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MANAGEMENT OF INVENTION AND INNOVATION IN CIVIL ENGINEERING

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A Dissertation submitted to the Faculty of Engineering

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for the Degree of Master of Science in Engineering

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ABSTRACT

MANAGEMENT OF INVENTION AND INNOVATION IN CIVIL ENGINEERING

DISON, Leon

This dissertation studies the management of invention and innovation in civil engineering, and in construction companies in particular. Literature on this subject concentrates on problems of large research organisations, financed either by manufacturing industries or by government, and practical guidelines for innovation management are therefore not available for the somewhat different style of management required in civil engineering.

Through the pursuance of a series of innovation programmes, which are described in this dissertation, a general modus operandi has evolved. The projects undertaken include (i) attempts to develop industrial and mining wastes as alternative materials of construction, (ii) transfer of technology from abroad into the local construction system, (iii) an investigation into alternative support structures in underground mining.

The more important of the guidelines, conclusions, and recommendations that have emerged are here summarized:

(i) construction companies are advised not to establish permanent innovation departments or research laboratories within their own organisations. Innovation programmes should be instituted only when specific ideas, inventions or proposals arise, and companies should make use of specialist consultants and reputable laboratories rather than try to execute the whole programme in-house.

(ii) each project needs to be headed by a "product champion" who should have a personal interest in the realisation of the project.

(iii) companies intending to embark on innovation programmes should budget for at least R100 000 per year, at 1984 rates.

(iv) the organisation or company financing the programme must insist on regular technical and financial appraisals, and should appoint a senior officer as overall watch-dog to the project.

(v) the initial invention and laboratory-testing phases are inexpensive and the costs incurred should generally be able to be carried by company overheads. The implementation stage would increase costs about tenfold, and the innovative company might well be advised to take in a strong financial partner once this stage has been reached.

(vi) by necessity and tradition, both the civil engineering and mining industries are conservative and not inclined to modify existing techniques lightly. Tactful negotiation is a pre-requisite, and in both industries it is wiser to deal initially at the technical rather than managerial level.

(vii) the role of invention and innovation is not well understood by the general public, or by economists, or even by most practising engineers. It is incumbent on the scientific and engineering community to rectify this gap in public awareness.

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



LEON [illegible]ISON

30th day of January, 1985

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PREFACE

This dissertation sets down the record of a long series of attempts, not all of them successful, to introduce new materials and systems into the civil engineering and mining industries. The author has been associated with the various attempts from their inception and was initially obliged to work from first principles, having had no experience in the management of this particular field of activity. Over the years, and with each successive project, a systematic approach emerged. The author hopes that the conclusions reached and the recommendations made in the dissertation will prove of use in the future to aspirant innovators in the industry.

In the course of the programme, contact was made with numerous individuals and organisations connected with civil engineering and mining; in South Africa, Europe and the U.S.A. Particular appreciation is recorded to the following :

Professor G.E. Blight	:	University of the Witwatersrand, who supervised the research.
Mr. H. Vidal	:	Inventor of Reinforced Earth
Mr. A.C.S. Smith	:	Managing Director of Reinforced Earth (Pty) Ltd.
Mr. C. Digue	:	Formerly Senior Engineer of Entreprise Jean Lefebvre, Paris
Mr. R.C. More O'Ferrall	:	Group Rock Mechanics Engineer, Gencor Ltd.

LIST OF APPENDIXES (Separately bound)

No.	Description
1	EJL tests on pfa 3rd December, 1974 and 6th March, 1975
2	Digue report to Johannesburg City Council, 3rd February, 1976
3	Blight on pfa - Paris Conference, 12th December, 1978
4	Dourdan laboratory report on pfa, 23rd February, 1981
5	Reinforced Earth brochure
6	EJL report on slag, 7th June, 1978
7	Digue report on S.A. slags, 19th June, 1978 and author's reports and translation
8	Digue report on S.A. slags, 4th October, 1978
9	Blight's proposals for laboratory programme on slags, October, 1978
10	Blight's report on Paris Conference, 13th December, 1978
11	Blight's report on slag investigations, 22nd January, 1979
12	Blight's report on slag investigations, November, 1979
13	PCI report on slags, 25th March, 1980
14	Blight report on trip to Paris 19th September, 1980
15	Blight report on trip to Paris July, 1981
16	Blight report on Sunswart slags, 6th June, 1980
17	Blight report on Samancor slags, 18th December, 1981
18	Blight report on Samancor slags, February, 1982
19	United States Patent No. 442087 Method of Mining
20	Paper and contributions to SAIMM, October, 1982
21	Paper to Symposium at Lulea, Sweden, June, 1983
22	Stress-strain curves, November, 1984.

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14	Blight report on trip to Paris 19th September, 1980
15	Blight report on trip to Paris July, 1981
16	Blight report on Dunkerk slags, 6th June, 1980
17	Blight report on Samancor slags, 10th December, 1981
18	Blight report on Samancor slags, February, 1982
19	United States Patent No. 442057 Method of Mining
20	Paper and contributions to SAIMM, October, 1982
21	Paper to symposium at Lulea, Sweden, June, 1983
22	Stress-strain curves, November, 1984.

MANAGEMENT OF INVENTION AND INNOVATION IN CIVIL ENGINEERING

1. INTRODUCTION

The rapid industrial expansion which has come about in South Africa over the past forty years has been accompanied by a similar expansion in its civil engineering industry. The rate of growth of this industry has been further accelerated by reason of a conscious decision on the part of most state public works authorities to make use of private enterprise in the design and execution of their works. Thus have arisen companies of consulting engineers and contractors, capable of realizing the large and complex projects which have had to be brought into being in order to meet the demands of the country's infrastructure.

The contracting sector of the industry presently comprises hundreds of companies, the largest of which handle annual turnovers of several hundred million rand. At the time of writing (1984) the contracting industry's total annual turnover is in the order of R2 000 million.

Despite this overall growth pattern, and the country's constant demand for new infrastructure, contracting companies have found that they too are subject to the vagaries of the business cycle. When the state decides, as at the present time, to restrict its capital expenditure, the construction industry becomes an easy and obvious target.

From time to time contracting companies therefore find themselves faced with a shortage of work and a surplus of men and machines; and for this reason several companies have taken the step of diversifying to some extent into activities removed from direct construction-by-contract.

In order to accomplish such diversification, two major strategies have been used :

(i) investment in industries totally divorced from construction and civil engineering;

(ii) extension of investment and activities within the construction field itself, so as not to move too far from the company's field of experience and expertise.

It is common for those who adopt the latter strategy to enter the field of construction materials, because, in civil engineering, it is probably less hazardous to be a supplier than a contractor. Companies have therefore diversified into activities such as quarrying, aggregate supply generally, steel fabrication, manufacture of precast concrete products, and even brickmaking.

This dissertation has originated from just such a diversification effort into materials supply, in this case an attempt to produce alternative construction materials from mining and industrial wastes. The diversification programme started in 1976, but has since strayed a long way from its original objectives. It has moved from what at first appeared to be a straightforward effort in materials supply into the fields of invention, innovation and technology transfer. It has also, in one instance, moved out of civil engineering itself into a new field concerned with support systems in underground mining.

In the course of pursuing the various projects which have formed part of this programme, it became apparent that management of the programme left room for considerable improvement, and that the education, training, and experience of those directing the projects had not equipped

them for dealing with innovation in its various aspects. It further became clear that no set of rules or criteria was readily available which could have guided the aspirant technical innovators in their specific field.

The dissertation therefore addresses itself to the problem of management of technical innovation within the civil engineering industry. Its objective is to set down guidelines which would enable aspirant innovators

(i) to follow logical procedures in appraisal and management of their projects, and

(ii) to utilize available physical and intellectual resources effectively and economically.

Essentially the problem will be tackled from the viewpoint of a civil engineering contracting company which has reached a size capable of allowing it to contemplate diversification or innovation. The guidelines are specifically not directed to organisations which might already possess substantial R & D establishments ; but in civil engineering such establishments are rare, even in the largest of companies. The guidelines might also apply, with variations, to consulting and supply firms within the industry, and perhaps even to public authorities.

The method of tackling the problem will be to describe the various projects which have been undertaken, to analyse and appraise critically each project in turn, and, finally, to co-ordinate the varying conclusions and recommendations into a set of guidelines. Over the years, some measure of skill has developed in dealing with the innovation process itself, and what is more, contacts have been established with a spectrum

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of organisations involved in the innovation process: with research organisations run by government and industry, with Universities, with patent attorneys, and with potential investors in new technology. All this experience will be brought into account in producing the final guidelines.

In addition to the field work, a study has been made of some of the available (and considerable) body of literature dealing with management of industrial R & D. Although most of this literature is related to the problems of very large research institutions, an attempt has been made to relate it to the somewhat different and smaller-scale projects which form the subject of this dissertation.

The books and papers comprising the literature survey are set down in the Reference List.

2. TERMINOLOGY

Most technological activities develop their own special vocabularies, or special meanings for commonplace words and phrases, and the field of innovation is no exception. Magasere and Chant, for example, set down definitions of seventeen different roles which individuals could play in the innovation process; ranging from "scientist", "discoverer", and "inventor" on the one hand to "marketer", "manufacturer", "purchasing agent" and "user" on the other. This extensive list might have application in the sort of operation that is carried out in large R & D organisations, but for the purposes of this dissertation the terms "innovation" and "research and development" will be used interchangeably and given their commonly-accepted dictionary meanings.

Worthy of note, however, are some definitions attributable to Joseph Schumpeter, a renowned economist, who attached great importance to the role of innovation in the promotion of economic progress. Sir Ieuan Maddock[7] explains how Schumpeter divided the process of innovation into three phases :

(a) Invention, which occurs when the feasibility of a new product or production process is postulated or established.

(b) Innovation, which occurs when, for the first time, an organisation sells a new or better product or uses a new or better production process with demonstrable success.

(c) Diffusion, which is the process whereby a new or better product or production process is adopted by an ever-increasing number of organisations on a national or global scale.

This dissertation will deal mainly with the first two phases. It is necessary, however, to add two further definitions : those of "product champion" and "transfer of technology".

Kingston[3] defines the product champion as the controlling innovator who holds together both the idea and the ultimate embodiment. In more detail, Mogavero and Shane[4] define him as a "never-say-die person who perceives a societal need, takes the invention in hand, and keeps the project alive and going : the champion may turn out one or more entrepreneurs as he or she tries to push the product to full success." They go on to say that the champion might be the inventor, or the entrepreneur, but that without him most projects would probably peter out before evaluations could be made of their probable value. The champion keeps the project together and provides the energy to keep it moving towards its ultimate goal.

Technology transfer is defined by Mogavero and Shane[5] as the "use of knowledge". They point out that transfer in this sense does not mean movement or delivery, and that there is no transfer of technology unless, or until, the technical knowledge has been used. Even if the use does not come up to expectations technology transfer has still occurred.

1. LITERATURE SURVEY

The history of these innovative efforts, which will be recorded in chronological and anecdotal form, bears out the absence of system in the approach used and gives rise to the thought that a preliminary study of the history and methodology of R & D and innovation might have saved time and expense. As it happens, the study was carried out only in the very late stages of the programme.

On the other hand, the literature study has revealed that writings devoted to the management of R & D generally refer to activities in large research organisations, financed either by government or by large corporations. It is probable only by discovering wrinkles through a few attempts at innovation that the literature can be successfully interpreted and applied to real cases.

The study shows that the bulk of R & D carried out in the world's industrialised countries relates to the manufacturing industries, more especially, the chemical, electrical and electronic industries. It is true that research plays an important part in both construction and mining, but literature on management of innovation in these two industries appears to be sparse. The potential innovator in this field, even if he had tried, would have found few publications to guide him in his initial efforts.

Nevertheless, some background to the philosophy underlying invention and innovation, of the history of innovative efforts in other industries, and of the setbacks and triumphs of some of the pioneer innovators, could at least have made those concerned with the programme

realise that their path had been trodden before and that the process of innovation would probably be long and hard. For this reason some of the main points gained from the literature survey are here set down :

Economics

A line of thought running through the literature is that classical economics has generally paid too little attention to the influence of innovation on economic growth and welfare. Kingston[3] states that even Keynes was at fault in that "his thought assumed throughout a technology which is essentially static, and is correspondingly less relevant to the modern world." The economist who is held in most regard is Schumpeter, and Kingston[3] says "it is tempting to think that Schumpeter gave pride of place to innovation in his economics because of his own Austro-German culture, which left him aware of how much more widespread creativity is in German life than is often thought."

Most writers however find it difficult to place an exact value on economic benefits derived from innovation. A successful innovation will obviously benefit the inventor and the particular firm introducing the innovation, but it is difficult to compute benefits to the economy as a whole. Nevertheless, some interesting statistics and statements come to light :

- More than 62% examples of National Aeronautics and Space Administration (NASA) technology have been put to practical use by public and private organisations. In four selected areas (integrated circuits, gas turbines, cryogenic insulation and computer programmes) the economic benefits are in excess of 7 billion dollars.

- A study carried out in the U.S.A. for a variety of industries, including primary metals, machine tools, industrial controls, construction, drilling, electronics, and chemicals, showed that the median social rate of return from investment in innovations in these industries was 56% and the median private rate of return 25%.

- "The initial work in the laboratory or experimental workshop which leads to invention might be small, but if a certain body of effort is needed for R & D leading to the initial invention, a further effort of at least twice as large is needed to take the product through the phases of engineering and product design. Furthermore thereafter there is a sevenfold increase of effort which must be added to the cost of start up in order to carry out the necessary tooling and perfect the manufacturing technology. This means that after the R & D phase there is at least a tenfold increase in cost and effort before the product can reach the marketplace in any credible form." (Maddock[7].

- There is no unanimity on the size of company best suited to innovation Kingston writes :

"Although many writers stress the important role played by individual inventors and smaller companies, there is no doubt that all participants in the process, whether individuals, small companies, large companies, or government research organisations, have their own particular role to play in the process. Schumpeter appeared to favour the small firm and there is no doubt that many major innovations were adopted by small firms when their larger contemporaries were not prepared to assume the risks involved. A classic example in recent times is that of steel-making in an oxygen furnace which was invented

and innovated in a small industrial firm in 1940, introduced into the U.S.A. by a small steel company in 1964 but not taken up by the giants for a further 10 years."

Nevertheless, projects beyond a certain size cannot be handled by the smaller organisations when, at the appropriate time, they require new financial and management skills to deal with the problems of rapid growth and a large organisation.

- The time at which an invention or innovation is developed bears a tremendous relationship to its economic applicability. "Once an idea has clicked in the mind of an inventor, there is still a long way to go before it becomes a successful innovation. Rayon was invented 200 years before it was innovated : a computer at least a century before and aeroplanes even earlier." (Freeman)[1].

- Finally, Kingston[3] quotes the following from Schumpeter : "An idea or scientific principle is not, by itself, of any importance for economic practice; the fact that Greek science had probably produced all that is necessary in order to construct the steam engine did not help the Greeks or Romans to build a steam engine; the fact that Leibnitz suggested the idea of the Suez Canal exerted no influence whatever on economic history for 200 years."

Protection of Innovation : Patents and Monopoly

In order to protect a new idea which might have commercial value from imitation and exploitation by others, an inventor or innovator will try to protect himself by obtaining a government grant of exclusive privilege of making or selling the new invention;

i.e. he obtains a patent. This patent gives what amounts to a temporary monopoly, so that within a given period of time he is free from competition by imitators.

Kingston[3] states, however, that the age of the individual inventor has passed its heyday. He divides the industrial revolution into three distinct stages or three distinct revolutions. "In the first of these, the characteristically important events, such as the building of the canals, Watt's steam engine and Stephenson's railway locomotive came about on a basis of scientific knowledge that was so slender as to be virtually zero. The keynotes of this first industrial revolution were empiricism and ingenuity, not knowledge. In the second revolution, applied sciences and a more analytical approach are increasingly the characteristics of innovatory activity, from roughly the mid-nineteenth century to the First World War. A significant example of the change in approach is Stephenson's rail bridge across the Menai Straits which was preceded by a comprehensive programme of deliberate testing to destruction of samples of the material and models of the design which Stephenson had in mind. This approach also was adopted in the development of chemical industries and electrical power. Ingenuity however, still played an important part. The characteristic of the third revolution is that science, absent in the first and on a basis of rough equality in the second, moved into the dominant role. This can also be called the age of organised inventing, when both government and private companies began investing in research and development."

According to Kingston[3] each of the three revolutions had its own particular pattern of innovation. In the first, practical capability

was the keynote and invention and innovation generally the works of the same person. In the second, the characteristic vehicle of innovation was a newly founded firm. In the third stage the typical innovating unit is not a new firm but an established one, very probably operating internationally. The third phase also saw an enormous growth in the field of marketing.

He goes on to say that in this third stage of innovation, patents are less likely to protect an inventor than know-how and marketing monopoly and that the golden age of patents has passed. Correct or not, most inventors will still look to the patent system to provide them with protection, however temporary or tenuous, and it is significant that the very large organisations file patents almost on a daily basis. For the individual inventor and the smaller company, there appears to be no other way than the patent system of preventing large organisations from taking over new ideas without having to pay a price for them.

Personal and Psychological Factors in Innovation

Most of the work studied in this survey make great play of the personal factor in promotion of invention and innovation, and they all point to the importance of the role of the product champion. More often than not the champion might have a vested interest in the success of the venture, but this does not detract from the importance of his role. Schumpeter made the same point by stating that successful innovation was a matter not of intellect but of will or leadership.

The literature also makes a point of what is called the RC factor or Resistance to Change. Some writers call the same phenomenon the NIH

syndrome : "not invented here". Potential innovators have to steel themselves against those who tend to decry anything new, and this again stresses the importance of the role of a strong product champion.

Great inventors themselves have not been immune from the NIH syndrome. Henry Ford rejected the self-starter, Thomas Edison saw no future in alternating current, and Parsons, who invented the steam turbine, thought that the gas turbine was intrinsically impossible. The potential innovator will have to learn, sooner or later, that he is going to strike opposition; not only from those who resist change because of inertia, but from others, with reputation and experience in innovation, whose opposition might be based on subjective grounds.

Some writers are prejudiced against large research organisations and decry their value, probably because of personal experience. Kingston[2] quotes Fessenden, Edison's secretary and an inventor in his own right, who said that "there is less prospect of obtaining development in a given field from organisations engaged in that field than from any other conceivable source. No organisation engaged in any specific field of work ever invents any important development in that field; or adopts any important development in that field until forced by outside competition." This view appears somewhat prejudiced, but even within the experience which will be set down in this dissertation, some justification for it can be found.

On the other hand, it is important not to take the attitude that the inventor is always right and generally persecuted by potential rivals who might resent his achievements or potential success. Freeman[1]

points out that it is necessary to guard against "optimistic bias" and that the "social content of project estimation is a process of political advocacy and clash of interest groups rather than a sober assessment of measureable probabilities." Enthusiasm in pushing through an innovation is essential but it requires to be controlled.

A possible obstacle to innovation can also lie in the clash of scientific and financial personalities, stemming from the circumstance that innovators frequently have to convince financial institutions of some sort or other to back their ideas. Very few financial organisations, devoted specifically to the promotion of innovation, have proved successful, and much of this failure might be attributable to lack of understanding between inventor and businessman. Kingston goes so far as to say that apart from "The Two Cultures" described by C.P. Snow, in which people educated in science have no intellectual common ground with those educated in the humanities, there is a third culture, which is also insulated from the other two. This is the modern business culture which has its own value systems and structures and which creates a perennial lack of mutual comprehension between scientists and engineers on the one hand and accountants and bankers on the other. He sees the two coming together only when there is a common interest in the creative process.

The literature study shows how useful it would be for the potential inventor or innovator to have some background to the difficulties experienced by his forerunners, and that he must expect criticism, lack of sympathy and outright rejection. To keep a project going requires belief in the innovation, doggedness, and in fact a mild measure of fanaticism.

4. RECORD OF PROJECTS UNDERTAKEN

4.1 BACKGROUND

The attempts at innovation to be discussed in this record were originally directed towards developing and promoting the use of alternative materials of construction, essentially those derived from waste materials such as pulverised fuel ash (pfa), metallurgical slags, and mine tailings, but also included is the introduction of a new patented material known as "reinforced earth".

In the period 1970 - 1980 a French construction company, Entreprise Jean Lefebvre (EJL), was conducting business as a contractor in South Africa, in a joint venture with a local partner, under the name of Reef Lefebvre (RL). Early in this association EJL France suggested to RL that it should look into the properties of certain types of mining and industrial wastes, with a view to their commercial exploitation as construction materials.

In France and overseas, EJL's main activity lay in construction of roads and airports; and it had developed a particular expertise in the field of construction materials. Moreover, EJL had proved itself as an innovator, particularly in promoting the use of industrial wastes. In this connexion, it is important to bear in mind that the French construction system (unlike that in S.A.), encourages innovations and alternative designs by contractors.

Although EJL was aware of the restricted scope in S.A. for proposing alternatives, it recommended that the possibilities and potential should at least be investigated as a diversification exercise, starting with the use of wastes in road construction. The waste materials which EJL had helped turn to use in France included pfa (derived from coal-burning power stations) and various types of slag, produced in the processing of iron and steel; and the same, or similar, types of waste were being produced in appreciable quantities in South Africa. The South African company (AL), although unfamiliar with this approach or type of activity, agreed to pursue the required investigations, and to be guided in this endeavour by EJL engineers and consultants.

Regretfully, for reasons that will be advanced later in this dissertation, the hoped-for successful transfer of technology did not materialise, but despite these initial disappointments in the investigations into pfa and slag, the South African company itself started to become interested in innovation. This eventually led to :

(i) the introduction into South Africa of a new material, known as REINFORCED EARTH;

(ii) investigations into the potential of manganese slags; and

(iii) a research and development project on the use of reinforced waste materials as mine supports.

(The last-named project was eventually not sponsored by EJL or its associates, but came as a direct follow-up of the original attempts sponsored by EJL).

4.2 NOTE ON WASTE MATERIALS

As part of the necessity to conserve and replenish natural resources, the industrialised world is looking more and more closely into the possible use or recycling of the enormous quantities of wastes which are produced by manufacturing and mining activities. The countries of Western Europe, as could be expected, have taken the lead in research and development in this field. In civil engineering, the research effort into waste materials has largely been directed towards finding substitutes for concrete or bituminous aggregates, and replacements, or partial replacements for cement and lime. Materials which have received a great deal of attention are the various types of ash produced in coal-burning power stations and slags produced in the reduction and refining of iron and steel.

By the early 1970's, France, for example, was already using about 3 million tons of pfa annually, in both road construction and the production of cement and concrete. Originally French engineers had seen pfa merely as a substitute for bulk fill in areas where natural materials were at a premium; but as use of the material intensified its applications became more sophisticated. It was learnt, for example, that pfa possessed pozzolanic properties and in the course of time therefore pfa won its spurs as a stabilising agent in conjunction with lime and cement. Furthermore, pfa became increasingly used as a basic feed stock in the cement manufacturing process and in the production of concrete. The use of pfa has spread to most countries in Europe and also to the U.S.A., and its value as a construction material in those countries is now undisputed.

The potential of iron and steel slags is better known, and these materials have been commercially exploited in most countries, including South Africa, for many years. In their air-cooled form, blast-furnace and steel slags are similar in their properties to certain types of igneous rocks and used as aggregates in concrete and bituminous mixes; with some restrictions placed on them, because of their chemical make-up, for particular types of construction. In its granulated form, blast furnace slag is classed as a latent hydraulic cement and is therefore a valuable product. In South Africa, the milled product is used on a large scale as a partial replacement for ordinary portland cement (opc), while the tendency in Europe goes more towards using it as a feedstock in the cement manufacturing process.

Coming to the field of mining wastes, and to South Africa's gold-mining areas in particular, the bringing to surface and refining of mineral ores creates vast quantities of tailings. On the Witwatersrand, the construction industry has always utilised waste mine rock as concrete aggregate, railway ballast and roadstone; but the sands and slimes produced in the reduction and refining of gold have barely been exploited until very recently. More attention has now been focused on these wastes; firstly, by re-refining them to extract gold, sulphur and other products; and, secondly, by returning them underground for support, in order to boost safety and production. With the exception of extraction of valuable metals and minerals, the commercial application of mine wastes is not yet pursued with general enthusiasm in South Africa at the present time.

INVESTIGATIONS INTO PULVERIZED FUEL ASH (pfa) 1972 - 1984

Historical Record

November, 1972 - August, 1973

In November, 1972, Albert [illegible], a Provincial Director of Works in the service of the French Government, paid a visit to South Africa at the request of EJL to look into the prospects of further investment in the South African road building industry.

[illegible]'s report to EJL recommended, amongst others, an investigation into the potential of waste materials, notably pfa and slag. This report evoked little initial reaction either from RL or EJL, and interest was only aroused about two years later when EJL invited the writer, then a director of RL, to inspect pfa applications at first hand in France.

The sites visited were all in the industrial areas of Northern France, and it was learnt that two major factors had promoted the cause of pfa in that region :

(i) natural road-building materials were not readily available, and expropriation of new land for quarries and borrow-pits would have been difficult and costly.

(ii) the area contained within it numerous coal-burning power stations, and consequently numerous ash dumps, which could possibly provide a source of aggregate.

EJL had shown considerable insight in appreciating that pfa produced at power stations could in some way meet the demand for road materials. It had studied the potential of the material and had then set about obtaining sole rights on suitable dumps. It then established mixing plants at strategic locations, generally for the production of stabilized subbase- and base-courses.

A few notable features of EJL's operations are here set down :-

- all mixing was carried out at well-equipped and electronically controlled central plants (as distinct from in-situ mixing in South African stabilization practice);

- proportions of pfa used in the mixes varied according to requirements; as low as 5 - 10% when used as a stabilizer, up to 80% when used as a substitute aggregate;

- all pfa was obtained straight from dumps, some of these many years old and with moisture contents in the order of 10%. No effort was made to extract dry pfa directly from precipitators in the power stations.

- both lime and cement were used as activators, depending on specific requirements - gypsum was used occasionally;

- a pfa dump at a power station near Petit-Theran deserves mention. Material from this dump had been extensively used, not only for works in its immediate vicinity, but also for construction of roads and parking areas at the new Paris market at Rengis, about one hundred kilometres distant.

Half a million tons in all had been supplied to Rengin, the material having been transported to the site by barge. A further half-million tons had been used for local works, thus giving a total usage of 1 million tons from one dump, all handled by EJL.

August, 1974 - Mid 1975

As a result of this visit, RL in South Africa was encouraged to conduct investigations into pfa with a greater sense of purpose. At that time, Escom was producing about 8 million tons of pfa annually and it was clear that this quantity was going to be greatly increased by Escom's projected expansion programme. Preliminary analysis of Escom's pfa from different power stations had not shown significant differences from French pfa, chemically or physically, and the prospects of exploitation appeared to be favourable. Furthermore, ash produced at Sasol I had also been reported of good quality, and so it was decided to embark on a programme which would test pfa from both Sasol I and Escom. It was further decided that the tests would be conducted at EJL's laboratories in France.

In the course of RL's talks with Escom, it was discovered that another South African company had already made approaches to Escom in the matter of pfa and had obtained certain optional rights on the material. These rights apparently applied to dry pfa, extracted from the precipitators, and not the wet dump ash. Further, the company concerned appeared to be specifically interested in the potential of pfa in concrete technology and not in its use as a road stabiliser; and there appeared to be no corflict of interest, as long as RL confined itself

to trying to exploit dump ash. RL hardly considered this as a drawback, having seen the work in Northern France where dump ash had been used exclusively.

The test results conducted at EJL's Orlwans laboratory in late 1974/ early 1975 proved to be a disappointment, in that South African pfa was found to be much less reactive than its French counterpart. This was the first indication to RL that the application of pfa to roadworks in South Africa was not quite as simple a matter as had been expected. The results of the first tests are given in Appendix 1.

A problem that now emerged, assuming pfa in South Africa to be only slightly reactive, was that pfa could not be used as a stabilizer in small proportions [3 - 6%] similarly to cpc and lime. The cost of transporting large quantities of pfa for long distances would rule out its use in South Africa, where natural gravels suitable for road building were generally readily available.

This led to the realisation that, if pfa were to be exploited economically its parent power station would have to be reasonably close to construction sites. In a sense this ruled out many of the power stations in the Eastern Transvaal, where pfa itself was plentiful but the road building demand, outside of special development projects, would be fluctuating and small in relation to the quantity of pfa available.

Consequently RL started looking into the characteristics of pfa produced at power stations in the immediate Johannesburg area, on the assumption that a constant market for pfa-stabilised mixes could possibly be found in the annual road and street construction programmes of Johannesburg and other large municipalities on the Reef. This line

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A problem that now emerged, assuming pfa in South Africa to be only slightly reactive, was that pfa would not be used as a stabilizer in small proportions (1 - 5%) similar to cement and lime. The cost of transporting large quantities of pfa for long distances would rule out its use in South Africa, where natural gravels suitable for road building were generally readily available.

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Consequently BL started looking into the characteristics of pfa produced at power stations in the immediate Johannesburg area, on the assumption that a constant market for pfa-stabilised mixes could possibly be found in the annual road and street construction programmes of Johannesburg and other large municipalities on the Reef. This line

of thought led eventually to discussions with the City Engineer's Department, Johannesburg (CED) and to agreement to a joint programme.

It was decided to concentrate the experiments on waste mine sand as an aggregate and using pfa from Kelvin B power station together with various standard activators or stabilising agents. Mine sand was chosen as the basic aggregate because crushed stone for road bases has become both expensive and scarce in the Johannesburg area. Tests were conducted at the Orlean laboratory of EJL, but with CED itself carrying out certain confirmatory and check tests in its own laboratory.

The results of this work are given in Appendix 2, together with recommendations and comments by Charles Digue, an EJL engineer who had helped develop EJL's programme in Northern France. Digue recommended building an experimental stretch of road, using sand-pfa-lime-gypsum mixes, and that RL itself should be prepared to help finance the design and construction of such a strip. A feature of this proposed programme was that Digue was prepared to recommend the use of pfa from Kelvin B power station (belonging to Johannesburg Municipality) the quality of which had been regarded as somewhat suspect prior to the above experiments.

Regrettably, the proposal to build an experimental strip of road fell foul of bureaucracy, on the part of both CED and RL, and the entire project lapsed. In any case, RL was becoming despondent, at that time, about the potential of pfa in South Africa, because researchers in other organisations and institutes were tending to confirm the viewpoint that, for some reason not yet determined, South African pfa was of

inferior pozzolanic quality and could not be expected to provide the benefits produced by pfa in Europe and North America. Moreover, at that time RL itself was becoming interested in other diversifications and felt no great disappointment in the project being temporarily suspended.

During the period of testing, RL had established contact with the National Institute of Transport and Road Research (NITRR) of CSIR to inform the Institute of the programme and to find out the chances of co-operation with that body. The Institute's response to RL's enquiries was not actively supportive, its attitude being that pfa technology was well known and it was up to private companies to develop possible applications which NITRR would monitor. It was several years later before NITRR, and later generally, began to take a more serious and active interest in pfa.

RL therefore discontinued its active experimentation into pfa, but decided to maintain its interest by keeping in touch with research being carried out by other organisations and institutions.

Mid 1978 - present date

In November 1978, some 2 years after the joint experiments with the Johannesburg City Engineer's Department, the writer and Professor G.E. Blight, acting as consultant, attended an international conference in Paris on the use of by-products and wastes in civil engineering. The conference had been organised jointly by French road and road research authorities. Blight's report on the pfa aspect is contained in Appendix 3, and indicates that the contributions

to the conference had shown no developments which might encourage RL to revive R & D work on pfa. The state-of-the-art appeared to be very much as RL had left it in 1976.

A further conference, or symposium, on the utilisation of pfa in all its aspects was held in June 1979, this time at CSIR in Pretoria. Several contributions were received from Europe and US.A. based on both laboratory work and field experience.

In regard to near construction, the papers from Gerenberg, of the University of Illinois, and Digue of EJL, confirmed the pozzolanic properties of pfa as a stabilising agent in their respective countries. This contrasted with the contributions from South Africa, which generally painted a gentle picture. The reasons for the difference in performance were not fully analysed or discussed, but again RL felt that its decision to abandon its own R & D effort had been justified.

The matter of pfa was brought up again about a year later at a meeting in Paris, where RL and EJL were discussing their previous joint efforts at diversification and the disappointing results obtained with South African pfa. EJL representatives at the meeting felt that it would probably be worthwhile to take one further look at the potential of South African pfa, but to carry out the experiments this time at thier main laboratory at Dourdan, instead of the regional laboratory at Orleans. The Dourdan laboratory was not only better equipped, but also under supervision of research workers of great experience, who had played, and were still playing an important role in EJL's materials programme.

[illegible] carried out at Dourdan are shown in Appendix [illegible] and can be summarised as follows

(i) [illegible] was reactive when French pfa;

(ii) [illegible]vity of South African pfa is improved by the addition of gypsum;

(iii) South African pfa reacted better with French lime than with the South African lime supplied to Dourdan, the performance of French lime + French pfa being about equal to French lime + South African pfa + French gypsum

At about the same time the Dourdan laboratory gave details to RL of a new type of stabilising agent it was promoting and marketing in France. Known as LH30, this was a mixture of pfa, quicklime and gypsum blended together in such proportions as to produce a stabilising agent which would compete with either opc or lime. This appeared to be an attractive idea and RL agreed to look into South African prospects.

Shortly after completion of the above tests at Dourdan, EJL decided to withdraw its investment in South Africa, and RL itself became inoperative. The effort at promoting the use of pfa in road construction therefore came to an end as far as this particular group of companies was concerned

Since that date the Co-operative Scientific Programmes of CSIR has formed a steering committee to look into all possible uses of pfa and to promote research in the sphere at appropriate institutions. In road construction, the research effort is being carried out by NITRR, which is looking into all work done to date on pfa and trying to pinpoint the reason for the relatively poor performance of South

African pfa

Outside of this particular programme there appears to be very little work being done in South Africa at the present time on the potential of pfa for roadworks and construction generally

DISCUSSION AND CONCLUSIONS ON pfa PROGRAMME

The rate of progress on this project for the period 1972 - 1984 is hardly impressive. The effort was sporadic, lacked direction and purpose. As a result no definite conclusions could be reached about the acceptability or otherwise of the material.

Nevertheless, the project brought to light several interesting features, which could be typical of the efforts of other companies indulging themselves in R & D without benefit of background or experience, and as such be of some potential significance for future attempts by others. Some of these features are here set down :

Lack of urgency.

The investigation did not start because of an urgent need in South Africa for better stabilisation materials or road aggregates, but simply because of a suggestion made by a parent company to its subsidiary. No special priority was allocated to the project, and no funds set aside for it. In fact those individuals who did get involved regarded the time spent as something of a break and as a sideline to their normal activities.

The investigations into pfa were not allowed to interfere with the main business of the company, and it is small wonder that progress was slow and sketchy.

Lack of Experience in R.U.D.

Although RL carried a high complement of qualified engineers, not one of them had had any experience in research, or the problems of applying the results of research to practice. This accounted for several major mistakes in the policy of experimentation that was adopted.

In the first place, the major portion of the testing was allowed to be carried out in France. RL should have known that South Africa has numerous well-equipped laboratories, in all respects capable of carrying out the tests required, and manned by experienced staff who could easily have adapted themselves to any new techniques required by RUC in France. The decision to carry out the tests in RUC laboratories created not only unnecessary delays in the sending of large samples of material by air to France, but also prevented direct contact, except for occasional visits, between laboratory personnel in France and operational personnel in South Africa. The sheer physical remoteness dispelled any sense of urgency or reality on either side.

Secondly, RL should not have embarked on the project without recruiting to the project a South African research consultant. To have imagined that French expertise alone could handle the problem is an indication of the wide gap that existed, and probably still exists, between practitioners and research workers in the civil engineering industry in this country.

Finally, as experienced contractors, RL should have known better than to embark on an investigation of this nature without allocating to it some form of budget. The fixing of a budget creates the

obligation of accountability which in turn creates a sense of responsibility in those involved in the activity.

Difficulties of exploitation of the material

In defence of the apparently half-hearted effort put into the pfa investigation, one has to bear in mind the difficulties of commercially exploiting the use of pfa. Essentially the material has fulfilled the promise expected of it. The bulk of pfa in South Africa is produced by Escom, and discussions with that body proved that the obtaining of rights to the material, even at nominal pfa, would be a difficult process. RL's mistake was that it did not try harder to enter into a provisional partnership with Escom for joint exploitation of the material.

Looking back, it seems as if RL refrained from making a direct approach to Escom because it felt that Escom might already have had an agreement (or better access), also attempting to develop the use of pfa, but as a cement additive or replacement. Incorrectly, RL carried negotiations with the latter company no further than one initial meeting. RL should have laid its cards on the table, especially because its interest at the time was in dump ash where there would have been little conflict of interest. In any case, there would have been considerable merit in the two companies pooling their financial and technical resources in order to promote the idea of using pfa in all its possible ramifications.

RL did look into the possibility of protecting its research by making applications for patents. Consultations with patent attorneys on this issue revealed that applications for patents were only possible in the event of RL developing a specific blend of materials which would produce an adequate stablising agent, i.e. patent protection might possibly have been obtained for a composite material such as LH38, mentioned above.

There would have been little possibility of protecting the general idea of using pfa as a stabilising agent in road construction, because the principles and processes of that operation were not only well known, but also very well covered in the literature. The chances of permanent commercial application were therefore not great.

Natural road building materials

A prime reason for the original popularity of pfa in Europe was because of the scarcity of natural materials of construction. It had already been pointed out that pfa's use as a stabilising agent came only after it was first used as a fine aggregate. In Europe, high population densities, intensive farming, and past exploitation of sources of stone had all contributed to the scarcity. Although a similar situation is predicted for certain areas in the not-so-distant future, South Africa is still far from a crisis point in the state of its resources of natural materials of construction. The pressure to use waste materials or substitute materials is not great, unless some tangible economic advantage is likely to be gained. Research in this field was therefore not regarded as urgent and RL's efforts evoked only mild interest amongst road-building authorities.

Transport costs

Quite early in its investigations RL realised that the cost of transport of material would play an important role in assessing the feasibility of pfa as a construction material. Hence RL's switch to Kelvin B pfa, produced close to Johannesburg and close to its possible point of use. When the CED Johannesburg proved reluctant to carry the joint research further, RL discontinued

its active efforts into the use of the material.

Pfa produced in the Eastern Transvaal power stations was superior to that produced at Kelvin P, but could only have been exploited on a national scale if it were found to be of high quality and therefore usable in small quantities. In such event, transport costs in relation to the total cost of road building would not have played too important a role. The disappointing results of early tests justified RL's caution in this respect.

Lack of communication and enthusiasm within the group

Engineers and senior managers of construction companies are generally so intensely occupied with the complexities and day-to-day crises of the direct job in hand, that they have little time or interest to devote to ideas which bring small promise of immediate yield to their contracts or to their companies. This attitude is understandable and as later records will show, is repeated in other activities and industries.

In the Lefebvre group in France and South Africa, the original enthusiasts for pfa were Messrs. Albert Paré and Jean Lefebvre himself. Paré's report on his visit to South Africa, and his strong recommendations for investigations to be initiated immediately, fell on deaf ears both in France and in South Africa. On checking back, one finds that not one of the directors of RL in South Africa, including the then-resident French director, ever studied Paré's report in any detail; and, what is more, the same applied to engineers and managers in the head office in Paris. Nothing was done

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For two years until the writer's visit to France in August, 1974, which took place at the invitation of the Paris office, and which in turn had been activated by Jean Lefèvre himself. The absence of action and lack of communication lay really in the different outlooks of those who advocated innovation and those who were supposed to carry it out. The project really needed a champion of the order of René or Jean Lefèvre himself.

A further indication of operational staff's lack of interest in innovation can be seen in the fact that EJL head office allowed the original experimentation to be carried out in a provincial laboratory and not by their highly equipped principal laboratory at Bourdan. The more skilled and experienced researchers at Bourdan only came into the picture six years after the start of the project.

Costs

This investigation did not give a clear indication of the cost of the R & D effort, because so much was undertaken in EJL laboratories in France without charge to RL in South Africa. The project did show however, that an investigation of this nature could be carried out without a company having to invest in laboratories, laboratory equipment or laboratory personnel. Judicious use of outside laboratories, guided by expert opinion, would have been adequate for the purpose.

Considering the savings that it effected in having virtually no laboratory expenses, RL made a serious mistake in its joint venture with CED, Johannesburg. After having seen the reasonably favourable

result[illegible] of th[illegible] joint experimentation, RL should have sponsored the construction [illegible] kilometres, and jointly monitored its performance with the CSIR. This construction would have been done without any financial aid from CSIR. Such success would have produced a favourable reaction throughout the field of road and street construction in the Witwatersrand area.

Resistance to change

Quite early on in its efforts, RL discovered that it would not be easy to change existing procedures and specifications in the road-building industry. This factor crops up again in later investigations and will therefore be discussed after considering the innovation problem in its totality.

4.0 Promotion of a new construction material : "Reinforced Earth"

Introduction

R's attempts at diversification started in 1974, and by 1975 the idea of developing new technologies as a means of company diversification was beginning to look attractive. At that time, a fair amount of publicity was being given to a new construction material, developed in France by a French engineer Henri Vidal, and known as "Terre Armée" or "Reinforced Earth". Reasons for the publicity were twofold; firstly, the uniqueness and ingenuity of the system, and secondly, a legal action in the U.K. in which Vidal was suing the Department of the Environment for infringement of his patents.

R became intrigued by the system, realizing that it had application in South Africa, and decided to pursue its investigations further. In this respect it was fortunate that the invention had been developed in France and contact could easily be established with the inventor through R's partner Ellis. The writer and one of his co-directors were then able to make a first contact with Vidal in Paris early in 1975.

As a result of this meeting, Vidal visited South Africa a few months later in order to see for himself whether he should initiate a Reinforced Earth company in S.A. R took advantage of his visit to arrange meetings and lectures in the major centres with organisations which might become users of the system, and also with groups of engineers comprising consultants, academics and

researchers. The reception to Vidal's campaign appeared to be positive and it was decided to form a company which would be jointly owned by Vidal's company in France (La Terre Armée) and RL.

By mid-1975 RL had started appointing staff and an engineer was sent to Paris to receive instruction in design procedures and the proposed manner of organising and operating the company. A few months later the writer attended an internal Reinforced Earth conference in Washington D.C. where progress and problems of the system were discussed and, more importantly he was able to see practically the various operations of design, procurement and construction.

Description of the material

At this stage it is necessary to give a broad outline of what the invention system of reinforced earth generally comprises. Its basic principle is to use the frictional association of granular soil and linear reinforcements to create a cohesive material which is highly resistive to lateral forces and loads. Its classic application is in the construction of retaining walls in mountainous terrain and some of its first structures are to be found along the highways of Cote D'Azur in the South of France. Applications of the material have since extended to retaining walls on urban freeways, bridge abutments, sea walls, loading ramps for industrial plants, and mineral storage facilities.

The basic elements of Reinforced Earth comprise an outer protective facing, reinforcing strips, and granular backfill. A brochure describing the system and its applications is enclosed as Appendix 5.

Modus Operandi

Vidal's method of exploiting the system commercially is apparently simple, but it is well thought out and known in the civil engineering industry as design-and-supply. The function of the company is to find suitable applications for Reinforced Earth, to design the relevant structures and then to quote for the supply of materials to the site, the price to include not only the cost of materials but also the cost of design and subsequent supervision of construction. This means that the Reinforced Earth company fall somewhere between a consultant and a contractor. It cannot operate as a consultant because it is promoting a specific commercial product; and it does not choose to operate as a contractor because it's work force would need to be in too many places at the same time. It is therefore more practical to allow the contractor on site to execute the work. The biggest advantage of this system is that a large volume of work can be handled by a relatively small skilled staff, which could be augmented fairly easily in busy times and which need not be drastically cut during comparatively quiet spells.

Record of company progress

The company was formed in 1975, its first full-time engineer-employee was sent to Paris in that year for training in La Terre Armée's headquarters, and the first contract was obtained early in 1976.

The Reinforced Earth concept appeared to attract users of construction facilities, both in the private and public sectors, and the company's

[illegible] critical objections. In the public [illegible] field most applications were found in road construction while in the mining sector the system found its maximum application in the construction of tip walls in process plants, crusher plants and the like. Small contracts were also obtained in Lesotho and Botswana and a major one in Malawi. In its eight years of operation the company has been responsible for close to 200 structures in Southern Africa.

The company suffered a major setback on one of its projects at a diamond mine in South West Africa. The backfill material used in this particular instance was known to be highly corrosive and the company, together with its client, decided to use a form of cathodic protection to eliminate corrosion. The anti-corrosion system failed and the walls had to be demolished.

This failure brought some the most serious objection to the Reinforced Earth system; doubt about its long-term service life. At the time of writing, in 1984, the first Reinforced Earth structures constructed in France are not yet thirty years old, and although tests show few signs of corrosion, conservative clients would prefer to see others take the risk on new technology before committing themselves to it. In the S.W.A. case, it is accepted that the Reinforced Earth company made a mistake in adopting cathodic protection and that the circumstances were unique; but it is not difficult to appreciate the reluctance of that particular client to use the system again, or of others, who hear about the failure to embark on a reinforced earth policy.

Reinforced Earth has not been able to construct major works for South African Transport Services for the sound technical reason that, in direct current electrified lines, stray currents are created which might cause corrosion in the reinforcing strips. The company has now intends undertaking a research programme, in consultation with CSIR, in order to try to determine finally whether it is safe to build Reinforced Earth structures under electrified lines, AC or DC.

Patents and Patent Applications

Vidal, at the start of his development programme, patented his system world-wide and he successfully applied for patents in South Africa. Reinforced Earth (Pty) Ltd. was granted a licence by Vidal to exploit his patents in South Africa and Vidal was granted permission by the Department of Commerce and Industry to levy a royalty charge on all work done in terms of this licence.

In other countries, particularly in the U.K., Vidal has had a fair amount of opposition to his patents and has on occasion been obliged to sue organisations which were alleged to have infringed his patents. Generally speaking, Vidal has successfully defended his patents, but alternative systems are already in use and these will probably increase in number as Vidal's original patents expire.

In South Africa the Reinforced Earth company has encountered no problems with competitive designs, possibly because the market at present is too small. Nevertheless engineers in the company are encouraged to search for new ideas and applications and to

In the long term, Reinforced Earth's patents will expire and others will be freely entitled to use the system. From a strictly commercial point of view, the original proponents of the system must already, at this stage, beware of resting on their laurels - must remain ahead of their competitors. After expiry of its patents, Reinforced Earth will have to depend on expertise and reputation, and not on legal protection.

Discussion and Conclusions

It is interesting to note the quick success and transfer of technology in the case of Reinforced Earth compared with the almost complete lack of progress in the effort to promote Sifa, especially when both efforts were put in by the same organisation and personnel. The following factors played a part :-

- Reinforced Earth was able to be introduced into South Africa without the need for any research into local applicability. Successful and safe structures could be built, as long as Vidal's criteria were observed.

- Reinforced Earth had been given respectability in that it had been accepted by road authorities of high esteem, by "Ponts et Chaussées" in France and the Federal Highways Administration (FHA) in the U.S.A. Much of

South Africa's highway design policy is based on U.S. practice and material utilization, therefore, was a statement by FHA that it accepted the system and no longer regarded it as experimental.

