pipes which would not induce precipitation or get damaged easily, and if so, which could be renovated easily. They are not interested in such aspects as construction costs, efficiency of joints etc.

Executors, on the other hand, are first of all interested in the range of manufacturer's offer (which would include pipes, joints, and fittings), easy assembling (simple and quick join), long and light-weight pipes etc.) etc. Not essential for them is resistance to corrosion, durability, interaction between material and water (sewage), costs of maintenance etc.

Although interests of particular user groups differ, it should not affect their main target which requires selection of an appropriate material. This target (in great simplification) is to provide reliability of pipes at the lowest possible costs of construction and maintenance.

The concept of reliability includes a number of properties of offered products which are essential to all the users of a system [1]. In this case the concept of pipline elements' reliability could be defined as follows:

"Reliability of the piplines' elements is their ability to facilitate the transmission of a certain amount of water (sewage) while keeping its quality in defined conditions of pressure, environment, way of maintenance and time."

Therefore, reliability of the offered elements will be represented by durability and so quality of the product, renovation tractability and the pipline's **failures.**

Durability of pipes and other elements depends on quality of work, kind of raw materials used and anti-corrosion protection.

Quality of a product covers structural and thermal strength, interaction between materials and water (sewage), resistance to environmental influence (such as e.g. water and ground conditions), proper maintenance.

Resistance to environmental influence is an essential property of pipe material. It is also important what influence is exerted on the material by the transmitted liquid.

The pipe should be easy to operate, to repair or renovate and should not inhibit modernization of the system.

It is easy to interprete failures, which facilitates estimation of reliability of piplines made from a particular material. It is also convenient to define this property on the basis of maintenance data.

While selecting pipe materials the offered product and service range is important. It is also essential whether the offered products allow quick and simple assembling.

Costs are perhaps the most obvious aspect of material selection. However, if the material selection has been properly and thoroughly calculated this criterion should be understood as more than just the costs of purchase of materials.

Beside formulating the criteria it is equally necessary to define their priority. It is mainly connected with individual needs and possibilities of a user.

Considering needs and expectations of users, one could formulate the above mentioned criteria as follows:

1. **necessary range of product and services**
2. **elements'tractability in assembling**
3. **suitable structural static and dynamic strength**
4. **resistance to environmental influence**
5. **resistance to interaction with transmitted liquid (mechanical, chemical and biological)**
6. **tractability in repairs and facilitating maintenance**
7. **minimum failures**
8. **minimum costs.**

Additionally one should consider local conditions, which might sometimes determine the possibility of execution of work, or the user's special requirements.

Estimation according to particular criteria of materials used in pipe construction and renovation is a broad topic and therefore cannot be discussed in great detail in this paper. Nevertheless, out of the above mentioned criteria four have drawn particular attention, namely: interaction between material and water (sewage), failures, tractability in renovation and maintenance and costs.

INTERACTION BETWEEN MATERIAL AND WATER (SEWAGE)

Interaction between material and water (sewage) can be, in most cases, of biological or chemical nature. It can result in deterioration of water quality and on the other hand in pipe material incrustation. This can endanger human health and might lead to precipitation in the pipe, which inhibits operation and raises costs.

Water's corrosive influence on the inside of the pipe can be far more intensive than the outside corrosion.

Deterioration of water's quality might be caused e.g. by washing out asbestos fibres, vinyl chloride or dissolving of WWA from same protective coatings. There can also appear secondary growth of microorganisms in water pipes which is caused by existence of biogenes in treated water and by water erosion of compounds which might become bacteria nutrients.

It must be observed that pure mineral materials and metals such as cement mortar, asbestos cement, high quality steel or tough pipes made of PVC and PE do not tend to grow bacteria on their surface, provided they are efficiently cleaned from protective and conserving substances etc. (table 1) [3]. However, cement mortar enriched with plastics, which promotes quicker setting, might encourage bacteria growth in water (table 2) [3,4].

Protective coatings like e.g. bituminous, chlorinated rubber paints, epoxy resins or soft PVC coatings, on contact with water, might cause secondary growth of microorganisms (table 2).

