VICTOR F. B. DE MELLO, Professor, President, International Society
of Soil Mechanics and Foundation Engineering

OFERECE
VICTOR F. B. DE MELLO

Opening Address

Specialty Techniques as Pre – Eminent Contributions of Creative Soil Engineering

There may have been a justified first impact of query at the intent of a lecture with such a title. Indeed, it was sought on purpose. It is very appropriate that both individually and collectively we should choose special occasions to mark our way-faring. "Man and his symbols": we need symbols, we need discontinuities to take cognizance of a continuum. It would seem to be a just tribute to yourselves to choose this venue and occasion for such attention, since it is within a limited radius around here that the biggest challenges of creative soil engineering are being met in terrain uncharted by conventional soil mechanics.

Creativity, or inventiveness, is difficult to predict: the future cannot be charted. That is the reason why we must delve somewhat into history, to assess the presumed remarkable facts, and to compare the past development of different trends or Schools" vs. inventive episodes.

It is my impression that the past twenty years have been fertile in two rather different directions: one, the vast produce of institutionalized "engine engineering", and the other, the very productive breakthroughs of "ingenious engineering" generally engaging very few persons and limited effort. But it would further seem that some of the efforts along institutionalized analysis-synthesis are entering a period of discredit, and are falling along the exhausting hyperbolae typical of all benefit/cost ratios within a fixed physical model.

There was a period 15 to 10 years ago, of great hope that civil and geotechnical engineering hinged on the ability to predict behaviour, such ability being fostered by the vastly improved capacities for investigation, testing, and computation. And, after floods of research papers prematurely divulged under the EUREKA COMPLEX, and repeated frustration in the capacity to predict what exactly will happen in a given soil engineering problem, it has occurred to me that we should relinquish our own taut self-conscious requirements of increasingly precise quantifications, and should give somewhat free bridle to dreams and desires.

On the one hand I recall a statement by Dr. Land, inventor of the Land Polaroid instant-developing camera, back in 1948, when asked at a Faculty Club lunch at M.I.T., how he did, to have made himself so successful an inventor: his recipe was simple though exacting, comprising the two components - first, give free bridle to your dreams, visualizing what you would like to be able to do; secondly, work hard to make is possible.

On the other hand, I would emphasize that civil engineering is predominantly based, not on predicting what exactly will happen,but on predicting and assuring what will not happen. Our PRESCRIPTIONS for solutions are based on limits that the predictable values should not exceed; which is why whereas behaviours may often relate to statistical averages, the PRESCRIPTIONS have to resort to percent confidence bands around such averages.

It is in such a context that I consider more significant the order of merit: a. Inventive or ingenious engineering; b. Engineering by Prescription; c. Theorization and Engineering by Analysis-Synthesis. Casagrande (1961) well opened the First Rankine Lecture by emphasizing the distinction, defined in Rankin's inaugural address (1856), between the scientist's preoccupation "what are we to think", and the engineer's obligation to devote himself to "what are we to do". We shall devote our attentions to (a), and somewhat to (b).

Before embarking on my task, however, I should clarify my position regarding terms. The question concerns the distinctions between engineering, engineering science, analytical pursuits and ability, computattional ability within a given theory or working hypothesis, and the practice of engineering tasks within socio-economic restrictions. There has been increasing confusion regarding these distinctions. Society has wrought requirements of vast numbers of engineering workers as organized performers of tasks defined, conducted and finalized under routines temporarily accepted unquestioned. But the numbers dominating Society's temporary needs should not overwhelm us into the confusion. All the above different facets have equivalent collateral importance, like different organs sustaining a living body; and the proportions of different organs and activities must be appropriately balanced.

1. Creative Soil Engineering

Our discussions of the history of soil mechanics and soil engineering almost without exception start with

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Terzaghi. circa 1923. That in itself would seem to emphasize the role of analytical work, with some disregard for the truly important place of engineering creativity in "constructive procedures" and/or "specialty techniques".

Of course, we must begin by emphasizing that there is periodic creativity of remarkable value in procedures of analysis-synthesis (both by Terzaghi, and by others) that we would by no means demean. Moreover, we must concede that the attention presently sought is to ourselves and not to Terzaghi. We are in the Terzaghi era: that is our first reality. And we concede some validity to the proverb that reminds us that when you are inside a forest you do not see the forest but the tree trunks.

However, there is somewhat more to be extracted from the observation. There are important reasons why inventive engineering and specialty techniques tend to be set aside. We are principally concerned with the great numbers of engineering workers to be put to their tasks,and we are dominated by the needs of communication, of theories, procedures and rules, for others to apply, often unquestioningly. Thus we are subconsciously influenced in our assessment of the profession by the prevalence of tasks pertaining to academic circles. Soil engineering becomes what can be taught and learnt, and not what can be done. And we must further recognize that whereas professionals prior to around 1940 were sent out to fend for themselves with relatively little subsequent subjugation to academic production, in the recent past the rate of production of additional information and the intensity of technological development has greatly increased, and perennialized throughout professional life the subconscious dominance by academic activity. We are eternal students; but nowadays, much less so of life than of the flood of writings of teachers. We have imperceptible allowed processes of information to occupy the biggest space of education and of professions, to the detriment of formation. Without any undue emphasis, may we remind ourselves that when we understand, we may do nought but stand-under; or slightly less pungently, when we comprehend, we are fettered together.

Creativity is not created in frequency, and is not generally taught. It is difficult to institutionalize an academic structure whereby creative students are instigated to question, challenge, disagree, and propose other solutions,presumably more elegant. Yet we cannot deny the preeminence of engineering creativity as a physical visualization of a solution that so elegantly and superabundantly sets aside or dominates a set of problems, that calculation and analysis most frequently become quite dispensable.

In the past the engineering endeavours have been accompanied by a relative affluence of the ratio possibilities/requirements, doubtless because "requirements" had always been quite modest. Thereupon progress was always forged by a "breakthrough", statistically well ahead of the routines, that was tried, and achieved success; and thereupon the eminently imitative animal, man, stored the curtural gain through the "copying of success". Noticeable success to be imitated was always conservative in the sense that it was much better than necessary to meet the immediate requirements. Inventive progress is intrinsically by steps or leaps, each development opening a possibility that takes a considerable time to be used up by increasing demands. It is thus that good engineering in design or construction, avoids king cornered, from its position of affluence of ingenious ideas, into being better calculation or more conscientious engineering labour.

It might be very important to the future of civil, and principally geotechnical engineering, to pay more attention to the relative productive perspective of the efforts of cumulative work exploring an idea to exhaustion, in comparison with occasional quantum rebellions (both in theoretical breakthroughs and in inventiveness of equipments and techniques). We tend to be overwhelmed by the progress of industrial production, which uses both contributions to special advantage. In industrial fields there is possibility of turning the laborious cumulative investment into high benefit/cost ratio despite the very high cost, because of the principle of synthetic multiples by the myriads equally desirable all over the world. In the case of geotechnical engineering, for true optimization we still like to insist that each case is specifically individual, a particularity.

