Zambezia (1977), **5** (i).

PRACTISE BEFORE YOU PREACH*

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THE PRESENTATION OF an inaugural lecture is an occasion to which the incumbents of all Chairs look forward with varying degrees of trepidation. One feels that the University authorities themselves also exhibit trepidation in the matter and for this reason they require a softening-up period before allowing the candidate to take the floor. I prefer to compare this to that well-tried procedure in reinforced concrete work of allowing final set to occur and following this by curing, before the shuttering and props are stripped and removed. That is the moment of truth for a structure, and that moment has now arrived for me and the new Department of Civil Engineering.

My first duty must be to repeat the thanks expressed to the contributors to, and supporters of, the Faculty Fund Raising Appeal. The response of the profession, industry, local authorities, large public companies and finance houses, has been extremely generous. Without their faith in our Faculty and thus in its constituent departments, there would, as yet, be no Faculty of Engineering in Rhodesia. We wish them to know that we very much appreciate their acts of faith; and that we are eager to accept the challenge implied, and will do our utmost to justify their confidence in us. We are particularly delighted with the response in terms of student numbers and to them and their faith in joining us we intend to respond as effectively as lies within our power.

I feel it incumbent upon me to treat the broad field of civil engineering, rather than to choose a topic within my own experience or particular interest. This makes it necessary to look at the development of the subject and the profession from its very beginnings, but without involving us in too detailed a history of technology.

Engineering achievements in early history before the advent of machinery, invariably involved the expenditure of very considerable effort in terms of manhours; and the civil engineering projects of those days, just as they do today, not only required the ability to conceive the completed project and the methods to be used during construction, with due regard to feasibility and to the materials available, but also were particularly dependent on the ability to manage men. The failure of the Tower of Babel was assuredly an example of a failure in engineering management rather than a foundation or a structural failure. In fact, the Tower of Babel was probably a Ziggurat or temple and some of the most massive of these structures are reputed to have been

* An inaugural lecture delivered before the University of Rhodesia on 8 May 1975

250 m in height — veritable man-made mountains, beside which the great pyramids pale into insignificance. The city walls of Sumeria were also of monumental proportions; the highest were of the order of 60m, with base widths of 30m. Irrigation and flood control techniques, coupled with fertile soils, gave rise to an agricultural surplus and, on this hinged the ability of the Assyrians and Sumerians to indulge in the structural excesses already mentioned. The responsibility of the engineer builder was brought home to him by the Hammurabic code which would have put him to death if failure of his structures caused loss of life, and the sentence might well include members of his family if a family were killed in a collapse: a mantle of responsibility which rightly continues but is more humanely applied today.

The materials available dictated the structural forms used and the life of the structures. The Tigris-Euphrates people worked largely in sunburnt brick with little timber or stone; and as their rivers were relatively wild, few of their engineering achievements survived the ravages of time. The Egyptian civilization was better protected by the desert barrier, and the Nile was naturally regulated and more predictable. This enabled consistent agricultural surpluses to be used for trade. Barges and ships were built, and stone and timber were added to brick as the principal building materials. Structural form was still largely confined to columns and lintels but larger spans were feasible. The engineer reached a peak in the public esteem and the quality of life was high.

The first major revolt against technology appears to have been that of ancient Greece. There, philosophical thought, music and the arts, and sport, caused an eclipse of technology. Scientific principles tended to be confined to their pure and philosophical applications rather than to any engineering applications. Greek civilization spread to Syracuse in Sicily where probably the best known exponent of engineering was Archimedes. It was symptomatic of those times that he is best remembered for his principle, the problem of the alloy of King Hieron's crown, rather than for his war machines which were fine engineering developments. Regrettably, even he was conditioned to decry his own practical achievements compared to his contributions to scientific principles. The Romans were well aware of his potential usefulness and Marcellus gave explicit instructions that Archimedes be taken alive. Unfortunately, he was killed while busily engaged in sketching new designs on the beach sands.

The Romans were a motivated and pragmatic people with a real sense of purpose in life. While we may dispute just who introduced the arch and the use of concrete, they certainly deserve the credit for having had the courage to exploit new structural forms and to advance the art and practice of engineering by venturing forward to ever larger spans, new materials and novel techniques. Concrete was made by mixing natural pozzolithic volcanic materials with lime, shuttering and centering, and propping techniques were established. The timber truss was introduced and developed, and simple lintels became rarer. The 43m dome of the Pantheon, and the long span semi-circular arches of their bridges and aqueducts, such as the Pont du Gard, continue to bear testimony to the excellence of their work. However, foundation engineering was not the Romans' strong point and they failed to appreciate the need to use bonded piers or to design to resist scour in river beds. This led to many bridge failures and, following the collapse of the Roman Empire, bridge building became a lost art.

The eras which we have dealt with all depended upon the increasingly efficient labour-management techniques which the rulers had delegated to their armies. Doubtless there are still wild moments when the civil engineering contractor might relish the re-introduction of slavery. The slaves, of course, were those who practised and could benefit technically, particularly in times of peace, when the art of engineering could be perfected and propagated. Therein lies the reason for degeneration of the public esteem in which the engineer was held. Engineering had the taint of a servile profession.

No survey of engineering could omit the Roman Road. That these roads served their purpose for Roman needs cannot be disputed, but they again illustrate the economic excesses in which one could indulge with slave labour. Pavement thickness of 1 to 1½ metres in mortar, concrete and masonry were common and could have carried the abnormal loads of today. Unfortunately, their route location technique was generally confined to taking a direct bearing from A to B. This resulted in steep gradients and disadvantageous crossings of marshes and rivers. They attempted to come to conclusions with nature rather than to persuade and seduce her: these two essential arts of the Civil Engineer had yet to be learnt. The Roman road provided good access to later invaders and the Anglo-Saxons and others soon learnt the advantages of living as far from them as possible, and made little effort to maintain them.

Bridge building was revived in the twelfth century by the Benedictine order, Fratres Pontifices. London Bridge (is falling down) was one of their products. The ability to build bridges was then considered to require divine inspiration and vouchsafed only to men of extreme piety. This probably accounts for the Pope's title retained to the present day of Pontifex Maximus or bridge builder-in-chief!

The schism between the Structural Engineer and the Architect was inevitable, as no man can be everything to all men, yet who is to say just when it occurred? Perhaps it was in Roman times and perhaps in the Byzantine period or the perpendicular or even the late Renaissance, the seventeenth or even in the twentieth century, where we have had our Le Corbusiers and Nervis. Structural form began to flex its muscles again in Norman times with a revival of basic Roman techniques. The dome which had been perfected at St Sophia, Constantinople, in the sixth century in all its glory with penditive arches and semi-dome buttresses, returned to Venice in the shape of St Mark's which was commenced in 977 A.D. An interesting feature of Byzantine domes was the use of earthenware jars as void formers to reduce dead loads.

The permanence of stone for roofing as opposed to timber, led to the development of vaults and groins, the pointed arch and the flying buttress. A sympathy for structural action and interaction developed and theory began to be related to practice. The fine cathedrals of France and England bear testimony to the development of structure. In England the overall charge of engineering work was vested in the Surveyor-General and holders of this office were men such as Inigo Jones and Sir Christopher Wren. The latter, in my view, was one of the last who could really claim to be the embodiment of Architect, Engineer, and Town Planner. Wren's masterpiece, St Paul's, incorporates a triple dome each serving its own particular purpose. The outer dome is lead on timber to resist the weather, the intermediate conical brick structure supports the stone lantern and the ball and cross, while the inner brick dome is serving a purely decorative function. The previous and even larger St Paul's, a grander version of Salisbury (Wilts) Cathedral, had the highest spire of its time, but was so badly damaged in the Great Fire that Wren's attempts at renovation were unsuccessful and led to a serious collapse. Doubtless he benefited from the experience. The present structure indicated a return to a more conservative solution. St Paul's has shown signs of distress and the chain which resists the dome's thrust has required strengthening and replacement. After 300 years small settlements continue to occur and the building has now been monitored for over fifty years since the major renovations (1925-30) with precise levelling to an accuracy of three hundredths of a millimetre, with linear checks to a tenth of this accuracy and continuous records of subsoil water levels. It is a moving experience to go down into the crypt of St Paul's and study the model of the original spired church to see the massiveness of the present columns and to take note of Wren's epitaph 'Si monumentum requiris circumspice'.

The Rebellion of 1715 in Britain clearly illustrated the need for better communications in the North; and the Army, which still carried out this type of work in peacetime, set to under that fine Engineer, General George Wade. In the next thirty years, he planned and constructed some 260 miles of the 1 100 miles of military roads eventually constructed in Scotland and built some 30 bridges. As slavery was now a thing of the past in Britain, he paid his labour — 1*s.* a day for sergeants and artificers; 8*d.* for corporals and drummers, and 6*d.* for privates. The 30 bridges cost a total of £7 183 and the roads £16 000 (or £67 per mile). The couplet was coined by Caulfield:

> If you'd seen these roads before they were made
> You'd lift up your hands and bless General Wade.