Rubber, used in joint sealing or in coating metal surfaces, usually helps bacteria grow [4] although some sorts of it have not got such properties [5].

Other sealing non-hardening substances are characterized by a varied intensity of microorganisms growth on their surfaces [4] but for example adhesive remains on joints of PVC pipes might constitute a source of bacteria growth.

In sewers, chemical interaction between sewage and material,is very intensive. It is particularly strong if unprotected cement based pipes conduct sewage that produces sulfuric acid and hydrogen sulfide.

It is highly important that pipe materials used in sewer systems should be abrasion-resisting. Figure 1 shows results of the adequate research conducted in Germany in Technische Hochschule

Darmstadt [3]. Fig. 1 shows that the highest abrasion resistance characterizes composite pipes and those made of HDPE. PVC pipes are less resistant and the least abrasion resistance belongs to asbestos cement pipes.

FAILURES

For users this is the most noticeable feature of pipes. Nonetheless, to make it a significant criterion for material selection, there has to be a thorough reliability research done.

Information about damages should be credible, reliable and exact.

To achieve this, collecting data should take place while the system is working.

Table 3 shows individual frequency of pipe damages calculated on the basis of research conducted in various countries, including Poland. This could provide some information about damaging water piplines.

Although one cannot generalize conclusions from table 3, one could observe, however, that the lowest failure are pipes made of PVC, PE, and ductil iron. The most failures have asbestos cement and steel pipes. While estimating frequency of failures one has to consider factors affecting the results, for example ground conditions, anti-corrosion protection if any etc. In Canada, for instance, cast iron pipes were laid in highly corrosive grounds. The most reliable research results come from Sweden and Germany.

Furthermore, reasons for damage are also very important. They show which elements get easily damaged. It requires stressing that the most often damaged parts are joints. Swedish research proves that joints of PVC and PE pipes get damaged 2-4 times as often as the pipes. Thus most manufacturers' technical developments concentrate on improving and modernizing ways of joining produced pipe elements. Sweden, for instance, is aiming at reaching the level of 0.01 damage/kilometre per year in PVC and PE pipes [7].

TRACTABILITY IN RENOVATION AND MAINTENANCE

It can be accepted that pipelines of any material are renovation tractable. With modern renovation techniques there is only one problem, which is to establish its range. Generally, pipes which can still keep their structure after damage (cast iron, steel pipes etc.) can be reconstructed while preserving the old pipeline. Pipes which lose their structure (usually made of PVC, PE, concrete) must be replaced with new ones.

One could assume that following factors enhance pipes' tractability in renovation and maintenance:

- availability of pipe elements (pipes, loints, fittings etc.) for "spare parts"; practically it depends on the range of manufacturer's offer,
- mechanical properties of material allowing to keep the pipe's structure after damage, which limits the range of renovation.

During maintenance water hammer create a lot of difficulty. Beside numerous well known methods of preventing negative effects of this phenomenon, it is possible to use in construction pipes of certain elasticity which allows suppressing the shock wave. In practice this elasticity is indicated by the velocity of pressure wave propagation in the pipe. The velocity depends mainly on the pipe material, thickness of its walls, and the kind of transported liquid. Pipes made of PE, PVC, and composite show very small, thus good, values of that velocity. Average velocity of wave propagation in such pipes is 170-200m/s, 240-380m/s and 420m/s respectively. In standard materials like steel or cast iron, average velocity adopted in designing is approximately 1000 m/s.

COSTS

Most often this is the decisive criterion in material selection. But it must be stressed that it is treated too superficially.

Usually, while deciding on a certain material, one takes into consideration the costs of elements purchase and occassionaly the costs of construction. Frequently forgotten, though, are the costs of future exploitation/operation xxx of pipelines build from a given material.

Obviously costs should be considered at a certain period of time. Usually it happens that selecting a cheap material brings some savings at a given time and these are unmistakably measurable. On the other hand, selecting a more expensive material, usually of better quality, involves a single, relatively big expense. In practice, however, it appears that in the former case the operation and maintenance costs (electric energy, repairs of damaged parts etc.) are generally higher than in the latter.