There has been a sudden awakening to the importance of engineering creativity and intuition,partly due to the shock which the beehive of routine academic production suffered when a few youngsters not yet sterilized by analysis-synthesis impositions solved the Rubik's cube riddle intuitively in minutes as compared with the predicted x-illions of trials that would be required by obedient computers. The recent First Prize of ASCE Civil Engineering's 1982 Essay contest being given to S. Bonasso's paper "Can we become more creative" stimulates our reflection. Everybody does recognize indeed that "outstanding design usually has an elegant simplicity": but in order to train for such aptitude (for, as all aptitudes, it is partly inherited but partly whetted or numbed by training) we must be willing to accept with glee some "whole ideas" that generate spontaneously in a flash, as compared with the two institutionalized sources of steady learning, which are the authoritarian method and the scientific method of systematic trial and error, and Bayesain iterations thereof.

2. Looking at Case Histories with Recognition

Many an elegant invention inherited from the past tends to be taken for granted with a gross underestimation of the degree of creativity involved at the time. Such instances as: the age-old use of bamboo and sticks as fascine on top of swampy terrain, for support of shallow embankments; or even the use of driven piles as a support, extending columns downward in such a manner as to cut across the soft foundation soils (the physical universe statistically questionable); and any such; let us train our thinking to recognize them as remarkable inventions, however anonymous and remote. Before proceeding let me emphasize the frequently sought preferential engineer solution which is to cut across the universe of variabilities and statistical uncertainties with a deterministic action. An example to be recalled is of some old buildings that used wood piles and that, in the face of fears of future lowering of ground WL that would expose the pile to rotting, rather than predicting possible lowest future water levels, incorporated a watertight cylindrical recipients being maintained permanently filled with water by direct connection to the building's water tank.

Recent documentary evidence shows that the Romans used a most elegant offshore foundation for a lighthouse, still standing: they filled a boat with the hydraulic cements of the time and the base rocks, floated it out to position, and sank it. There is hardly need for discussing the relative potency of the two facets of engineering activity, the visualization of a physical model for setting aside the problem, as compared with better detailing within a preestablished physical model. It is of interest to mention the case of the international competition held about four years ago for a possible design-construction turn-key project to solve the problem of the leaning tower of Pisa. Of course, only the best supported international civil engineering companies, aided by the top most geotechnical consulting services, participated. Unfortunately the contract was not awarded and the different solutions have not been divulged: a lecture on the comparative solutions, even schematic, would constitute a fantastic object lesson on civil engineering. In the face of a serious problem, even though more fully and carefully documented than any that can be imagined, there, were essentially as many different physical solutions as there were contestants (15-20). When faced with a problem of high ratio of reponsibility/feasibility, it is not in better analytical work that engineers seek solutions, but rather in different physical solutions, different statistical universes that are meant to set aside quite definitely the possible histogram of degrees of unwanted behaviour.

Why are we in foundations so generally subservient to the would-be requirements of industrial engineers, architects, mining and water-supply superstructures, etc. In Fig. 1 I show schematically two examples in which intense discussions were required to succeed in intreducing obvious changes, in favour of great technical and/or economic advantages. The first (1a) is the most routine excavated water or sludge tank for which generally the foundations are designed after an independent reinforced concrete structure has been visualized. The construction sequence requires a stable excavation slope, and there is never any difficulty in grade support of a uniform pressure smaller than the soil pressure removed. Why not just use a trapezoidal tank (with minor adjustment required to the paddles and hydraulics) so as to have a very much cheaper structure with none of the incompatibilities of stress-strain behaviour of soil-fill-concrete wall?

The second (Fig. 1b) concerns an absurd case where a steel high pressure spherical tank was designed for an "immovable" foundation for the full load (2700t) of water-pressure testing (1 day in the life) whereas settlement limitations was only to garantee against trouble with en-brittled piping connections during life when storing high pressure gas (total loading 220t). The simple economic solution was to support on grade while running the water pressure test (rotating sphere as necessary if desired that small air bubble help detect minimal leaks), and then lifting the empty sphere (≃ 50t) to its definite berth and foundation garanteed for the minute settlement at no more thab about 300t rather than 2700t.

A third example (Fig. 2) was chosen to elucidate an important civil engineering principle, that significant dispersions in parameters and their determination close to zero, make it undesirable to design important structures based on behaviors at around such physical conditions: such is the case, for instance, on the design of the conventional erodible fuse-plug spillways. Any behaviour depends on "infinite" number of parameters, and when one reaches close to zero, others, often unsuspected, become more significant. An alternate recently designed for a project just completed, is very much more effective and amenable to definitive design ... a fuse-plug embankment based on hydraulic blowout.

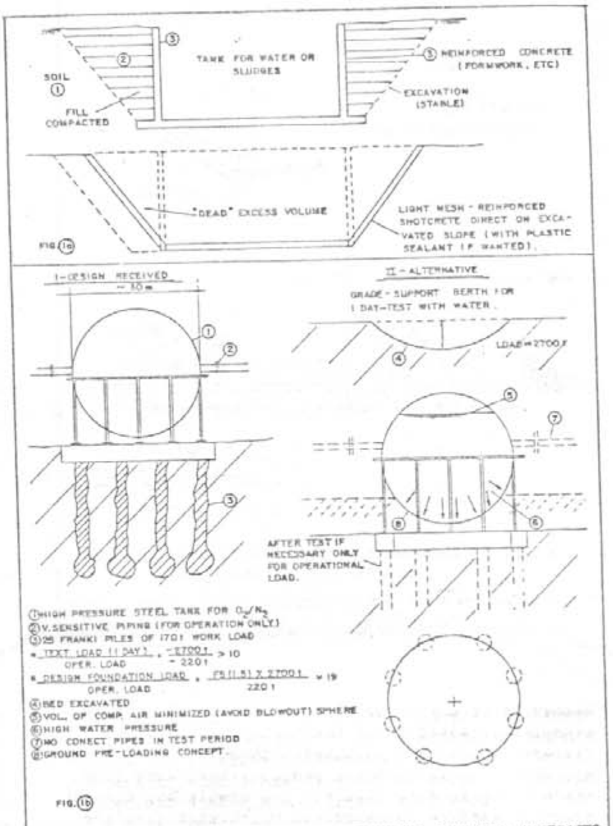


FIG. 1 ILLUSTRATION OF GAINS IF GEOTECHNICAL ENGINEER INTERACTS WITH SUPERSTRUCTURE DESIGN

It would be wrong and most unjust, however, to leave any impression that the prevalence of creative engineering is limited to projects and construction. It occurs also in theory, with equivalent impact. A single example may be mentioned wherein mathematical brillance opened very effective practical solutions: we may recall Nabor Carrillo's mathematical solution to the problem of subsidences generated by pumping-out (oil wells), through analysis of stress-strain changes in a pseudo-elastic medium ("Subsidence in the Long Beach-San Pedro, Cal. Area: the effect of a tension center", 1949); the highly profitable engineering follow-up of judicisously employing pumping-in (recharging wells, using preferably ocean water, etc.) for allaying subsidence (and, in the case of oil wells, continuing to optimize oil production) can thus fall into the category of fertile interaction between existing theoretical tools and intuitive breakthroughs (Fig. 3a).