Good roads are a two-edged sword and Bonnie Prince Charlie made good use of Wade's roads in midwinter 1745-6 in advancing right through Scotland to Derby before lack of local support convinced him that discretion was the better part of valour. Wade and his army were cut off by snow in Newcastle and even the invocation of the fourth verse to the then British National Anthem which ran as follows:

> God grant that Marshall Wade
> May by thy mighty aid
> Victory bring
> May he sedition hush
> and like a torrent rush
> Rebellious Scots to crush
> God save the King

proved to be no substitute for a full road network. The '45 did lead to the construction of three times as many further military roads in the following half century and provided much of the motivation for engineering training and skills in Scotland. Whether Robert Burns had been travelling on Wade's roads or others is not recorded, but he did have this to say about 1780:

I'm now arrived — thanks to the gods!
Thro' pathways rough and muddy,
A certain sign that makin' roads
Is no this people's study.

Engineering was developing fastest in continental Europe in the eighteenth century, notably in France, with the establishment of the Ecoles des Ponts et Chaussées in 1747; in Germany at Karlsruhe, and in Holland where the problems of sea defences and drainage were paramount.

The canal as a means of economical transportation sparked developments in Britain. It led to the associated canal aqueducts, canal tunnels, and locks of Brindley and Telford and to the development of that marvel of brawn and muscle in the muck-shifting field, the navvy who worked on the navigations.

Economic pressures and the competition of free enterprise became paramount; the railway rapidly overtook the canal and there was no longer time for the tried and trusted system of training based solely on apprenticeship and experience. Experience had to be distilled and the initial dose of engineering education in theory and principles was conceived. The pooling of practical observation and knowledge led first to the foundation of the Smeatonian Society of Engineers, and independently, thereafter, to the Institution of Civil Engineers in 1818, with Thomas Telford as its first President. The adjective 'civil' was chosen about this time to distinguish them from military engineers, both branches having previously co-existed simply as engineers prior to this.

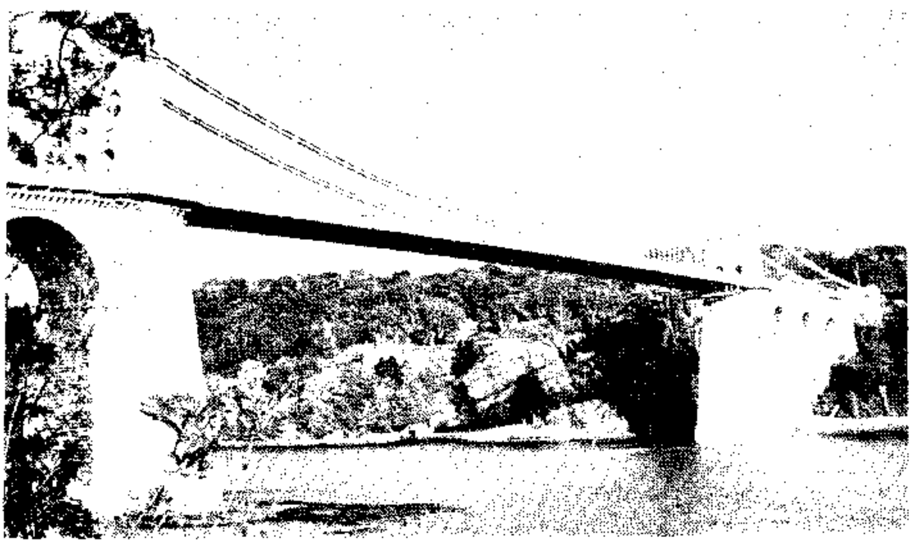

Figure 1: TELFORD'S MENAI SUSPENSION BRIDGE

Figure 1 illustrates Thomas Telford's suspension bridge across the Menai Straits in Wales. This was an unprecedented and remarkable achievement for its time (1820), spanning 168m and permitting the passage beneath it of tall men-of-war, an admiralty requirement. Telford assembled his suspension chains across a nearby valley as a preliminary check on their adequacy lest on erection on site over the water he might lose them due to a failure. A pragmatic and eminently logical engineering approach to a problem.

Figure 2 illustrates the Britannia Tubular Bridge constructed across the same Straits in 1825 by Robert Stephenson. Understandably his railway bridge had to be constructed on the next best site and here the waterway was 300m in width but a rock in mid-channel, known as Britannia Rock, enabled a solution using two main spans of 150m each to be adopted. The magnitude of the bridge can be appreciated by noting that the height of the main towers at 70m approximates to that of Salisbury's highest buildings. Stephenson proposed an arch solution initially but this was rejected by the Admiralty who had previously rejected a similar initial proposal by Telford. Stephenson designed and built a one-sixth scale model to satisfy himself as to his proposals before adopting the tubular box girder solution; even then he made provision for the use of ancilliary suspension cables from the towers as can be clearly seen in the figure. Recently the Britannia Bridge was damaged by a fire involving wooden railway sleepers and it is ironic that the solution adopted to recommission it has been the provision of arch supporting structures below the box girders.

Figure 2: STEPHENSON'S BRITANNIA BRIDGE

Figure 3 shows the Dome of the Rock Mosque in Jerusalem, a reminder that construction of considerable intricacy had been carried out by the Moslems at an even earlier date. Spare little thought for the present golden dome; it is mere anodized aluminium less than a decade old, but concentrate on the model of the Dome of the Chain on the lower right which was built as a model prior to construction of the Mosque itself, and appreciate the usefulness of models of structures in their conception and development.

The earliest recorded teaching of engineering at a university in Britain was that of Professor Robison in Edinburgh, one of whose most famous students was John Rennie, who replaced London Bridge, after it was finally

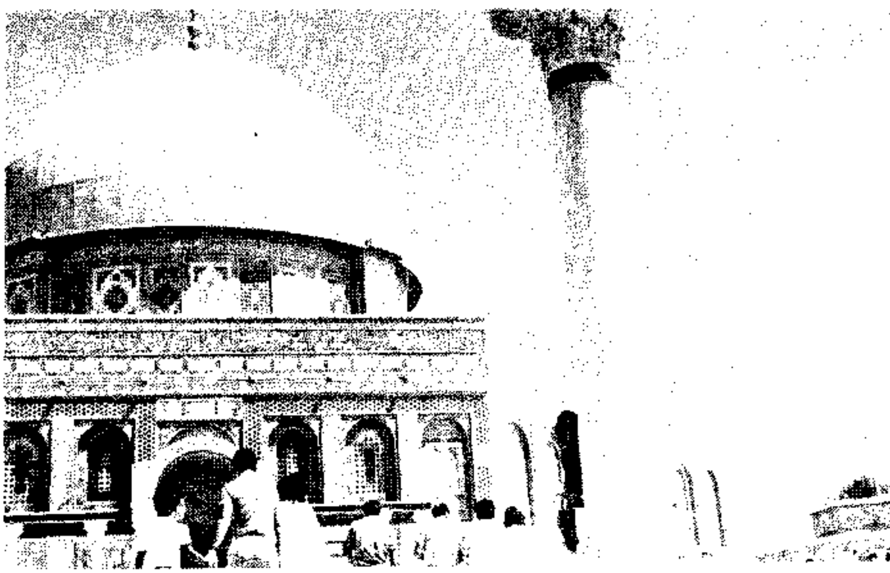

Figure 3: THE DOMES OF THE ROCK AND THE CHAIN, JERUSALEM

permitted to fall down, with the most elegant arch structure which has only recently been dismantled and re-erected in America.

University College London, introduced courses in engineering in 1827, but the Inaugural Professor failed to take up his appointment. Thus, credit for the first full University School of Engineering in the English-speaking world goes to King's College, London in 1838. The Massachussetts Institute of Technology opened in 1865; Cambridge appointed its first engineering professor in 1875. The University of Cape Town's first Professor of Civil Engineering took his seat on their Senate in 1903. Oxford only followed suit as recently as 1909 and even Professor Southwell stated in 1930 that it would be rash to assume that the respectability of engineering as a University Faculty was yet beyond dispute.

The Institution of Civil Engineers has maintained its involvement with civil-engineering education throughout. The contribution they have made has stood the test of time and flourished in the English-speaking world save in America, where, I am convinced, they are the poorer for it. While the progressive division of the profession into constituent institutions — mechanical, electrical, and many others — was understandable, it can only be regretted. This division of influence and purpose was confined to Britain and South Africa and I can only express my delight that this is not the case in Rhodesia, nor in the other countries of the Commonwealth.