It could be assumed that both capital expenditure and subsequent operational costs are determined first of all by: quality of material, quality of connecting solutions, ways of protecting pipes and pipes' durability.

It is difficult to present a common comparative analysis of all materials in question, simply because of the lack of reliable information. Moreover, such an analysis should refer to particular conditions of work (ground and water conditions, local conditions, construction techniques etc.).

Nonetheless, one could assume that in the nearest future, with a wide use of modern materials, such analyses will be possible.

METHOD OF MATERIAL SELECTION

The method of material selection is based on assuming a five-grade scale for evaluating the usability of a given material according to each criterion. Therefore the following grading has been adopted:

5 - **excellent**
4 - **good**
3 - **fairly good**
2 - **satisfactory**
1 - **unsatisfactory**

It must be observed that material classification according to the above grading refers to a relative comparative evaluation of materials in question (comparing materials between each other). It is not an absolute evaluation of the usefulness of a given material in construction of a particular pipe as every material can be used for an assumed purpose. This is confirmed by permissions to use in construction and positive hygienic opinions which have been issued by authorized institutions in Poland. Therefore this scale functions in a situation of a defined quality of materials.

It goes without saying that not all the criteria are equally important for a particular investor. The importance of criteria will be different for different users of a water system or sewer. This will be influenced by many factors such as **affluence, culture and technical progress, local conditions and ground and water conditions.**

Thus, in proper selecting of materials it is essential to ascribe definite "values" to individual criteria. Such "values" will result from the assumed importance of a given criterion. They might be expressed as parts of a whole or as a percentage. Assuming that the criteria in question cover all conditions to be fulfilled by a pipline, the sum total of their "values" will equal 1.0 or 100%.

And so the general evaluation of the degree of criteria fulfillment for a given material will be represented as a sum of products:

$$D = \sum Oi*Wi \qquad (1)$$

where: D - evaluation of degree of fulfillment of all criteria
Oi - evaluation of degree of fulfillment of an i-criterion
Wi - value ascribed to i-criterion
n - number of considered criteria

In order to illustrate the way of material selection there follows an example of pipe material selection for construction of a water system. Following materials have been considered:

- grey cast iron
- ductile iron
- steel
- PVC
- PE
- asbestos cement
- reinforced concrete
- multi-ply - "sandwich" type
- multi-ply - composite type

The evaluation of each material's fulfillment of particular criteria, graded from 5 to 1, has been done basing on the analysis of the properties mentioned above, without considering the costs. Following "values" of the criteria have been assumed:

1. interaction of material and water - 0.3
2. failures - 0.2
3. other criteria - 0.1 each, which gives 5*0.1=0.5

TOTAL - 1.0

The results have been presented in table 4.

Taking into consideration the results of partial evaluations, the adopted "values" of particular criteria and the degrees of fulfillment of all the criteria by a given material (calculated according to formula (1)) the pipes chosen for the example were those made of ductile iron and composite. These have received the highest evaluation of criteria fulfillment, which was 4.9 .

FINAL REMARKS

The presented method of material selection is an attempt at solving the problem of an appropriate selection of materials for construction and renovation pipes in sewers and water systems. Nevertheless, the idea of this method could also be used in material selection for other transmission systems. It is a clearly formulated problem of practical importance although the necessary condition for solving it is a wide range of information on the part of the user.

Some of that information such as technical data, properties of products and the range of offers is easy to obtain. However, most of the data, like information about failures, resistance to ground and water conditions, interaction with transported liquid, tractability in assembling, renovation and repairs, operational and maintenance costs could only be obtained as a result of eksploitation tests and direct observation of construction process. Some data can also be taken from laboratory tests (resistance to abrasion, resistance to chemicals, growth of microorganisms on walls of pipes, thermal and mechanical strength etc.).

Without diminishing the role of other sources of information, it seems that the most important of them are operation and mainetance tests. Such research is based on constant (in a given period of time) observation of system's functioning and systematic recording of degree of fulfilling requirements, criteria, expressed by the user. This way one can acquire true information from natural conditions, which best reflects the actual technical state of pipes.