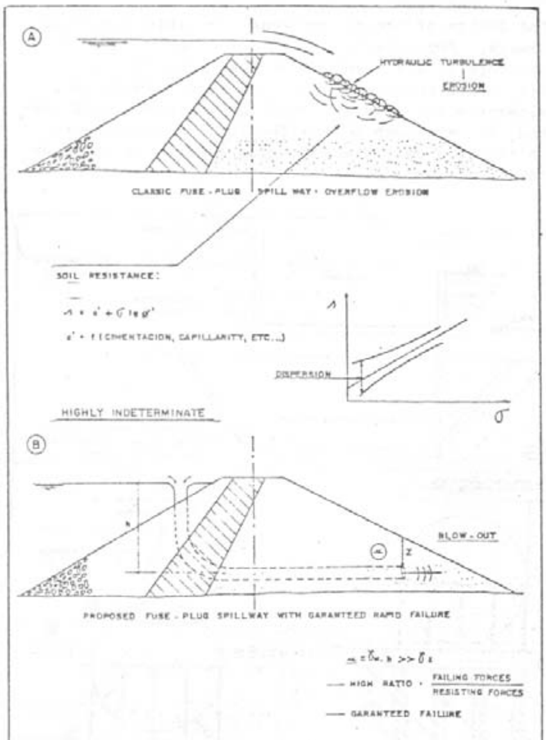
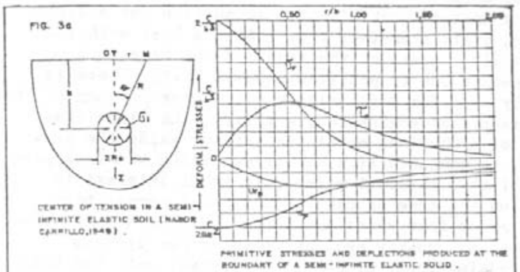


FIG. 2 - ILLUSTRATION OF DESIGN PRINCIPLE AVOIDING UNDEFINABLE FAILURE BEHAVIORS AROUND "ZERO".

FIG. 3a



CENTER OF TENSION IN A SEMI-INFINITE ELASTIC SOIL (NABOR CARRILLO, 1949).

PRIMITIVE STRESSES AND DEFLECTIONS PRODUCED AT THE BOUNDARY OF A SEMI-INFINITE ELASTIC SOLID.

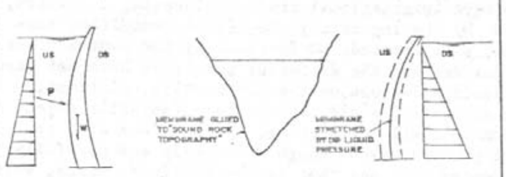
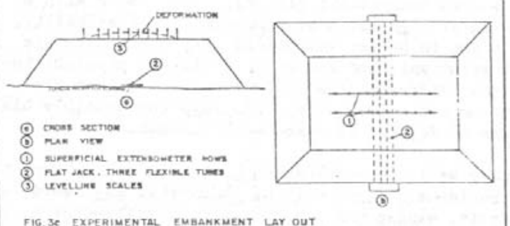


FIG. 3b ROUGH MODEL OPTMIZATION OF DOUBLE-CURVE ARCH-DAM SHAPE



ⓐ CROSS SECTION
ⓑ PLAN VIEW
① SUPERFICIAL EXTENSOMETER ROWS
② FLAT JACK, THREE FLEXIBLE TUBES
③ LEVELLING SCALES

FIG. 3c EXPERIMENTAL EMBANKMENT LAY OUT

FIG. 3 EXAMPLES OF CREATIVE ENGINEERING IN THEORETICAL SOLUTIONS

Meanwhile it may be of interest to recall as many examples as possible of the high potentialities of "lateral thinking", purposeful theorization but via unbeaten tracks, to solve problems-that were long since recognized in theory. Two simple but elegant examples suffice to emphasize my message that the best way to train for creative engineering is be searching with zest (and no hidden jealousy) to recognize occasions when it did occur. Fig. 3b shows schematically that a first-order approximation of an optimized double-curvature arch dam shape (ideally to work in compression only) was established by liquid loading from downstream a pure-tension material such as a rubber membrane; self-weight problems call for the minimum immediate adjustements. In a similar vein of "inverting the problem" Fig. 3c presents shematically the manner recently employed in Spain to investigate the question of differential deformations that would cause cracking of clay cores of dams near the crest. Indeed, centrifuge testing employing the multiple accelerations to increase apparent self-weight behaviors sprouted as as inventive solution to problems of model-testing of soils wherein for about 3 decades the attempts had been conditioned by structural models that solved their problems satisfactorily via adjustments of materials of appropriate stress-strain behaviours.

The message herein will be conveyed by merely listing some of the specialty techniques that if recognized with due credit should stimulate respect and catalyse emulation. Although nothing novel will be presented, it might be productive to set aside the contempt of intimacy and to foster new attitudes by looking at matter-of-fact present-day routines in new lights. Moreover, it appears that depending on how one organizes mentally the existing techniques, there might be inducement to further improvements and/or inventiveness, often no more than by transplanting from one area of routine to one of novelty.

3. Soil Improvement

So many different techniques have been developed into routine use that it requires effort, almost frustrating, to organize them into groups, depending on the soil component to which the principal activity is imparted.

3.1 Solids. Densification by tighter packing of the grain to grain structure. Two separate trends may be recognized, one of

a) general "uniform" densification; the other of

b) exaggerated improvement of columns within the soil mass, the improved behaviour relying on internal redistributions.

Under the a) category, for shallow effect and construction by lifts, the concept is "compaction": optimized equipment the soil's greater susceptibilities to kneeding, compressing (pneumatic-tired roller), tamping (impact), and vibratory rolling (Fig. 4). The great emphasis on optimum moisture contents was followed by dominance by laboratory, that led to insistence on "homogeneity" (i.e. prior protracted moisture "curing", and laboratory scale homogeneity). By reasoning on prototype scales and the very satisfactory internal redistributions of behaviour accepted in most soil improvement techniques, I suspect that in the near future significant economies might be achieved by equipment improvements so that the roller itself will inject controlled moisture increments while giving the compaction passes. Further, considering the successful uses of chemical additives in other sectors one might conjecture that in kneeding rollers there might be incorporation of high pressure jets to inject controlled shots of beneficial additives (cement, lime, etc.). Finally, in fact, considering the "soil nailing" development, one could visualize equipment that would "fire" nails into the lift during some compacting pass.

The mechanical stabilization procedures that resort to the admixing of appropriate (in proportions and grainsizes) stone aggregates have been evolving to admit incorporation of industry or consumer-society solid rejects (e.g. fills "reinforced" by used tires, etc.).

For effect throughout the thickness of the compressibility stratum, we must distinguish between saturated clayey soils, and unsaturated and/or sandy profiles.Consolidation of soft clayey soils by preloading is possibly the most used soil improvement technique. By far the most frequent hitherto considered is ballast (soil fill, later removed). Kjellman's very inventive procedure called "vacuum preloading" (Fig. 4b) has not been well enough marketed and only occasionally used, duly adjusted to realities of leaks etc. Moreover, whereas subsidences due to pumping out (in common operation of batteries of wells) are thoroughly understood and corrected when undesirable, it is strange to note the almost inexistent application of pumping drawdown for the preloading. Electrosmosis also has not been sufficiently used under analogous conditions although it finds regular use in Mexico city to obviate the big bottom heave when floating foundations are excavated: Fig.5 (a) illustrates the initial uses of electrosmosis for applying favourable gradients for slope stabilization, and the same principle applies for loading of excavation bottoms.

