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Session 6

Environmental Geotechnics — State-of-the-Art Report

La Géotechnique de l'Environnement

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"... mankind always takes up such problems as it can solve; since looking at the matter more closely, we will always find that the problem itself arises only when the material conditions necessary for its solution already exist or are at least in the process of formation".
(K. Marx)

1 - PROPOSING ENVIRONMENTAL GEOTECHNICS

Engineering's horizon has dilated: from the principle of science as discovery to the ethics of responsibility. In recent years, as if the time rhythm had accelerated, we realized that man is facing not a series of isolated problems, that can be defined and solved one after the other, but rather a number of interrelated facts so closely knitted that it proves to be nearly impossible to untie one of them without affecting the others, although they may be apparently remote.
If information is not knowledge, we are now learning that knowledge is a different thing from wisdom. To make our point clearer, let us replace knowledge and wisdom by more familiar words that, in a way, may be used as their synonyms: Soil Mechanics and Environment.

Soil Mechanics is certainly a specialized branch of civil engineering. In this nature soil mechanics solve limited problems which are part of wider undertakings.
Seldom is a soil engineer called to direct an entire project (exceptions may be the cases of earth and rock dams) and even less frequently is he really alone in doing this. Both the subjects of their concern and their role induce soil engineers to take a position of well defined but limited responsibility.

Environment is in itself a sum of facts and therefore its dealing is irrefutably interdisciplinary. More than interdisciplinary we should probably consider the environment as undefined not only as regards its contents, but also the methods of analysis and more than anything else, as regards the responsibility for it.
As ultimate responsibility tends to migrate toward the outer and largest circle enclosing a given problem, and because environment, as a sum of different facts, is a far frontier of any given problem, environment inherently implies a high load of volatile responsibility.

Interdisciplinarity rather than specialization, ultimate and comprehensive responsibility rather than a well defined one appear as the far, if not opposed, characteristics of Environmental Control and Classical Soil Mechanics. Yet we have to reconcile them, we have to obtain Environmental Control within and through Soil Mechanics activities, we must achieve both knowledge and wisdom and show science responsibility.

More things than would appear at a first look need to be analyzed and discussed to understand better the differences, interrelationships, the mutual positions and the way to get Environmental Control in Soil Mechanics. Shall we start this analysis and discussion asking ourselves what a Soil Engineer should control in the environment?

Present Abandonment of otherwise usable materials like ashes and sludges, wasted with their energy content, mostly because the notions leading to their reuse stay with others rather than of the producers of the materials, will it or will it not require the control of Soil Engineering?

Future Potential Use of filled or mined out areas like urban wastes fills, tailing dumps, or borrows, usually handled merely as sanitary or mining operations but susceptible of becoming the support to human activities, will it require the control of Soil Engineering or not?

Pollution induced by geotechnical activities like filling, excavations or dredging, should it be controlled or not?

Vibrations (sonic or subsonic) from geotechnical activities like piling, drilling and blasting, should it be controlled or not?

Aesthetics of geotechnical works like highway cuts or large enbankments usually designed with the sole intervention of soil engineers, should it be controlled or not?

Let me just pose these questions for the time being and proceed further leaving them unanswered.
The next point to consider is the role of the Soil Engineer in this environment control operation. To facilitate this meditation let us take fields which soil engineers consider to be obviously within their specialization.

On Subsidence cases is the Soil Engineer simply called to design non-settling structures or settlement-proof ones? Should he not work in the first place to find a way to ease or stop subsidence? Or should he rather take a wider responsibility and a more outstanding role and participate in the planning process when the harnessing of a water or gas resource is decided (and a subsidence phenomenon set into being) or when the use of a territory is decided or an urban development planned?

On Mine Wastes projects is the Soil Engineer solely to concentrate on the problem of designing and building safe tailings dams or should he be given the task of finding a useful and rewarding reuse for the waste material and perhaps be called in to participate in the general, initial planning and help to place in a proper light the parallel realities of exploitation of mineral resources, by-products disposal, requirements of surface facilities and the maintaining or betterment of landscape quality?

On Landfills and Reclamation projects, do we see the soil engineer's task as limited to producing proper grades and walkable surfaces only? Or expanded to ascertain the changes in subsoil characteristics, drainage pattern and their effects on human settlements, wild life and flora?

On Urban Developments should the Soil Engineer be called in to design the understructures and to supervise their constructions? Or, rather, should he not be called in well beforehand, to study and understand the nature of the soils in the area and the implications of a superimposed urban reality?

On Man-made Reservoirs and Dams is the Soil Engineer only to form a lake at a given place limiting his contributions to selecting the dam axis and cross section? Or should he not intervene at an earlier stage to assess and accept the overall suitability of the site as far as general slope stability, induced seismicity and groundwater conditions are concerned?

It is clear enough that these are key questions, and depending upon our answers the soil engineer's task, required capabilities and final responsibility will differ greatly. It is readily clear that an answer to these questions is needed from all of us and not only for the purpose of this Report.

Recent experiences give the clear perception that Environmental Control cannot be just an extension of classical Soil Mechanics. No definite answers or precise images actually come from the past neither can they possibly result from a forcibly short meditation.

In default of a clear answer your Reporters would like to offer a proposal. This proposal is aimed at defining the difference between the specialized nature of Soil Mechanics and the interdisciplinarity of Environmentalism. This proposal is also aimed at clarifying the different responsibilities, and therefore the right to a different place in the process of planning and engineering human activities, of Soil Mechanics and Environmental Control.

We propose first of all to use, instead of environmental control, the term ENVIRONMENTAL GEOTECHNICS to identify A TOOL that contains all the different branches of soil and rock mechanics. A tool shaped to investigate, to understand and decide, USED BEFOREHAND to avoid geotechnical problems that might materialize and geotechnical activities that might later develop into problems. A tool aimed at minimizing the entropy of a given process through geotechnical knowledge. A tool to be used together with other similar ones in a planning effort shared by many disciplines.

Environmental Geotechnics is not to be mistaken with Soil Mechanics, as we generally understand it today, which is a method to solve problems fairly well defined, i.e. after they have come into being or when they exist. A method that is usually not applied to identify and analyse secondary effects of the main action.

If we had to try to condense the differences we might say that Environmental Geotechnics forecasts and minimizes while Soil Mechanics accepts and solves or we might call Soil Mechanics a homogeneous discipline and Environmental Geotechnics a polyhedric one.

Environmental Geotechnics emerges as a new form of Soil Mechanics aiming at forecasting rather than solving. Two case histories might help in clarifying the meaning of what we have been saying.

In the early forties, gas was discovered in the eastern Po valley. The need for energy was high and the return from the exploitation of local resources very attractive. Drilling of gas

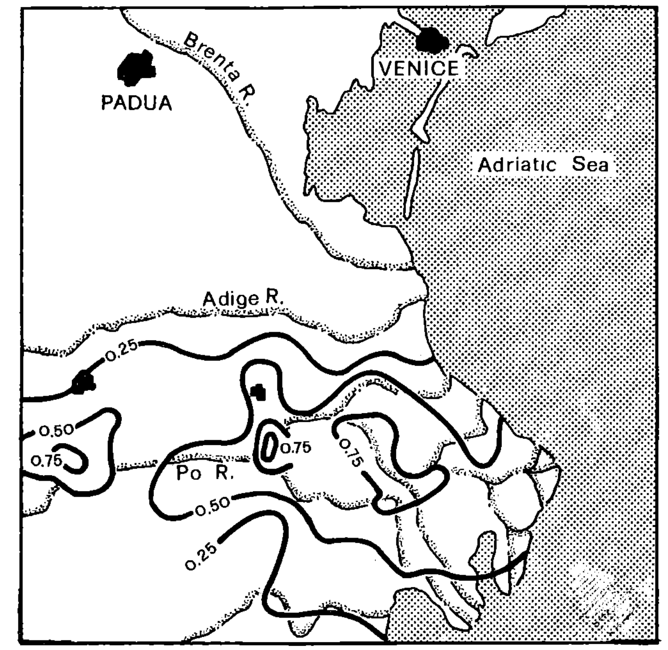

Fig.1 - Subsidence induced in the eastern Po valley by gas extraction. Contours show settlements measured from 1958 to 1963, in m (from Caloi).

wells and gas exploitation went on almost unchecked through a number of small private groups: a regional subsidence soon was in progress: it progressed for nearly a decade, total settlements exceeded 2.5 m with settlement rates up to 0.35 m/year in 1959.

The subsiding area is near the sea and its axis is formed by the largest river of Italy. The average ground elevation is less than 2 m above sea level and the river flows with a small gradient well above the surrounding lands in between high dykes. In 1951 a flood breached the dykes and 300 km^2 of land inhabited by nearly one million people were flooded. As a result of the subsidence all dykes had to be raised and new defenses created along the coastline. The area is in between Venice and Ravenna: two monumental cities that, shortly after this phenomenon, were the seats of subsidence problems.

So far no attempt has been made to compare the benefits derived from the exploited gas with the damages produced by floods and subsidence, or with the expenses for dykes and drainage which otherwise would have been unnecessary.

Environmental Geotechnics as we propose it here should first of all understand the mechanism and its direct (settlements) and induced (modified river hydraulics) effects. Based on

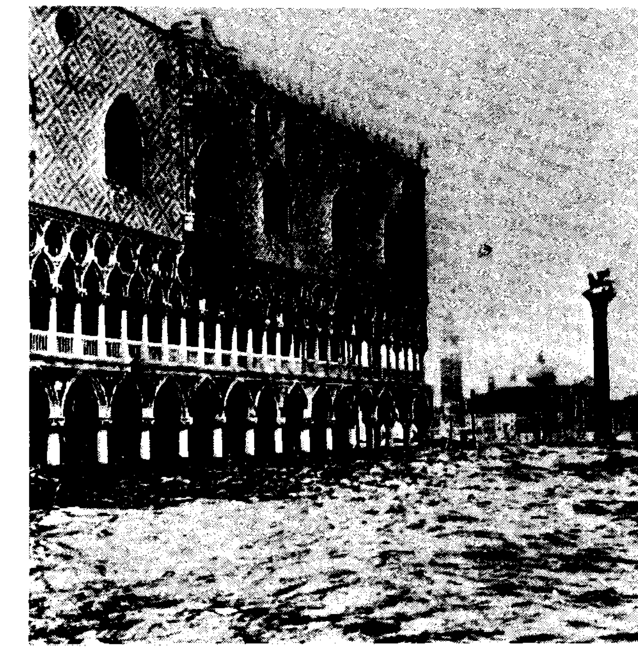

Fig.2 - Venice ingulfed by the sea. A few hundreds of millimeters additional subsidence would make this a permanent situation (from Pirelli).

stratigraphy, soil characteristics and on going or potential consolidation processes, it should evaluate the effects of gas extraction in terms of ranges of settlements vs. volume extracted.

Environmental Geotechnics should have been called in to participate in the decision process, to exploit or not to exploit gas, indicating a safe rate of exploitation in the light of the latest knowledge of the phenomenon, taking its share of responsibility. Actually, over the whole process, the profession involvement and responsibility were practically zero.

In the mid fifties the planners of an electric company recognized the need for additional capacity near the end of a long tunnel conveyance feeding one of the largest hydropower plants in Europe at that time: Soverzene 300 MW. The only way was to create a reservoir in

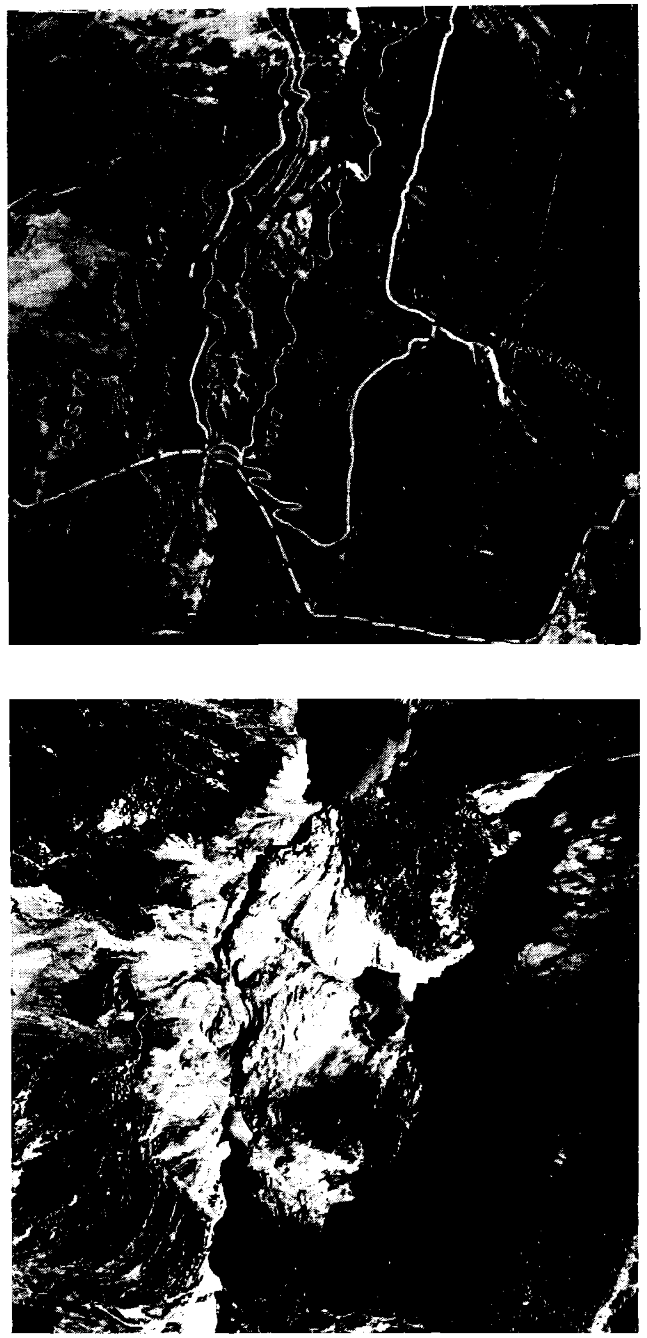

Fig.3 - The site of Vajont slide in twin aerial pictures taken before and after the slide. A rock mass of 300 000 000 cubic meters moved on October 9, 1963. In 50 seconds the front of the sliding mass moved 400 meters forward and raised 150 meters. The rock plounger produced a 100 meters surge in the reservoir and the jet spill of 22 000 000 cubic meters of water that jumped over the dam and rushed downstream. The pictures are approx to the scale of 1:30 000.

one of the valleys crossed by the conveyance: Vajont gorge a few tens of meters wide and carved in excellent rocks was the obvious site for a high dam. Design was supported by the usual studies and the reservoir slopes were the subject of geological reports: the dam was built and impounding started.