Owing to all that research, one can obtain data which allow for the numerical expression of all adopted criteria for evaluating pipe materials. Conducting such research is not only beneficial for users but also for executors and manufacturers of all necessary elements.

BIBLIOGRAPHY

1. Kwietniewski,M., Roman,M., Kłoss,H., *Niezawodność wodociągów i kanalizacji* , Arkady, Warszawa 1994.
2. *Poddziemna korozja rur wodociągowych w miastach kanadyjskich* Caproco Corrosion Prevention Ltd. Edmonton, Alberta, Report no ENG-83/240, 1983 and 1985.
3. Wichrowska,B., *Zanieczyszczenia wody do picia w przewodach wodociągowych w zależności od ich rodzaju,* Informacja INSTAL no 4/1994, pp. 7-11.
4. Kaplan,L.A., Bott,T.L., *Nutrients for bacterial growth in drinking water: Biossayevaluation,* EPA 600/S2-89/030, Feb.1990.
5. Schoenen,D., *Influence of materials on the microbiological colonization of drinking water,* Aqua 38/1989, pp. 101-113.
6. Kirschman,O., *Problem of Abrasion in Pipes,* Steinzeugin Formationen, 1966 no 1, pp. 3-13.
7. Bjorklund,I., *PLastic pipes in water distribution systems. A study of failure frequencies,* The Nordic Plastic Pipe, Association, Stockholm 1990.
8. Roman,M., Kwietniewski,M., Kłoss,H., Own materials.
9. Kondoh,I., *Materials selection standard of distribution and service pipes in Nagoya,* Special subject, Congress IWSA, Budapest 1993.
10. Olah,F., *Selection of pipe materials for water supply systems,* Congress IWSA, Budapest 1993.
11. Kłoss,h., Kwietniewski,M., Roman,M., *Eksploatacyjne wskaźniki niezawodności przewodów tranzytowych i sieci rozdzielczych w wiejskich systemach wodociągowych,* Gaz Woda i Technika Sanitarna no 12/1990, pp. 244-248.

Table 1
List of pipes and their evaluation according to bacteria growth on their surface [3].

Pipe material or kind of pipe	Bacteria growth on surface
Polyvinyl chloride (PVC)	no
Post-chlorinated polyvinyl chloride (cPVC)	no
Polyethylene (PE)	no
Polypropylene (PP)	no
Polybuthylene (PB)	no
Polyamide (PA)	yes
Flexible pipes and hoses of PE	yes
Flexible pipes and hoses of PA	yes

Table 2
List of examined protective coatings and sealing materials in pipes and evaluation of their influence upon microorganisms growth [3].

Coating or sealing material	Bacteria growth on surface
Bituminous coatings with solvents	yes/no
Bituminous coating without solvents	no
Chlorinated rubber coatings	yes
PVC coatings	yes
cPVC coatings	no
Plasticated PVC sheetings xxx	yes
PVC sheetings with copolymer	no/yes
Cement mortar with synthetic additives	yes/no
Cement mortar without synthetic additives	no
Teflon (PTFE)	no
Epoxy resin with solvents	yes
Epoxy resin without solvents	yes/no
Sealing materials with epoxy resin	yes
Sealing materials with	yes
Sealing materials with silicon	no/yes
Pipe adhesives with PVC and cPVC	yes

yes/no - means different influence depending on a variety of material, its composition, conditions of environment, work etc.