- Reinforced Earth offered a clear and definite alternative to the conventional structure it was designed to replace, thus enabling cost comparisons to be made quickly and accurately. It was not difficult for a potential user to come to a decision on whether or not to use the new material. Reinforced Earth submitted full design calculations with its offers, and these could easily be checked by the potential user's own design staff.

- Reinforced Earth offered not only cost advantages, but in many cases advantages in ease and speed of construction.

Promotion Policy

Taking its cue from the parent company, the South African company decided against a "hard sell" approach. The policy adopted was to convince potential clients that the method was technically sound and that design would conform to standard factors of safety. Reinforced Earth was not offered as a universal panacea, but as a specific material and technique which could solve certain problems.

It is believed that this approach was appreciated by the client bodies, especially in SATS, where Reinforced Earth has decided not to promote itself until research can conclusively prove its safety and durability.

Durability:

Without doubt Reinforced Earth's biggest present promotional problem is also all. fears about its service life, especially in South Africa where a major failure has occurred. No quick solution is at hand, but certain measures have been taken, which include :

- control and increased monitoring of structures;
- continued research into all aspects of non-atmospheric corrosion and the effects of stray currents;
- continuation of the present open approach of explaining to authorities about the durability problem;
- clear understanding at design stage about the client's durability requirements. (This applies in particular to industrial clients).

Research

Reinforced Earth was developed in France, and it is natural that up till now most of its research development effort has been concentrated in that country, with the various subsidiary companies playing very little part. France's research programme has included investigations into such

matters as corrosion, alternative reinforcement materials, improved friction factors, criteria for backfill materials, and new applications for the Reinforced Earth as terraced revetting.

Group policy is now changing, and countries outside France are being encouraged to carry out their own research to meet their particular problems.

In the case of the South African company, its policy is to concentrate its research into the problems of stray current corrosion on electrified railway lines, and into possible applications of the method in the mining industry.

Fear of innovation

It is not difficult to understand a cautious attitude towards innovation on the part of organisations or officials concerned with public works in the design of structures generally. The risks taken in adopting a new technique sometimes seem hardly worthwhile, especially, as in the case of Reinforced Earth, if the savings effected are not large in relation to the total costs of a public works budget. Nevertheless, the positive attitude taken towards Reinforced Earth by most South African participants in the structural design activity is commendable.

The Reinforced Earth Company, from its inception, has realised that it is essential to appreciate the reasons for cautious or hesitant attitudes, and not to condemn such

Attitudes traditionally unfavourable to change.

A senior design engineer, employed by a major governmental authority, explained his dilemma in simple terms : "In my position you don't fire people for mistakes, they just don't forget."

Lessons learnt

Although the introduction of this technique has generally proved a success, the past eight years of practice has taught a number of lessons :

- Inspection of construction

The Reinforced Earth technique usually provides an alternative to construction in reinforced concrete, and Reinforced Earth's performance is going to be measured against that of concrete. It is therefore essential to avoid failures, however slight, which might have been caused, not by inherent flaws in the design or theory, but by mistakes in construction such as inattention to line and level, mishandling of materials, omission of steel, inadequate compaction of fill.

Slipshod supervision is common to all forms of construction. Experience has shown however that failures in concrete construction are more generally attributable to mistakes

in actual design or construction than to inherent defects of the material. The theory and practice of reinforced concrete is too well-established to have doubts cast on its basic acceptability. In the case of a new material, failures will cause doubts to be created on the validity of the method itself; hence the importance of reducing construction mistakes to a minimum.

- Service Life

Durability has been pointed out as the major obstacle to be overcome before the technique is fully accepted. It is therefore essential for both client and designer to establish what service life is expected from the reinforced earth structure, and to confirm the agreed service life in the contract.

Reinforced Earth has specific advantages in certain types of industrial and mining structures, which might originally be envisaged to have service lives of relatively short duration. In the event of an owner wishing to prolong the service life of a structure, he should be made aware of what was contemplated at the stage of design and construction, and should not have to rely on the subjective memory recall of those connected with the projec in its early stages.

Monitoring Procedures

It is essential for the promoters of a new technique of this nature to pay close attention to monitoring of its structures, in order to allay apprehension and even suspicion. This process is difficult to and tedious, and becomes more so as the number of structures increases, but the problem has to be faced.

Complacency also plays a part in inhibiting monitoring, and is illustrated by the following example. A Reinforced Earth retaining wall was erected by a major road-building authority, subsequent to a landslide which destroyed one lane of an expressway. The new wall was fitted with a number of measuring devices to record deflections, settlements and movements generally. After the first few years of successful operation of the reinforced earth wall, and with the structure exhibiting no apparent signs of distress, all monitoring has stopped. It would surely be in the interests of the Reinforced Earth system, and of the client, to revive monitoring, even on a reduced basis.

Alternative systems

The South African company has not yet experienced competition in this field but, if experience in the U.K. and U.S.A. is any guide, the attitude towards competition should not be antagonistic. New methods and materials would rather help to expand markets yet untapped than to close traditional markets. Looking for protection in the form of patents only, and not in "know-how", could have a negative effect on future progress.

4.2 Investigations into metallurgical slags

Introduction

This activity started in 1979, subsequent to

(i) launching the Reinforced Earth Company; and

(ii) abandonment of the active programme on pfa.

E.U., France, again played an active part in stimulating and guiding investigations on this programme.

The research focused into various slag types and possible applications :

- granulated blast furnace slag as a stabilizing agent in road construction;
- air-cooled steel slag as an aggregate;
- manganese slags as both stabilizing agents and aggregates.

Note on slag

This section explains certain commonly-accepted terms and processes in slag technology. The information is derived essentially from the publication "Blast furnace and steel slag" by A.R. Lee[9].

Lee defines slag as "the molten silicate complex formed by the combination of agglomerated earthy matter with the ore, fuel and fluxes added to the charge in iron-smelting operations". In iron and steel making the greater proportion of slag is produced in blast-furnaces,

which convert iron ore into iron, while steel slags, comprising the smaller proportion, are formed in the refining operation of converting iron into steel. Slags vary greatly according to the composition or refining process used.

The annual production of blast-furnace slag throughout the world is about 100 million tons, and production in the U.K. reached a peak figure of 11¼ million tons in 1964. While the pioneer ironmasters were concerned only in producing iron, and their interest in slag restricted to the quickest and cheapest way of disposing of it, the situation is now radically different. In the U.K. virtually the whole of the currently produced slag is processed for profitable industrial uses; mostly as roadstone and aggregate for concrete, as railway ballast, as a source of slag-portland cement, as a filter medium for sewage disposal plants, as a fibre for making the heat-insulating material Rockwool, and as an agricultural fertiliser.

As stated above, blast-furnace slag is produced in the conversion of iron-ore into iron. Iron-ore is a mixture of oxides of iron, silica and alumina and the chemical reactions within the blast-furnace reduce the iron oxides to iron; the silica and alumina compounds combine with calcium in the fluxing stone (limestone and dolomite) to form slag. The blast-furnace operation is a continuous process, the raw materials being fed into the top, and the products, molten iron and liquid slag, being drawn off from the bottom at regular intervals.

Liquid slag is usually run into iron ladles for conveyance to the cooling pit, or it may run straight to a cooling pit situated close to the furnace. In some cases it is allowed to solidify in the ladle. In the liquid slag are gases under pressure from the furnace, and the conditions of cooling and solidification determine the quantity and size of bubbles that

cannot escape before solidification. Consequently the density and porosity of slag are affected by conditions of cooling as well as by its chemical composition.

In the U.K., unlike S.A., the ironmaster is obliged to consider not only production of good iron but also the quality of his slag. Accordingly, the blast-furnace burden is controlled to ensure that the chemical composition of the slag is in accordance with the requirements of the relevant British standard specification. In the U.K., blast-furnace slag is produced in three main forms : air-cooled, granulated and foamed; South Africa produces the former two types but no foamed slag.

Air-cooled blast-furnace slags exhibit properties similar to igneous rocks. Crushing and screening of this material follows normal quarry practice and conventional quarry plant is used for this purpose. In the U.K., air-cooled slag is used extensively as a roadstone, concrete aggregate, railway ballast, and filter medium. In South Africa, it is used mainly as a roadstone. Its use in concrete construction is severely limited by specification and it has not yet been approved as a railway ballast. Iscor is the only producer of blast-furnace slag in South Africa, and the production of aggregate from its air-cooled slag is in the hands of a single company.

Granulated slag is produced when molten slag is cooled rapidly by means of high pressure water jets, and excess water is maintained. Crystals then have no time to form and the slag solidifies as a glassy material which, as its name implies, takes the form of small granules. When ground to a powder and mixed with an alkaline activating agent such as lime or portland cement, granulated slag has hydraulic setting properties. In the U.K. the material is used for manufacture of a

[illegible] cement [illegible] without blast-furnace cement. In South Africa the material is milled to cement fineness and extensively used in concrete and road construction as a replacement for ordinary portland cement. The milled material is marketed under the name "Slagment" and is classed as a latent hydraulic cement. Portland blast-furnace cement is also produced in South Africa, but only in limited quantities mainly because contractors prefer to save costs by buying coal and slagment separately and blending these materials on site.

Coming to steel slags, several processes are currently used; namely open-hearth, basic Bessemer, electric arc and Duplex; and the basic oxygen process is now apparently the most favoured. Slags derived from all these processes are air-cooled and not granulated. In South Africa, in addition to Iscor, several of the smaller steelworks produce steel slag; namely, [illegible].

Depending on the process, steel slags vary in type and chemical composition, but most of them are unsuitable as aggregates for concrete. They are, however, generally accepted as roadstone and are widely used as such in the U.K. This practice has not been followed in South Africa and steel slags remain largely dumped and unused. Slags are also produced in the reduction and refining of metals other than iron, such as zinc, copper and manganese.

Activities from December, 1[illegible] - December, 1[illegible]

These activities concentrated on the potential of off-the-dump granulated slags. The concept of using this type of slag, without processing or milling, had come to RL via EJL, who had gained experience of the new road-building material, developed in France and known as "grave-laitier" (gravel-slag). The originator of this process, L. Prandi, had developed a gravel-granulated slag-lime mixture which had proved itself as a strong and economical material for sub-bases and base courses, and EJL was of the opinion that a successful transfer of this technology to South Africa could be effected.

At this time, as has already been pointed out, granulated slag was already being exploited commercially in South Africa, but in a form that required it to be milled. The company producing the milled slag, Slagment Ltd., also possessed proprietary rights on all granulated slag produced by Iscor.

RL could therefore not enter the field of milled slag, nor did it wish to do so. Slagment Ltd. was marketing a milled product as a cement replacement, whereas RL aimed to develop the unmilled product as a cheap and effective stabilizing agent in road construction, along the lines of the Prandi process of "grave-laitier" in France.

"Graves-laitier" comprised a mixture of aggregate (gravel, air-cooled slag, or sand), granulated slag off-the-dump, and road lime. Depending on design criteria, the proportions of aggregate and slag varied appreciably from 75 - 90% for aggregate and from 10 - 25% for slag.

The outstanding characteristic of the mix was the comparatively low proportion of lime used, in the order of 1%. This small quantity of lime, plus the relative cleanness of off-the-dump, unprocessed slag, made possible a low total cost. In South Africa, considering the large quantities of slag then being produced at Pretoria, Vanderbijl, and Newcastle, "Granu-Lattice" seemed to offer great opportunities.

RL made contact with Slagment Ltd. and discovered that RL and Slagment Ltd. had no conflict of interest. In fact, Slagment Ltd. were not able to exploit Iscor's total output of granulated slag for their milled product, and were pleased to co-operate in a joint venture which might enable them to use part of the balance of roadworks material. It was therefore agreed that the companies would jointly investigate off-the-dump slags, assisted and guided by EJL.

Already at this stage, Slagment expressed reservations about the chances for successful technology transfer. Their viewpoint was also confirmed by Dr. A. Buttermann, a "Slagment" pioneer, who stressed the problems posed by the high magnesia content of South African slags. Nevertheless, RL decided to pursue the investigation, mainly because of reassurances from EJL that similar high-magnesia slags were used in France in the Prandi process.

As in the case of pfa, it was decided to carry out the test programme at the Orleans laboratory of EJL, the programme being directed by Messrs. Digue and Marchi. First tests started in February, 1978. By June 1978 it became clear that the granulated slag from South Africa was inferior to its French equivalent as a stabilising agent. Appendix 6 shows results conducted with sand-slag and gravel-slag mixes, and

leaves no doubt that the Slagment and Stutterheim warnings had been confirmed.

A report by Digue on the test programme (Appendix 7) sets down the following :

(i) South African slag develops lower strengths than its French counterpart, and shows no increase in strength after sixty days;

(ii) The phenomenon is probably caused by differences in chemical composition, in that the South African slag has a higher magnesia content and lower lime content than French slags.

(iii) It might be worthwhile investigating whether the required strengths could be obtained with activators other than lime, which had been the activator used in the Orleans experiment. Digue suggested gypsum, caustic soda, or a material patented by Prandi known as gypsonat (a combination of gypsum and caustic soda.)

Digue went on to suggest a joint programme, most of which would be conducted in South Africa. Digue's sub-division of tasks for the new programme was for the Orleans laboratory to try to find the appropriate activator and, after that, for the South African laboratory to carry out routine testing. This programme was agreed, and the Orleans laboratory started its investigations.

Results became available in September/October 1978 and again proved disappointing. Digue's reports on this matter are given in Appendix 8 and his conclusions and recommendations can be summarised as follows :

(i) the results proved discouraging, in that appreciable gain of strength with time was not obtained with any of the catalysts used.

(ii) it appeared that South African slag would have to be ground or milled before it could develop much pozzolanic potential.

(iii) French practice with granulated slag was now also tending towards grinding of the slag prior to use.

(iv) an interground slag-cement mix might be more appropriate than slag-lime. This product would be coarser than opc and might produce advantages in workability and a more gradual gain in strength.

RL might have been forgiven at this stage for calling a halt to the project, but decided to press ahead; this time carrying out the experimentation in South Africa. RL appointed Professor G E. Blight as consultant to the project; and, after discussions with RL and EJL and study of the Orlean results, Blight submitted his research proposals in October 1978. The proposals were accepted (Appendix 9), and it was decided to start the programme in 1979. The reason for delaying the programme slightly was to give Blight and the writer an opportunity to attend a waste-materials conference in Paris in November 1978, which might shed new light on the project and proposed programme.

November 1978 : Conference on Waste Material in Paris

The conference was organised by the French road-building authority, and contributions were received from most of the world's industrialised countries.

Silgrd's report of the conference is enclosed as Appendix 10, and its specific comments on slags are [illegible]:

- "Graves-Laitier" was successfully used in France, generally at an 80 : 20 gravel to slag ratio.
- France was looking into partial pre-grinding of the slag and into alternative activators to lime.
- Aircooled blast-furnace slags show hydraulic properties, when used as aggregates for concrete.
- Steel slag also was application as an aggregate, but mainly for bituminous concrete surface dressings.
- Undesirable chemical constituents in both blast-furnace slags and steel slags have impaired their effectiveness as aggregates.
- Slags have been successfully used as embankment fills.
- Steel slag, as distinct from blast-furnace slag, has a potential use as a fertilizer.
- Granulated slag can be pelletised in order to manufacture light-weight aggregate for concrete.
- Energy savings can be effected if granulated slag is used to produce an interground slag cement.
- Pollution hazards of using waste slags had not received a great deal of attention.
- When using slags in road construction attention should be paid to the problem of shrinkage cracking of the surface material.

On the strength of the report and what had been presented at the conference, RL decided to continue its investigations; in particular to look into the partial grinding of blast-furnace slag to improve its hydraulic or pozzolanic properties, and the possibilities of steel slags.

A useful contribution was made at the concluding session of the conference when an American delegate suggested a list of questions that should be asked before embarking on a waste-materials project :

- What is the market?
- What are the institutional problems, i.e. legislation, specifications, environmental constraints?
- Are there economic advantages; i.e. what are the costs of production, comparative costs of conventional methods or material, special costs such as transport?
- Are there unsolved practical technological problems?

The questions appear simple and obvious, but if asked at an early stage, could point the way to approaching projects rationally and objectively.

Activities in 1979 : Blast-furnace slags

These activities consisted essentially of laboratory investigations conducted at the Wits Civil Engineering laboratories. Blight's preliminary report, 22.01.79, is enclosed as Appendix 11. Several types of activators had been tried using standard sand-slag mixes, and with the exception of the lime-caustic soda activator, all others gave disappointing strengths at 28 days. Blight indicated that he intended trying out the effects of partial milling of the granulated slags, as indicated at the Paris conference.

In the above tests, two types of sand were used, a washed, weathered concrete sand and a Witwatersrand quartzite crusher sand.

Blight's final report was submitted on 23.10.79 and is enclosed as Appendix 12. The main points emerging from this report are here summarised :

- The aggregates tested included concrete sand, crusher sand, dump sand and slimes. Tests showed improved strengths with increasing fineness, and slimes proved to be the most satisfactory aggregate.
- Three different types of slags were included in the tests, namely granulated slag, partially milled slag, and slagment. Tests showed, what could probably have been forecast, that the finer the slag, the higher the strength achieved, and also that there was little point in using granulated slag without increasing its fineness by either grinding or milling.
- Activators included opc (which was also used as a reference), lime, lime-caustic soda, lime-gypsum, gypsum-caustic soda. Excluding opc, the most successful activator was the lime-caustic soda combination; and the gypsum-caustic soda combination proved generally disappointing.
- All tests attempted to achieve a relatively high pH in the mixes. This requirement was established by the work done in France the previous year.
- Generally, South African slag could not be used to produce "gravel-laitier" in the Brundi fashion. Nevertheless, further investigations should look into the use of slimes and aggregate, and into reduction of total slagment - and activator content.
- Table 3 of the report, with accompanying graphs, gives an outline of the progressive development of experimental policy.

The report produced no immediate prospects for commercial development and RL decided to abandon the active laboratory programme. RL did decide however to keep up contact with developments in slag use, both in France and South Africa.

As an adjunct to the work carried out by Blight, the Portland Cement Institute in South Africa carried out a minor investigation into slags during 1974 and early 1980. This investigation was prompted by the personal interest of the Director of the Portland Cement Institute.

RL supplied the Portland Cement Institute with samples of both South African and French blast-furnace slags for comparative testing. The Portland Cement Institute report is enclosed as Appendix 13, and again shows the superior strength properties of the French slag, particularly at early stages. The investigation confirms that high magnesia content in South African slags seems to be the most likely reason for their inferior performance.

Activities from January 1980 to September 1981 : Granulated slags

This was a period of merely keeping in touch with problems and developments of granulated blast-furnace slag, while pursuing more active investigation into steel and manganese slags.

RL maintained contact with EJL's principal laboratory at Dourdan, near Paris, and also with an EJL affiliate company Salviam/Brun, a road construction company with extensive experience in both air-cooled and granulated slags. As in the case of pfa, Dourdan and Salviam decided that they would like to take a fresh look into the problems of slag, and asked for samples in order to start their respective testing programmes. Dourdan duly carried out experiments on pfa but neither Dourdan nor Salviam ever produced results of their slag tests. By this time, RL had in any case become convinced that there was little future in pursuing the investigations, and made no effort to find out whether any testing had been carried out at all.

In September 1980 Blight paid a short visit to France in which he had discussions with :

(i) EDF at Bourdais,

(ii) CERILH which is the French counterpart of the South African Portland Cement Institute; and

(iii) LCPC, a French Government organisation devoted to research on roads and bridges.

Blight's report on his discussions are given in Appendix 1A and are here summarised in order to show the amount of work required in order to come to a final decision about the advisability of exploiting the material :

- A reverse experiment should be designed in which French materials are tested in South Africa, and vice versa, so as to eliminate any doubt as to differences in testing techniques.
- Electron microscope studies of the progress of hydration in slag and pfa should be carried out so as to give a possible clue of what caused the lack of pozzolanicity.
- The quenching temperatures of slag should be checked, because reactivity is much reduced below 1400°C, especially in the unmilled form.
- In France it is practice to grind granulated slags partially in order to improve pozzolanic properties, and this process should possibly be tried using South African slags.
- It might be necessary to add more lime to the South African mixes in order to obtain the required pH, accepting that this procedure might increase costs.

No further action was taken until June 1981, with another visit by Blight to Paris. Blight's report on his meeting with Belgium and EJL is contained in Appendix 15, which also covers his discussions on matters outside of granulated slags.

On granulated slags, he raised the following points :

- There was a possibility of South African limes being at fault, it not being able to produce the required pH and strengths.
- The density of the test samples might be important - this matter had not been raised previously.
- Electron microscope techniques might be useful in investigating the glassiness of slags.
- The use of air-cooled slag as aggregate, with granulated slag as pozzolan, could stimulate pozzolanic activity.
- It was also possible that the use of gypsum could be harmful, because of reduction of pH by phosphoric acid.

Taking all the above into account, Blight made a series of suggestions in page 3 of Appendix 15, in order to try to bring the investigations to a conclusion. BA decided not to involve itself in further costs, in view of the relatively low chance of success, and abandoned the project entirely.

Steel slags : December 1978 - June 1981

As stated earlier, steel slags are produced in the process of refining iron into steel. A characteristic of these slags is that they contain proportions of metallic iron, and in many steelworks it has been found profitable to extract the metallic iron, by magnetic separation, and return the reclaimed iron to the works. In South Africa, the iron-free slag is usually placed in dumps and, for the most part, left unused.

It had been therefore interesting to learn, at the November 1978 Paris conference, that in several countries steel slags were being used as aggregates in construction. RL took no action on this matter at the time because its activities were still centred on granulated slags. At the end of 1978, however, after Blight's somewhat pessimistic report on granulated slags, RL decided to look into steel slags.

RL started investigations by making contact with a British company, Clugston Holdings, which was active in the field and had made a great contribution, in theory and practice, to the development of slag technology in the U.K. Clugston was based in Scunthorpe, Lincolnshire, and had interests in slag aggregates, foamed slag, pelletized slag and Cemsave (a material similar to Slagment). Further, in initial discussions in the U.K. in December 1979, Clugston indicated that it would be interested in providing expertise, and probably specialized equipment, for a joint venture with RL in South Africa.

RL and Clugston agreed that in the first instance they would concentrate on the potential of steel slag as aggregate. Clugston

had pointed out that its own steel slag aggregate met the British specifications for aggregate in bituminous premixes and had accordingly been widely used on the road- and freeway network in the environs of Scunthorpe and even beyond. Clugston also warned that certain chemical constituents of steel slags had precluded them from being used in concrete.

As a result of the initial meeting with Clugston, RL decided to start investigations on the potential of steel slags in South Africa, and by April 1980 had assembled a considerable amount of information:

- Iscor was not the sole producer of steel slag, although it was by far the largest. Steel slags were produced at a number of smaller works; including Highveld Steel & Vanadium, Usco, Scaw, Dunswart and Cape Steel.
- The rights to all Iscor slags (blast-furnace and steel) were in the hands of a company called Heckett, a 50-50 partnership between Iscor and a U.S.-based multi-national company (Heckett) which specialized in slag recovery and processing in integrated steelworks.
- Heckett operated plants in Pretoria and Vanderbijl, and at that time was preparing to open a plant at Newcastle.
- Heckett's primary function was the recovery of the metallic element from steel slags. It also produced crushed slag aggregate, but used only air-cooled blast-furnace slag in this operation. Steel slags, after extraction of the metallic iron, were not exploited for commercial use and were simply accumulated in dumps on steelworks property.

- [illegible] large-scale exploitation of slags as aggregates. Although crushed, air-cooled slag was accepted as suitable in road construction and, in a limited way, as aggregate in concrete foundations, Heckett South Africa had not penetrated the market to any extent and exploited only a small proportion of the total slag produced. Slag aggregate had not been accepted, for example, for high-grade structural concrete, for road-surfacing or for railway ballast.
- At the smaller steelworks, with the exception of some agricultural lime production at Highveld, no effort was being made to exploit steel slags.

On the basis of the above information, RL decided to approach Heckett with a view to forming a joint venture which would promote increased utilization of [illegible] steel slags as aggregates. While Heckett owned all rights to the material, RL suggested that its own experience and knowledge of civil engineering and the manner in which the civil engineering industry operates in South Africa, could speed up investigations and boost any promotional or research programme.

After a series of meetings, the final one attended by Heckett's U.S. directors, Heckett decided against any co-operative venture. RL was therefore obliged to abandon Iscor as a potential source of steel slag.

The above enquiries and negotiations took place within three months of RL's first meeting with Clugston, and in April 1982 a delegation from RL visited Scunthorpe where it was able to see the full range of Clugston's operations at first hand. It became clear to the delegation that the Clugston organisation was indeed expert in the field and that RL would be well advised to work with it, assuming a suitable source of unworked steel slag could be found in South Africa outside of Iscor.

Such a source was located; at Dunswart Iron & Steel Works near Benoni on the East Rand. Although a small works by Iscor standards, Dunswart had, over the years, accumulated a large slag stockpile which the Dunswart management had been to exploit or get rid of in some way or other. Outside of any commercial exploitation, the dump was creating environmental problems; it was not only becoming an eyesore but was beginning to encroach on a municipal recreational dam and pleasure resort.

With the consent of Dunswart's management, RL commissioned Prof. Blight to test the slag for possible utilization as an aggregate for bituminous surfacing. The slag contained metallic iron in proportions of 5 - 10%, and it was accepted that any exploitation process would require a preliminary magnetic separation of the metallic fraction. Dunswart indicated that a ready market existed for the recovered iron. Blight's test results are given in Appendix 16 and show that the slag aggregate met specifications for bituminous premix but not for chippings in bituminous surface dressings.

Concurrent with the laboratory testing programme, RL had conducted investigations of a different nature :

(i) a survey of the dump showed its volume to be in excess of 300 000 cubic metres, and that a supply of potentially usable material was available for a matter of about 10 years.

(ii) enquiries at East Rand municipalities and premix suppliers revealed that a steady market was available for premix slags, and that Dunswart aggregate would be accepted as long as it met SABS criteria.

RL therefore made a formal proposal to Dunswart for exploitation of its slag. The proposal comprised setting up a plant at the dump which would first extract the metallic fraction and then crush and screen the balance as premix aggregate.

RL's ambitions were unfortunately again frustrated in that at the same time as it submitted its offer, Dunswart received a counter-offer. This was from a group which was already processing and selling Highveld steel slag as agricultural lime and wished to do the same at Dunswart. The counter-offer proved more attractive to Dunswart, because,

(i) the market appeared to be more secure;

(ii) the offer would enable Dunswart to get rid of all the slag in the dump, including the fraction reduced to sand and dust. The EJL proposal would only remove the solid rock-like fraction.

As far as is known Dunswart accepted the second offer, but [illegible] (four years later) no signs of activity are visible. Whether shelving of the project was caused by Dunswart's subsequent change of ownership, or a breakdown of final negotiations, or collapse of the fertilizer market as a result of droughts, is not known. In the meantime, the dump is growing in size and is still a potential environmental hazard. As far as is known, no great effort is presently being made by any person or organisation to exploit steel slags in South Africa; at Dunswart or any other steelworks.

Manganese slags : October 1980 - February 1982

South Africa is an important manganese producer, and much of the reduction and refining of the ore is carried out at the Samancor works, Kookfontein, near Meyerton in the PWV area. Large quantities of different types of slags are produced at the Kookfontein works; and, as a natural consequence of its interest in iron and steel slags, RL came to the conclusion that these manganese slags would warrant an investigation.

Contact was established with Samancor, and the two companies agreed, without argument or hesitation, to embark on a joint testing programme under the direction of Professor Blight.

Kookfontein produces three products; ferro-manganese, ferro-silicon and phosphorus metal, and thus three different types of slag. The slags are derived from an electric-arc process and are all air-cooled and deposited in dumps on the site of the works. The ferro-manganese slags have been passed as suitable for certain types of roadstone, and

are crushed and marketed by a private company under contract [illegible] Samancor. The [illegible] as concrete aggregate in the world.

Glight's programme included tests on both air-cooled and granulated slags, the process of granulation having been devised to be carried out on a small scale especially for the tests. The findings were submitted in two reports, December 1981 and February 1982, both of which are enclosed as Appendixes 17 and 18.

The reports gave little hope for successful economic exploitation of the products (other than aggregate production for the FeMn slags where the rights were already ceded to another company) and the parties to the joint programme were reluctantly obliged to abandon the venture.

DISCUSSION AND CONCLUSIONS

Management of the programme

The history of this programme shows that previous experience with pfa has taught the potential innovator several valuable lessons, and that the technique of investigation was improving.

Most importantly, it was realised that there was not much point in conducting research into waste materials projects unless rights were secured on the materials being investigated. For that reason, at the start of each investigation programme, agreements were made with either the owners or option holders; Blagmont Ltd. in the case of granulated slag, Dunswart in the case of steel slag and Samancor in the case of manganese slags. Secondly, although the initial laboratory trials on blast-furnace slags were carried out in France, the project ended by using South African laboratories throughout. The advantages of having such investigations carried out on-the-spot are self-evident, and it was realised that overseas laboratories should only be used for checking, or for expertise not available in this country.

Finally, an attempt was made to adhere to the guidelines which were proposed at the Paris conference and set down earlier in this dissertation. Adoption of the guidelines confined the project to the realms of reality and thus helped to reduce costs.

Costs

At a conservative estimate the total cost of the investigations into all three types of slag amounted to about R20 000. This, by present R & D

standard, is a comparatively low figure, but there might be different ways of assessing whether the investigation was worthwhile or not.

On the one hand, the expenditure could be considered justified because the investigators might have found a highly useful and profitable avenue of exploitation of the slags at relatively low cost.

Taking a converse view, the R20 000 spent on the programme could be considered wasted; not because it produced negative results, but because the effort dragged on for too long and it wasted resources that might profitably have been used in other activities.

One important and positive feature that emerged from the investigations was that it showed that in order to carry out at least the first stages of an R & D programme it is not necessary to make investments in the form of laboratories, laboratory equipment, and the engagement of laboratory personnel. The system of contracting out research work by commissioning outside experts was successful and would have been continued in any future work of similar nature.

Objectives of the programme

The programme confined itself to looking into potential applications of slag in the civil engineering and road building industries. With hindsight, it is clear that the objectives were restrictive, and this was made particularly evident in the Dunswart case where a far better potential was found in agriculture, but by another organisation.

Wright's report on the Paris conference already pointed out that steel slags were being used as fertiliser, but B.I.S.'s sights were so fixed on its own industry that the potential application was missed. Subsequent investigations and enquiries have shown, furthermore, that the chemical make-up of many slags makes the material potentially far more valuable as a source of minerals than as an aggregate in construction or even as an ingredient in cement manufacture. Waste material investigators should therefore not restrict their objectives to limits which include only their own particular interests or expertise.

Special note on granulated slag

The research into granulated slag started off with a question mark against it because of the high content of magnesia present in the material. The fears about magnesia proved to be well founded and reasonably early on it became evident that a simple transfer of French technology was not feasible.

By the time research on this material was stopped, investigations had reached the stage of testing mine sands with partially milled slag or slagment, and there appeared to be a reasonable chance of producing a pre-mixed sub-base or base course material at a competitive cost. However, that type of pre-mix was only marketable in the immediate environs of Johannesburg and the Witwatersrand generally, and the current road and street programme at that time hardly justified any further research or investigation.

Since 1979, however, a new market has arisen, because of a switch in government policy on the future of urban black communities. For many years government policy was based on the supposition that blacks should be induced to return to their homelands, and such money as was spent on infrastructural services was allocated to homeland areas rather than to concentrations of population in industrial urban areas.

This policy changed dramatically in the early 1980's and very large sums have since been spent in those areas on the provision of more adequate roads, stormwater drainage, water supply, and sewerage. The greatest proportion of expenditure is on roads and streets, and if a cheap and adequate road building material had been developed in 1979 there is a strong chance that it might have been used on a large scale in 1980 - 1983. As it is, because of the pressure to get something done quickly, the authorities in charge of the project are loath to try anything experimental, and standard methods and materials are being used in most of the programmes.

There is unfortunately, also, little incentive for research of this nature to be undertaken on a private basis. Undoubtedly a need for alternative and cheaper materials of construction does exist in the street building programme in Soweto and other similar towns and cities; but public works authorities will need to be convinced.

Special note on steel slags

After the failure of its tender to Dunswart, RL had no option but to terminate the exercise on steel slags. It is unfortunate however that no effort was made to find out how the successful tenderer's work was faring. Once it had established that the project was not going ahead, R.L. might have been encouraged to make a further bid.

Steel slags usually contain high proportions of lime, in the order of 50%, and thought was given to granulation of this material. Dunswart contended, however, that granulation of steel slags would produce dangerous explosions and so this line of enquiry was dropped.

Since the closing of this investigation, Dunswart has changed ownership, and thought is being given to reviving the project at some future stage if funds become available.

Note on manganese slags

The sponsors of this project had no option but to abandon it when they did. Test results were either inconclusive or disappointing, and the maangement of Samancor had little inclination to carry the research any further.

There was little prospect in developing the use of manganese slags as road aggregates, the markets being too limited; and any attempt at granulating the slags in order to produce pozzolanic materials would have required expenditure on a scale to which neither partner in the venture was prepared to commit itself. Any future work in

this field would of necessity involve a wider-ranging approach and a commitment to look into aspects of the use of manganese slags outside of the civil engineering and building industries.

4.0 REINFORCED UNDERGROUND SUPPORT

Introduction and background

The severity of the task of introducing innovation into large well-established, and successful organisations is tellingly illustrated by Field-Marshall Lord Wavell[10] in his book "Generals and Generalship" published shortly before World War II : "Whenever in the old days a new design of mountain gun was submitted to the Artillery Committee, that august body had it taken to the top of a tower, some hundred feet high, and thence dropped onto the ground below. If it was still capable of functioning, it was given a further trial; if not it was rejected as flimsy". In dealing with the South African mining industry, the potential innovator faces almost a similar merciless style of examination.

The particular proposed innovation in this case developed from the work described in previous sections of this dissertation, and involved both waste materials and the theory and practice of reinforced earth. The basic concept was to develop a system of underground supports comprising granular material, preferably industrial or mining wastes, suitably strengthened and reinforced so as to act as substitutes for existing supports or support systems, and providing advantages in either cost, performance or percentage extraction of ore. The original target was underground coal mining, but in the course of progress of the project,

potentially more attractive applications were found in the mining of gold and platinum.

The project, after three years, has now reached a stage of being close to full-scale testing underground. The discussion will not go into detail on laboratory investigations or theory, these aspects having been dealt with in contributions to appropriate professional institutions; it is rather aimed at looking into the manner in which it was managed, in the hope that the experience might act as a guide to others who might be sufficiently ambitious, enthusiastic, or foolhardy, to attempt something similar in the future.

The concept of this proposed innovation, of reinforcing granular wastes to form mine supports, had its origin at the CSIR flyash conference in 1979, to which reference has already been made in the pfa section of this dissertation.

Among the papers presented at the conference was one by Drs. Wagner and Galvin of the South African Chamber of Mines Research Organisation, which described a research and development programme designed to augment extraction ratios in underground coal mining. The paper set down the rationale behind the programme :

- the most-commonly practised method of underground coal mining in South Africa is termed bord-and-pillar (also known as room-and-pillar) mining, in which only a fraction (less than 50% on average) of the available coal is extracted, the balance being left in place as support pillars. In plan, the bord-and-pillar method

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produce a checkerboard pattern of square pillars surrounded by mined-out voids or bords.

- vast quantities of ash are produced by coal-burning power stations, which in South Africa, are usually located in the close vicinity of the mines which supply them with their coal.
- It would therefore be worthwhile to look into the possible beneficial effects of pumping waste ash underground so as to fill, or fill partially, the bords. Backfill should improve the load-bearing characteristics of coal pillars and thus point the way to augmentation of extraction ratios.

The paper further went on to analyse the structural and rock-mechanics aspects of backfilling, and to point out that a programme of full-scale backfilling had already been initiated at Springfield Colliery, captive to Escom's Grootvlei power station.

The presentation of this problem and project gave rise to the idea of taking the concept of underground backfilling one step further by devising supports which, by cementation and reinforcement, could possibly permit of the construction underground of substitute pillars. This differed from the Chamber of Mines concept of merely strengthening existing pillars by means of mass backfilling. Theoretically, the pillar-substitution technique would augment the extraction ratio to a far greater extent than the pillar-strengthening technique.

For various reasons, mainly financial, but probably also disbelief in its eventual success, neither Reinforced Earth nor RL (then renamed EJL (S.A.)) was prepared to sponsor research into the new concept. However, an alternative financial backer was found, who in fact supported the project for three years, until March, 1984. Since that

date, the project has been taken over by the author, working in collaboration with a major mining house, Rencor Ltd.

Soon after the start of full-time investigations in 1981, the original sponsors of the project formed a company, Stratafix (Pty) Ltd. which was to direct the research programme and eventually exploit the system commercially. For convenience the word Stratafix will from now on be used to designate this project.

Stratafix made two early important policy decisions :

- realising that its system was innovative and might contain patentable matter, it took steps to protect itself by means of applications for patents in terms of South African and international law;
- in order to test and prove the system on a sound and acceptable scientific basis, it invited Professor Blight to act as its consultant.

Testing has, since the start of the project, been carried out at two venues, the Civil Engineering Laboratories at the University of the Witwatersrand and the Mine Equipment Research Unit, CSIR, Johannesburg.

Description of the Proposed System

The system is now described in greater detail in order to better understand the evolution of the project, and the changes in design and objective that took place over the years.

The description will be supplemented by Appendix 19 which is a copy of Stratafix's patent family [illegible] in the U.S.A. (The patent date of January 10, 1984, is misleading. The application was filed several years earlier, at the same time as in South Africa, but getting a patent accepted internationally is a lengthy process).

Although several features embodied in this patent have since been discarded, its text includes descriptions, specifications and drawings which explain the basic principles, and which amplify the description here set down :

(i) the proposed process envisaged building barriers or columns comprising reinforced, precompressed granular materials which would be designed to accommodate the loads imposed on them by the overlying rock in the manner required by the particular mining system being used. A further object of the system was to use waste materials as a backfilling medium; pfa in the case of underground coal mines, slimes or sand in the case of gold and platinum mines.

In the text of the patent itself, a more detailed description is set down in Column 4, final paragraph, leading into Column 5, first paragraph :

"The invention extends also to a method of building pillars underground for supporting the hanging wall in underground mining operations, which method involves calculating the vertical load which a pillar is to take, calculating the horizontal component of load associated with such vertical load,

laying particulate material in layers between hanging wall and footwall, consolidating each layer, and providing reinforcing material with such layers, and providing reinforcing material within or between the layers to accept, with the required degree of safety, the horizontal components of load associated with the vertical load which the pillar is expected to take."

A typical cross-section of the proposed pillar is shown in Fig.6 of Appendix 19.

(ii) The reinforcing medium considered to be most suitable was mild-steel "wire-mesh" as commonly used in the construction industries.

(iii) The original concept envisaged a system of supports in coal mines, which would enable existing coal pillars to be replaced. In order to obtain a stiffness approaching that of natural coal pillars, the artificial pillars would have required precompression, preferably by jacking the pillars against the roof of the mine. A mobile press was designed and built for this purpose, shown diagramatically in Fig. 17, reference 130 of Appendix 19.

(iv) After precompression, the space between the roof and top of the pillar would be filled by cemented load-taking material and wedges, in order to provide an active support against the roof or hanging wall.

(v) the supports could be square or rectangular in shape, or built into long continuous walls.

During the course of research and testing, ideas developed and concepts changed so that new patents had to be filed both on matters of detail and of general function of the proposed system. In 1983, when direction of the project switched from coal mining to mining of gold and platinum, two new lines of attack had to be followed :

- in order to provide initial stiffness and strength, and also to cope with the speed and intensity of underground operations, precompression had to be abandoned in favour of cementation.
- gold and platinum mining took place at considerable depth below the surface, and artificial support pillars in such mines would eventually fail. Close attention had therefore to be paid to failure characteristics of the support system, over and above characteristics of initial stiffness and ultimate strength.

Progress of the project can now be set down, and it is classified into distinct calendar year phases :

Activities in 1981

1981 saw the development of basic theory through a programme of laboratory testing. At that time it was thought that the system would be applicable essentially in underground coal mines, and the supports envisaged were either square pillars or long rectangular walls running between existing coal pillars.

Proposed methods of complete extraction, where walls were built more or less concurrently with coal extraction, were also devised and thought to be feasible. With the evolution of a theory came also the analysis of costs; special stress being laid on the cost of materials.

In the strengthening and reinforcing of the proposed waste material pillars, it was envisaged that steel would remain the reinforcing medium, probably in the form of a welded mesh, as commonly used in civil engineering and building construction. It soon became evident that the major proportion of total cost of these artificial supports would be the reinforcement, and research was therefore constantly directed towards diminishing in some way the total quantity of steel required. Taking into account the value of coal which the pillars were [illegible] to replace, it appeared that the system would probably only become economical in export collieries, which obtained considerably higher prices for their product than collieries serving local consumption and power generation. The cost figures looked gloomy and it might have been a rational decision to abandon the project there and then. What kept it going were hopes of using less steel through improved design techniques, of using steel of higher tensility, and of reducing the selling price of weldmesh by expansion of demand which success of the system would evoke.

During 1981 efforts were also made to get to know more about underground coalmining and its problems. This was achieved by underground visits and discussions with officials on the collieries, consulting coal engineers, and research workers at the Chamber of Mines research laboratories in Johannesburg. A well-known export colliery in the Eastern Transvaal showed interest in the idea, and it was hoped that this colliery would eventually provide a venue for testing the system underground.

One somewhat elaborate item of equipment, demanded by the system, comprised a mobile tractor-jack, which would precompress the structures in situ, in order for the pillars to reach a stiffness or modulus somewhere in the region of that provided by pillars of natural coal. For this

reason, Stratafix representatives visited the U.S.A. in 1981 to investigate jacking systems and techniques. Companies were canvassed in Minnesota, Illinois and New York and various ideas and technologies investigated. Fortunately, the most promising ideas came from a company which was represented in Johannesburg; and from then on jacking investigations were carried out through that particular agency.

Throughout the duration of this project and as new ideas originated, Stratafix filed applications for patents. Much of this was done during 1981, because the research was still in its early phase and ideas were constantly developing and changing. Several of these patents have since been accepted.

Activities in 1982

By the beginning of 1982, it was felt that the time had come to test the system underground, and negotiations were initiated with the export colliery referred to above, which appeared to have the necessary interest and ability to help conduct such a trial. Because no direct financial advantage would have accrued to the colliery at the experimental stage, two questions arose; firstly who was to bear the cost of the underground experiments, and secondly, how would the mine stand in relation to patents and any new inventions that arose? Regrettably, it proved impossible to settle these two matters to mutual satisfaction, and negotiations were abandoned. Nevertheless, during the negotiation period, a trial pillar was constructed in the same colliery for purposes of demonstration to a coal research committee.

After this setback, Stratafix decided that it would be preferable to perfect its techniques on its own, as far as possible, and that no alternative negotiation would be tried for some months.

By that time Stratafix had also designed and built its mobile jacking unit, which had served with limited success in building the triad pillar underground. This equipment was later modified but, by force of circumstances, has lain idle since its commissioning, and in the light of latest alternative developments will probably never be used.

During 1982, on a visit to the U.K., Stratafix made its first approaches to the National Coal Board in that country. It became clear from the discussions that little progress could be made in countries outside South Africa until the South African industry itself, with its acknowledged international reputation, had tested and accepted the system. Nevertheless, the NCB provided valuable information about subsidence, environmental problems in the U.K. and the mining systems used there.

Part of 1982 was also spent in making further accquaintance with problems and conditions in the South African coalmining industry itself. Several collieries were visited, including Springfield Colliery where the original ash-filling project had been carried out under the auspices of the Chamber of Mines. It was discovered that Escom had decided to abandon this particular project, by virtue of its not having produced the benefit originally forecast.

In that year, contact was established with the Co-operative Scientific Programmes (CSP) Section of CSIR (now called Foundation for Research and Development, FRD). One of the CSP's projects was to promote the use of waste ash produced in power stations, and Stratafix became a member of this project's steering committee. Through CSP, Stratafix was introduced to SAIDCOR (South African Inventions Development Corporation) which agreed to look into a possible joint venture as soon as Stratafix passed out of the research and into its development phase.

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During 1981, the South African Institute of Mining and Metallurgy accepted a paper describing the theory and practicable practice of the [illegible] system. The paper was published in the December 1981 edition of the SAIMM journal and eventually provoked some controversial contributions, which will be discussed in more detail in a separate section of this dissertation. The paper and contributions are enclosed as Appendix 20.

Another interesting feature of the 1982 programme was testing of the concept of external reinforcing, in the form of spirals or parallel rings, as a substitute for internal mesh reinforcement. This development also prompted a move towards circular pillars as against rectangular pillars or walls. The theory and experimentation relevant to this concept was written up in a second paper, completed at the end of 1982, and accepted for presentation to an international symposium, scheduled to be held in Sweden in June 1983.

During 1981 and 1982, contacts were established and maintained with three major bodies, namely, Escom, the Office of the Government Mining Engineer (GME), and the Chamber of Mines Research Organisation.

Escom is the major coal user in South Africa and is in a position to influence the policy of the collieries which feed its power stations. While Escom has no immediate problems of support or supply in its captive collieries, it appreciated that the Stratafix system might have application in the future, either by lengthening the life of particular stations, by solving environmental problems through returning waste ash underground, or by releasing coal sterilized under services such as roads, railways, power lines and housing estates.

The office of the GME was kept informed of Stratafix's research from the outset of the programme, and officials of the Department have since been kept in touch through laboratory demonstrations and state-of-the-art meetings. It is this office, primarily responsible for safety in the mining industry, which would have had to give its approval for the use of any new support system underground, and it was therefore important to keep it well informed of progress.

At intervals, Stratafix arranged meetings with representatives of the Chamber of Mines Research Organisation where the state-of-the-art was reported and discussed. It was felt that this contact was essential, not only for airing of technical problems, but also because of the research organisation's high stature in the mining industry itself.

The research organisation originally agreed to monitor the proposed Eastern Transvaal trial which, as was explained, failed to materialize. Its advice to Stratafix was to look for special applications, such as barrier pillars or supports under services, before embarking on a pillar extraction - or combined mining and support programme. The organisation's principal doubts about the system lay in the degree of stiffness achieved in precompression, and in the possible increased cost of mining.

By the end of 1982, therefore, the project had reached a reasonably advanced stage of theoretical progress but had still made little practical progress towards getting the system tested in real life.

Up to the end of 1982 attention was focussed on provision of total and permanent support, and it was thought that the system had application only in shallow mines. However, publication of the SAIMM paper led to discussions with rock mechanics engineers, in daily contact with support

problems, and they experienced the removal of yielding supports, especially as practised in the South African gold mining industry. This led to the project taking a different turn in 1983.

Activities in 1983

In deep-level mines, supports cannot be expected to take the full load of the overlying rock. What is required is initial stiffness, when load first develops on the support, and then a pattern of gradual failure, at constant load, when the support is no longer capable of taking the load. Supports used in the gold mines at present fulfil the above function with varying degrees of success and the idea was put forward that the Stratafix system of horizontal reinforcement, combined with cementation or precompression, might stand a good chance of achieving this desired pattern of initial stiffness and subsequent gradual failure. This concept was introduced to Stratafix by the Chief Rock Mechanics Engineer of Cencor Ltd., who has always taken an active and personal interest in the programme.