Only when small slope failures developed and a huge unstable mass (some 300 000 000 m^3 in volume) became known, was Geotechnics called upon: the reservoir water and commissioning dead lines hindered observations and actions. A major rock slide killed the reservoir only three years after completion: the dam held firm.

Environmental Geotechnics, as we propose it here, and in today's knowledge, should be a component of the earliest studies. Its concepts and findings should be combined with all other information to understand as fully as possible the project in its physical reality (weak rock strata) and implications (slides and reservoir surges), to evaluate the potential evolution of each major parameter and the possible long term effects of the intended actions. Adopting this new viewpoint in the earliest assessments of acceptability and feasibility of projects, would, on the other hand, place a share of the overall responsibility on Environmental Geotechnics.

The Soil Mechanics community's awareness of the importance of Environmental Geotechnics should not be mistaken for adequacy to deal with its problems. The reporters' proposal is consistent with the observation that man is actually a morphogenetic factor and that geotechnical engineering has, in this process, a place of relevance. It will be enough to recall here man-made lakes associated with earth and rock dams, and to remember that the highest dams in the world are presently of embankment type. It will be enough to mention open pit mines, tailings dams (the largest artificial fills on earth), reclamations, the withdrawal of water, oil and gas from the earth crust.

We too often assume that our work has an environmental content only because it has environmental effects. This is mistaking the consequences of an inadequate focusing of the problem with the desire of a fashionable presentation of a work performed with the same concepts of the past.

There certainly are several and excellent examples of Environmental Geotechnics' approach but few professional papers. In fact, this is not the current way in which we used to think and write. Focused in this very light this State of the Art would end with a tiny yet not

discouraging product. There are, however, dispersed sometimes in the work of many colleagues, hints and considerations for more than a report.

One activity should be mentioned in these introductory lines, because it is finely consistent with the focusing outlined above for Environmental Geotechnics: the compilation of Geotechnical Maps. The relative oblivion shown by soil engineers for this subject may indicate that Environmental Geotechnics needs indeed to be framed anew, to be proposed under a fresh light and to be reconsidered by the entire profession.

2 - TOOLING ENVIRONMENTAL GEOTECHNICS - GEOTECHNICAL MAPS

A map, as a polydirectional and multitarget document, is a typical tool for a complex investigation to be done beforehand. Truly, many of the available maps cannot be taken as eminent examples but one should not forget that the largest majority of geotechnical maps have been produced through individual, uncoordinated efforts and often well before the date when the word environment started to acquire the meaning and relevance it has today.

Even with their limitations, geotechnical maps are probably the best link and interface between geology and soil mechanics and the natural background for all geotechnical analyses. The earliest examples of geotechnical maps were developed after 1913 in Germany by Langen for a number of towns including Erfurt and Danzig. This pioneering work was continued by others and for the first time in 1932 Stremme prepared a map showing allowable loads and unstable zones. The first atlas of several maps, each emphasizing a different aspect, was the work of Muller who prepared it for the Municipality of Marke. Muller's maps included a map of suitability for construction based on bearing capacity and groundwater flow criteria. For the first time in 1956, Gwinner introduced the concept of geotechnical units as zones of uniform behaviour, even if having different structure and pertaining to different formations, in the geotechnical map of Gottingen.

Extensive work was developed in Czechoslovakia from 1954. Remarkable contributions came from Pasek, Rybar and Simek who were the first to accompany the map of Prague with a file of numerical data. Work along the concepts of data storage was done in Australia by PUCE (Pattern, Unit, Component, Element) and in South Africa (Brink). In South Africa since 1962, parallel experiences concentrating on mapping with data

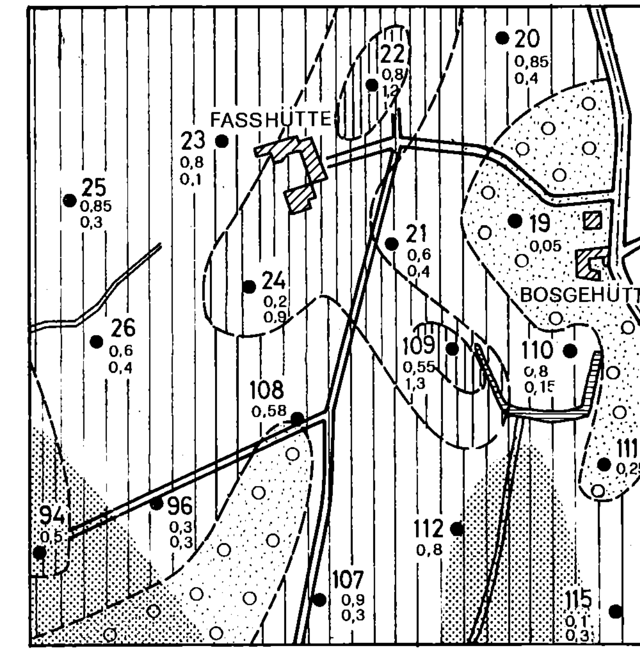

Fig.4 - Plan 1.5 m below surface showing soil type, soil thicknesses and water-table. One of the 5 geotechnical maps forming the atlas for the town of Meerbush, Germany (from Kalterherberg).

storage as a secondary purpose, were developed and applied (Kantey).

In recent years important and original contributions have come from the French Bureau des Recherches Géologiques et Minières that supplied, in the Atlas of geotechnical maps for the town of Ecouen, a map of geotechnical interpretation. Maps of subsidence of Nobi Plain in Japan have been issued by a special Committee since 1972.

There is nowadays a general consensus regarding the principles inspiring the preparation of geotechnical maps. As far as their form is concerned, atlas are normally preferred. Regarding their content, while it is considered necessary to convey with a map an appreciation of the different conditions existing in an area, it is equally agreed that information should not be purely in numerical form. Besides recording, a good geotechnical map should also help to foresee possible developments of natural or induced phenomena. Unfortunately, a review of existing maps shows that in the priority list stratigraphy still ranks first, followed by mechanical properties while existing or potential mutual influences are generally neglected. The need for good and true geotechnical maps is still acute.

Along with the concepts recently developed by

French colleagues, an atlas of geotechnical maps should include, among others, a map of geomorphological processes, a map of risks and a map of attitudes toward construction. Several contributions to the systematics of geotechnical mapping come from Peter, Meneroud and others besides UNESCO, yet there is ample opportunity for more work and better coordination among individuals and Authorities who have produced specifications and rules on geotechnical mapping like the Academy of Sciences of Prague or the British Geological Standard.

A few comprehensive mapping works have been started, among which those sponsored by the French Government under the code name of ZERMOS (Zones Exposées aux Risques de Movements du Sol et du Sous-sol - Zones Exposed to Risks of Surficial and Deep Movements) and GEF (Groupe Etude Falaises - Group for the Study of Reefs). The Japanese Geographic Survey Institute has issued a 1:25 000 land condition map of some areas of the country. The interests for maps suggested to IAEG, the International Association of Engineering Geologists to form a Committee on geotechnical maps currently active. Similarly, the Italian Centre for Research CNR, created and financed in 1976 a five-year nationwide project for soil conservation started in 1976 and carried out by 150 operating groups.

A program geosemantica was jointly undertaken in 1970 by the Royal School of Mines of the U.K. and the French Ecole des Mines to establish unified and univocal terms and methodology for geotechnical maps. The problem of semantics is of utmost importance when trying to establish a common way of exposing facts and an international transfer of information. This becomes specially true for any bank of geotechnical data as, more than storage, retrieval and proper interpretation entirely depend on the existence of a common semantics.

A large share of work and cooperation is certainly needed on the front of banks of geotechnical data where the program gossip (set up by Reading University) seems so far an isolated example. Hungary established a long time ago a Register of Soil Mechanics and Engineering Geology where results of all borings and tests made in the country were to be recorded. More than 70 000 borings are already in the Register's files.

Together with the Chairman of this Session, the Reporters would like to use this rostrum to propose the creation of a Library of Geotechnical Maps.

Such maps are in fact rare and often prepared for public authorities. They remain out of the normal channels of geotechnical information and being difficult to reproduce, receive in any case a limited circulation.

The task of running the Library and of making maps available to engineers and geologists at large by adequate technical facilities could be assigned to a National Society. Support should be granted from the International Society of Soil Mechanics and Foundation Engineering which may seek additional financial aid from other International Organisations.

3 - SHAPING ENVIRONMENTAL GEOTECHNICS

After this digression on maps which we consider to be a proper introduction to our subject, we shall acknowledge the work that several colleagues have been doing in many other fields with the precise goal of alleviating environmental problems. Often, pioneering activities attain better results than is usually recognized. As a matter of fact, in recent years, an increasing awareness of environmental effects paved the way to theoretical and technological progress, without which this proposal of your Reporters would not be possible. All this work pertains with good reason to a State of the Art Report. All this work, once compiled, forms an impressive amount of documental information.

The scope of this Report is essentially to identify and organize the matter forming Environmental Geotechnics. When one has to process and present a plentiful and heterogeneous material, certain systematics is unavoidable. Schematism rather, is likely to be a more appropriate word to define and qualify the presentation that follows, which has had to remain within definite space and time limits.

We have knowingly decided, however, to deal in short with all subjects rather than leaving some topics aside. We are sure that the eventual readers of this Report will share our view point and thus excuse an often abridged treatment of the matter.

In organizing the matter, we adopted as beacons, the physical actions usually performed by men (excavate or pile-up material, tap or feed-in fluids) rather than a subdivision by problems and solutions (consolidation, stability, seepage) customary to geotechnical literature. By so doing, we hoped to make the matter easier to understand by laymen and this Report a bit of glue to set Environmental Geotechnics into practice.

Extensive reviewing of literature and some meditations about the subject, that from time to time seemed to fatally revert to a magmatic state, resulted in the following subdivision of ENVIRONMENTAL GEOTECHNICS as proposed in this Report:

A - MODIFYING PHYSIOCHEMICAL PROPERTIES OF MATERIALS AND REUSE OF WASTES

B - SOLIDS REMOVAL ON SURFACE

C - SOLIDS REMOVAL FROM UNDERGROUND

D - SOLIDS ACCUMULATION ON SURFACE

E - FLUIDS EXTRACTION FROM UNDERGROUND

F - FLUIDS STORAGE ON SURFACE

G - UNDERGROUND DEPOSITS

H - TOWNS

All points that will be dealt with later fall under two categories:

- Studies and activities intended to minimize negative impacts related to geotechnical works or to activities of a geotechnial nature;
- Studies and activities intended to turn an unfavourable existing situation, or the product of non-geotechnical activities, into a better one through an intelligent use of geotechnical knowledge and practices.

While most of our activities today are likely to fall under the first group, is in the second group of actions where Soil Mechanics can bring important net contributions and gain an open recognition to Environmental Geotechnics.

A - MODIFYING PHYSIOCHEMICAL PROPERTIES OF MATERIALS (AND REUSE OF WASTES)

		ENVIRONMENTAL GEOTECHNICS	
Meaningful Actions	Likely Negative Impacts on Environment	Main Goals	Activities to Protect Environment
Production of wastes (+)	Pollution Peptization	Reuse waste materials	Mechanical stabilization
Exposing new soil surfaces	Surficial degradation and loss of soil	Reduce waste impact	Chemical stabilization
	Contamination of surface waters	Control pollution via leachates, suspended solids, dust	Inertize noxious wastes
	Change of agricultural value of soils		Produce new materials from waste
	Heave		Treat with micro organisms and bacteria

(+) This is normally resulting from non-geotechnical activities

Physiochemical properties and processes in soils have always attracted marginal attention from the soil fraternity. The majority of the investigations and research has been devoted to engineering properties and technological processes. Through this definitely oriented effort, geotechnics was able to provide a solution to nearly all the problems that modern engineering has to face and to develop new and winning ways of safely constructing the largest structures of today's human activity. Classical geotechnics is a substantially ploughed field and a well established discipline.

Physiochemistry, biochemistry and mineralogy of soils grew under the shadow of this success.

Yet, it will probably be through soil physio and biochemistry that soil mechanics will be able to take once more a major step and probably the first one of significance in Environmental Geotechnics. Much still remains to be done but attempts and advances made so far foster the greatest hopes.

From ages of integral use of available materials we have moved far too rapidly to a society of wastes. Wastes, initially the sign of man's dominance, have mushroomed beyond acceptable levels and possibly beyond control.

They are at the same time a condition for and the threat to our present way of life. This is so true that whenever an environmental problem is discussed, wastes are immediately associated to it as a cause and not only by laymen.

Even if environmental geotechnics is not necessarily always to be associated with wastes, nevertheless the containment of wastes and the transformation of as much wastes as possible into by-products, is the battle of our immediate future: a vital one indeed. Soil engineers and scientists are, probably without knowing it, on the forefront and soil mechanics has already assisted in many ways.

The largest tonnage of wastes is nowadays turned into usable materials by geotechnics. A list of the most significant and widespread wastes is given in Table A/1 which also shows the classification of the Organization for Economic Cooperation and Development (OECD), Road Research Group. Those wastes whose potential for reuse is high and already established fall into Class 1. Wastes with a presently very low potential fall into Class 3 and into Class 4 fall the non-usable wastes needing control measures to limit their environmental impact.

Attempts toward the reuse of waste materials thus reducing negative environmental impacts, have been many and the problem has been seen under many lights. For the moment, we shall limit ourselves to the technical side of the problem, economic feasibility depending upon the location where the waste is produced, the existance in the area of alternative materials and the efficiency of the geotechnical process.

Possibly the oldest and most widespread use of waste materials is in fills, embankments and road bases (colliery spoils, mine refuse, blast furnace slags, quarry waste are currently used). The only modification to their original characteristics is through compaction. Unburnt colliery wastes were for a long time considered unsuitable for the fear of spontaneous combustion, it has been proved that appropriate compaction efficiently prevents combustion. The presence of pyrite is sometimes a negative fact preventing certain applications. Slags, definitely still active materials, are used widely but showed unpredictable behaviour in some instances under certain conditions of exposure and temperature (Brink). Positive experiments were done with fly ash as a light embankment material in the U.K. at Trenton, in Jugoslavia at Zelenka and elsewhere (Isakowic).

A more refined use of waste has been made as a primary or secondary stabilizing agent of otherwise unsuitable materials. Fly ash, bottom and incinerator clinker, kiln dust are currently used as stabilizers and their application is relatively simple. The waste is mixed with soil and then compacted. Fly ash + lime is a typical nearly all waste stabilized mix (Ghosh). Recently a 91% fly ash + 5% phosphogypsum + 4% lime mix was used for stabilized base courses (Popovic - Colombier). An interesting application used roasted bauxite red muds as booster to the stabilization effect of lime on lateritic gravels (Hammond).