In all cases of consolidation of clayey strata the big problem has been the need to accelerate the time of preloading, by drainage. First solutions obviously resorted to sand drains; these later proved to be technically undesirable because of the tendency to detain settlements by column effects (forgetting the often repeated mistakes, in sensitive clays, of drain installation in displacement piles), and because of strictions and shearing of drains by settlements rendering them ineffective. The present big market vies intensely on equipments and materials for optimized industrialized applications of Kiellman's drain-wicks.

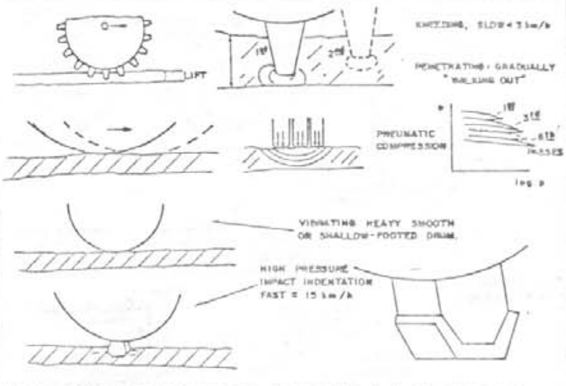


FIG. 4a - DENSIFICATION OF SOLIDS, COMPACTION AND OPTIMIZATIONS.

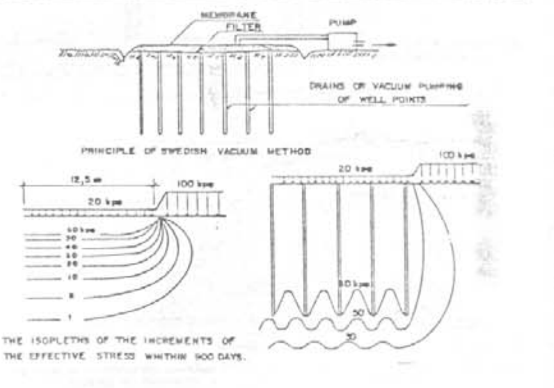


FIG. 4b - VACUUM PRELOADING INCLUDING VACUUM PUMPING OF WELL POINTS.

Considering the davances of hydraulic fracturing from boreholes, and the so-called "squeeze-grouting" techniques that insert wedges and tongues of cement in the cracks, one conjecture would be to incorporate sand-drain planes where the hydraulic cracking has been caused" the obstacle is doubtless the unpredictability (present) of such an indirect array of drainage planes.

For essentially pure sands the densification treatment to significant depths was based on driving compaction piles (e.g. Franki pile procedures, but filled with gravels), then shifted to vibroflotation, and, as a variant, the pushing down and withdrawl of vibrating columns by high-powered equipment. The compaction pile presents disadvantages of heavy pounding, but, in principle, best fulfills the desire of a treatment that simultaneously tests its own effectiveness and consequent need to intensify or abandon.

"Deep compaction", or densification by macro-pounding, was obviously suggested for successful use in deep unsaturated loose fills, wherein damages to soil structure and time effects would be minimal. However its extension to many other subsoils (with consequent questionable results) represents to me an extreme of a trend towards brutally treating a subsoil profile by use of the potentialities of heavy equipment. We should

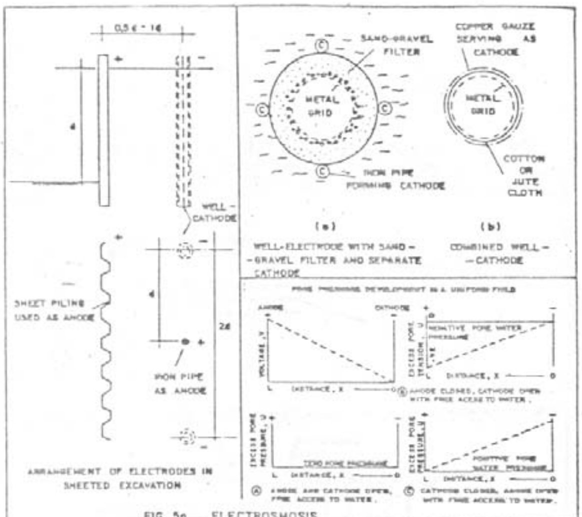


FIG. 5a ELECTROSMOSIS

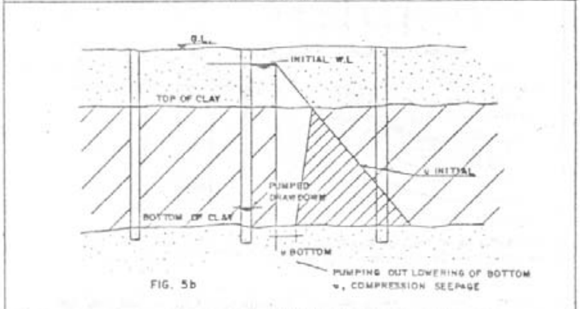
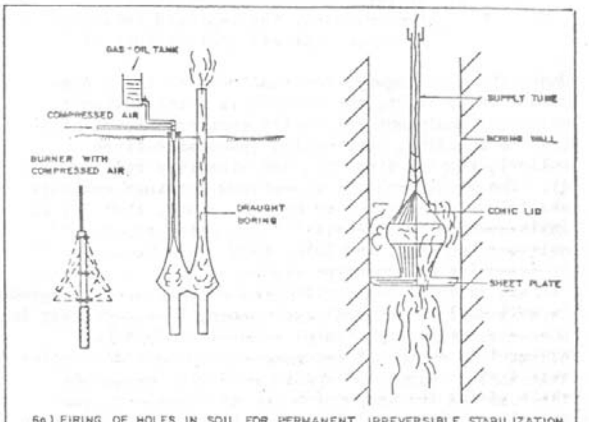


FIG. 5b

FIG. 5 APPLICATION OF ELECTRICAL AND HYDRAULIC GRADIENTS FOR LOADING



6a) FIRING OF HOLES IN SOIL FOR PERMANENT IRREVERSIBLE STABILIZATION

6b) FREEZING

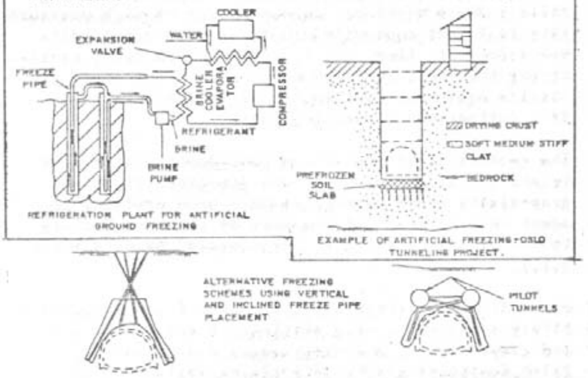


FIG. 6 - USE OF THERMAL ENERGIES FOR GROUND IMPROVEMENT

recognize the vicious cycle often engendered for excessive and/or misplaced promotion of the use of a technique when equipment capital costs are relatively high in comparison with need for attention to details of soil investigation and behaviour.