Research on yielding pillars was therefore pursued for most of 1983, and produced promising results. It should be noted here that the backfill material used in the 1981/1982 programme was generally coarse ash from Escom power stations, this being the most available and economical waste material at hand. As soon as a gold mine possibility emerged, tests were conducted on the wastes produced in the refining of gold, namely sand and slimes.

Several factors favoured the development of new support systems in deep-level gold mines :

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Several factors favoured the development of new support systems in deep-level gold mines :

- gold mine supports did not need to be designed for long-term durability, because all supports would eventually fail under the massive overburden loads to which they were subjected.
- the accent was on initial stiffness combined with acceptable failure characteristics, and there was no need to design using factors of safety.
- support systems were an everyday feature of gold mining practice, and substitution of one kind of support for another would require no basic change in the method of mining. In coal mining, coal itself provided the support and an artificial support system would have required a revision of basic mining techniques. Coal mining engineers could be excused for regarding the proposed innovation as far-fetched.
- gold-mining permits of a higher cost of the support system, by virtue of the higher value of its product.

The above advantages also applied in several respects to the mining of platinum, which opened up an extra field of application for the Stratafix system.

The 1983 laboratory work produced a crop of new developments :

- cemented columns, combined with horizontal reinforcing, to take the place of standard grout packs in wide stopes in gold mines. Cementation would provide initial stiffness, and precompression was rejected as being impractical for gold mining.
- mesh-reinforced circular pillars, using either standard square weld-mesh, or specially designed mesh arranged in concentric

circles and radial spokes. This concept has since been abandoned.

- Pillars made up of blocks or bricks, suitably reinforced, pre-compressed away from the face, transported to the work site and then built into position in the stope. This was another attempt to eliminate the pre-compression jack and suggested a possibility for eventual application in coal mines.

In June, 1983, Stratafix's technical paper was presented to an international symposium in Luleå, Sweden (Appendix 21). The reaction by delegates to the symposium was sympathetic, but it again became evident that the international mining community would wait for its system to be tested and proved in South Africa, before adopting it themselves.

The switch in emphasis from coal to gold mining did not mean that Stratafix had entirely abandoned interest in the former. Contact was maintained with certain collieries whose managements had indicated interest in the project and suitable venues were sought for underground trials. Successful trials in gold mines would in any case have opened the door to new approaches in the coal mining industry. One feature related to coal mining was found to be of potential importance. Where railway lines traverse coal fields, the Government Mining Engineer, for safety reasons, "sterilizes" vast quantities of coal which underlie the line. By virtue of this sterilization, SATS might, in the future, be obliged to pay out many millions of rand as compensation to the mines for loss of profit. The possibility of using the Stratafix support system to free this sterilized coal was investigated and discussed both with SATS and GME. Again it was felt that successful implementation in the gold mines would have to be a precedent to any trials in coal mines.

Activities in 1984

With the active collaboration of the Rock Mechanics Department of Gencor Ltd. the project made important forward strides. The programme has concentrated on transversely-reinforced cemented pillars, looking into applications in both platinum- and gold-mines and, for the first time, tests were conducted on full-size packs or pillars

To repeat, the required load-compression performance in gold mines comprises initial stiffness, adequate yield strength, and deflection at near-constant load after failure. Successive series of tests in this period have shown that these characteristics can be obtained by a correct combination of cement content, reinforcing steel content, and pillar dimensions and that a design method can be evolved which would cater for the varying sets of underground circumstances at different levels and in different types of mining.

Two important additional features have come to light during the 1984 programme :

(i) Suitable backfill for the packs can be produced from gold mine tailings, hitherto considered to be too finely graded for the purpose. Fine material is extracted by means of a process of two-stage cyclonings leaving a coarse residue for use in support packs.
This development obviates the necessity to import natural sand at relatively high cost, conserves resources of natural sand, and makes use of a hitherto unutilized waste material.

(ii) ductility of the mesh has proved to be a most important factor in obtaining the required characteristics of strength, stiffness and post-failure deflection. Normal welded mesh is made up of hard-drawn wire, which has largely lost its ductility, and in order to restore ductility a process of annealing is required after welding. Appendix 22 is enclosed which shows :

- graphs comparing ductility of annealed and unannealed wire;
- graphs comparing performance of packs reinforced with both annealed and unannealed welded mesh. The superior performance of the annealed mesh is evident.

At the time of writing, November, 1984, an underground trial is being planned for early 198[illegible] for a gold mine in the Gencor Group. The prospects for eventual implementation and diffusion of the system appear now to be reasonably hopeful.

Note on experiences with the mining industry

From the inception of the programme, Stratafix made a point of keeping in touch with the Chamber of Mines Research Organisation (CMRO) : The impression gained at meetings held with this organisation was that the idea was worth pursuing, even though practical snags were evident.

It therefore came as a surprise, when its contributions to the Stratafix paper were published, that the organisation gave the concept little encouragement.

CMRO's contributors raised several objections:

- that Stratafix had overclaimed the merits of the system;
- that theory had not advanced far enough to justify underground testing;
- that rock mechanics aspects had not been sufficiently taken into account, especially in regard to behaviour of the roof;
- that the proposed artificial pillars were probably not stiff enough to accommodate roof movements adequately; and
- that the cost of primary and secondary mining had not been sufficiently looked into.

Stratafix's reply to the criticisms voiced by the Chamber confined itself to technical points. It decided, however, that further contact with CMRO was neither desirable nor likely until new material could be presented.

Other than the Chamber of Mines Research Organization, Stratafix also made contact with the production side of the industry and with departments of rock mechanics in the various mining groups. On the production side, and this includes both consulting engineers at head offices and management on the mines, the reception was courteous but bland. It took Stratafix some time to appreciate the pressure placed on those responsible for production and to understand their consequent reluctance to devote time to apparently far-fetched and impractical innovations. Nevertheless, the experience gained by these contacts proved to be useful, because of the occasional opportunity to see both underground conditions at first hand and the modus operandi of the industry.

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The most useful contacts with the mining industry were those made with rock mechanics departments. By their very function, rock mechanics engineers have the knowledge and interest to look into problems of this nature, and it was in these departments, in particular that of Gencor, that several fruitful ideas emerged. Not all rock mechanics specialists saw merit in the Stratafix system, but all of them were prepared at least to debate the issues.

Generally speaking, Stratafix suffered from its lack of contacts and experience in the industry. In an activity such as mining an elite establishment builds up amongst individuals who have been working on similar problems for many years and who have probably developed a commonly-accepted line of approach. Outsiders are therefore not regarded too seriously; and Stratafix should have taken greater cognisance of this state of mind.

Evaluation of progress and policy

After about 3½ years of research and investigation, and with the system close to being tested underground (although not in the form originally envisaged), it is perhaps useful to look critically at the manner in which the project was directed. Such an analysis would not merely be an exercise in hindsight; the project still has a long way to go and there is no need in its future direction to repeat the mistakes of the past.

It seems reasonably certain, in looking back, that the present state-of-the-art could have been reached earlier. The slow progress achieved could be attributed to a number of factors, some of these created by faulty internal policies and others by outside circumstances. These factors have been identified and are here set down in as objective a manner as possible.

Lack of familiarity with the mining industry

The basic Stratafix idea was inspired by a new development in civil engineering, and it was therefore up to the innovators to get this civil engineering technique accepted by the mining world. Until 1983, the apparently obvious application of the system seemed (to Stratafix) to be in the underground coal mining industry, and this was the only application originally discussed with officials and research workers in the mining industry.

What Stratafix did not appreciate at the time was that the project needed the services of a technical mining consultant, in the same way as it saw the need for a consultant in geotechnics. Such an individual, as part of the team, could have opened the door to aspects of mining which were eventually appreciated only after months, or even years. He could have looked into the effect of the system on mining costs and practice, and into possible applications to mines other than underground coal mines. He would also have had contact with all South African mining groups and been able to advise Stratafix on where it should concentrate its activities.

It is true that Stratafix did not work completely in a vacuum, and that it did attempt to establish contacts with the mining industry. It failed, however in four four major respects. Firstly, its original deal-

ings were with one mining group only and when negotiations broke down, there was for a time no one else to turn to: secondly, it naively placed its faith in obtaining the goodwill and co-operation of the Chamber of Mines Research Organization; thirdly, it made insufficient contact with the rock mechanics departments of the various groups; and finally, it should have made clear that it proposed a step-by-step approach to the innovation and that it was not attempting to revolutionise the industry.

It was only after publication of the paper in the journal of SAIMM and contact was established with certain key individuals in the industry, that these alternative lines of action became more obvious.

The need to maintain confidentiality

The originators of this project never left any doubt about their intention to transform their idea into a commercial venture. This meant that their proposed system, methods, and equipment were obliged to be protected by patents, which, in turn, raised difficulties in regard to interchange of ideas with individuals outside of the organisation itself.

The inventors were obliged, therefore, to adopt a cautious approach, realising that they had to take the inventions a long way down the road before they could talk freely about certain aspects. Because they did not have day-to-day access either to mines or to individuals in the mining industry, it meant they frequently had to work from first principles on matters that might well have been common knowledge in the industry itself.

The need for a partner

The retarding effect caused by the need for confidentiality suggests that Stratafix should have tried, from the outset, to interest a strong partner with access to the mining industry in the project, even at the risk of losing a share of its patent rights. The contribution such a partner might have made would have been to use its financial strength and resources of money, men and engineering, to speed up progress, particularly in the holding of an underground trial.

The difficulties of finding the right partner, in such circumstances, are not under-estimated, but the idea of looking for one was not contemplated seriously enough in the early stages of the project.

Stratafix ran the project on as tight a budget as possible especially during the early stages of laboratory work and the development of theory. Once the theory was developed, it might have been better policy to spend at a greater rate; and this is where the financial partner could have pushed the project ahead without waiting for joint participation by others. The success of Stratafix's collaboration with Gencor in 1984 is proof of the folly of trying to go it alone with limited resources.

Attitude adopted by CMRO

Stratafix raised the idea of horizontal reinforcement with CMRO in 1981, and it does seem strange that at that time CMRO did not suggest a measure of research co-operation. Such a joint effort might well have led to faster rate of testing and possible implementation.

Perhaps both sides were guilty of not laying their cards openly on the table; Stratafix being wary of protecting its patents and CMHC possibly seeing merit in the system but inclined to follow the research in its own way. In any case, CMHC did subsequently pursue a project in horizontal reinforcement, an indication that it did not completely reject the Stratafix concept.

4. DISCUSSIONS AND CONCLUSIONS ON THE TOTAL PROGRAMME

This dissertation so far has described several attempts at innovation, which have met with varying degrees of success. It will now look into the general advisability of companies getting involved in such effort: and, in the event of involvement, how best to manage the effort. The discussion will confine itself to the management of innovation within civil engineering companies, but will cater for cases where the scope of innovation might extend to other disciplines, mining in particular. The two industries, mining and civil engineering, are closely related in several respects, and in South Africa, the size and nature of the mining industry establishes it as a target for new ideas from all quarters.

Are Innovation Programmes worthwhile?

Before attempting to answer this question, the two industries concerned need to be scrutinized a little more closely.

Civil Engineering

Purchasers of civil engineering services are, in the main, either public authorities or large corporations. This means that attempts at innovation, when they arise, have to be directed towards the upper bureaucracy of government or business and not towards the man in the street. The innovation in this field is not producing an article which might have a potential market made up of millions of individuals; his investigations and promotions have to be directed to a limited number of technical clients. His innovative effort is therefore obliged to take this circumstance into account.

Furthermore, in civil engineering, safety is an overriding factor. This means that those responsible for instituting such services have to be bound by strict codes of practice, established by research and experience over the years, and that changes cannot be lightly introduced. Potential innovators must realise that resistance to change in the industry is governed essentially by concern for the welfare of the public, and by official laws, regulations, and specifications. They must not expect to find too ready a response to untried methods and materials, and must overcome what Kingston[3] calls "the rut of established practice".

Change in this field therefore has to come about slowly, in that new systems and materials have to be thoroughly tested before they can be officially approved and adopted. The history of the development and final approval of pre-stressed concrete is an indication of how long it takes a brilliant and effective idea to be universally accepted.

In South Africa, new techniques of this nature are generally adopted because of successful experience in the larger industrial countries of the world. South Africa therefore depends on technology transfer more than on direct innovative efforts of its own. The record given in this dissertation of the promotion of Reinforced Earth in this country is a case in point. Acceptance of the material in Europe and the U.S., and the ability to create the same conditions for its construction here, enabled the method to be accepted reasonably easily; without such international acceptance, the effort to introduce the technique into South Africa would have been futile.

It is true that the very presence of established codes of practice and specifications provides, in some cases, too easy an excuse for conservatism and a disinclination to look into anything new; but the innovator has to be prepared to face such a conservative outlook, which will be based on a combination of reason and prejudice.

In regard to the type of innovation itself, novel ideas might arise either in design and construction of permanent works, or in improved techniques of construction of temporary works, or in improvements in plant and equipment.

It is easier to innovate in the latter two categories, because the potential inventor or innovator has virtual free rein, having to deal with far fewer restrictions or laid-down standards and regulations. Innovation in these fields is therefore not uncommon, and is evidenced in constant improvements to equipment in earth moving, rock drilling, compaction, shuttering, tunnel supports, and the like. These improvements need not emanate from the civil engineering profession, but also from manufacturers and suppliers; and when innovation in construction is mentioned in the literature on R & D, it usually refers to this type of improvement.

For better or worse, this dissertation relates to the first of the above categories, specifically the introduction of new materials of permanent construction, and the most difficult category to penetrate. This is where institutionalized practice and codes of safety present formidable obstacles to innovative effort.

Finally, as difficult it may be to innovate generally, it is even more difficult to introduce patented systems into this industry. Employing authorities have a firm faith in the competitive tender system, and do not favour one competitor having a protected advantage over his rivals. Some authorities are even against the submission of alternative designs. For example, in the case of "Reinforced Earth", which has been accepted by most authorities, tender documents usually specify "Reinforced Earth or equivalent".

Overall, there is therefore little incentive, for civil engineering companies to search for patentable or innovative material. They might well find that they will obtain a once-only advantage before their system is copied, or that the employing authority refrains from specifying their system. The competitive tendering system has distinct advantages, but in the field of innovation and invention it tends to discourage initiative and creative thinking. This accounts for the almost complete absence of research departments in even the largest construction companies.

Mining

The mining industry in South Africa is enormous and many of its activities are subject to attempts at innovation. This dissertation deals specifically with an activity in which civil engineers are also supposed to have some expertise, namely that of "strength of materials".

As in civil engineering, the potential innovator in this field is obliged to realise that he is governed and restricted by stipulations concerned with safety. He must work within regulations drawn up and controlled by the office of the Government Mining Engineer (GME) and must accept and understand official conservatism in approval and adoption of proposed new techniques.

Further, the great bulk of R & D in the industry is carried out by a single body, the Chamber of Mines Research Organisation (CMRO). This organisation has pioneered research into mine support and rock mechanics, and the CME have great input in its advice on underground safety procedures. The innovator therefore has to meet the requirements and specifications of two powerful bodies, who speak virtually with the same voice.

A further feature of mining in South Africa, as distinct from civil engineering, is that internationally the industry is a leader rather than a follower. A novel idea only needs local approval to be accepted, even though obtaining that approval might not be the simplest of tasks.

Finally, the outsider to the industry is usually hampered by lack of access to real-life mining conditions. If he tries to manage on his own, he considerably reduces the possibility of implementation of his invention or innovation.

The advisability of innovation

In the light of the above, and also of what has been set down in the earlier sections of this dissertation, it is clear that a civil engineering company should not lightly decide to embark on an R & D or innovation programme on a permanent business basis.

It is important, however, to distinguish again between technical innovation and general diversification. Diversification includes branching out into completely new business activities, and is capable of reasonably precise financial forecasting. It is a matter of assessment of risk, both by financial and technical management, and business accepts that from time to time such decisions involving risk have to be taken.

In the case of technical innovation, however, the decision becomes one involving both risk and uncertainty, and the burden of the decision will fall on technical management. Financial management tends to look somewhat apprehensively at the usually very imprecise forecasts - technical and financial, - put forward by proponents of innovation and invention.

Nevertheless, despite all these built-in obstacles to the introduction of innovation, there is always a possibility that some individual in an organisation produces an idea which shows commercial promise, or that an outside inventor approaches a company in order to finance some new discovery. In order to cope with such eventualities, companies should have at their disposal a method of appraising any suggested innovation, and of managing it if it is pursued further.

If companies were to build up expertise and experience in the management of innovation, they would ensure that a valuable discovery is not allowed to go astray. They would also encourage original thinking, from within and without their organisations, and have the know-how to deal with new ideas expeditiously and economically.

It is therefore not proposed that companies should invest in permanent R & D establishments. Rather, it is suggested that innovation and invention in civil engineering should be pursued on an "as-and-when" basis; and it is with this basic policy in mind that the recommendations which follow are made.

5. RECOMMENDED PROCEDURES

While accepting the principle that innovation programmes in a civil engineering company should be instituted only when specific projects crop up, it still remains necessary, in order to use available time and resources to the full, to conduct the programme methodically, and in accordance with some basic set of rules. Formal literature on R & D, being devoted essentially to large-scale programmes and projects, gives little guide to procedures of this "as-and-when" nature.

Nevertheless, some extracts from the literature are here quoted, because they do provide guidelines towards approaching the problem. Jack Morton[2] in "The R & D Game" advocates the adoption of "systems engineering" in carrying a project through from the invention stage to eventual utilisation and diffusion. He outlines the steps as follows:

- Define and state objectives.
- List alternative solutions.
- Put best hypothesis to test through experiment.
- Synthesis i.e. the process of forming something which did not exist before, together with further testing and monitoring.
- Manufacture and marketing.

The U.S. General Electric Company has evolved a similar set of rules in its "creative engineering programme" :

- recognize the problem
- define
- search
- evaluate
- select
- follow through.

.../...

The recommendations which follow attempt to provide a more specific and practical guide, but only to the invention and innovation stages, as defined by Schumpeter. The diffusion stage does not fall within the scope of this dissertation.

STEP 1 : Feasibility Appraisal

Let it be assumed that a company receives a proposal to introduce an innovative method, or to help develop an invention. The proposal might have come from within the organisation, or from an outside inventor or entrepreneur looking for financial support. Clearly, the company will have to examine the proposal in some detail, and in so doing will have to involve the originator of the idea in the discussions. If there seems to be any probability that the proposal will be adopted, the company will at the same time be having a look into a possible manner of conducting the project, its probable cost and who should direct it.

The first step in the programme therefore comprises three separate tasks, which have to be addressed more or less concurrently :

- appraise feasibility
- appoint product champion
- evolve short-term budget and plan.

These three tasks will be dealt with individually, but the fact of their concurrence should always be borne in mind.

Feasibility appraisal

This should take into account the normal obvious considerations, such as technical and financial merits of the proposal, probable costs of

the R & D stage, and the potential market available for the final product or process. Some extra guidelines for the appraisal stage are given by Maddock[6], and, although written to apply to large-scale conventional projects, they apply also to the type of innovation being considered here.

Maddock sets down the following prescriptions :

- Match the size and scope of the project to the market to which it is addressed.
- Check for existing techniques which might be adapted to meet the required objectives.
- Appreciate the unwillingness or inability of workforces and the general public to accept new methods.
- Accept that even the most pessimistic time forecasts are usually too short for actual realisation of the project.

Yet a further consideration that should be given attention at this time is that of patents. This means that the company should check whether the proposed invention or innovation contains patentable material or, conversely, whether it might infringe existing patents, trademarks or licences.

It would be prudent, even at this early stage, to seek the advice of patent attorneys and possibly retain their services for the duration of the project. This precaution is particularly necessary if the invention happens to touch on the interests of large corporations, or of bodies like the Chamber of Mines or the South African Transport Services, who might resent having to make large royalty payments and might therefore look for opportunities to challenge the validity of patent applications.

Having stipulated the questions that ought to be looked into at the feasibility stage, it is necessary to issue a word of warning. The feasibility appraisal is not designed to find final answers, but to determine whether the innovation is worth taking a step further. Initial stages of the project would not involve high costs, and so a decision to proceed further would not be too risky or irrevocable.

Looking back on the projects described in this dissertation, it is almost certain that a conventional feasibility appraisal at its initial stages would have put an end to the proposed mining innovation. An appraisal of a technical proposal must therefore be accompanied by imaginativeness, ingenuity, and willingness to take a measure of risk. Innovation will not emanate from an organisation that overdoes financial considerations at this early stage. A good idea might eventually find practical applications undreamt of in earlier feasibility appraisals.

Product Champion

It is essential that as soon as possible, responsibility should be placed on a single individual, conventionally termed the project manager and, in the case of innovation activities, the product champion.

The champion might well be the inventor, if an invention is involved, or the proposer of a suggested new technique or subject of technology transfer. On the other hand, high technical ability is not always accompanied by concomitant administrative skills and the choice of champion could fall elsewhere, with the inventor acting as technical adviser.

It is not essential for the champion to be an engineer or scientist, although this would probably normally be the case. Some emotional involvement with the project is desirable (with reservations which will be outlined later) and enthusiasm is a prime requirement.

The following somewhat idealistic quotation from Kirgston[3], might serve as a guideline to selection :

"If there is one characteristic which marks out an innovator more than anything else, it is a capacity for and an enjoyment of learning. He learns from books, from calculations, from experiments, from other men. This curiosity is vital, because without it there is none of that special kind of learning which results in ideas becoming embodied. Thus the innovator stands at the point of intersection between several areas of life, between art and technology, between invention and business, between ideas and artefacts".

Even the best and biggest organisations might have difficulties in locating such a paragon. Nevertheless, in more simple terms, Kingston is recommending an allrounder rather than a specialist, who has also a facility for moving outside his own particular sphere of education, training and experience.

In regard to administration, the champion should be given sufficient authority to enable him to activate the company bureaucracy and allow his views and requirements to be heard. The company itself should also make a point of letting key members of its administration know about the project, its aims and proposed modus operandi. In project management terms, the product champion should operate in a matrix organisation, where he will work under a specific director or committee for the project

itself, but have easy access also to the various departments and sub departments within the company.

Short-term budget and plan

In the early stages of a project it is not possible to make accurate cost forecasts in the long term. Nevertheless, it is possible to forecast costs at short intervals, say one year, and it is essential that this be done.

The first series of activities of the programme will probably not involve much more than desk research, laboratory testing, patent applications, discussions and travelling. These costs might be slight and easily covered by the company's overhead structure, but it is essential that they be set down on a programme and that the product champion be made accountable for them.

The very existence of such a preliminary plan and budget will prevent the project from being regarded for certain individuals, as a pleasant diversion from routine, and as lip service to the cause of diversification and keeping contact with the latest technology. Much of the slow progress in the RL diversification efforts, described earlier in this dissertation, can be ascribed to lack of formality in the programme and consequent absence of accountability on the part of the nominal product champion and the board of the company generally.

Summary of Step 1

The step termed feasibility appraisal comprises three separate activities - appraisal itself, selection of champion, and short-term plan - which run concurrently, but which point the way to logical implementation of the steps which are to follow.

STEP 2 : Selection of working group

The product champion will operate on his own to start with; and will gradually form a working group to assist his test programmes and investigations. This group will not necessarily be made up of company employees; in fact the champion might find it easier to use specialist staff on a part-time basis.

The projected innovation will be of a technical or scientific nature, and will probably call for laboratory testing of some sort. RL's initial experience with pfa and slags, and its later experience with mining supports, all go to show that the Wits laboratories plus CSIR/MERU laboratories at Cottesloe, adequately coped with the testing facilities, and even a company with existing facilities would be well-advised not to extend to but to use established and reputable outside laboratories. Besides being well-manned and well-equipped, the established laboratories produce results which the outside world would recognize as objective and credible.

In the same vein, rather than appoint research staff on a permanent basis, it is preferable to commission experts to act as consultants on a retainer, as-and-when basis. In this event, and also in regard to

laboratory staff, confidentiality agreements would be entered into in order to preserve secrecy (if required) and to protect patentable material. The system of using outside consultants has worked smoothly and adequately in the several activities described in this dissertation.

Administration of the project, and control of finance, could be handled by the company's establishment without serious addition to its normal workload. The essence of the innovation policy should therefore be directed towards keeping the working group small and flexible, and to avoidance of empire-building. An eventual decision to suspend the project would thus involve little disruption; and, in the event of the project showing signs of success, appropriate staff appointments and increases to the R & D establishment could be effected as required.

An important appointment, over and above that of project champion, is that of overall guardian or watch-dog to the project. This watch-dog could be either a committee or a senior company officer, the latter preferably someone of the status of technical director. This appointment is essential in order to avoid the tendency to optimistic bias. Even the most sincere and devoted product champion sometimes needs cool and objective reason applied to his enthusiasm.

STEP 3 : The Invention Stage

In this activity, a somewhat formal approach is advocated, not in order to look after the budget, which is small, but to keep in intimate touch with the activities of the product champion and his advisers. This

approach is required not so much to police the product champion, but to prevent him from drifting into a world of his own where he might lose touch with practical issues and realities. Although the product champion should be given a relatively free hand, he should also be made aware that during the course of the project, he will be subject to full and free criticism from his technical peers.

If the project starts on a modest scale, which it should do, there are bound to be long periods of apparent idleness while waiting for results of tests or field investigations. This is one of the principal reasons for keeping the staff complement small, until the project passes from invention to innovation.

In RL, the product champion returned to routine duties during these waiting periods; but this was a mistake and indicated the general lack of direction in the company's innovation effort. These waiting periods afforded an opportunity for the product champion to make himself thoroughly familiar with the subject and the problem through study, discussion, and even travel if necessary; and this opportunity was not sufficiently appreciated.

In these apparently idle periods, therefore, the product champion should make a point of updating himself on recent technical developments, of keeping in touch with investigations of a similar nature by a wide reading of journals whether technical, economic or of general news interest, and of establishing and maintaining contacts with organisations operating in areas potentially affected by the innovation. This activity comprises what in military terms would be termed "intelligence", and should be regarded as an essential and continuing ingredient in the total

programme. The product champion ... keep an overall perspective of the project; its ... capabilities, and potential rivals, besides carrying out ... and technical investigations.

The product champion must at this stage also strive to build a group of co-workers who will develop a loyalty to the project. Goldhar[4] in his final review states this requirement succinctly : "... R & D engineering management is, in essence, the task of designing and maintaining an environment within which innovation can take place."

On the more formal side, regular reviews and appraisals should become a feature of the programme and should direct themselves to the following questions :

- Are the original objectives still valid, or should the project change direction and emphasis?
- Is technical progress leading towards a solution of problems and realisation of objectives?
- Should procedures be changed?
- Should the effort be strengthened or reduced?
- Is there hope of commercial success?
- Does progress and hope for the future justify continuation of effort?

Appraisal of this sort requires to be candid and unsparing of the susceptibilities of the product champion. Tendencies towards optimistic bias should be looked for, and in this search consultants and the "watchdog" will play an important role.

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Nevertheless, such vigilance must not become an excuse for impatience. Maddock's warning about forecasts usually being too short for actual realisation should be borne in mind, and decisions to continue, despite setbacks, should not be difficult if both programme and project have been designed so as not to stretch the company's resources beyond its capacity.

Accountants and financial directors are in general averse to the uncertainty of R & D efforts, and the company's management must be prepared to take a strong hand to ensure that :

(i) decisions on the future of the project be based on technical grounds and

(ii) costs in the invention stage be strictly controlled, so as to prevent premature abandonment of the project.

STEP 4 : Follow-through : Innovation stage

Having arrived at this step implies that the company is forecasting eventual success and intends to pursue the project further. This in turn would involve an intensification of the whole investigative effort and a dramatic surge in costs.

Previous references have stressed the difficulty of obtaining any degree of accuracy in forecasting the costs of innovation, but this does not provide an excuse for avoiding the exercise. The invention phase can probably easily be accommodated, or even hidden, in company overheads; the innovation will require more serious attention.

The literature on the subject talks generally of an investment in R & D of about 1 - 2% of turnover. This figure might be feasible for the manufacturing industries, but is excessive for construction companies, whether contractors or consultants.

In civil engineering contracting companies, for example, 1% of turnover represents from 10 - 20% of profits, and would be far too high a figure to allocate to innovation. Civil engineering companies should therefore think in terms of far lower percentages of turnover and possibly simply in terms of cash available.

To give an example; at present day salaries, and making allowances for transport, purchase of laboratory facilities, engagement of consultants,

and administration, it seems that no serious attempt at innovation could be made at anything less than R100 000 per year. This represents 1% on an annual turnover of R10 million and 0.2% on an annual turnover of R50 million. A systematic innovation policy should therefore not be attempted until a company has attained at least the latter turnover, which means it will have reached, by present-day South African standards, the status generally classified as medium-sized.

Worthy of mention is another way of financing innovation which, according to Kingston, is practised by certain banks. These institutions set aside sums called "racing money" which represent a small proportion of their funds and to which their normal criteria for investment do not apply. They appreciate that these funds will be invested in uncertain or high-risk areas and that the decision to invest is not based on their usual cautious and rational approach. They might then be prepared to give the innovator a limited period of time in which to prove his point; if unsuccessful the losses have not been great and if successful the rewards could be out of proportion to the funds invested. This sort of approach might well be applied to a construction company or consultant which could reserve a special fund for the contingency of future efforts at innovation.

A consideration that might well be taken into account at this stage is that of entering into a partnership with a company which might be interested in, or affected by, successful implementation of the innovation. An alliance with a manufacturing company or a mining company, depending on the nature of the project, would not only relieve the financial burden but also speed up final implementation of innovation and diffusion.

The civil engineering company in this case is faced with relatively clear alternatives : take a partner and accept a smaller share of the final profits; or go it alone, be prepared for the implementation process to be slower and more costly, and remain sole owner of all rights and profits. The former option appears to be more prudent.

Taking the above into consideration, the step of follow-through is obviously largely governed by financial considerations. If all experimentation and appraisals at invention stage have pointed towards the project having a reasonable chance of success, the company must appreciate that if it carries on it is entering a phase of heavy expenditure. It has to make funds available for such expense, whether derived from the company's own resources or from a joint-venture, and the funds must be regarded as risk-money.

The product champion must be made aware of how much has been made available and for how long, and the budget must be handled as if it were non-elastic, in the way of "racing money". Moreover, the functions of appraisal and the watch- dog will have to be intensified.

If such a sober and realistic policy is adopted from the inception of the innovation phase, the company will stand a chance of passing through it and into the final phase of profitable implementation and diffusion.

Note : Guidelines have not been set down for the diffusion phase. Diffusion is essentially a marketing operation, which will have to be adapted to each particular product or process, and only one of the projects described in this dissertation (Reinforced Earth) has reached the diffusion stage.

7. GUIDELINES TO NEGOTIATIONS WITH INDUSTRY

On several occasions, in the course of this dissertation, mention has been made that civil engineering does not easily lend itself to change, and that the mining industry, although more attuned to innovation, also presents problems to the unwary inventor or innovator. Innovation, if attempted, should therefore be tackled with a knowledge of the way in which the two industries work.

In South Africa, some specific guidelines apply :

Civil Engineering

If the three stages in the execution of civil engineering projects can be classified as concept, design, and construction, then the industry itself can be sub-divided into three operating groups : employers, consulting engineers, and contractors. In this total effort it is the employer, or employing authority, who calls the tune. He pays for the projects, he lays down specifications and contract conditions, he appoints consulting engineers, he sets rules for selection and award of contracts. Inventor or innovator must therefore know that if any changes are to be effected in the design and construction of permanent works, it is the employer who will eventually decide whether such change will be allowed to take place.

A further feature of this industry is that research in it is not centrally co-ordinated. Each major government department conducts research of a kind and in isolation, usually with objectives devoted more to check-testing of construction or potential technology transfer. Fundamental research is only carried out at the Universities and at CSIR in the National Building Research and Transportation and Road Research Institutes. In this field, there does exist some communication and interchange of ideas between the academic institutions and CSIR; but the interchange of information is not industry-wide. Research effort by contractors and consultants is minimal.

This fragmented state of affairs accentuates the need for the innovator to approach each employing authority separately. No central body exists, even in CSIR, which can approve of a new method or process, or advise on its adoption, except for the Agrément Board which exercises control over new techniques in housing.

In approaching employing authorities, innovators would be well advised not to start at the top. Heads of major departments are, by their very function, heavily committed to administration and finance, and their patience should not be tried. It is more preferable and practical to approach technical sub-departments, where developments in science and technology still occupy the minds of those in charge.

Depending on the nature of the innovation, the departments to approach are those concerned with design, geotechnics or construction. Without the approval and support of day-to-day practitioners in these departments no amount of influence at the top would be of much assistance in achieving an innovational breakthrough.

Consultants and contractors could also play their part, although a somewhat limited one. Consultants, for example, are in a position to encourage innovative design, even if the decision for approval does not finally rest with them. In fact, Reinforced Earth obtained its first contract through the enthusiasm and good offices of a consulting engineer, who managed to persuade his Employer to introduce the system on a relatively small scale. Contractors can contribute by agreeing to submit alternative designs, either at the bidding stage, or on jobs under construction. Generally, however, their hands are tied.

Supply companies have played an important role in innovation. Prestressed concrete, for example, was largely introduced by commercial design and supply companies, and not by professional consultants or client bodies. Another innovation introduced by a supply organisation was that of precast box culverts in road construction, the technology

having been transferred from Australia. Here again it took the company several years of consistent effort to get approval from each provincial road administration in turn.

These innovative companies were prepared to incur large costs in promoting their ideas, but it was always the client who had to be approached, and who had to be convinced of the strength, safety and viability of the alternative solution.

The Mining Industry

These guidelines are based on a single project and cover only a single facet of innovation in this industry. Nevertheless, a pattern of dealing with this particular aspect of mining seems to have emerged.

In South Africa, the main difference between mining and civil engineering in regard to innovation, is that the mining industry itself runs a large, well-equipped, and prestigious research organisation, internationally acclaimed and famous, while civil engineering carries out its research in a multiplicity of different, separate establishments. The mining research organisation therefore plays a major role in deciding on the acceptability and implementation of suggested innovations.

Although Stratafix itself appeared to get off on the wrong foot in its dealings with the Chamber of Mines Research Organisation, the organisation is in principle not against the introduction of new technology by outsiders.

The Research Advisor to the Chamber of Mines writes as follows [9]:

"Past experience has led to the introduction of a more tangible

scheme for encouraging the introduction of [illegible] scheme referred to as underwriting [illegible] When a new system or equipment approaches final production trial, then a mine (or mines) is locked for to purchase the equipment necessary for the trial. At the same time minimum performance targets are agreed upon and the results of the trials are evaluated in the light of these targets. If the targets are not met, the purchasing mine is reimbursed by the Chamber of Mines for the cost of the equipment. In this manner, the risk involved in the introduction of some new method, process etc. is spread over the whole industry. This insurance scheme has been used on a number of occasions with success."

It is possible that the Research Advisor is referring more to mechanical equipment and mining devices and that there is little previous experience in having to deal with innovations such as the one described in this dissertation. It is to be hoped that the two industries could work more closely together in the future, perhaps even as a result of this particular attempt at innovation.

With regard to guidelines in the specific field of underground support, the innovator should bear in mind the following :

- build the innovation around mining methods currently in practice;
- avoid attempts to alter present mining methods;
- realise that it is usually a waste of time talking to line management, or even head office consulting engineers directly involved in production. Demands on targets and deadlines afford production personnel little or no time to deal with potential innovations introduced by outsiders and which stand a chance of creating problems in the short term;

- establish contact with research departments, but more particularly rock mechanics departments. It is here where there is a chance of obtaining a sympathetic and understanding hearing.
- civil engineers should make no excuse for venturing into the mining field. The two professions are closely related, and civil engineers could make a valuable contribution to support problems by virtue of their involvement with theory of structures and strength of materials. The two professions should have no difficulty to work harmoniously together, but it is essential for the outsider professior (in this case civil engineering) to present its case as tactfully as possible.

8. FINAL REMARKS

This dissertation, in describing a series of attempts at innovation, has attempted to propose methods of management of R & D and of introduction of innovation into two specific industries. The recommendations apply specifically to small-scale R & D, as distinct from R & D carried out classically in electronics, or chemical engineering, or by government institutions. This final section sets down a few further aspects of the innovation process, not directly related to the theme of the dissertation.

The lone inventor

The general guidelines laid down for R & D in civil engineering companies could possibly also be followed by an individual inventor who lacks financial backing and who will eventually have to approach a financial institution or entrepreneur which might interest itself in his project. His suggested method of approach could well be similar to that laid down in the guidelines, with the added proviso that he should choose his potential backer with care, if indeed he finds himself to have a choice.

Lone inventors in South Africa should also know of the existence of the Inventions Development Corporation (SAIDCOR). If it considers an invention to have promise, SAIDCOR could provide the inventor not only with a good proportion of necessary finance, but also valuable know-how on patents and the total process of commercial innovation. A possible disadvantage of working with SAIDCOR is that by its constitution it cannot take action as freely or as swiftly as can a private entrepreneur.

The Teaching of R & D management

Several authors in the quoted references advocate formal teaching of R & D management. Goldhar makes the point : "No business or engineering programme that we know of requires a course in the management of technology/innovation yet, for most organisations, understanding technology and innovation and being able to manage technological change is fundamental to its successful growth. Ultimately, however, we must create a greater demand pool for training in the management of technological innovation."

In South Africa, it is possible for engineers and scientists to pursue long and successful careers without ever becoming consciously aware of the role that innovation has played in the development of modern industrial civilization or of the significance of relatively down-to-earth issues such as patent law, licences and trade marks. This gap in knowledge should be rectified, preferably by appropriate courses at both undergraduate and post-graduate level in engineering and science syllabuses.

Innovation and the general public

Although most people in advanced technological countries pay lip service to the role of science and technology, very few understand the role of the industrial scientist, the inventor, or the innovator. David Allison[2] makes this point in discussing those who have to sanction expenditures for R & D : "If they are to be intelligent guardians of the public purse or the company treasury it is essential that they understand innovation. They must understand for example that innovation is not simply a flash of genius, not just a brilliant idea, but that it is a chain of

event that stretches from the idea to something targible and socially valuable. One need not be a scientist or engineer to know how the innovation process works, but if that process truly is to work, it is imperative that the supporters and managers of the process be something more than generous men of goodwill."

Freeman[1], an economist himself, makes a similar point : "Although most economists have made a deferential nod in the direction of technological change, few have stopped to examine it." Freeman goes on to say that this paradox can be explained in terms of three factors : ignorance of science and technology, preoccupation with trade cycles and employment problems, and the lack of usable statistics.

The responsibility for creating an atmosphere of understanding, in the public at large, of innovation and invention falls largely on the scientific and engineering communities, as much as they may be unversed in the skills of public relations and self-advertisement. This is a task to which the South African scientific establishment should address itself with some sense of urgency.

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GROUPE JEAN LEFEBVRE

LABORATOIRE CENTRAL

RUE DU 1' OCTOBRE - 45400 FLEURY LES AUBRAIS

TELEPHONE 87 87 59

COMPTE RENDU N°148/74 suite

DOSSIER | AFRIQUE DU SUD

ETUDE DES CENDRES VOLANTES S.A.S.O.L. & E.S.C.O.M.

LABORATOIRE CENTRAL - E.J.L.

à

Le 03.12.74

E.J.L. - SIEGE

A F R I Q U E D U S U D

Etude des cendres volantes S.A.S.O.L. et E.S.C.O.M.

- (Complément du C.R. N°148/74 du 22.10.74)

ETUDE DES CENDRES VOLANTES S.A.S.O.L. & E.S.C.O.M.

COMPLEMENT DE RESULTATS DU TABLEAU II

C.R. 148/74

	Cendres grossières ESCOM.		Cendres fines SASOL.		Cendres grossières ESCOM.	
	chaux française		chaux Sud Africaine.			
	sans gypse	avec gypse	sans gypse	avec gypse	sans gypse	avec gypse
FORMULE N°	3	4	5	6	7	8
COMPRESSION :						
Résistance en compression à :						
60 jours - air	9,9 bars	15,5 bars	31,6 bars	45,4 bars	8,4 bars	13,6 bars

C. CHAUMONT

ETUDE DES CENDRES VOLANTES S.A.S.O.L. & E.S.C.O.M.

COMPLEMENT DE RESULTATS DU TABLEAU II

C.R. 148/74

	Cendres grossières ESCOM.		Cendres fines SASOL.		Cendres grossières ESCOM.	
	chaux française		chaux Sud Africaine.			
	sans gypse	avec gypse	sans gypse	avec gypse	sans gypse	avec gypse
FORMULE N°	3	4	5	6	7	8
COMPRESSION :						
Résistance en compression à :						
60 jours - air	9,9 bars	15,5 bars	31,6 bars	45,4 bars	8,4 bars	13,6 bars

C. CHAUMONT

APPENDIX 1 (b)

GROUPE JEAN LEFEBVRE

LABORATOIRE CENTRAL

RUE DU 11 OCTOBRE - 45400 FLEURY LES AUBRAIS

TELEPHONE 87-87 59

COMPTE RENDU N°039/75

DOSSIER | AFRIQUE DU SUD

ETUDE DE CENDRES VOLANTES EN PROVENANCE
DE LA CENTRALE DE KELVIN A JOHANNESBOURG

LABORATOIRE CENTRAL JEAN LEFÈBVRE

ESSAI DE COMPACTAGE

"PROCTOR" ~~Normal~~ Modifié

$$d_s = \frac{d_h}{1+\alpha} \qquad \alpha_o = \frac{1}{d_s} - \frac{1}{\delta}$$

$$n_a = 1 - \frac{d_s}{d_{s_{ao}}}$$

d_h = densité humide — α_o = teneur en eau pour $n_a = 0$

n_a = vides d'air — $d_{s_{ao}}$ = densité sèche pour $n_a = 0$

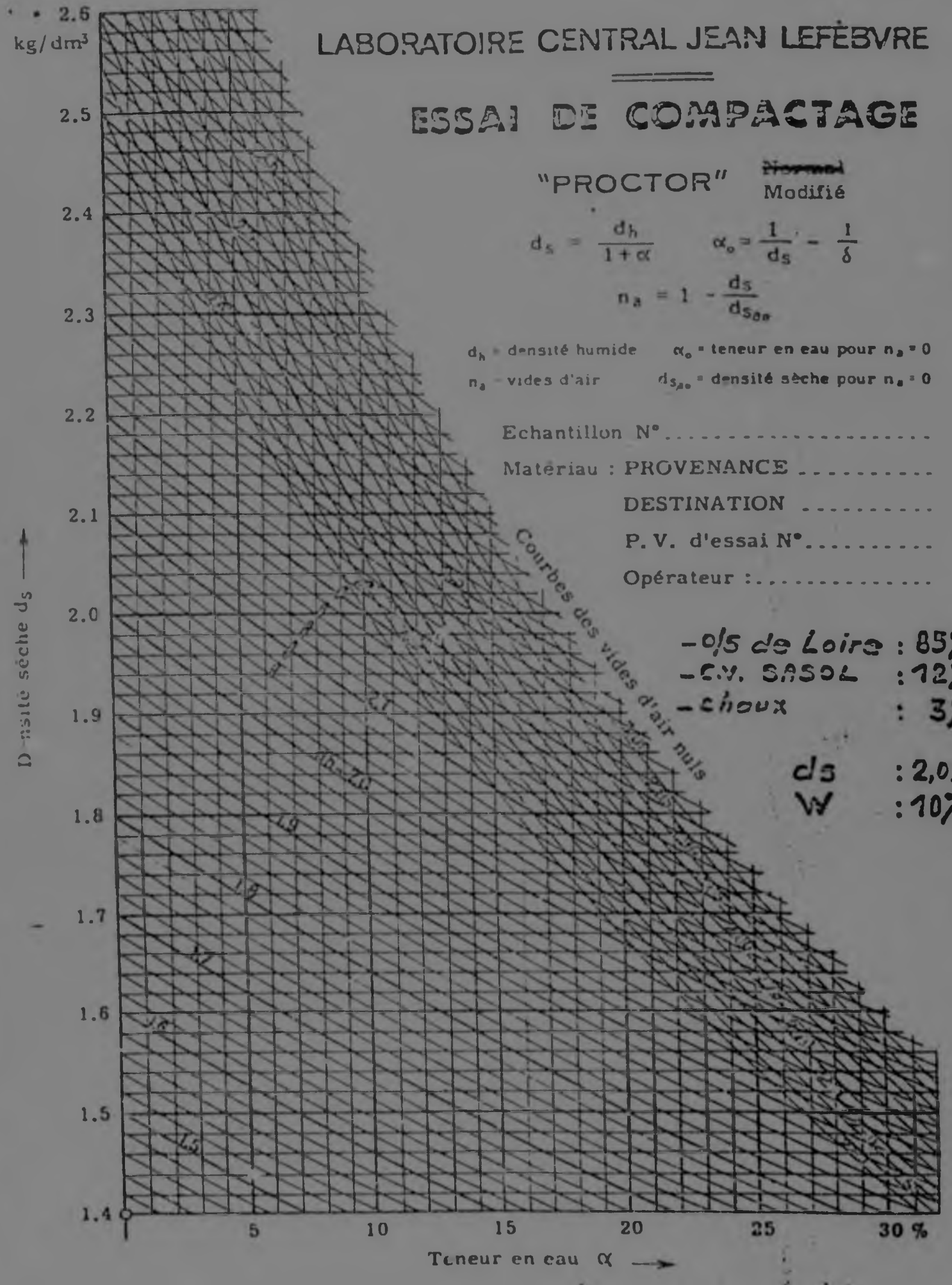
Echantillon N° .....

Matériau : PROVENANCE .....

DESTINATION .....

P. V. d'essai N° .....

Opérateur : .....



-o/s de Loire : 85%
-C.V. SASOL : 12%
-chaux : 3%

ds : 2,03
W : 10%

LABORATOIRE CENTRAL JEAN LEFÈBVRE

ESSAI DE COMPACTAGE

"PROCTOR" ~~Normal~~ Modifié

$$d_s = \frac{d_h}{1+\alpha} \qquad \alpha_o = \frac{1}{d_s} - \frac{1}{\delta}$$

$$n_a = 1 - \frac{d_s}{d_{s_{ao}}}$$

d_h = densité humide — α_o = teneur en eau pour $n_a = 0$

n_a = vides d'air — $d_{s_{ao}}$ = densité sèche pour $n_a = 0$

Echantillon N° .....

Matériau : PROVENANCE .....

DESTINATION .....