Table A/1 - Wastes and their potential for re-use

Mining Wastes			Metallurgical Wastes			Industrial Wastes			Urban Wastes		
Coarse	Colliery spoil	1	Ferrous	Furnace slag	1	Ash	Fly ash	1	Incineration	Ash	2
	Quarry waste	2		Steel slag	1		Bottom ash	1		Clinker	2
	Mine refuse	2					Kiln dust	2			
	Slate waste	2					Sulfur	1			
	Oil shale residue	1					Boiler slag	1			
	China clay	1					Pyrite				
	Salt mine	3					Cinder	3			
Tailing	Colliery tailing	4	Non Ferrous	Zinc-lead	2	Solid	Waste plastics	2	Demolition	Building rubble	1
	Iron ore	1		Copper	2		Sawdust	2		Asphalt pavement	3
	Taconite	1		Nickel	1	Fluid	Dredge spoil	4		Concrete	1
	Fluorspar	2		Phosphate	2		Pyrolysis residue	1			
	Lead-zinc	3		Foundry sand	3	Sludge	Lime sludge	4	Private	Domestic trash	4
	Copper	3		Ceramic waste	3		Heavy metal sludge	4		Glass	3
	Gold	3					Paper mill liquor	3		Tires	2
Sludge	Red muds	4								Oils	4
	Phosphate clays	4								Plastics	3

1 indicates OECD classification for reuse potential 1 = minimum, 4 = nil

Similarly, of extreme interest seem all attempts of producing, with proper manipulation of wastes, materials suitable for structural units like concrete blocks, pipes etc. The results obtained with cement stabilized ashes need a mention (Shimizu).

Among all wastes, those produced in the form of fluids, tailings, and sludges are the most intractable and environmentally harmful. In several areas of the world, tailings and sludges range by far ahead of any other waste. It will be enough to mention here that some 160 000 000 m^3/year of phosphatic clay slurries are produced in the USA, over 180 000 000 m^3/year of gold tailings are produced by S. Africa and comparable volumes of uranium mill tailings, copper tailings and coal slurry are produced in Canada, Peru, Chile and the U.K. Advances in modification of physiochemical characteristics of these materials are therefore extremely meaningful.

Cement stabilization of high water content slurry has been successfully applied to gold tailings making them adequate for the hydraulic filling of deep stopes (Blight). A twofold benefit is achieved by providing a yielding support in the mine and reducing the volume to be disposed of on the surface. Not sufficiently encouraging results in back filling underground workings with cement stabilized coarse tailings are however reported (Mackechnie), this points to the need for more studies in this field.

The formation of cement crystals (cement bacilli) through a lime + alumina + gypsum stabilization has been applied to sludges containing heavy metals (Ariizumi). This attempt is made even more interesting by the fact that the stabilizers were in a large portion waste materials themselves. Beside producing a sufficient improvement of the mechanical characteristics of the sludge, the cement bacilli proved efficient in fixing several heavy metals thus eliminating also leachate problems.

Combustion on a fluid bed has been tested as a means of drying high moisture colliery tailings.

Effluent turbidity and related direct (foreign fines) and secondary environment pollution (chemicals adhered to the solid particles) has been reduced successfully by a careful combination of gravity sedimentation and chemical flocculation (Zimmie).

An intelligent use of pervious and impervious geomembranes allowed acceptable results to be obtained with otherwise intractable materials like heavy metal sludges (Kuwayama).

An almost entirely new field has been explored lately by pioneering works in soil bio-chemistry. Reducing bacteria, producing free Na^+, HCO_3^- or S^{--} and operating as dispersants, are well known. The presence of biologically degradable matters and of active bacteria (like desulphuvibrio-desulphuricans) has been recognized as being as important as the chemical composition (i.e. Sodium Adsorption Ratio) in determining the behaviour of dispersive soils (Duncan). Spectacular pollution phenomena have been traced back to microbial H_2SO_4 attack on soils and rocks both in situ and in embankments or tailings dams (Haldane). The action of bacteria has been recognized as being determinant in the processes finally leading to swelling phenomena at Ottawa's black shale (Quigley). Indications are being obtained of detrimental effects of humic acids and detergents on the shear strength of soft clays (Soderblom), while an increase in strength, compressibility and permeability has resulted from the seeding of the multimineral Osaka-Nanko soft clay with fungi, actynomicetes and

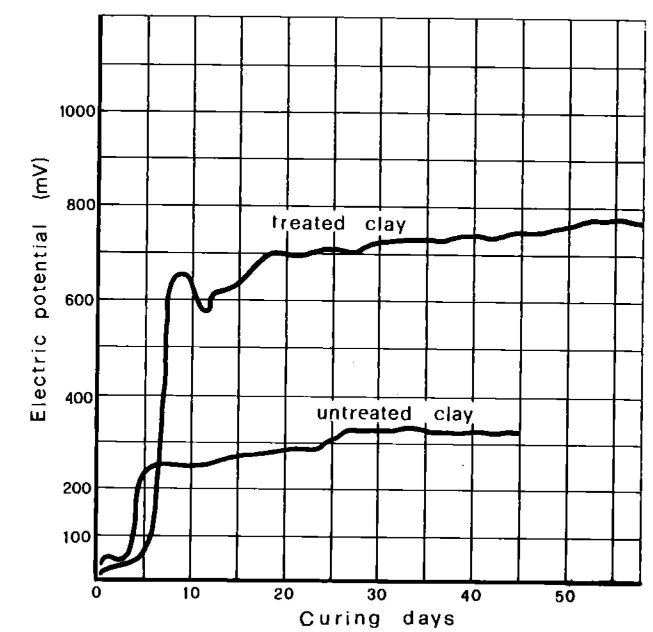

Fig.5 - Electric potential generated by microbial oxidation-reduction effects in Osaka-Nanko clay inoculated with Bacillus Cereus and Aspergillus Orizae (from Kamon)

bacteria (Matsuo).

Fascinating are the openings suggested by still infant studies on electric potentials generated in soft clays by microorganisms (Kamon) and in general on electrostatic spontaneous potential differences existing across the interface between different materials. Such potentials have been suggested as the origin of natural electro-osmotic processes inducing ground waterflow and slope instability (Veder). They could be used and enhanced through the insemination with bacteria, to provide small sources of natural electricity or to cure cheaply areal phenomena.

If these are the results of actions strenuously taken by geotechnical engineers to reduce environmental impact, other changes in physio-chemical properties of soils currently take place. Most of these changes are the result of processes unrelated with geotechnical activities or, at most, can be seen as their secondary effects. They often produce tremendous negative effects.

Through the modification of physiochemical properties of soils, Geotechnics may help bring under control phenomena that are often of regional scale and currently acknowledged as the most critical environmental problems like deterioration of soils by erosion (spurred by deforestation, tilling, cuts, acid rains) and salt built up in soils (consequence of improper irrigation, reclamation, modifications to groundwater pattern).

Important modifications of physiochemical properties take place on many soils upon exposure. Progressive hardening and loss of agricultural value in some lateritic porous clays of South America and Africa has been well documented. Similar but less marked effects are induced by dust or gasses dispersed by industrial plants but have not been equally investigated (Singh).

Radical changes in the characteristics of soft or overconsolidated clays and clayish formations can take place in several ways. Leaching by rain waters (by far the most frequent weathering agent) may produce substantial changes in ionic level and suction, i.e. on the overall erodibility of the exposed material, or it can affect the amount and proportions of amorphous materials which will also change the soil's engineering properties (Yong-Woo).

Important changes in the physiochemical properties of soils can take place through oxidation. Oxidation of organic soils, like peats, leads to important volume changes. It is not uncommon to observe that upon reclamation, the characteristics of exposed soils are rapidly modified often in an undesirable way. In some extreme cases, the volume change produced by oxidation exceeds the lowering of the water-table and the entire reclamation operation becomes worthless (Tate).

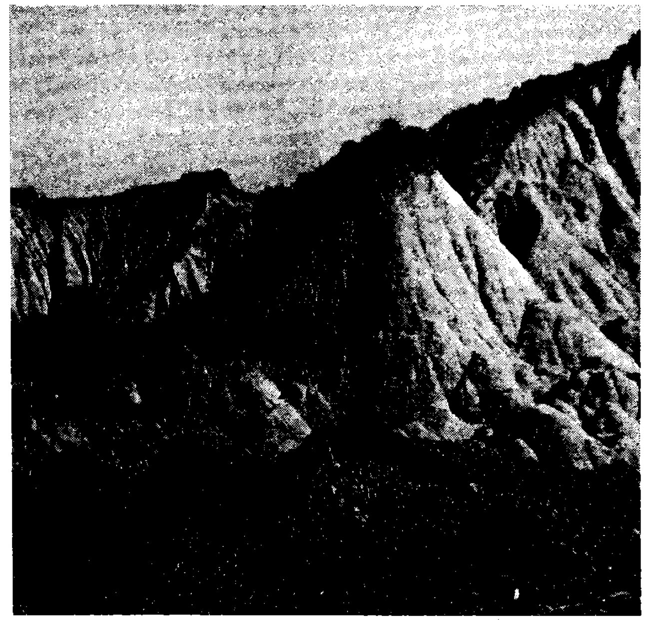

Fig.6 - Loss of territory and land value produced by enhanced surface erosion consequent to physiochemical changes in overconsolidated marls (from Cotecchia)

Soil contamination by different waste disposal and waste or leachate migration processes can be associated to the above phenomena. The limited amount of studies carried out so far and the even more limited number of practical applications suggest that soil characteristics (percentage of coarse particles, amount and type of clay minerals, organic matter content) as well as their conditions of existence (water content, density, homogeneity) affect the vulnerability of a given soil to contamination and the difficulties of any detoxification process (Kastman). It is therefore reasonable to believe that soil engineering and environmental geotechnics may bring an important contribution to this type of problem.

Further research activities in this field are highly needed. The majority of the papers in the literature essentially deals with mechanical properties and engineering behaviour of soils. It is rather the chemical side of the problem that must be emphasized or at least chemical data should always accompany other information. Most wastes are, to all effects,

chemically active materials.

Much needed and promising are those researches that deal with the action of bacteria and microorganisms on geotechnical materials. A front where this type of research might result in extremely important benefits to the environment is that of degradation of exposed soils in bad land areas.

Direct use of wastes, use of wastes in combination with other materials as stabilizers or stabilized products, use of wastes mixed with other wastes to produce a material without the negative characteristics of parent wastes and finally finding safe and economically acceptable ways of rendering inert the toxic wastes all merge to form a front on which we shall work for the future.

The renewed interest for coal as a primary energy source obviously places all wastes deriving from this material under the limelight. Probably the most comprehensive research program now under way goes under the name of KHM Project (for coal, hash, environment) commissioned in 1979 by the Swedish Government to the Swedish State Power Board.

B - SOLIDS REMOVAL ON SURFACE

		ENVIRONMENTAL GEOTECHNICS	
Meaningful Actions	Likely Negative Impacts on Environment	Main Goals	Activities to Protect Environment
Highway and similar cuts	Erosion	Foresee impacts	Ecoconsistent design of slopes
Urban cuts	Offense to landscape and poor aesthetics	Reduce offense to landscape	New concepts in design of retaining structures
Borrow pits	Alterations to groundwater circulation	Control subsidence	Considering grassing and planting
Open pit mines	Subsidence		Convert pits to useful purpose
Strip mines			Protecting works for groundwater table

Removal of solids from the surface of the planet is certainly the oldest and by far the most widespread activity susceptible to acquire environmental relevance. Housing projects, roads and highways, quarries and borrows, open pit and strip mines, all require or depend on excavations. Highways and highway cuts produce the largest and the heaviest impact on environment. The expansion of road networks, more stringent requirements for alignments, grades and overall widths and increasingly powerful and efficient earth moving machinery, all contributed to this fact.

Geotechnical engineers are intimately connected with excavations and usually play a decisive role in deciding their size, shape and details. The associated environmental concern unfortunately is almost nil. It seems, as it is, that geotechnical engineers pay all their attention to the mechanical stability of the slopes, to their drainage, to the statics of retaining structures and to the economy of excavation. Very few are the cases in which the environmental impact of extensive or high cuts is perceived as one of the problems to be dealt with. Thus it is not surprising to find comparatively few papers in the literature dealing with this special aspect. The absence of any established methodology should be expected.

Indiscriminate and careless cutting is probably the most immediate and widespread origin of the blame placed by the general public on geotechnical engineers. Care and concern for the cut appearance is in general terms the answer but, unfortunately, engineers have never majored in aesthetics. While in the case of cuts in rock the engineer should be aware that an unconventional design might be required to minimize environmental impact. For cuts in soils, the designer's care should be directed toward making it possible to put grass and plants on the slope or to design imaginative supporting structures. More often than realized, the best potential contribution of Geotechnics does not come at the time of deciding the cut slopes or the type of support but well before when the overall concepts of a road project have to be defined and surface solutions weighed up against tunnels.

In many instances, ecoconsistent road design results not only in a better appearance but also in a lower cost. Excellent examples of eco-consistent road cut design come from Switzerland, Austria and S. Africa (Kantey). Far more are the examples of poorly selected road alignments where a lack of appreciation for the actual characteristics of the slope led to environmental fiascoes. We should not forget that quite often what is accepted as a simpler construction is merely a simpler design. In other words the engineer saves himself troubles and risks by adopting standard design methods and the usual construction procedures: the final cost can be criticized only if somebody provides an alternative one based on alternative design. If we all design along the same lines or, even worse, with the same manual, an alternative design is unlikely to come along. But improper solutions inevitably show up and are detected by the public under the species of ugliness.

Fig.7 - Disastrous design over 0.5 km of mountain road which led to a 200 m high rock cut and to a downslope dump nearly 500 m high. A permanent scar to a scenic valley.

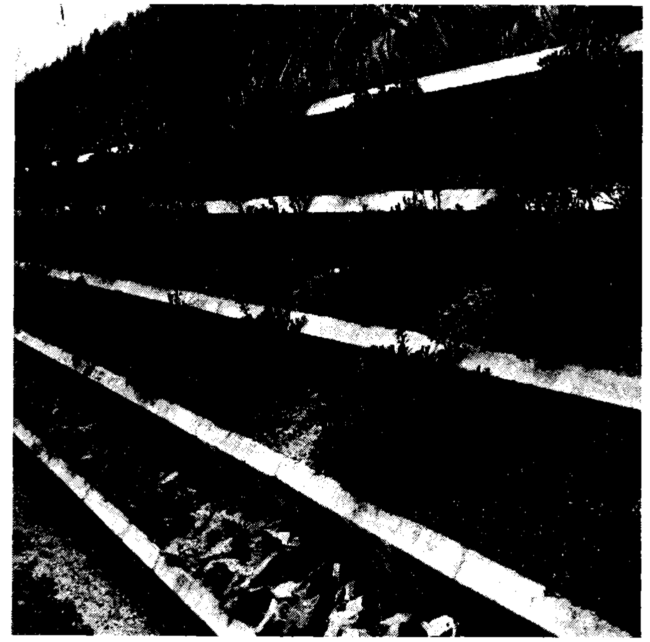

Fig.8 - A fine example of ecoconsistent retaining structure fulfilling stability, cost (note that part of the structure is precast) and aesthetic requirements (Prefectural Highway, Toyota, Japan).

