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# A geotechnical centrifuge for TUKS

The Department of Civil Engineering at the University of Pretoria has recently been awarded a grant from the National Research Foundation (NRF) to acquire a geotechnical centrifuge.

Geotechnical centrifuges are used to accelerate soil models to create a stress field in the model analogous to that occurring in the full-scale situation being modelled. At present there are approximately 110 geotechnical centrifuges around the world and only one in Africa, namely at Mansoura University in Egypt

IT IS WELL KNOWN that physical modelling is used to study, amongst others, hydrological, structural and aerodynamical problems. Physical modelling can, however, also be applied in the investigation of geotechnical problems. The difficulty with physical modelling in geotechnical engineering is that the stress-strain behaviour of soil is highly non-linear. As the stresses in a model will be low due to the model's small size, the behaviour of the soil in the model will be unrealistic and not representative of the prototype (full-scale) situation. This problem can be overcome by accelerating

the model to artificially increase the stress in the soil to that of the prototype situation. This is accomplished by placing the model in a geotechnical centrifuge to replace gravity by centripetal acceleration. The geotechnical centrifuge at the University of Western Australia is shown in Figure 1.

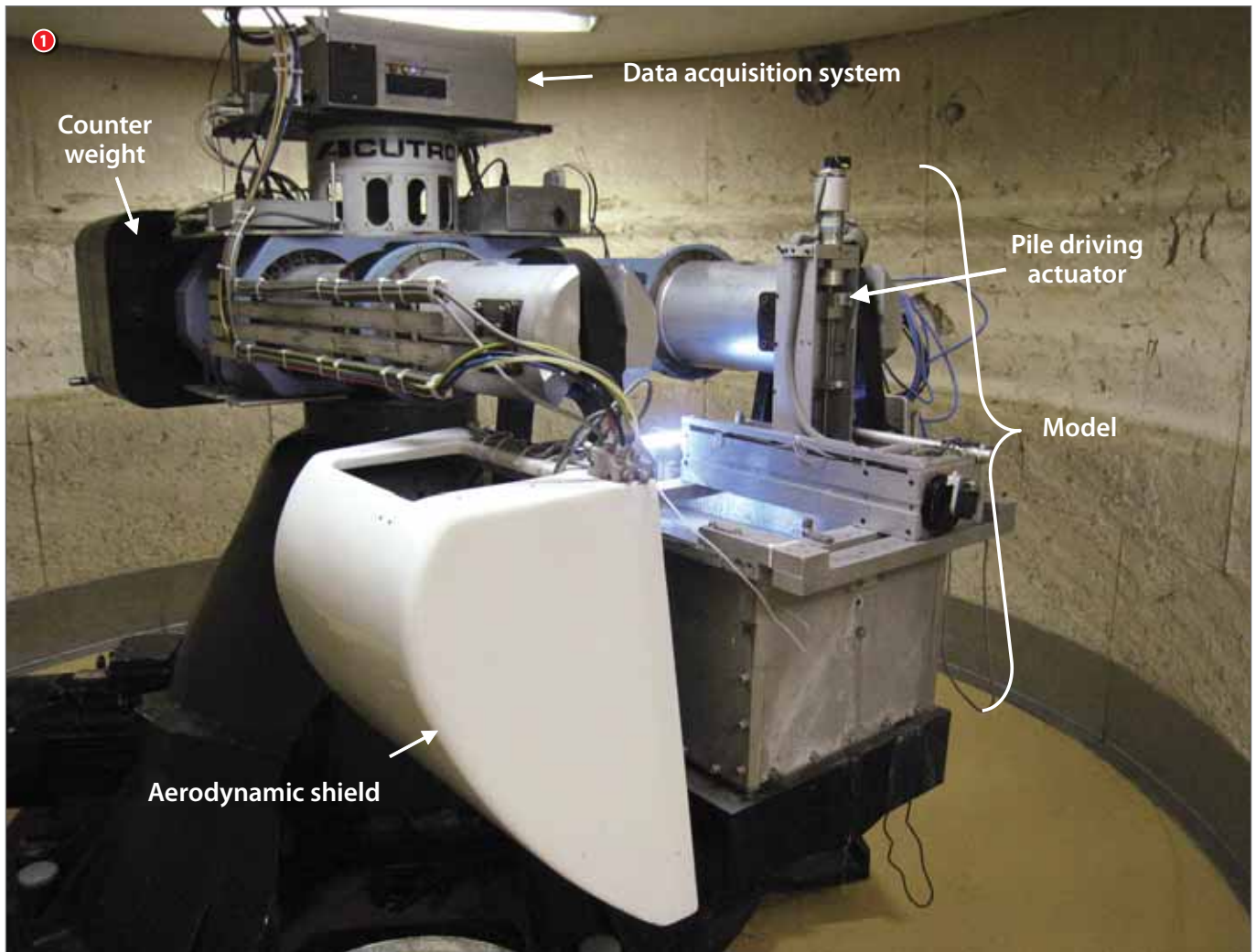
Centrifuge modelling in the study of geotechnical problems was pioneered in the West by Prof Andrew Schofield at the University of Cambridge, starting in the early 1970s after he became aware of Russian research under Prof Pokrovsky, carried out as early as the 1930s. Pokrovsky realised that physical modelling can be successfully applied in geotechnical engineering if the self-weight of a soil model can be increased to give the same stress distribution as in the full-scale situation. Some hints as to the nature of selected Russian foundation research using centrifuge modelling were presented in a one-page paper in the *Proceedings of the First International Conference on Soil Mechanics and Foundation Engineering* (Pokrovsky & Federov 1936). When Prof Schofield became interested in centrifuge modelling, Russian centrifuge technology had already advanced to a state where they were investigating the explosive power required to attack deep underground bunkers, work which was naturally shrouded in secrecy! After Prof Schofield initially tested his geotechnical models on an aeronautical centrifuge in Luton (UK), he commissioned the design and construction of the Cambridge Geotechnical Centrifuge, which was funded from grants from the British government and industry.

