Transportation – Application of Geomechanics to Roads and Bridges

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1. Geomechanics, which is the comparatively new science of soil and rock mechanics, is playing a significant and increasingly important role in the development of transportation in Australia, and particularly of roads. It is true, of course, that roads have been successfully built without the aid of such scientific methodology since the days of the Roman Empire. The Romans realised the importance of good communication in their quest to conquer new territories, and the greatness of their empire was due largely to the excellence of their land and water transport systems. Those early road builders were fortunate in that labour and materials were plentiful, and consequently their roads were seemingly built to last forever, so much so that many are still capable of carrying present day traffic. By today's standards, of course, their roads were very much over-designed. Today we must be much more rational in our design of road pavements.

2. With limited resources we are faced in Australia with the task of providing an expanding road system to meet the needs of a steadily increasing population with a steeply rising rate of vehicle ownership. Although the opening up of new agricultural areas, to which much of our road building efforts have been directed in the past, has virtually ceased, new basic developmental work must continue in order to service the expanding needs of a mineral boom which is taking place in many remote areas, and at the same time provide for the backlog of road needs in our capital cities. Geomechanics is a most important tool which is helping to make this formidable task possible. By providing a more basic understanding of the characteristics and behaviour of soils and road materials encountered in road and bridge foundations geomechanics has made it possible to achieve economies in design and improve construction methods.

3. The multi-layered flexible road pavement system is a complex structure made up of materials whose engineering properties themselves vary and are very much affected by the loading to which they are subjected, and also by environmental conditions. Despite our vastly increasing knowledge, present methods of pavement design are largely empirical. Considerable research effort is being applied both overseas and here in Australia by the Australian Road Research Board, universities and others to develop a better understanding of the behaviour of pavements and the soils underlying them. The aim is to be able to design a road pavement in a similar manner to that used in other engineering structures whereby stresses and deformations at critical points may be limited to acceptable values. While this aim is unlikely to be achieved in full in the foreseeable future it is a fact that any significant increase in our knowledge in this field of geomechanics will have a considerable impact on road and airfield engineering, and might well lead to a considerable saving in national investment.

4. A most important application of geomechanics in connection with road pavements is its use in determining the limitations to be placed on wheel and axle loads and overall vehicle weights. Such limitations have nation-wide economic implications. While increased axle loading could result in significant savings in transport costs any saving must be offset against the increased cost to the community of new roads and the strengthening of existing roads and bridges. The member authorities of the National Association of Australian State Road Authorities are at present conducting a survey in each State to determine the axle load distribution on the Australian road system.

5. From these few remarks on the application of geomechanics it can be seen that this science has become an important tool in highway engineering. Besides the uses mentioned it is used to assess varying pavement materials sometimes involving alternative methods of construction, and it is also used in bridge foundations. In recent years the theory of consolidation, originally propounded by the founder of soil mechanics, Terzaghi, has been extensively used in highway projects. This theory enables the amount and time of settlement to be determined for each increment of load. A spectacular achievement in this application of soil mechanics theory by the Main Roads Department of Western Australia has been the Narrows Interchange which forms part of the Mitchell Freeway project in Perth. There are many features of this project which are believed to be unique in Australia and New Zealand.

6. Urban freeways, and more particulary interchanges, have an almost insatiable demand for land which in developed areas is very expensive, so it is often necessary to use areas which were previously avoided because of poor foundations. Today the cost of strengthening the soil or of providing complex foundations in these areas is usually much less than the cost of acquiring already developed land. The land reclamation project on the Swan River estuary for the Narrows Interchange in Perth is an interesting

example of this.

7. A complex traffic interchange involving freeways and important arterial roads at the south-west corner of the city near the Narrows Bridge required an overall area of about 90 acres which includes an area for a city car park. In order to avoid resumption of heavily built-up areas and adjacent parkland it was decided to reclaim this area from a shallow and somewhat stagnant area of the river where there was an underlying very soft organic silty clay layer, varying between 40 ft. and 100 ft. deep. The mud layer was so soft in its original state that many of the cylindrical samples almost collapsed under their own weight. After blanketing the area with a few feet of dredged sand the maximum height of embankment which could be built in this situation without failure was less than 7 ft., yet it was necessary to contemplate an embankment height of over 40 ft. to accommodate a third level bridge. Had it been possible to gradually add more filling over a period of 100 years or so the area could have been stabilised without any special measures being taken. A maximum settlement of 26 ft. would have occurred in the mud layer.