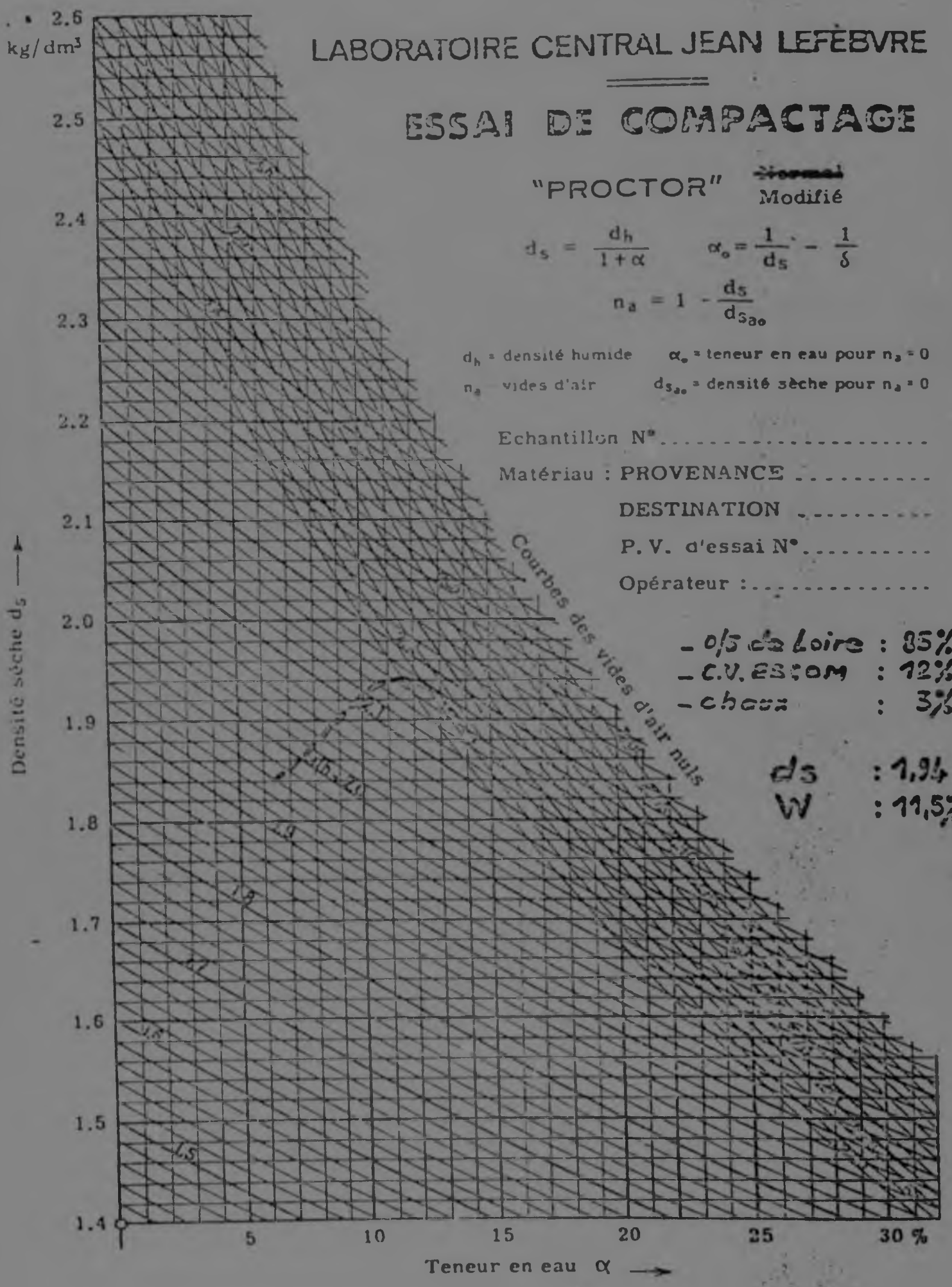
P. V. d'essai N° .....

Opérateur : .....

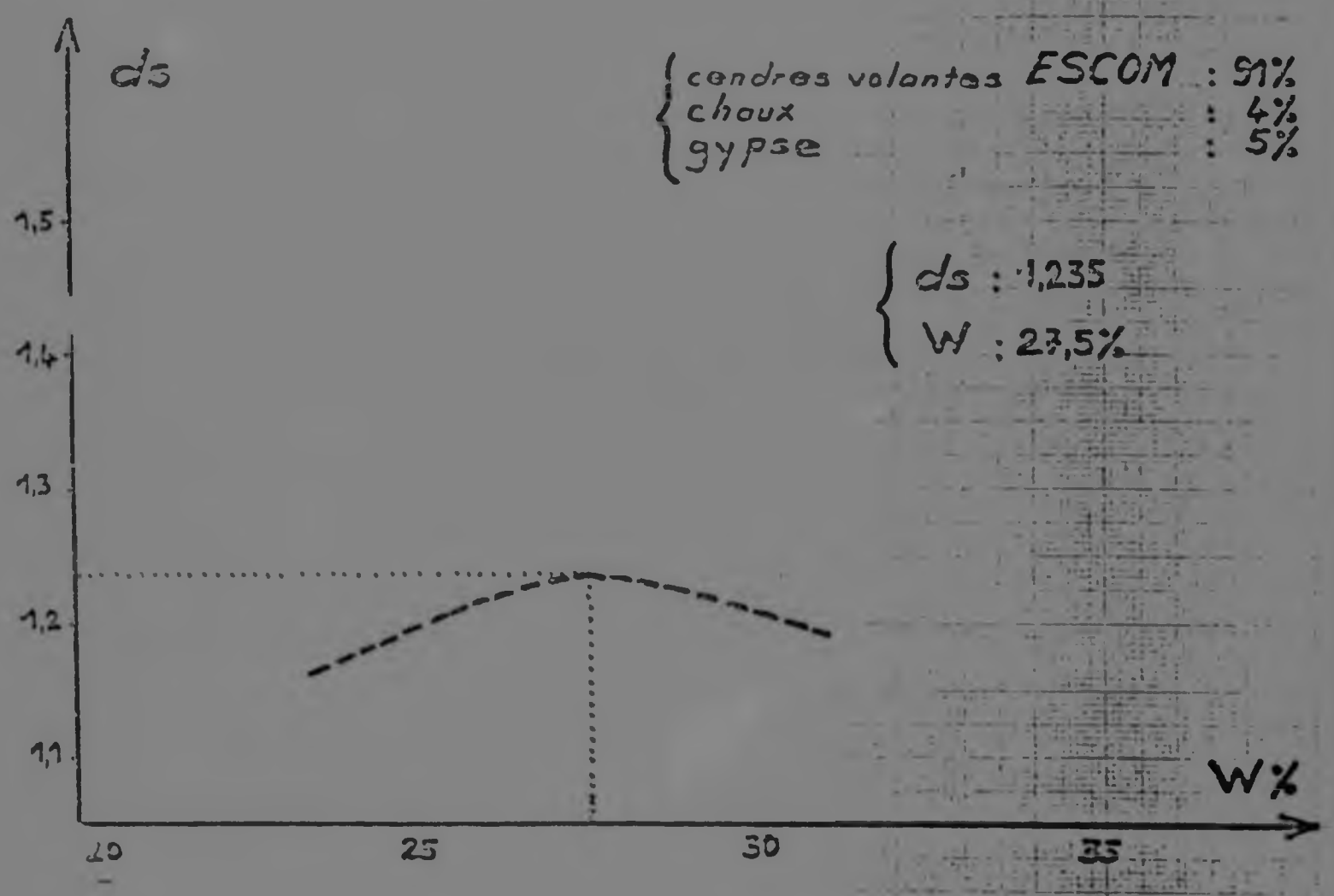
- o/s de Loire : 85%
- C.V. Estom : 12%
- chaux : 3%

ds : 1,94

W : 11,5%



Essai Proctor Modifié



{ cendres volantes ESCOM : 91%
{ chaux : 4%
{ gypse : 5%

{ ds : 1,235
{ W : 23,5%

LABORATOIRE CENTRAL - E.J.L.

à

E.J.L. - SIEGE

C.R. N°039/75

Le 06.03.1975

AFRIQUE DU SUD

Etude de cendres volantes en provenance de la Centrale de KELVIN à JOHANNESBOURG

1° - OBJET :

Dans notre rapport N°148/74 du 22.10.1974 nous avions établi les caractéristiques de différentes cendres volantes en provenance d'Afrique du Sud ainsi que leur possibilité d'utilisation pour le traitement des sables et des graves.

De nouvelles cendres, produites par la centrale de Kelvin à Johannesbourg nous étant proposées, il s'agit ici de comparer leur qualité aux cendres SASOL et ESCOM déjà étudiées.

2° - IDENTIFICATION DES CENDRES VOLANTES DE KELVIN :

Les principales caractéristiques de l'échantillon de cendres que nous avons reçu sont indiquées ci-dessous :

21 - Granulométrie
Sédimentométrie
} Elles sont définies par les courbes ci-jointes

22 - Surface spécifique Blaine : 4 725 cm2/g

23 - Poids spécifique : 2,18

...

3° - TRAITEMENT D'UN SABLE 0/5 ROULE DE LOIRE :

31 - Formules étudiées :

Nous avons étudié deux mélanges dont les compositions sont précisées ci-dessous :

- Formule N°1 : - sable 0/5 roulé de Loire : 85 %
  - cendres volantes de Kelvin : 12 %
  - chaux de Boran : 3 %

- Formule N°2 : - sable 0/5 roulé de Loire : 84,4 %
  - cendres volantes de Kelvin : 12 %
  - chaux de Boran : 3 %
  - gypse : 0,6 %

La courbe granulométrique caractérisant ces deux formules se trouve jointe en annexe.

32 - Essais mécaniques :

Les résistances en compression ont été mesurées dans les deux cas à 14 et 28 jours sur des éprouvettes d'élancement 2, compactées statiquement à l'O.P.M.

Les résultats sont consignés dans le tableau ci-joint.

4° - CONCLUSION :

Les cendres volantes de Kelvin que nous avons examinées sont, à notre avis, de bonne qualité et peuvent convenir pour le traitement des sables et surtout des graves.

...

Par leur granulométrie et leur finesse elles sont très proches du premier échantillon de cendres volantes SASOL que nous avions reçu d'Afrique du Sud.

Les performances obtenues ici dans le traitement du sable roulé de Loire sont intermédiaires entre celles correspondantes aux formules N°1 et N°2 (cendres SASOL) d'une part et N°3 et N°4 (cendres ESCOM) d'autre part, figurant dans notre compte-rendu N°148/74. Ces résultats témoignent d'une prise très nette des cendres de Kelvin, tout à fait comparable à celle que nous constatons habituellement avec les cendres produites en France.

F. LE BOURLOT

TABLEAU DES RESULTATS

Formule N°	1	2
1 - COMPOSITION :		
- sable 0/5 roulé de Loire	85 %	84,4 %
- cendres volantes de Kelvin	12 %	12 %
- chaux de Boran	3 %	3 %
- gypse	-	0,6 %
2 - PROCTOR MODIFIE :		
- densité sèche maximum	2,015	2,015
- teneur en eau optimum	10,0 %	10,0 %
3 - COMPRESSION :		
- Résistance en compression à :		
- 14 jours - air	4,5 bar	5,3 bar
- 28 jours - air	7,5 bar	20,2 bar
4 - Module de déformation à 28 jours - air	590 bar	2 390 bar

LABORATOIRE CENTRAL JEAN LEFÈBVRE

ESSAI DE COMPACTAGE

"PROCTOR" ~~Normal~~ Modifié

$$a = \frac{1}{d_s} - \frac{1}{\delta}$$

$$\delta = \frac{d_s}{d_{s_{a_0}}}$$

w_0 teneur en eau pour $n_a = 0$

d_{s_0} densité sèche pour $n_a = 0$

Échantillon N° .....

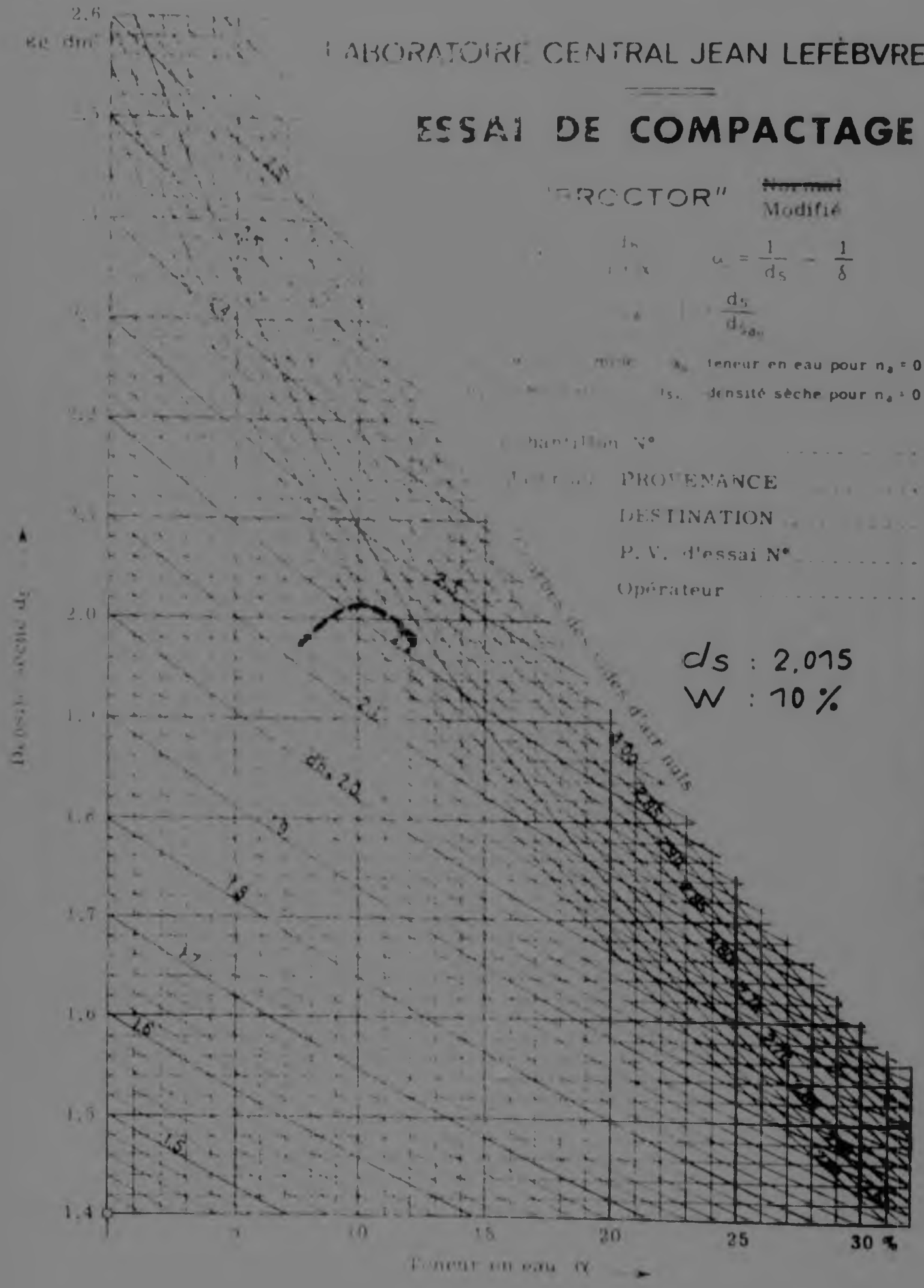
PROVENANCE .....

DESTINATION .....

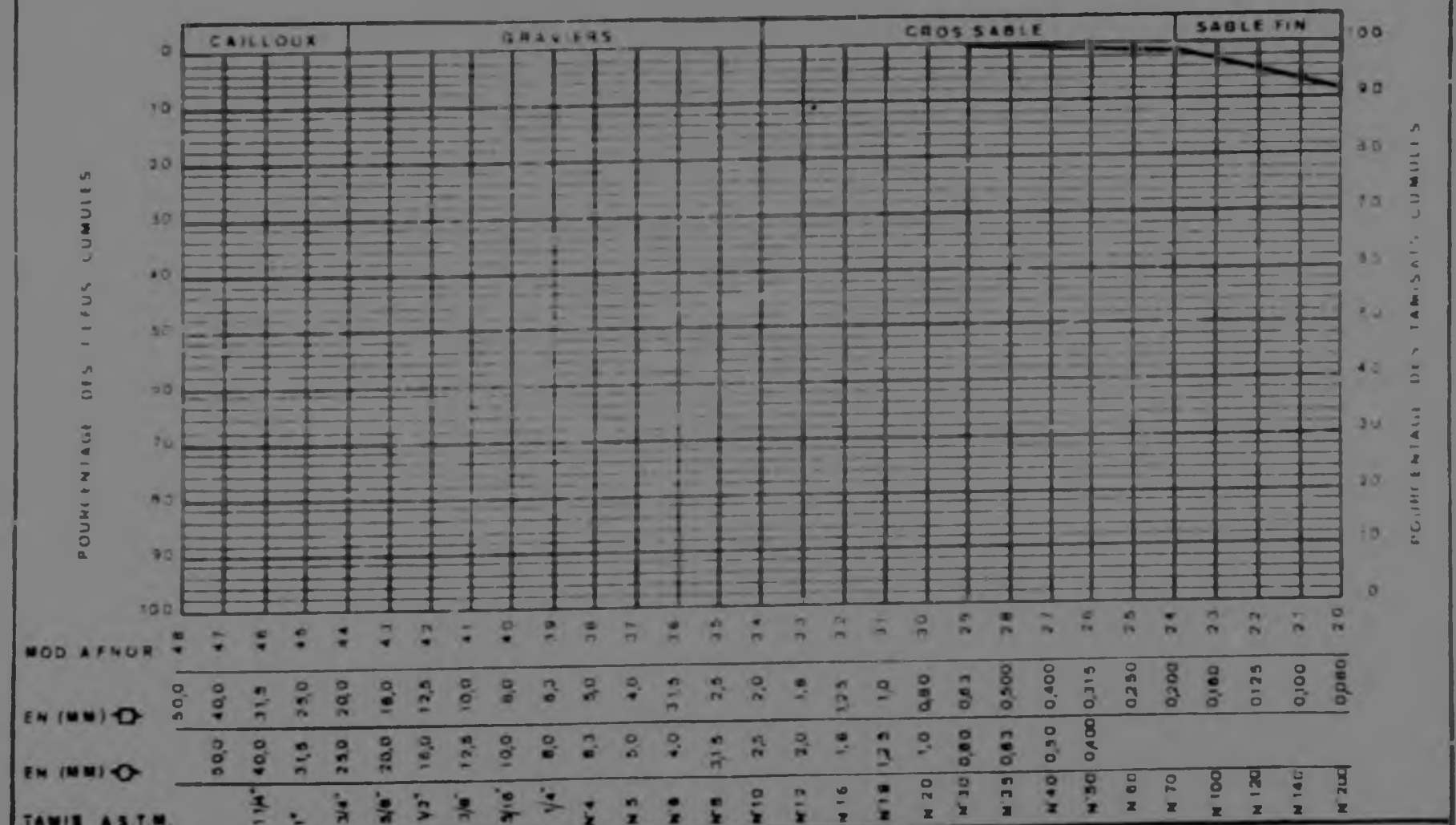
P. V. d'essai N° .....

Opérateur .....

ds : 2,075
W : 10 %



Centres volantes de Kelvin



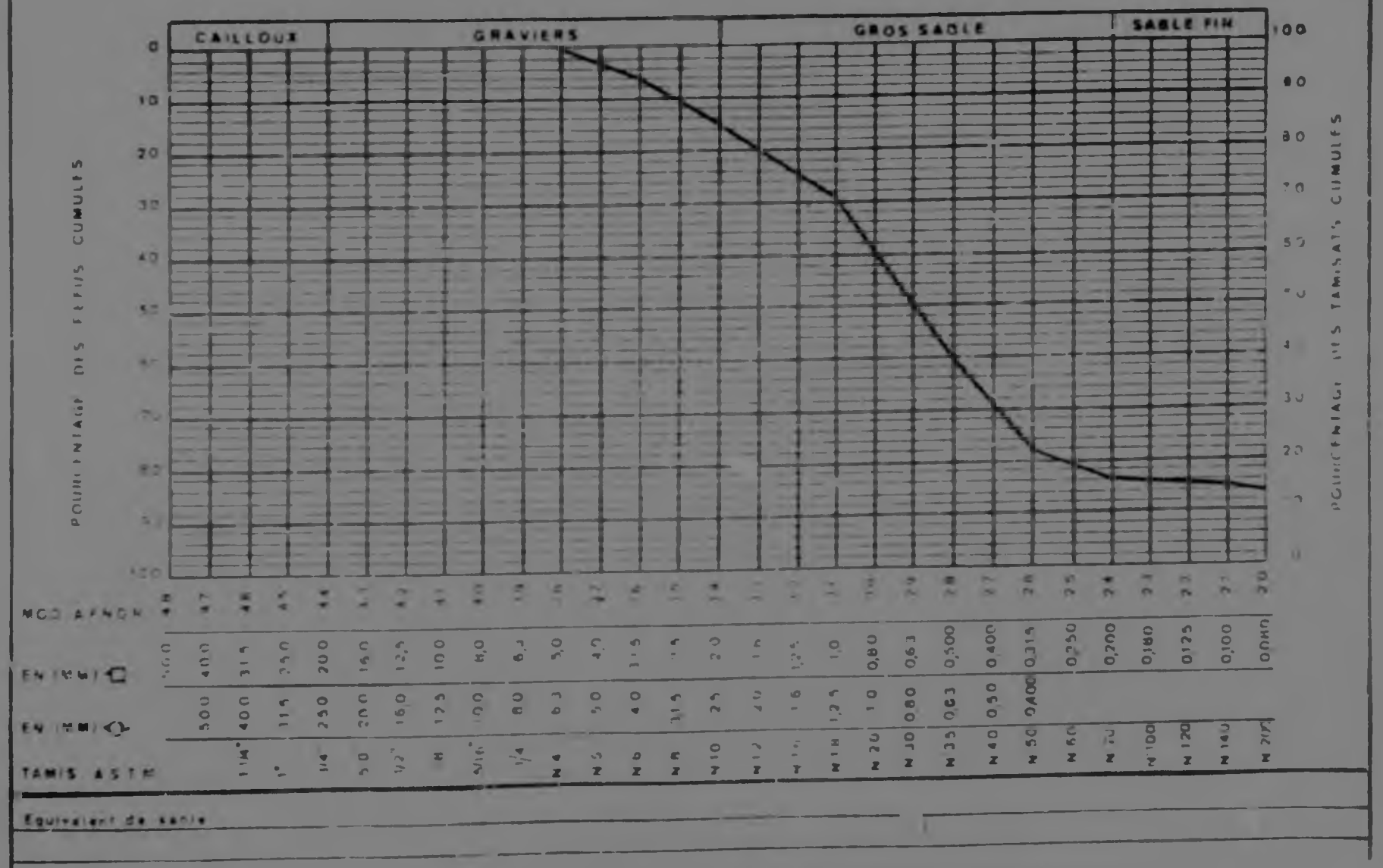
Equivalent de sable

Surface spécifique Blaine : 225 cm²/g

Poids spécifique : 2,18

Sable - C.V. - Chaux

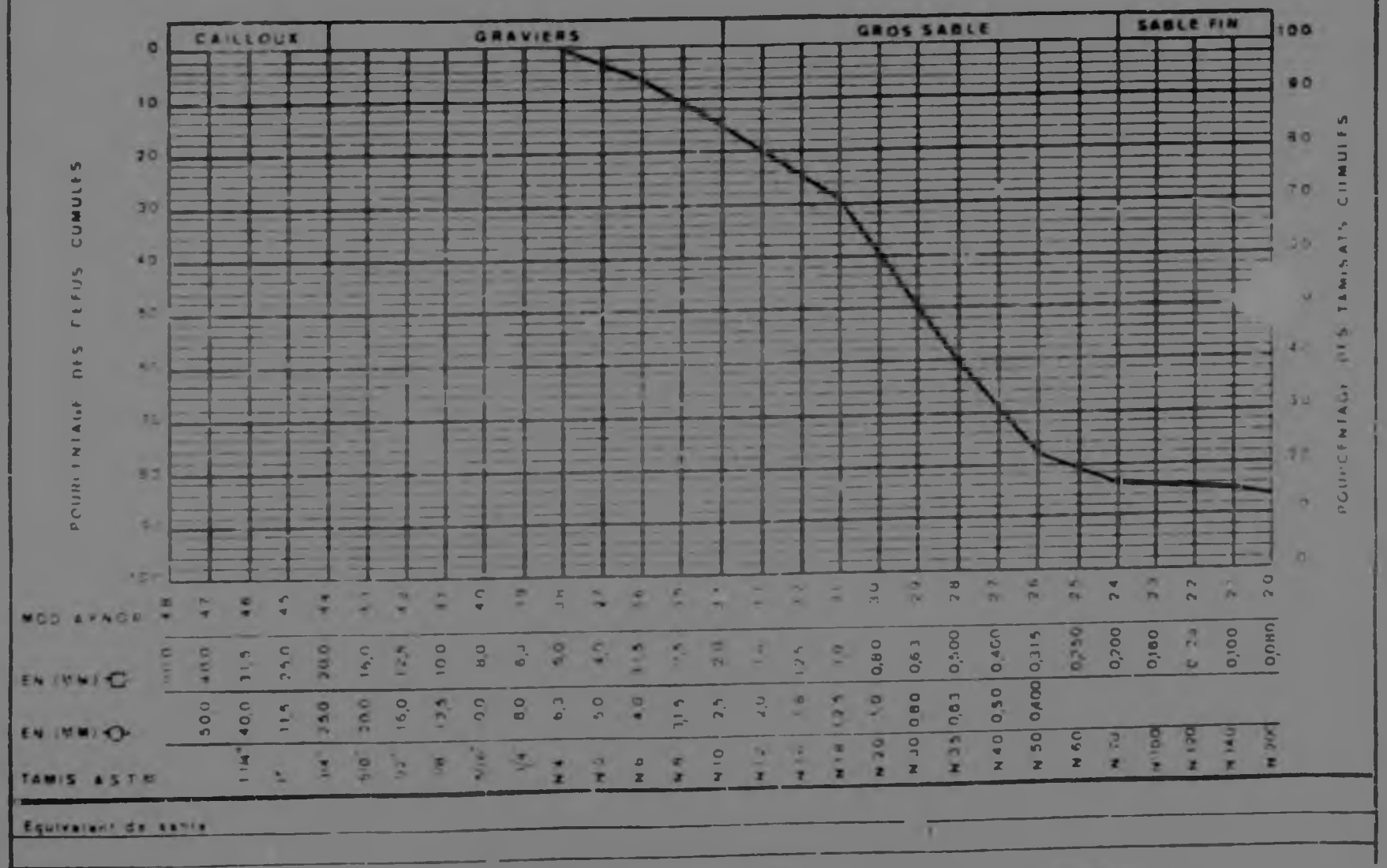
- sable 0/5 roulé de Loire : 85%
- C.V. de Kelvin : 12%
- Chaux : 3%



Equivalent de sable

Sable - C.V. Chaux

- sable D/S roulé de Loire : 85%
- C.V. de Kelvin : 12%
- Chaux : 3%



Equivalent de sable

Ets M. PERRIER 41 Av. Albert Bartholomé PARIS XV

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N° ZY21 22

ANALYSE GRANULOMÉTRIQUE

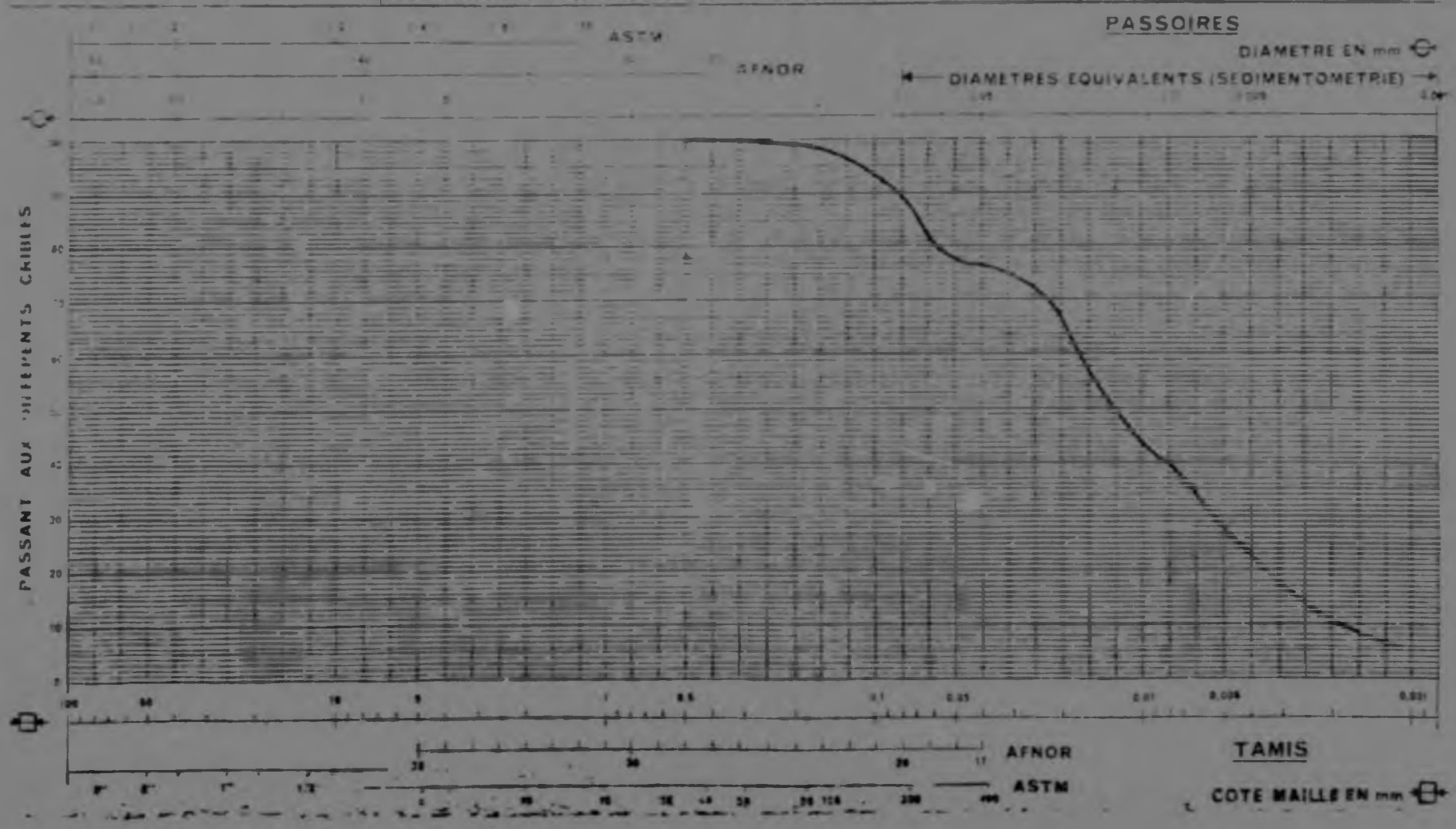
DOSSIER Afrique du Sud

DATE

OBSERVATIONS

PROVENANCE Centrale de Kelvin

ECHANTILLON Cendres volantes



LABORATOIRE CENTRAL — DOURDAN, le 20.01 1981

COMPTE REN[illegible] (013/81)

DOSSIER : AFRIQUE DU SUD

Etude de la réa[illegible]vité des cendres volantes produites en Afrique du Sud

---

DESTINATAIRE

M. AGIUS
M. DIMITRI
M. DELIGNE --- M. CHAUMONT
M. LE BOURLOT

1° - OBJET DE L'ETUDE :

Le but de cette etude est de tester la reactivité des cendres volantes produites en Afrique du Sud en les utilisant, d'une part, sous forme de melange : cendres volantes - chaux - gypse, et, d'autre part, comme liant pour le traitement d'un sable, avec activation à la chaux.

2° - IDENTIFICATION DES PRODUITS :

Les échantillons de produits reçus d'Afrique du Sud à cet effet ont été identifiés comme suit :

1 - Cendres volantes :

- Granulométrie :

- passant à :	1,0 mm	:	100 %
	0,5	:	99,5
	0,315	:	99
	0,200	:	98
	0,100	:	91
	0,080	:	86

- surface spécifique Blaine : 4120 cm2/g

- Poids spécifique : 2,176

- Imbrulés : 7,9 %

2 - Chaux vive :

- Granulométrie :

- passant à :	3,15 mm	:	100 %
	2,0	:	99
	1,0	:	89
	0,500	:	71
	0,315	:	59
	0,200	:	48
	0,100	:	33
	0,080	:	30

- surface spécifique Blaine : 3980 cm2/g

- Poids spécifique : 3,109

.../...

- Reactivite à l'eau (test L.C.P.C.) : t° = 35° C
- chaux libre : 80 %

3 - Gypse :

- Granulometrie :
  - passant à : 0,080 mm : 99,6 %
- surface spécifique Blaine : 6100 cm2/g
- Poids spécifique : 2,30
- pH (solution à 25 %) : 10,9

Les produits français utilisés comparativement aux précédents présentent les caracteristiques suivantes :

1 - Cendres volantes de Vitry sur Seine :

- Granulométrie :
  - passant à : 1,0 mm : 100 %
    0,500 : 99
    0,315 : 99
    0,200 : 99
    0,100 : 89
    0,080 : 82
- Surface spécifique Blaine : 3150 cm2/g
- Poids spécifique : 2,253
- Imbrulés : 6,7 %

2 - Chaux vive Réty :

- Granulométrie :
  - passant à : 3,15 mm : 100 %
    2,0 : 99
    1,0 : 96
    0,500 : 88
    0,315 : 82
    0,200 : 75
    0,100 : 64
    0,080 : 62

.../...

- surface spécifique Blaine : 5820 cm2/g
- Poids specifique : 3,162
- Réactivité à l'eau (L.C.P.C.) : t° = 66° C.
- chaux libre : 82 %

3° - ETUDE DE LA REACTIVITE DES CENDRES VOLANTES :

31 - Mélange cendres volantes - chaux - gypse :

Les cendres d'Afrique du Sud ont été testées à partir de la formule classique suivante employée en France :

- C.V. d'Afrique du Sud : 91 %
- chaux d'Afrique du Sud : 4 %
- gypse d'Afrique du Sud : 5 %

Les résistances à la compression de ce mélange, mesurées sur éprouvettes d'élancement 2 (5 x 10 cm) moulées à l'O.P.M., sont les suivantes :

- Résistance à : 7 jours - air : nulle
  14 jours - air : 0,75 MPa
  28 jours - air : 3,24 MPa
  90 jours - air : 3,45 MPa

Des gonflements tres importants et des fissurations sont apparus sur toutes les éprouvettes.

Le même mélange à partir de produits français n'a pas été essayé dans le cas présent, mais l'expérience que nous en avons nous permet de dire que les résistances obtenues à 90 jours avec les cendres d'Afrique du Sud sont fréquemment obtenues à 7 jours avec les cendres françaises, pour depasser ensuite 10,0 MPa à 90 jours.

32 - Traitement d'un sable fin par un mélange Cendres + chaux vive :

Les cendres d'Afrique du Sud et les cendres françaises de la centrale de Vitry sur Seine, activées successivement par la chaux vive d'Afrique du Sud et la chaux vive Réty, ont été employées comparativement pour stabiliser un sable fin de la région parisienne.

.../...

321 - Caractéristiques du sable :

- Granulométrie :

- passant à :	0,500 mm	:	100 %
	0,315	:	99
	0,200	:	97
	0,100	:	10
	0,080	:	4,8
- Equivalent de sable :	E.S.v.	:	38
	E.S.p.	:	28

322 - Formulation du mélange :

L'étude a été menée à partir de la formule de base suivante :

- sable fin	:	80 %
- cendres volantes	:	16 %
- chaux vive	:	4 %

Une formule supplémentaire a également été moulée avec incorporation de 1 % de gypse.

Les performances mecaniques, determinées comme précédemment sur éprouvettes d'élancement 2 (5 x 10 cm) compactées à l'O.P.M., sont inscrites dans le tableau ci-dessous :

Formule N°	1 (temoin)	2	3	4	5
1 - Composition :					
Sable fin	80 %	80 %	80 %	80 %	80 %
- C.V. Vitry (France)	16 %	-	16 %	-	-
- C.V. Afrique du Sud	-	16 %	-	16 %	15 %
- chaux vive Afrique du Sud	-	4 %	4 %	-	4 %
- chaux vive Réty (France)	4 %	-	-	4 %	-
- gypse Afrique du Sud	-	-	-	-	1 %
2 - O.P.M. : - ds max.	1,69	1,69	1,69	1,69	1,69
- W. opt.	13,5 %	13,5 %	13,5 %	13,5 %	13,5 %
3 - Compression :					
- Résistance à :					
- 7 jours	0,17 MPa	0	0	0,17 MPa	0,08 MPa
- 14 jours	0,43 MPa	0,10 MPa	0,07 MPa	0,25 MPa	0,27 MPa
- 28 jours	0,95 MPa	0,21 MPa	0,135 MPa	0,48 MPa	0,42 MPa
- 90 jours	2,45 MPa	0,63 MPa	0,59 MPa	1,23 MPa	1,57 MPa
-180 jours		(*)	(*)		(*)

(*) gonflement

.../...

Les melanges N° 2, N° 3 et N° 5 donnent lieu à un gonflement tres important (non mesure), alors que ce dernier reste très limité pour les compositions N° 1 et N° 4.

Les resultats a 180 jours seront communiqués ultérieurement.

4° - CONCLUSIONS :

Les principales conclusions de cette etude peuvent se résumer comme suit :

- les cendres d'Afrique du Sud font prise en présence de chaux, mais elles se revèlent sensiblement moins reactives que les cendres produites en France (comparaison des formules N° 1 et N° 4).

- des gonflements importants sont observés sur certains mélanges. Ils résultent de l'emploi de la chaux vive en provenance d'Afrique du Sud (comparaison des formules N° 1 et N° 3 d'une part et N° 2 et N° 4 d'autre part).

  Il s'agit d'une chaux très grossiere, vraisemblablement difficile à hydrater, qui n'est pas, à notre avis, adaptée à cet usage.

  Nous rappelons que les chaux vives employées en France avec les cendres volantes doivent posséder les caractéristiques suivantes :

  - teneur en chaux libre : $\geqslant$ 80 %
  - refus au tamis de 0,080 mm : $\leqslant$ 50 %
  - refus au tamis de 0,2 mm : $\leqslant$ 10 %
  - granularité : 0/2 mm
  - test de réactivité à l'eau : t° $>$ 60° C. en moins de 25 mm

- l'apport de gypse dans le mélange (formule N° 5) améliore les résistances mais ne supprime pas le gonflement et la fissuration.

En définitive, on peut dire que les cendres d'Afrique du Sud, moyennant l'emploi d'une chaux vive convenable à rechercher localement (voir spécifications ci-dessus), font prise mais les performances mécaniques obtenues restent, même dans ce cas, notablement inférieures à celles habituellement relevées avec les cendres produites en France.

F. LE BOURLOT

Laboratoire Central ENTREPRISE JEAN LEFEBVRE
rue LAMBERT — 21 de la Gaudiée
91410 DOURDAN — Tél 492 77 73

Equivalent de sable ES.v = 38
ES.p = 28

TAMIS ASTM	⌀ (mm)	⌀ (mm)	MODULE
		50,0	48
	50,0	40,0	47
1 1/2"	40,0	31,5	46
1"	31,5	25,0	45
3/4"	25,0	20,0	44
5/8"	20,0	16,0	43
1/2"	16,0	12,5	42
1/8	12,5	10,0	41
5/16"	10,0	8,0	40
1/4	8,0	6,3	39
N 4	6,3	5,0	38
N 5	5,0	4,0	37
N 6	4,0	3,15	36
N 8	3,15	2,5	35
N 10	2,5	2,0	34
N 12	2,0	1,6	33
N 16	1,6	1,25	32
N 18	1,25	1,0	31
N 20	1,0	0,80	30
N 30	0,80	0,63	29
N 35	0,63	0,500	28
N 40	0,50	0,400	27
N 50	0,400	0,315	26
N 60		0,250	25
N 70		0,200	24
N 100		0,160	23
N 120		0,125	22
N 140		0,100	21
N 200		0,080	20

POURCENTAGE DES REFUS CUMULES

100 90 80 70 60 50 40 30 20 10 0

CAILLOUX
GRAVIERS
GROS SABLE
SABLE FIN

0 10 20 30 40 50 60 70 80 90 100

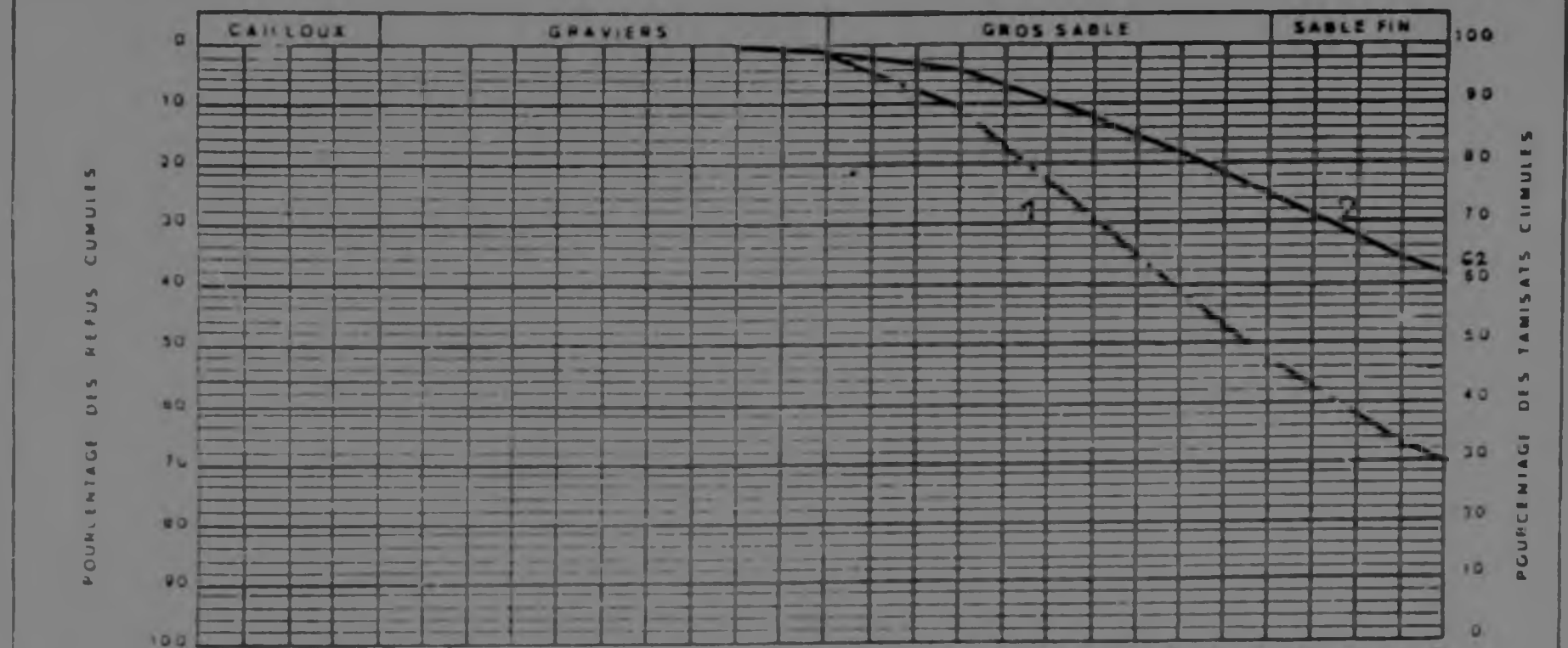
POURCENTAGE DES TAMISATS CUMULES

Sable Fin

Laboratoire Central ENTREPRISE JEAN LEFEBVRE
rue LAMBERT 21 de la Garenne
91410 - DOURDAN - Tél 492 77 73

Chaux vives

1_ Afrique du Sud
2_ France (Réty)



| | | |

APPENDIX 2

DATED 3RD. FEBRUARY, 1976

(NOTE: This letter was written when it was thought that the Government Mining Engineer would prohibit the use of minesand)

SUBJECT: FLYASH MIXTURES:

1) The inability to use minesand is a great setback because the studies based on this material now become redundant.

Perhaps it will be found possible to use at least some of these minesands.

As it seems difficult to find suitable materials to replace the sand in an urban area we shall be able to use the preliminary studies which dealt with the stabilization of flyash alone as a base material.

2) It would seem that in this case one can obtain a base layer capable of supporting average traffic with a mixture of 94% flyash, 5% lime and 1% gypsum.

A 15cm thick layer of such a mixture will permit of an interesting experiment.

3) It is not impossible to treat an in situ soil with a mixture of flyash, lime and gypsum but it will be necessary to carry out experiments with the soil to be used.

For the construction of such a work we unfortunately cannot give a practical example. In France we have always used a central mixing plant for this type of work.

Construction on a large scale, that is to say on a number of projects, will require a preliminary trial to determine a method of mixing the stabilizing materials with the insitu soil.

The sequence of operations will be relatively standard and will include the use of a cement spreader and PULVI-MIXER, plus watering and compaction equipment.

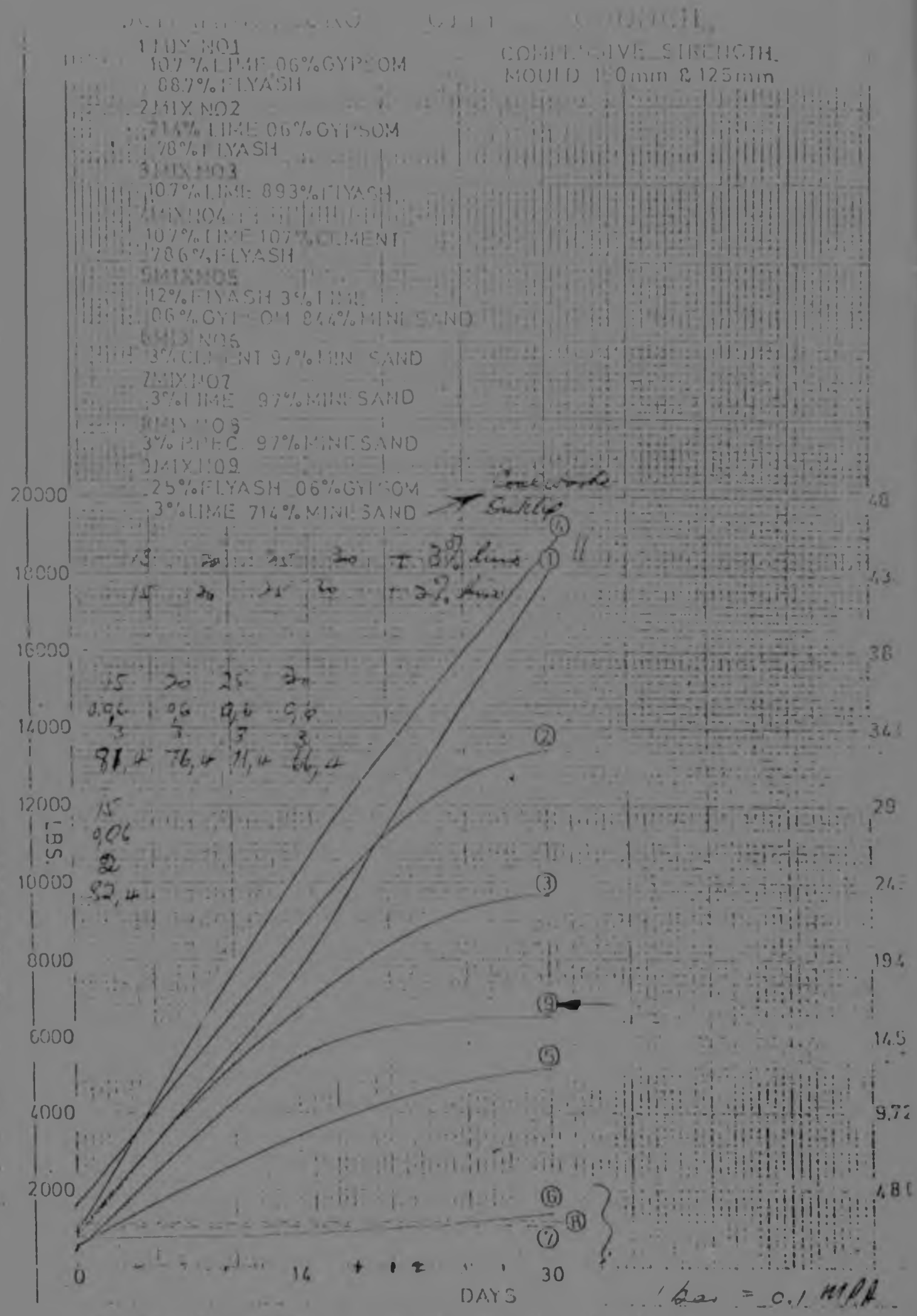
It is not impossible to carry out a demonstration experiment with successive spreading of first the soil, then the flyash, then the lime and finally the gypsum.

