Geomechanics in the National Development of New Zealand

J. H. H. GALLOWAY
(Ministry of Works, New Zealand)

The theme of this symposium is "Geomechanics - A Tool in National Development" and I was asked to talk specifically on "Earthquake Engineering and Geothermal Power". But, bearing in mind that the stated purpose of the symposium is "to help define the relatively new term Geomechanics in the mind of the profession and the public" I feel that such an approach is too narrow. I might have thrilled you with tales of earth-shaking powers and hellish energy; of Hephaestus forging his divine armour in the bowels of the earth; of Ruaumoko, the earth-shaker, cleaving the mountains. But in my view Geomechanics is much more than the awesome or spectacular. It underlies all man's economic development and is the literal and metaphorical foundation of every nation's wealth. Therefore I have chosen a much wider theme and attempted to give a review of the place of Geomechanics in New Zealand's national development; if it is the fundamental basis of national development where the national wealth is almost wholly tied to agriculture, how much more it must be the foundation of economic wealth in countries where mining and manufacturing provide the main occupations.

New Zealand has only two major resources, an equable climate with an abundant, well distributed rainfall and a fairly fertile soil. The whole history of the development of the country has revolved round the processing of these two major resources into saleable commodities, a development which to date has been based upon pastoral farming.

Following in the English yoeman tradition New Zealand agriculture developed as many separate holdings each farmed by the owner. There was no corporate farming, and corporate investment and development were largely limited to the freezing works, dairy factories and like facilities necessary to process the products of the land.

This almost total dependence on individual pastoral farmers has proved very profitable for New Zealand. A high standard of living was built up and advanced social legislation developed. But now that the terms of trade for pastoral products are changing the dangers of almost total dependence on a few animal products are evident and strenuous efforts are being made to diversify. This diversification is leading to corporate development of other ways of using the two major natural resources of New Zealand but to date these corporate projects have hardly begun to be significant and I doubt whether they will contribute more than a sizeable minority of the nation's exports by the end of the century. Certainly in the year 2000 climate will still be the basic ingredient of our exports (after all, aluminium ingots and newsprint are only ways of packaging an abundant rainfall for sale!) and no likely development of manufacturing or discovery of mineral wealth will contribute more than a few percent of our exportable surplus.

The present high standard of living in New Zealand arose because not only did the farmers produce enough to support their families and continue to develop their land but a substantial surplus was available for investment in community and national development. National development started early because Central Government recognised the need and set up the Public Works Department to build roads, railways and public buildings. As the needs of national development grew so did the responsibilities of the P.W.D. to include irrigation, hydro-electric, water supply, airport and large-scale development projects till by the end of its first century the Department, now called the Ministry of Works, had become consulting civil engineer to Government. In this capacity it supervises about $250,000,000 worth of works every year, the vast majority of which are designed and a sizeable proportion constructed by the Department. Thus the history of national development in New Zealand is largely the history of the Ministry of Works and it seems likely that the Department will dominate this sphere for many years to come. It is thus particularly appropriate that I, a civil engineer of that Department, should be discussing the place of Geomechanics in national development, and it is a happy coincidence that 1971 is the centennial year of the Department.

To a civil engineer like myself it is almost axiomatic to regard Geomechanics as the basis of national development. True I have spent the bulk of my career in the study and application of soil mechanics but apart from this almost everything done by the engineer uses the natural resources of the earth and relies upon the earth for support. To the layman this dependence may not be so obvious as even the names of the three main disciplines of Geomechanics - Soil Mechanics, Rock Mechanics and Engineering Geology - may not be familiar to him.

It is apparent that soil mechanics - the art of using the natural properties of soils to best structural advantage - must be of great importance in conceiving and building a large earth dam, and that the skills of engineering geology - the application of the knowledge of geology to engineering problems - are fundamental to assessing the water-tightness and

safety of the reservoir basin.

It is also fairly apparent that both rock mechanics - the art of using the structural properties of rocks to best advantage - and engineering geology are the basis on which tunnels and underground caverns are designed and constructed. Both these structures feature in hydro-power, mining and underground railway developments.