3.2 Pore and pore fluids. Besides a direct densification of the grain-to-grain structure of the solids, another basic principle of soil improvement has been by acting on the pores and pore fluids. We shall include into this category the many instances (e.g. chemical treatment etc.) in which the improved pore fluid incorporates beneficial actions on the solids, through colloid-chemical reactions, cementation, etc.

Direct use of thermal energies has found some places of successful application. In some areas (e.g. Romania) the firing of low-grade coals and fuels in perforations made into the soil achieves a permanent, quite comprehensible in view of the irreversible effects in firing clays (Fig. 6a). At the other extreme we find some instances of successful use of soil freezing for effective temporary stabilization (Fig. 6b).

Moreover, some electrochemical soil hardening techniques by a variety of chemicals are well understood to act via the pore fluids, with direct effects on the hydrophilic behavior of the clay fraction, and also often on grain to grain bonds. Generally for such treatments to be economically suggestive it becomes necessary to rely on cheap by-products of local industries. Any such treatments (e.g. lime stabilization) can be easily applied in admixture and construction of fills by lifts. In the case of in situ soils (foundations, subsoil profiles) the basic hindrance lies in the limited penetrability of the chemical solutions even when fostered by electrochemical gradients (e.g. electrochemical hardening of a marine clay by using calcium chloride piles at cathodes and anodes). Thus, attention is attracted to the significant progress created by the tube-a-manchettes technique for a) selective grouting (Fig. 8a) of soil sediments by solutions, depending on varying permeabilities of strata; b) the hydrofracture (claquage) squeeze grouting technique that opens preferential planes of slurry penetration, while simultaneously compressing the soil masses on either side; c) the joint use of pressure grouting of sodium silicates associated with electrosmosis has been of considerable interest (cf. Bally and Klein, Helsinki, 1983) not only because electrosmosis increases 1.5-2 times the speed of penetration and therefore the radius of penetration of grout, but also because there is a gradual increase of Na ions towards the cathode and of SiO_3 towards the anode which compensates the peripheral dilution of the grout in contact with the porewater.

Many details of the choices of proper slurries, proper hydrofracture pressures for opening the manchettes against the soil-cement sleeve, and proper criteria for grouting (controls by pressures up to grout "rejection", or controls by volumes) are subjects hitherto maintained in some degree of mystique and lacking desirable quantifications. The fundamentals are irrefutably simple, but there has been a systematic tendency to leave the design, specifications, and conduct of the construction to the specialist companies, under an implicit "turn-key concept". The situation derives partly from the success associated with inventiveness, in part from subsequent commercialization, and finally, in part from the weak point that is the relative unpredictability, having been ably transformed into an asset, put forth under the guise of exploratory treatments to be optimized as work proceeds. Unpredictability reflects in foregoing "design" and budgetting.

4. Control of Water and Slope Stabilization

I shall not mention herein the procedures of soil strengthening (e.g. electrosmosis, heat-treatment etc.), nor those of using various forms of piling to intercept the sliding plane for providing elements of shear resistance.

4.1 Large masses, flatter slopes.

The early principles of groundwater control were directed at lowering groundwater, decreasing pore pressures on the boundary of the sliding mass; drainage treatments acted only via hydraulic heads, by pumping (either deep well, or multiple well-points). The introduction of vacuum was an obvious advance, especially for well-points, wherein the incremental effect is proportionally big. Since the promising use of selective grouting by double packers and hydrofacturing, it may be conjectured that one should develop a selective pumping-out system for analogous advantages.

For slope stabilizing drainage, such a development as the Hydrauger equipment for installing deep subhorizontal drainholes from the toes of slopes, was hailed in the mid-fifties as very worthwhile. In practice, however, the subhorizontal drains often turn out but modestly efficient: average slopes being about 1V:3H the lengths of drains have to be great to achieve a certain lowering ΔZ of the water table, and much of the drainage follows along the outside of drains because of ovalling and longitudinal bending of the holes and pipes; for optimized efficiency the drainage should be effective at the end of the hole (Fig. 7).

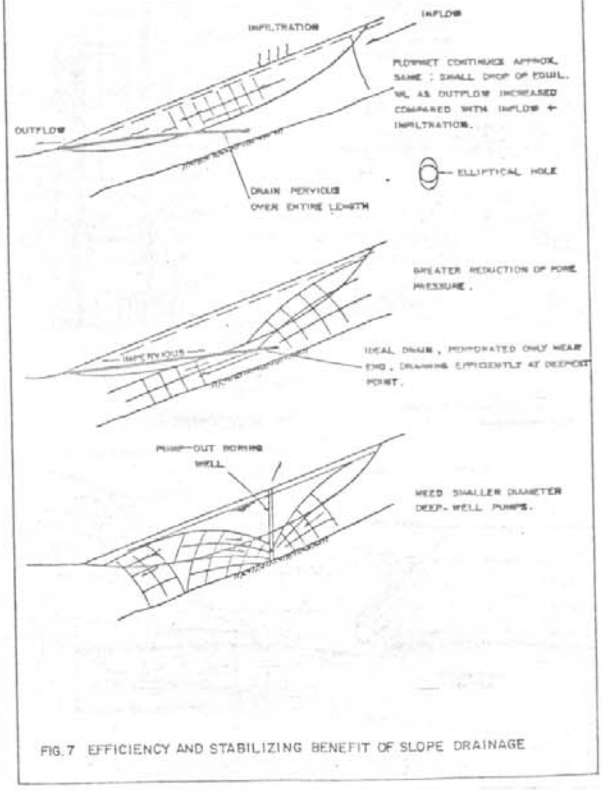


FIG.7 EFFICIENCY AND STABILIZING BENEFIT OF SLOPE DRAINAGE

Whereas with regard to hydraulic gradients the routines established themselves directly within the realm of "drainage", and control of "boundary neutral forces" on the sliding rigid body, the electrosmotic treatment showed the importance of (a) immediate favourable effects by reversing gradients, and, thereby, the seepage stresses applied as mass stresses (b) medium and long-term effects of consolidation and cation exchange. Excluding cation exchange, in the case of hydraulic gradients the same reasonings of seepage effective stresses (vectors, directional) apply immediately, as soon as the pumping (instantaneously) changes the tendencies to seepage in the incompressible fluid of the saturated soil; consolidation improvements set in with time. The fact is that when borings are made for investigation and installation of piezometers, if they are made of somewhat bigger diameters (e.g. 6"), they can immediately serve for pumping-out, causing immediate stabilizing benefit, (Fig. 7). For long-term treatment, to avoid permanent pump operation, it is enough to install subhorizontal drains later, within the depressed WL cones, avoiding their rising.