Among the few examples of eco-consistent retaining structures some interesting results have been obtained in Japan (Fukoka) and worth mentioning for its potential is the technique of reinforced earth.

A strong and far reaching impact on the environment generally comes from dewatering of open pits. The borrowing of sand and gravel form riverbeds or the opening of large borrow pits inland, are other activities nearly impossible to suppress but unfortunately carrying a strong impact on landscape. Open pit mines are of the same nature with the only difference that they are usually in remote areas yet of a much larger size. Typical problems of such excavations are slope stability and dewatering.

Dewatering operations, at some borrow and pit may acquire impressive proportions and their impact may be felt on surrounding aquifers and lands. At an Australian open pit mine, land subsided 1 m at distances of 800 m from the edge of the open cut and ground movements extended to more than 20 km away from the pit (Gloe). Dewatering effects are amplified and may become dramatic in areas of fossil karst.

Ten years of dewatering at an open pit gold mine in the West Rand caused more than 200 sinkholes in a 300 m thick residual cover lying on karstic dolomite. Some of the sinkholes exceeded 120 m in diameter and 100 m in depth. Losses included 34 lives and some 35 millions of U.S.$ in compensations. The literature is very scarce of papers showing that groundwater circulation has been studied on an areal scale, looking beyond the strictest needs of conventional stability analyses of the pit slopes and of estimating sump capacity. Here too Environmental Geotechnics can be of help by adding, when the venture is still in the planning stage, those suggestions and additional provisions that might allow optimum location of the pit, minimum disturbance to water circulation and to the water table at large.

A lowered water table will in general improve the stability of the side slopes of open excavations. But if water table control is stopped and these excavations are allowed to flood on the cessation of active working, this improvement in stability may be imperilled and major slips may occur. In certain conditions their magnitude and backward reach may be very important and may progress so much as to represent another environmental threat.

Economical restoration or conversion of the pit to useful purposes once exploitation is completed, could be delineated from the beginning. Introducing remedial measures in the overall planning will, first of all, reduce the environmental impact of the excavation process, secondly, allow a timely healing of the inevitable scars on the landscape (even as excavation is still in progress) and, last but not least, modify the public attitude of rejection for the whole operation.

Renewed efforts and enhanced attention to Environmental Geotechnics concepts, above the design procedures, are certainly necessary. Geotechnics should identify and impose on itself the necessary evolution so as to acquire the right to participate in the planning stage of all large projects. One early step of this walk is probably to accept compatibility with the landscape as a binding design criterion.

Eco-consistent design practices, as ways and means to blend the cut slope in with nature and to improve the project's general appearance should be established. New and imaginitive solutions for supports and retaining structures should be developed.

When coming to estimate the mass and areal effects of excavation like induced stress relief and lowering of piezometric levels: Environmental Geotechnics should probably approach them considering geostatic stress distribution, reorientation of stresses upon excavation, progressive failure and energy concepts as derived by Finite Element Method and Fracture Mechanics (Rice, Mitchell). The problem of local stability of cut slopes should be dealt with among the tasks of classical geotechnics, through the conventional and well established geotechnical methods.

C - SOLIDS EXTRACTION FROM UNDERGROUND

		ENVIRONMENTAL GEOTECHNICS	
Meaningful Actions	Likely Negative Impacts on Environment	Main Goals	Activities to Protect Environment
Mining	Settlements	Foresee impacts	New technique for excavation support
Tunneling	Alteration to ground water circulation	Limit settlements	
Underground facilities	Subsidence	Control subsidence	Protecting works for ground-water table
Artificial caverns			

Important technological advances in drilling equipment explosives, mechanical excavation, supports, linings, etc., have brought the underground to be an attractive solution to safety, space and appearance requirements for many structures and projects that were traditionally developed on the surface. Progress in machinery and technologies for excavating through soft ground has opened new fronts to shallow tunnelling mainly to the benefit of mass transit projects in urban areas. The same reasons have resulted in such a striking change in the relative economy of going underground vs. staying on the surface that cost alone is now a good enough reason to place large facilities underground.

In average terms, and in the early eighties, the cost of a building to house large machinery, like a power plant, exceeds the costs of an equivalent underground cavity in rock, whenever its volume approaches 0.1 Mm^3.

In the last decade, the practice of removing solids from underground has therefore received a major boost on top of the traditional mining activity. Along with the accepted idea that curing is not worse than preventing, geotechnical engineers have concentrated their attention on surface settlements and building stability often leaving underground operations, especially excavation technologies and types of support, to the responsibility of other groups, often represented by ore or coal developers.

Geotechnical engineers have been more closely connected with excavations in soft ground for mass transit projects. Also because of the greater sensitivity of urban areas, efforts and advances in this front have been greater.

A large part of the underground excavations like mine workings and mass transit tunnels, are dictated both in depth and alignments and several constraints force their geometry too. These excavations are therefore the source of displacements in the surrounding rock or soil mass that forcibly extend as far as the ground surface.

The magnitude of said movements is such that in most cases settlements are disturbing and buildings damaged. We can say that nowadays a reasonable forecast can be done beforehand to establish a likely pattern and the amount of subsidence to be expected in a given area. Making use of geotechnical knowledge in the planning stage should therefore allow environmental impact to be dimmed either by properly locating facilities and structures on the surface or by defining tolerable limits to the extraction of solids from underground.

Geotechnics can be of help in providing guidelines for construction in excavation of subsiding areas or by assisting in improving the stability of mine stopes, pillars etc. The mechanisms of deformation onset and progress are well understood (Jimenez Salas). Rules and formulae for computing shapes of the deformed ground surface resulting from underground excavations have been developed particularly in those countries where coal mining was an important activity (Nat. Coal Board U.K.).

Today's geotechnics has the possibility of minimizing immediate and delayed deformations of underground cavities and Environmental Geotechnics could help to incorporate them in the original project scheme. The prediction of deformations and the selection of appropriate countermeasures is possible and currently applied (Peck, Yokel). For excavation in soft soils the technique of the slurry shield is gaining favour and is such as to avoid major problems even in very sensitive conditions.
It must be noted that the heaviest impact felt, related to the removal of solids from underground, is of transient nature. As a matter of fact, the travelling disturbance moving along with underground excavation is represented by: i) horizontal displacements of extension type, ii) slight upward vertical displacement, iii) pronounced settlements and again iv) horizontal displacements of

Fig.9 - The cutterhead of a slurry shield tunnelling machine. Pressurized bentonite slurry circulates behind the 6.75 m dia. cutter allowing excavation without affecting the watertable (from Okumura Corp.).

compression type (Kapp). Once all this has passed, the resulting subsided ground is quite stable and generally acceptable for structures and human activities.

As for other cases, the modifications to groundwater circulation and piezometric levels are an often neglected source of environmental effects. Most mining operations require pumping of groundwater so that the workings can be kept dry. Pumping is likely to affect water tables

in the area and might significantly change the pattern of ground water movement. Even if excavation is placed well into rock, other materials much more sensitive to a change in the piezometric levels may be affected: consolidation settlements may result and add to the above ones. A classical example produced during the construction of the Oslo subway (Karlsrud).

Sufficient theoretical work has been done to enable soil engineers to plan ahead remedial or attenuating measures. Recent application with recharge wells and infiltration tunnels proved the point. In Norway a recharge system was designed as an integral part of a large tunnelling work in rock below very sensitive and compressible clays across an already built-up area (Andreasson).

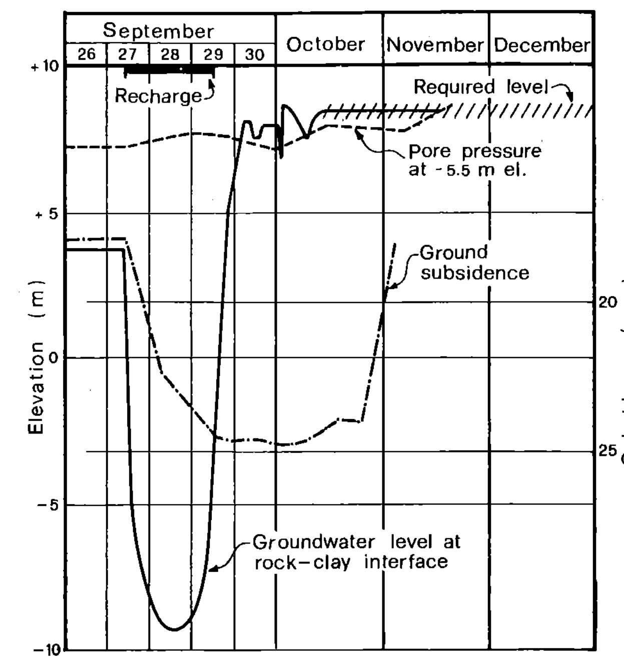

Fig.10 - Effects of recharge on aquifer's piezometric level and induced effects on aquitard's pore pressure and thickness, Oslo (from Andreasson).

The absence of soft soils does not mean that equal or more dramatic consequences are excluded. Depressing to a substantial degree the joints between a set of relatively rigid blocks, may change the pre-existing lateral thrusts or buoyancy forces throughout masses of unsuspected volume and extent. The presence of relatively weaker (shear or compression wise) strata and uneven morphology may magnify the resulting effects. Whenever dealing with relatively rigid materials, the movements take place quickly, if not suddenly, and before the phenomenon is detected and understood it might have already developed into an irrecoverable, if not catastrophic, damage. It will be enough to remember the case of an arch dam in the Alps that after more than 20 years of service cracked because of movements in the order of 100 mm of its abutment rock. The movements were apparently related to rock drainage caused by a tunnel driven 1.5 km away and more than 300 m below the dam crest (Schneider).

Even minor movements involving large rock masses produce microseisms strong enough to be detected. This was the case at Vajont and Zeusier and has been reported in connection with mining works (Cook).

Wells and streams may be affected too. The quality of pumped waters is usually highly mineralized and their discharge may affect the quality of surface water which will have multi-uses.

On a long term basis other problems may have to be dealt with. The abandonment of a mine or underground work is often limited to blocking the entrances to access by people. The workings will have caused a major disturbance to the hydrogeology of the area and the consequences of ceasing to pump or failing to maintain gravity drainage may be far reaching. A major landslide in Blaina, U.K., involving 1 000 000 m^3 is reported as associated with partly blocked mine levels and the uncontrolled discharge of water from an old quarry led in 1925 to the failure of Skelmorlie dam (Hawkey).

The same may happen if an underground excavation is later pressurized to serve its purpose. Cases of shallow pressure tunnels passing at a certain height along valley slopes that became the cause of sometime huge slides are so many that a specific mention becomes unnecessary.

The need for further research is undeniable especially on the early assessment of induced effects on groundwater circulation and piezometric levels and related thrust and uplift forces. The proper prediction of the amounts of drained fluid and of the related changes in pressure over large distances within isotropic or stratified masses is probably the basic issue.

A systematic monitoring, analyses and publication of the different phenomena associated with underground excavations, their drainage and the abandonment of underground activities also deserves more attention than it receives today. Probably too much emphasis is on the mechanics of the phenomena to the detriment of their hydraulic side.

Studies on recharge, from a theoretical and technological view point will be of great help.

D - SOLIDS ACCUMULATION ON SURFACE

Meaningful Actions	Likely Negative Impacts on Environment	ENVIRONMENTAL GEOTECHNICS: Main Goals	ENVIRONMENTAL GEOTECHNICS: Activities to Protect Environment
Forming coal tips	Instability and failures	Foresee impacts Control ground-water pollution	Design tips and dams for controlled drainage
Mine waste piles	Pollution of surface and ground-water	Control air pollution	Stabilize wastes
Building tailings dams and lagoons	Salting of land	Make available new lands for urban or industrial development	Consider reshaping grassing and planting of dumps
Dredge dumps	Air pollution by dust or gases		
Reclamation fills	Radioactive contamination	Restore lands for agricultural or foresty use	Combine solids extraction with waste disposal
Sanitary fills			
Uranium mill tailings	Offense to landscape		
Hazardous chemicals waste		Improve aesthetics	

Nearly all activities produce refuse. With the industrial society, wastes have increased greatly in quantity and multiplied beyond all possible forecasts in type. While, until recently, wastes were, so to speak, compatible with the recycling capability of the planet, this is no longer so today. In the past, the amounts of wastes have been small and therefore their presence has gone unnoticed. Today a huge, varied and non-digestible mass of wastes has little place to go apart from being stored on ground surface. The accumulation of wastes has grown out of different local conditions, waste materials and technologies and has developed into traditional practices, hard to modify and harder still to change. This is natural enough as practices and standards were dictated by the people in charge of obtaining the main product, obviously careless about the associated wastes. Soil engineers were not in the picture until very recently.

The immense volumes of wastes presently being accumulated makes the problem a top priority one. The USA alone produce over 2 700 millions Mg/yr of wastes of all types.

The situation appears now as one that needs great care given to existing dumps and at the same time a contribution made towards improving dumps still being formed and the future ones. Problems and failures with waste accumulations have been countless. A few major disasters (Aberfan in the UK, 1966, Saunders USA 1972) have brought the problem to the public and official attention. Analysis and research programs were spurred on and basic facts understood. Yet, it is probably wise to say that not all problems are under control and that a relatively small percentage of the world wastes is disposed of in an environmentally acceptable manner.

A major environmental threat (especially from mining wastes) is associated with stability. Marginal factors of safety usually result from lack of space (i.e. steep slopes) and the limited financial allocations in favour of forming waste accumulations. The growth beyond reasonable limits or exceptional loading conditions (earthquakes) can tip the mass over. In many instances, the stability of sluice dams is enhanced by the fact that sluices are partly saturated when placed, and the resulting larger effective stresses, and therefore strength, is often mistaken for an inner quality of the dam

(Blight). Except for very peculiar climatic conditions, this is however something which may disappear without warning. The placement in layers, usually accompanied by compaction, is a safe enough procedure for coarse granular wastes like colliery spoil. This automatically eliminates the steep slope angles typical of tipping techniques. It also allows ample freedom in the outer geometry of the tip which can therefore be accomodated to landscaping and re-use requirements (Hawkey).

It is generally accepted that tailings and sluice dams require at the toe or over the whole outer slope, a retaining structure. The retaining structure begins with a so-called starter dam and is then gradually built up, either with superimposed dykes (the upstream method) or with new structures that keep embodying the older one (the downstream method). The downstream method uses larger volumes of selected foreign materials but provides larger safety margins and is presently the preferred solution. Treatment and separation of the slurry by cycloning, spigotting and compacting, a technique advocated by many authors (Klohn), enables the building of the retention dam with the sandy fraction of the waste materials. Downstream retention structures offer at the same time, fair conditions for beautification works by seeding and planting and flat slopes that can be used as parks and recreational grounds.