8. The fact that embankments under these conditions would most certainly have been avoided not so many years ago gives a meaningful indication of the advances which have been made in geomechanics in recent times. Even at the planning stage ten years ago the problem of constructing stable embankments in this area was considered unrealistic by many engineers who would have preferred to build the whole interchange in structure.

9. However, building the interchange in structure was not favoured because of higher cost and the fact that it would inevitably create a concrete jungle. By contrast, embankments could be landscaped to give a spacious park-like appearance. In fact, I believe it is of interest to note that the whole of the interchange is being developed as a park with two man-made lakes, a fountain and extensive pedestrian walkways accessible via special subways and bridges. This feature is possibly unique in the world for a traffic interchange of this magnitude.

10. Tests were carried out in 1962 and a feasibility study undertaken to determine if it were possible to stabilise the area and strengthen the soil in the time available before construction of the interchange was required to start. Advanced geomechanics theory was applied to these studies which, backed by large-scale drainage and failure tests, confirmed that it was feasible to construct the embankments and that the post-construction settlement could be reduced so that they could safely carry the heavily-trafficked roads of the interchange.

11. 43,000 sand drains were sunk in staggered rows. These were 18" in diameter and had an average depth of 58 ft. The total length of sand drains was about 500 miles. They were spaced between 5 ft. and 10 ft. apart, depending on the height of the embankments and the time available for consolidation. Four million cubic yards of sand filling was imported from 11 miles away by truck and placed over the reclaimed area. The weight of the sand filling in effect squeezes moisture out of the mud into the sand drains. This is accompanied by settlement and an increase in the strength of the mud. Surcharge loading, i.e. filling in addition to that provided by the embankments, was used to accelerate the process.

12. Geomechanics theory was constantly applied during the course of construction. Various measurements were made using sophisticated instruments to determine the effectiveness of the operation and to control the rate of loading to avoid construction failures. The study predictions were largely borne out in practice and the embankments completed within the time allowed. Total depth of fill including up to 15 ft. of superload exceeded 70 ft. in some places with a settlement of up to 23 ft. taking place. The 60-ft. mud layer was reduced to approximately two-thirds of its original thickness.

13. The whole reclamation project has proved a most economic exercise. Land for the interchange has been obtained at a cost of about $52,000 per acre, which is very much less than city property values.

14. Geomechanics theory has continued to be applied to the unusual problems encountered in the design and construction of the foundations for the five bridges in the interchange.

15. Although most of the expected settlement had taken place before the bridge structures were commenced, residual settlement of 2 ft. or more is expected to occur over a long period. Such settlement will cause significant horizontal movements within the clay stratum which could cause large unacceptable stresses in piles supporting the bridge piers. The solution finally adopted after a study of alternatives was to build the pier foundation within a concrete caisson and provide an annular space between them. The estimation of the horizontal movements to be designed for was a difficult problem on which only limited work had been done previously.

16. A unique feature of the caissons was that they were built in segments each of which could slide horizontally with respect to adjacent segments. This was to accommodate differential horizontal movements at various depths. Each segment was 12 ft. high and was separated from the adjacent segment by a one-inch-thick neoprene sliding joint.

17. The internal diameter of the caissons varied between 25 ft. and 30 ft. depending on the diameter of the pier shaft and the annular space varied between 9 inches and 32 inches. The wall thickness of up to 39 inches included 3 inches of sacrificial concrete to allow for predicted bacterial attack. The skin friction during sinking was reduced by the provision of a sleeve filled with bentonite slurry around the caisson.

18. Many difficult construction problems were encountered in the sinking of the caissons. These problems and their solution will be described in technical literature to be published later. Ten of the thirteen caissons have now been sunk to the required depth and three are nearing completion.

