International Journal of Integrated Engineering, Vol. 6 No. 2 (2014) p. 24-34

Overview of Innovations in Geotechnical Engineering

Devapriya Chitral Wijeyesekera[1,2*]

[1]Research Centre of Soft Soil, UniversitiTun Hussein Onn Malaysia, Johor, MALAYSIA.
[2]School of Architecture Computing and Engineering, University of East London, England, UNITED KINGDOM.

Received 10 September 2014; accepted 19 December 2014; available online 28 December 2014

Abstract: This paper outlines some historical and current innovative concepts that underpin the developments in geotechnical engineering. The far reaching aim is to inspirationally encourage further innovation in that innovation need not necessarily be entirely new and unique ways of doing things. Accordingly, the lessons from the historical development, bio mimicry and emerging concepts are illustratively presented. The importance of creating added value to projects through innovation is endorsed. A number of examples based on the author's research and experience, ranging widely across the themes of the conference are presented. In many ways geotechnology has reached maturity over the last century, but some scenarios continue to remain as challenging engineering problems. In the recent times, geotechnical engineering finds benefit in being at the crossroads with the advancements in high-tech solutions and the expanding geo technology applications, and in multi disciplinary collaborations with nanotechnology, biotechnology and information technology. The goal of innovative geo engineering research must provide effective solutions in both short and long term, with knowledge and understanding to solve problems with more sustainable certainty

Keywords: Geotechnical engineering, innovation, conceptual models, sustainable solutions, soft soil engineering

1. Introduction

The word "innovation" comes from the Middle French word "innovacyon" meaning renewal or new way of doing things. Innovative solutions are developed by further implementing a concept, regardless whether it is old or new. "Added value creation" must necessarily be the cornerstone of innovation. Innovative solutions can thus be created from an idea borrowed from another discipline, but applied to a new challenging problem in a different way.

Engineering is a profoundly *creative* profession and psychological literature says very clearly that creativity is derived from an individual's life experiences. As a result, a diverse workforce will enhance the set of life experiences that an engineering team will have and consequently, international conferences are catalysts to the creativity (innovation) that it can be brought to bear. Stereotype engineers are not necessarily creative folks — but are circumstantially constrained to be pocket protectors (white socks and big glasses!!). Such stereotype engineers are deeply wrong and are unfortunately developing an incorrect perception of the nature of engineering, driving the engineering profession into a spirally destructive and negative-feedback cycle which should be stopped and innovation encouraged. Geotechnicians receive an undergraduate / diploma level understanding and training to a state of the art but researchers and postgraduate training demands "digging deeper" (in the intellectual sense) to refine and improve (innovate) our understanding and methods. In the western world (UK, US etc.) there is a notable decline in the proportion of indigenous students enrolling for engineering in their local academic institutions despite the fact that starting salaries are about twice that for those people with B.A. degrees. Is engineering becoming a repugnant profession? Academic budget holders therefore look for alternative sources of incomes through overseas student recruitment, developing niche degree programmes and innovative learning and teaching technologies without affecting the standards and meeting the needs for professional institution accreditations. A further notable observation from Engineering Education in the UK is that the proportion of women in engineering is under represented and a minority. A reverse trend is apparent in the East and Far Eastern countries that will encourage innovation. The western world continues to face economic uncertainties whilst many Asian and other economies show growth.

A quick definition of what an engineer does is "design under constraint." The rationale is to "design — or create — solutions to human problems, to raise the living standards and therefore not any solution will do. Human beings cherish the hunger for ever improving the quality of life. It invokes constraints on cost, size, weight, ergonomic factors, environmental impact, reliability, safety, manufacturability, repair ability, power consumption, heat dissipation, and on and on — an incredibly long list of such constraints.While reflecting on how far engineers have come and are capable (state of the art), the profession needs to be tuned to what is still unknown (problem statement) and cannot yet do (objective/ outcome). Geotechnical Engineering must face the future challenges with opportunities to develop ways forward through taking stock of the current geo technology and how other technologies can contribute to

*Corresponding author: dcwijey@gmail.com

penerbit.uthm.edu.my/ojs/index.php/ijie

its advancement through innovation. In all disciplines, "science of today is the technology of tomorrow". Geo technology is very closely associated with nature and geo technology can and must evolve through cross fertilization of disciplines such as emulating nature through innovative research involving bio mimetic.

2. Historical Perspectives of Innovative Scientific Discovery.

The knowledge and understanding of current science did not develop in a flash nor was it developed by just one person. Many scientists have toiled to contribute as engines of ingenuity to help evolve the state of art of modern science.