Perhaps the greatest difficulty is not the

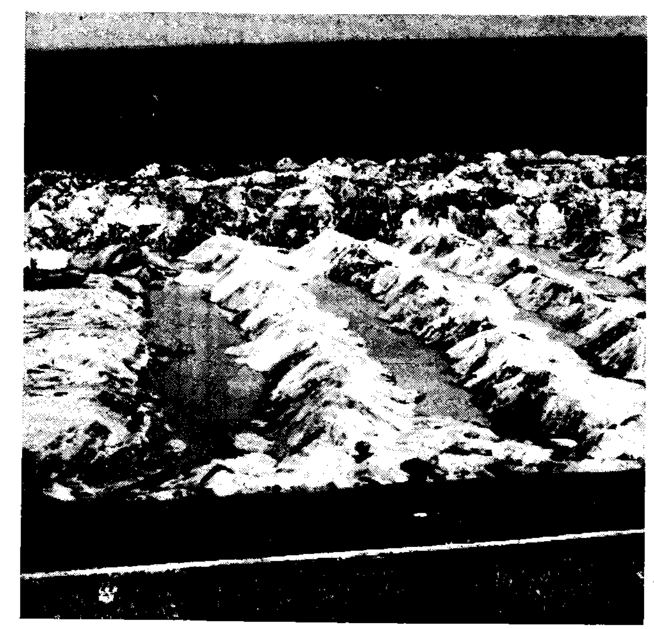

Fig.11 - Environmental damage caused by the surface accumulation of phosphate mining waste, Florida (from Bromwell).

ultimate appearance of the completed tip which may be difficult to identify a few generations later, but the appearance of the site during the active phase of the mining operation. These particular operations will continue for many years. It will, therefore, the necessary to develop methods of waste disposal that involve relatively small active areas, at any one time and screening works to conceal them.

The combined use of wastes of different nature and origins like fly ashes and slags to create zoned tailing dams is a twofold beneficial course of action from the environmental point of view as the wastes are concentrated, and stability is improved (Lousberg). Examples of this type are however few and not the result of an environmental approach but rather applied as a remedial measure to failing dumps.

More important from an environmental point of view is the drainage of the disposed materials and of the retaining structure. Improper drainage can affect the environment in two ways: by promoting structural failures and by polluting surface or groundwaters. Two courses of action are therefore required when dealing with this particular part of the problem; ensuring proper drainage and limiting contamination. Proper drainage is ensured by adopting the same provisions developed by the earth-rock dam practice, like coarse granular blankets of sand and even rock zones. Analytical methods help to check the seepage line through consolidating materials of gradually variable coefficients of permeability (Kealy).

Avoiding undesired or excessive contamination of streams and/or aquifers requires that the Environmental Geotechnics' outlook be adopted. The characteristics and the amounts of effluents should be known, together with the pattern of groundwater circulation and the actual mechanisms of pollution. The solutions are many and may go up to a full lining of the retaining dam and pond's bottom.

Uranium mill tailings represent the newest and environmentally most hazardous waste. Mechanically speaking, this is not different from other wastes. The difference lies in the radium which is usually disposed of with rock fines. A fraction of radium Ra 226 can be dissolved by water and taken along with the effluents, yet, the largest part of radium will stay in the waste pile. But radium decays, forming a gaseous isotope: radon Rn 222 which tends to migrate into the atmosphere. Uranium mill tailings, to be disposed of properly, will therefore require, besides the usual strengthened precautions, that the surface be blinded as soon as possible, that the rainfall inflow be reduced as much as it is practicable and that the effluents be completely checked (Advisory Panel on Tailings). This might even require that the entire fill be isolated from the outside. Clearly enough, the indefinite life that has to be envisioned for any structure built to hold this particular type of waste, requires not only extremely conservative design criteria but also a truly environmental approach i.e. foreseeing and preventing.

Hydraulic fills, both as a way of reclaiming wet lands or as a deposit of dredged soils has received comparatively less coverage in the literature. Yet, especially in the second case, they are susceptible to remaining exposed for a long time, to become dessicated and finally to pollute the air with dust. One problem associated with this type of activity is the quality of source materials and the possibility that they be contaminated by heavy metals or noxious chemicals. As a matter of fact, dredge soils normally come from areas of low value, the natural place for unregulated dumping and discharge. Such areas and soils also have to be reclaimed in some way by the operation (Rutledge).

Large fills along a shore for the reclamation of wetlands, may have important effects on inland groundwater table by blocking its free discharge and by displacing the saltwater-freshwater interface (Putalloz).

Disposal sites for urban trash, also called land fills or sanitary fills are a major environmental problem present worldwide and whose number is extremely high. It is enough to remember that the U.S.A. currently produce 180 000 000 Mg/yr of trash. Not only do the materials to be disposed of, have undesirable mechanical characteristics but the products of the waste piling operation (leachates and gasses) are usually harmful. Stability of trash piles is seldom a major problem in view of the limited size of such heaps but compressibility and bearing capacity of the final fill surface are of outstanding relevance as the majority of sanitary fills is formed in areas likely to be occupied by an expanding town. Clearly of great interest is the possibility of creating space and support to new urban facilities or structures although simple and light over abandoned sanitary fills. The straightforward application of classical tests which found some difficulty (Moore) but it seems that placing the trash in layers under a traffic compacted soil cover ensures satisfactory results.

Leachates are confined within clay or synthetic barriers. Concepts of classical soil mechanics can be used to advantage in the design and construction of impervious clay blankets. Reducing the standard deviation of pore volume by wet of optimum compaction proved far more important than reducing the average value of

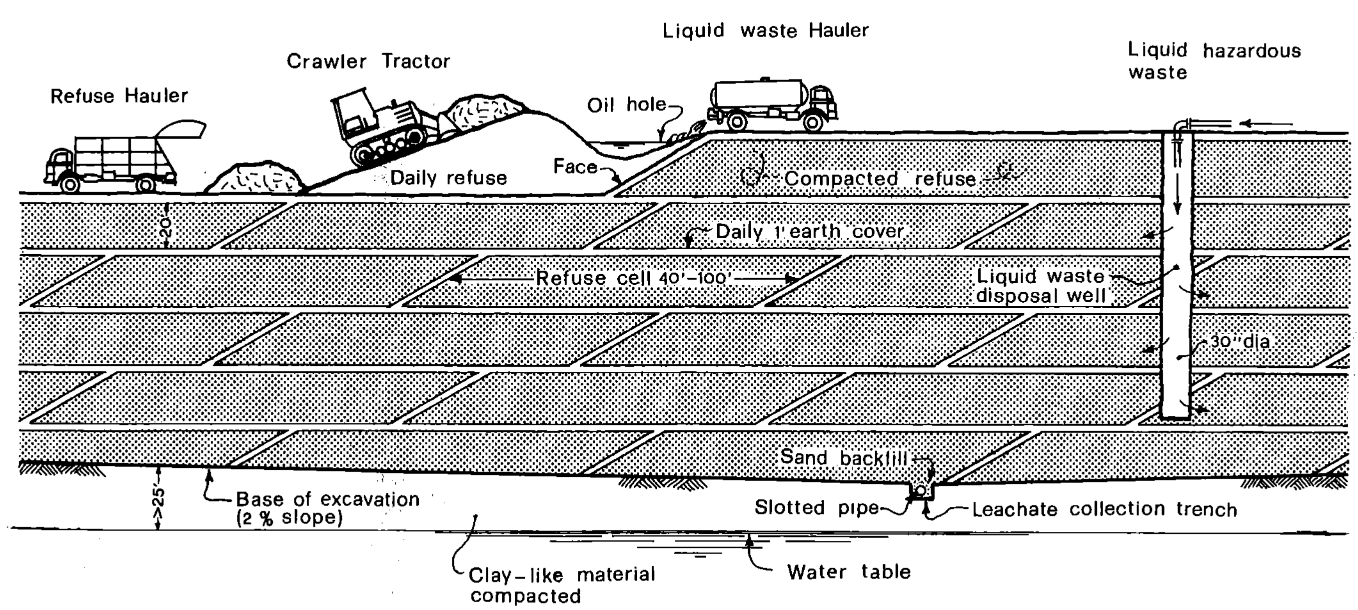

Fig.12 - Schematic representation of a sanitary fill to handle urban garbage by the cell method. Provisions are incorporated for the contemporary disposal of hazardous liquid wastes and oils (from Sanitation District, Los Angeles Co.).

pore volumes (Auvinet). Interesting is the confinement of the leachate within an 'excess pore pressure' barrier set up in the underlying soils by the weight of the fill itself (Florian). Opposite results have however been observed too, like leachate penetration rates two times faster than anticipated, even against an excess pore pressure barrier (Goodall). One more thing must be added to the check list of stability and effluents control: the control of developed gases. At present, gases are treated as water, collected in coarse stone ditches and vented through pipes (Esmaili).

Special attention should be paid in the future particularly to technological aspects of large accumulations of solids on the earth's surface. Environmental Geotechnics concepts should help from the earliest planning stage when sites are selected. The use of old clay borrow pits or open pits mines as dump sites seems particularly appealing for a concentrate and contain policy of waste disposal (Mundy).

The leachate migration and the formation and circulation of gases in sanitary fills deserves more study.

E - FLUIDS EXTRACTION FROM UNDERGROUND

		ENVIRONMENTAL GEOTECHNICS	
Meaningful Actions	Likely Negative Impacts on Environment	Main Goals	Activities to Protect Environment
Water pumping	Subsidence	Foresee impacts	Analyze and forecast subsidence
Oil draft	Fissures		
Gas tapping	Horizontal movements	Control subsidence Protect groundwater levels	Analyze and forecast groundwater changes
Geothermal vapour tapping	Alteration to groundwater flow		Recharge aquifers
Salt/sulfur brines extraction	Salt water Intrusion		
Coal gasification in situ	Oxidation of organic soils		Mudjacking
	Induced seismicity		

Until recently, subsidence was a term used by geologists, and unknown to the public. Today, the general public is aware of it and subsidence has become a familiar word to engineers, particularly to geotechnicians. The reasons are simple: nearly all large cities around the world are subsiding: Los Angeles, Tokyo, Austin, Taipei, Bangkok, Venice, Mexico City. In the Nobi seaside plain, over 270 km^2 of partly urbanized area subsided to below mean sea level. Only in a very few instances the starting of subsidence phenomena can be pushed back for more than forty years.

The majority of subsidence phenomena produced while soil mechanics was flourishing but some reasons could not provide a timely helping hand. Even more, they produced while soil engineers were making considerable efforts to design settlement proof foundations on subsiding grounds. The lack of the very approach that we are proposing here as Environmental Geotechnics can only be regretted.

Subsidence phenomena are of great frequency (forty cases are currently known in Japan alone) and of greater variety. Mexico City settled 9 m and 8.5 m is the maximum subsidence in the San Joaquim valley, California. The downward movements in the Nobi Plain reached 2.4 m, while in Venice they were of only 0.1 m. The impact of subsidence, however, must not be taken as proportional to the absolute change in elevation. The sensitivity of each site may be very different. The problems in Mexico City or in the mostly farmlands of the San Joaquim valley, were less crucial than those of the Nobi Plain where 87 km^2 became lower than the mean low-sea level. Being 100 mm lower might be nearly terminal to a city like Venice which literally sits on water. Small vertical movements might severely affect a canal unlike horizontal ones which instead would easily become intolerable to a railroad.

Subsidence phenomena invariably get to the environmental size and are all to be reconducted to the extraction of fluids from under the ground. The response in terms of surface subsidence depends upon the depth of fluid extraction and the nature of the soil strata thereupon. In some cases (oil extraction from deep formations) the extraction process had to pass a threshold level before any subsidence started at all (Nunez).

Over 25 mathematical models have been worked out to predict subsidence, especially in connection with medium depth phenomena which are the majority (Finnemore). They range from one dimensional (Helm) to very complex (Lofgren). The results of predictions are generally satisfactory, and only lose accuracy for deep reservoirs (Schoonebeek).

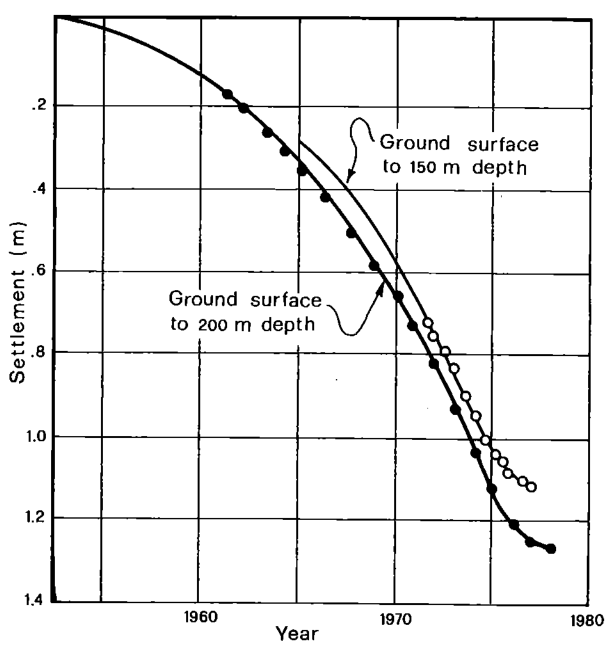

Fig.13 - Settlement prediction through a mathematical model (lines) and actual observations (dots) for two different aquifer-aquitard thicknesses, Nobi (from Ueshita).

Vertical displacements are often coupled with horizontal ones usually of lesser magnitude. With regard to horizontal movements, the existence of a zone, surrounding the subsiding area, where movements are mostly extensions must be remembered. These movements might develop into cracks especially in connection with fault systems. A well known but sad occurence of this very phenomenon led to the failure of the Baldwin Hill dam (Lee). In some instances and in particular conditions, subsidence may develop into a number of open cracks (Winnikka). This possibility is to be feared as large localized movements are much more disruptive than gradual deflections or of even changes in absolute elevation.

Geotechnical engineering is now in a position to estimate the amount and type of compaction in an aquifers-aquitards system. It can also estimate the attenuation of the compaction and thus surface movements for different draw down or piezometric levels with one dimensional finite element consolidation models. Groundwater levels inducing zero- subsidence conditions can thus be derived (Ueshita). Similarly, three-dimensional groundwater flow models based on Darcy's law and mass conservation concepts can be used to define the maximum allowable yield to maintain or reach zero-subsidence.