19. Geomechanics has played an important role in the development of the Australian road system. This is due not only to the diverse geological and climatic conditions which occur in this continent but also on account of compelling economic factors. In order to meet the heavy demands for roads in the rapidly

developing regions of Australia it has been necessary to develop and make maximum use of low-cost construction methods. Considerable success has been attained in achieving relatively low costs by the use of natural locally-occurring materials. These techniques made the construction of large mileages of road possible during the early development of the Australian road system at a time when funds were grossly inadequate. Besides extensive use on lightly-trafficked roads, these methods were also used on some important arterial roads. On the Hume Highway in Victoria, for instance, one of Australia's most heavily-trafficked rural roads, long sections of sealed loam and non-standard gravels which were built for light traffic have only recently been reconstructed after thirty years of satisfactory service. These are many similar examples in New South Wales, Western Australia and the other States.

20. Low-cost methods have certainly played a dominant role in the development of the Western Australian road system. Fortunately the earliest demands for roads in the beginning of the motor-car era were for agricultural development in the south-western corner of the State where very good lateritic gravels are readily available. Outside this area, however, normally acceptable roadmaking materials are scarce, and so-called substandard materials have had to be used. Satisfactory construction procedures have been established for these substandard materials following extensive laboratory investigations and field trials. It is of interest that for some years the Australian Road Research Board has been sponsoring a research project at the University of Western Australia to determine more realistic parameters for the selection of such base-course materials for use in low-rainfall areas.

21. The highway to Carnarvon, some 600 miles north of Perth on the coast, provides a good example of the use of mechanical stabilisation using local materials. The pavement of a 180-mile section of this road where there were no gravelly materials was constructed by stabilising the in-situ fine sands with silty clays and loams imported from nearby deposits. The maximum size of these materials was about the size of a pin head. This construction cost considerably less than the more usual methods of stabilisation using additives. The construction and sealing of the road was completed about ten years ago and has given satisfactory service. One still-unsolved problem which has been experienced with this type of construction is that the shoulders are susceptible to scour and are consequently difficult and expensive to maintain. The Department is continuing to investigate ways of overcoming this difficulty. Similar soil-stabilising techniques for low-cost road construction which have been developed and widely used over a long period of years have made an important contribution to the agricultural and pastoral development of the extensive light lands in the coastal regions of Western Australia from north of Port Hedland, more than 1,000 miles north of Perth, to Esperance situated on the south coast some 450 road miles from Perth.

22. An interesting example where geomechanics has been used as a tool in evaluating the economic feasibility of various forms of road treatment concerns the construction of the Western Australian section of the Eyre Highway — some 450 miles in length — between Norseman and the South Australian border. The section between Balladonia and Cocklebiddy, a distance of 140 miles, was completely devoid of suitable gravels. The natural soils along this section are highly calcareous. They disintegrate to "bulldust" when dry and are very sensitive to moisture, becoming boggy after even limited rain. An extensive laboratory testing programme on various alternative stabilisation treatments using bitumen, cement and lime, followed by field trials, was carried out. Cement and lime stabilisation proved most satisfactory, but because of the high cost of transporting these materials to this remote area they were discarded in favour of crushed rock base.

23. Another problem encountered on the Eyre Highway project arose from the need to use highly saline water for pavement and subgrade compaction. Normally such water is considered unsuitable. In this case, however, it was found that because of the relative absence of soil moisture movement due to the arid conditions, it was possible to use water with up to 2,000 grains of soluble salt per gallon without harmful effects, provided that the quantities of water used were closely controlled.

24. In Queensland, geomechanics is being used to develop more efficient methods of construction on the highly expansive black soils which are so prevalent in that State. In these areas conventional roadmaking materials are very scarce, making road development in these potentially highly productive areas most expensive.

25. The dramatic increase in car ownership and growing urbanisation in Australian cities has led to the adoption of large freeway and expressway programmes costing many millions of dollars in most States. Because of the very high cost of these facilities a high standard of construction, which would not be possible without controls based on geomechanics, is required. The Sydney-Newcastle expressway — one of the most exciting and sophisticated road projects in Australia, constructed by the Department of Main Roads, New South Wales — is a striking example. The expressway has been carved through rugged terrain requiring many large cuttings through sandstone. Some of these rock cuttings were up to 150 ft. deep, while the largest fill was 215 ft. high and measured 1.7 million cubic yards. The closely controlled compaction of these fills and the pre-splitting techniques for the rock cuttings are but two of the construction operations which have been greatly assisted by geomechanics.