The magic of the appeal of civil engineering is in the catholic nature of the civil engineer's involvement in the requirements of society. Few civil engineering projects do not require that breadth of knowledge — defined in the Charter of the Institution of Civil Engineers (London) as 'being the art of directing the great sources of power in Nature for the use and convenience of Man' — or the possession of the attributes noted on the coat of arms, 'Science and Ingenuity'. Examination of the 1828 Charter shows that it goes on to define the scope of the profession in detail

> as a means of production and of traffic in States both for External and Internal trade as applied in the construction of roads, bridges aqueducts, canals, river navigation and docks for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and lighthouses and in the art of navigation by artificial power for the purposes of commerce and in the construction and adaptation of machinery and in the drainage of cities and towns.

While some of you may gasp, we in the profession can only say that, while some of these topics have been delegated, the increase in scope has been vast and a concise definition is no longer possible. The Civil Engineer must set his sights on an expanding universe. He cannot afford to enter a restrictive field because that will result in a particular identity, and thus loss of the civil engineering identity, which depends on leadership and breadth of vision. When I joined the University, I was asked to consider a name for my department other than 'Civil Engineering' to indicate the unity and commonness of purpose which we certainly intend to foster and develop here in the Faculty of Engineering in Rhodesia. I gave the matter earnest consideration and was faced with 'civil' engineering or a string of ten adjectives to only one of which I could dare profess. I believe that the decision to retain the original title of 'Civil Engineering' was the correct one, and that any other title would be either divisive or pretentious.

The growth of cities in the eighteenth and nineteenth centuries led to ever increasing problems in the provision of services particularly the provision of water and the disposal of sewage. I trust you will not think me too jingoistic if I continue to refer to London and Britain on a few further occasions before coming closer to home. In 1815 the cesspools of London could be connected to the sewers; there followed serious cholera epidemics between 1831 and 1854 with up to 20 000 deaths in the worst years. The sewers discharged all along the Thames and the 'big stink' of 1858 is said to have been so bad that the committee rooms of Parliament were untenable. This probably explains the speed with which the amending legislation was passed to enable the main-drainage system (still functioning) to be financed. However, there was a resistance to the proposals from many quarters who showed a strong resentment at London's good sewage being thrown into the sea and not being retained as manure for their benefit. I think this illustrates that we are not necessarily at the bottom of the trough today but may well be climbing back to conditions of sanity and reasonableness in the pollution field.

The railways reigned supreme for the remainder of the nineteenth century; bridges, and viaducts, cuttings, embankments and tunnels proliferated, and theory and engineering materials developed in an attempt to keep pace with the natural challenges presented by topography. The bridge of the century was certainly the Forth Bridge (Fig. 4), with its three massive cantilever double frames in tubular riveted steel. Sir Benjamin Baker's

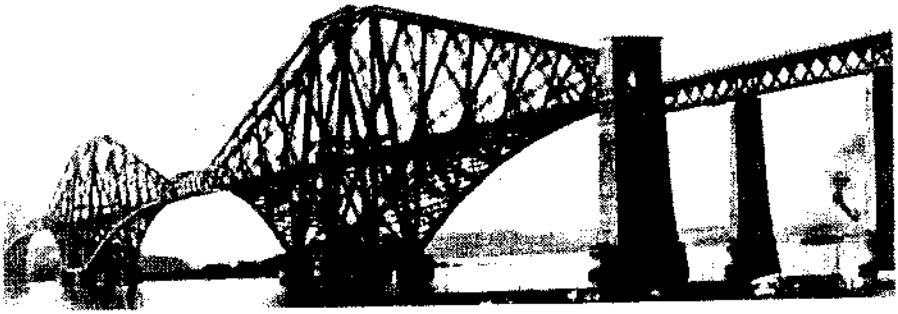

Figure 4: THE FORTH RAILWAY BRIDGE *(Benjamin Baker)*

structural concept and Sir William Arrol's triumph of construction, a technique you will not see repeated, as it represents a labour-intensive system which would be just as uneconomic today as rebuilding Hadrians Wall, using stone masons.

That the Firth of Forth has been bridged once more we all appreciate (Fig 5). The new suspension structure leaps the waters with grace and power

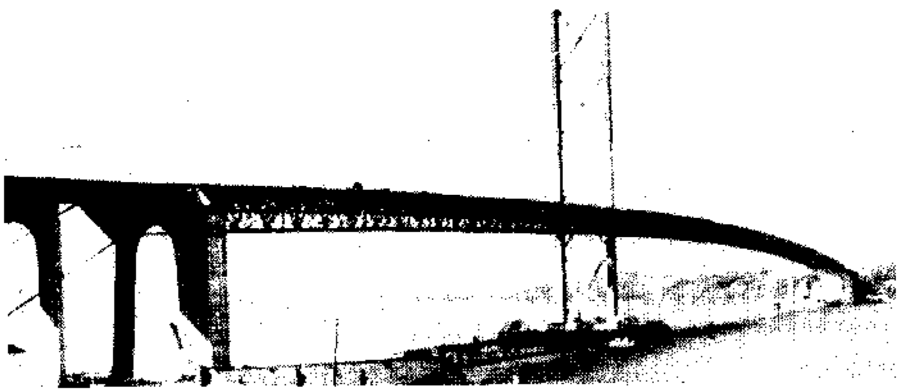

Figure 5: THE FORTH ROAD (SUSPENSION BRIDGE)

and particular lightness in the towers — a by-product of a recent and more logical approach to combined compression and bending stress analysis.

The estimate for rebuilding Hadrians Wall in 1850 was £1,1 million in the currency of that time, and the contractor would have used the same skills and methods as the Romans. A well-known international contractor carried out an estimate in 1974 and would have quoted £55 million! While this may simply represent a steady rate of inflation of only 3,2 per cent per annum, the important point to note is that the method previously used is now completely unthinkable and the present day 'economic' alternative is a reinforced concrete wall, with a cantilevered walkway, a considerable proportion of the cost being in shuttering rather than steel or concrete.

The civil engineering heritage of Rhodesia has always outstripped the imaginings of visitors to the country and it is right and proper that we should review this briefly. There is much that we can be proud of and yet there is still boundless motivation in what obviously requires to be done. The development of the railway system was rapidly carried out and it was a good engineering solution in which the narrow-gauge lines pointed the way and were progressively lifted and relaid in more remote areas once the current gauge could be provided. While George Pauling's methods and manners might have to be modified to make him socially acceptable today, he certainly achieved his end. His feats of converting the 60 miles from Beira to Bamboo Creek from 2ft. to 3ft.6in. gauge, between Thursday morning and Sunday night, or of constructing 400 miles of the line through Bechuanaland to Bulawayo in under 400 days are still outstanding. It must be admitted that standards were different then. There were a considerable number of derailments and the track structure was lighter; stone ballasting only followed later, and major river crossings were laid on the wide sand beds of rivers until the bridges were built. On the Shashi, for instance, the approach gradients were 1 in 25, and the locomotive threw up a bow wave when the river was flowing unless, of course, the trucks became buoyant or the track was washed away and caused the derailments which occurred from time to time.

The road network developed more slowly. The first motor vehicles reached Bulawayo in 1902 and Salisbury in 1905-6, but it was not until Christmas 1909 that the first car journey between these two centres was completed and that took six and a half days! I must admit to finding my motivation to become a civil engineer strongly influenced by childhood memories of Christmas trips on this same route and early involvement with tyre chains and delays at almost every low-level bridge on the way in one year or another. The strip road was the equivalent of the narrow gauge railway and I am pleased to see some portions preserved as national monuments; perhaps we should treat some of our early low-level bridges in the same way.

Rhodesia has been fortunate in being a land in which people have had confidence and where they have been prepared to match their thoughts by action. Typical of this has been the action of one of our Faculty's major benefactors, The Beit Trust, whose contributions have been very significant in the civil engineering field. Communications and transportation were the areas of obvious need to which they first turned their attention by making loans to the Railways and by donating large sums (£200 000) for the construction of branch lines such as the Gwelo-Fort Victoria line.

The major bridges which were paid for by the Beit Trust were the Alfred Beit Bridge across the Limpopo; the Birchenough Bridge across the Sabi; the Otto Beit Bridge across the Zambezi; and the Kafue and Luangwa Bridges in what is now Zambia. In addition to these they contributed the cost of some 90 low-level bridges in Rhodesia, a total, in terms of cost at the time of construction of £1 000 000.

With the advent of civil aviation the Trust contributed £50 000 for the construction of airfields and paid half the capital required to establish RANA (Rhodesia and Nyasaland Airways).

During the last forty years, the Trust has turned its attention to educational and hospital buildings. The provision of engineering scholarships commenced in 1931 and continued annually from then until the close of the

1950s, two junior scholarships for first degree purposes and one senior scholarship for postgraduation training purposes were awarded. Two Fellowships for postgraduate study and research together with other bursaries for first degrees continue to be awarded and are open to students wishing to study in any chose discipline. No fewer than three of the current academic staff of our Faculty have been Beit Scholars or Fellows, and within the University and Rhodesia there are many others who have so benefited.

In engineering on a wider scale we can mention men such as Dr J. R. Rydzewski and Dr H. Olivier in the field of irrigation engineering, and Professor E. Hoek in rock mechanics.