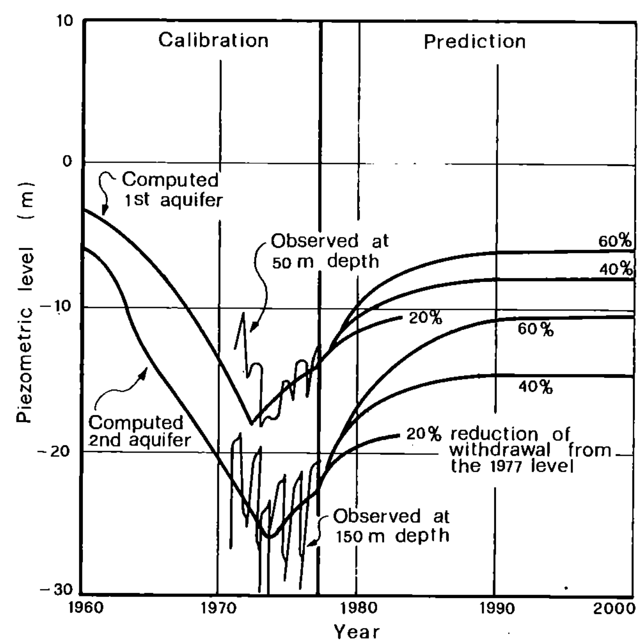

Fig.14 - Calibration of a finite elements model and its use for predictions in view of deciding a safe yearly withdrawal of water from an aquifer-aquitard system, Nobi (from Ueshita).

In some cases, if a maximum allowable subsidence is accepted, then the associated pumping rate can be established. Different, often conflicting, design concepts are currently applied in actively subsiding areas with obvious consequences and problems. An important contribution that Environmental Geotechnics should provide are guidelines related to the selection of alignments for sensitive facilities like canals, railroads, sewage works, etc., and to the conceptual design of foundation structures.

A fair command of the problem now allows geotechnical engineers to plan for subsidence. In other words, a certain volume of fluid can be mined producing a given subsidence and the associated changes in moduli and response of the soil strata. While sandy soil will compress quickly, elastically and will rebound, all clay horizons will compress slowly and irrecoverably during the first draft and will acquire an overconsolidated behaviour on subsequent cycles thus compressing faster and rebounding appreciably. The replenishment of the underground reservoir can be equally anticipated. Subsequent, intense, fluid draft (within the past maximum draw down) would be possible without major surface movements. Even if this process most probably leads to changes in the transmissivity of aquifers and aquitards, planning for subsidence can be applied, and was applied, to create artificial ponds (Herrera).

Experience with large scale recharge is still limited but seems encouraging and seems to suggest that this method could be used not only to stop but to recover part of past subsidence. As subsidence is directly related to the extraction of fluids from the ground and the increase in effective stress level associated with the piezometric drawdown, restoring the original pore pressure is the way to stop or curb subsidence. This can be done simply by interrupting or reducing the amount of fluid extracted (San Joaquim valley). In some cases, recharge wells can be used so as not to interrupt withdrawal as at Wilmington oil fields (Fairchild). Reinjection of brackish water at Niigata produced an upheaval of 0.03 m/year (Aoki).

Certainly, an exceptional remedial measure, applicable on a relatively small scale only, is controlled mudjacking to compensate for the loss in elevation applied so far only on an experimental scale in Venice (Marchini).

Important subsidence phenomena can be associated to the extraction of vapour at geothermal fields. Even if a geothermal field is usually fissured rock, and therefore of limited compressibility, large subsidence can occur. Vertical movements up to 4.7 m and horizontal ones up to 0.8 m have been measured in New Zealand (Stilwell). This can be explained by the fact that at geothermal fields extreme conditions exists (piezometric changes up to 40 MPa in comparison with 25 MPa at hydrocarbon developments and 1.5 MPa at water wells). To the extremely high drop in fluid pressure, high pressure gradients and rock temperature changes must be added.

Extraction of water and lowering of piezometric surface might produce subsidence in organic soils via shrinkage and, more than else, oxidation (or nitrification) of organic material. A yearly subsidence of 0.03 m is reported to take place at the Everglades, Florida (Tate).

Heavy pumping from coastal aquifers may result in salt water intrusion and damage to water quality and vegetation. In Orange Co. California, sea water intrusion extended as far as 6 km inland.

A special place, although not secondary at all, among the extractions of fluids from underground, goes to salt extraction with saturated brines, sulphur extraction by vapour and in situ gassification of coal. Each one of the above operations is potentially and actually inducing important localized settlements and/or areal subsidence. The way in which all processes are advanced is such as to make it impossible to keep the process development under complete control. Monitoring is usually not easy. In addition, the physical disuniformities of the mines formations, like the presence of marly interbeds in the rocksalt help to make the process unpredictable. It is rather the rule in rocksalt districts that subsidence is heralded by the sudden collapse of craterlike features that then develop into clusters and coalesce to give linear depression (Howell).

Fig.15 - Pronounced horizontal displacements coupled to subsidence and their disruptive effects on alignment sensitive facilities (from Howell).

The possibility of induced seismicity triggered by the withdrawal of fluids from underground has been proven (Caloi). Tests have been conducted at Rangley oil fields, U.S.A. and in other places.

Most of the environmental problems associated with the withdrawal of water for urban, agricultural or industrial use could be largely attenuated just by reducing the rate of pumping below the sensitivity threshold of the aquifer. Now this threshold level is not a constant but usually varies along with the meteorological cycle. On the other hand, water requirements are likely to remain fairly constant or even to vary out of phase with respect to the aquifer potential yield.

Impounding within the aquifer system, part of the yearly flow (during months of high yield and low demand to tap them at times of low yield and peak demand) would help to raise the minimum safe pumping threshold. Equally, isolating portions of aquifers whose depletion would lead to a consequent ridden subsidence might be justified in some instances. Classical soil mechanics has been using for a long time, established solutions and technologies which allow both operations to be performed, i.e. underground water storage and aquifer separation. Unfortunately such applications have so far been few and mostly applied without subsidence in mind (Matsuo). It goes without saying that underground water storage could be a sensible answer to several surface ponds with associated environmental impact like: resettlements, exposure of dried shores, breeding of disease vectors, etc.

Forecasting, controlling and relieving subsidence is a topic of utmost importance today, studies and applications should be pushed further with all energies. It is worth remembering that the International Association for Hydrological Sciences created, a long time ago, a Committee on Subsidence. Among the many fronts of research, creating and operating artificial underground reservoirs deserves top priority.

F - FLUIDS STORAGE ON SURFACE

Meaningful Actions	Likely Negative Impacts on Environment	ENVIRONMENTAL GEOTECHNICS: Main Goals	ENVIRONMENTAL GEOTECHNICS: Activities to Protect Environment
Man made reservoirs	Erosion downstream	Foresee impacts	Preconstruction instrumentation
	Alteration to groundwater table	Control slope instabilities	Analyze with other specialists conditions of slopes
	Slope instabilities		
	Induced seismicity		Conduct erosion studies

Storage reservoirs are practically the largest artificial feature on the earth crust. Embankment dams together with the water they retain represent by far the largest loads imposed by men on the planet; they are sometimes larger than equivalent natural features. Therefore it is not surprising that man-made lakes almost invariably acquire environmental relevance.

The engineering of dams for a long time and of large dams in the last decade, has been rapidly evolving in its design methods, technologies and concepts. Probably due to this propensity for widening horizons it was first among the branches of geotechnics to adopt an environmental position.

The concern for the effects of the reservoir on the banks and downstream is commonplace in the profession and the impact of a dam on its environment (through the accumulation of a huge mass of water) is clearly understood. The accepted environmental impact of a large body of impounded water can be simply explained as three types: accrued erosion downstream from the dam, modifications to groundwater levels and to the pattern of groundwater circulation, induced seismicity.

The first item has seldom been dealt with by soil engineers and has remained rather a subject for hydraulics. As a matter of fact, when reservoir releases are always of clear

water, the potential for material pick-up and transport as suspended sediment is maximum. The presence of the dam forbids the replenishment from upstream of whatever is carried away. This results in reactivating all erosive phenomena past the damsite, especially if they develop into fine grained soils that will naturally go away as suspension. Normally, the regulating effect of a reservoir reduces the frequency of peak discharges and thus proportionally cuts the bed load of the stream. Few reservoirs however are able to route the flow for a long return period and therefore the bed load transport capacity (and the subsequent erosive potential of the river) is not substantially decreased.

A greater potential for a suspended load superimposed on a nearly unchanged bed load carrying capacity is therefore the likely effect of a man-made lake on a stream. This is obviously enough to produce effects of importance to soil mechanics: undercutting, instability, modifications to the groundwater pattern in the river banks. Only in a very small number of cases have similar phenomena been traced back to their real cause. Again the interest of the profession has been primarily to solve the problem. Your Reporters would like to find records of study where the effects of activated erosion downstream of a large reservoir have been analyzed and evaluated prior to the design of the dam.

As for the second class of effects the literature is extensive and the assessment of the reservoir banks stability is usually part of the fulfilment of most preliminary designs.

There are few reservoirs without instability problems along their banks. In many cases they are easily dealt with or can even be ignored but sometimes they can develop into major slides capable of killing the project altogether. In the case of Vajont the slide volume was 6 times larger than the overall capacity of the reservoir (Muller). The evaluation of the sliding potential of a number of natural slopes, like those affected by an artificial reservoir is not merely a problem of geotechnics and therefore requires a special approach. First of all, in the case of large areas, the genesis and structure of the natural building must be known: this requires the work of competent geologists. As the different masses under scrutiny will probably involve both rocks and soils, rock mechanics and soil mechanics are likely to be equally necessary and important. If the mechanical facts and the effects of submerging different types of material are thus covered, the modifications to the groundwater flow, especially those induced by very high dams, will require the involvement of geohydrology.

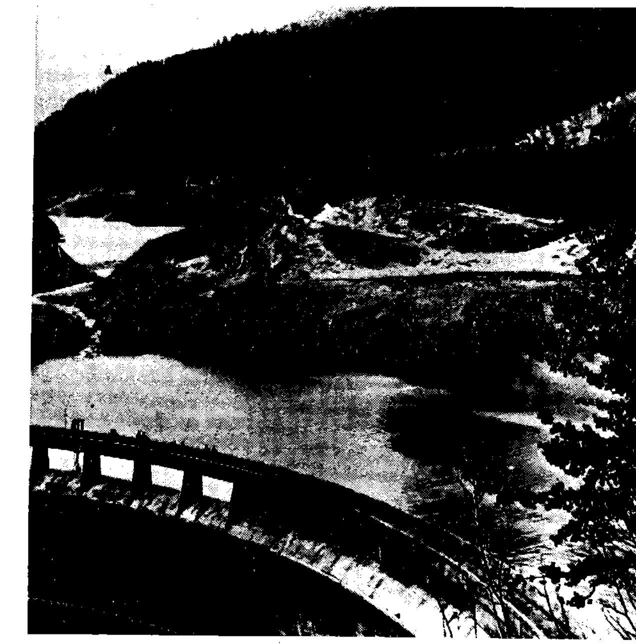

Fig.16 - Raising the watertable by nearly 100 m in the reservoir banks produced a slide of 5 000 000 m^3 that nearly reached the dam. The resulting wave surged 3 m over the crest level.

Preconstruction instrumentation and large scale tests are the only support that geotechnical engineering can use to this end (Sembenelli). It will not be enough to recognize the need for availing of the knowledge belonging to these four branches of engineering: the best capabilities will offer little help once a distress has materialized. What is actually needed is at least a way of foretelling the phenomena of greater momentum.

When dealing with flat reservoir surroundings the problems of slope stability disappears but the resulting change in the level of water table acquires importance. The water table can be affected for a long distance away from the reservoir shore line and this may result in several undesirable facts: loss of agricultural value on lands where the water table may become exceedingly high, hydrocompaction of soil strata sensitive to wetting, reduced or disturbed drainage and an increase in pollution levels, etc. A higher water table may establish active water circulation through soluble rocks formerly dry or anyway volumetrically stable. Upon the impounding of the reservoir in the Italian Alps a century-old village started to suffer from cave-in and settlements. The cause was, in the end, traced back to gypsum formations and the only solution was to move the village altogether.

Induced seismicity is an entirely different front and can be easily looked upon as a problem for seismologists. Yet, soil mechanics has proved itself vividly interested by new research and able to move into borderland subjects. As a matter of fact, today's geotechnics is aware of the problem, is also receptive to pertinent information and is capable of making an appropriate use of seismic inputs.

Since the classical case of seismicity following the impounding in the Lake Mead area, in U.S.A., over sixty cases of reservoir induced seismicity, of various levels of intensity, have been detected all over the world. It is obvious that quite a few cases, especially those of a minor level of intensity, have remained undetected. Only a few cases, namely Koyna, Kariba, Kremasta and Hsinfenkiang could be classified under the category intense (magnitude M greater than 6), while the others fall under the categories of medium and minor.

The accepted mechanism for reservoir induced seismicity sees the reservoir water as the last straw to trigger off seismogenic movements. The increase of pore pressures due to reservoir impounding reduces the effective stresses necessary for crustal readjustment, the reservoir load itself causes earth movements and physical interactions between water molecules and rock crystals, like quartz, leads to fatigue weakening which in turn gives rise

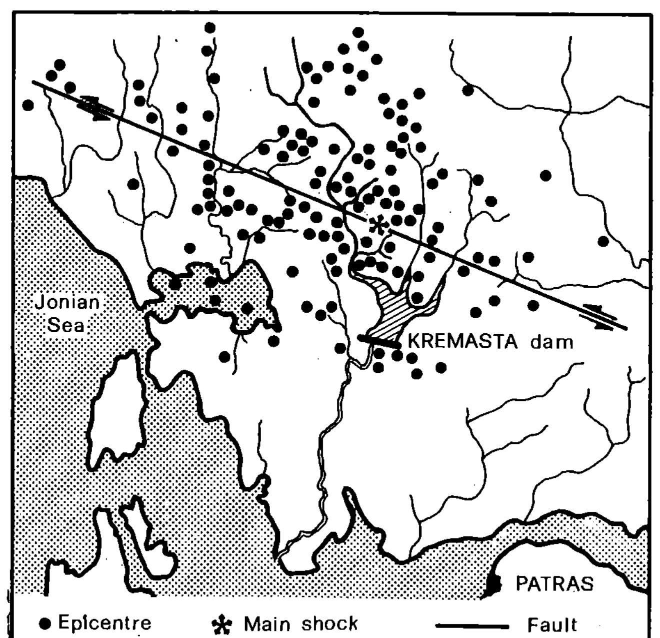

Fig.17 - Distribution of epicenters of seismic activity following the impounding of Kremasta reservoir, Greece (from Guha)

to a seismographic yield of the material.

