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SESSION 4 — GENERAL REPORT

SOIL IMPROVEMENT

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INTRODUCTION

When engineers encounter difficult foundation conditions they would normally consider alternatives such as avoiding the particular site, designing the planned structure accordingly or removing and replacing unsuitable soils. In addition they would evaluate the suitability of various methods of soil improvement, possibly including:

1. Compaction: resulting in increased soil density by reducing air voids.

2. Dewatering and consolidation (by pumping or preloading): a process which involves water flow out of the soil.

3. Grouting: an injection of admixtures under pressure at depth.

4. Stabilisation by physically mixing additives with surface layers or columns of soil at depth. The additive may then chemically react with the soil.

5. Thermal stabilisation: heating of soils resulting in physico-chemical changes in the soil.

6. Freezing.

7. Reinforcement (including anchoring) by incorporating structural elements with tensile or compressive strength exceeding that of the natural soil.

As more and more land becomes subject of urban or industrial development, good construction sites are difficult to find and the soil improvement alternative more frequently is the best option, technically and economically.

RECENT FORUMS

It is of interest to record how much attention was devoted to specific soil improvement techniques at major conferences held during the last four years. A measure, albeit not a reliable one, is to count the number of papers presented on the various topics, as listed in Table I. Conferences selected for this analysis are:

1981 Tenth International Conference on Soil Mechanics and Foundation Engineering, Stockholm (ICSMFE).

1982 Symposium and Short Course held at the Asian Institute of Technology, Bangkok (AIT).

1983 Eighth European Conference on Soil Mechanics and Foundation Engineering, Helsinki, dedicated to the topic "Improvement of Ground" (ECSMFE).

1984 Fourth Australia-New Zealand Geomechanics Conference, Perth.

It is of course not always easy to categorize a particular technique or case study under one topic only: the compaction and consolidation process may occur at the same time; deep compaction forming piles of dense material may be referred to as compressive reinforcement; geotextiles may not only assist dewatering, but also provide reinforcement, and so on. Nevertheless, if one assumes that each paper contributes to the advance in the state of the art, it appears that precompression and dewatering have experienced major developments in recent years, followed by deep compaction and soil reinforcement techniques. However considerable importance has also been given to stabilization using admixtures, at the surface or at depth, while interest in high-energy consuming methods such as thermal stabilisation seems to be declining.

It is generally acknowledged that the principles of soil improvement are not new. Indeed, some of the techniques used today may be more than 2000 years old. However, significant advances have been made in recent times. They cover many aspects:

1. Development of new machinery, particularly for deep compaction.

2. Availability of new construction materials, such as geotextiles.

3. Emergence of better guidelines for determining the suitability of specific techniques for certain types of soils and site conditions.

4. Better understanding of the processes involved and appreciation of the significance of construction sequence.

5. Refinement of methods of analysis and computer modelling techniques.

6. Advances in the techniques of performance evaluation of treated soils, such as pressuremeter tests, seismic shear wave velocity measurements and others.

TABLE I

PAPERS PRESENTED AT RECENT CONFERENCES

Topic \ Conference	ICSMFE Stockholm 1981	AIT Bangkok 1982	ECSMFE Helsinki 1983	ANZGC Perth 1984	Total
Deep Compaction	9	4	30	0	43
Precompression, dewatering	13	1	32	3	49
Injection, Grouting	4	4	15	2	25
Admixture Stabilisation	11	3	19	1	34
Thermal Stabilisation	1	0	0	0	1
Freezing	0	2	0	0	2
Soil reinforcement, anchors	8	12	22	2	44
Other	-	16*	69**	-	85

* incl. papers on piles, geotextiles, local practice, historical accounts etc.
** incl. papers on laboratory and field testing, improvement of special soils, soil improvement under water etc.

It will become clear that each of the papers selected for this session of the 1984 ANZ Geomechanics Conference contribute in one or more of the above ways to progress in soil improvement.

EMERGING TRENDS

Traditionally the aims of improving soils as foundation or construction materials have been one or more of the following:

1. Increase strength.
2. Reduce compressibility.
3. Control shrinking and swelling.
4. Decrease permeability, reduce water pressures, control seepage.
5. Prevent detrimental physical or chemical changes due to environmental conditions.
6. Reduce susceptibility to liquefaction.

These benefits are directly related to engineering properties of soils in foundations and soil structures.

Environmental Geotechnics

Today, soil improvement is no longer seen in only a narrow technical sense, where it assists in solving well defined problems related to stability, deformation and seepage. It has become a major activity in the newly emerged discipline of "Environmental Geotechnics" subject of an illuminating State-of-the Art Report at the last ICSMFE, presented by Sembenelli and Ueshita.