We have in Rhodesia a number of exceptionally fine examples of the bridge. The Victoria Falls Arch (Fig. 6), the Chirundu Suspension Bridge,

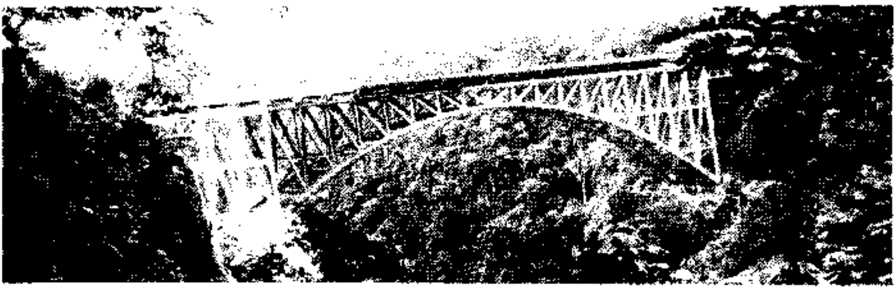

Figure 6: THE VICTORIA FALLS ARCH BRIDGE
(Painting Maintenance Work in Progress)

and the Birchenough Bridge high tensile steel arch were all, at the time of their construction, examples of the state of the art which could hold pride of place on a world-wide scale. They continue to be capable of serving their purpose and, although increasing wheel loads will call for strengthening, this demonstrates that the original designs were not too conservative. The bridge has developed in Rhodesia within the limits set by the materials available, the topography, and the economic constraints. Composite construction in steel and concrete, and open spandrel concrete arch, the precast prestressed concrete beam, the void formed slab, and the concrete box girder, to mention a few types of bridge, have been developed for local application to give us

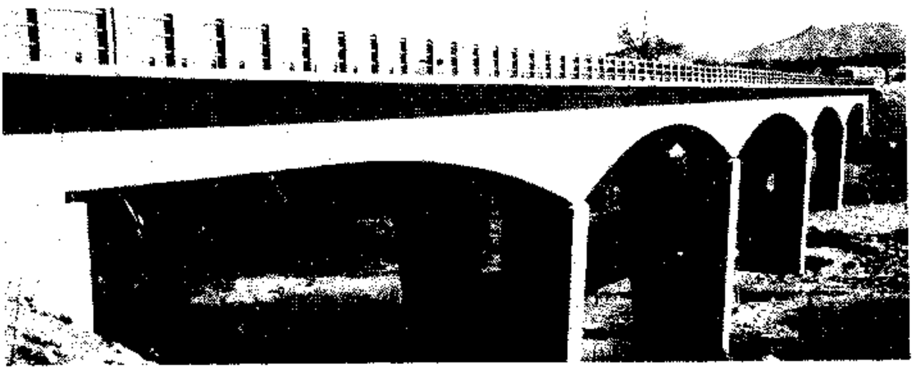

Figure 7: LUNDI RIVER BRIDGE

the efficient graceful structures we take for granted today. Figure 7 shows the Lundi River Bridge on the Fort Victoria-Mashaba road which is a typical example of such a structure.

We are reminded of some of the trials and tribulations of crossing rivers in the early days when, for instance, one of the solutions offered to solve the transport crisis which followed the decimation of the trek ox by rinderpest, was the camel. Now I do not believe that a civil engineer was guilty of serving on the committee which designed the camel because Colonel Flint soon discovered that if you wished to keep a swimming camel's head above water, it was essential to apply an aft to fore moment by swimming behind and pulling down on the camel's tail! A civil engineer would surely have insisted on a reasonable longitudinal metacentric radius.

The development of water resources is another area in which Rhodesia has a proud record. There has always been a consciousness of the need for control, and of the impingement of that control on other natural resources. The rapid growth of population at the present time is focusing attention on the need for a realistic approach to water development, and particular projects must now be considered in the context of the catchment as a whole. The progressive granting of water rights and the *ad hoc* construction of dams is only in the national interest, to the extent that the developments mooted are intuitively correct. This position requires to be reviewed and replaced by more logical planning, which is in the overall national interest. Whether existing water rights granted in perpetuity can remain as granted, must be carefully examined now rather than at the turn of the century when the provision of alternative solutions will be circumscribed by increasing pressure on resources or even completely compromised. There is a need to plan our non-consumptive use of water to enable it to be re-used in such a way that unavoidable contamination is kept acceptably low for the secondary and tertiary users with consumptive use following thereafter wherever possible.

The marvellous and equable climate of this land enables us to construct low-cost housing at lower costs than in many other countries but do we necessarily make the best engineering decisions in this respect? Our breadth of vision must be such as to consider the medium and long-term consequences of our decisions. We may be required to construct as much housing as we have today in the next 15 or 20 years, merely to mark time with respect to the proportion of the population housed, but the houses we build in that period must have a longer life free of major maintenance and obsolescence if we are not to find ourselves building our society as a cantilever which will eventually do one of two things — overbalance into the abyss and fall as a whole, or fail at the root with the same end result.

Housing requires urban and regional planning; transport systems must evolve or we will strangle ourselves. No one will dispute that there are many advantages of decentralization and even in untrammelled Rhodesia, this is an obvious solution. Nevertheless, the natural response of established centres is to resist it. As the standard of living continues to increase, even a relatively static population in terms of total numbers will generate exponential increases in traffic and vehicle numbers. The challenge for Rhodesia today is to have the courage to provide the infrastructure in advance to woo the citizens away from inefficient transport to the rapid-transit mass transportation systems of the future. That this requires changes in population distribution and density is regrettably inevitable. Our problem is to make this transition a desirable goal and not an irksome imposition of authoritarian decree. We see the civil engineer as one of the prime professionals in this sphere, and I am pleased to note our involvement with the postgraduate course in urban and regional planning recently established in the University, to which members of the staff of my department are contributing. Figure 8 shows a pedestrian Mall in Vallingby, Sweden photographed in 1956. All vehicle traffic is excluded and access is by underground road and rail. Hopefully, the shape of things to come in First Street, Salisbury!

Figure 8: PEDESTRIAN MALL, VALLINGBY, SWEDEN

All structures depend on a satisfactory foundation and, although Rhodesia has less than her fair share of problems in this field, nevertheless we have our volumetrically active clays and our loose leached profiles which cause distress by shrinking, swelling, or collapsing. The foundation engineer can solve these problems for an outlay of some 10 per cent of project cost but the highway engineer has to contend with the problem and defuse the situation by managing nature, keeping moisture contents constant as far as possible, or by collapsing unstable structures by subjecting the profile to a very much higher intensity of compaction and vibration than that to which it will ever be subjected in its service life. Roads are constructed on local materials largely with local materials to suit local traffic and to perform for many years in the local environment.

This has called for the adaptation of methods established elsewhere to our particular environment, and has resulted in our acquiring experience, and often having to learn from varying degrees of failure. We have, however, established how certain methods and materials do perform, and more important, why they failed to conform here, and how to overcome their imperfections. Dolerite gravels decomposed with remarkable alacrity until lime or cement stabilization was found to inhibit the process; full-width road surfacing promoted hydrogenesis, the build-up of moisture in the base, and failures occurred just when the wet season appeared safely past. There were a few pleasant surprises. Our Kalahari sands were not the ogres with respect to either roadworks nor heavy structural foundations that they had been made out to be, and simply cannot compare with the reputedly similar, but highly leached, materials of the Zambian Copperbelt where, for many metres, soil has such an open texture that if we could only keep the water out of it, it would float quite readily.

All civil engineering is highly dependent on the materials available in the locality of the project, and materials such as timber, steel, cement, sand, rock, bricks and blocks develop their own particular local characteristics. The time is fast approaching when it will be essential to have our own research institute investigate and develop applications for the engineering use of such materials. A construction industry research institute has so much to commend it. The dividends should soon reach the economy and should ensure the best return on this research investment. It would not preclude contact with neighbouring institutes and overseas research centres. We would submit that it would make existing contacts even more positive, meaningful and useful than they are at present. The start must, of necessity, be small but the country cannot afford not to start. The creation of such an institute should provide that trinity we require for complete interaction and interchange of profession and industry, University, and applied research. It would provide the full motivation to retain our engineering manpower and permit full development of professional talent.

A typical example of such involvement is Professor Alec Skempton of Imperial College, who came back to teaching and research from the British Building Research Establishment, bringing with him that blend of practice and theory that was to lead to the establishment of what is probably still the leading school of thought in soil mechanics, and he still continues active consulting practice. May I take this opportunity of commending his publications to you all whether student, professional colleagues, or laymen. The written word is there so clear, so concise, and so logical, that it cannot fail to inspire.