Stresses generated by reservoir impounding are of very low order and thus inadequate for initiating fresh fracturing processes. The pore pressure effect could be expected to be the predominant mechanism in most of the cases, especially since the activity is seen to be mostly initiated with a time lag after the first impounding (Guha). The acceptance of a triggering role for reservoir water implies no relation between the stress perturbation and the amount of stored energy released. Even a relatively small reservoir can therefore induce important or major seismic activity. There is no agreed set of criteria that would point to a site with a potential risk of inducing damaging earthquakes: known tectonic force fields, high topographic relief, competent basement rocks capable of storing elastic energy and of failing in a brittle manner, water pathways to deeper levels and rock susceptible to strength deterioration are among those regarded as more significant (Skipp).

The consequences of intense seismic shocks need not be mentioned. Clearly they will affect the reservoir slopes, the dam and surroundings which may be populated and particularly sensitive to an increase in seismicity level. Investigations and evaluations to foresee induced seismicity are proper to specialized branches of geotechnics and the awareness of the profession with regard to this problem is even more necessary.

As the effects of an artificial reservoir are of widely different nature and closely connected to other disciplines like hydrology, geology, geohydrology and seismology, continued interest is essential. The investigation and assessment of the stability of large heterogeneous natural slopes seem especially important and challenging. Preconstruction instrumentation and the combined use of geotechnical and geophysical tools may be the best approach today. Getting the ability to evaluate the propensity of a given reservoir site which might become the source of seismic shocks otherwise absent, will increase the confidence of dam designers.

Induced seismicity has been looked so far as an undesirable development. It may however be the source of invaluable benefits. It seems in fact possible to gain a lot of knowledge of the mechanism of earthquakes from the study of micro and macro seisms at reservoir sites. Understanding more and more the prerequisites and actions resulting in a given shock, we may well get to the point where artificial controlled eartquake could be induced to stir a gradual relieve of the earth's crustal stresses thus averting catastrophic seisms.

G - UNDERGROUND DEPOSITS

		ENVIRONMENTAL GEOTECHNICS	
Meaningful Actions	Likely Negative Impacts on Environment	Main Goals	Activities to Protect Environment
Recharge	Groundwater Pollution	Protecting Groundwater	Study ground-waterflow
Storage of water	Induced Seismicity	Protecting vegetation	Underground dams
Storage of thermal Energy	Reduction of strength	Minimizing induced seismicity	Sealing
Disposal of Wastes	Radioactive Contamination		
Grouting			

The underground has definetely become one of men's dominions. By going underground not only with wells and shafts as he had done for millennia but with roads, warehouses, tanks, etc., man has actually pushed still further the frontier of its environmental impacts. The underground choice however should be accompanied by the clear notion that any damage inflicted to the earth is going to last forever. The earth's cycles are in fact clocked on a much slower time than those of the biosphere or of the surface waters. Dealing with the earth itself requires therefore increased awareness and discipline. Such a strong warning may seem unnecessary. A closer look to the problem shows however that the propensity for depositing something underground grows proportionally to the level of danger associated with it. Water deposits underground, either in soils (Matsuo) or in rock (Bjorstrom), created to store the water or its thermal energy, are not many. Interesting examples come from China and Swede where hot water is kept to recover the heat during winter months. The injection of hot water might have important geochemical impacts depending on the chemicals entrained by the water and the mineralogical nature of the aquifer. It can produce precipitates (phlogophyte and montmorillonite) or solutions (feldspar) or promote organic processes.

More frequent are underground deposits of industrial liquids or fuels. Contamination of the groundwater is in this case immediately in the picture particularly in seismic areas.

To date the underground is the traditional and preferred depository of noxious sewage and industrial wastes. Groundwater pollution and soil contamination are therefore daily occurrences (Freeze). A case of heavy contamination to the drinking water of many thousands of families in the U.S. originated in south western Ontario, Canada, because of sewage dispersed in shallow wells (Simpson). Criteria and facts on shallow and deep well injections have been recently organized and published (Mullican).

In a way, grouting may have to be looked upon as moderately to highly noxious wastes dispersed underground. Accidents related to chemical grouting are not new and a classical one happened in 1974 in Fukoka (Japan) where an acrylamide polluted groundwater used for domestic purposes (Ueshita). Injecting waste + cement slurries into deep shale formations has been so far successfully attempted but the potential for long term leaching remains to be evaluated.

The deposition of Nuclear Wastes deep underground within stable and impervious formations seems at present the preferred way to dispose of highly contaminating matters. The best burial sites are either in granite or in salt and the usual confining technique is that of a bentonite barrier. Metal canisters containing spent fuel are embedded in highly precompacted bentonite, lining deposition holes bored from the floor of a number of tunnels at large depths. The extremely long life of nuclear wastes makes imperative to evaluate the suitability of the rock case based on geostatic and geotectonic criteria, rather than purely geotechnical ones. At the periphery of salt domes (a depository for most spent fuels) rocks tend to be decompressed and highly fissured just because of the buoyant behaviour of the domes. Within these fissures water and/or oil accumulate and are usually exploited. It is readily apparent how leackage from the waste deposit could easily spread and strike. Several calculations have been attempted to evaluate the effects on rock and groundwater circulation of the heat generated within the fuel as a consequence of decay phenomena and the possibility of water-borne leakage of radioactive nuclides back to the biosphere (Robinson). These aspects are not at all understood as fully as they should before the method is given a wide acceptance and application.

The vital importance of nuclear fuels and of their safe disposal for our civilization today, makes imperative that studies, research analyses and financial means be devoted to the problem of underground deposits.

The deposits of spent nuclear fuels deserve of course utmost attention and will require the largest financial means. The Environmental Geotechnics approach requires that the subject be viewed from afar and under a wide angle so as to include earth crust stresses and tectonic mechanisms, fracture mechanics and seismogenic processes.

Again Swede has been taking the lead with its KBS programme conceived to study how to handle spent nuclear fuels.

H - TOWNS

Meaningful Actions	Likely Negative Impacts on Environment	ENVIRONMENTAL GEOTECHNICS: Main Goals	ENVIRONMENTAL GEOTECHNICS: Activities to Protect Environment
Overloading of weak formations	Structural distresses	Foresee impacts	Participate in town planning activities
Increasing water content of cohesive formations	Instabilities (slides, cave in, ...)	Ensure long term stability	Formulate building codes (+)
Modify groundwater pattern	Changes in groundwater levels		Formulate groundwater use codes (+)
Subsoil pollution with bacteria or/and chamicals	Pollution of ground water		Formulate urban and industrial waste disposal codes (+)

(+) Limited to aspects pertinent to geotechnics

The building of towns is the oldest and most significant engineering activity that implies, by definition, that the environment will be affected and upset.

The impact of urban developments and of other building activities required by the industrial society on soils, groundwaters and environment in general, is really perceived at the design stage and has been, insofar, generally neglected. Not surprisingly, therefore, towns and urban areas represent the hot spots of the entire environmental issue. Not surprisingly most cities are really suffering. Not surprisingly many among the oldest towns feel the approaching end to their time.

A town may mean higher stresses imposed to the underlying formations, reduced groundwater circulation, lessened capillary tensions through superficial formations, enhanced water infiltrations in the subsoil, bacterial attack on the soil system or a combination of all the above. Threatening erosions, repeating localized failures, area instabilities, settlements, subsidence, heave, alteration to the groundwater pattern are only too easy to detect in most of the cities where we still live and work, perhaps oblivious of the problem. The majority of towns are living crucibles of environmental effects. Many examples are only to be seen. The many ghost cities in the world are to remind us that things may worsen beyond possible endurance.

In refusing to accept that the profession has been so far unaware of the problem, we have to admit that the majority of our efforts was put into designing safe and sometimes ingenious structures for the isolated building rather than in analyzing the problem as a whole, at its origins. The material available on this specific subject is therefore scanty, to say the least.

Too many urban complexes suffer because generalized active erosion (produced by rivers, rainfall, winds or simply by physiochemical processes) is eating away the platform of the city. In some instances city planners selected a firm ground resting on softer strata. The increased building load and the city effluents have overstressed the stronger slabs and plasticized the softer beds. This is the case of many cities in Central Italy founded in Roman or Etruscan times on competent volcanic hilltop platforms resting on overconsolidated clays. Orvieto is quite emblematic: the volcanic tuff slab on which all the buildings rest (including several historical landmarks and architectural masterpieces) is sliding away all along its border over a softened clay seam. Gradually, the city will topple into the underlying ravine (Sciotti).

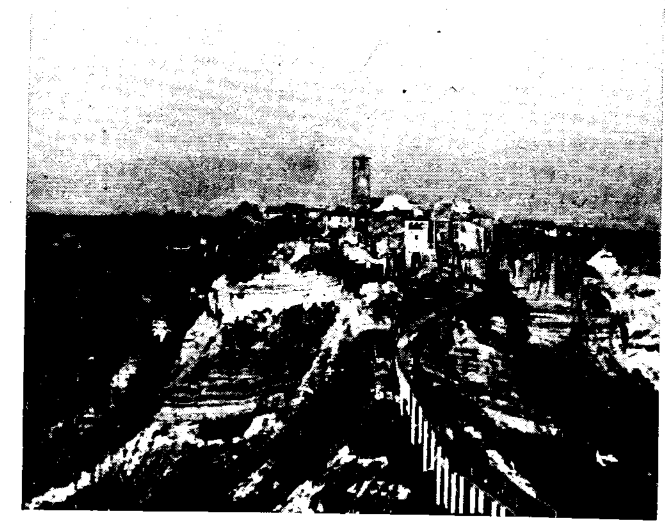

Fig.18 - The city of Civita in Central Italy is slowly falling away. More than 2 000 years old and once an important settlement, Civita will not live one century more.

Even more frequent are the cases of town extensions allowed over hilly grounds of inadequate strength. The modifications induced by developing previously virgin land is enough to start off a whole series of structural damages (Chowdhury).

Towns and industries are likely to modify groundwater levels and quality in order to suit the needs that were at the origin of their foundation and growth. Modifications can be chemical, bacterial or thermal. They can take place within and/or outside the city limits. Their causes can be the drawing off or injection of matter or heat, they can be voluntary or accidental, known or undetected and their effects may or may not affect the zone of partial saturation above the water table. Modifications can be indirectly caused by water exchanges within and at the periphery of the acquifer, by works, like sheet pilings, diaphragms, grouted curtains, waterproofings, river training, borrow pits.

The foundations of basements and buildings are usually a major obstruction to shallow aquifers and subway or sewage tunnels are even more so. Large underground or even surficial structures with very important linear extension may actually act as dams to underground water flow and substantially modify groundwater levels. Long linearly extended structures are rather typical of modern civil engineering and the modifications they induce on ground water levels may affect a large number of older buildings whose formerly safe foundations become inadequate to the new conditions (softening of the soil underneath or wipe out of the capillary zone).

The presence of town pavements may seriously reduce the infiltration of rain waters while leaks from water supply pipelines may represent an important net gain to groundwater flow. Figures of 3 10^{-3} $m^3/s\ km^2$ and 8 m^3/s have been accepted to represent average infiltration loss and average leakage for Paris and suburbs (Monition).

The geotechnical engineer has now very powerful tools to investigate groundwater systems: different chemicals and isotopes can assist in defining the pattern of groundwater flow so as to calibrate mathematical models of a single or multiple aquifer. In addition to the classical geometrical models of aquifers, models are now available to analyze the evolution of meaningful parameters like temperature and/or chemical concentrations along a flow line as well as to establish isochrones of moving fronts through the same aquifer (Russelot).

Humans are often the vector of microorganisms like bacteria which can promote and sustain geochemical alterations like the sulphides sulphates swelling mechanism induced by Thio and Ferro bacilli in Ottawa black shale (Quigley). It has been recently reported that over 30 000 homes in Adelaide suffer damages from swelling soils attached by microorganisms (Mitchell).

When considering the effects of a town or industry, we cannot separate hazardous wastes from the items specifically related to geotechnics. A main concern for chemical and sanitary

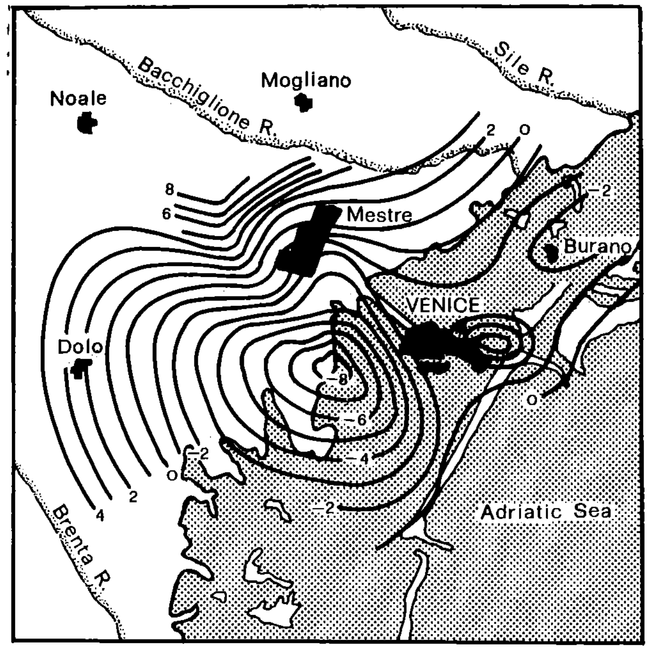

Fig.19 - Equipotential lines of a confined aquifer subject to intense localized pumping (from Carbognin).

engineering and for official Authorities, the hazardous waste threat depends also on the way in which they are channeled through a physical media: soil and water. Many case histories stand to tell how a greater geotechnical awareness and guidance, in disposing and caring for hazardous wastes might have helped to avoid frightening consequences (Dellaire).

If there has ever been a period of paroxysm in man's drive to building and expanding his towns, this is certainly the situation today. That geotechnical engineers can and should contribute to alleviate most of the environmental illness grown along with a hectic and thoughtless urbanism is self-evident. The proper way of doing it, is, however, not through deeper involvement in foundation design or via advancing established branches of geotechnical knowledge (e.g. soil structure interaction). What is needed is a shift in the perspective and the participation of soil engineering right at the planning (or replanning) stage, in the spirit of Environmental Geotechnics as proposed by this Report.

4 - THE FUTURE OF ENVIRONMENTAL GEOTECHNICS

At this point we can try to draw some conclusive remarks to this State of the Art Report.

Environmental Geotechnics has been born and is bound to enjoy a development comparable to that made by its parent discipline. It does not mean that Environmental Geotechnics is the omega of geotechnical activities. On the contrary: Environmental Geotechnics is only a facet of our profession.

A few facts readily under the light beam issuing from this facet of geotechnics have been the subject of this Report. An attempt has been made to assemble and organize the matter of Environmental Geotechnics in a clear and meaningful way. Framing up this new field of activity and improving the definition of Environmental Geotechnics proceeded in parallel throughout the work of your Reporters with continuous mutual influences and conditions.