The task of Environmental Geotechnics is defined as identifying and understanding the environmental significance of geotechnical processes and predicting its consequences. These processes include making cuts and fills, creating reservoirs, excavating at the surface or underground, dewatering, redirecting seepage and more.

Desirable soil improvement activities within the framework of Environmental Geotechnics are:

- Use and if necessary modification of waste materials.
- Stabilisation of newly exposed soil surfaces so as to reduce dust in the air and suspended solids in the runoff.
- Prevention of subsidence due to mining.
- Preservation of quality and flow patterns of groundwater,
- and others.

Especially difficult and intractable is considered the treatment of wastes transported and disposed of in form of slurries. To solve that problem, many studies are currently being undertaken, and, as reported by Sembenelli and Ueshita, some are quite novel. They include cement stabilization, the formation of cement crystals (cement bacilli), physico-chemical methods, even the use of bio-chemistry. In some instances the purpose of the process may be fixation of heavy metals or other serious pollutants, rather than the improvement of engineering properties.

High-Energy Waste Materials

Of increasing concern to environmentally conscious engineers is the constructive use of high energy waste materials such as slag and flyash. Part of this concern arises from the estimated increase in ash production in the years to come. In the U.S.A., it has been predicted that by the year 2000 coal burning will produce 200 million tons of ash per year.

Flyash is wellknown as an admixture to portland cement. This use, however, is unlikely to exceed 10% of the total production of ash. If larger quantities are to be used constructively, it is likely to be for highway construction and soil amendment.

Flyash has low unit weight and good shear strength. It is suitable as structural fill and, in combination with lime or cement, as a stabilizing agent for road bases. Its long term pozzolanic properties are thought to reduce road maintenance costs. Ongoing pozzolanic reaction also provides the capacity for autogenous healing, the ability for cracks in a pavement to heal themselves.

Sommerfeld (1982), reviewing a U.S. Federal Highway Administration Demonstration Project at the Sixth International Ash Utilization Symposium (IAUS), emphasised that flyash must be designed and engineered for a particular application. With proper quality control, flyash can then be a durable, cost effective construction material.

Flyash has also been considered for soil amendment (IAUS, 1982), acting as a soil conditioner, neutralizing agent or nutrient supplier. For these purposes it has been incorporated in strip-mine spoils and other marginal land. Benefits may arise from a combined amendment by flyash and organic wastes.

Low-Cost Building with Soil

Principles of soil stabilisation can be applied to the making of low-cost earth walls and building blocks.

The use of adobe and mud brick construction techniques has seen a revival in interest (Rutten, 1982). Selection of the appropriate type of clayey soil, compaction at the optimum moisture content and inclusion of straw or saplings were the key to soil construction methods used last century in Australia. Stabilization with cement or lime and mechanical pressing is a newer development.

A new process involving heating of fine grained soil and the addition of finely divided iron oxide and sodium silicate in solution has been developed by Ingles and Lim (1980). In his state-of-the art report, Mitchell (ICSMFE, 1981) considers this new method of soil improvement as being of equal significance as the product termed cement bacillus, mentioned earlier.

Rather than low initial costs, Baggs (1983) highlights the low life-cycle costs of earth covered housing. It is claimed that heating and cooling costs can be reduced by as much as 80% if the thermal insulation properties of soil are taken advantage of. Over a period of 50 years, the cost of building and maintaining an earth-covered dwelling may be less then one third of that of a standard above-ground structure. Geotechnical engineers so far have had very little input into the architect led movement towards earth sheltered buildings, which was subject of an International Conference held in Sydney (1983). The result has been that research and development in this area has concentrated on physical, financial and aesthetic aspects and the use of soil as a passive constituent rather than as a construction material. There appears to be considerable scope for the use of engineered soil improvement in the building of earth-contact structures.

Geotextiles

Geotextiles refers to man-made fabrics used in geotechnical engineering. In most applications, geotextiles are permeable to water, although treatment with rubber, bituminous and synthetic compounds may make the woven or non-woven fabric impermeable. For impermeable sheeting the term geomembranes appears to be preferred, although mechanically speaking all fabrics act as membranes.

The last decade has seen a rapidly increasing use of synthetic fabrics in construction. Figures for the U.S. and Canadian market are presented in Table II. It is believed that Australia also experienced a solid growth in geotextiles application, although no detailed figures are available.