This year marks the fiftieth anniversary of the publication of *Erdbaumechanik* by Karl Terzaghi whose pre-eminence as a geotechnologist was the catalyst leading to the formation of the International Society for Soil Mechanics and Foundation Engineering in 1936. The forceful and continued development of this branch of engineering has been dependent on the logical and single-minded approach of the practitioners such as Casagrande and Skempton. The very essence of all the considerable advances which have been made has been to relate theory to observation in practice: to recreate in the laboratory the stress conditions to which the soil sample was previously subjected in the field, to relate stress paths in laboratory to those developing in the geological time-scale, and thus to establish the best possible parameters to feed back into the theoretical analysis. That the analysis is only as good as the applicability of the theory to the actual problem is self-evident, but, with a mixture of scientific integrity and engineering intuition and ingenuity, we are able to use the developing monitoring techniques of stress and strain measurements on full-scale projects and couple these to computerized analysis such as the finite element method, and so obtain results which develop our feel for the actual behaviour of, say, a deep tied-back basement excavation or a large earth dam or the ability to decide with confidence whether a large structure can be founded on spread footings or must be supported by a piled foundation.

Each problem is unique to its particular site. Nature presents the upper layer of the earth's crust to us to explore, to learn, to love it for the beauty of its consistency in some places, but more often for the capriciousness and variability of its engineering imperfections or shortcomings. The greater the bond of love between engineer and the environment, the more stable and secure the structure he sets out to create.

Figure 9 shows the redevelopment of a central Johannesburg site using earth anchors for tie-backs. The previously existing basement wall appears at the top of the excavation in the centre, cast *in situ* tied-back piles on the right protect the site access ramp and the Cathedral structure beyond that. The heavy piling equipment is to place piles below the base to bedrock at a further 10 to 20m depth. Johannesburg has had the advantage of having had its basement excavations effectively dewatered by the mining industry.

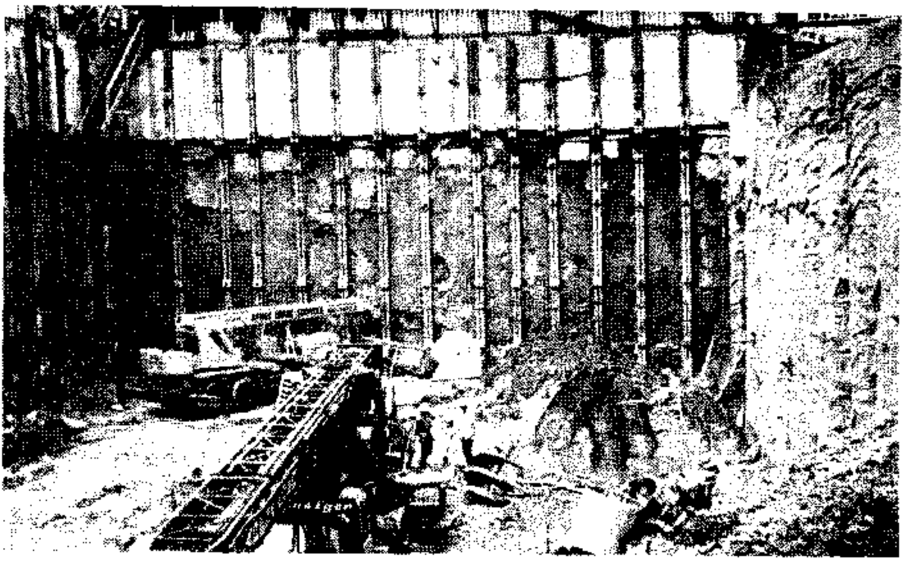

Figure 9: TIED-BACK BASEMENT CONSTRUCTION, JOHANNESBURG

In order to investigate these sites, holes are drilled with such piling machines and engineers and geologists descend these for visual inspection and sampling of the soil *in situ*. Figure 10 illustrates a typical trial hole. One need scarcely add that the day seems all that much more pleasant when one emerges from the last hole and sheds one's protective clothing and safety harness.

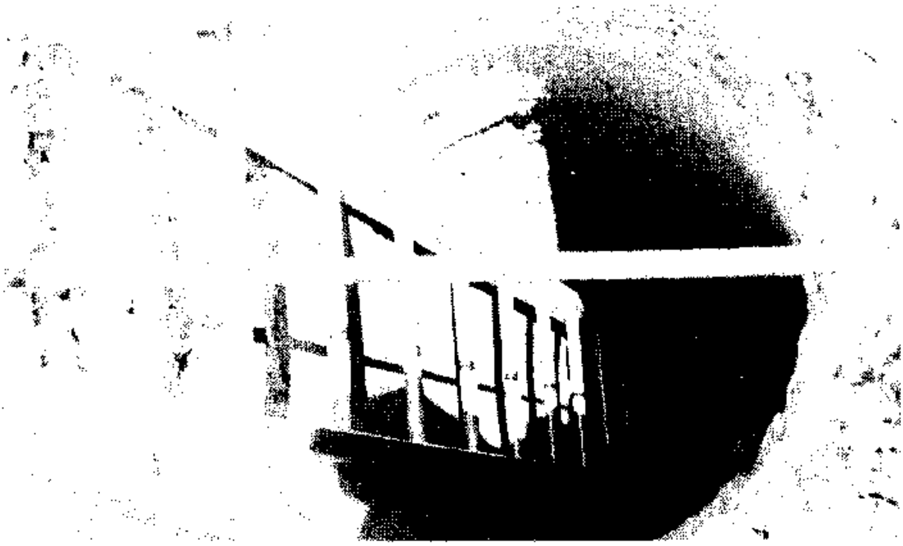

Figure 10: AUGER-BORED TRIAL HOLE IN SALISBURY PHYLLITE

The foundation engineer is often called upon to investigate a site years in advance of its development. When the site is opened up it invariably seems to occur in a much wetter season than that during which the initial predictions were made. The engineer then has agonizing reappraisals regarding the system he has recommended and good practice dictates that he should satisfy himself before the project proceeds.

Figure 11 illustrates a typical situation in a Salisbury basement excavation. Happily, persistence enabled the contractor to place his concrete blinding and trim the excavation, and Figure 12 shows a much improved situation with a contact between the metamorphosed mudstones and volcanics at the bottom of the foundation excavations. Perhaps it is understandable that only the final successful erection of such a structure (Fig. 13) permits the engineer to relax and enjoy the roof-wetting ceremony.

Figure 14 shows the first of the large silos constructed for the bulk handling of maize in Rhodesia. These structures are extremely sensitive to settlements and their design and excavation presented a challenge to all concerned in Rhodesia. The success of the system resulted in further depots being constructed on a variety of sites and the foundations used have proved entirely satisfactory while the thin-walled large diameter free-standing bin solution has, in addition, been found to be a continuing economic success.