Environmental Geotechnics emerges from this work as a polyspecialized contribution offered by geotechnical engineers in an interdisciplinary context and in the earliest stages of a project. This contribution is aimed at identifying possible effects induced by the project on areas which would normally be considered as outside of the project limits. The contribution result of this exercise should be to point out ways and means to avoid, compensate or at least limit negative effect while enhancing all positive developments.

Environmental Geotechnics is not going to substitute any of the previous sections of our discipline. It only aims at minimizing and possibly avoiding that the same capabilities be used too late to counteract or heal unnecessary wounds.

The large majority of geotechnical engineers will continue to work, as in the past, on well defined subjects with a precise methodology. Alongside, there will be a markedly interdisciplinary professional activity often progressing along undefined paths. This will require highly experienced men, conversant in soil, rock mechanics and groundwater flow, who will be capable of taking a new and critical stand in front of the problem, to imagine, understand and control its implications at large.

The engineers in Environmental Geotechnics will work at times and at levels which will be different from those of their colleagues providing a more classical contribution: the latter will not be displaced by the former.

It is advocated that Environmental Geotechnics will provide a substantial contribution and will actually become an essential morsel of any

Environmental Impact Statement to be prepared at the start of any important project.

Remarkable self-discipline and attention to legal aspects will be essential in order to raise and righteously occupy the position of an independent branch of geotechnics. The geotechnical fraternity will certainly produce and offer information material and practical suggestions for the unavoidable legal frame that the community will impose on its technicians. Legal aspects are now beyond the scope of this State of the Art Report but a few remarks may be pertinent.

Normally laws have a largely autonomous genesis and tend to incorporate a limited amount of technical knowledge. It is the rule for different Countries to legislate in different ways about essentially the same matter. This is already the case for Environmental Geotechnics. Several countries have issued fundamental laws to protect the environment.
In the U.S. the Congress passed in the last decade six basic laws among which are the following:

- Coal Mine Health and Safety Act of 1969 and subsequent regulations on refuse piles and retaining dams;
- NEPA The National Environmental Policy Act of 1970;
- The Solid Waste Disposal Act of 1970;
- SMCRA The Surface Mining Control and Reclamation Act of 1975.

In France among several other laws and decrees, the need for impact studies was established by:

- Loi No. 76-629 of 1976 relative to the protection of nature.

Great Britain has had for a long time, Acts and Codes originated from environmental disasters in the coal regions of South Wales, like the:

- Mines and Quarries (Tips) Act of 1969 and subsequent regulations.

South Africa issued:

- Mines and Works Act, Regulation R537 of 1980.

Japan has promulgated the basic law for Environmental Pollution Control in 1967 and several environmental laws have been issued recently.

Swede issued:

- Stipulation Law of 1977 stating that new nuclear plants cannot be commissioned until it proves that the waste problem can be solved in an absolute safe manner.

If engineers tend sometimes to stay with facts and concentrate their efforts on finding proper and new solutions to contemporary problems, we must all be aware that it will not be possible to make full use of the technological advances produced by the work of many outstanding colleagues or to apply the concepts of Environmental Geotechnics without some legislative aid.

Not the least, international cooperation, exchange of support, use of fall-out from similar experiences and finally the actual exchange of materials and industrial products largely depends on the legal instruments.

It is advocated that The International Society of Soil Mechanics and Foundation Engineering for its standing and technical authority, should offer to act as the point of convergence and coalescence of information and recommendations and should provide, through the National Societies, a lead to the world for an integrated approach to Environmental Geotechnics.

Reconsidering what has previously been described in some detail, some subjects seem to require earmarking for increased attention or further research:

i. The re-use of waste materials through the modification of their physiochemical properties. First of all, among the different wastes, tailings, slimes and heavy metal sludges. Techniques contemplating the mix of different wastes into stabilized product are certainly attractive. An equal potential seems to stay within the use of micro-organisms as modifying agents.

ii. The relieving of subsidence phenomena, particularly connected with the withdrawal of water from shallow aquifers. Recharge techniques and the concept of artificial underground reservoirs seem quite promising and not exploited to their full extent.

iii. The eco-compatible design of cuts and retaining structures including dams: a front where contributions may appear too obvious and irrelevant to attract the interest of the profession. Any progress in this field will come under the attention of a large section of the public and will herald Environmental Geotechnics.

iv. The preparation and use of geotechnical maps. Repeated applications and gradual refinement of this tool through the contribution of large sectors of the profession are needed.

Environmental Geotechnics will derive from them an easier understanding and better applications.

The only recommendation that we would like to make in ending our service deals with this Report. Your Reporters, more than anybody else, are aware of the limitations and deficiencies of their work as it is presented here to you. Probably with more time, through the scanning of a wider amount of information and holding more discussions with colleagues, this Report could have been improved. If the result of our work is questionable, it is certainly not because its sources were insufficient or inadequate.

Yet the vital importance of this subject and the need for Environmental Geotechnics at its best, both demand a State of the Art Report of the maximum standard possible. It should serve as a charter and as an organizing document.

Your Reporters, therefore, recommend that Environmental Geotechnics, as delineated herein, be one of the subjects of the next International Conference too and that the Reporters and Panelists be given the task of reviewing and completing this very Report which, for the time being, we hand over to you as an outline only.

SELECTED REFERENCES

The subject Environmental Geotechnics and its relative novelty justify that specific literature should be mentioned. A list of references has been prepared which proved to be large enough to suggest that it is necessary to divide it into sections, corresponding to the sections of this State of the Art Report. Although long, this reference list is certainly not complete: the Reporters, while apologizing for involuntary omissions, would appreciate any indications of corrections.

With the exception, perhaps of the section on geotechnical maps, which has been kept as comprehensive as possible, the titles quoted have been selected in the optics of environmental geotechnics as proposed in this Report. Papers that deal with the solutions of a problem along the lines of classical geotechnics (rather than those that deal with focusing, prediction and prevention of environmental impacts) are not likely to be found herebelow.

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Environmental Geotechnics — General Report

La Géotechnique de l'Environnement

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Your reporters prepared "Environmental Geotechnics" as the State-of-the-Art Report for Session 6. They cannot add much more comment, but would like to introduce papers presented to Session 6 in the order of the technical questions of Bulletin No. 2.

The Organizing Committee announced the following technical questions for Session 6:

(I) Waste material in earth structures and protection against groundwater pollution

(II) Erosion protection

(III) Change of geotechnical properties due to pollution

(IV) Subsidence due to lowering of the groundwater level and to the withdrawal of oil and mining

Calling for papers under such questions, 21 papers were finally delivered to reporters of Session 6.

16 of the papers are related to waste materials and protection against groundwater pollution.

(I-a) Use of wastes
(See Chapter 3.A of the S.o.A. Report)

Ballisager and Sørensen reported a relative favourable characteristics of fly ash as fill materials.

Broš also stated that lagooned ash from coal-fired plants is a good material for building retaining embankments of ash lagoons.

Gatti and Tripiciano presented the results of a series of laboratory tests of coal fly ashes from a power plant in northern Italy. The experimental results show that the use of virgin ashes is preferable for fields under water, while for compacted embankments both virgin and recovered ashes can be adopted.

Vazquez and Alonso reported results of experimental investigation on the use of fly ash as an effective way of stabilizing a sandy soil. An optimum fly ash content was about 10 percent by weight. Lime addition by small percentages (3 percent) strongly increased the strength.

Gorle and Reichert reported an experience of test embankment with phosphogypsum which was a by-product of phosphatic fertilizer. The concluded that phosphogypsum could be suitable for embankment provided solutions are found to reduce settlements and shrinkage.

(I-b) Environmental Geotechnics of Tailings Dams
(See Chapter 3.D of the S.o.A. Report)

Blight, Rea, Caldwell and Davidson reported the measures currently being taken to prevent air and water pollution from abandoned tailings dams in the Witwatersrand area of South Africa.

Mackechnie reported recent geotechnical contribution on the impoundment of tailings in Zimbabwe. The control of construction by monitoring of the geotechnical and hydraulic factors has been undertaken there and has paid dividends in terms of reduced costs, fewer failures and acceptable environmental impact.

Busch and Lamy presented their design of tailings dams for storage of phosphate waste. In the case of phosphate plants in Brazil, the cycloned tailings are considered too impervious for building dams by conventional methods. Therefore, they proposed to use a modification of conventional design.

(I-c) Portection from Failure of Waste Accumulation
(See Chapter 3.D of the S.o.A. Report)

Lousberg, Lejeune and Thimus reported their improving method of stability of filled ash which was in critical state, and their instrumentation to evaluate safety.

Broš showed examples of piping failures of ash lagoons. The ash lagoons with the decant pond immediately behind the dike are much more susceptible to piping failure than those in which the decant pond is situated as far as possible from the retaining dike.

(I-d) Settlement of Organic Sludge Landfills
(See Chapter 3.D of the S.o.A. Report)

Wardwell and Nelson presented their study on the compressibility behavior and resulting leachate generation of a combined sludge composed of organic cellulose fiber and inorganic minerals. Based on their long-term one-dimensional consolidation tests conducted on the organic sludge to determine the effects of fiber decomposition, they proposed a rheological model to represent the compressibility of the saturated organic sludges, both with and without fiber breakdown.

(I-e) Disposal Site Criteria for Hazardous Wastes
(See Chapter 3.D of the S.O.A. Report)

Smith and Middleton explained the pollution-producing mechanism of calcine which is a waste product of the manufacture of sulphuric acid, and proposed environmental control measures and waste disposal site selection criteria for calcine.

Their proposal for the design of calcine disposal facilities stated in their paper should be also considered for any hazardous waste accumulation in order to avoid groundwater pollution.

(I-f) Protection against Groundwater Pollution
(See Chapter 3.D and 3.G of the S.o.A. Report)

Loxham advocated that simulation studies of contaminant mobility in peats are important in assessing the pollution risk of peat-lands caused by waste disposal. He also stressed that the determination of parameters to be used can cause difficulties and an understanding of the structure of the peat pore space and physiochemistry is of great importance.

Zimmie, Doynow and Wardell introduced their important recommendations on permeability testing of impervious soils in order to know the ability of interception at the hazardous waste disposal sites based on a large amount of information gathered on test results, equipment and test procedures.

Lundgren presented the results obtained in a study on the application and durability of soil/bentonite mixtures as sealing blankets under sanitary landfills. He found many important factors in preparing suitable sealants with bentonite for sanitary fills.

Pusch reported his evaluation of bentonite as a barrier relating to Swedish work on finding a suitable technique to isolate unreprocessed nuclear reactor wastes from the biosphere. After studying unsaturated and saturated flow in highly compacted bentonite, he concluded that the flow rate would not be higher than approximately 1 mm in 30 000 years with a regional gradient of 10^{-2} and a permeability of 10^{-13} m/s.

This research work would encourage the confining technique of nuclear wastes.
Kastman and Huibregtse reviewed available literature and evaluated current research regarding mechanisms of soil detoxification. Their report states that current detoxification methods and procedures are relatively slow and would be quite expensive for actual large scale use. Therefore, more research and field performance testing needs to be done to develop cost effective soil detoxification systems.

(II) Erosion Protection
(See Chapter 3.A, 3.F and 3.H of the S.o.A. Report)

Sciotti reported environmental problems of some old towns in Central Italy. He gave examples of towns on hills being eroded and an outline of the geotechnical and morphological situation of the site where most old towns in Northern Latium were built. He discussed the influence of anthropic factors on the rate of evolution of instability. He points out that measures should be planned on the basis of an exhaustive analysis that keeps account of all the various factors and placed them within a global framework even though such factors may appear to be unrelated, being separated in time or space.

McDonald, Stone and Ingles showed practical methods of ensuring safety and water quality for earth dams in dispersive soils which were susceptible to erosion. They explained two case histories exemplifying these problems. One involved gypsum treatment of the water in connection with repair of a failed dam and the other a soil treatment to suppress storage turbidity.

(III) Change of Geotechnical Properties due to Pollution
(See Chapter 3.A of the S.o.A. Report)

Sridharan, Nagaraj and Sivapullaiah reported the problem of distress to the floors, pavements and foundations in a fertilizer plant caused by heaving of the soils due to phosphoric acid contamination.

(IV) Subsidence due to lowering of the Groundwater Level
(See Chapter 3.E of the S.o.A. Report)

Ueshita and Sato reported the numerical analyses for the land subsidence of the Nōbi plain. They found a desirable groundwater level to prevent subsidence and the allowable withdrawal of groundwater with finite element models. Also they are predicting the future subsidence there.

(V) Geotechnical Maps useful for Environmental Control
(See Chapter 2 of the S.o.A. Report)

Kantey and van der Merwe proposed to use geotechnical maps as a vital tool for assisting the multi-disciplinary teams which co-operate in planning a reduction of the impact on the environment of the many projects.

PAPERS SUBMITTED AND CLASSIFIED TO SESSION 6

Ballisager, C.C. and Sørensen, J.L. Flyash as Fill Material.

Blight, G.E., Rea, C.E., Caldwell, J.A. and Davidson, K.W. Environmental Protection of Abandoned Tailings Dams.

Broś, B. Pollution from Ash Lagoons and Use of Ash for Embankments.

Busch, R.G. and Lamy, L.F. Tailings Dams in Phosphate Mines.

Gatti, G. and Tripiciano, L. Mechanical Behaviour of Coal Fly Ashes.

Gorle, D. and Reichert, J. Un remblai expérimental en phosphogypse (Experimental Embankment in Phosphogypsum).

Kantey, B.A. and van der Merwe, W.J. Geotechnical Mapping, Aid to Environmental Control.

Kastman, K.H. and Huibregtse, K.R. Mechanisms for Detoxifying Soil.

Lousberg, E., Lejeune, M. and Thimus, J.F. Contrôle continu d'un massif à stabilité critique (Permanent control of a Mass in Critical State).

Loxham, M. Pollution in Peats.

Lundgren, T.A. Some Bentonite Sealants in Soil Mixed Blankets.

Mackechnie, W.R. The Impoundment of Tailings by the Mining Industry in Zimbabwe.

McDonald, L.A., Stone, P.C. and Ingles, O.G. Practical Treatments for Dams in Dispersive Soil.

Pusch, R. Unsaturated and Saturated Flow in Swelling Clay.

Sciotti, M. Some Problems of Environment Protection in Italy.

Smith, A.C.S. and Middleton, B.J. Environmental Control of Calcine Waste Disposal.

Sridharan, A., Nagaraj, T.S. and Sivapullaiah, P.V. Heaving of Soil due to Acid Contamination.

Ueshita, K. and Sato, T. Study on Subsidence of the Nōbi Plain.

Vazquez, E. and Alonso, E.E. Fly Ash Stabilization of Decomposed Granite.

Wardwell, R.E. and Nelson, J.D. Settlement of Sludge Landfills with Fiber Decomposition.

Zimmie, T.F., Doynow, J.S. and Wardell, J.T. Permeability Testing of Soils for Hazardous Waste Disposal Sites.