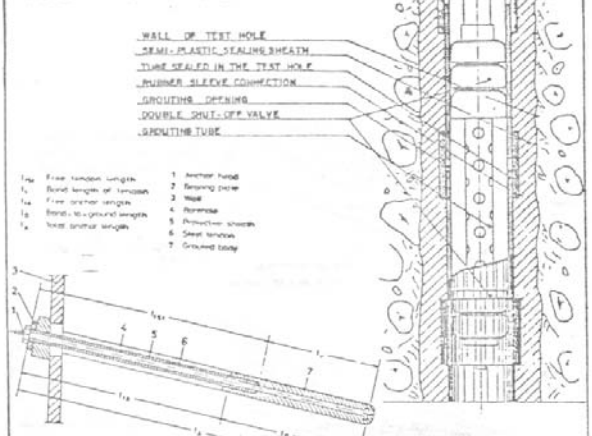
Bentonite-slurry stabilized excavations (trench) will be mentioned under pile foundations, and compressed air control of water under tunneling, although both are quite general.

Under electrically activated control of seepage one may mention the trend towards development of monomers that polymerize rapidly under electrophoretic conditions of intense seepage velocities; the search for a self-generating clogger for fissured foundations of high dams has been one of the invenstor's dreams at which work has been progressing.

4.2 Steeper slopes, smaller masses, mostly urban

Steeper conditions of smaller soil masses, such as were traditionally supported by retaining walls are

FIG. 8a – TUBE-À-MANCHETTES



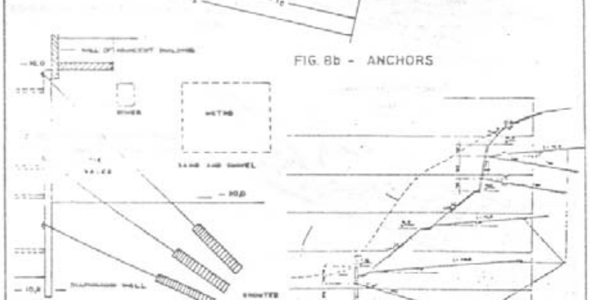
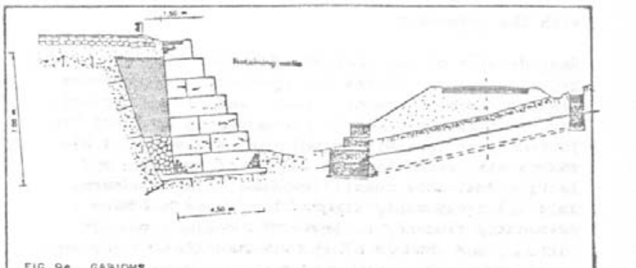


FIG. 8b – ANCHORS

FIG. 9a GABIONS



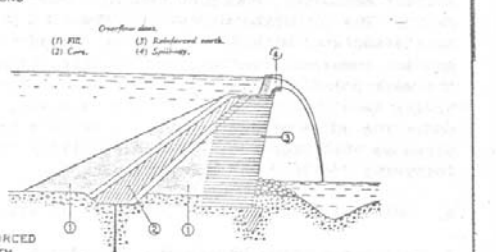


FIG. 9b REINFORCED EARTH

FIG. 9c SOIL NAILING – EXAMPLES

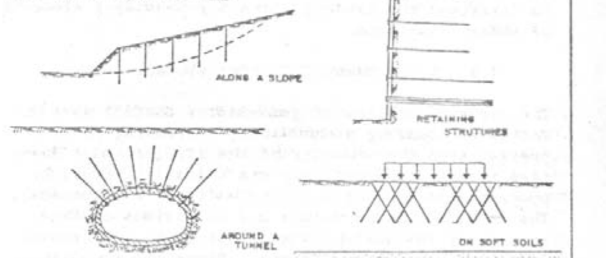


FIG.9 EXAMPLES OF CREATIVE TECHNIQUES DEVELOPED TO SUPPORT SOIL MASSES

being retained much more reasonably by (a) gabions (b) reinforced-earth (c) so-called "soil nailing" which is a form of reinforced earth, and (d) soil anchors coupled to reinforced concrete face slabs. (Figs. 8, 9). To these much quoted modern techniques one should add the geniality of crib-walls (much older).

5. Foundations for Earthwork, Embankments, Dams.

This topic encompasses some of the most voluminous efforts of geotechnical engineering, since civilizations have mostly developed near shores and water courses, and, is cities expanded explosively the advances have been on flatlands of soft clays. The principal distinction of this category in comparison with that of shallow foundations is the acceptance of the "flexible load condition" and a compartively much greater acceptance of settlements and differential settlements. Correspondingly the effectiveness of the soil improvement or reinforcement necessary is much more modest.

In principle the developments have been based on (a) geotextiles (b) aggregates (c) cheap chemicals. As regards concepts the basic evenues are: horizontal tensile reinforcement; vertical and horizontal enhancement of drainage; execution of spaced "columns", that combine rigidity and stress distributions, as well as drainage or chemical reaction including water absorption. The concepts are very simple: on the one hand it is of interest to impart tensile resistance to soils; on the other hand it is obviously beneficial to absorb a proportion of the weight of overlying fill on more rigid columns, and, finally, it is advantageous to provide drainage of soft saturated silty-clay soils.

Thus, these examples qualify principally as developments fostered by industrial output. The only creativity was the decision to employ varied manners of reformulating soil conditions closer to the desires and needs, rather than passively investigating to greater detail the in situ parameters.

6. Shallow Foundations

Two really creative ideas may be singled out for recognition. One is the floating foundation (greater number of basements to compensate a part or all of the weight of the superstructure). It is claimed to have been conceived by an architect, in Mexico city, around 50 years ago: the intuitive reasoning is said to have been that a very soft saturated soil could be no worse than water, and, after all, boats are structures, and they are made to float on water as a foundation. The National Lottery building in Mexico city employed watertight compartments in the basement, to fill with water or empty, in order to compensate for undesirable trends of differential tilts. Mexico city clay is not only very compressible, but also ipso facto significantly swelling on stress release. Thus, since excavation and construction back up to grade cannot be instantaneous, significant heave occurred in some cases, causing subsequent incremental settlement. In order to combat this tendency, over the past 15 years approximately, electrosmosis has been used to maintain a "gradient loading" to avoid heave until the structural load gradually takes over.

The other interesting idea was to drive "picots" or shallow stubs into the soil within the pressure bulb. (Fig. 10). "Soil-nailing" if applied to reinforce the pressure bulb under the footing would constitute a similar treatment which is not quite the equivalent of the piled-raft interaction employed much more frequently of late. The picots are not rigidly attached to the base of the footing but merely serve to reduce compressibility-deformability of the pressure bulb, and to increase bearing capacity.

7. Pile Foundations

It is doubtless in this vast area of geotechnical activity that there has been the greatest variety of inventive initiatives on construction methods.

It seems certain that the driven displacement pile was the first type used. In this category we must note with special interest the remarkable inventiveness of Edgard Frankignoul's development of the Franki pile in comparison with heavy piles driven by hammering at the top (compression) or the mandrel driven piles with metal shells (Fig. 11). By pounding at the bottom the steel casing is pulled down in tension with minimized tendency to damage, and optimized conditions for forming a bigger pedestal. The length of the internal plug can be increased to force deeper penetrability. For tugging retrieval of the casing it is important to observe the syncopated "mystique" of pounding and tugging slightly asynchronically, so as to avoid pulling up the concrete plug, with severe risk to the integrity of the pile. Many a company now use Franki piles, but sometimes the finer points of the inventive specialty techniques are missed, and the results are disastrous.