26. Airfields have much in common with roads. The most important difference is the greater magnitude of aircraft wheel loads compared to those of trucks, and the fewer load repetitions which airfield pavements carry. The development of larger jet aircraft with the consequent need for heavier and longer runways constitutes a continuing and difficult problem for airfield engineers. The extension of the main north-south runway of the Kingsford Smith Airport is an interesting example of such a problem. The runway had to be lengthened by 3,000 ft. which extended it into Botany Bay. A tunnel had to be included in the project to carry an important six-lane highway that would otherwise have been cut off by the extension. The construction of the embankment which involved about $4\frac{1}{2}$ million cu. yards of sand dredged from Botany Bay, its protection against erosion, stability considerations together with

de-watering and site construction problems associated with the tunnel, were some of the problems which were overcome by the application of geomechanics.

27. Similar geomechanics problems are being encountered in the construction of a causeway $2\frac{1}{2}$ miles in length linking Garden Island with the mainland south of Fremantle in Western Australia. The causeway which will carry a 24-ft. road is being built by the Federal Government as part of a naval defence complex.

28. The basic problems involving geomechanics which are encountered on roads are also experienced on railways, one difference being that these problems are often more severe because the critical gradient requirements of railways result in considerably larger cuttings and fills and often traverse terrain which would be avoided for roads. In recent years Australia has experienced an active period of rail construction. First there were the rail standardisation programmes in Western Australia and South Australia, followed by several new railways in the Pilbara in Western Australia for the transport of iron ore. Geomechanics has been a valuable tool in these projects.

29. Australia's increasing trade and commerce necessitates frequent enlargement of its ports. As in other transport facilities which have been mentioned, geomechanics is again involved — particularly in the dredging of navigation channels and the foundations of wharf structures. The ports for the iron ore industry in the Pilbara in Western Australia are an interesting example. The viability of the industry depends on economic transport. Carriers of up to 150,000 tons which can be accommodated at existing ports are able to transport the ore economically to Japan. Export to more distant countries, however, will require carriers of up to 300,000 tons. Planning for a port at Legendre Island capable of handling these shipe is being undertaken. The design of such a port will depend very heavily on geomechanics.

30. These few examples of the use of geomechanics give some indication of the importance of this comparatively new science in the construction of roads, railways, harbours and airports. Significantly, its importance has been increasing - for recent developments in massive earth-moving equipment have enhanced the importance of soil as an engineering material. Increased efficiency in earth-moving equipment has caused a dramatic shift in the balance between the cost of earth and rock compared to other types of structures. Thus today it is generally more economical to build an earth embankment for a road or railway than an additional span on a bridge. Typically also the large Ord Dam in Western Australia is being constructed of crushed rock rather than concrete for largely economic reasons. This increased importance of soil as an engineering material is inducing much new research into geomechanics.

31. I should like to make some brief reference to the work of the Australian Road Research Board which is playing an important role in carrying out or promoting research in fields of geomechanics related to highway engineering. In addition to its own research the Board sponsors a significant amount of research at Australian universities.

32. One of the important tasks carried out by the Australian Road Research Board was the determination of those characteristics and physical features of the Australian environment which govern pavement behaviour. The most notable of these characteristics relate to soil moisture movements on which much of the earlier work was carried out by C.S.I.R.O.,some of which was done in conjunction with NAASRA. ARRB has made a useful contribution in the study of structural analysis of layered pavements. Besides such theoretical work, a wide range of compaction studies and several field evaluation trials involving a variety of natural materials and dry compaction methods have been carried out in various parts of Australia. In developing non-destructive testing techniques the Board has developed a roughness meter for assessing the structural condition of roads. The Board has also made useful contributions in other branches of geomechanics. Studies were performed on various aspects of the support provided by soft sediments along the length of slender point bearing piles. The principles established by these studies have already been applied in the design of important road bridges and of building foundations.

33. In conclusion, I believe that of the many factors which have contributed to the remarkable growth and development that Australia has experienced since the war there is little doubt that the development of transportation — by road, rail, sea and air — has been one of the most significant. Geomechanics has been an important tool in making this development possible. By providing a basic understanding of soil characteristics and performance with which the pavements of roads and airfields, rail tracks, bridge foundations and harbours are so intimately connected it has made possible major improvements and economies in design and construction methods which have contributed very largely to more efficient transportation.