I would be able to help you prepare such a demonstration on a test section of about 300m long.

These operations will have to be investigated thoroughly and a specific method will have to be evolved which will be practical on a commercial scale.

Could you perhaps find out whether the Municipality is prepared to carry out such an experiment and to ask them to proceed with a laboratory study on which we could base the demonstration.

SIGNED: C. DIGUE



COMPRESSIVE STRENGTH
MOULD 150mm & 125mm
1 MIX NO1
107% LIME 06% GYPSOM
887% FLYASH
2 MIX NO2
714% LIME 06% GYPSOM
78% FLYASH
3 MIX NO3
107% LIME 893% FLYASH
4 MIX NO4
107% LIME 107% CEMENT
786% FLYASH
5 MIX NO5
12% FLYASH 3% LIME
06% GYPSOM 844% MINE SAND
6 MIX NO6
3% CEMENT 97% MINE SAND
7 MIX NO7
3% LIME 97% MINE SAND
8 MIX NO8
3% RPEC 97% MINE SAND
9 MIX NO9
25% FLYASH 06% GYPSOM
3% LIME 714% MINE SAND
Cockwork
Sunlip
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
LBS.
0
14
30
DAYS
48
43
38
34
29
24
19.4
14.5
9.72
4.80
1 bar = 0.1 MPA

1. Curves (1) (4) show that 10,7 lime + 0,6 gypsum give the best stabilizing agent with a strength very close to 10,7 lime + 10.7 cement

2. Curve (2) shows that beyond 10 - 12 % lime, the increase of lime is not useful.

3. Curve (3) shows the effect of gypsum, without with strengths are significantly lower.

4. Curve (5) (6) show the increase of strength for sand. Lime fly ash mixtures with the increase of

It is to be noted that the last point of c -v seems a bit too low, so the shape of the curve is not of the general shape of others curves.

From the gap between curves 6 7 8 and others, the influence of lime fly ash can be clearly shown

5. The shape of curves 2 3 5 9 - lead to forecast a further increase of strength with time of significant importance. That confirm the "pozzolanic" action of lime fly ash.

5

These tests are very significant and allow to go the case studies for implementation of the project of F.A. through many alternatives

For example, for stabilisation of sands, we must try to obtain

Medium traffic
10 bars at 14 days for foundation course
15 — — — base course
Heavy traffic
15 bars — — foundation c/
20 bars — — base c/

The thickness being 6 in. for medium traffic and 8 in for heavy traffic, minimum figures.

To obtain the above data, we can vary
— % lime between 3 and 5%
— % F.A. — 15 — 30%

It would be interesting to see if the mix of curve 5 would improve with the addition of 2 to 4% cement while the action of cement seems not useful in mixes with pure fly ash, it may prove beneficial with sand-FA-lime mixtures.

Neuilly 12 17 75

Ch Sigue

It also became quite obvious that although the use of metalliferous slags in road construction is a promising development, and should be explored for application in South Africa, one of the big problems experienced in France relates to shrinkage cracking of the surfacing. Under the drier South African climatic conditions this problem may prove to be even more severe, and we may find ourselves faced with severe cracking problems similar to those experienced a few years ago with cement-treated crusher-run road bases.

Session V : Fly-Ash

General Reporter Nicolescu : report read by Bonnot.

It is evident that fly-ash from different countries reacts differently and that fly-ash will have different properties from time to time, even when taken from the same power station. There are two basic types of fly-ash : silica-alumina ashes which require activation in order to develop cementing action, and sulpho-calcic ashes which are self cementing. The bulk of fly-ash is transported hydraulically to storage, and therefore loses some of its cementitious properties.

When used as fill the density of fly-ash is found to be fairly constant regardless of origin. The compaction characteristics are good with a flat compaction curve that is relatively insensitive to moisture content. The shear strength of the material results almost entirely from internal friction, and is excellent. Fly-ash is currently used in road construction and building construction. Its uses in road construction are to construct fills, for pavement foundations and as a filler in asphalt premixes. When used as a fill its main advantage is its light weight which makes it suitable for constructing embankments over marshy ground. In pavement foundations fly-ash can be used to improve the grading of certain soils, e g single sized sands, and it can also be used as a cementing agent to stabilise soils. When added to clay soils the liquid limit is decreased, although the plasticity index remains almost constant. Free swell and swelling pressure are also decreased. Similar results are obtained whether the precipitator ash or lagoon ash is used, but lagoon ash is less active than precipitator ash which has never had access to moisture.

Fly-ash lime mixes have the advantage of a slow rate of strength gain. This however, does have the disadvantage that the material cannot be trafficked soon after laying. The rate of strength increase can be accelerated by adding phospho-gypsum, a typical mix consisting of 75% ash, 15% lime and 10% phospho-gypsum. When used as a filler in asphalt fly-ash is just as effective as lime and its effect on the grading of the aggregate may actually result in an overall decrease of the bitumen requirement. When used in concrete the main disadvantage of fly-ash is its low rate of strength gain. This rate may be accelerated by adding vitreous silica dust. Fly-ash may also be sintered to produce lightweight aggregate. This aggregate is porous and open-pored which results in an increased water demand.

When used in grouts the fluidity of the fresh grout may actually be increased by the spherical nature of fly-ash particles.

In discussion, Rheinhart of Sweden described a pilot plant to recover vanadium and nickel from fly-ash resulting from the burning of fuel oil. This fly-ash has been found to contain 2 to 5% of vanadi and 1 to 3% of nickel. Germanium also occurs in certain fly-ashes. The recovery process has proved so successful that the capital cost of the installation is expected to be recouped within 3 years.

Session VI : Incinerator Refuse

Incinerator refuse results from the incineration of domestic refuse. The untreated domestic refuse is incinerated, after which the material is screened and the content of magnetic material removed. The screened material consists of glass, scoria, ceramics etc. The material has been used with some success in as road fill and for road bases and sub-bases, but is not recommended for wearing course as the particles break down easily under traffic. There are some indications that autogenous setting occurs in compacted incinerator refuse., and that the strength increases with age. Surfaced roads constructed over incinerator refuse have been observed to develop blisters. The cause did not appear to be known, but in discussion with General Reporter, Hirt, after the session, it transpired that these are probably salt blisters. Incinerator refuse cannot be successfully stabilised with cement, as an alkali-aggregate reaction

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occurs between the cement and glass content. The toxicity of incinerator refuse has scarcely been studied. Thin layers covered by relatively impervious surfacings are thought to be harmless. The refuse does however, cause severe corrosion of services buried in it.

In discussion, it was pointed out that mercury, lead, chromium and tin may occur in incinerator refuse in quantities exceeding 10 mg per kg. They may also contain organic acids which may be carcinogenic. Hence particular care should be taken with dumps of these materials.

Session III : Mine Refuse

Reporter : Sherwood

The trend to use lower grade ores together with the expanding demand for metals has resulted in an ever increasing accumulation of mining wastes. As sources of conventional building aggregates are limited, especially in Europe, mining waste is being increasingly used by the construction industry. The main material available in Europe is colliery waste. As the quantity available far exceeds any possible demand for reutilization, extensive landscaping and vegetation of colliery waste tips has been undertaken in Great Britain and elsewhere. Both unburned shales and shales which have burnt by spontaneous combustion, or been ignited by dumping hot ash on the tip, have been used in road construction. There is no record of fills constructed of unburned colliery shale ever catching fire by spontaneous combustion, as a dense fill provides little opportunity for the access of the oxygen necessary to support combustion.

Unburned shale may also be used as raw material in cement manufacture, and to make burned clay bricks and light weight concrete aggregate.

Concluding Remarks

The Conference proved to be most interesting and informative - Of particular interest to South Africa is the research which has been carried out into the utilisation of granulated slag and fly-ash in road construction. In particular, the technique of partial grinding should be investigated as a means of increasing the hydraulic reactivit of both South African granulated slags and fly-ashes. Partial grinding

does not appear to have been applied to fly-ashes by anyone so far, but as the main shortcoming of South African fly-ash appears to be its coarse grading, it would appear to be well worthwhile investigating the possibility of increasing the reactivity in this way.

The main defect of the Conference was that both contributions and attendance were dominated by French and British delegates, both of whom tended to be somewhat insular in their outlook, and to be interested only in waste materials which are a particular problem in their respective countries.

JEAN LEFEBVRE
travaille pour vous

AD/CG-32-

APPENDIX 4

Direction Technique
et Laboratoire Central
Rue Lambert
Z.I. de la Gaudrée
91410 DOURDAN
Tél. : 492.77.73
Télex : 692687 F Tarfile

ENTREPRISE JEAN LEFEBVRE
S.A. (PTY) LTD
P.O. Box 91231
AUCKLAND PARK 2006
Republic of South Africa

For attention Mr R. DISON

OBJET : S.A. FLY ASH - Lime -
Gypsum testing at DOURDAN

DOURDAN, 23/2/1981

Dear Dirk,

You will find enclosed herewith a report concerning our testing of samples you sent, sometimes ago, to determine the comparative reactivity of french and S.A. Fly Ash and lime.

You will notice that cross testing has been performed such that S.A. Fly Ash has been tested using french and South African lime and equally S.A. lime has been tested with french and S.A. Fly Ash.

You will read in detail the report but I may summarise it by saying that :

1 - S.A. Fly Ash is less reactive than french Fly Ash whe ther treated with either quick limes

2 - S.A. quick lime is far less reactive than french quick lime and more, it has a swelling action which is not at all common in France

3 - When adding 1 % gypsum to an S.A. mix the performance are quite comparable to the mix containing S.A. Fly Ash and french quick lime

It therefore appears that the main problem is the quick lime. It may of couse be this particular sample of quick lime which must be incriminated. You will find in the report the french specifications for quick lime and it might be of interest to compare with S.A. spécifications.

ENTREPRISE JEAN LEFEVRE
Société Anonyme au capital de 36 135 000 F régie par les articles 118 à 150 de la loi sur les Sociétés commerciales
Siège Social 11, bd Jean Mermoz 92202 Neuilly sur Seine Tél 747 54 00 Télex 620510 Tarfile X Nilan
R.C. Paris B 542 067 541 CCP Paris 1792 77 Adresse Tél TARFILMAC PARIS Conditions au verso

.../...

Fly ash on the other hand, though weak, may still be considered if an adequate lime is used and gypsum is added.

You will understand that we have not gone any further in our testing, and particularly in the LH 38 field, considering the very disapointing resistance values and the very worrying swelling and cracking of the test cylinders.

We remain of course at your disposal for any further testing as soon as you have solved the problem of lime.

Best regards

A. DIMITRI

Copie : Mr AGIUS
Mr DELIGNE

REINFORCED EARTH : APPLICATION OF THEORY AND RESEARCH TO PRACTICE

David P McKittrick*

This technical paper was presented as the keynote address at the Symposium on Soil Reinforcing and Stabilising Techniques sponsored by the New South Wales Institute of Technology and the University of New South Wales on October 16, 1978 in Sydney, Australia.

In the eleven years since the first commercial use of Reinforced Earth®, over 2,200 structures have been completed These structures have included retaining walls and bridge abutments for transportation applications industrial structures including material processing and storage facilities containment dikes for crude oil and liquified natural gas storage and foundation slabs and hydraulic structures such as seawalls flood protection structures sedimentation basins and dams Structures have been completed in all parts of the world in a variety of environmental settings structures have been designed for, and been subjected to, a variety of loading conditions including static, moving and dynamic loads thermal stresses and hydraulic and seepage forces The performance of these structures has been closely monitored either through gross observation or by precise instrumentation This experience has provided the opportunity to critically examine theoretical and applied research, to compare predicted with actual performance, to refine design procedures, and to improve construction methods and technology to optimize economics This paper reports on the present state of the art from a practicing engineer s viewpoint and proposes design procedures that are consistent with both basic soil and structural mechanics theory as well as observed behavior of completed structures

INTRODUCTION

In his "State-of-the-Art" address prepared for the American Society of Civil Engineers (A S C E) Symposium on Earth Reinforcement, our late colleague, Dr Kenneth Lee (1) reviewed not only the papers that had been submitted for publication but also the status and results of research programs that he had actively directed, supported or reviewed during the several years that he and his associates had been involved in this topic In his paper he listed several topics that he believed were in need of further study and advised caution in drawing far reaching conclusions from limited basic research data (this list is reproduced in Table I) A conscientious reader of his paper might, however, be somewhat puzzled by what would appear to be a contradiction contained therein that is, his acknowledgment that "today (1978) the practice of using Reinforced Earth for appropriate geotechnical engineering projects is well established, and rational design procedures have been developed and demonstrated on many successful projects" and his admonition that "the behavior of Reinforced Earth is actually very complex and many more years will elapse before the basic mechanisms are clearly established to everyone s satisfaction" The same conscientious reader must then ask from what sources do practicing engineers derive the confidence and experience to design and construct civil and industrial works using this new material, knowing full well that the failure of these structures could imperil the public safety and cause significant economic disruption and monetary loss These sources are, of course, the same theoretical and experimental studies known to and reviewed by Dr Lee, augmented and interpreted in the light of experience with the design, construction and constant surveillance of actual Reinforced Earth structures In this paper, I will attempt to re-examine those several topics cited by Dr Lee in light of actual field experience in the United States and other countries, in an attempt to demonstrate that Reinforced Earth structures are designed on the basis of rational and usual engineering procedures and that, while certain behavior mechanisms may be complex, they still may be explained by basic soil mechanics theory and appropriately conservative parameters can be selected to account for these behavior mechanisms in the design of actual structures

Proposed by Kenneth L Lee 1978
1 Sliding shear resistance between soil and reinforcing material
2 Fundamental behavior mechanisms and practical design parameters
3 Long term durability or corrosion of reinforcing materials
4 Backfill of cohesive soil or soil with fines

Table I: Reinforced Earth Topics for Further Study (Beginning with the most important)

Reflecting on the present state of the art from a practitioner s standpoint and reviewing the amount of published data now available, I cannot disagree with the content of Dr Lee s table I would, however, rearrange and combine some of the topics Table II contains a somewhat parallel listing of the factors or topics dealing with Reinforced Earth which are most important from a design and performance viewpoint The order is derived not only from personel experience but also from the expressed concerns of the engineers with whom we deal on a daily basis

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Because they are interrelated, I have chosen to discuss items Ia and b and III in sequence. The durability question will be presented last, not because it is unimportant, but because it can be conveniently separated.

I	Basic Mechanics of Reinforced Earth
	a State of Stress in a Reinforced Earth Structure
	b Frictional Relationship between Soil and Reinforcements
II	Durability of Buried Metal Reinforcements
III	Selection of Soil for Use in Reinforced Earth Structures

Table II Topics of Major Importance to the Safety and Economy of Reinforced Earth Structures

In all project specific discussions of Reinforced Earth, the first question asked is "how does it work?" Having explained that the basic working mechanism depends on the efficient combination of metallic reinforcements and granular soil, the engineer's concern immediately shifts to the durability or service life question because it appears that most engineers, either through their work or educational experience, have concluded that metal buried in the earth will corrode in a time period inversely proportional to their years of experience. Engineers believe they understand the concept of friction and they have apparently decided that the complexities in data published by the researchers are the result of bad testing. They seem less interested in the selection of the backfill, believing this question to be one merely of economic concern. Before reviewing the status of research on the listed topics, it is important to understand the basic mechanics of the material under consideration.

I. Basic Mechanics of Reinforced Earth

The basic mechanics of Reinforced Earth were well understood by Vidal and were explained in detail in his early publications. A simplification of these basic mechanics can be illustrated by Figure 1. As shown in Figure 1a, an axial load on a sample of granular material will result in lateral expansion in dense materials. Because of dilation, the lateral strain is more than one half the axial strain. However, if inextensible horizontal



Fig 1: State of Stress in Reinforced Earth

reinforcing elements are placed within the soil mass, as shown in Figure 1b, these reinforcements will prevent lateral strain because of friction between the reinforcing elements and the soil, and the behavior will be as if a lateral restraining force or load had been imposed on the element. This equivalent lateral load on the soil element is equal to the earth pressure at rest ($K_o\sigma_v$). Each element of the soil mass is acted upon by a lateral stress equal $K_o\sigma_v$. Therefore, as the vertical stresses increase, the horizontal restraining stresses or lateral forces also increase in direct proportion. Thus, for any value of the angle of internal friction ϕ normally associated with granular soils, the stress circle lies well below the rupture curve at all points. Failure can occur only by loss of friction between the soil and the reinforcements, or by tensile failure of the reinforcements. This fundamental principle was examined and confirmed by Schlosser and Lorige (2), Hausman (3) and others. Theoretical relationships were developed between the spacing and tensile resistance of the reinforcements and the increase in anisotropic pseudo-cohesion of the reinforced materials. Finding conclusions from this earlier research restrictive of wider applications of earth reinforcing, Bassett and Last (4) have further investigated this concept with analyses of a non-cohesive soil reinforced with a uni-directional reinforcement system subjected to plane strain. Using a Mohr circle of strain rate, Figure 2a, the investigators have determined the direction of the major and minor principle strains, ϵ_1 and ϵ_3, and also the direction of the zero strain planes α and β which define an arc segment containing the minor principle strain direction ϵ_3, within which all normal strains would be tensile and reinforcement horizontal in line with the maximum principle tensile strain. This direction is used in actual Reinforced Earth retaining walls. Figure 3b shows the effect on the same strain fields and potential failure planes when reinforcements are inserted in the soil matrix in a direction parallel to ϵ_3. Since the modulus of the reinforcing material is generally very much greater than that of the soil and as efficient frictional bonding occurs between the soil matrix and the reinforcements, the direction of the reinforcement must be aligned with one of the zero extension characteristics. Referring to Figures 2b and 3a, the β characteristics of a composite material would be rotated to become very nearly horizontal and the α characteristics are forced to follow. The potential rupture or failure mechanism would also attempt to re-align with these new characteristics. Such a re-alignment is in substantial conformity to the locus of maximum tensile strains measured in several full scale structures, Schlosser et al (5), Figure 23. Vidal assumed that this composite material could be used to construct a coherent gravity structure, and that the properties of the structure would be similar to that of the theoretical and experimental models. Certainly, empirical adjustments would have to be made to account for horizontal and vertical discontinuity of the reinforcements. Adjustments would also be made for boundary conditions at the facing of the structure, point and magnitude of applied loading, foundation conditions, thrust of the backfill and other project-specific conditions.

In most research programs involving a study of the mechanics of materials, a fundamental behavior or failure mechanism is assumed. All studies thereafter build from that initial hypothesis. Experiments are designed to examine properties or individual components of the material, and very often many years are spent trying to rationalize and modify data to fit the initial assumption. Such has apparently been, and unfortunately continues to be, the case with Reinforced Earth. Many researchers have embarked on extensive research programs using the hypothesis that Reinforced Earth structures, in particular retaining structures, are analogous to tied back walls. The literature on Reinforced Earth is replete with references to "tie forces," Rankine failure planes, and other topics relevant to the analysis and design of anchor systems. These conscientious investigators have apparently neglected or misunderstood the basic mechanics of the material or the significant and substantial

documentation that has existed for several years that should when seriously considered in the light of actual structural performance, eliminate the tie-back or anchor approach as a conceivable failure mechanism. Before investigating structural behavior in more detail I believe it is useful to compare the two hypotheses i.e., composite material and tie-back, to determine if, in fact, they are so different.

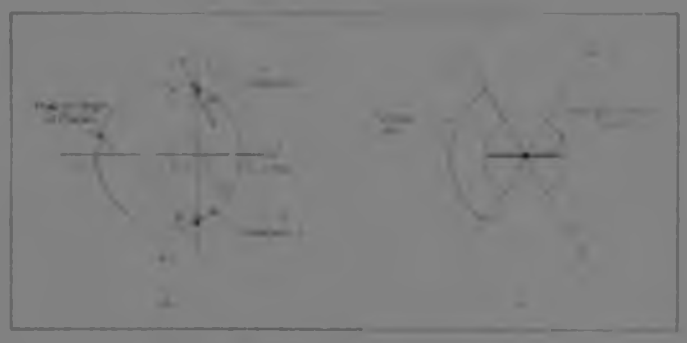


Fig 2 Mohr Circle of Strain Rate

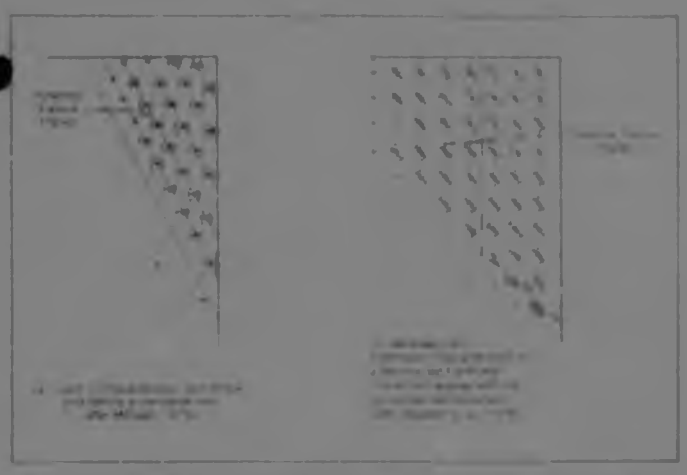
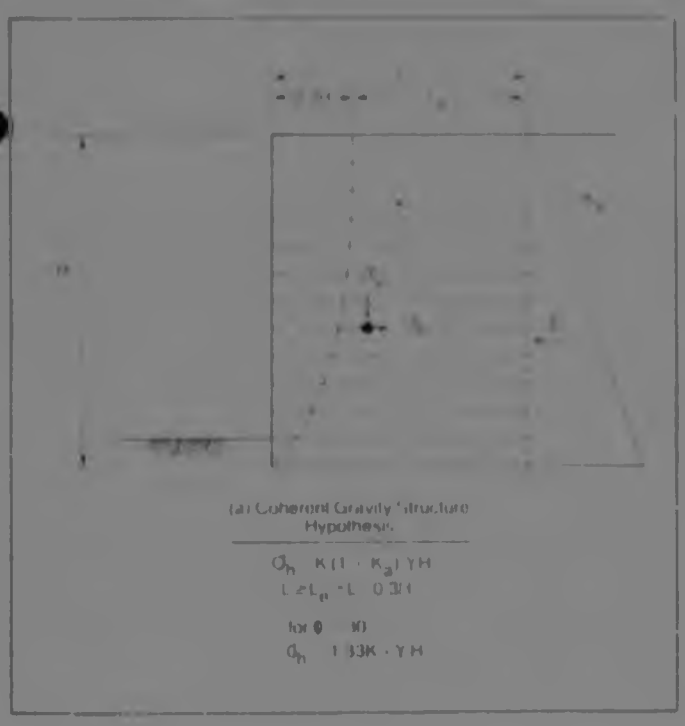


Fig 3 Strain Field Orientation-Cantilever and Reinforced Earth Retaining Walls



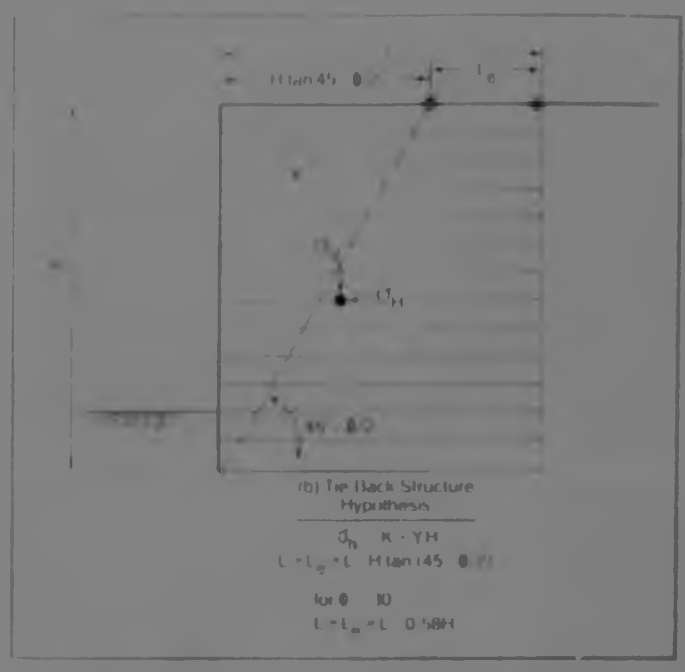


Fig 4 Design Hypotheses for Reinforced Earth Walls

Figures 4a and b demonstrate the significant differences in fundamental dimensions and stresses which can be obtained by use of the design procedures ordinarily used for the two basic mechanism theories. (The derivation of the design procedure and dimensions from the "coherent gravity structure" hypothesis will be developed later in this paper.)

For the same earth pressure coefficients, the use of Vidal's approach would require more reinforcements to resist the higher calculated stresses, but the required length of the reinforcements would be shorter than that calculated by the anchor theory. Referring briefly to a published case study reported by Al Hussaini (6), Figure 5 demonstrated that use of the "coherent gravity structure" analysis would have predicted a conservative and safe design. It would not have been necessary to rely on empirically adjusted values.

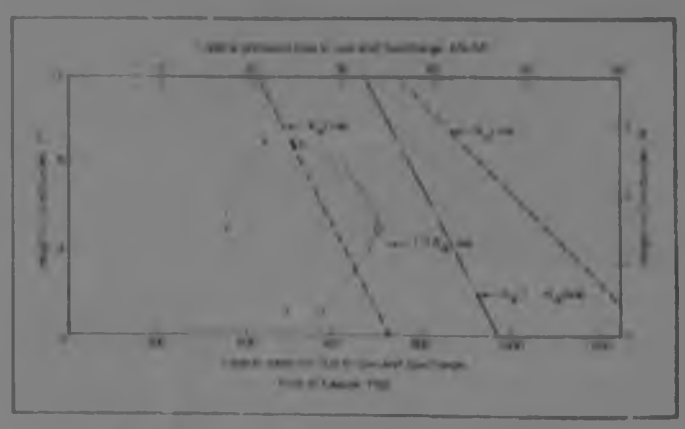


Fig 5 Measured Lateral Pressures W.E.S. Wall (after Al-Hussaini, 1978)

With the potential for calculating divergent answers to the important questions which govern safety and economics, it is important to determine what hypothesis can be supported by field experience. Unfortunately, we have convincing answers to this query. Field experience strongly supports the coherent gravity structure theory, as demonstrated by gross foundation failures under structures at Aguadilla, Puerto Rico, and Roseburg, Oregon.

At Aguadilla a nine meter high retaining structure presumably founded on rock, was instead constructed on a compacted structural fill placed on a clay foundation. Unknown to The Reinforced Earth Company and in violation of the specifications of the Puerto Rico Department of Public Works, the foundation had not been benched and so it sloped down and away from the rear of the structure. The backfill used to construct the structural fill and wall was a clean, uniform beach sand and the fill within the wall was compacted by ponding. As the structure neared completion, the reduced shear strength of the saturated and presumably remolded clay foundation was not sufficient to resist the mobilizing force of the mass, and the structure moved outward as a unit approximately two meters. The wall face remained essentially vertical during wall movement and no structural distress was evident in the precast concrete panels. The structure remained coherent, and it was possible to disassemble the structure and salvage all wall panels without danger to the workers. The initial and final locations of the structure are shown in Figure 6. Photographs taken before and after sliding occurred are shown in Figures 7 and 8.



Fig 6 Movement of Structure at Aguadilla, P R

In Roseburg, Oregon, a 10-meter high Reinforced Earth retaining wall had been constructed to reduce the amount of fill required for a highway embankment and to prevent encroachment of the embankment on a river which paralleled the highway. A cross section showing the wall and its relative position in the embankment is shown in Figure 9a and b. As the embankment above the wall was nearing completion, a slide occurred at the wall location. The slide failure plane, which was positively identified through continuous sampling, and by the use of inclinometers, passed behind and beneath the structure. The top of the Reinforced Earth wall was displaced seven meters horizontally and the wall dropped approximately 3.7 meters vertically. The final location of the wall and the location of the slide plane are shown in Figure 10. Remedial measures are also shown. In spite of these large movements, the structure remained intact as shown in Figures 11a, b and c. Subsequent analysis revealed that the slide was caused by overstressing the weak foundation soils located approximately six meters below the base of the wall.

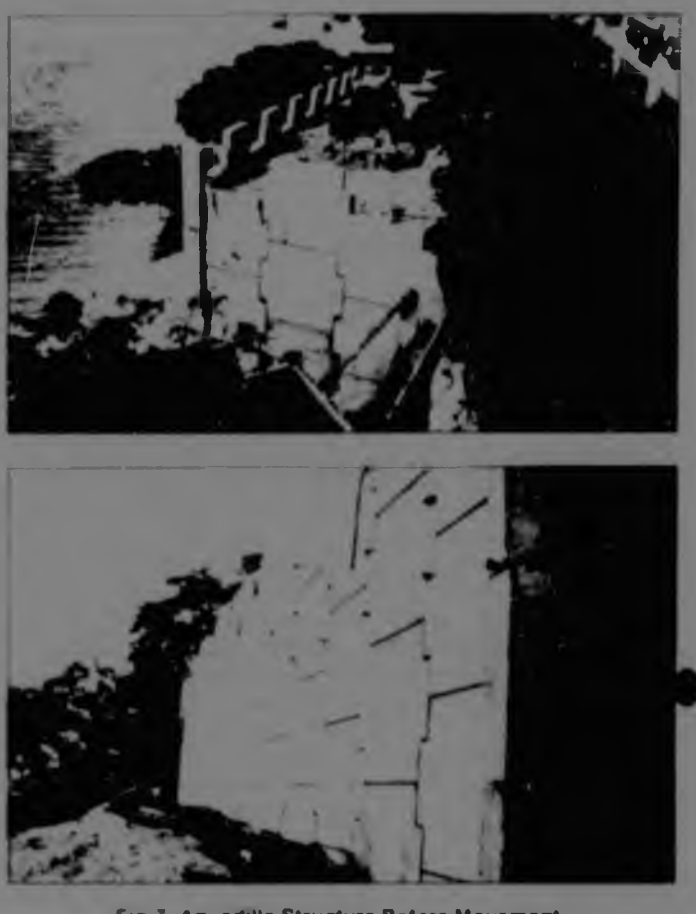


Fig 7 Aguadilla Structure Before Movement

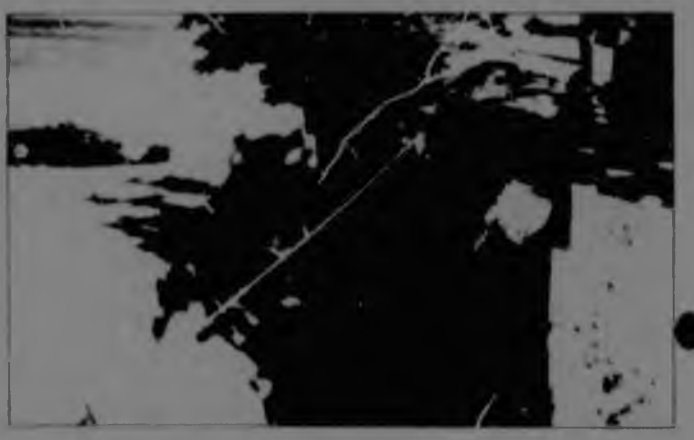




Fig 8 Aguadilla Structure After Movement

In its report on the Roseburg landslide the Federal Highway Administration (7) concludes "it should be emphasized that the subject problem was a landslide problem and not a Reinforced Earth wall failure. Unfortunate as it was, the slide did provide a dramatic full-scale test of a Reinforced Earth wall (the first we know of in the world) and demonstrated (1) the internal strength of a Reinforced Earth structure and (2) that a Reinforced Earth wall does, in fact, perform as a coherent gravity structure."

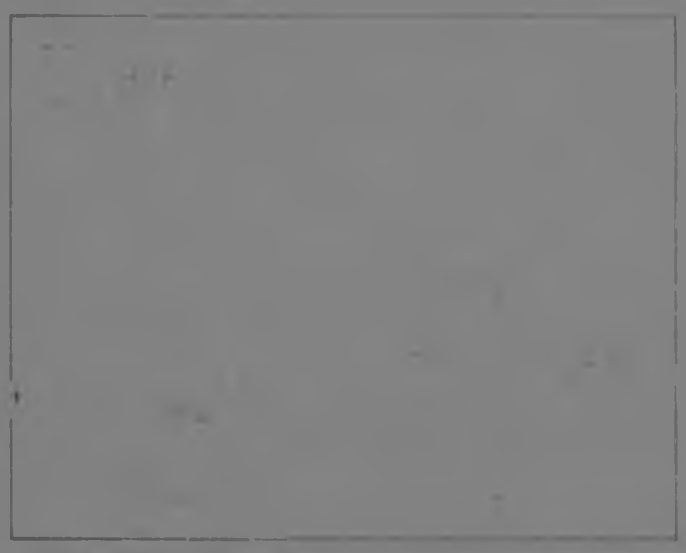


Fig 9: Position of Reinforced Earth Wall Before Slope Failure



Fig 9: Roseburg Structure before Movement

In other cases, when Reinforced Earth structures have experienced important and expected settlements, careful measurements have confirmed that the reinforced volumes reacted as coherent masses.



Fig 10: Roseburg-Coos Bay Highway Oregon Route 42

In light of substantial theoretical analyses supported by actual field performance, it seems reasonable to adopt the coherent gravity structure theses as a basis of design and to re-examine experimental data derived or interpreted on the basis of a "tie-back" or anchor wall failure mechanism.

(a) State of Stress in a Reinforced Earth Structure

The essential calculation in designing Reinforced Earth structures is the calculation determining the lateral or tensile stresses which must be resisted by the reinforcements. Overstress could promote tensile failure of the reinforcement which in turn would produce a catastrophic structural collapse. The calculation regarding the sliding shear resistance between the soil and reinforcements is less critical since slippage will cause only re distribution of stress and a slow deformation of the mass.

Instrumentation of Reinforced Earth structures has shown that the state of stress within these structures varies and cannot be consistently predicted using, for example, a single earth pressure assumption adjusted as required for the effect of the thrust of the backfill. Schlosser (8) has previously reported in this conference a summary of earth pressures calculated from strain gauge measurements made in actual structures. This data, which is repeated in Figure 12 and is consistent with Vidal's early qualitative observations, as shown in Figure 13, can be explained by the relationship between the critical void ratio and applied stress. Studies such as those by Castro (9) have shown that the critical void ratio decreases with increasing stress. Accordingly, relative extension of the soil compared with the reinforcing strips becomes less for higher walls with their corresponding higher stresses. Thus, for higher structures the effective lateral stress is reduced and approaches an active state.

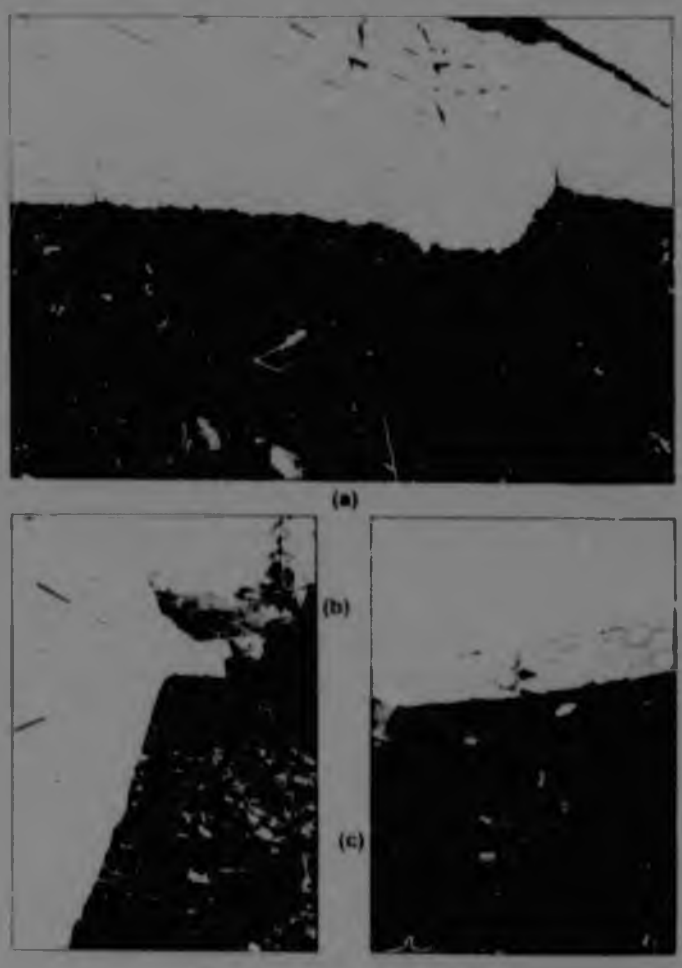


Fig 11: Roseburg Structure after Movement

The effect of the Factor of Safety in designs is to move the Mohr circle away from the failure envelope, in effect designing for a coefficient of earth pressure K, greater than the active coefficient K_a

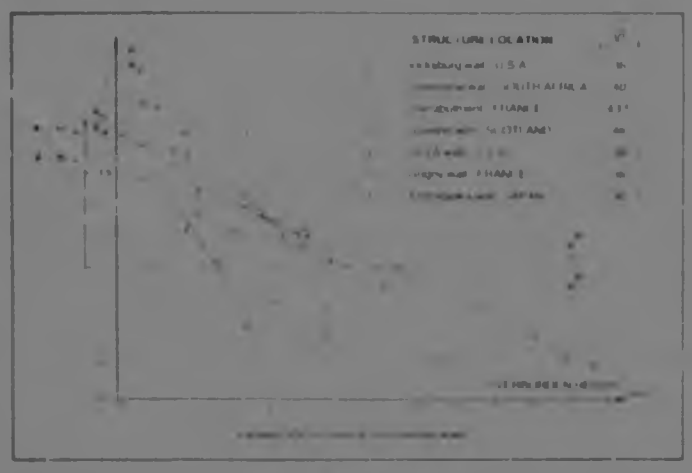


Fig 12: Earth Pressure Variation in Reinforced Earth Structures

This phenomenon was reproduced experimentally by Hausmann (10) and he reports similar observations during measurements of full-scale structures at Dunkirk, Thionville, and Granton

The empirical distribution shown in Figure 14 has been develop[illegible] to conform to observed stress distributions in Reinforced Earth structures and is consistent with results of theoretical analysis

(b) Frictional Relationship Between Soil and Reinforcement

Having determined appropriate conservative values for the horizontal stresses in a Reinforced Earth mass and proportioned the cross section and horizontal and vertical spacing of the reinforcements therein, the designer must satisfy himself that the horizontal stress can be effectively and efficiently transferred to these reinforcements. The designer must also be able to predict, within certain limits, the margin of safety available in the completed structure

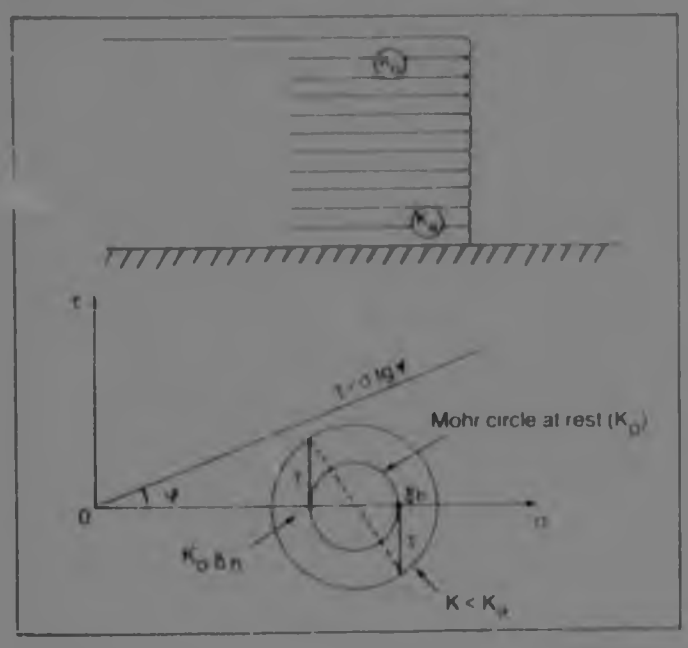


Fig 13: State of Stress in a Reinforced Earth Wall (after Vidal, 1969)

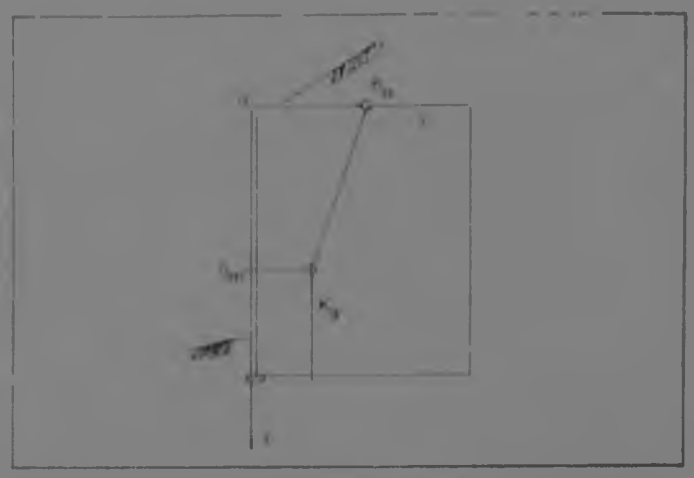


Fig 14 Earth Pressure Distribution in a Reinforced Earth Structure

Equations governing the frictional relationship are presented in Figure 15

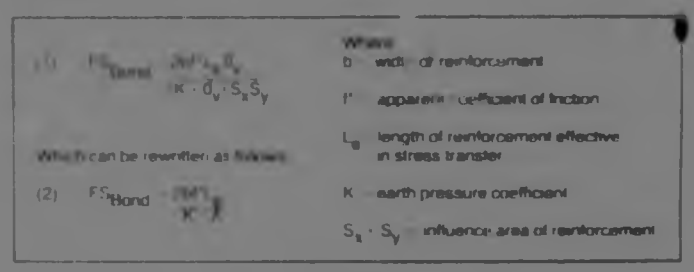


Fig 15

The solution of equation (2) in Figure 15 requires not only knowledge of the geometry of the structure, but also the selection of appropriate values for the apparent friction coefficient, f*, the effective length of the reinforcement, L_e, and the earth pressure coefficient, K. Let us examine first the apparent friction coefficient

(b-1) Apparent Friction Coefficient, f.*

The topic of sliding shear resistance between the soil and reinforcements has been the subject of numerous research studies in several countries. These studies have produced abundant data that on first examination are difficult to explain but will, after more detailed scrutiny, generally yield to the usual concepts of the shear strength properties of granular materials and sliding friction between materials. Several types of tests have been used to measure the value of f*. These include

(1) Direct shear (sliding shear) tests between soil and reinforcing material–model and prototype scale

(2) Reinforcing strip pullout from a Reinforced Earth wall–model, prototype and full scale

(3) Reinforcing strip pullout tests from embankments

(4) Reinforcing strip pullout tests from a rigid moving wall–model scale

(5) Reinforcing strip pullout tests during vibration–model scale

Of all the testing procedures used, the direct or sliding shear test is the one most available to practicing engineers for the evaluation of design parameters. Other testing procedures require more specialized equipment, and generally involve higher cost which may not be justified by either the size of the project or

the economic gain that may result from more refined and extensive data From a designer s standpoint therefore it is important to know if direct shear test results can be used with reliability Let us first generally examine the results of the other testing programs In the following discussions the terms apparent friction coefficient pullout resistance and shearing resistance will be used interchangeably to describe the frictional bond between soil and reinforcement

Reinforcing strip pullout tests in the laboratory and in full-size structures have shown the peak and residual shearing resistances to be dependent on the density of the soil, the effective overburden pressure and the geometry and surface roughness of the reinforcements Some typical results from field pullout tests are shown in Figures 16 through 19a, b and c

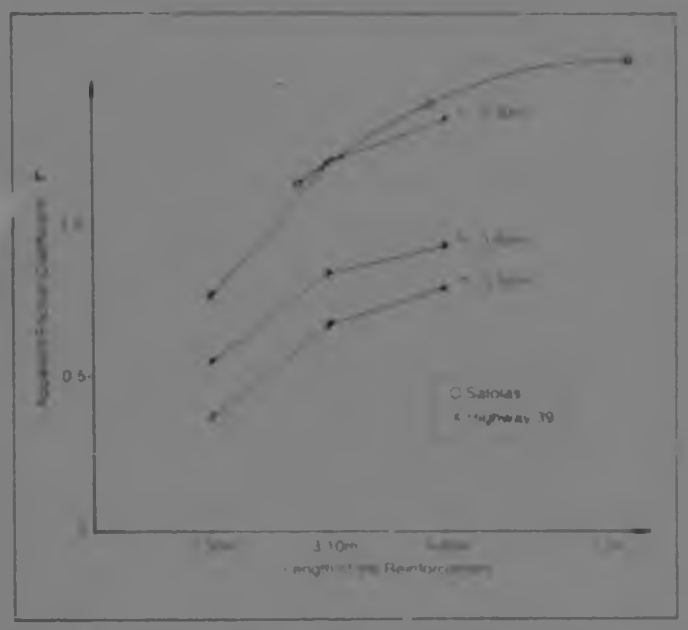


Fig 16 Pull-out Tests Apparent Friction Coefficient (Influence of the Length of the Reinforcement)

Data from field pullout tests have shown the shearing resistance developed by reinforcements to be directly proportional to length Results from both the Satolas (11) and Highway 39 (12) tests show that the apparent coefficient of friction reaches a maximum value at a strip length of about eight meters For longer lengths, strips experience ductile flow and therefore the testing procedure is no longer relevant to the determination of the sliding shear resistance