It should be obvious, but is often forgotten, that every building or structure must rest upon a foundation. The design of these foundations is one of the main pre-occupations of soil mechanics experts.

It is perhaps not so obvious that the development of geothermal power depends heavily on Geomechanics. Once the natural steam has been brought to the surface its conversion into electricity or use as a source of heat involve more or less routine problems of mechanical engineering. But the location of the steam-bearing strata and the proving of its extent are very much in the province of geology while the tapping of the steam reservoir and the bringing of the steam safely to the surface requires all the skill and experience of the oil well driller.

In the same way earthquake engineering depends heavily on Geomechanics. No matter how expert the structural engineers are in calculating the strength and safety of their structures they have to rely on the geomechanics disciplines to provide them with information about the foundations beneath those structures and the earthquakes they may be called upon to resist. The response of a structure to an earthquake depends not only on the structure itself but also on the properties of the foundation on which it sits. And the earthquake shaking felt at the site is itself greatly influenced by the nature of the foundation soils, the ground water level, the depth to rock and the nature and surface configuration of the rock itself.

Less obvious again is the role Geomechanics plays in our roads, railways and airports. All vehicles produce rolling loads on the earth beneath and soil mechanics helps clarify the way these loads are dispersed by the structure of the pavement so that they can be safely carried by the underlying natural soils. Certainly durable roads could be made without the help of Geomechanics but they would not be economical roads.

Least obvious of all perhaps is the influence of Geomechanics on our buildings. Concrete has become the sine-qua-non of modern civil engineering and concrete itself is basically an exercise in Geomechanics. The whole art of concrete design - and make no mistake good concrete is much more than a random mixture of stones, water and a grey powder which goes hard in a few days - is to produce the desired properties at minimum cost. Cement is the essential and most costly ingredient, but in terms of volume, only a minor one. The majority of the concrete consists of shingle and sand and the quality of the finished concrete depends greatly on the judicious selection and blending of these ingredients. Geological study of the minerals in both shingle and sand will indicate their likely strength and durability and show whether any unwanted reaction with other ingredients of the concrete or the reinforcing steel might arise. Rock mechanics plays a considerable part in determining the most economical, effective and safe way of operating the quarries which produce the shingle and in predicting its likely quality and surface texture. The theories and practices of soil mechanics are called upon in determining the most economical blend of the available sand and shingle. This blend is usually the one in which the maximum amount of these relatively cheap materials is packed into a unit volume thus minimising the space which has to be filled with expensive cement. So even the home handyman who lays a concrete path to the clothesline is, unwittingly perhaps, making use of Geomechanics!

I am sure that what I have said about the fundamental position of Geomechanics in New Zealand's national development is quite typical of other countries too. That the task of national development is divided in different ways between Central Government, Local Government and private industry in different countries is a political fact, but this political arrangement only overlies the basic Geomechanics principles upon which man's economic development depends.

I hope I have now given an adequate picture of the fundamental position I believe Geomechanics occupies in national development and would like to move on to more specific treatments and to ride a few hobby horses of my own.

Firstly I wish to thank my Department for permission to attend this Conference and to mention some of its achievements in Geomechanics. Currently something like $80,000,000 to $100,000,000 of the work it supervises (and mostly builds) is directly in the sphere of geomechanics - roading, airport works, railway tunnels and hydro-power developments. Some of these are in world class for size and in a country as geologically complex as New Zealand, few have been simple. At present we are driving tunnels through thermally active ground, building a hydro-power development in the fringes of a volcanic rubbish tip, setting up a hard-rock tunnelling machine to drive a six-mile railway tunnel and have under design a dam founded on deep peri-glacial materials to raise a large glacial lake by 150 feet, all developments in the forefront of geomechanics technology. Quite a number of our dams and tunnels were, at the time of their building, high in the world lists of "greats", either for sheer size or because of geological complexity. For example there must be few dams in the world where the rock abutments are underlain by large depths of uncemented sediments yet we have several such. Perhaps this is what is meant by antipodean!