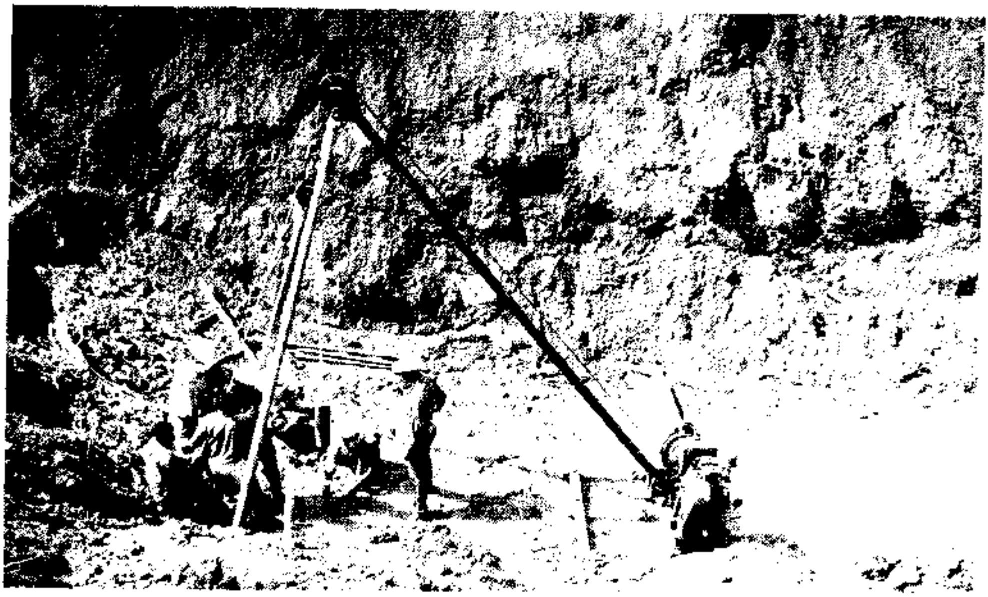

Figure 11: PENETROMETER TESTING TO CONFIRM BEARING CAPACITY PREDICTIONS, MONOMATAPA HOTEL

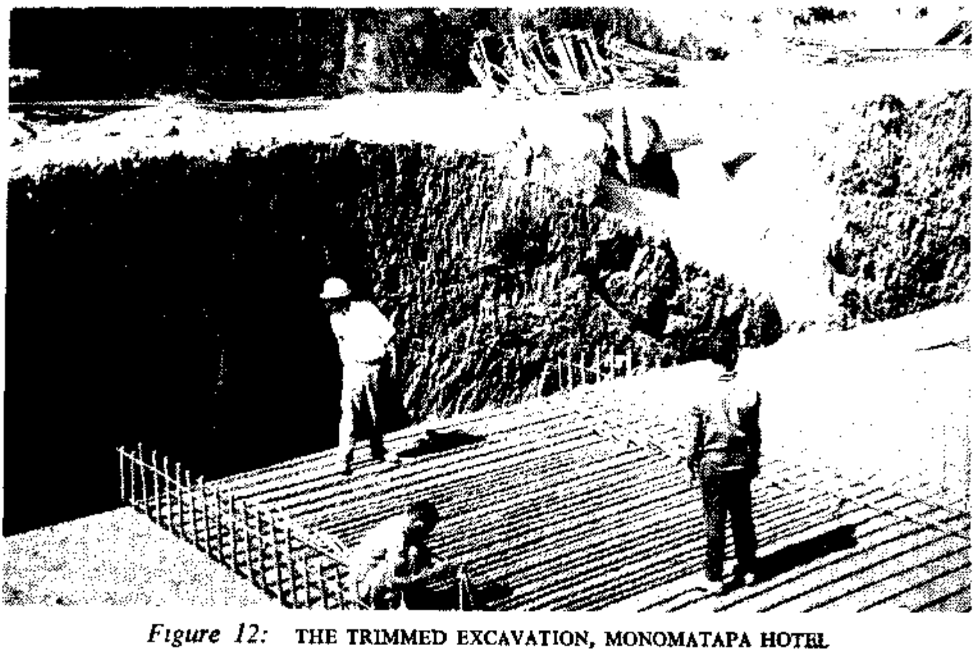

Figure 12: THE TRIMMED EXCAVATION, MONOMATAPA HOTEL

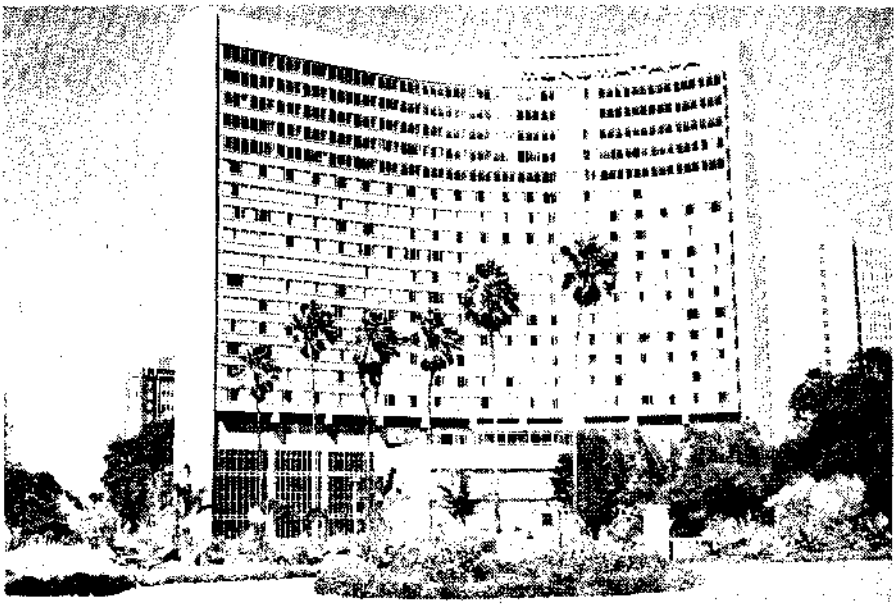

Figure 13: THE COMPLETED MONOMATAPA HOTEL

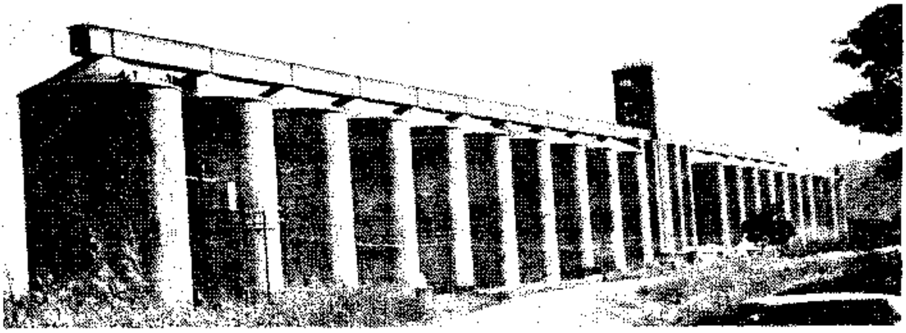

Figure 14: GRAIN SILOS 80 000 TON CAPACITY, CONCESSION, RHODESIA

Probably the dam presents the designer with the essence of this challenge. Here one is concerned with construction on a site of obvious imperfection, which leads to the development of the river valley. Not only is one concerned, as André Coyne stated, 'with the foundation on the base and flanks, but with the basin as a whole. It is there that the greatest risks lie and where nine out of ten failures occur. There are always faults of shape of mechanical resistance, of water tightness, or, in more general terms, of resistance to water.' Possibly the most dramatic illustration of this was the Vajont disaster in Italy in 1963, where rising waters of the lake caused a massive slip 200-300 million cubic metres (equivalent to the volume of water in Lake McIlwaine) of rock and soil which displaced water in a veritable tidal wave which overtopped the double curvature 265m high arch dam (still the highest

Figure 15: A COMPRESSOR DWARFED BY A SPILLWAY EXCAVATION IN ROCK: LESAPI DAM

in the world) by 150-250 metres. Within the narrow confines of the mountain valley, this wave dealt a devastating blow to the village of Longarone, killing 2 500. Sadly the likelihood of the slip was foreseen and it was being monitored. The cause of the disaster was the inability to visualize the mechanics of the failure, the enormity of the ground movement which would develop and the speed at which the mass would drop into the lake.

The magnitude of construction on dam works is vast and the design of structures dealing with water involves loadings which are finite and which do eventuate. Figure 15 indicates the scale of the work showing a compressor dwarfed by granite boulder and the sheer depth of cut. The solid rock incidentally well illustrates structural variations all of which have to be predicted, investigated, observed and interpreted, and finally, dealt with appropriately.

Rhodesia has many dams of which it can be justly proud. Kariba Dam (Fig. 16) springs to mind. No apology is made for showing it under construction rather than completed. The object is to remind you that the engineering took place before and during construction and further that the defects discovered in the rock of the southern abutment involved a very considerable extension to the contract by the provision of four large subterranean buttresses to transfer the arch thrust to sounder material at depth.

It is particularly pleasing to note that Rhodesian engineers have come of age and now design and build their own, not inconsiderable, arch dams.

Figure 16: KARIBA DAM DURING CONSTRUCTION 1959

This development has flowed from their partial involvement with Kariba Dam and further involvement with Kyle Dam. Kyle Dam, Rhodesia's largest internal reservoir, overflowed for the first time in 1975 and I think you will agree that in Figure 17, it presents a pleasing and satisfying sight; truly a happy event and ultimately vindication for the hydrologists who, in typical Rhodesian manner, have taken advantage of nature by raising the top water

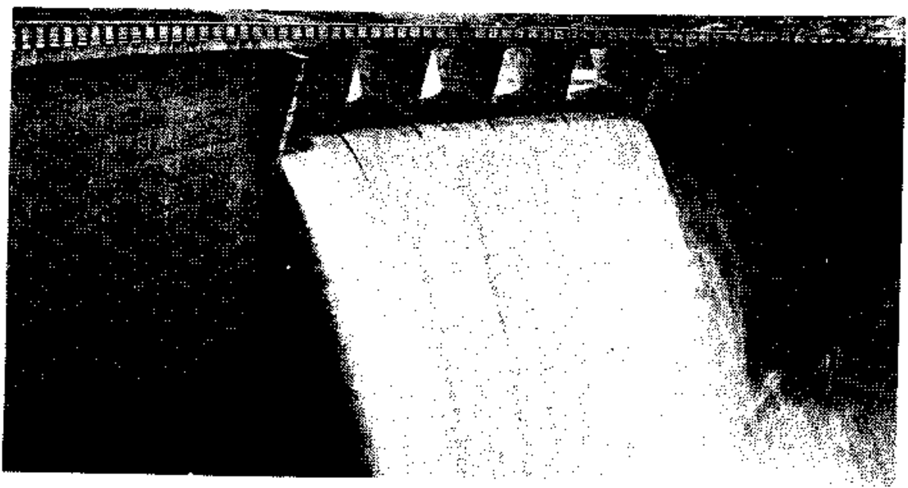

Figure 17: KYLE DAM SPILLING FOR THE FIRST TIME 1975: HYDROLOGISTS VINDICATED!

level by spillway gates and have impounded in the top metre a very considerable additional volume of water for the agricultural industry's benefit.