The surface roughness has an obvious ...ly understood effect on the sliding shear resistance St... and Vidal (13) reported results of direct shear tests per... on samples of leucate and calcareous sand sheared ... and in contact with, smooth and roughened reinforcements The results of these tests are shown in Figure 20 Examination of the reinforcements after shearing revealed striations on the smooth strip oriented in the direction of the displacement This is evidence that sliding of the soil particles along the strip had occurred Examination of the roughened reinforcement did not reveal such striations, evidence that shearing had taken place along a soil-soil interface Examination of the high adherence reinforcements now in use tested in prototype direct shear and full-scale field pullout tests reveals similar evidence Thus, it is reasonable to assume that the use of reinforcements with appropriately designed surface roughness can result in an apparent friction coefficient approximately equal to the shear strength of the soil as determined by direct shear or sliding shear tests

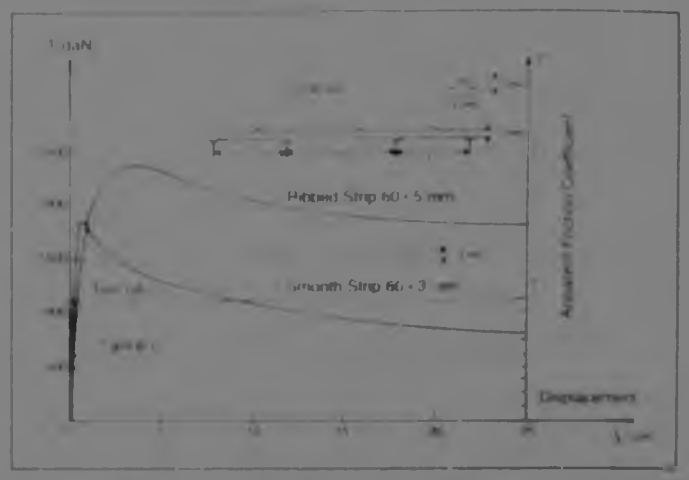


Fig 17 Pull-out Test in Reinforced Earth Walls (influence of the Nature of the Strip Surface)

The relationships shown in Figure 19a, b and c are calculated using the expression $T = \sigma_V \tan \Psi \cdot 2bL$ to determine the apparent friction coefficient f^* (i.e., $f^* = \tan \Psi$) As shown in these Figures frictional values exceed those which could be calculated using a value of Ψ or ϕ determined by direct shear testing procedures Since these results could strongly influence overall safety and economy, it is important to determine if they are a function of the testing procedure or in fact represent a phenomenon which can be expected in the performance of actual structures To more easily understand the influence of density and overburden pressure on a Reinforced Earth mass let us first examine the influence of these parameters on the shear strength of a granular material Figure 21 shows the effect of density on the stress-strain-volumetric relationships in granular soils tested under drained shear conditions Dense sands exhibit a high peak deviator stress at low strains, and a residual deviator stress, less than the peak stress, at high strain The dense material expands, or dilates, during shear The loose sand exhibits a much lower deviator stress, no peak value, and a volumetric contraction or compression during shear A further insight is gained by examining the same stress-strain-relationships during undrained shear where no volume changes are allowed to occur This restriction of volumetric expansion is a condition like that which exists in an actual structure The undrained relationships are shown in Figure 22 The negative pore pressures which are induced in a saturated sample during shear may be used qualitatively to estimate the apparent increase in overburden stress when volumetric expansion in unsaturated samples (or structures) is not allowed to occur (a localized

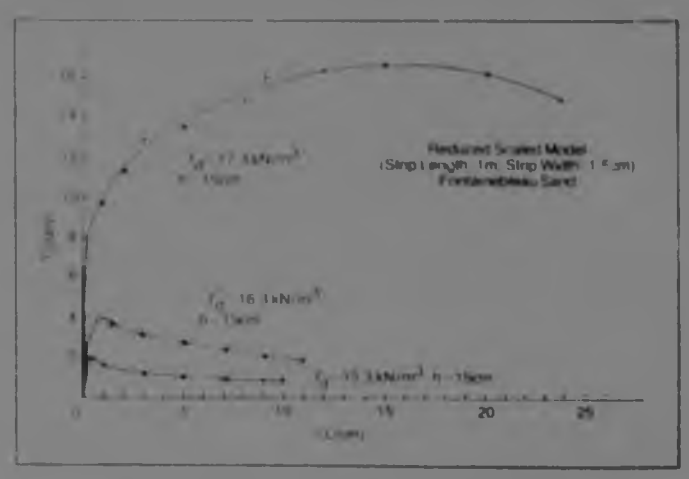
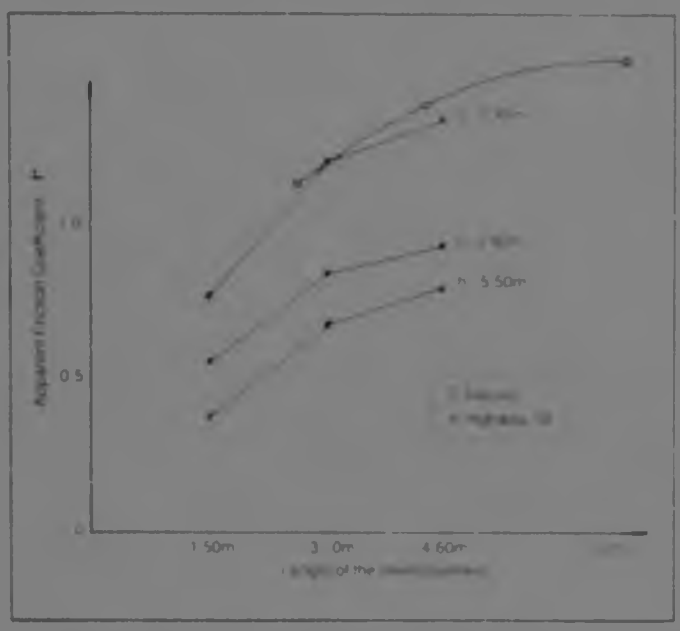


Fig 18: Influence of the Density in Pull-out Test

the economic gain that may result from more refined and extensive data From a designer s standpoint, therefore, it is important to know if direct shear test results can be used with reliability Let us first generally examine the results of the other testing programs In the following discussions the terms "apparent friction coefficient" "pullout resistance," and "shearing resistance" will be used interchangeably to describe the frictional bond between soil and reinforcement

Reinforcing strip pullout tests in the laboratory and in full size structures have shown the peak and residual shearing resistances to be dependent on the density of the soil the effective overburden pressure and the geometry and surface roughness of the reinforcements Some typical results from field pullout tests are shown in Figures 16 through 19a b and c



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The surface roughness has an obvious and long understood effect on the sliding shear resistance Schlosser and Vidal (13) reported results of direct shear tests performed on samples of leucate and calcareous sand sheared along, and in contact with, smooth and roughened reinforcements The results of these tests are shown in Figure 20 Examination of the reinforcements after shearing revealed striations on the smooth strip oriented in the direction of the displacement This is evidence that sliding of the soil particles along the strip had occurred Examination of the roughened reinforcement did not reveal such striations, evidence that shearing had taken place along a soil-soil interface Examination of the high adherence reinforcements now in use tested in prototype direct shear and full-scale field pullout tests reveals similar evidence Thus, it is reasonable to assume that the use of reinforcements with appropriately designed surface roughness can result in an apparent friction coefficient approximately equal to the shear strength of the soil as determined by direct shear or sliding shear tests

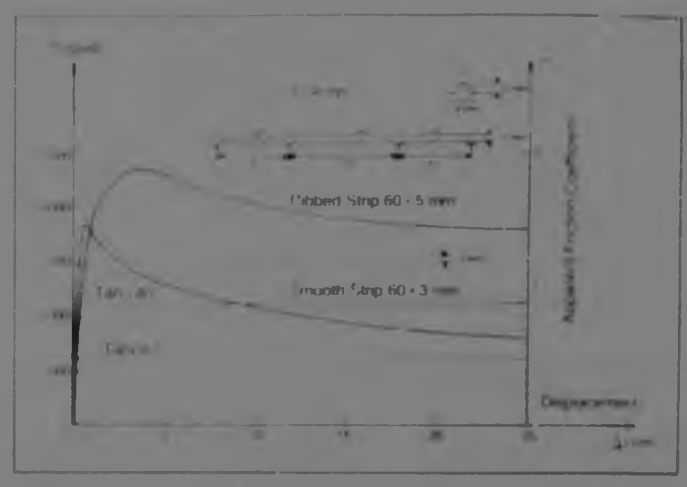

Fig 17 Pull-out Test in Reinforced Earth Walls (Influence of the Nature of the Strip Surface)

The relationships shown in Figure 19a, b and c are calculated using the expression $T = \sigma_v \tan \Psi \cdot 2bL$ to determine the apparent friction coefficient $f^* = \tan \Psi$ As shown in these Figures, frictional values exceed those which could be calculated using a value of Ψ or ϕ determined by direct shear testing procedures Since these results could strongly influence overall safety and economy, it is important to determine if they are a function of the testing procedure or in fact represent a phenomenon which can be expected in the performance of actual structures To more easily understand the influence of density and overburden pressure on a Reinforced Earth mass, let us first examine the influence of these parameters on the shear strength of a granular material Figure 21 shows the effect of density on the stress-strain volumetric relationships in granular soils tested under drained shear conditions Dense sands exhibit a high peak deviator stress at low strains, and a residual deviator stress, less than the peak stress, at high strain The dense material expands, or dilates, during shear The loose sand exhibits a much lower deviator stress, no peak value, and a volumetric contraction or compression during shear A further insight is gained by examining the same stress-strain relationships during undrained shear where no volume changes are allowed to occur This restriction of volumetric expansion is a condition like that which exists in an actual structure The undrained relationships are shown in Figure 22 The negative pore pressures which are induced in a saturated sample during shear may be used qualitatively to estimate the apparent increase in overburden stress when volumetric expansion in unsaturated samples (or structures) is not allowed to occur (a localized

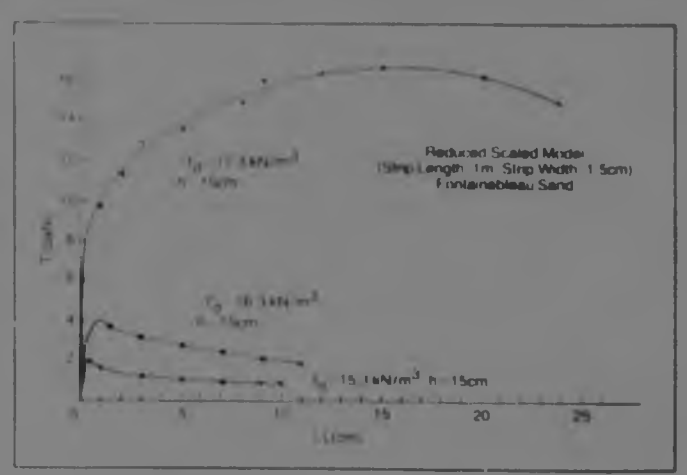

Fig 18: Influence of the Density in Pull-out Test

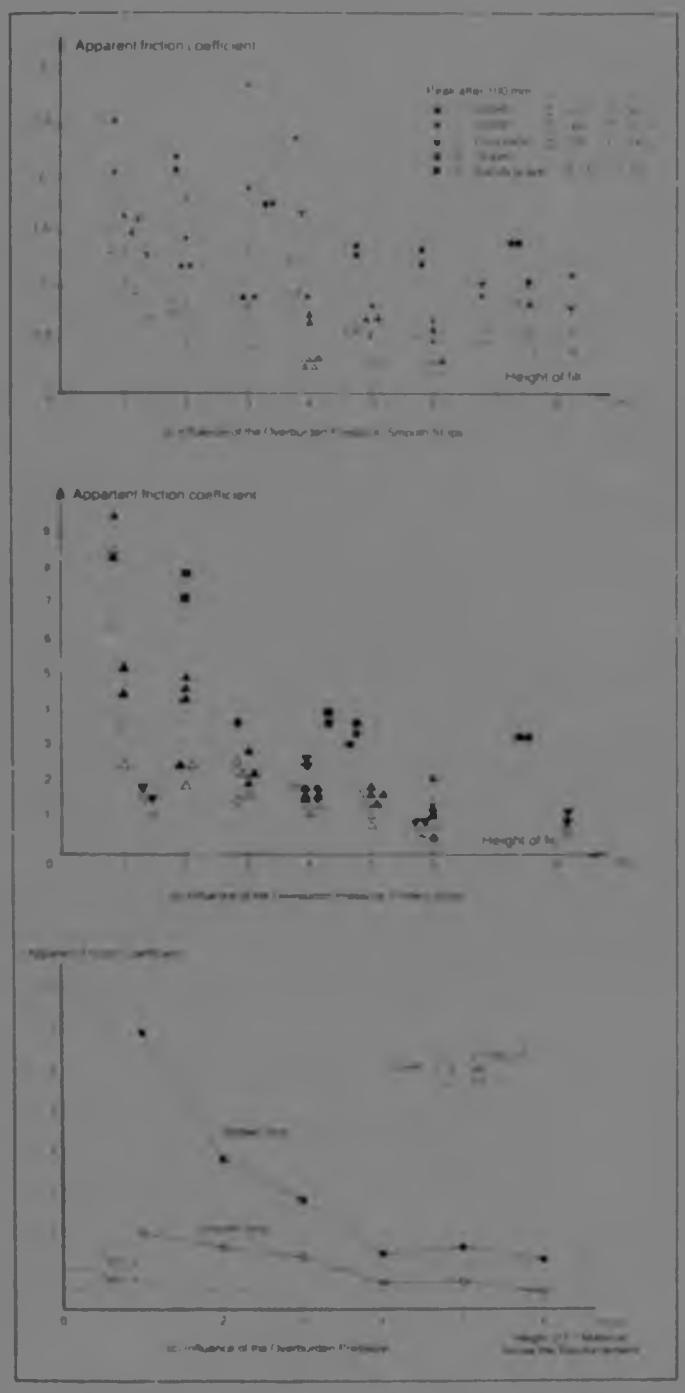

Fig 19: Pull-out Tests: Apparent Friction Coefficient

condition). Higher densities can, therefore, increase the normal stresses acting on the strip and the apparent coefficient of friction, at least in those ranges of overburden pressures where the soil will be dilatant (i.e., void ratios less than the critical void ratio). Test results which indicate that at high density the values of the apparent coefficient of friction are much greater than the value of tan Ψ, as determined in direct shear results on soil-strip interface, can therefore be rationalized by taking into effect a factor to allow for the dilatancy of the soil. (In recent tests where volumetric expansion was not allowed to occur during direct shear tests, calculated values of Ψ were 10-15 degrees higher than tests where free expansion could occur.)

An interrelated phenomenon is the effect of the overburden stress on the apparent friction coefficient. To gain insight into this, let us investigate the effect of normal or overburden stresses on the shearing resistance of granular soils.

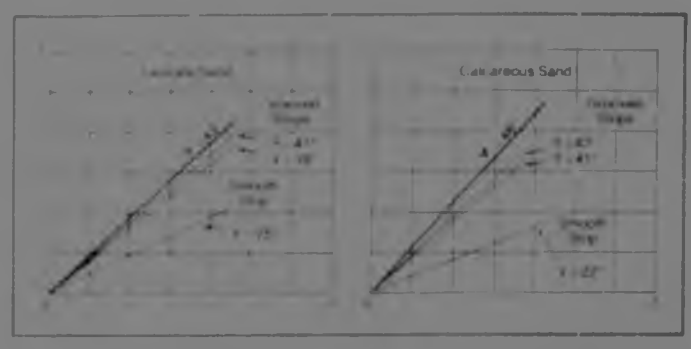

Fig 20: Coefficient of Earth-Strip Friction ($f^* = \tan \Psi$).

Figure 23 contains a display of peak stress ratios determined from 60 mm square direct shear box tests and 80 mm square plane strain compression samples compacted to a relative density of 0.70 (17.0kN/M²) (14). At small normal stresses (< 20kN/M2) the peak angle of shearing resistance is approximately 50°, but this drops to 42° as the normal stress rises. Peak results from direct shear test and plane compression test results are significantly greater than 33°, the ultimate strength determined after the peak in direct shear tests and from loose slope angles (14). These results are consistent with the results of

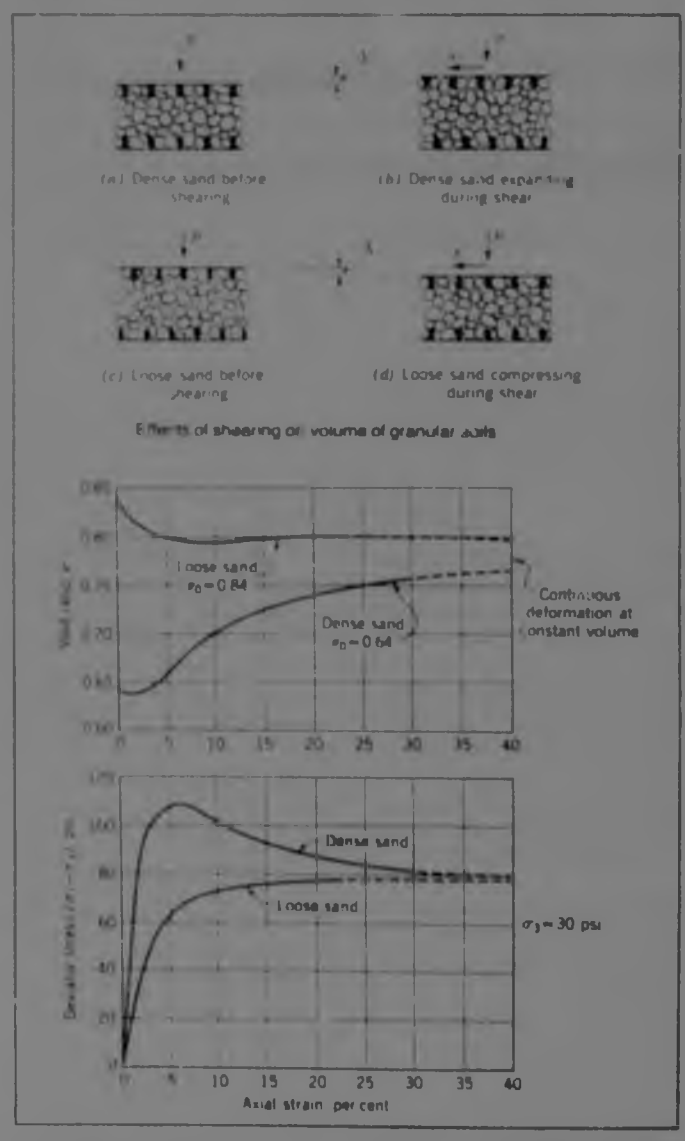

Fig 21: Effect of Density on Stress-Strain-Volume Relationships in Granular Soils. Drained Shear Tests. (after Leonards, 1962)

F once and Bell (15), who report an angle of shearing resistance increasing with the reduction of normal stress and with Cornforth (16) who established that peak (strength) angles will exceed ultimate angles by up to 17° in a typical dense sand in plane strain

As soils used in Reinforced Earth structures are (1) granular (2) subjected to low strain levels (3) normally stressed in plane strain (except under point loads) and (4) compacted to relatively high densities, it is reasonable to evaluate their static performance in a reinforced state using peak values determined in plane strain compression tests adjusted as required for the appropriate overburden conditions. Using such assumptions, it is possible to rationalize the values of f* shown in Figure 19 with soil mechanics theory

For example, Schlosser (8) reports the average of residual and peak values for f* equal to approximately 1.35 for pullout tests of smooth reinforcements in fine sand with an ultimate strength $\phi = 35°$. If we assume a 30 percent increase in normal stress due to the effect of restrained volumetric expansion, a value of 53° is calculated, a peak strength result consistent with Cornforth's observations

The factors affecting sliding shear resistance are thus seen to be at least qualitatively consistent with basic soil mechanics theory. A knowledge of the density, shear strength, void ratio and strain state is therefore important in selecting the value of f* to use in design of actual structures. It is also important to consider the nature of the reinforcement surface

For smooth reinforcements, the value of f* obtained in direct shear tests, selected at strain conditions consistent with anticipated structural performance, should be used. In most cases this value will be equal to the residual sliding shear value ($\tan \phi_r$).

For reinforcements with deformations or transverse ribs, such as those shown in Figure 24, values of f* consistent with soil parameters adjusted for the effects of plane compression, dilatancy, and overburden pressure can be used with confidence. In the case of smooth strips, the soil-strip friction characteristics will control behavior. In the case of ribbed or roughened strips, the soil-soil characteristics will most often control

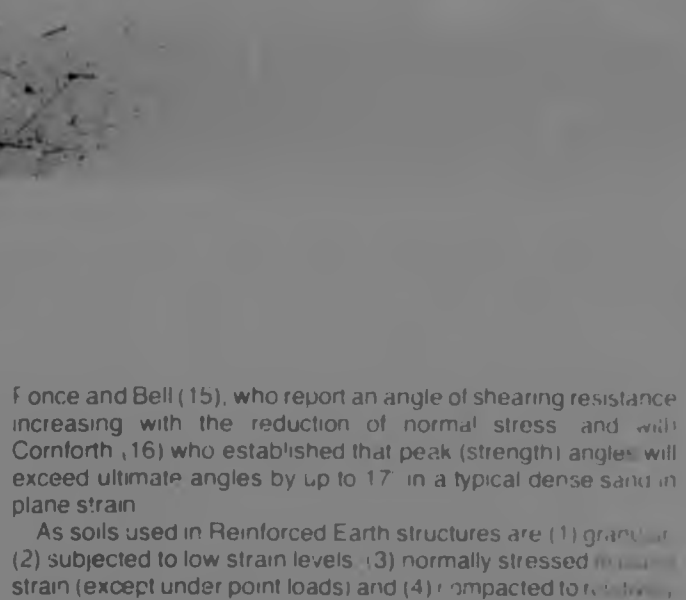

Fig 22: Undrained Shear Tests on Very Loose and on Moderately Dense Saturated Sand. (After Bishop and Henkel, 1957)

(b-2) Effective Reinforcement Length.

Analysis of Reinforced Earth structures has shown that the tensile stress in the reinforcements of a structure is not maximum at the facing, but at a distance behind the facing. As shown in Figure 25, the locus of the points of maximum tension

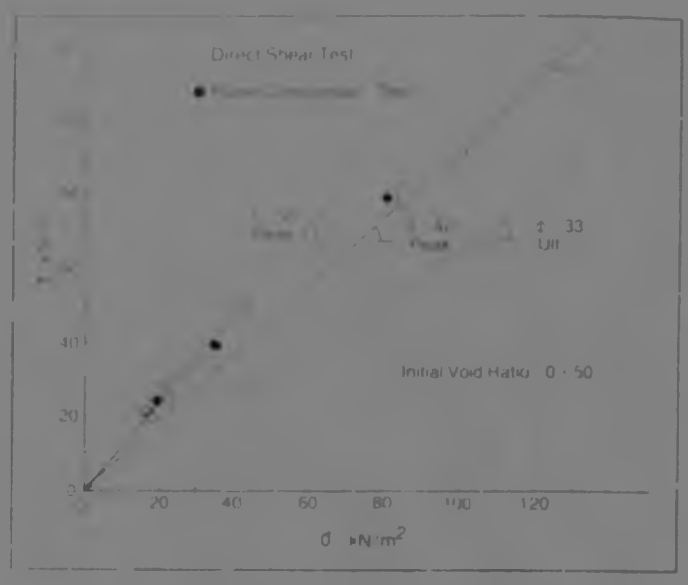

Fig 23: τ/σ on Plane of [τ/σ] Peak (Bolton et. al., 1978)

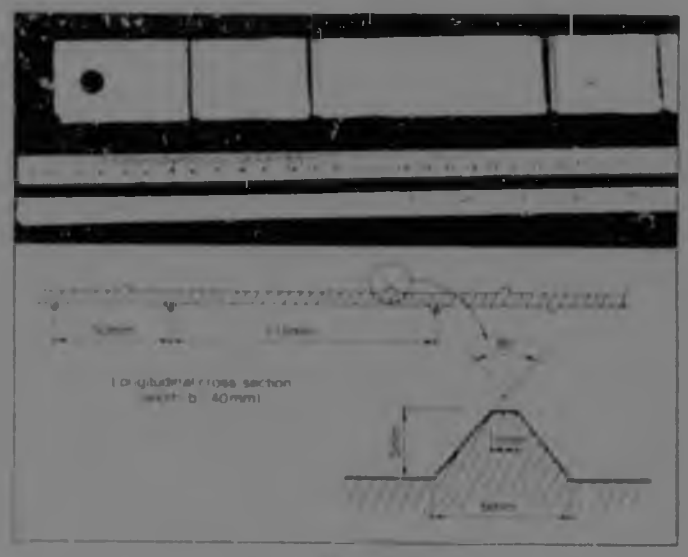

Fig 24: Ribbed Strips

define two zones within the structure: an active zone in which the shearing stresses exerted by the earth on the reinforcement are directed outward, towards the facing, and a resistant zone in which the shearing stresses are directed towards the free end of the reinforcement. The boundary of this "active zone" varies with the type of structure, the foundation soil, and the location and magnitude of applied external loading. The boundary of the active zone, as determined by instrumentation of full scale structures designed in accordance with working stress principles, as well as the boundary determined by theoretical procedures as previously reported by Schlosser (8) in this conference, can be enveloped by the straight lines shown in Figure 25

This boundary is qualitatively consistent with hypothetical ideal distributions of shear stress along reinforcing strips presented by Hausmann (10). This graphical illustration is reproduced in an extended form in Figure 26. The ideal reinforcing case can be symbolically represented by Vidal's paper reinforced rock pile, Figure 27. Here, all particles are in contact with the reinforcements and shear is a maximum at the center. In an actual Reinforced Earth wall, the discontinuity of the reinforcements, the soil loading imposed on the facing by the construction procedures, the stiffness of the facing, and other factors cause the redistribution of stress shown

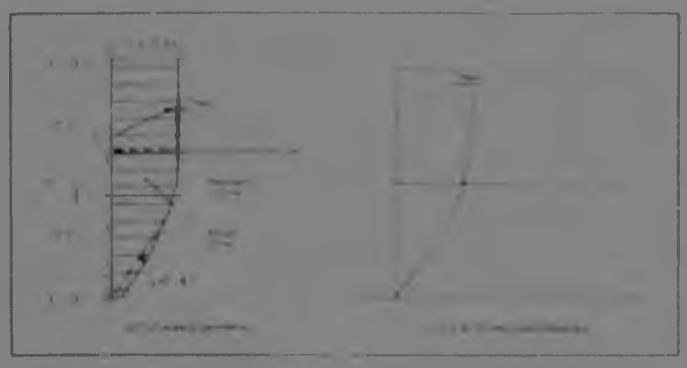

Fig 25 Tensile Forces Distribution Along the Reinforcements

(b-3) Design Procedures

Based on these foregoing discussions it is possible to formulate design procedures to adequately (and safely) proportion the reinforcement surface area This procedure is shown schematically in Figure 28a and b For granular backfills (compacted to at least 90 percent standard Proctor density) and ribbed reinforcements the use of values for f^* indicated in the figure can be supported by empirical data However one may also select a value of $f^* = \tan\phi$ (peak stress determined from plane compression tests) approximately adjusted for the effects of dilatancy For nondilatant soils a value for $f^* = \tan\Psi$ (direct shear test value) should be used for both ribbed and smooth reinforcements Appropriate safety factors should be used



Fig 26 Hypothetical Ideal Distributions of Shear Stress Along Reinforcing Strip & Tie-Back (after Hausman, 1978)

II. Selection of Soils For Use in Reinforced Earth Construction

Three principal considerations which influence the selection of soils for use in Reinforced Earth structures are

(1) Long-term stability of the completed structure

(2) Short-term (or construction phase) stability

(3) Physiochemical properties of the materials

It is evident from the previous discussions that granular soils compacted to densities that result in volumetric expansion during shear are ideally suited for use in Reinforced Earth structures Where these soils are well-drained, effective normal stress transfer between the strips and soil backfill will be immediate as each lift of backfill is placed, and shear strength increase will not lag behind vertical loading In the range of loading normally associated with Reinforced Earth structures, granular soils behave as elastic materials Therefore, for structures designed at working stress levels, no post-construction movements associated with internal yielding or readjustments should be anticipated



Fig 27 Idealized Reinforced Mass

On the other hand fine-grained materials are not especialy suitable for Reinforced Earth structures They are normally poorly drained and effective stress transfer will not be immediate, thus requiring a greatly slowed construction schedule or an unacceptably low factor of safety in the construction phase Fine-grained materials often exhibit elasto-plastic or plastic behavior thereby increasing the possibility of post-contruction movements In addition, if a significant portion of the strength of the fine-grained material is derived from its clay content, the rational design procedures used heretofore to evaluate the safety of the structure will not be applicable With such sharply contrasting performance, it is necessary then to define clearly the boundary between granular and fine-grained soils, as this boundary or limit applies to Reinforced Earth construction



Fig 28 Design Methods for Evaluating Safety Against Failure by Lack of Adherence

Writers of the first specifications for Reinforced E arth projects (including, of course Vidal) clearly understood the shear strength, density and dilatancy relationships and specified clean granular materials for use in all structures Reflecting on this, it is interesting to note that by specifying such a material they virtually eliminated from concern such problems as drain age, corrosion and post-construction movements The first specification published by the U S Federal Highway Adminis tration in 1974 was derived from the early French specification and allowed the following limiting gradation

Sieve Opening or Screen Size	Percent Passing (By Weight)
10 inches (254mm)	100
4 inches (101 6mm)	100 75
No 200 (75 μ m)	0-15

Table III Specification for Select Granular Backfill Material from F H W A Specification FP-74(17)

In addition, the specification further required that all backfill material exhibit an angle of internal friction of 25 degrees as determined by standard triaxial or direct shear testing methods This caveat was added in recognition of the fact that many gravels in the western part of the United States are highly degradable and normal design assumptions would not be applicable to them The specifications were appropriately con servative given the state of the art at the time they were pub lished However as more experience with actual structures was gained and as the results of theoretical and applied research were analyzed, it became evident that a significant relaxation and broadening of these specifications could be done safely thus extending the spectrum of usable materials and further improving the potential for economy to users of the system

From 1970 to 1974 an extensive research program was carried out by Schlosser and Long (18) to study the relationship between the fine grained portion of a soil and the development of the angle of internal friction In this study two types of soil test were conducted (1) an artificial soil made with a mixture of glass balls and powdered clay and (2) mixtures of natural soils Saturated soil samples of both types with varying amounts of fines were tested in a direct shear box Results were conclusive in demonstrating that the parameter controlling shear strength is the relative volume of the fine grained portion to the granular portion Some typical results are shown in Figure 29 Additional tests have shown that the grain size which separates the fine grained portion from the granular portion is 15μ

While this theoretical research was carried on several pro jects were constructed using materials which differed from the original specification in the amount of fines passing the 75μ sieve These materials were typically nonplastic residual soils such as those derived from decomposed granites and meta sedimentary formations high in quartz and mica content (schistose and schistose gneisses of the Piedmont Plateau) Fine content (percent greater than 75μ) varied from the allow able 15 to as much as 40 percent This field experience was generally favorable but did require the designers to focus more closely on questions of short term stability, and to develop construction procedures necessary to effectively incorporate soils with higher fine contents into Reinforced Earth structures Two examples illustrate this point

At Cove Point Maryland over 800 linear meters of single and double-faced Reinforced Earth containment dikes 3 to 5 meters high were constructed using sandy silts with as much as 40 percent passing a 75μ screen Extensive laboratory tests were conducted to evaluate the apparent coefficient of friction be tween the aluminum reinforcements and the sandy silts These test results were used to determine safety factors for the com pleted structures which were designed with the usual working stress factor of safety allowed by U S practice Wall backfill had previously been excavated and stockpiled at future tank loca tions During construction of the walls, work was stopped for one week due to heavy rains (which eventually totalled 25cm for the week) after which construction was immediately re-started Backfill was brought to the wall location with 25cu meter self-loading scrapers Two days after construction had resumed, outward deflections were noticed in several areas along the dikes Construction was stopped so that the situation could be assessed



Fig 29 Evolution of the Angle of Internal Friction and Cohesion (after Schlosser and Long, 1974)

At another project along Interstate Route 70 near Vail Colorado a similar but slightly more dramatic episode occurred The construction of the highway through the highly scenic Vail Pass in the Colorado Rockies required the construction of approximately 27,000 square meters of retaining wall to control embankment encroachment on streams and wilderness areas Of the total, approximately 75 percent or 20,000 square meters were Reinforced Earth structures built using conventional, as well as curved panels Wall heights varied from 3 to 26 meters, and walls were built vertically in a single step or in tiers Typical structures are shown in Figures 30 and 31 Due to the short construction season contractors often worked 20-24 hours per day on a six day work schedule Wall backfill was a decom posed granite with up to 25 percent passing a 75μ screen, the normal requirement for structure backfill in the State of Colorado Early in November of 1975 as the contractor was nearing completion of a Reinforced Earth structure, a section of wall 300 feet long tilted outward during placement of the backfill Some panels were cracked and broken, and the reinforcing strips had obviously been drawn out of the fill As in the case at Cove Point, construction was halted and an investigation undertaken

The two cases are, quite obviously, related to the water content and loading conditions of the soil which was placed within the Reinforced Earth structures At Cove Point, the loading from the scrapers was far greater than the loading considered in static wall designs This increase in overall load ing combined with a temporary decrease in shear strength caused by the higher water content and poor drainage charac teristics of the soil, combined to create a marginally stable situation Thus, outward movement of the panels occurred Review of the calculations showed no problem with long-term stability, and construction was allowed to continue after the soil had dried out and lighter equipment was brought in. Continuing observation showed no further movement of the walls.



Fig 30 Vail Pass-Tiered Wall

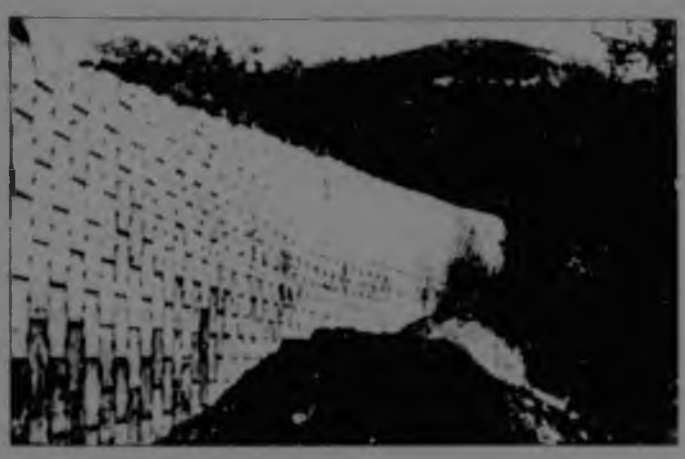

Fig 31: Vail Pass-Standard Panel Wall

At Vail Pass, investigations revealed that the filling operation had been intermittently shut down for several days prior to the wall deflections due to snow and freezing temperatures It was not possible to determine if the contractor had cleaned, scarified and recompacted the fill surface after filling operations resumed However samples taken in several locations in the embankment and wall after the failure, showed water contents of 6 to 8 percent over optimum It was, therefore, reasonable to deduce that high pore pressures were created in the wall backfill under the influence of the heavy haul equipment Shear strength, as well as sliding resistance were drastically reduced and the panels moved outward virtually without restraint At Vail the affected portion of the wall was removed, and construction resumed with proper attention to compaction water content To completely eliminate such occurrences in the future will probably be impossible However, if specifications are correctly written, many similar problems can be avoided

Drawing on these and other experiences, as well as an understanding of the basic mechanics of Reinforced Earth it has been possible to define a wider spectrum of materials suitable for use in Reinforced Earth structures These broader limits are shown in the new F H W A specification which will be issued at the end of 1978

Sieve Size	Percent Passing
6	100
3	75-100
No 200	0-25
and P I < 6	
OR if percent passing No 200 is greater than 25 percent and percent finer than 15 μ is less than 15 percent material is acceptable if	
ϕ > 30 as determined by AASHTO T-236	
P I < 6	

Table IV Minimum Specification for Select Backfill (Adopted by F H W A , 1978)

When the percent finer than 75μ is greater than 15 percent special attention to moisture-density relationships is required The compaction specifications should include a specified lift thickness and allowable range of moisture content above and below optimum Special attention must also be focused on design details such as internal and external drainage

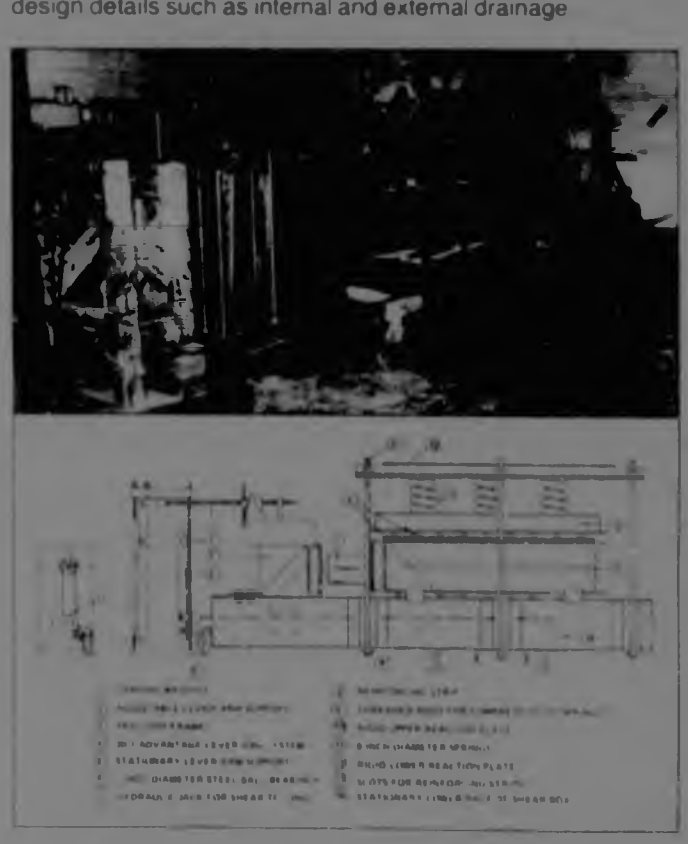

Fig 32: Large Direct Shear Box with Creep Test Setup

The broader specifications still restrict the spectrum of suitable materials to those which are non-plastic and whose deformation properties will be essentially elastic in the normal load range of Reinforced Earth structures Even assuming that a rational design procedure could be developed for cohesive soils, we believe that the potential for large post construction movements due to creep would be significant A laboratory testing program is now in progress to evaluate this

phenomenon Testing procedures are shown in Figure 32 Preliminary results of a reinforcing strip pullout test in residual silts with between 70 and 90 percent passing a 75μ sieve are shown in Figure 33 The tests show significantly lower values of apparent friction are obtained with these materials and more importantly, the values are significantly less than the shear resistance of the soil even with deformed or ribbed strips Figure 34 shows the result of two creep tests conducted at stress levels which varied from 34 to 49 percent of measured peak load High deflections are seen to continue after 50 hours loading Other testing programs now in progress will evaluate the possibility of using admixtures such as flyash, lime or cement to reduce the plasticity of cohesive soils to eliminate or minimize creep We hope to be able to report on the results of these tests in one or two years At the present however it is not possible to use such soils reliably in permanent structures

In addition to the mechanical complexities as soils become more fine-grained, their resistivity generally decreases Soil resistivity is an important factor controlling the rate of galvanic corrosion, and low resistivity is often associated with aggressive soils This topic will be discussed in greater detail in the following section



Fig 33 Strip Pullout Tests-Fine Grained Soils

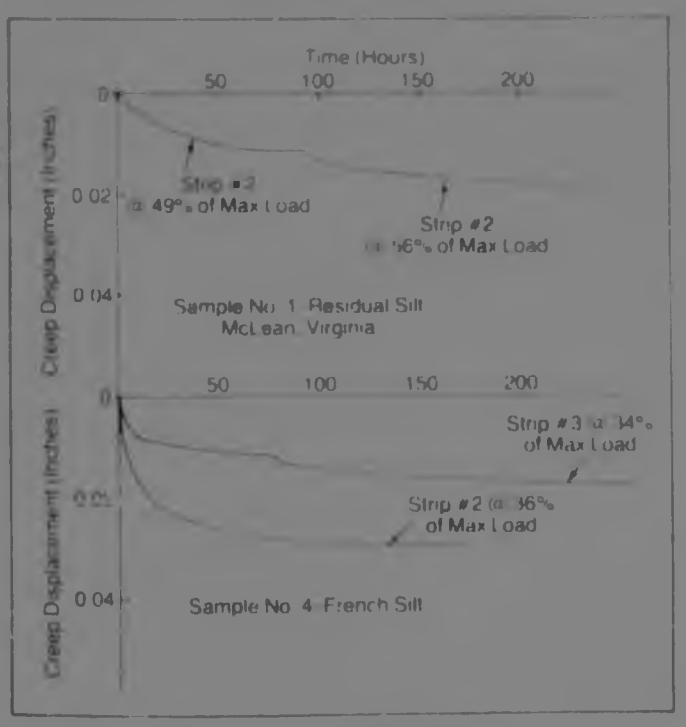

Fig 34 Creep Tests-Ribbed Strips

III Durability of Buried Metal Reinforcements.

In the many discussions we hold with potential users of Reinforced Earth the most frequently asked question is How long will it last? Everyone knows that ferrous and other metals corrode and that metallurgists might spend whole careers creating a single exotic alloy to resist the aggressive attack of a predictable environmental setting (such as aluminum boats in sea water) Reinforced Earth structures are normally designed for a service life of 75 to 100 years Reinforcements are typically thin metal strips varying in thickness from 3 to 9 mm thick depending on the physical forces to be resisted and environmental setting in which the structure will be erected What special information therefore, is required to safely proportion the structural components to resist a physical phenomenon that is as undeniable as it is seemingly unpredictable? What margin will exist and what will be the consequences if the predictions are incorrect?