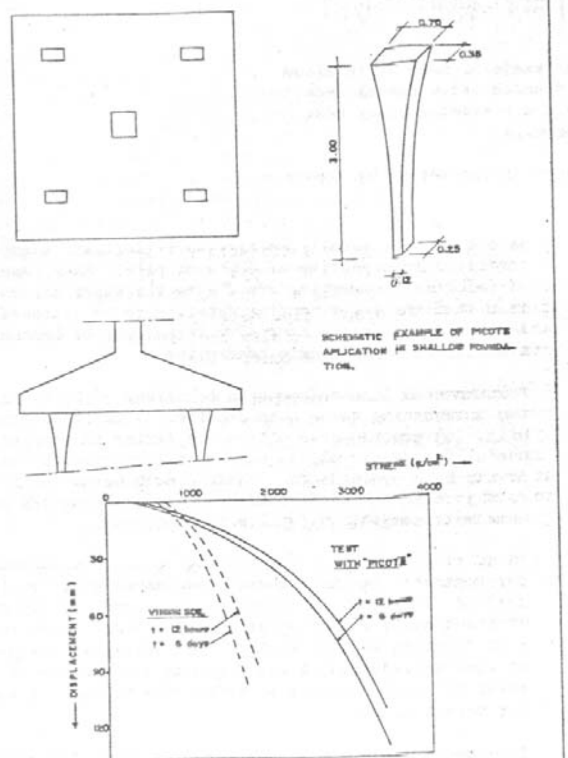


FIG. 10 SHALLOW FOUNDATIONS : "PICOTS" DRIVEN TO REINFORCE THE PRESSURE BULB.

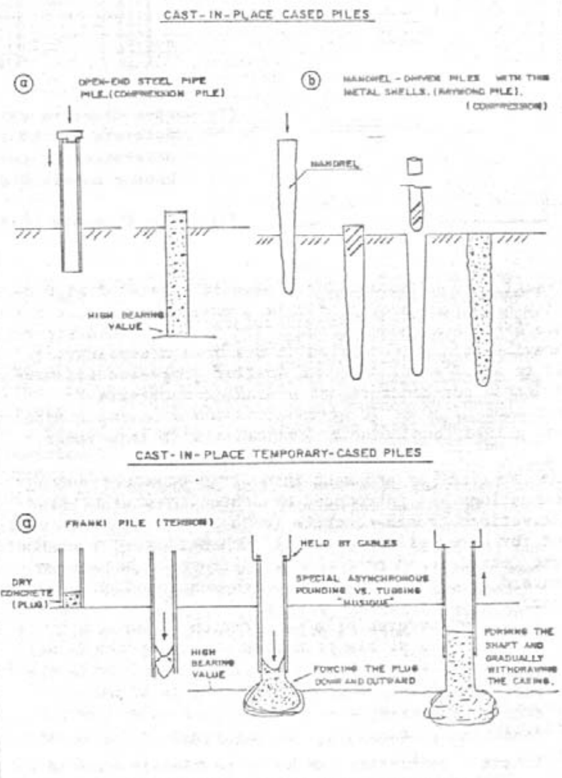


FIG. 11 - STEEL DISPLACEMENT PILES AND FRANKI PILE.

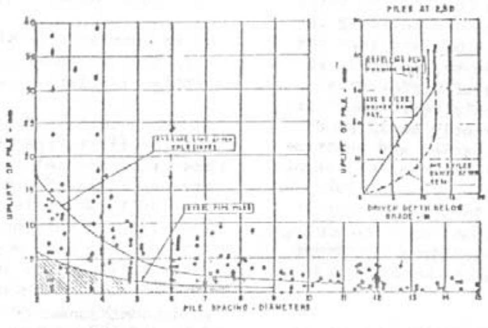
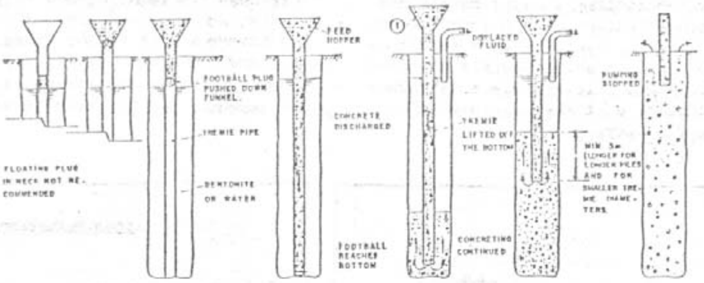


FIG. 12- UPLIFT MEASUREMENTS IN FRANKI PILES(REF).



(1) - Care never to raise tremie so much as to allow concrete column to descend below funnel neck, otherwise air pockets are trapped under next hopper concrete discharge.

Fig. 13 - Comments on stages of concreting by tremie.

Franki pile penetrability even in strata of high density has often proved to be a source of serious trouble because of heave (Fig. 12). Thus, obviously for heavier-load driven piles it has been necessary to go to steel sections (much smaller cross-section needed than for concrete, at nominal compressive stresses of 60 to 70 kg/cm^2, and the open-end pipe has gained considerable advantages in this range.

The important advancement into large capacity deep foundations was introduced by bentonite-stabilized excavations tremie-concrete (both for diaphragm walls, and for bored piles). Fig. 13.schematically presents some details that make the big difference between garanteed success and the yet often-mentioned cases of concreting defects. Firstly it should be emphasized that a "dry" augered pile perforation above W.L. is often much more stable than when soaked by the bentonite slurry that would be meant to stabilize the wall: the mistake has been often made of blindly accepting bentonite as a stabilizer under any and all conditions. Secondly, the requirements for continuous tremie concreting can be quite clearly equated by equilibrium of the concrete column within the tremie pipe and the theory of expansion of cavity at its bottom, against the confining pressure of the outside concrete column. It can be seen that the same diameter pipe cannot be equally satisfactory (for same slump concrete) irrespective of depth of pile. Many cases of defective concreting are due to the eager assumption that there are no fine detailes to be reasoned and optimized in the specialty techniques of bentonite stabilization and tremie concreting.

For improved load-deformation behaviour of bored piles two interesting techniques are the (a) multiple-reamed pile, (b) grouted-base pile. The latter is specially useful for deeper piles, wherein the grouting pressure at the base preloads the pressure bulb below the base so that base and shaft load-deformation behaviors become more compatible (at low deformation).

In steel piling it is interesting to note two opposite developments: in cases wherein increased adhesion is desired, there have been instances of application of electrosmosis, at the other extreme, where negative skin friction is anticipated, the coating with asphalts of specialized-studied rheology has often achieved great success, reducing skin friction to about 10% of the normal value.