At present we have in hand a most interesting series of studies of the dynamic behaviour of buildings. These rely on the vibrations of wind, traffic etc. to excite the buildings and hence allow us to measure their natural frequencies in the elastic range. They show quite clearly there is normally a significant component of foundation compliance which will substantially modify behaviour in an earthquake. All modes of compliance can be present and there will be much interesting analysis to be done in relating site properties to measured compliances.

I would also like to be able to make claims for our current work in the field of geothermal power. Regrettably this is not a vintage year for this activity and at the moment our prospecting work is closing

down. The truth of the matter is that blocks of 100 to 200 electrical megawatts that could be developed from known steam fields are too small to be significant in the national electricity scene, but too large and remote to interest industry. There have been corporate proposals recently to use geothermal steam for sulphur mining but this development has not yet started.

This catalogue only includes some of the current works of geomechanics interest of the Ministry of Works and much else is under way not only in the public but also in the private sector. Much of this is the normal run of geomechanics - building foundations, slope stability, tunnels, dams, oil exploration, mining developments, roading - but one aspect that should be given further mention, to give it due place in the New Zealand scene, is earthquake studies. Rightly earthquakes are a cause of continuing concern and occupy a good deal of our thinking. But it is only fair to point out that the total loss of life in New Zealand as a result of earthquakes since European settlement began is less than one year's road toll. In fact the statistical risk is so slight that it does not equal that of accidental drowning or compensate for the small difference between the Australian and New Zealand road death rates. But it is only by continual vigilance that this record can be maintained and there is economic loss as well as loss of life to be considered. Two ways in which this vigilance is being maintained are the studies in the dynamic strength properties of soils and the vibrational characteristics of foundation strata at present in hand in our Universities and the seismic microzoning being undertaken by the Department of Scientific and Industrial Research (Ref. 1). Seismic Microzoning is a technique in which all the factors which influence the ground shaking liable to be experienced at a point on the earth's surface are assessed so that a rating of the risk can be made. Involving soil mechanics, rock mechanics, geology, seismology, and geophysics, seismic microzoning is of the very essence of Geomechanics.

Secondly I wish to talk in my capacity of Chairman of the N.Z. National Society for Soil Mechanics and Foundation Engineering. In this capacity I wish to thank the Society for the honour they have done me in electing me Chairman and for the confidence they have shown in nominating me to contribute to this Symposium.

For years soil mechanics in New Zealand was haunted by the spectre of "overseas standards". These standards had been developed against a background utterly different from ours and when applied here in New Zealand were quite inappropriate. What could one make of a material whose optimum moisture content changed with the moisture content at which the test started or whose density lay above the zero air voids line? Or of a clay whose "secondary" consolidation vastly exceeded its "primary" consolidation? Precious little in terms of "classical" soil mechanics and as such materials continued to turn up with alarming regularity one became a little sceptical of the worth of soil mechanics. It was something of a relief when Terzaghi published his paper on the Sasamua dam to find that many of the contributors to the discussion had run across oddities similar to ours and that, therefore, we were not alone in our troubles. I hope we have now got past the stage of slavish dependence on overseas standards but as we have not made as much progress in publishing standards of our own as I would like to see; we may not yet be out of the wood. But one lesson I hope we have learned is that there is not enough communication of ideas at an informal level. We wait too long attempting to produce the "perfect" publication with all the loose ends sewn up when our ideas, imperfectly formed though they be, might be of immediate use to others.

In an attempt to remedy this lack of communication the N.Z. National Committee has recently expanded its newsletter and given it the title of N.Z. Geomechanics News. This will appear from time to time as material accumulates and is intended primarily as an informal forum in which society members can try out ideas, do a bit of coat trailing, offer opinions and generally discuss their experiences. This, we are sure, can only benefit Geomechanics as will other attempts to bring about a genuine exchange of ideas. One such is the recent formation of the Australian Geomechanics Society to whom we offer our congratulations and hope shortly to emulate.

But I have rather strayed from the theme of this Symposium and what real use is mere talk of co-operation and communication? I therefore now will endeavour to show that informal co-operation in Geomechanics between disciplines and countries already exists and that there are good reasons why it should continue. I will do this by quoting a few case histories of which I have personal knowledge.