Table 3
Selected frequency of damage (damage/kilometre per year) of pipes in water distribution system in different countries

Material	Sweden 1986 [7]	Canada[1] 1980 [2]	Germany[2] 1986 [8]	Japan[3] 1991 [9]	Hungary[4] 1991 [10]	Poland 1987 [1,11]
ŻŻ	0.19	0.50	0.06	0.06	0.27	0.074***) 0.536****)
ŻS	0.04	0.29	0.06*) 0.01**)	0.0007	0.18	-
S	0.47		0.13		0.94	0.021***) 0.51****)
uPVC	0.10		0.006	0.168	0.67	0.20***) 0.086****)
PE	0.03				1.0	-
AC			0.13	0.7	0.28	0.5***) 0.53****)
Ż						0.29***)

ŻŻ - grey cast iron, Żs - ductile iron, S - steel, uPVC - unplasticised polyvinyl chloride, PE - polyethylene, AC - asbestos cement, Ż - reinforced concrete

1)-Calgary (particularly corrosive ground conditions), 2)-Hamburg; 3)-in Nagoya; 4)-Budapest (with house connections); *)-no protection;
)-inside coating of cement mortar, outside coating of polyethylene; *)- duct pipes; ****)-countryside water distribution systems

Table 4
Evaluation of degree of criteria fulfillment for particular materials of water distribution system pipes (example)

Material	Evaluation of criteria fulfillment							Final evaluation acc. to formula (1)
	1 (0.3)	2 (0.2)	3 (0.1)	4 (0.1)	5 (0.1)	6 (0.1)	7 (0.1)	
ŻŻ	4	4	4	4	5	4	4	4.1
Żs	5	5	5	4	5	5	5	**4.9**
S	3	4	4	5	5	4	5	4.0
PVC	4	5	5	3	4	5	3	4.2
PE	5	5	5	3	4	5	3	4.1
Ż	4	4	4	4	4	4	4	4.0
H	5	5	5	5	4	5	5	**4.9**
W	4	4	5	4	4	4	4	4.1
AC	1	3	4	3	4	5	3	2.7

ŻŻ-grey cast iron, ŻS- ductile iron, S-steel, PVC-polyvinyl chloride,
PE-polyethylene, Ż-reinforced concrete, H-composite pipes, W-multi-ply pipes "sandwich" type, AC-asbestos cement
1 - interaction between material and water (sewage), 2 - failures
3 - durability of elements and resistance to ground and water conditions 4 - tractability in renovation and operation, 5 - range of product and service offer, 6 - tractability in assembling, 7 - structural strength

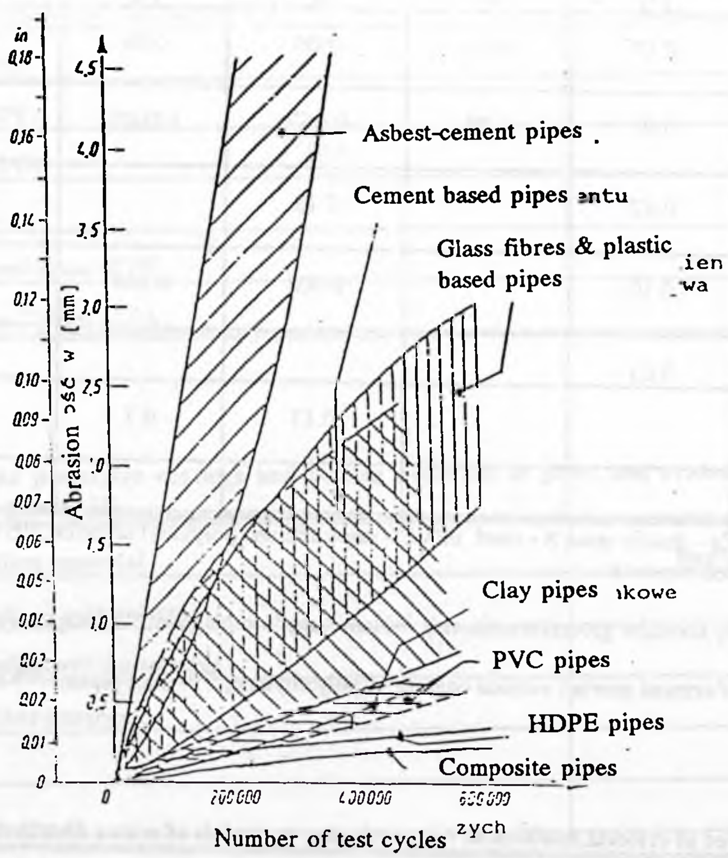


Fig. 1. Range of abrasion for pipes made of different materials