Nothing is static or absolute in civil engineering and this can be illustrated by many examples typical of which are the following extracts taken from

Professor Sir Charles Inglis's classic lecture on the aesthetics of civil engineering design. When discussing suspension bridges, he stated: 'Owing to their great diameter, the cables cannot be kinked by any localized live load and consequently no truss was required for stiffening the roadway'. The failure of the Tacoma Narrows suspension bridge gave the lie to this a little later when it developed dynamic instability and failed in resonance in gale force winds. It was significant too that in the same lecture, Sir Charles stated that 'the economic limit of span for a reinforced concrete arch is about 500 feet, the limit being imposed by the prohibitive cost of the moulds and falsework if this span is exceeded'.

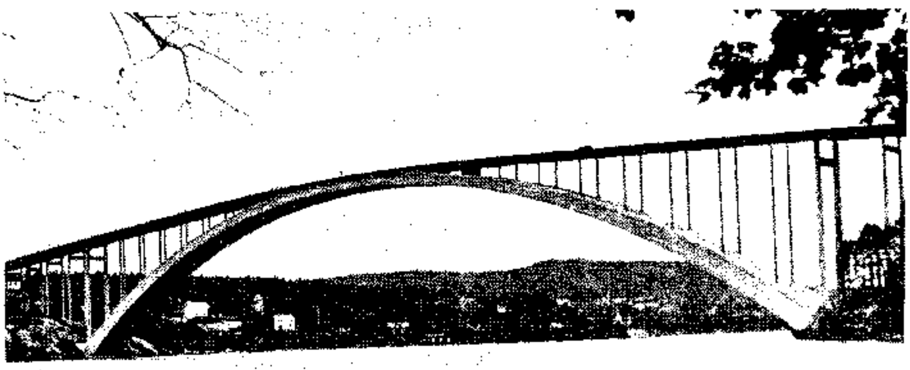

Figure 18: SANDO BRIDGE, GULF OF BOTHNIA, SWEDEN

It was not long before the Sando Bridge (265m span), a hollow box girder reinforced concrete arch, was completed despite the washing away of one set of falsework (Fig. 18). The reduction of dead load and the maximum utilization of materials, where the development of resistance to stress was most required, was the reason for the breakthrough. The individual roadway spans on the other part of the Sando Bridge are significant prestressed concrete continuous beam structures in themselves, spanning up to 70m. The Sando Bridge is a most pleasing example of engineering aesthetics — a factor in design work which we hope our graduates will keep in the forefront of their thoughts. It is certainly a bridge warranting a considerable pilgrimage to admire.

The dependence of civil engineering education on a knowledge of engineering practice makes it imperative that a fair proportion of the academic staff teaching engineering should have had recent or better still, continuing involvement in the profession in both the design and construction of projects. It is interesting to note that the Institution of Civil Engineers (London) currently desire that some members of teaching staff have recent design and others recent construction experience, for the purposes of degree recognition. It is important and gratifying that the University of Rhodesia is prepared to take a realistic view with respect to consulting practice by members of its staff. To run a civil engineering department without the benefit of a continuing involvement in active practice would be akin to attemping to teach medicine without a teaching hospital. The very real contact that a lecturer can give to his students by involving them in his work can create motivation and interest far earlier. The possibility of having students work on projects in which the solutions they offer can have real application, results in an atmosphere of real purpose so essential for true understanding and enthusiasm to develop.

The emphasis must always be on our own particular environment and to this end it is essential that we recruit senior staff who can bring these very ingredients of knowledge of local materials and of local methods of construction to our course. It is gratifying to report to you that recruitment of staff is following this particular specification closely and we hope to build a team comprised of a blend of practice here and overseas with teaching and research experience on a similarly widespread basis. This is the advantage of a new school of engineering and we cannot afford to miss this opportunity for cross-pollination of background, training and experience in practice and teaching.

The students must be equipped with a scientific background on which to base the fundamental engineering principles that we must teach them; this should go far to equipping them for the forty years of active professional life which lies ahead of them. The four-year degree course is followed by the period of training, currently a minimum of three years, before full professional status is reached. There is a very real need for close co-operation between the graduate, the employer, and the University in this training period. This is the equivalent of a medical housemanship and there is need on the graduate's part to accept that the real engineering challenge is to conceive, to create, and to crystallize the opportunities opening up before him. He may feel that the intellectual challenge of the training period is an anticlimax after an intensive academic course, but he must find the humility to recognize that it is this basic training which will enable him in the course of time to make better engineering judgments than his predecessors. Initially, however, he must come to terms with the environment and with men and machines before he will have full responsibility to give reign to his own new concepts and be permitted to commit other people's money. Likewise, the employer must be prepared to chart a meaningful programme to develop experience often in conflict with the most advantageous use of the new graduate within the organization as a whole. The most difficult aspect of the employer's responsibility is to be prepared to put the young graduate on work of sufficient challenge and importance that it will be possible for the young graduate to make a critical mistake. This is the challenge that the graduate requires and his response will invariably be immediate and more than adequate. The University must involve itself with both the graduate and the employer since we need the feedback to see how best we can contribute to the needs of both graduate and employer. The graduate may need research facilities at some stage, preferably after he has completed his full training period, and has achieved professional status and found out his real engineering bent. The employer doubtless needs mid-career refresher courses in new design techniques, research findings must be disseminated to him by forums, and seminars, all preferably in association with the Institution of Engineers. Similarly, the employer must feed back data on management techniques, design computations, construction methods, and field observations. His comments on the shortcomings of our graduates in relation to his requirements must be given objective study and action taken to correct and improve the university curriculum as appropriate. Each group must interact to keep up to date with the advance of knowledge and be ready to profit from their experience particularly from any failures or shortcomings.

The recently published report of the Chilver Committee on 'The Education and Training of Civil Engineers' in the United Kingdom gives considerable food for thought. The British Engineering degree is normally of three years duration from A-level entry. This does not compare favourably with any of the E.E.C. countries where the university course is of at least five years duration, except in Denmark and Germany where some courses are of three and a half years duration only. The continental countries have only minimal statutory periods of practical training. Denmark, which requires six months for those taking the three and a half to four-year academic university course and *nil* for those taking the five-year technical university course has the longest period! There is no statutory period of professional experience required in any country on the continent. Only Eire follows U.K. practice but they have a five-year degree course! It appears that the Institution of Civil Engineers thus has before it recommendations which are that they should fail to grasp the nettle and should persist with the three-year university degree course and follow this with an even longer period of training and experience requiring three years training, one year's approved experience and then, after satisfying a professional interview panel, a further three years of practical experience, with definable responsibility.

Finally, there is to be an assessment of professional competence before admission to full professional status making a total of ten years from A-level. The load thrown on supervising engineers for training has always been a heavy one, but to effectively double this training period without increasing the formal university course length, appears both expensive and unrealistic. The most worrying aspect however is the inference that a fair proportion of engineering graduates will not be permitted to follow through at will and are to be diverted into technician posts and not become professional engineers at all! Surely this selection process should be made before the graduation stage and by this I do not imply a selection on the basis of a points count at A-level as a sole entry criterion to a university course. We already have a clear indication in Rhodesia that motivation matters most and entry to an engineering degree course from a successfully completed technician diploma course appears to be a means of clearly demonstrating motivation. This is a means of entry which must be preserved.

The British Universities Central Council on Admissions have published figures showing that of all university students some 14,7 per cent elected to study engineering in 1969, but that this percentage was dropping steadily to 11,26 per cent in 1973. Civil Engineering represented 3,13 per cent of total intakes in 1969 and fell to 2,90 per cent in 1973, remaining a relatively steady demand as all other major engineering disciplines showed larger drops in intake rates in the order of four times the reduction shown by civil engineering. Even in the sophisticated economy of Britain today, civil engineering had regained the narrow lead it had lost for a short while to electrical engineering by 1972.

The dilemma appears to have two possible solutions for Britain; either they are over-producing engineers for want of a better process of selection and production of graduates, or there is insufficient engineering work for the graduates to engage in. One feels reasonably confident that the latter is the major reason and that the lack of sufficient opportunity relates largely to the economic constraints imposed on society by society itself, and not in any way from a reduction in the demand for engineering services. This is a factor of which we in Rhodesia must be constantly aware. We are embarking on a long-term project to provide the men and women who will meet this country's engineering needs. Each and every one of us requires the tolerance, the vision and the plain common sense to make the best use of our resources of manpower, materials and motivation to make this land of ours truly great and to continue to hold it forth as an example of the well-engineered society which it has always been. We must not permit political restraints to deflect us from our purpose which is to improve the services to, and standard of living of, all. Rhodesia may never, in our lifetime, assume a roll of dominance in any particular technology, but it must continue to surprise the visitor with the excellence of its development and its ability to innovate in relation to its size, period of development and resources.