## ADVANTAGES OF PHYSICAL MODELLING

Physical modelling in geotechnical engineering is attractive as it enables a physical event to be observed, albeit at model scale. With the aid of a wide range of scaling laws it is possible to extrapolate model observations to the full-scale situation. This is beneficial, indeed, as even the most complex numerical models in soil mechanics are only mathematical approximations of reality, requiring a large number of parameters which are difficult to determine. The use of physical modelling avoids the need for a complex constitutive model to be selected. Complex three-dimensional geometries can readily be modelled. Centrifuge modelling in the study of time-related geotechnical problems, like seepage and contaminant transport, is especially attractive because the seepage rate is accelerated in proportion to the scale factor, or even the square of the scale factor. Once a geotechnical centrifuge facility is in place, tests are relatively cheap and quick to carry out.

## GENERAL LAYOUT, GEOMETRY AND EQUIPMENT

A typical geotechnical centrifuge comprises a beam which rotates around an axis. The model is suspended at one end of the beam and a counterweight at the other side. Construction sequences and other events can be modelled during rotation of the centrifuge with the aid of remote-controlled actuators. These are typically electrically, pneumatically or hydraulically powered. For this purpose geotechnical centrifuges are equipped with electric, pneumatic and hydraulic slip-rings feeding electric power and



compressed air (and in some cases also water) to the model through the centrifuge axis. Events taking place in the model can be observed by a vast array of instrumentation, e.g. displacement and pressure transducers, or even video or still cameras, enabling complex image processing techniques to be applied in the analysis of results.

A centrifuge is supplied with a data acquisition system, typically comprising an on-board computer with analogue-to-digital conversion technology which can easily be controlled via a wireless or fibre-optic network link.