TABLE II

GEOTEXTILE FABRIC MARKET 1980-1983
(Geotechnical Fabrics Report, Summer 1983)
(in millions of square metres)

	1980	1981	1982	1983
Non-Woven	63.5	68.5	69.0	81.5
Woven	21.3	29.3	31.4	33.9
Total	85.3	97.8	100.3	115.4
% of Change		+15%	+2.5%	+15%

Table III identifies the major areas of application as reported by manufacturing and marketing oriented sources (Taylor, Nov. 1983). There may be some inconsistences in classifying the areas of use of the fabrics by the various authorities, but the trends appear clear. Road works account for most applications; but a significant proportion of the fabrics are also used for stabilisation and drainage. Another fact which is apparent is that nonwovens dominate the market at the present time.

Table IV identifies the major functions of a fabric used in the main areas of application.

The functions considered are:

Filtration : The fabric prevents migration of soil particles without impeding water flow (longterm).

Drainage : The fabric collects and conveys water.

Separation : The fabric prevents mixing of adjacent dissimilar soils during construction or during repeated external loading of the soil-fabric system.

Reinforcement : The inclusion of the fabric adds tensile strength, re-distributes stresses, provides confinement, thereby increasing stability or reducing earth pressures or decreasing deformation and susceptibility to cracking.

The most important fabric properties related to each function are listed in the last column of Table IV. The newly established Committee on Geotextiles of the Standards Association of Australia has recognized the significance of these characteristics and related basic information and will proceed with developing standards under the following headings:

1. General principles (Terminology, Product Description, Sampling).
2. Physical properties (Dimensions, Mass).
3. Mechanical properties (Tensile, Tear and Grab Strength).
4. Hydraulic properties (Permeability, Transmissivity, Equivalent Pore Size).
5. Durability.

In the longer term, fabric-soil interaction tests and in-situ performance tests will be considered. This follows the trend set by overseas standards associations.

An important event in the last four years has been the Second International Conference on Geotextiles, held in Las Vegas in 1982. Significant progress in all aspects of geotextiles in civil engineering was reported at that forum.

The geotechnical engineer can look forward to improved data available on geotextiles which should assist in the rationalisation of selection and design procedures.

At this stage, the SAA Committee has decided to limit its terms of reference to geotextiles, rather than to include geomembranes and geogrids or meshes which nevertheless are also areas of exciting new developments.

TABLE III

MAJOR AREAS OF APPLICATION OF GEOTEXTILES
(Taylor, Nov. 1983)

Application	Europe (%)	South America (%)	Southern Africa (%)	U.S.A. (%) 4	5	6
ROAD WORKS Embankments Access Roads	60	40[1]	60[1]	42[7]	47	
RAILWAYS	5	3[2]	10	5	4	
STABILISATION				24[8]	21	37
DRAINAGE including Agriculture	15	40[3]	13	11	18	
EROSION CONTROL	5	10	20	10	7	12
PROTECTION with Geomembrane	10					
OTHER	5	7	10	6	10	33[9]
Non-Woven Share	90	84	99	67	90	
Woven Share	10	16	1	33	10	

Notes:
1. Includes Drains.
2. Mainly Drains.
3. Excludes Roads.
4. International Fabrics Product Review, May 1983.
5. Testing Authority Close to Market.
6. American Fabrics & Fashions, 1983, No. 128.
7. Excludes Embankments.
8. Excludes Road and Rail.
9. Waterproofing 18%.

TABLE IV

THE FUNCTION OF FABRICS IN MAJOR AREAS
OF APPLICATION

Application	Major function in order of priority	Special conside-ration	Most important properties
Primary roads Railroads	Separation Drainage/ Filteration Reinforce-ment	Repeated loading	Pore size Permeability Strength Elongation
Retaining walls Embankments Foundations (May incor-porate Soil Drainage) see below	Reinforce-ment Separation	Creep	Strength/ Elongation Soil/fabric friction
Unpaved roads	Reinforce-ment Separation	Repeated loading	Strength Elongation
Erosion protection Subdrains Seepage control	Filteration Drainage Reinforce-ment	Rapid changes in water level Construc-tion stresses Abrasion	Pore Size Permeability Strength
Soil drainage (accelerate consolida-tion, reduce water pressures)	Drainage Filteration	Clogging	Transmissivity Pore size

SUMMARY OF PAPERS PRESENTED TO THIS CONFERENCE

The papers are grouped under the following topics:

1. Dewatering (3)
2. Grouting (2)
3. Reinforcement (2)
4. Stabilisation (1)

Dewatering

Three papers are related to the dewatering of bauxite residue in the Darling Ranges of Western Australia. This residue, left after alumina has been extracted from bauxite, consists of finely divided iron and silica minerals in a caustic solution. According to its grain size, it may be about equally divided into a coarse fraction of fine to medium sand and a fine clayey silt, also referred to as red mud. The latter is the cause of low settled density, slow rate of consolidation and low strength. Because of the large volume involved, the proximity of population centres and the possible damage to agricultural production through caustic infiltration of the groundwater, the disposal of bauxite residue represents a major environmental problem.