The future will see developments at a rate which will prove any forecasts of mine invalid but I feel it is of interest to note some of the areas in which the challenge of civil engineering is being taken up today.

The construction of drilling platforms and storage tanks for off-shore oil drilling is one area in which the scale of the structures and of the forces to which they are subjected is opening up a whole new world to the Civil Engineer, where he is engaged with larger structures than heretofore. The forces which are imposed by deep-seated wave action in off-shore waters are immense and out of all proportion to previous experience. In the foundation field the ocean floor is opening up a vast new area to which the foundation engineer must apply himself. Should he continue with the off-shore piling techniques developed in the Gulf of Mexico, with steel piles ten times larger than lifesize and lengths in terms of hundreds of metres and not tens of metres as on land? Should he plump for a flexible membrane pumped full of sea-bed sands which will mould itself to the sea floor? Will his concrete caisson structure settle uniformly through over 100m of water onto a satisfactorily uniform seabed without distress and danger? The area of base contact may approach one hectare — is there any means at his disposal to level the sea-bed site and ensure uniform bearing resistance?

Hydro-electric power potential must be developed to the full; pumped storage schemes to meet day-time peaks in electrical demands will become more common. The nuclear power station will make its presence felt increasingly with the consumption of the present reserves of oil and coal. Can the civil engineer provide the answers to the problems which will follow successful reactor shielding and containment? Could the proposal to build a complete floating nuclear power station come to fruition? If so, will the structure ride out storms at sea? And if not, what breakwater requirements will ensure its safety close off shore? Certainly, cooling water requirements will be satisfied by siting such stations on the coasts and could lead to a minimum of pollution from waste heat if they floated.

Water transportation by canal is about to see a revival and countries such as Russia and Canada have vast scope in this respect. The impoundment of water by rockfill and earth rock fill dams proceeds apace. Some such dams are now over 300m in height and are being constructed with a section which is arched in the upstream direction to contribute to the stability by the compressive thrust thus developed on the earth core. Bays and channels open to the sea are being dammed for fresh water impoundment; a second such scheme is currently under way between one of the Hong Kong Islands and the mainland and follows the damming of a bay on another island some years ago.

Towers and structures reach ever higher; larger domes, shells and arches are being built, but behind all the successes is the background of the developing art and science of engineering, a better understanding of the environment and the materials we mould to our purpose. Established methods tend to be adapted to new materials without due consideration of the applicability of old methods to the new material's characteristics. The use of elastic modular theory was developed for steel structures and carried through into reinforced concrete. The revolution is now only occurring with the introduction of limit state analysis which accepts that concrete is unlike steel. It is a material which develops strength with time and exhibits greater strengths when subjected to relatively high rates of stress increment, but creeps under long sustained loads and in such circumstances exhibits minimum ultimate strength. Each material in a structure composed of composite materials has its own strength characteristics and by applying a factor of safety which is statistically acceptable to each component to ensure against its failure, it is possible to produce a far more meaningful assessment of a composite material's performance. Loading limits of structures tend to be abused and depending on the structure a meaningful statistical assessment can be made of this factor also. In combination a design system for reinforced concrete which tends to approach reality can be developed and should lead to greater economics of materials in some areas and equally to the improvement of actual factors of safety in others.

Collapse and total failure of engineering structures as opposed to mere distress, is usually the outcome of a complete lack of appreciation of structural function on the part of the designer or, alternatively, is due to culpable negligence on the part of the contractor. Structures do not fall down simply as a result of an overstress of 20 per cent: they may then show some mild distress and should be capable of being load tested under full load plus 25 per cent of live load and perform satisfactorily. The careful instrumentation and observation of a load test can produce a wealth of information and valuable confirmation of theory and leads to an understanding of structure which no laboratory equivalent test can provide. The testing to destruction of the old Dental Hospital of the University of the Witwatersrand and of the Alliance Building Society Building in Cape Town, provided unique opportunities to compare actual ultimate performance with design forecasts. The effect of sun and shadow on a structure under test quickly brings home to the young engineer the realities of structural behaviour. He develops confidence when cracks appear in the areas where they are predicted. He is enabled to diagnose and prescribe a cure. This ability to cure structural failure or distress is a fascinating area of civil engineering. An example that typifies it was the failure of the Transcona Grain Silo complex in Canada (Fig. 19) — a case of rotational shear failure of the clay beneath the foundations. It was not the classical slip circle failure which impressed, but the fact that it was possible to recover the structure, and place it upon a satisfactory foundation and then bring it back into commission once more.

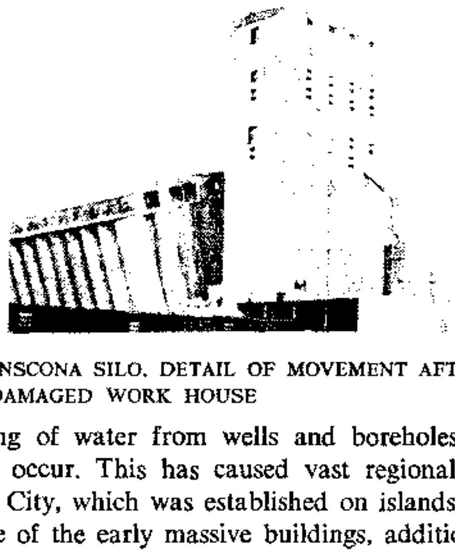

Figure 19: TRANSCONA SILO, DETAIL OF MOVEMENT AFTER FAILURE SHOWING UNDAMAGED WORK HOUSE

The pumping of water from wells and boreholes permits accelerated consolidation to occur. This has caused vast regional settlements such as those in Mexico City, which was established on islands in a former lake. In the case of some of the early massive buildings, additional local settlements have given rise to differential movements of the order of 3m. Thus the ground floor of the Palace of Fine Arts is now at first basement level and the road has had to be curved down to suit as illustrated in Figure 20. The problems which are currently occurring in Venice have the same root cause.

I hope I may be forgiven for wondering what memories the engineering students will take away of this lecture. I recall some memories of mine; for instance, Alec Skempton's joy at his inaugural lecture of noting that he had just scraped into the first fifteen (the fifteenth man to become a professor of soil mechanics). He is a rugby enthusiast and was a former captain of the Imperial College team. Or the sudden flash of understanding when Professor A. J. Sutton Pippard bent a cane and released one end and said: 'This is a cantilever and it will come to rest at a position of minimum strain energy.

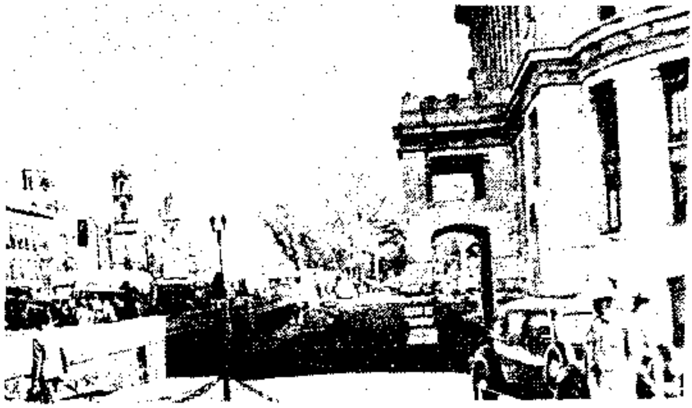

Figure 20: PALACE OF FINE ARTS, MEXICO CITY

Anyone who wishes to dispute that may step up here now!' An even earlier memory clearly imprinted on my mind is that an intensity of six on the Richter scale for earthquakes is about all that the average person can tolerate, not because this is the stage when people start to panic and plaster and masonry to crack, but simply because Professor R. G. Robertson was able to convince us, with the authority born of actual practical experience, that at this stage the whisky bottles all fell off the bar shelves in Quetta and this was a calamity of the first magnitude!

I hope that I have been able to convey to you all a little of my care for a subject which is so vast that none of us can profess to it but which I hope with the aid of my colleagues to approach in all humility as something worth striving to propagate and improve. I am deeply honoured and I consider myself extremely fortunate to have been given the opportunity and privilege of being offered the Chair of Civil Engineering, and, in accepting it, I will attempt to do all that I can to justify your confidence in this respect.

Perhaps I may conclude with the second verse of Robert Burns' epigram on rough roads, which was —

Although I'm not wi' Scripture cramm'd
I'm sure the Bible says
That heedless sinners shall be damned
Unless they mend their ways.

ACKNOWLEDGEMENTS

Figures 1, 2, 8 and 18 are from photographs taken by G. H. Francey in 1956; Figures 4 and 5 are from photographs by Woodmansterne, Ltd.; Figure 17 is from a photograph by L. M. Muggleton, and Figures 19 and 20 from photographs by White and Zeevaert from *Foundation Engineering* by Little. The remaining Figures are from photographs by the author.

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