Equipment developments have been put forth for efficient techniques of simultaneous perforation, development of soil slurry in situ in the perforation, and admixing cement for a satisfactory soil-cement pile. Such are, in principle, the Japanese jetted pile (using water and air jets simultaneously), the Italian CCP pile (water jet only) and the DM (Deep Mixing method) using rotating blades (in soft clay only). Although high pressure pumps are used in the first two, the fine jets emerging into the slurry do not have much energy (head) left beyond that necessary for eroding to the diameter desired: the pressure is confined by the column of soil slurry, and thus at increasing depths the pumping pressure should be increased, as it should also when material more resistant is to be eroded. There is no high-pressure grouting or hydrofracture effect into surrounding soil.

Grouting does indeed offer attractive opportunities to small diameter boreholes, for developing much larger load capacity. Such is the principle of the Root-pile, very successfully used in underpinning and soil reinforcing.

Deep foundation psecialty techniques are automatically associated with greater capital costs on equipment, and tend to be used with greater disregard for peculiarities of soil profiles.

8. Tunnelling Advances

Tunneling is but briefly mentioned herein, principally to mention the use of compressed air as an inventive idea of great interest whenever it was first introduced. The concept of working "in the dry" by having air pressure establish equilibrium vs. water pressure, was doubtless a landmark in underground work. Further significant factors for success in tunnelling were and are forepoling, drainage, and rapidity. In a recent project we had occasion to advance drill-holes ahead of the face, use the drill-hole casings for "reinforcement" equivalent to a light forepoling, and simultaneously use such cased holes as vacuum drains ahead of the face. The gains were very noticeable: although there was no real novelty in principle, it required the adjustment of the cycle of construction operations quite beyond recognized practices.

The significant development in tunnelling is recognized to be the bentonite shield (Fig. 14) It can be reasoned that such a development lay in the obvious path of systematic improvements profiting of available knowledge and specialized techniques.

9. Concluding Remarks

I have attempted to cite examples of specialty techniques that pervade our practice of geotechnical engineering, and that we should reflect on, for the exercise of stimulating further creativity. The worst that happens to us is to take such developments for granted.

On the other hand, there has been an attempt to distinguish between the simplicity of the "whole idea" and some finer details that if disregarded lead to failure of the anticipated solution.

Thirdly, it has been necessary to warn that in a significant number of cases there is a tendency to force the use of a specialty techniques in a wider spectrum of conditions than really merit or warrant it. Such is the case especially when high capital costs of equipment are involved, inducing the owners of the procedure to promote continuous use of the invested capital. Often such situations lend themselves to the nurturing of a black-box mystique for easier commercial promotion directly to lay clients. One of the sad realities is that at conferences on specialty techniques most papers presented belong either to one end of the statistical histogram, or to the other: either only the fully successful cases, or a few of the total failures (the latter being presented as a background for presentation of the corrective solution adopted by the author). An effort must be made to obtain on all such treatments a complete realistic histogram of varying degrees of success of case histories.

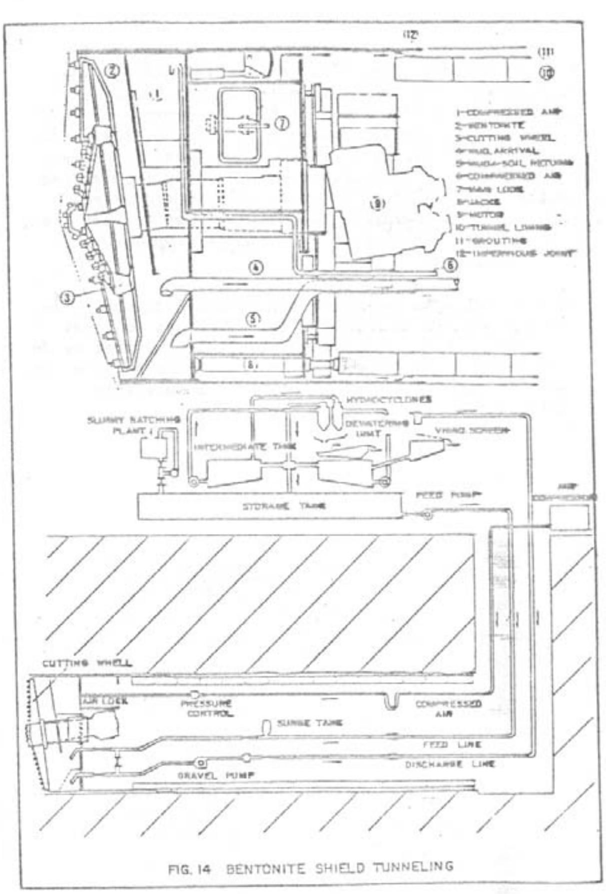
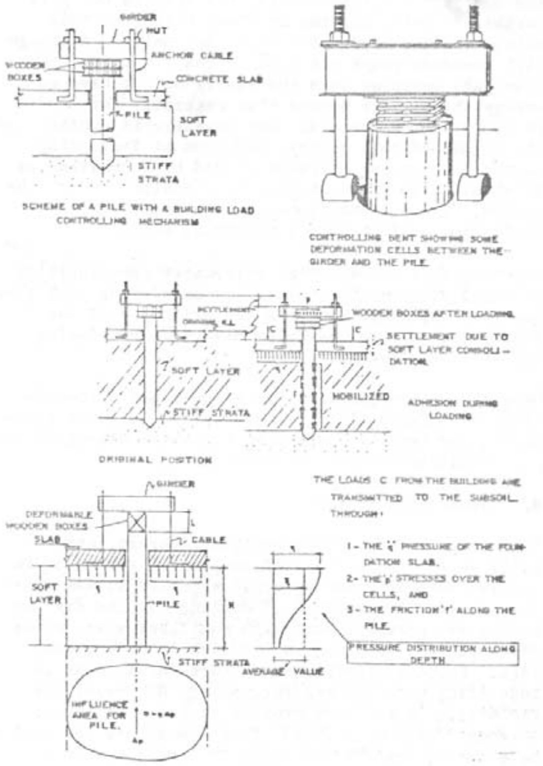


FIG. 14 BENTONITE SHIELD TUNNELING

At the start I pointed out the recipe for inventiveness, the freedom to dream what would be desirable, and thereupon the zest to work towards transforming the dream and desire into reality. There is also the proverbial mother of invention that is necessity: and in such cases it is often accompanied by a somewhat more singular degree of acceptance. One of the big obstacles to local application of geotechnical engineering has been the presumption of the obligation to meet the same levels of acceptance every where in the world. In closing I therefore find it appropriate to mention Mexico City's solution to the problems of of big settlements of buildings alongside with those of subsidence, skin friction and so forth. It is Pilotes Control (Fig. 15). A very inventive solution indeed: and in a city often shaken by major earthquakes, a solution that has not proven unacceptable despite the appearance of leaving buildings on movable foundations. Besides the gradual adjustment of loadings and deformations effectively transmitted to the soil, Pilotes Control permits periodic resetting of the building to new levels as desired: it establishes underpinning as a routine applicable without trauma.

To such extremes ingenious engineering can carry varying practices of geotechnical solutions to local problems. In engineering it is often true that we do first, and later we analyse what was done and how, in order to explore better the success intuitively achieved.



PILOTES CONTROL – PERIODIC
RESETTING OF STRUCTURES TO NEW LEVELS AS DESIRED.

Fig. 15