To attempt to answer these questions we must again reflect on the mechanism of corrosion, the results of theoretical studies and whatever actual performance data exists In interpreting these studies and data, we must be careful to interpret them in the light of our own concerns For example, a buried metal conduit might be considered to have failed if a pitting type corrosion completely penetrates the conduit wall and fluid or pressure is lost In contrast pit type penetrations of a sheet or strip may do little to reduce the effective cross section resisting stress Therefore for the same corrosive effect, the strip is serviceable and the conduit is not With this in mind let us examine the phenomenon of corrosion as it applies to the serviceability of Reinforced Earth structures

The corrosion process is essentially an electrochemical process For corrosion to occur there must be a potential difference between two points that are electrically connected in the presence of an electrolyte A typical galvanic cell is shown in Figure 35 Current flows from the anodic area through the electrolyte to the cathodic area and back through the metal to complete the circuit In the case of buried metals the electrolyte consists of water rich in oxygen and dissolved salts wetting the soil particles in contact with the metal Among the factors that govern corrosivity of a given soil are (1) porosity (aeration) (2) electrical conductivity (3) dissolved salts, including depolarizers or inhibitors (4) moisture and (5) acidity or alkalinity (pH) Let us look at the influence of each of these parameters

A porous soil may retain moisture over a longer time or may allow maximum aeration, both factors which tend to increase the initial corrosion rate The situation is complex, however, because corrosion products formed in an aerated soil may be more protective of the base metal than those formed in an unaerated soil In addition, it is probable that aeration of soils may affect corrosion not only by direct action of oxygen in forming protective films, but also indirectly through the influence of oxygen reacting with an decreasing concentration of the organic complexing agents or depolarizers naturally present in some soils which greatly stimulate localization cells Another factor to be considered is that in poorly aerated soils containing sulfates, sulfate reducing bacteria may be found These organisms often produce the highest corrosion rates normally experienced in any soil However, the beneficial effect of aeration extends to soils that harbor sulfate reducing bacteria because these bacteria become dormant in the presence of dissolved oxygen

The electrical continuity allows current to flow between anodic and cathodic zones on the metal surface The loss of metal from the anode is proportional to the intensity of the current which in turn is directly proportional to the conductivity of the electrolyte between the two poles of the electrochemical cell Normally, the method used to measure this important soil parameter is the resistivity, the direct inverse of the conductivity Resistivity is dependent on the soil's content of soluble salts and varies

greatly with degree of saturation

For purposes of determining service life, the resistivity of a soil at 100 percent saturation the worst case, is always used Generally a high resistivity is associated with a slightly aggressive soil Table V shows some typical resistivities of soils

Moisture, even in small quantities, is a necessary agent in corrosion Usually the speed of corrosion increases with increasing water content of the soil The conductivity of water increases with increasing concentration of dissolved salts again increasing the potential for increased corrosion

The acidity or alkalinity (pH) of a soil also controls the rate of corrosion Certain protective oxides that form on the surface of a metal are insoluble within certain pH ranges For example, experience has shown that the by-products of the corrosion of zinc are insoluble within a 5 to 12 pH range

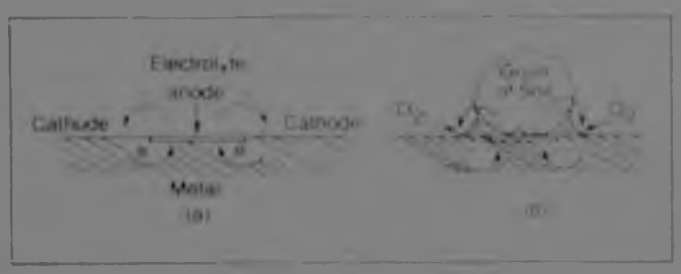

Fig 35 Idealized Galvanic Cell in Buried Metals

DESCRIPTION		RESISTIVITY AT SATURATION
and Gravelly Sands		
Silty Clay		1540
or Clayey Fine		2300
From Natural		
Organic & Silt Alluvium		

Table V Some Physiochemical Properties of Soils in the Washington, D C Area

The potential difference between the poles of a galvanic cell is dependent upon the nature of ion concentrations on the surface Certain ions, such as chlorides and sulfates are aggressive others such as magnesium and calcium are inhibitors of corrosion

Thus, the high number of interrelated factors which influence the initial and long-term corrosion rate makes the study of corrosion and service life an inexact science, especially when one considers that many of the parameters will most certainly change with the passage of time As in other sciences where exact solutions are not possible and I suggest that soil mechanics is certainly one, it is necessary to determine the possible upper and lower limits to the effects or results under study and then, using prudent engineering judgment to provide for a reasonable margin of safety This approach is applicable to the study of corrosion of buried metals

The most extensive series of field tests on various metals and coatings in all types of soils was begun in 1910 by the U S National Bureau of Standards (NBS) These tests continued until 1955 and now constitute the most important sources of comprehensive data available in the field of underground corrosion This information therefore, constitutes the data base of the entire sub-science, and it is against this data that all new experience and subsequently derived empirical relationships must be compared and contrasted It is useful, therefore, to briefly review the results of this study

In the NBS study, samples of ferrous and nonferrous metals were buried at 128 sites Plain and galvanized steel specimens were buried at 47 sites where the soil water environments were different but representative of soil conditions in the United States The resistivity and pH were measured at each site in an attempt to determine a quantitative correlation between these measurable (but somewhat time and environment-dependent) parameters and metal loss Romanoff (19) the author of the NBS study demonstrated that the rate of corrosion is greatest in the first few years after burial and decreases to a much lower constant rate thereafter He indicated that this damping of corrosion was a more significant parameter than the initial rate He proposed quantitative empirical relationships to calculate average loss of thickness of plain steel as a function of time

Darbin (20), in his comprehensive review of the NBS data, has selected burial site data more or less consistent with the normal range of environments for buried reinforcing strips and extended this data in accordance with Romanoff's proposals He compared the results of this extended or extrapolated data with other pertinent studies such as the performance of sheet piles and culverts This comparison for galvanized steel samples and metal culverts is shown in Figure 36 This data demonstrates that even in an aggressive environment (ρ = 13,000 Ω cm, pH = 4 7), the galvanized steel reinforcing strips currently in use would have a service life of 120 years

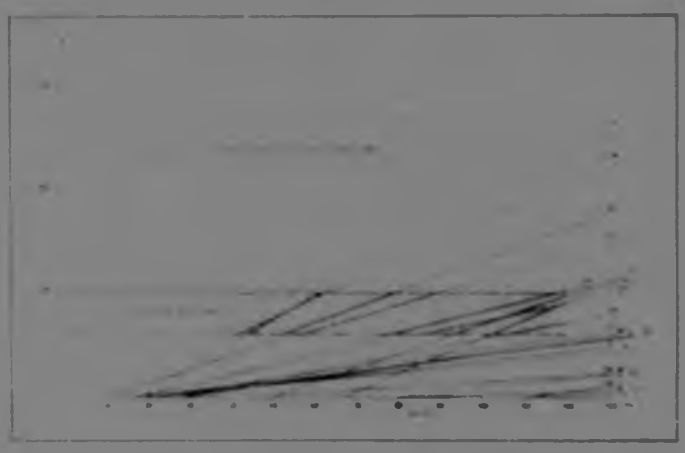

Fig 36 Synthesis of Extrapolated NBS and Metal Culvert Data (after Darbin et al , 1978)

The extrapolation of the Romanoff data requires the solution of the exponential equation

$$X = kT^n$$

where X = average loss of thickness with time
k = a site characteristic
T = time in years
n = site dependent and is always less than 1 0

Since selection of k and n requires some subjective interpretation it is useful to see if some more general quantitative conclusions can be drawn from the Romanoff data In an attempt to obtain this, the NBS data from the 47 steel burial sites has been re-plotted Figure 37 is an attempt to show a relationship between metal loss and resistivity The figure shows that a well defined relationship does not exist, but clearly demonstrates a trend of smaller metal losses with increased resitivity for sites whose pH is greater than 5 Figure 38 is an attempt to show a relationship between metal loss and pH The figure again demonstrates that a well-defined relationship does not exist However, it does show greater metal losses at sites with pH values less than 5 Using pH as the only guide, it is difficult to draw a conclusion However, if only well-drained sites are plotted as in Figure 39, it can be concluded that metal losses at such sites will not exceed 0 15 oz /sq ft /yr

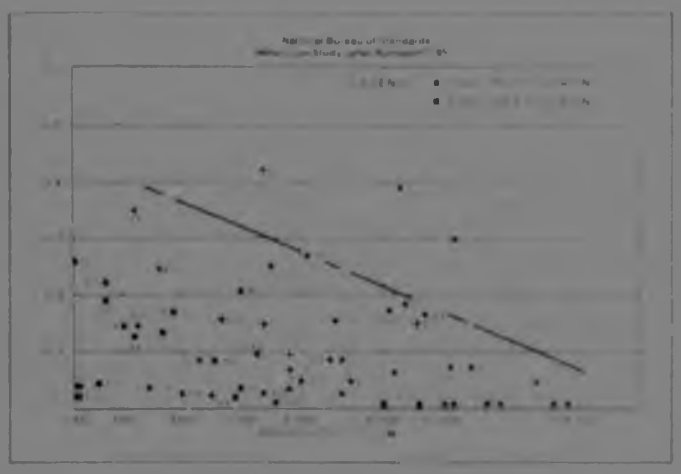

Fig 37 Weight Loss versus Resistivity

The abundance and reliability of this data and the ability to extrapolate it to the time period normally associated with engineering works has led to the selection of galvanized steel as the material most commonly used for Reinforced Earth structures. The zinc coating on galvanized steel forms a sacrificial anode which corrodes while protecting the base metal. In addition, zinc promotes a more uniform corrosion by preventing the formation of pits during the highly aggressive initial stages of burial

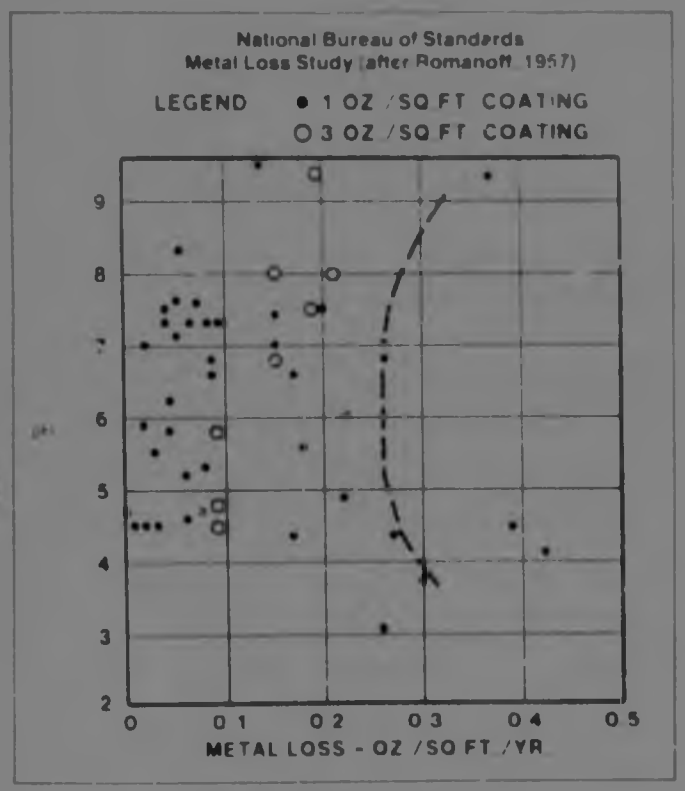

Fig 38 Metal Loss versus pH

Other materials currently used for reinforcements include plain carbon steel for temporary structures and some marine structures, and a fusion-bonded epoxy-coated steel reinforcement for highly acidic or warm marine environments

Other materials have been used as reinforcements with mixed results. Stainless steel was used in ten structures in France. Nine of these structures showed no evidence of corrosion when examined several years after completion. In one structure, there was some evidence of surface corrosion and pitting. Aluminum magnesium reinforcements were used on several structures in France and the United States. When placed in clean, well aerated backfills, this material demonstrated excellent performance. These passive metals such as stainless steel and aluminum are highly reactive in the presence of oxygen, and under favorable conditions are rapidly coated with a protective film of oxides that prevents corrosion of the base metal. However, when this protective layer is destroyed, either by physical or chemical processes, rapid corrosion can occur

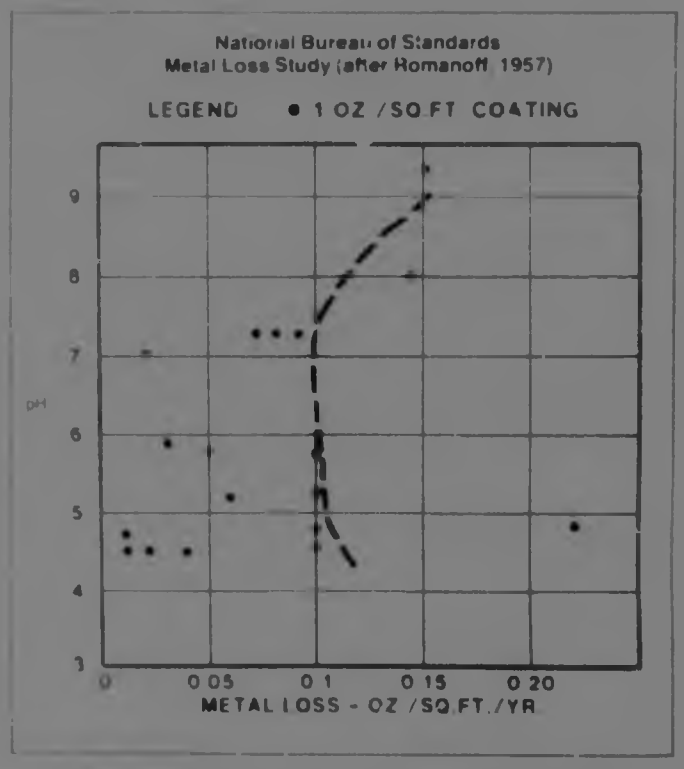

Fig 39 Metal Loss versus pH-Well Drained Sites Only

Plastics and other synthetics have also been used as reinforcements, but their performance has been disappointing. These materials are too brittle or too flexible to withstand and sustain the construction loads, and their corrosion performance is unpredictable (but in our experience uniformly poor)

In summary, we can state that there is sufficient data available to permit the selection of the cross-section and coating weight of galvanized steel reinforcements to insure a minimum service life. Design procedures for this important determination include the following

(1) the calculation of anticipated weight loss based on laboratory or field measured values of resistivity and pH at saturated conditions

(2) the selection of suitable site dependent characteristics for precise calculation according to Romanoff s formula

(3) comparing answers found in (2) with upper limits inferred by a broad interpretation of the Romanoff data

(4) proportioning the strip dimensions such that the stresses in the equivalent cross section at the end of the anticipated service life will be less than or equal to the yield stress

(5) applying whatever factor of safety to calculation (4) is required by the site and project characteristics

CONCLUSIONS

The excellent structural performance of the more than 2,000 Reinforced Earth structures completed during the past 11 years demonstrates more than any other fact that these structures have been safely designed. Measurements and observations of movements and stresses confirm that the working stress design procedures derived on the basis of a coherent gravity structure analysis, accurately predict subsequent performance. As improvements are made in the technology, such as the recent introduction of high adherence reinforcements, basic soil mechanics theory, supported by laboratory and field testing, can be used to modify design procedures to anticipate the effects of these improvements.

This experience has demonstrated that from all considerations of performance, stress, structural deformation and corrosion, the use of wall backfill that is a well-drained granular material, compacted to a field density that results in dilation during shear, will result in an extremely safe structure with a long and highly predictable service life. As backfill materials become more fine grained, caution must be exercised in selecting design parameters and factors of safety to allow for the more complex shear strength and corrosion characteristics of these finer grained materials. However, even with these finer grained elastic materials, adequate designs can be developed.

At present, at least, plastic materials should not be used for Reinforced Earth structures. No rational design procedure exists and their anticipated long-term performance, even assuming an adequate structural design, cannot be assured.

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reinforced earth

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Telephone 726-6180, Telex 4-24247, P.O. Box 91231, Auckland Park 2006

APPENDIX E

Origine : Destinataire :

D

N TARFILE A NLLSN
158 1608
C SALVIAM FLELA

ORLEANS LE 07.06.78

TELEX NO 151

A L ATTENTION DE MR MICHEL

LAITIER AFRIQUE DU SUD

ESSAIS DE RESISTANCE A LA COMPRESSION SIMPLE :

SABLE LAITIER : SAND-SLAG

AGE (EN JOURS)	7	14	28	60	90	
LAITIER EST TEMOIN R C	2	2,9	5,25	9,6	13,75	(French slag)
LAITIER A F S NO 1	1,2	1,65	2,6	3,5	3,5	CS.A slag)
A F S NO 2	1,1	1,3	2,5			CS.A slag)

GRAVE LAITIER GRAVEL-SLAG

AGE (EN JOURS)	7	14	28	60	90	
LAITIER EST TEMOIN R C	3,5		13,8			(French)
LAITIER A F S NO 2	0,5	2,4	4,6			CS.A)

COEFFICIENT ALPHA . 29 . AFS

FRIABILITE . 12 . + Facile que Est (16)

SURFACE SPECIFIQUE (BLAINE) . 2376

P MARCHI

TARFILE A NLLSN
SALVIAM FLELA
0

APPENDIX 7

ÉMETTEUR	RÉFÉRENCE	DATE	NUMERO	DESTINATAIRE
Ch. DIGUE	CD/RN	15.06.78	4-5986	L. DISON
DEPARTEMENT ou SERVICE	1	2	3	DEPARTEMENT ou SERVICE

ORG 9002

OBJET : PROGRAMME D'ESSAIS POUR LA GRAVE LAITIER

COPIE : M. MARCHI (Sal am Orléans)

Les resultats obtenus jusqu'ici au Laboratoire d'Orléans montrent qu'à l'inverse du laitier français, le laitier granulé provenant de Pretoria ne développe que des resistances faibles et qui cessent de croître à partir de 60 jours de prise.

Ce phénomene peut être dû à une composition chimique différente, notamment à une teneur en oxyde de magnesium supérieure et à une teneur en CaO inférieure.

Le catalyseur employé au cours des essais a été jusqu'ici de la chaux. Il reste donc à vérifier si l'augmentation de résistance souhaitée pourrait être obtenue avec un catalyseur different, c'est à dire soit du gypse, soit de la soude (NaOH), soit du gypsonat.

Dans le programme des essais, nous allons donc distinguerdeux parties :

1ère Partie - à executer en France

Déterminer comme indiqué ci-dessus le meilleur catalyseur,

2ème Partie - à effectuer en Afrique du Sud

Selon les resultats obtenus dans la 1ère Partie, les essais d'application pourront être conduits au Laboratoire Slagment pour répondre aux deux objectifs suivants :

a) Essais de contrôle de la qualité du laitier granulé et du catalyseur choisi.

Les essais consisteront à relever les résistances à 7 - 14 - 28 - 60 et 90 jours d'éprouvettes, moulées dans un moule de diamètre 2 pouces ½ de hauteur 4 pouces.

L'agrégat à employer sera un sable quartzitique de concassage 0-2 mm de composition suivante :

TAMIS A MAILLES COULEES	% PASSANT	
n° 200	12	
0,2 mm	20	(18-22)
0,5 mm	55	(52-58)
1 mm	82	(78-86)
2 mm	100	(95-100)

...../..

On constituera un mélange de 80 % de l'agrégat ci-dessus et 20 % de laitier granulé. Et à cet agrégat total, on incorporera un catalyseur choisi selon le dosage tiré des résultats de la 1ère Partie.

On déterminera ensuite la teneur en eau optimum de compactage et la densité maximum selon les essais Proctor modifiés.

On moulera ensuite les carottes d'essais dans le moule défini plus haut, au moyen d'une presse . Les moules seront munis d'un piston à la partie inférieure. Les 2 pistons seront rapprochés de la presse jusqu'à ce que la distance qui les sépare soit de 4 pouces.

La quantité à introduire dans le moule résulte du calcul suivant :

Si V est le volume du moule, on pèsera une quantité égale à V multiplié par la densité humide maximum de l'essai Proctor, les matériaux étant humidifiés à la teneur en eau optimum de compactage.

Les carottes seront démoulées et placées dans un étui plastique pour être placées dans un cabinet de prise en atmosphère humide et à une température à peu près constante de l'ordre de 20° C.

Après la prise aux intervalles de temps indiqués plus haut, on écrasera les carottes dans un essai de compression simple (unconfined compression test) à l'aide d'une presse avec une vitesse d'écrasement de 1,27mm par minute et on relèvera l'effort correspondant à la rupture de l'éprouvette.

b) Essai sur grave laitier pour déterminer la formulation applicable à un cas de chantier donné.

Pourra être exécuté selon les mêmes principes en utilisant des moules de 100 mm de diamètre et 200 mm de hauteur.

Si les agrégats contiennent des éléments supérieurs à 25 mm, on introduira dans la fraction 0-25 un pourcentage d'éléments 5-25 égal au pourcentage d'éléments supérieurs à 25.

La densité maximum et la teneur en eau optimum Proctor modifiée seront déterminées afin de mouler les éprouvelles de la même façon que précédemment. La cure et les essais d'écrasement seront effectués comme précédemment et aux mêmes intervalles de temps.

Un cas d'application type nous a été proposé à l'occasion de la réalisation de chaussées en béton comportant une dalle de 23,5 cm placée sur une couche support de 10cm d'épaisseur en CTB constituée par un crusher run 0-37 mm et 5 % de ciment.

Au cours de la discussion au sujet de ce cas, les observations suivantes ont pu être dégagées :

Le calcul de la dalle de béton, soit par les abaques de calcul que l'on peut trouver dans le AASHTO INTERIM GUIDE FOR DESIGN OF PAVEMENT STRUCTURE (éd.1974), soit par le calcul que le Laboratoire d'Orléans pourra nous communiquer, montre que la couche support n'intervient que très faiblement dans l'économie sur l'épaisseur de la dalle de béton.

Il en résulte que cette couche support a pour but :

1° - de permettre les opérations de construction dans de meilleures conditions,

2° - d'éviter le pumping.

L'introduction d'une variante pour remplacer la couche de CTB prévue par une couche de grave laitier de même épaisseur composée de 80 % de crusher run, 20 % de laitier granulé auxquels on adjoindra le catalyseur présenterait les avantages suivants :

1° - La grave laitier ne présente plus les inconvénients relatifs aux exigences de délais pour le compactage et la grave laitier peut être retouchée aisément pour obtenir un nivellement précis de la surface.

2° - La résistance à l'eau qui est nécessaire une fois l'ouvrage en service peut être obtenue avec la grave laitier dans un temps raisonnable, c'est à dire à partir des 90 jours, répondant ainsi au souci d'éviter le pumping.

3° - Selon les prix pratiqués, une économie sur les matériaux résulte de l'application de cette variante et elle s'accompagnera d'une économie complémentaire sur la construction proprement dite de cette couche (régalage, compactage et fin réglage).

Cependant, cette variante ne doit être présentée que si les résultats de l'étude de formulation en Laboratoire faite avec le crusher run et le laitier granulé de Vanderbijl apportent la preuve que le durcissement est bien effectivement obtenu avec la chaux comme catalyseur (ou éventuellement le gypse).

Cdigue

C. DIGUE

GRAVEL [illegible] EXPERIMENTS

1) CD & LD visited the SALVIAM depot and laboratory at Orléans on 14/6/78 and also inspected field operations in the area. Discussions were held with Mr. P. Marchi of Salviam who has been directing the test programme for gravel-slag and to whom our thanks are due for arranging the visit.

2) Gravel-slag Tests:

- Tests with S.A. slag gave disappointing results
- Reason appears to be high magnesia content because of use of dolomite cf. limestone in most French steelworks.
- This means that lime alone is not an adequate catalyst.
- Other catalysts, with or without a proportion of lime could be gypsum, N_aOH or a special product developed by Prandi known as gypsonat.
- Salviam laboratory will carry out tests on vdBijl slag to attempt to determine correct catalyst.
- In France a similar problem has been encountered with slag from Dunkerque which is also dolomitic - apparently gypsum has been used as a catalyst in this case - a danger of using gypsum is that it could produce swelling of the layer after compaction - hence Prandi's gypsonat which is a mixture of gypsum and other constituents.
- Mr. Digue has written a testing programme to be carried out jointly in France and in S.A. and which is enclosed with this report.

3) Short Field visit:

- The construction unit was not engaged on gravel slag on that day but some final product was inspected.
- One of the sections showed signs of crumbling, the reason for which, it was explained, was insufficient curing.
- Practice in France is to use a finer aggregate (-22mm) than in S.A.
- A mixing plant operated by COLAS was inspected - this plant was preparing a cement-sand mix but could be adapted to gravel-slag - features of the plant, which was a continuous-mix type, included automatic weighing and feeding, constant flow devices, ability to use 2 separate aggregates, pugmill mixer (from old asphalt plant), capacity of 150 t p h. Estimated cost of plant was FF400 000 (R 75 000) and when the time comes we can get advice in design and manufacture.

Page 2/.....

Random Notes:

- Concrete roads: It was pointed out that in the design of concrete roads the subbase was not expected to take much load, the main purposes of the subbase being (i) to provide a smooth working platform in the concrete slab and (ii) to avoid "pumping" at and through the joints.

- Slurry Seal: Usual spread rate was $12m^2/Kg$ - interested in Felbitem's idea of thicker seals.

- Aircooled Slag: The sample of VanderBijl slag looked very much like the French product - the vesicular nature of the slag, caused by sulphur, could apparently be reduced by adding pellets of hematite to the hot slag - could reduce L.A. test value from 24 to 20 and even 17. (Blaine Test!)

- Slagment: A small sample of slagment was handed over for inspection and possibly testing. (Blaine Test)

- pH values Gravel-Slag: A pH value of about 12,5 was required in order to get pozzolanic action.

TATION FROM MR. DIGUE'S PROPOSALS)

TEST PROGRAMME FOR GRAVEL-SLAG

The results obtained so far at the Orleans Laboratory show that the ISCOR slag develops far weaker strengths than the French slags and further shows no increase in strength after 60 days.

This phenomenon is possibly due to differences in the chemical composition, the S.A. slag being higher in magnesia (MgO) and lower in lime (C_aO).

The catalyst used in the present experiments has been lime. It remains to be seen whether the required strengths can be obtained with different catalysts, either gypsum or N_aOH or gypsonat.

The proposed testing programme has to be divided into two steps:

STEP 1: TO BE CARRIED OUT IN FRANCE (EJL)

To find the appropriate catalyst.

STEP 2: TO BE CARRIED OUT IN S.A. : SLAGMENT LABORATORY

On the basis of the results of STEP 1 tests for possible practical applications to be carried out on the following lines:

a) Tests to check the quality of granulated slag and the chosen catalyst.

- The tests will comprise checking strengths at 7, 14, 28, 60 & 90 days.
- Samples will be prepared in cylindrical mould 2" dia. & 4" height.
- The aggregate to be used with the slag will be 0-20mm. quartzitic crushed sand, having the following grading:-

Sieve Opening	% Passing
200	12
0,2mm	20 (18-22)
0,5mm	55 (52-58)
1 mm	82 (78-86)
2 mm	100 (95-100)

- The ratio of aggregate to slag will be 80% to 20%. The selected catalyst will be added to this total mixture at an application rate determined by the results of STEP 1.
- The optimum moisture content and maximum density will be obtained from the modified PROCTOR test.

Page 2/.....

- Samples are prepared in the moulds [illegible] a test press. The moulds are fitted with pistons which can press the samples to the required height of 4".

- The quantity of material to be placed in the moulds is calculated as follows:

  If V is the volume of the mould the quantity required is the mass of the total mixture (including water) which will give the volume V at maximum density and optimum moisture content.

- After compression in the moulds the samples are extracted, covered in plastic, placed in a moisture curing room, kept humid and at a constant temperature of about 20°C.

- At the time-intervals indicated above the samples are tested to destruction (unconfined compression test) by means of a test press operating at 1,27mm/minute.

b) Tests with gravel-slag to determine the appropriate mixture for a given project.

- These tests can be carried out on the same principles as above but using moulds of 100mm dia. and 200mm height.

- If portion of the chosen aggregate is greater in size than 25mm it is excluded from the test. A fraction of 5-25mm is added to the sample, equal to the fraction greater than 25mm.

- The maximum density and O.M.C. at modified PROCTOR will be determined as previously. The curing and crushing of samples are carried out as before and at the same time-intervals.

NOTE: CONCRETE ROAD:

This note discusses the case of the construction of a concrete road, slab thickness 235mm placed on a subbase of CTB, 37,5mm crusher-run and 5% cement, and 100mm thick.

The following observations are submitted:

- The calculation for the concrete slab, according to either the design charts of the AASHTO Interim Guide for Concrete Structures (1974) or the EJL laboratory at Orleans, shows that the subbase layer plays a minor part in the economics of the thickness of the slab.

  The principal functions of the subbase are therefore:

  i) to permit construction of the concrete slab under the most favourable conditions (accuracy of grade, smoothness of working platform);

  ii) to eliminate "pumping".

An alternative to the CTB in the form of a gravel-slag mixture of the same thickness, comprising 80% crusher-run, 20% granulated slag and a suitable catalyst will give the following advantages:

i) Compaction specifications for gravel-slag mixtures do not call for the same short compaction periods as for CTB. Therefore the gravel-slag layer can be completed to finer tolerances.

ii) Resistance to the effects of water, required for any type of road in service, is obtained with gravel-slag after a reasonable time (say 90 days) and "pumping" can consequently be avoided.

iii) At current prices economies will result in costs of materials by using this alternative and the costs of mixing, compacting and finishing should also be reduced.

However this proposed alternative should only be submitted if the laboratory tests with the crusher-run and Vanderbijl slag prove that hardening can be obtained with lime and a chosen catalyst (or eventually gypsum alone).

ORG 9004

DE Mr Arnaud MICHEL

A Mr. Leon DISON

N° 018816

DATE 4 10.78

OBJET APPENDIX 8

Granulated Slag

BORDEREAU d'ENVOI

Les documents énumérés ci-dessous vous sont adressés

POUR :

Note of Mr Ch DIGUE

about Granulated slag

P.J. :

FN

ACCUSÉ DE RÉCEPTION

Date

Visa

TESTS RESULTS ON RATE OF STRENGTHENING FOR GRANULATED SLAG

Hereafter can be found the grading analysis of three granulated slag samples from South Africa the grading analysis of 2 mixes of sand and of gravel mixed with 20% G.S. and a table giving the unconfined compressive strength of mixes with a comparative test performed with French slag

The samples have been compacted in accordance to modified AASHTO compaction test T 180-74. So after that preliminary compaction test, the max dry density and optimum moisture content have been used to calculate the right weight of mixes to introduce into the moulds which must be used to prepare the compression test samples

The moulds are of two sizes:

For sand mixes ϕ 5 cm Height = 10 cm

For gravel mixes ϕ 10 cm 20 cm

The right density in the moulds were obtained by reducing under a piston press the calculated weight of materials until they are reduced at the very height of the mould.

The sample has been cured in a moist cabinet during the curing time at a temperature of about 20°C

The compression test was performed at a rate of deformation of about 1,27 mm/min and the strength at failure recorded.

From the test results it can be seen that the S.A slag does not harden at the same extent that french slag.

If the control test to be performed in S.A. confirms these results, we will have to modify our thinking about the development of the french process of

ground slag.

It can be considered to use a semi ground slag instead of natural slag and this is able to produce a better hardening of the mixes.

Besides it must be said that the evolution of the technique in France has a tendancy to adopt this semi grinding process.

Moreover, the grinding is sometimes continued up to the obtention of a cement coarse ground to provide a well suitable cement for cement treated bases. That cement bring some outstanding advantages in regard to the workability, because the hardening is much more progressive than for a Portland cement. However we must understand that this technique is not absolutely new in South Africa where the slag cement is already on the market and where the maker of slag cement can produce also semi ground granulated slag.

Neuilly 2nd of October. 1974

Chaigne

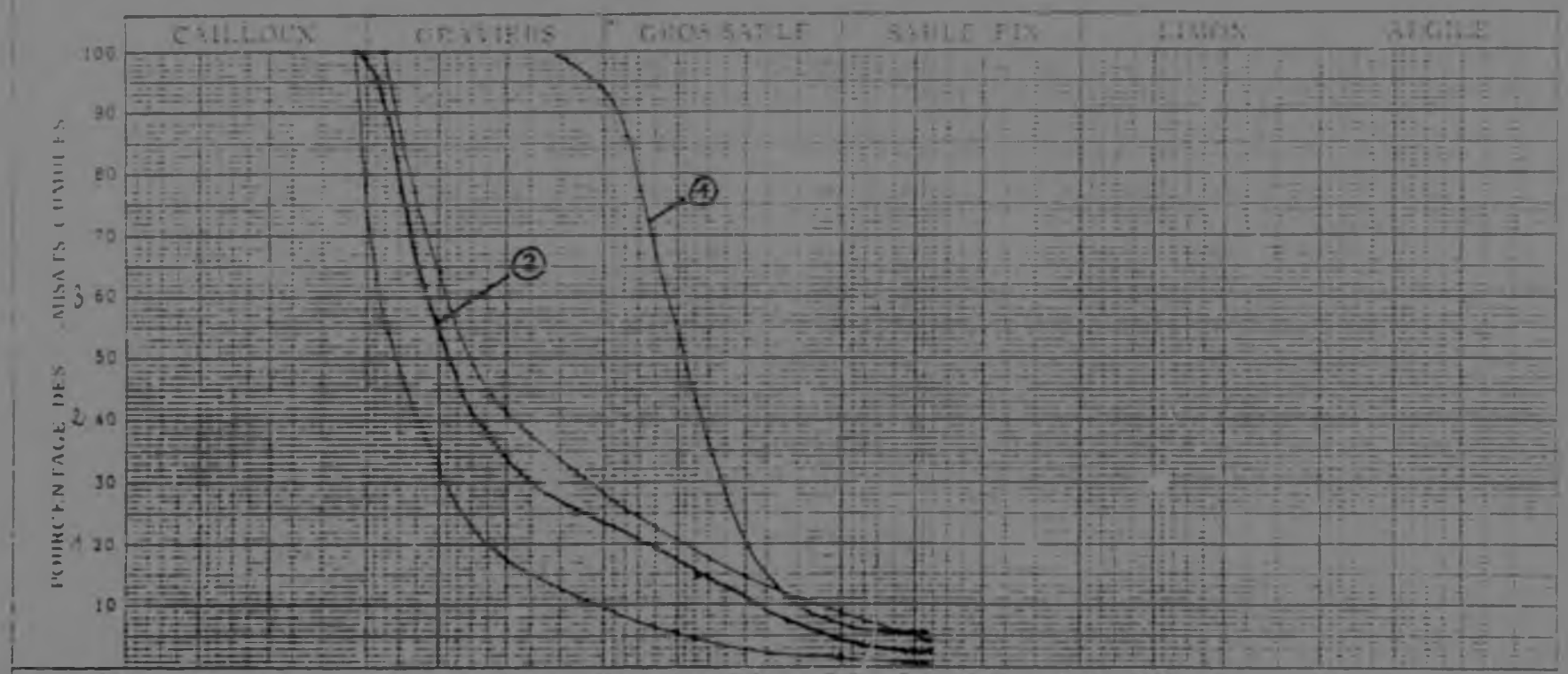
MIXES WITH GRANULATED SLAG AND SAND OR GRAVEL

(1) River sand 56 %
Grinded River sand (15 get 18 % pass N°200 in the Grinded sand) 24 %
Granulated slag 20 %
Lime (hydrated) 1 %

(2) 0/20 Gravel crushed (Silica-limestone) 65 %
2/6 Rounded fine gravel 15 %
Granulated slag 20 %

— Specifications Limits (Envelope)
—— Echantillon
N° d'essai N°

ANALYSE GRANULOMETRIQUE



LL = IP = ES =

Opérateur .....

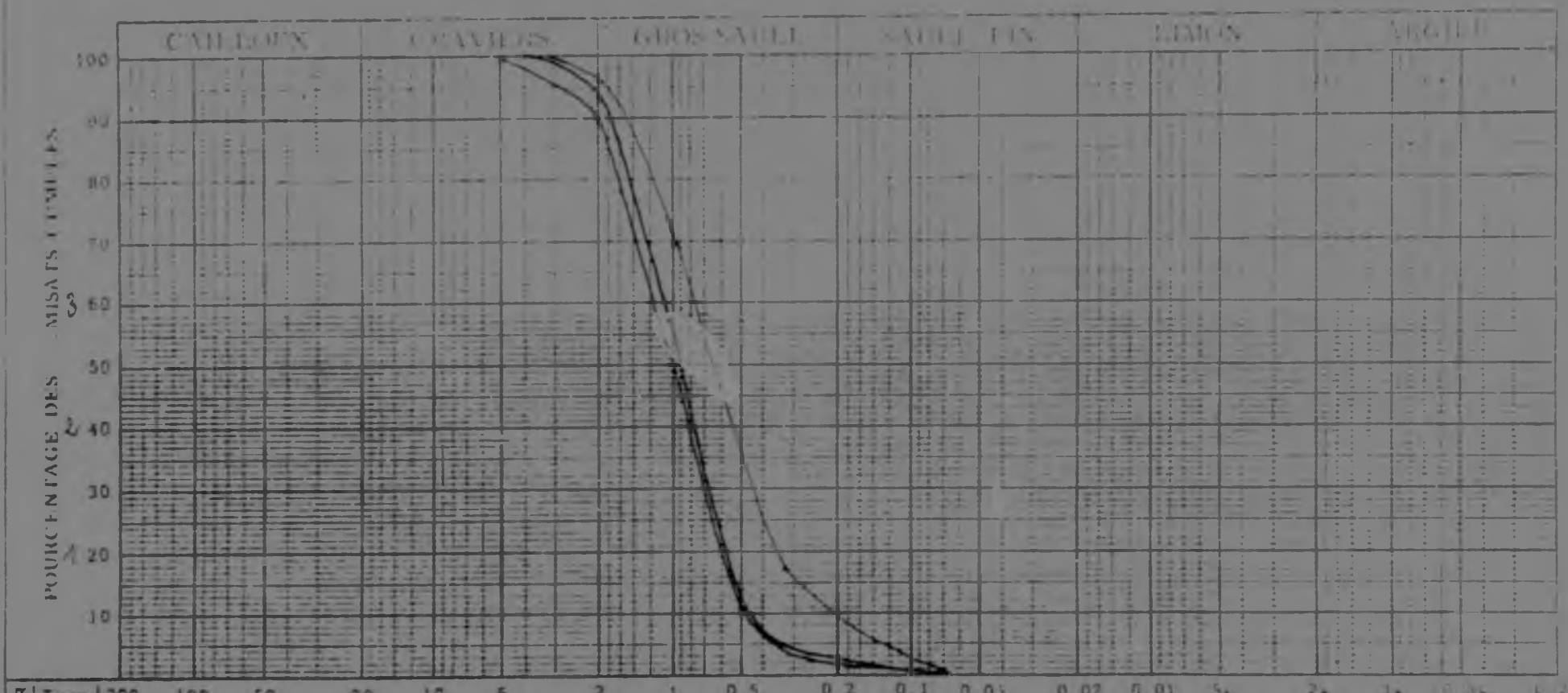
Saint-Quentin, le .....

— sample N°3 (03.07.78)
— sample N° 2 (24.04.78)
— sample N°1 (22.02.78)

GRANULATED SLAG

Echantillon
P.V. N°

ANALYSE GRANULOMÉTRIQUE



AFNOR																		
Tamis	200	100	50	20	10	5	2	1	0,5	0,2	0,1	0,05	0,02	0,01	5µ	2µ	1µ	0,5µ
Module	54	51	48	44	41	38	34	31	28	24	21							

ASTM											
	5"	2"	1"	1/2"	1/4"	n°10	20	40	80	200	

← - - - - - Passoires - - - - - ⋈ - - - - - Tamis - - - - - →

LL = IP = ES =

Opérateur .....

Saint-Quentin, le .....

UNCONFINED COMPRESSION STRENGTH OBTAINED WITH 1% HYDRATED LIME AS CATALYSER AT VARIOUS CURING TIME

OPTIMUM MOISTURE MODIFIED PROCIOR DENSITY	9% 1,83					7% 2.08 Kg/dm³				
	SAND SLAG ①					GRAVEL SLAG ②				
WITH FRENCH SLAG Bars	2	2,9	5,75	9,6	13,75	3,5	—	13,8	—	—
WITH S.A. SLAG Sample N°1	1,2	1,65	2,6	3,5	3,5					
Sample N°2	1,1	1,3	2,5	2,5	—	0,5	2,4	4,6	6,2	—
CURING TIME (DAYS)	7	14	28	60	90	7	14	28	60	90

PH OF THE MIX : 12,7

SAMPLES SIZE : area of circular section : 20 cm² for sand
80 cm² for gravel

height = 2 x diameter

WITH VARIOUS CATALYSERS

caustic soda in pellets was introduced by a solution 10% pellets + 90% water

TESTS PERFORMED WITH SAND GRAVEL FORMULA ①

Sample diameter x 2 = Height and section area 20 cm²

OPTIMUM MOISTURE CONTENT ← 9% → MODIF PROCTOR DENSITE ← 1,83 →										
CATALYSEUR	GYPSUM 1%		CAUSTIC SODA 0,25%		0,5%		1%		GYPSONAT 0,8%	
GRAN. SLAG ①	0	2	0	0,5	0	0,5	0	0,5	0	1,5
GRAN. SLAG ③	0	0	—	—	—	—	7	10,5	0	0
CURING TIME days	7	28	7	28	7	28	7	28	7	28
PH OF MIX	10		12,2		12,2		12,2		11,3	

PROPOSED PROGRAMME OF PRELIMINARY TESTS ON SAND : GRANULATED SLAG MIXTURES

(i) It is proposed to use two aggregates for the preliminary tests.

Aggregate 1 is a Witwatersrand crusher sand

Agregate 2 is a washed granite concrete sand (graded curves attached)

Both of these materials have the advantage that they have no natural cohesion, they have a range of particle sizes, and the maximum particle size is not too large for use with a 50 mm diameter mould.

(ii) Preliminary tests on mixtures of the sand and granulated slag will be made following the Eades and Grim method to find what percentages of hydrated lime, caustic soda and ordinary Portland cement are necessary to rise the pH to a value of 12,3. Specimens will then be made up for testing at 7,14,28,56 and 112 days with a ratio of aggregate : slag of 80% : 20% and the selected percentages of the three catalysts. Five specimens will be made for testing at each age. Specimens will be compacted by static compression at a moisture content corresponding to the optimum moisture content for modified AASHO compaction established for the sand slag, catalyst mixture, and will be compressed to attain the maximum density for modified AASHO compaction.
(Five specimens x five times x three catalysts x two aggregates = 150 tests).
After forming each specimen, it will be removed from the mould, wrapped in a polythene strip and aluminium foil and then wzxed to seal in the moisture. Curing will be carried out at 25°C. (Some difficulty may be experienced with the demoulding process. If this proves to be the case it may be necessary to add a small proportion of milled fines to the material in order to improve the early handling characteristics.)
After the appropriate curing period, the specimens will be tested in unconfined compression at a rate of approximately 1,25 mm per minute.

Session IV: Slags

The General Reporter, Thomas, summarised the papers submitted for this session. Anderson dealt with the stabilisation of road bases using both granulated and air-cooled slag. He reported that the cementing bonds developed by activated slag appear to behave visco-elastically. These materials therefore have superior cracking resistance to Portland cement stabilised material.

Blunk drew attention to the phosphate content of certain steel slags, and the possibility of using this material as a fertiliser. Germany apparently uses 100% of its slag production at present, and actually imports 1,2 million tons per annum of granulated slag.

Ambroise dealt with the use of pelletised slag in light weight aggregate concrete. Pelletised slag aggregate is superior as regards water absorption (i e absorbs less) to expanded shale aggregate, because each pellet has its internal voids sealed. Shrinkage, strength and modulus values are also quite adequate when pelletised slag aggregate is used in unreinforced or reinforced experimental applications.

Colombier dealt with the 80 : 20% gravel slag mix known in France as "graves laitier". This material has the useful property of slow but progressive hardening action. The ultimate strength value of graves laitier is approached after 6 months, but the strength at 7 days is only 10% of the 6 month strength. The large binder content of this type of material allows considerable latitude in mixing. However shrinkage cracking can be a problem.

A recent development involves the partial pre-grinding of the slag. There are also several alternative activators which can be used, e g sulphate-lime-soda activators, gypsum-soda activators etc.

Dussart dealt with the use of steel slag. Steel slag comes in both disintegrated and crushed forms. The slags' free-lime and magnesia content is a problem, as it may lead to expansion of compacted material, but it has a potential benefit as a source of hydraulicity. Both crushed and disintegrated slag have hydraulic properties.

A strength of up to 4MPa after a year has been recorded with disintegrated slag. Lower strengths occur with slag-sand mixtures. Crushed slag tends to disintegrate on exposure to water and should only be used as an asphalt aggregate when it is protected from water. Steel slag apparently has excellent wear characteristics. In standard tests up to 50% less wear has been recorded with steel slags than with natural materials.

Emery and Hooton described the use of partially ground pelletised slag as a replacement for silica-flour in auto-claved light-weight aggregate Portland cement products. They use the pelletised slag as an aggregate. The partial grinding produces fines which have hydraulic properties.

Mraz reported that failures had been experienced where blast furnace slag has been used as a road stone. The problem has been traced to the reactivity of unhydrated calcium oxide contained by the slag.

Popovics dealt with the use of slag as an embankment fill. He reported on a large industrial terrace build of a heterogenous mixture of slags. Triaxial shear tests showed very high angles of internal friction (in excess of 45°) and the fill proved to be almost completely incompressible.

Dubosc pointed out the energy savings which can occur when granulated slag is used to produce an interground slag cement. For example 116 kg per ton of fuel oil is used to produce pure Portland cement. The fuel oil requirement falls to 46 kg per ton for a mixture of 15% Portland cement and 85% slag cement.

Delegates at the Conference proved to be very aware and concerned with energy conservation, and the use of materials which have a latent energy content, which their use, in effect, reclaims (e g blast furnace slag). Delegates appeared less aware and less concerned with the possible pollution hazards of using wastes in civil engineering construction. It became quite clear that this lack of concern was not based on knowledge that the problem did not exist, but simply on the preconceived idea that no pollution problems would arise.

It also became quite obvious that although the use of metalliferous slags in road construction is a promising development, and should be explored for application in South Africa, one of the big problems experienced in France relates to shrinkage cracking of the surfacing. Under the drier South African climatic conditions this problem may prov to be even more severe, and we may find ourselves faced with severe cracking problems simila to those experienced a few years ago with cement-treated crusher-run road bases.

Session V : Fly-Ash

General Reporter Nicolescu : report read by Bonnot.

It is evident that fly-ash from different countries reacts differently and that fly-ash will have different properties from time to time, even when taken from the same power station. There are two basic types of fly-ash : silica-alumina ashes which require activation in order to develop cementing action, and sulpho-calcic ashes which are self cementing. The bulk of fly-ash is transported hydraulically to storage, and therefore loses some of its cementitious properties.

When used as fill the density of fly-ash is found to be fairly constant regardless of origin. The compaction characteristics are good with a flat compaction curve that is relatively insensitive to moisture content. The shear strength of the material results almost entirely from internal friction, and is excellent. Fly-ash is currentl used in road construction and building construction. Its uses in road construction are to construct fills, for pavement foundations and as a filler in asphalt premixes. When used as a fill its main advantage is its light weight which makes it suitable for constructing embankments over marshy ground. In pavement foundations fly-ash can be used to improve the grading of certain soils, e g single sized sands, and it can also be used as a cementing agent to stabilise soils. When added to clay soils the liquid limit is decreased, althouc the plasticity index remains almost constant. Free swell and swelling pressure are also decreased. Similar results are obtained whether the precipitator ash or lagoon ash is used, but lagoon ash is less active than precipitator ash which has never had access to moisture.

G. E. Blight, M.Sc.(Eng.), Ph.D., D.I.C.,
A.M.S.A.I.C.E.

Department of Civil Engineering,
University of the Witwatersrand,
Jan Smuts Avenue, Johannesburg, South Africa.

22nd January, 1979

Mr L Dison,
Reef Lefebvre (Pty) Ltd.,
P O Box 39431,
BRAMLEY

Dear Mr Dison,

PRELIMINARY RESULTS OF TESTS ON SAND-GRANULATED BLAST FURNACE SLAG MIXES.

We now have strength results for ages up to 28 days for 80% sand: 20% granulated slag mixes activated by a variety of materials. The results are summarized in the attached table. It will be noted that we have used Portland cement as a reference binder and the figures in brackets represent the percentage of the strength using cement which has been developed for the four other activators.

The most promising activator appears to be (90% lime + 10% NaOH) which produces approximately half of the strength produced with 100% cement.

We intend following up the following:

(i) the effect of partially milling the granulated slag in an attempt to increase its reactivity;

(ii) the effect of using larger percentages of the (90% phosphogypsum + 10% NaOH) activator.

Yours sincerely,

G E Blight

enc

TESTS ON 80% SAND : 20% GRANULATED SLAG MIXES - SUMMARY OF STRENGTH RESULTS

Sand 1: Washed, weathered granite concrete sand
Sand 2: Witwatersrand quartzite crusher sand.
All mixes consisted of: Solids: 80 parts sand
20 parts granulated slag
5 parts binder
All by dry mass

Water content: 5,5 % by mass of dry solids
Dry density of all specimens : 1500 kgm^{-3}

Age of Specimen	Strengths of 2 Sand-Slag Mixes Activated With Following Binders : (in kPa)									
	100% Lime		90% Lime + 10% NaOH		90% Lime + 10% Phospho-Gypsum		90% Phospho-gypsum + 10% NaOH		100% Portland cement	
Days	Sand 1	Sand 2	Sand 1	Sand 2	Sand 1	Sand 2	Sand 1	Sand 2	Sand 1	Sand 2
7	(18)* 59	(12) 52	(47) 156	(25) 109	(22) 74	(11) 47	(31) 105	(18) 79	(100) 334	(100) 442
28	(14) 129	(9) 77	(48) 441	(49) 396	(19) 177	(10) 79	(10) 91	(11) 93	(100) 915	(100) 815
56										

* Figures in ( ) represent strength as a percentage of strength developed with 100% cement.

APPENDIX 12

STABILIZATION OF GOLD MINE SANDS AND SLIMES USING BLAST FURNACE SLAG

A REPORT TO

E J L (S A) (P T Y) L T D

P O BOX 376
BERGVLEI, 2012

BY

G E BLIGHT

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

NOVEMBER 1979

1. INTRODUCTION

Mixtures of graded gravel or sand and 10% to 25% of granulated (ie water-quenched) blast furnace slag activated by means of a small percentage (typically 1%) of lime have been used extensively for road construction in France for a number of years, eg Prandi(1). Investigations along similar lines in the USA(2) have also been encouraging. Among the advantages claimed for activated gravel or sand/granulated slag mixes (graves-laitier and sables-laitier) are:

i) slow set, making placing and working easier;
ii) insensitivity to variations in water content;
iii) little shrinkage cracking, combined with self-healing properties;
iv) high strength; and
v) excellent durability.

Prandi reports unconfined strengths at 7 days of about 500 kPa rising to 2000 kPa at 56 days. The US National Slag Association reports strengths at 7 days of 450 kPa to 1050 kPa for slag contents of 10% rising to 2200 kPa to 3200 kPa at 90 days.

In the gold-mining areas of South Africa, large quantities of waste slimes exist and granulated slag is available from the Iscor works in Pretoria and Vanderbijlpark either as the water-quenched granulate or, via Slagment Ltd. as milled slag cement. In the central Witwatersrand area sand dumps exist, but most of these will probably be reprocessed in the near future to recover their gold content, the end waste-product being again slimes. Gypsum waste from the fertilizer industry is also available to the North of Johannesburg and at Potchefstroom.

It would clearly be of great advantage to the country if the slimes could be used in road construction. The advantage would be even greater if the other waste products mentioned above could be used to stabilize the slimes.

2. CHEMICAL DESIGNATION:

Granulated blast furnace slag is a pozzalonic material which, in the presence of water, reacts with free lime to produce calcium and aluminium silicates(3). These form cementitious bonds within the aggregate.

Lime stabilization occurs by the formation of calcium silicates (in the presence of water) by reaction between finely divided silica in the aggregate and the free calcium hydroxide. Both of these processes require an environment of high pH as the solubilities of both silica and alumina are greatly increased at high levels of pH(4).

iii) For this reason caustic soda, which has a higher pH (about 13,3) than that of slaked lime (about 12,5) has been used to promote lime stabilization by adding a small percentage of it to the lime(5). Caustic soda has also been used by itself to stabilize soils.

iv) Super-sulphated cement consists of 80 to 85% of granulated slag which is interground with 15 to 10% of gypsum and 5% of portland cement clinker(3). The addition of a small percentage (typically 0,1% of the total mix) of gypsum to the lime activator used in the French graves-laitier mixes is known to promote the gain of strength.

v) Finally, we have the phenomenon of alkali-aggregate reaction which can be a serious problem in disrupting structural concrete(6). The reaction occurs when silica in the aggregate is attacked by the alkaline sodium and potassium hydroxides derived from the cement with the resulting formation of alkali-silicates.