The capacity of a geotechnical centrifuge is expressed in terms of the maximum payload (in kg or tons) and the acceleration that it has been designed to achieve. For example, Pretoria University will acquire a 150 G-ton centrifuge, meaning that the centrifuge is capable of accelerating a model weighing up to one ton to an acceleration of 150 times earth's gravity! Given the centrifuge radius of 3 m, this means that the one-ton model will be moving in a circle at 240 km/h! It does not require much imagination

to understand that the consequences of something becoming dislodged from the model during testing can be catastrophic. For this reason a geotechnical centrifuge is either constructed in a bunker just below ground level, or surrounded by a heavily reinforced concrete enclosure designed to absorb a large impact.

### GEOTECHNICAL CENTRIFUGES IN RESEARCH AND PRACTICE

As mentioned above, there are currently approximately 110 geotechnical centrifuge facilities around the world and only one on the African continent. Many of these facilities are owned by large Japanese construction companies and are used to investigate complex problems, but often also everyday geotechnical problems from a new angle. Many universities with strong geotechnical research groups have geotechnical centrifuge facilities, e.g. University of Cambridge, University of Western Australia, City University (London), Massachusetts Institute of Technology, Hong Kong University of Science and Technology, Swiss Federal Institute of

❶ The geotechnical centrifuge at the University of Western Australia

Technology (ETH) in Zurich, University of Dundee (Scotland) and many more. These institutions all have large geotechnical research groups at post-graduate and post-doctoral level, producing many high-quality publications, and also doing a considerable amount of commercial modelling for industry.

The geotechnical centrifuge opens up many research opportunities because it enables practical engineering problems, which are difficult to investigate by other means (e.g. via numerical modelling or field experiments), to be studied. Due to the practical nature of problems which can be modelled by means of physical modelling, the problems are usually relevant and topical to industry. This opens up possibilities to obtain significant funding from industry to study problems which are relevant to them, and also to support research students. Applications include geotechnical engineering, earthquake engineering, structural engineering, especially in soil-structure

interaction, pavement studies, railway studies, offshore engineering, environmental engineering and many others.

In putting together its funding application, the University of Pretoria has approached several other southern African universities, local consulting engineering companies and organisations like the Council for Geoscience, the CSIR and the Department of Water Affairs to inform them of the intention to acquire a centrifuge and to encourage them to make use of the facility once available. It is hoped that this facility will improve the research standing of the university by attracting promising post-graduate students and interesting projects from industry.

Several South African engineers have had experience with centrifuge modelling, mostly during their PhD studies overseas. They include SW Jacobsz of the University of Pretoria, Eduard Vorster of Aurecon, several researchers at the CSIR and Council for Geoscience, as well as Gerhard Heymann of the University of Pretoria who was involved in modelling the foundations of the Pebble Bed

nuclear reactor at Case Western Reserve University in the United States.

Some applications that can be studied, relevant to the South African context, include several applications regarding engineering development on dolomitic land, e.g.:

- Studying the formation of sinkholes in dolomitic land.
- The effect of sinkhole formation on nearby piled and conventional foundations. This was an important problem that had to be addressed in the design of the Gautrain viaducts through Centurion.
- Modelling the performance of piled raft foundations and other 'shallow' foundation systems on dolomitic land. Piling in dolomite is extremely costly and difficult to conduct. Understanding how shallow foundations would perform when underlain by relatively compressible strata at depth could potentially enable large savings in construction cost to be realised. Again, examples include the Gautrain viaducts in Centurion.

- The performance of ground mattresses (compacted zones underneath buildings founded on dolomite); parametric studies can be carried out in the centrifuge to obtain a better understanding of the performance of these foundation types and to optimise their geometry (size) and properties (compaction density). This will be very costly and difficult to investigate using field studies.

More inner-city construction projects are likely to be undertaken in South Africa in the future, e.g. expansion of the Gautrain network and similar projects in other cities. This would most likely necessitate, for example, tunnelling or deep excavations near or underneath the foundations of existing structures. This type of project results in complex soil-structure interaction problems which are usually difficult to model and defend theoretically without adopting very conservative and hence costly solutions. A geotechnical centrifuge may go a long way to provide a means to refine and defend complex designs, and will be a national asset to the country. □