The most common method of disposal is to transport the residue in form of a slurry with a 20-30% solids content to a storage area formed by earth embankments. In the projects described, the disposal pond is sealed off by a clay blanket which in turn is covered by a layer of sand. In the storage ponds slurry solids settle into discrete coarse and fine zones. Excess liquor is decanted and returned to the process.

Glenister and Cooling report on the performance of a pilot disposal facility which was built in order to investigate the benefits of gravity underdrainage through the sand blanket on top of the clay seal. Slotted polyethylene pipes installed in the sand layer assisted this process. Some 1.2 million m^3 of mud were deposited over the 29 month trial period, with an average depth of 15 m. Flow, rainfall and evaporation measurements allowed a complete mass and volume balance. Pore pressures were monitored using piezometers installed in the underdrain as well as the red mud deposit. Field samples were tested in the laboratory in order to obtain density, shear strength and permeability values. Chemical analysis complemented the physical tests.

It was found that gravity underdrainage effectively reduces the hydraulic head acting on the clay seal, thus reducing the risk of leakage. The coarse residue fraction used for the drainage layer provided effective filtration, although traditional filter criteria were not met. The authors successfully modelled the deposition and consolidation process using finite strain consolidation theory. Experience gained will assist in predicting the behaviour of larger scale underdrained residue lakes.

Corless, Gibson and Glenister describe measures taken to rehabilitate old disposal sites with the aim of making them suitable for light industrial development. Dewatering is an essential step in this process; it removes surface water, aids consolidation and reduces the risk of groundwater pollution.

In the project described initial dewatering was achieved using wellpoints with venturi pumps. After installation in 1975, this eductor system became gradually less effective and was upgraded in 1982 by an additional 15 bores, each equipped with a standard windmill pump. On all pump sites, care was taken to sink the hole exactly to the sand layer protecting the clay seal, as it formed an essential part of the drainage plan. The new installation successfully lowered water levels further than ever before but surface settlement measurements have not yet shown any significant change. Some problems have been encountered with decreased flows but it is intended to use similar dewatering methods in other areas.

Prior to their installation the feasibility of dewatering of this site by individual bores was studied by Parker, Walker and Gibson using finite element modelling of the whole disposal area. The computer program developed allows analysis of both, steady state and transient flow in a system of water bearing layers of various permeabilities and specific yield. The analysis and parameters used are those preferred by groundwater hydrologists rather than soil engineers but the results are of course equally valid.

The theoretical model was fine-tuned by analysing past records of the performance of the existing eductor system. The authors then proceeded by evaluating the additional drawndown achieved by the proposed 15 new bores. The results demonstrated that substantial further deliquoring of the residue and a reduction of the pore pressure in the sand blanket can be achieved.

Grouting

Brett and Osborne report on the measures taken to minimise leakage from a reservoir planned to hold water contaminated with residual caustic soda used in the extraction of alumina from bauxite.

Finite element analysis of the seepage underneath the proposed 29m high dam containing the Refinery Catchment Lake indicated that leakage could be significant but that it could be virtually eliminated by grouting.

Grouting operations preceeded construction of the dam in 1981/82. Cement/bentonite or resin grout were injected using a Tube a Manchette system. A central batching process allowed consistent grout mixing. Control of mixing temperature for the resin grout assisted in maintaining appropriate viscosity and setting time.

Grouting pressure proved critical for the success of the work and site procedures were modified as more experience was gained.

More than 2500 borehole permeability tests showed that, on the average, permeability has been reduced by a factor of around five times and indications from current field observations are that seepage is well within design expectations.

Scott, Cooper and Knight describe a case where compaction grouting was successfully used to reduce settlement of a tiphead structure being built on mine waste fill. This work was initiated after some 50 mm of settlement was recorded after placement of 11 m out of 17.5 m of fill for the approach ramp. It was feared that additional settlement due to further filling, long term creep, collapse upon wetting and machine vibration would prejudice the plant's operation.