The above information resulted in the design of the first series of tests in which the activaters consisted of:

lime
90% lime + 10% caustic soda
90% lime + 10% gypsum
90% gypsum + 10% caustic soda
ordinary portland cement.

] Activators

The portland cement was added to the list purely as a standard of reference.

3. TESTS USING GRANULATED SLAG AND COARSE SAND AGGREGATES

This first exploratory series of tests was aimed at simulating the materials used in [illegible]rce and investigated in the USA. Two coarse sands having s[illegible] grading were selected, one being a Witwatersrand quartz[illegible]te crusher sand, the other a washed granite sand fr[illegible] Honeydew. The gradings of these two sands are shown in F[illegible]re 1. An 80%:20% mix of sand and granulated slag was used for all specimens which were activated by means of 5% of the above list of activators.

The percentage of activator of 5 was selected as a result of a series of Eades tests(4) the results of which are shown in Figure 2 and tabulated in Table 2. In all cases the maximum pH of the mix was reached at an activator percentage of 4. This was increased to 5% in case there should be a decrease in pH as a result of the cementation reactions.

The test specimens were 38 mm in diameter and 100 mm long and were compacted statically using double floating pistons(4) to a dry density of 1500 kg m^{-3} at a water content of 6%. The density and compaction water content were selected after carrying out static compaction tests to determine the optimum water content and maximum dry density of both slag/sand mixes activated with 2% and 5% of lime. The results of the compaction tests are recorded in Table 1.

After compacting the specimens, they were wrapped in aluminium foil, sealed in wax and stored at 25°C until the selected

test age had been reached.

The results of this series of strength tests at ages of 7, 28 and 68 days are tabulated in Table 3 and plotted in Figures 3a and 3b.

For both aggregates a strength of close to 1000 kPa was approached with portland cement as an activator. The lime-caustic soda activator gave strengths of between 400 and 600 MPa, but the remaining activators did not perform well. Of the remaining activators, the most promising appeared to be the mixture of (90% gypsum + 10% caustic soda). It was decided to use this activator as well as the (90% lime + 10% caustic soda) mixture in further tests.

4. TESTS TO INVESTIGATE THE EFFECTS OF FINENESS OF AGGREGATE AND FINENESS OF SLAG

The preliminary series of tests appeared to show that it is not possible to match French and American test results on slag/sand mixes with South African slags. The next stage in the investigation was to investigate the effect of using finer slag and finer aggregates.

In this series of tests, specimens were made with mixes containing 80% of dump sand and slimes (gradings shown in Figure 1) and 20% of granulated slag and a partly milled slag. Whereas the granulated slag has the particle sizes of a coarse sand, the partly milled slag has the particle sizes of a coarse silt/fine sand.

It was realized that the finer aggregates would have a higher optimum water content than the coarse. It was nevertheless decided to keep the variables of water content and dry density constant as before at 6% and 1500 kg m^{-3} respectively.

The results of tests on specimens activated with (90% lime +10% caustic soda) are plotted in Figure 4a, while those

for specimens activated with (90% gypsum + 10% caustic soda) are plotted in Figure 4b.

With granulated slag and lime/caustic soda activator strengths increased progressively as the aggregate became finer. With the gypsum/caustic soda activator, aggregate fineness had no effect.

On the other hand, there appears to be nc advantage in using a finer slag with a coarse sand, but there are very definite advantages in using a fine slag combined with fine aggregates. Both dump sand and slimes in combination with partly milled slag achieved strengths approaching 1000 kPa. The results of Eades tests on mixtures of granulated and partly milled slag and dump sand and slimes in combination with various activators are tabulated in Table 2. The pH appears in this case to be little affected whether the aggregate is sand or slimes, but this may not be so for aggregates from different sources, possibly containing a greater content of soluble salts. The pH of mixes containing the lime/caustic soda activator were in the region of 12,7 even when the percentage of activator was.doubled. The pH of mixes containing the gypsum/caustic soda activator, however, increased appreciably when the activator percentage was increased from 5 to 10. It was therefore decided to explore the effect of varying both activator percentage and activator composition on strength.

5. EFFECT OF ACTIVATOR PERCENTAGE AND COMPOSITION ON STRENGTH

The results of tests on mixes of granulated and partly milled slag and dump sand and slimes activated with lime/caustic soda are shown in Figure 5a. In general there seems to be no worthwhile advantage in increasing the activator percentage above 5. However, at later ages, there is a definite advantage in increasing the caustic soda content of the activator.

Figure 5b shows corresponding results for mixes activated with gypsum/caustic soda. These results were completely negative, showing no advantage in increasing the activator percentage or the caustic soda content of the activator.

6. EFFECT OF VARYING CONTENTS OF SLAGMENT

The work so far had shown that there are definite advantages in using finely divided slag in combination with fine aggregate. The next stage of the investigation concentrated on using slagment in combination with slimes.

It was also apparent that the costs of milling granulated slag to silt-size fineness would make the use of 80% aggregate: 20% slag mixes prohibitively expensive and it was therefore decided to investigate reducing the slagment content of the mixes progressively to 10% and then 5%. It was also decided at this stage to compact all specimens to Mod AASHO maximum dry density at Mod AASHO optimum water content, although static compaction would still be used. The results of the compaction tests are summarized in Table 1B. Figure 6 shows the age-strength curves for this test series. It is particularly encouraging to note that strengths of 2000 kPa can be reached with a 95% slimes:5% slagment mix activated with lime/caustic soda. On the other hand, the mixes activated with gypsum/caustic soda are uniformly disappointing.

However, one is left with the problem that a mix such as Z in Figure 6, although it reaches a satisfactory strength, has a binder content of 10 per cent. This immediately raises the question: Could not the same result be achieved by means of 5% of portland cement?

Although similar tests had previously been performed with negative results (see Figure 5b), it was nevertheless decided to reinvestigate the effects of

i) increasing the activator content; and
ii) increasing the caustic soda content of

the gypsum/caustic soda activator on the grounds that this activator should be very cheap. The results of this last investigation are shown in Figure 7 and once again proved to be completely negative.

7. PROPOSALS FOR FUTURE WORK

By a process of elimination it has been shown that dump sand and slimes can be successfuly stabilized using slagment stabilized with lime/caustic soda. It does not appear worthwhile pursuing gypsum-based activators.

It is proposed that the following programme be followed:

i) Investigate the effect of reducing the slagment/lime/caustic soda content below 10%

ii) Investigate the effect of reducing the activator content below 5%

iii) Investigate the effect of eliminating caustic soda from the activator

These proposals are scheduled in detail in the Appendix to this report.

8. REFERENCES

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(6) OLerholster, R E, Brandt, M P and Weston, A C, Cement-aggregate Reaction and the Deterioration of Concrete Structures in the Cape Peninsula, Civil Engineer in South Africa, Vol 20, No 7, 1978

9. APPENDIX - PROPOSED FURTHER TESTS

(a) General

i) All tests to be carried out on stabilized slimes

ii) All specimens to be compacted to a dry density of 1700 kg m^{-3} at a compaction water content of 18%

iii) After compaction specimens to be wrapped in aluminium foil, sealed in wax and stored at 25^{0} until the age of test

iv) Nine specimens to be made for each binder content and tested in unconfined compression as follows:

3 at 7 days
2 at 28 days
3 at 63 days

v) Binders and binder contents are to be as scheduled below:

Binder content as mass per cent of dry slimes	Binder Composition in per cent by dry mass		
	Slagment	Road Lime	Caustic Soda
(i) 10	50	45	5
6	"	"	"
3	"	"	"
(ii) 10	72,5	25	2,5
"	89	10	1
5	"	"	"
(iii) 10	50	50	-
5	"	"	

8 x 9 = 72 specimens

TABLE 1

RESULTS OF COMPACTION TESTS

A. Static compaction in 38 mm dia mould to stress of 2 MPa

Material	Optimum water content %	Maximum dry density kg m^{-3}
80% granite sand: 20% granulated slag		
+ 2% Lime	5,7	1493
+ 5% Lime	6,2	1509
90% crusher sand: 20% granulated slag		
+ 2% Lime	4,8	1529
+ 5% Lime	5,8	1560

B. Mod AASHO Compaction

Material	Optimum water content %	Maximum dry density kg m^{-3}
80% Slimes: 20% Slagment		
+ 5% of (90% Lime + 10% NaOH)	17,6	1690
+ 5% of (90% Gypsum+10% NaOH)	15,2	1735
90% Slimes: 10% Slagment		
+ 5% of (90% Lime + 10% NaOH)	18,4	1660
+ 5% of (90% Gypsum+10% NaOH)	16,4	1720
95% Slimes: 5% Slagment		
+ 5% of (90% Lime + 10% NaOH)	19,2	1645
+ 5% of (90% Gypsum+10% NaOH)	16,6	1725

TABLE 2:

RESULTS OF pH DETERMINATIONS IN EADE'S TESTS

(A1) Slag-aggregate-activator mixes

Slag	Activator	pH	
		80% Granite sand	80% Crusher sand
20% granulated	2% lime	12,7	12,5
	3% "	12,8	12,8
	4% "	12,8	12,8
	5% "	12,8	12,6
	2% cement	11,9	11,7
	3% "	12,0	12,1
	4% "	12,1	12,1
	5% "	12,0	12,0
	2% caustic soda	13,0	13,0
	3% "	13,2	13,2
	4% "	13,4	13,3
	5% "	13,2	13,2
	2% (90% lime + 10% caustic soda	12,7	12,8
	3% "	12,8	12,8
	4% "	12,8	12,8
	5% "	12,8	12,9
	Activator	80% dump sand	80% Slimes
20% granulated	5% (90% lime + 10% caustic soda)	12,7	12,7
	10% "	12,8	12,8
	5% (90% gypsum + 10% caustic soda	11,0	11,2
	10% "	11,9	12,0
20% partly milled	5% (90% lime + 10% caustic soda)	12,8	12,7
	10% "	12,8	12,7
	5% (90% gypsum + 10% caustic soda	11,6	11,7
	10% "	12,2	11,9
-	-	dump sand 4,4	slimes 3,8

TABLE 2: RESULTS OF pH DETERMINATIONS IN EADE'S TESTS (Continued)

(B) Activators

% Lime	% Gypsum	pH	% Gypsum	% Caustic Soda	pH
100	-	12,8	100	-	3,9
-	100	3,9	-	100	13,3
95	5	12,7	95	5	11,9
93	7	12,7	93	7	12,1
91	9	12,7	91	9	12,4
89	11	12,7	89	11	12,4

(A2) Slag-aggregate-activator mixes

20% Slag	5% Activator	pH with 80% of aggregate:		
		Crusher sand	Dump sand	Slimes
Granulated	90% gypsum + 10% caustic soda	12,3	12,1	12,0
	90% lime + 10% gypsum	12,7	-	-
	90% lime + 10% caustic soda	-	12,8	12,8

TABLE 3 SUMMARY OF RESULTS OF STRENGTH TESTS

Each strength is the mean of 3 determinations

All specimens were compacted to a density of 1500 kgm^{-3}

(A) Tests on 80% Aggregate: 20% Slag Mixes Using Slag and Aggregate of Various Fineneses

Age at test days	Type of Slag, Activator and Aggregate									
	Granulated Slag + 5% Activator									
	Lime		90% Lime + 10% NaOH		90% Lime+10% Gypsum		90% Gypsum+10% NaOH		Ordinary Portland Cem.	
	Granite sand	Crusher sand	Granite sand	Crusher sand	Granite sand	Crusher sand	Granite sand	Crusher sand	Granite sand	Crusher sand
7	59 kPa	52 kPa	4[illegible]0 kPa	109 kPa	74 kPa	47 kPa	105 kPa	79 kPa	334 kPa	447 kPa
28	179	79	441	396	227	74	91	93	815	815
56	197	170	586	406	253	152	298	329	1040	956

Age at test days	Crusher Sand + Granulated Slag											
	90% Lime + 10% NaOH				6.8%		90% Gypsum + 10% NaOH				6.8%	
	5%	6.8%	8.5%	10.4%	87% Lime 13% NaOH	85% Lime 15% NaOH	5%	6.8%	8.5%	10.4%	87%Gypsum 13% NaOH	85%G 15%
7	126 kPa	166 kPa	143 kPa	139 kPa	148 kPa	164 kPa	69 kPa	78 kPa	76 kPa	61 kPa	80 kPa	50
28	289	384	421	499	547	695	205	203	98	105	173	101
56	293	373	403	438	444	670	177	160	134	161	136	116

Age at test days	Crusher Sand + Partly Milled Slag			
	90% Lime + 10% NaOH		90% Gypsum+10% NaOH	
	5%	10.4%	5%	10.4%
7	128 kPa	157 kPa	182 kPa	195 kPa
28	167	135	283	325
56	312	451	292	301

Age at test days	Dump Sand							
	Granulated Slag				Partly Milled Slag			
	90% Lime + 10% NaOH		90% Gypsum+10% NaOH		90% Lime + 10% NaOH		90% Gypsum+10% NaOH	
	5%	10.4%	5%	10.4%	5%	10.4%	5%	10.4%
7	206 kPa	138 kPa	123 kPa	188 kPa	406 kPa	591 kPa	584 kPa	592 kPa
28	319	679	139	445	825	859	1027	534
56	395	1174	48	191	673	843	1054	618

Age at test days	Slimes										
	Granulated Slag				Partly Milled Slag				Slagment		
	90% Lime + 10% NaOH		90% GYpsum+10% NaOH		90% Lime + 10% NaOH		90% Gypsum+10% NaOH		90% Lime+10% NaOH		90%Gypsum+10%N
	5%	10.4%	5%	10.4%	5%	10.4%	5%	10.4%	5%		5%
7	306 kPa	384 kPa	123 kPa	184 kPa	695 kPa	684 kPa	249 kPa	346 kPa	1280 kPa		680 kPa
28	435	1398	128	165	914	1019	749	455	1459		582
56	745	1151	131	241	902	1383	789	401	2166		581

(B) Tests on Slimes: Slagment Mixes

Age at test days	5% Activator								10% Activator	15% Activator
	80% Slimes:20% Slag		90% Slimes:10% Slag		95% Slimes:5%					
	90% Lime+ 10% NaOH	90%Gypsum 10% NaOH	90% Lime 10% NaOH	90%Gypsum 10% NaOH	90% Lime 10% NaOH	90%Gypsum 10% NaOH	85%Gypsum 15% NaOH	80%Gypsum 20% NaOH	90%Gypsum+10% NaOH	
7	1280 kPa	680 kPa	1130 kPa	579 kPa	852 kPa	515 kPa	386 kPa	383 kPa	419 kPa	578 kPa
28	1459	582	1330	470	992	522				
56	2166	581	2043	509	2169	545				

TABLE 3 SUMMARY OF RESULTS OF STRENGTH TESTS

Each strength is the mean of 3 determinations

All specimens were compacted to a density of 1500 kgm^{-3}

(A) Tests on 80% Aggregate: 20% Slag Mixes Using Slag and Aggregate of Various Fineness

Age at test days	Type of Slag, Activator and Aggregate									
	Granulated Slag + 5% Activator									
	Lime		80% Lime + 10% NaOh		90% Lime+10% Gypsum		90% Gypsum+10% NaOH		Ordinary Portland Cem.	
	Granite sand	Crusher sand	Granite sand	Crusher sand	Granite sand	Crusher sand	Granite sand	Crusher sand	Granite sand	Crusher sand
7	59 kPa	52 kPa	196 kPa	109 kPa	74 kPa	47 kPa	105 kPa	79 kPa	334 kPa	442 kPa
28	128	77	441	396	177	79	91	93	915	815
56	137	170	586	406	253	152	298	329	1040	956

Age at test days	Crusher Sand + Granulated Slag											
	90% Lime + 10% NaOH				6,8%		90% Gypsum + 10% NaOH				6,8%	
	5%	6,8%	8,5%	10,4%	87% Lime 13% NaOH	85% Lime 15% NaOH	5%	6,8%	8,5%	10,4%	87%Gypsum 13% NaOH	85%G 15%
7	126 kPa	166 kPa	143 kPa	139 kPa	148 kPa	164 kPa	69 kPa	78 kPa	76 kPa	61 kPa	60 kPa	50
28	289	384	421	499	547	695	205	101	98	105	125	101
56	283	373	403	438	444	670	177	160	134	161	136	116

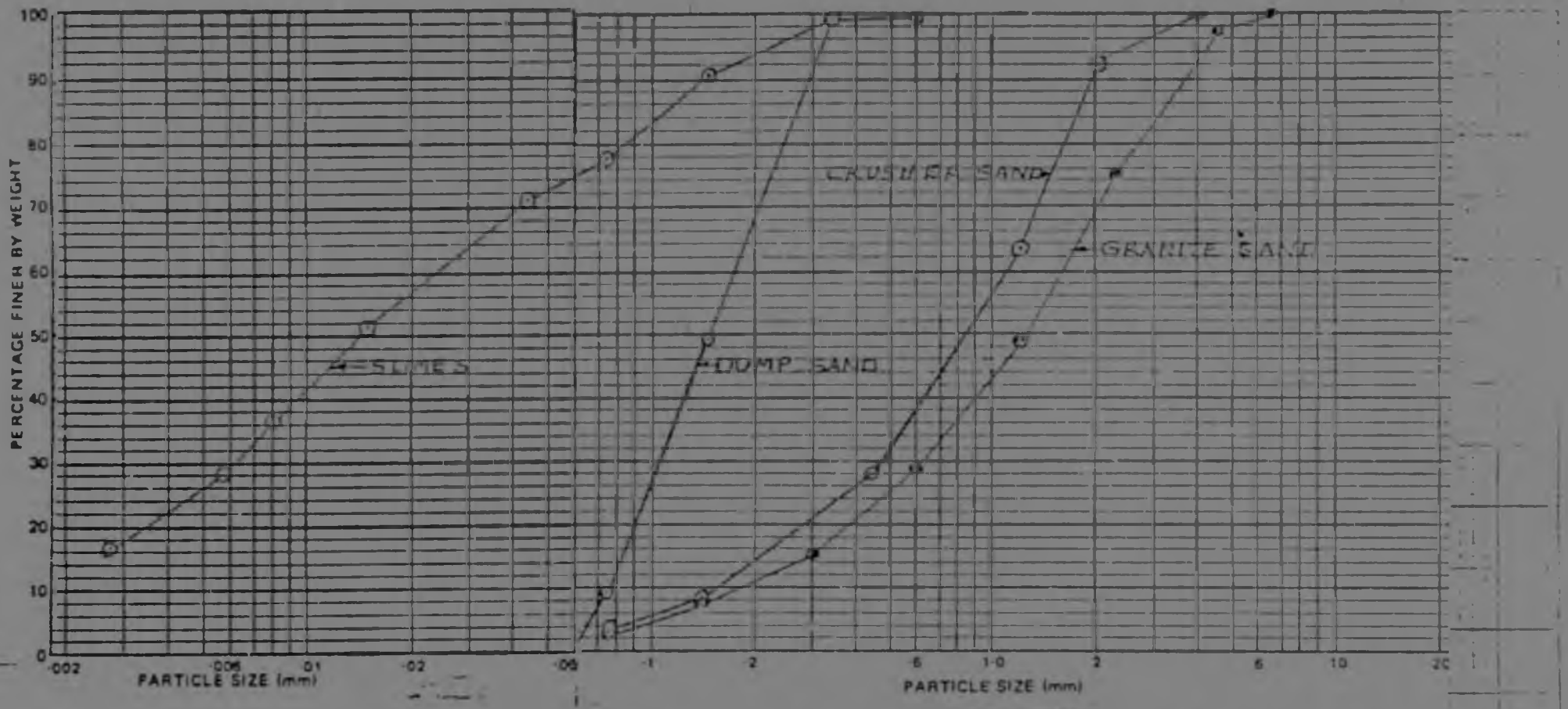
Age at test days	Crusher Sand . Partly Milled Slag			
	90% Lime + 10% NaOH		90% Gypsum+10% NaOH	
	5%	10,4%	5%	10,4%
7	128 kPa	152 kPa	182 kPa	195 kPa
28	167	155	283	325
56	312	291	292	301

Age at test days	Dune Sand							
	Granulated Slag				Partly Milled Slag			
	90% Lime + 10% NaOH		90% Gypsum+10% NaOH		90% Lime + 10% NaOH		90% Gypsum+10% NaOH	
	5%	10,4%	5%	10,4%	5%	10,4%	5%	10,4%
7	206 kPa	138 kPa	123 kPa	188 kPa	606 kPa	531 kPa	584 kPa	592 kPa
28	319	679	139	445	825	659	1027	534
56	395	1174	48	191	675	643	1056	658

Age at test days	Slimes										
	Granulated Slag				Partly Milled Slag				Slagment		
	90% Lime + 10% NaOH		90% GYpsum+10% NaOH		90% Lime + 10% NaOH		90% Gypsum+10% NaOH		90% Lime+10% NaOH	90%Gypsum+10%Na	
	5%	10,4%	5%	10,4%	5%	10,4%	5%	10,4%	5%		5%
7	306 kPa	384 kPa	123 kPa	184 kPa	695 kPa	684 kPa	349 kPa	348 kPa	1280 kPa		680 kPa
28	435	1288	128	165	914	1019	749	455	1459		582
56	745	1151	121	.41	902	1383	789	401	2166		581

(B) Tests on Slimes: Slagment Mixes

Age at test days	5% Activator								10% Activator	15% Activator
	80% Slimes:20% Slag		90% Slimes:10% Slag		95% Slimes:5% Slag					
	90% Lime+ 10% NaOH	90%Gypsum 10% NaOH	90% Lime 10% NaOH	90%Gypsum 10% NaOH	90% Lime 10% NaOH	90%Gypsum 10% NaOH	8 %Gypsum 15% NaOH	80%Gypsum 20% NaOH	90%Gypsum+10% NaOH	
7	1280 kPa	680 kPa	1130 kPa	579 kPa	852 kPa	515 kPa	386 kPa	383 kPa	419 kPa	578 kPa
28	1459	582	1330	470	992	522				
56	2166	581	2043	509	2169	545				



	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM
CLAY	SILT FRACTION			SAND FRACTION			GRAVEL FRACTION	

FIGURE 1- GRADING CURVES FOR CRUSHER-SAND, GRANITE SAND, DUMP SAND & SLIMES.

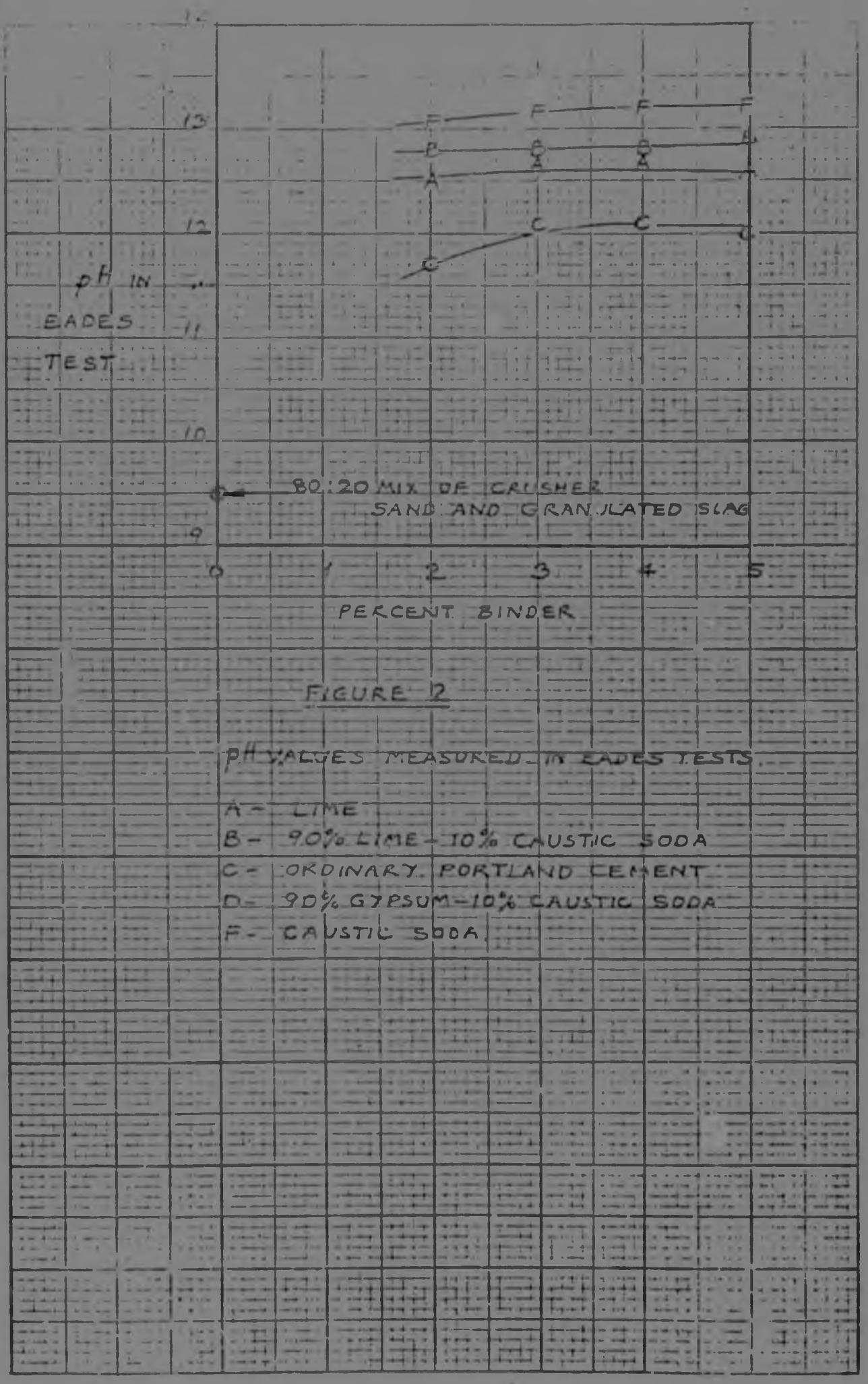


FIGURE 2

pH VALUES MEASURED IN EADES TESTS

A - LIME

B - 90% LIME - 10% CAUSTIC SODA

C - ORDINARY PORTLAND CEMENT

D - 90% GYPSUM - 10% CAUSTIC SODA

F - CAUSTIC SODA

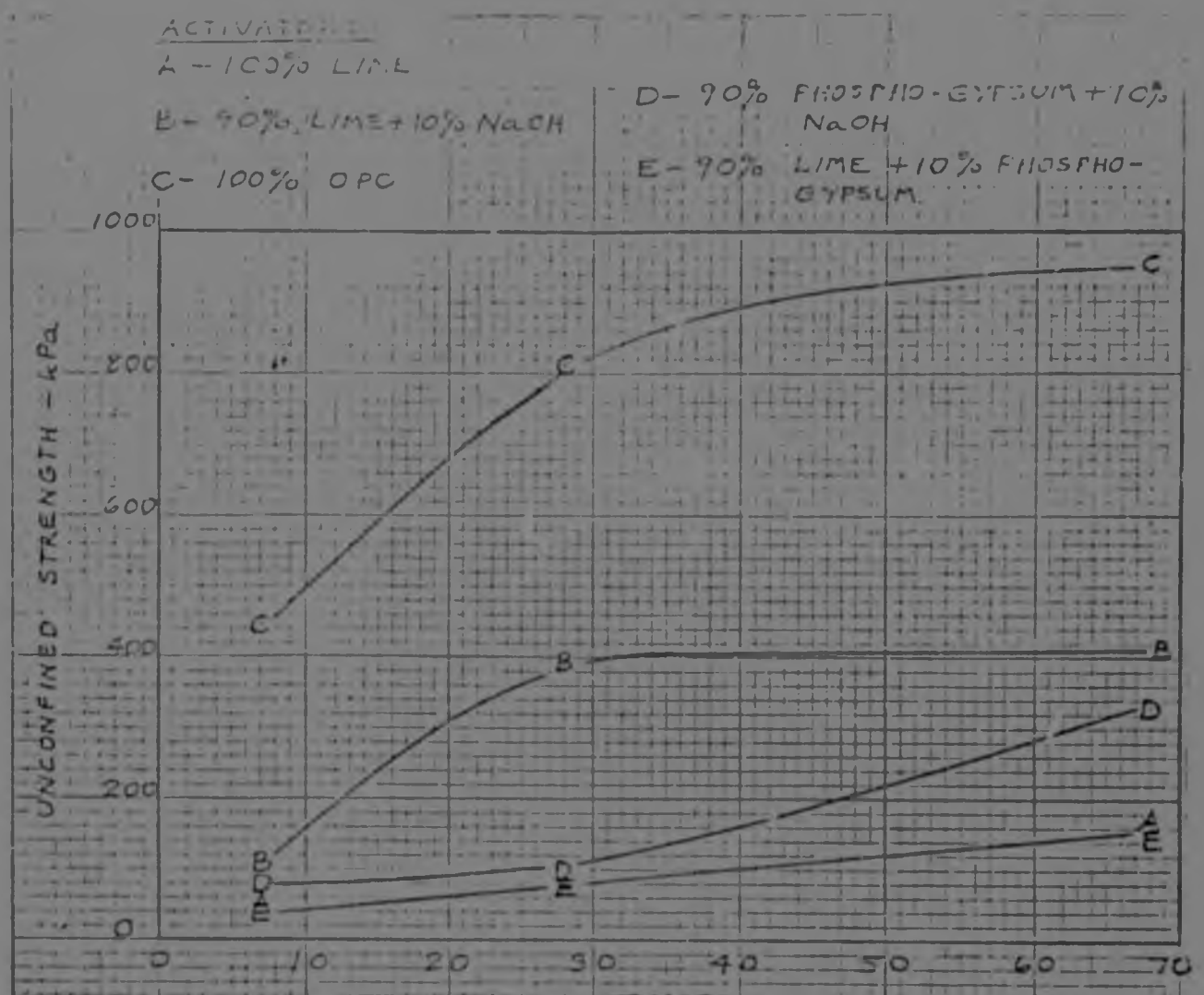


FIGURE 3a

STRENGTH – AGE CURVES FOR AN 80% : 20% CRUSHER SAND : GRANULATED SLAG MIX CONTAINING 5% OF VARIOUS ACTIVATORS

EACH EXPERIMENTAL POINT IS THE MEAN OF 3 DETERMINATIONS

Candidate Number of Question

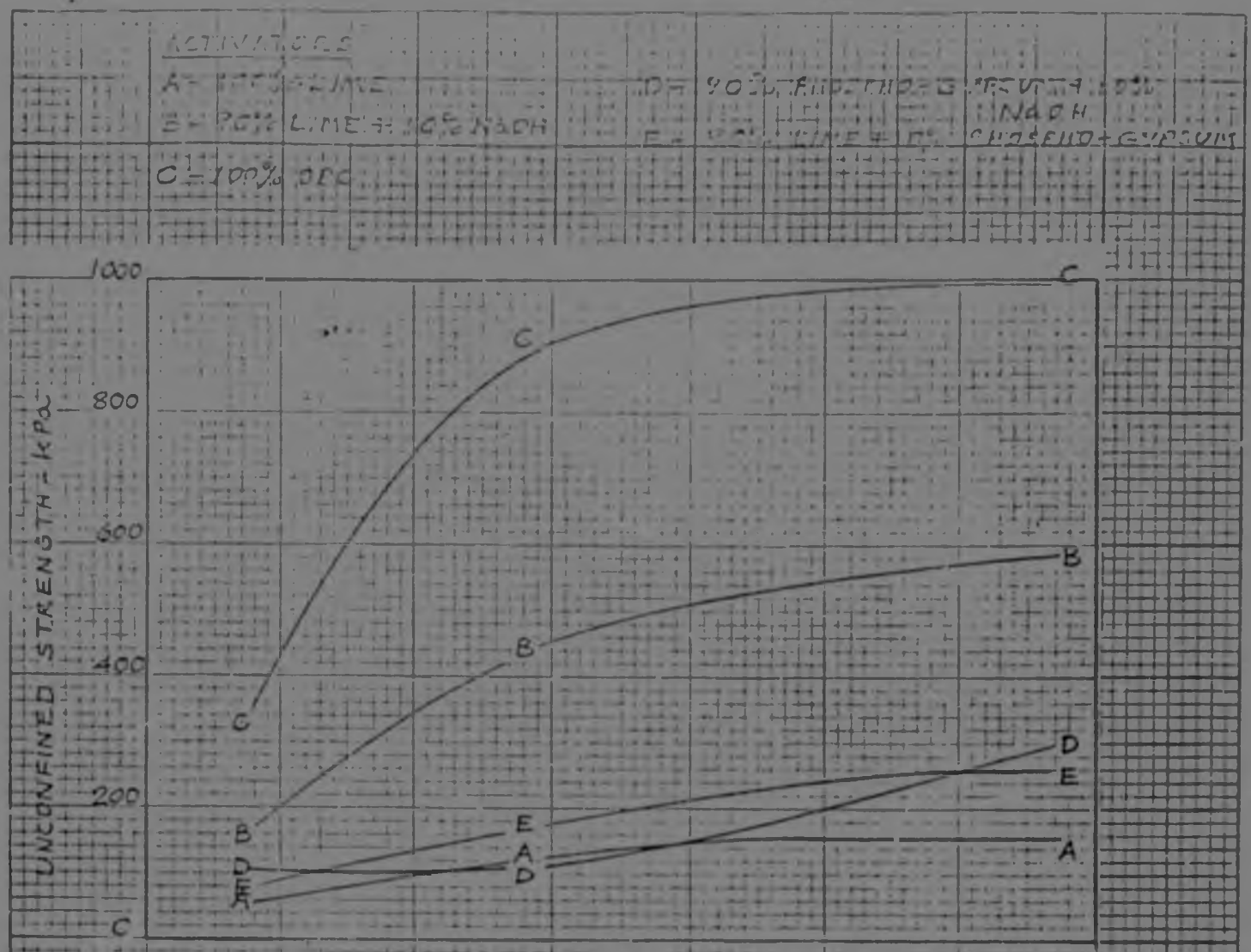


FIGURE 35

STRENGTH-AGE CURVES FOR AN 80% : 20% GRANITE SAND : GRANULATED SLAG MIX CONTAINING 5% OF VARIOUS ACTIVATORS

EACH EXPERIMENTAL POINT IS THE MEAN OF 3 DETERMINATIONS.

Tie in Answer Book opposite the answer to which it refers. 2cm/2mm squares

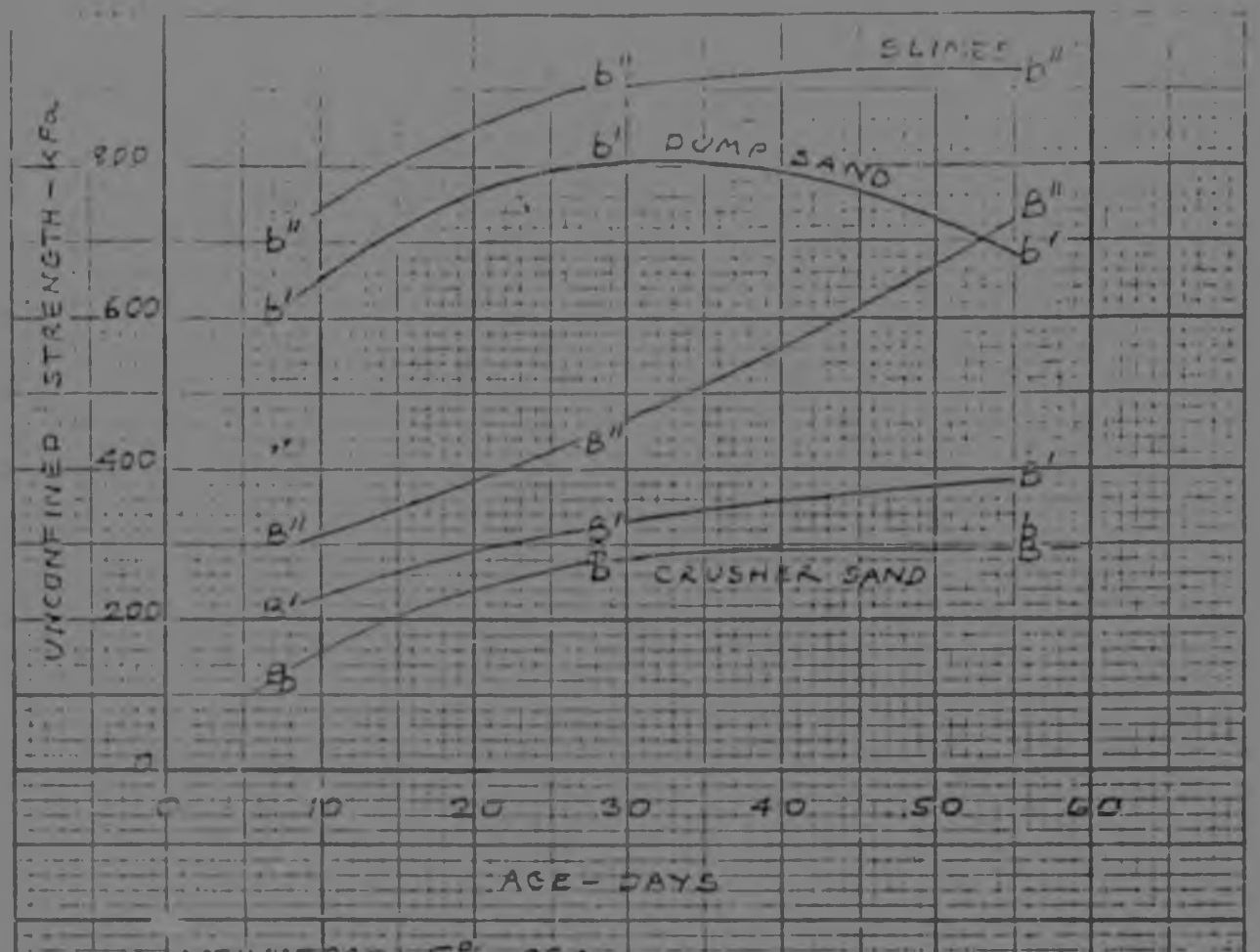


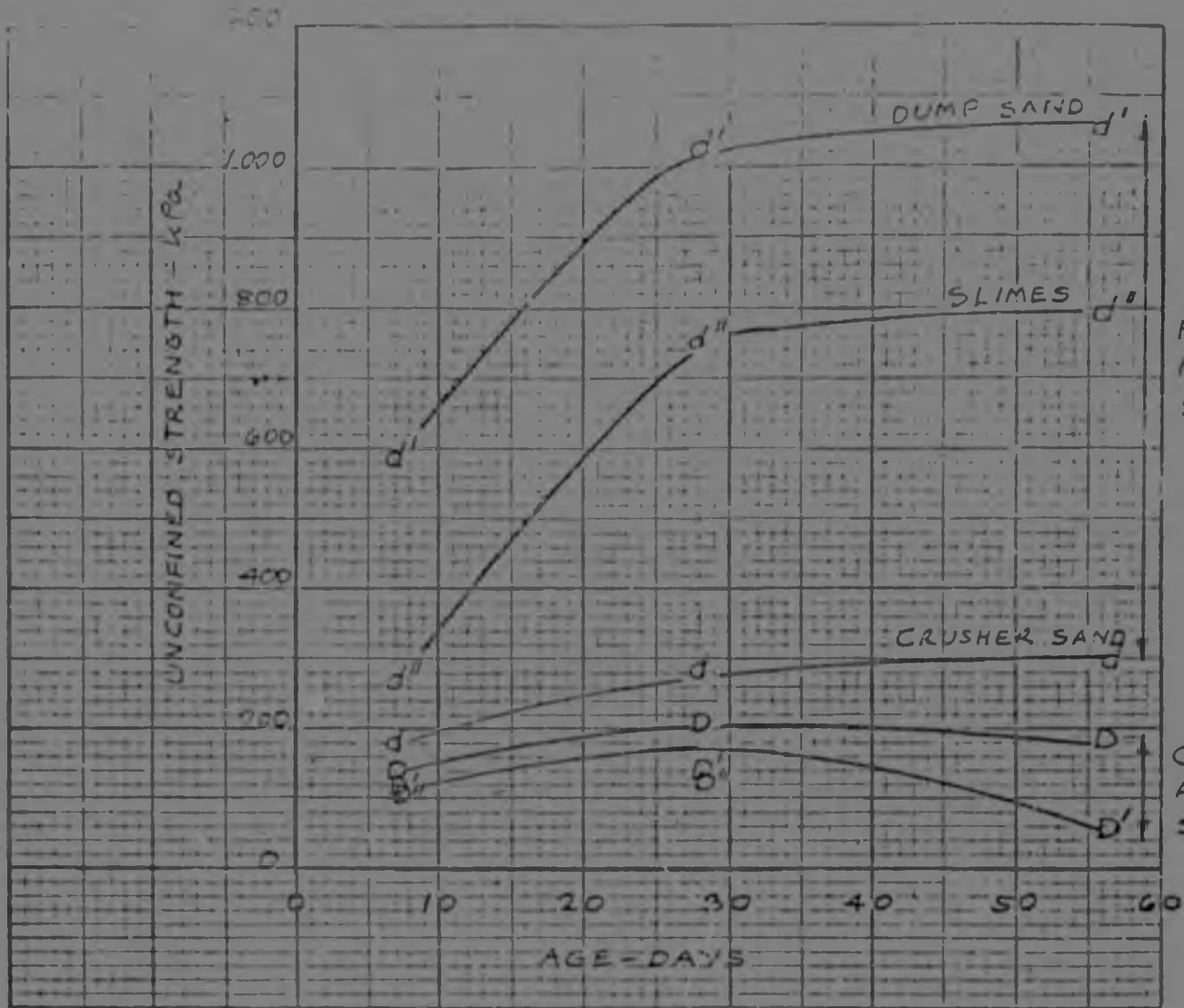
FIGURE 4a

EFFECT OF FINENESS OF AGGREGATE AND SLAG ON STRENGTH WITH LIME - CAUSTIC SODA ACTIVATOR

EACH EXPERIMENTAL POINT IS THE MEAN OF 3 DETERMINATIONS

ALL MIXES CONSISTED OF 80% AGGREGATE +20% SLAG.

90% LIME + 10% CAUSTIC SODA.



ACTIVATORS: 5% OF :

GRANULATED SLAG { D - 90% GYPSUM + 10% CAUSTIC SODA + CRUSHER SAND (pH 12,
D' - " " + SAND (p
D'' - " " + SLIMES

PARTLY MILLED SLAG { d - 90% GYPSUM + 10% CAUSTIC SODA + CRUSHER S
d' - " " + SAND
d'' - " " + SLIMES.

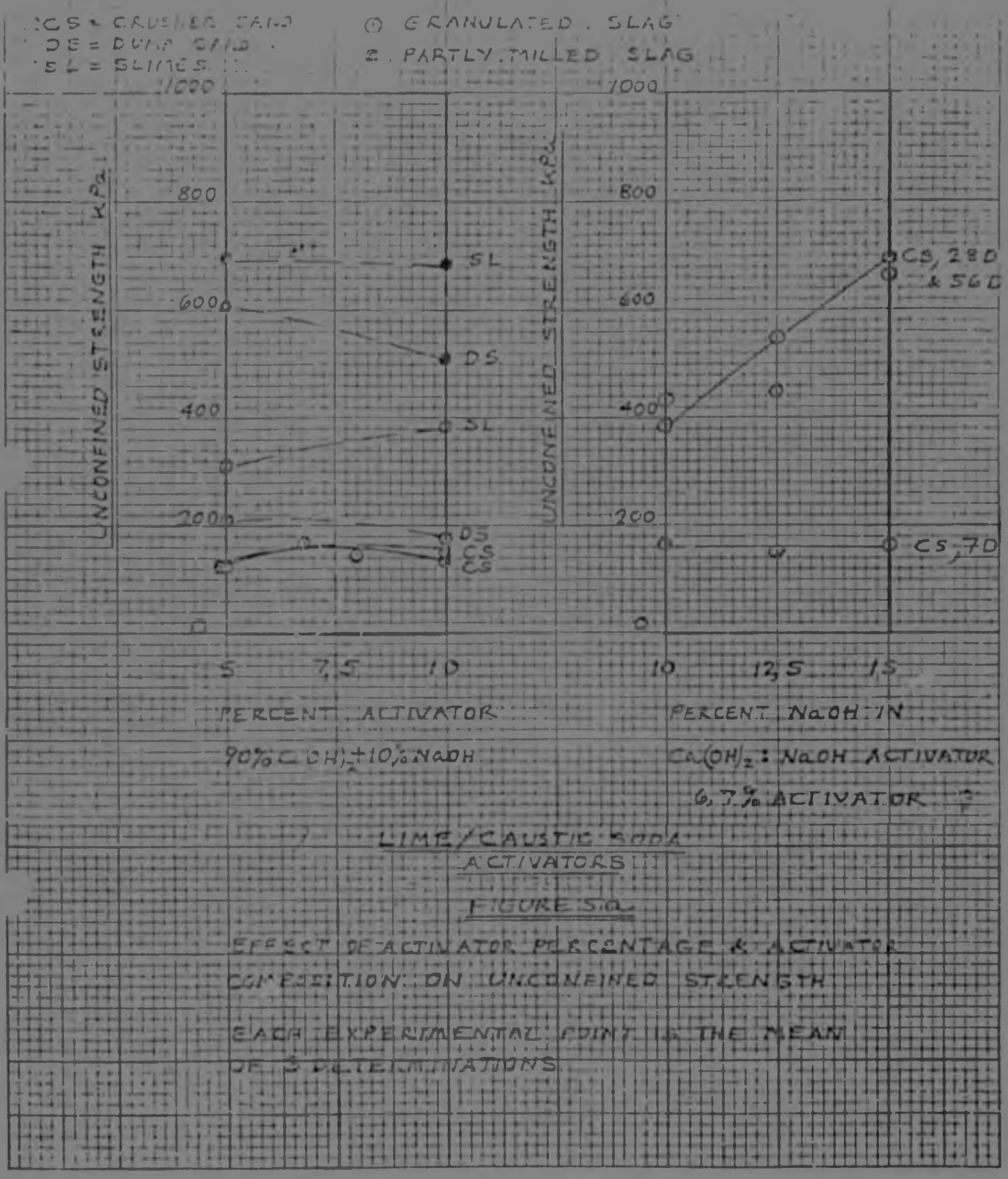
FIGURE 4b

EFFECT OF FINENESS OF AGGREGATE AND SLAG ON STRENGTH WITH GYPSUM - CAUSTIC SODA ACTIVATOR.

EACH EXPERIMENTAL POINT IS THE MEAN OF 3 DETERMINATIONS.

ALL MIXES CONSISTED OF 80% AGGREGATE + 20% SLAG

Candidate Number of Question



Tie in Answer Book opposite the answer to which it refers. 2cm/2mm squares

Author Dison L
Name of thesis Management of invention and innovation in Civil Engineering 1985

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