My first case refers to a recent tentative Australian standard for measuring the in-situ density of soil (Ref. 2). About 17 years ago I was involved in the construction supervision of an earth dam and one of the things we happened to come across was an article in a magazine describing the Washington "Dens-o-meter". The device looked viable so with the help of the plumbers' shop we made up something on the same lines from an assortment of scrap. The thing worked, (though we found out later when fuller details of the Washington device appeared that we had subtly altered the principle of operation), and I can remember showing it off with pride to my friends in the Snowy Mountains Authority when they visited us. During succeeding jobs our version of the device developed from an "ad-hoc" collection of bits into a fully manufactured article while our understanding of the philosophy of use deepened so that we became aware of the substantial change for the better involved in our originally unconscious modification of the operating principle. Meanwhile the S.M.A. people had built a device of their own based on our original drawings and had good success. By the time they were prepared to accept it as a really useful tool our formal development programme was complete and we were able to offer them full working drawings and operating instructions which, I believe, are virtually indistinguishable from those in the new standard.

Thus an idea originated in U.S.A., travelled across the Pacific to New Zealand (suffering a sea-change en route), developed there for a time and finally appears in an Australian standard. Surely an excellent example of international co-operation, mostly done through the "old-boy network".

My second example concerns a problem in road stone durability. Over the years we had found that in some parts of New Zealand there was a strong tendency for road stone to degrade badly when stock-

piled and this could happen even with the "superior" grades of stone used for sealing chips. The material gave "acceptable" results in such overseas standards as Los Angeles abrasion and the B.S. 10% fines test but would not stand up to the apparently minor rigours of being stockpiled. Frost riving was not a significant factor but it was known that some New Zealand rocks while highly competent in the mass suffered badly when separated from the living rock. Blocks cut from the river banks in stable gorges of the order of 500 to 1,000 feet deep would crumble to fragments if left out in the weather for a few months. Some powerful degrading effect was at work but its exact nature was unknown. With the exception of the sodium sulphate test, which was far too severe since few New Zealand rocks would pass, the only published test that seemed relevant was the New South Wales Department of Main Roads "shale test". This obviously was not wholly applicable as it applied severe mechanical shock to each test piece and this was certainly not a major factor in our case. But it did provide a starting point from which a simple ten-cycle drying and soaking test, in conjunction with light mechanical rolling, was evolved. The amount of break-down in this test, coupled with the cleanness value of the material after test provide a reliable indicator of how well the material behaved in the road. The test is now commonly used in assessing the quality of road stone in New Zealand and can also be applied to concrete aggregates. It has not been much publicised though it was described in a paper by J. Clelland in the New Zealand Roading Symposium, 1967. It could be of use to Road Authorities in Australia and I was pleased to see a recent request for further details from an Australian quarrying company.

The point of this example is not that a new, definitive test has been developed but the way in which it evolved. An Australian idea was adapted to meet a New Zealand problem; the development work was done in a laboratory primarily involved in concrete technology; and now is becoming of interest to Australians, surely a good example of the benefit of international and interdisciplinary co-operation.

My third example also illustrates the benefit to be gained from an informal exchange between disciplines. It is generally accepted that the higher the solids content the greater the stability of a road base (provided there is no question of pore fluid pressures being developed). Almost always natural gravels or crushed stone mixtures are not ideally graded for maximum solids content and some form of adjustment is necessary. Traditionally this has been attempted by specifying a grading which closely follows an exponential curve. Controversy has raged as to what exponent value was the best but this theoretical battle was quite beside the point to the quarry manager faced with producing the best result from the materials available to him. The exponentialists would have him instal ball mills and other expensive devices or else reject "excess" sizes to satisfy their preconceived ideas of grading but no one was looking at the justification for these preconceptions. The exponential curve certainly is the "ideal" one provided the assumption that all particles have the same shape, surface texture and packing arrangement regardless of size holds. But this assumption is so unlikely to be correct that, in most practical cases the exponential theory is highly suspect. Not only can it cost a lot to produce an exponential grading, but also this grading may in fact be inferior to one more readily obtained.