Drilling proved difficult due to the nature of the rockfill, particularly due to the high rock strength, high specific gravity of cuttings and high voids content. Grouting proceeded in stages. An initial grout curtain defined and limited the treatment zone. During pressure grouting, monitoring the quantity of grout used per metre run of drill hole assisted in selecting appropriate viscosity of grout and injection pressure. A total of 62,500 sacks of cement were used. The job proved more difficult and costly than originally anticipated, but the grouting successfully reduced settlement and was still considered the best alternative amongst the remedial methods of soil improvement considered.

Reinforcement

Brown and Poulos report the results of an analysis of the behaviour of two 3.66 m high experimental reinforced earth wall built at the U.S. Army Engineer Waterways Experiment Station in 1974. One wall was constructed with steel strips, the other with strips of nylon fabric coated with rubber. The Brown and Poulos analysis uses the finite element method; it allows for elasto-plastic behaviour of the soil and bond failure between soil and reinforcement. Calculated values of reinforcement stresses, horizontal pressures, lateral deformation and collapse height for the case of rupture of the reinforcement were compared to actually observed values.

For the steel reinforced backfill, a good correlation between predicted values and experimental results was obtained for all aspects except lateral deformation. In order to obtain a reasonable prediction of lateral deformation at the collapse stage, an artificially low modulus had to be introduced into the analysis; however for such an assumption all the other predictions had to be rated as poor.

For the case of rubber coated fabric strips, the finite element analysis proved useful in interpreting the failure mechanism but was found unsuccessful in predicting collapse height.

Mitchell reports the successful use of compressive reinforcement in the construction of the foundation for a wheat silo.

A 33.5 x 78 m concrete raft, 1 m thick, was placed on silty, clayey sand soil reinforced by a total of 413 compacted sand columns, reaching 4 m below the base of the raft, which was 3.5 m below the surface. The climate at the site is semi-arid. The soils were partly unsaturated and subject to "collapse" or significant softening upon wetting. In the unsaturated subsoil, construction of the sandpiles caused compaction of the surrounding soil, a benefit which was not achieved in the eastern half of the foundation area, where soils were wetter; consequently more sand piles were used in this part of the foundation. Maximum total settlements observed were in the order of 70 mm, maximum differential tilt was 20 mm; these values were in the same order of magnitude as predicted by computer analysis using elastic stress-strain moduli deduced from their empirical relationship with Dutch cone penetration resistance. This project illustrates the use of engineering judgement in the design and construction phase and the verification of theoretical predictions by performance measurements.

Stabilisation

Doshi, Mesdary and Guirguis report the results of laboratory and field tests on cement stabilised silty sand used for road construction in Kuwait. These studies were undertaken in order to find a way of reducing the thickness of highly temperature dependent asphalt layers in pavement construction.

The laboratory investigation comprised compaction tests, determination of CBR's, compressive strength; indirect tensile strength, modulus of rupture and dynamic modulus for a range of cement contents and curing times.

The field studies included the performance evaluation of 3 different pavement structures:

- a conventional multilayered asphalt pavement, 250 mm thick,
- a two-layer, 140 mm thick asphalt construction on 150 mm of sandy soil stabilised with 9% cement,
- the same system as above but with an unbound granular layer separating the asphalt from the soil-cement layer ("sandwich" or "upside-down" construction).

A number of useful correlations of laboratory tests results and valuable findings with respect to the efficiency of field compaction and batch plant preparation were obtained. The field investigation showed:

- compaction of soil-cement just below optimum moisture content caused less cracking after 28 days of curing;
- sealing cracks in soil-cement reduced deflection during a Dynaflect type dynamic load test;
- surface cracks in the finished sections were due to upward propagation of shrinkage cracks, which can be minimised by deliberate pre-cracking or the inclusion of an unbound sandwich layer. The latter appears to be the better solution.

CONCLUSIONS

The papers on soil improvement included in the proceedings of this conference contribute to our knowledge in several ways:-

1. They demonstrate advances in analytical techniques and computer modelling.
2. They prove the economics of observational techniques, where construction procedures are modified as the work progresses and more information on the subsoil is obtained.
3. They show the value of detailed field and laboratory studies in the development of cost effective rational design and construction procedures.
4. They underline the significance of soil improvement techniques in construction related to mining, bulk handling facilities and waste disposal.

They also illustrate how concern for the environment presents new challenges for the

the geotechnical engineer.

The papers presented at this Session only cover a limited number of activities in the field of soil improvement. Participants at this conference are referred to the proceedings and articles published elsewhere in order to complete their assessment of developments since the last ANZ Geomechanics Conference, in particular with respect to Environmental Geotechnics, the use of high-energy waste materials, low cost building with soil, and geotextiles.

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