While working with the design of grouts for prestressing ducts it was discovered that the suitability of a sand for this use could be assessed without actually mixing it with cement and water. The mass rate of flow of the dry sand through the standard grout cone was in fact a reliable indicator of the suitability of the sand. The higher the mass rate of flow of the dry sand the lower the water content (and hence cement content) required for a given grout fluidity. As the grout would only be fluid while there was an excess of pore fluid (in this case a cement-in-water suspension) it was therefore apparent that the mass rate of flow reflected the packing ability of the sand grains. Harsh angular grains, excess of fines, and a narrow range of grain sizes all led to poor flow rates while best results were found with well graded materials free of angular particles or silt sized fines.

When this knowledge was applied to the road stone grading problem it was soon apparent that in the sand flow rate we had a tool for directly assessing the packing ability of the sand fraction and that the exponent controversy could thus be relegated to limbo. It proved quite simple to show that with a range of natural and artificial sands better packing could be achieved (and at little trouble) by using the sand flow rate than by any exponential grading. In fact one could demonstrate that where a size fraction was particularly angular better packing could be achieved by replacing it with other sizes even to the extent of leaving it out entirely. It only remained then to measure the unit weight of the sand (by allowing it to fill a container of known volume as it fell from the grout cone) and a simple grading optimisation technique was available. The optimum blend of the coarser sizes is determined by trial and error (only a few size intervals are involved so the problem is not very complex) while the optimum blend, and the resultant unit weight of the sand fraction, is determined by use of the grout cone. Sufficient of this sand can then be added to the combined coarser fractions to take care of the void spaces left. The optimum blend should of course make allowance for the relative abundance of the sand sizes available as it can be economic nonsense to strive for maximum unit weight irrespective of expense or the rejection of large quantities of certain sizes.

It appears that the mass rate of flow idea could be extended to include the coarser sizes but this we have not yet done. The logistic problems of handling the much larger samples needed seem a bit daunting and could very well prove limiting. The method has been used on several occasions with good success and is described more fully in the N.Z. Standards Association Bulletin (Vol. 14, No. 4, October, 1968). It was recently used to optimise the concrete mix design for an arch dam. In this case, with a rather coarse, but within specification exponentially graded sand savings of up to 20% of cement (70 lb. per cu.yd.) were achieved by adding 20% of fine dune sand to the mix. The resultant sand grading was hardly conventional but a denser, more workable and economical concrete was achieved without any loss in strength. An incidential bonus was the considerable reduction in temperature rise that will occur in the dam structure.

My final example is of an informal exchange of

ideas between Canada and New Zealand. Over the years we have experimented with a variety of ways of measuring the in-situ unit weight of soils. Some of these proved successful, others not. One rather successful idea was the use of Suckling clover seed as a density "sand" in the sand replacement technique. The seed had many desirable properties in this application, it had a very narrow size range, was essentially spherical with a slippery slightly oily seed coat and gave an almost constant calibration irrespective of the method of pouring or the shape and surface texture of the calibration vessel. It was even quite resistant to the short term effects of moisture. But somehow the idea of using it as a calibrated material was slightly ludicrous and we were always a bit different about pushing its use.

Imagine my surprise and pleasure to discover from a chance conversation with the laboratory staff of the Saskatchewan Prairie Farms Rehabilitation Administration that they had found similar desirable characteristics in wheat grains. They too seem to have been diffident about publicising their findings, probably for much the same reasons as ours. Yet, between us we had gone a long way towards establishing that a calibrated sand has no need to be made of mineral grains and that, in emergency, any one of a number of common grocery lines such as sugar, coffee beans, rice or sago could serve perfectly well.

I hope these examples convince you of the benefits of informal exchange of information and ideas and that we in New Zealand are keen to foster such exchange. I also hope that I have done something towards establishing a clearer understanding of the scope of Geomechanics. But I fear I have done little to affirm the thesis of this Symposium. Geomechanics is not just a tool in national development, it is the fundamental basis of all economic development.

References:

1. OBORN, L.E. - Seismic Microzoning in New Zealand. Proc. First Int. Congress I.A.E.G., Paris, 1970.

2. STANDARDS ASSOCIATION OF AUSTRALIA - Draft Addendum to A89-1966: Determination of the Dry Density of a Soil in the Field: Balloon Densometer Test.