Even three hundred and fifty years after his innovative scientific formulations, Sir Isaac Newton (1642-1727) is one of the most revered scientists, in the history of not only western science, but world science. The circumstantial scenes of the closure of the Cambridge University, when the plague broke out in UK, and the falling of the apple when he was preoccupied with the studying and laying the foundations for his greatest work, the Principia, liaised to give him the inspiration to innovate and give shape to the basic instrumental laws of modern science of physics. The historically fundamental scientific and mathematical work by eminent scientists such as Archimedes, Euclid and Lucretius formed the stepping stones for Sir Isaac Newton's innovative contributions.

The later innovative work of Albert Einstein (1879-1955) formed the twentieth century physics. His innovative and conceptual theories of relativity provided a new basis for the understanding of fundamental laws of nature and the concepts of space, mass and energy. In the mid 1980s, these fundamental concepts of acceleration due to gravity, g , have been extended and incorporated in innovative conceptual modeling in Geotechnical centrifuge testing. Fig. 1 and Fig. 2 illustrate basic features of the Acutronic 661 Geotechnical centrifuge. Its specifications are 1.8m radius swing of the centrifugal arm, capacities of 200kg at 200 g / 400kg at 100 g, having a typical rectangular strong box of 400x 600x 220 mm to simulate 80x130x44m prototype.

Fig.1 London Geotechnical Centrifuge facility: "Acutronic" 661 Geotechnical Centrifuge.

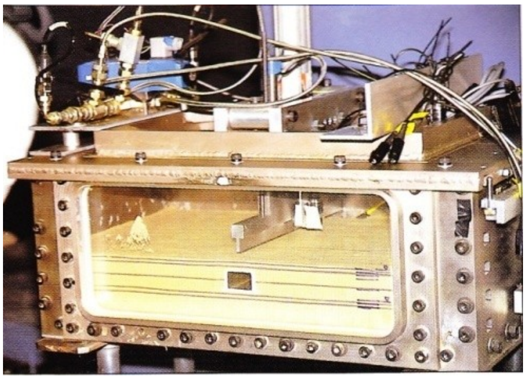


Fig. 1 London Geotechnical Centrifuge facility: Complex instrumentation within the 400x600x200mm strong sample box.

Centrifuge model testing hastens ideally the study of geotechnical problems where stresses due to self weight are of major importance and is therefore necessary to scale self weight effects. This is achieved by testing the physical model with a geometrical scale factor of **n** in the centrifuge with an induced centrifugal acceleration of **ng** (where g is the Earth's gravitational acceleration. Innovative physical model tests can thus be carried out with intricate and sophisticated instrumentation to investigate soil structure interaction, ground movements, pollution migration etc.

3. Innovative Developments in Conceptual Soil Mechanics

Ancient builders of even the mediaeval times perhaps knew intuitively, some basic principles of soil mechanics. Systematic and then innovative work started with the assimilation of useful practical data during the rapid construction programs of roads, bridges and harbours. Thus such increases in man's constructional activity, necessitated the innovative development of systematic principles of research in the field of Engineering Geology of which Soil Mechanics forms a part dealing with the soft rocks. Thus soil mechanics proper is a relatively young branch of applied sciences that use laws of physics, applied mechanics and hydraulics in assessing the behavior of foundation soils with reference to civil engineering.

During the 18^{th} and 19^{th} centuries, important contributions were made in Great Britain to soil mechanics, but it can reliably be said that the approach to most foundation problems was then empirical. Since 1775, U.S. Army Corps of Engineers has been active and even now provides the world's largest public engineering services in both peace and war times to strengthen national security, energize the economy, and reduce risks from disasters. California Bearing Ratio (CBR) developed before World War II by California Department of Transportation, is a renowned and widely adopted empirical penetration test for the evaluation of the mechanical strength of road sub grades and base courses Subsequently the CBR test was described in ASTM

Standards D1883-05 [1] D4429 [2], AASHTO T193 [3] and then further fully described in BS 1377 [4]. This pragmatically innovative test is used extensively even today to assess load bearing capacities and it measures the stress required to penetrate a soil sample with a standard plunger and expressing it as a percentage of the stress required to achieve similar penetration on a standard crushed California limestone.

Superstructures of the ancient civilizations were founded on rock as they desired zero tolerances in ground movement in their choice of sites for construction. Later, (and even sometimes now) towns were built on wooden piles where such locations demanded it. The lack of cases of challenging and difficult ground conditions, during those times facilitated the persistent use of empirical approaches for a long time. During the 19th century, engineers through their wisdom and common sense insisted on detailed ground investigations and also made use of full scale loading tests; (Example: 850 tons on the cylinders of Cannon Street Bridge.[5]. The natural variability, non homogeneity in soil and rock properties and groundwater regime, often presented the greatest risks and opportunities in challenging civil and building projects. Interaction between soil and structure is an ever-present challenge that used to be solved by empiricism and experience.

Table 1 is a chronological compilation sequence of some of the early innovative contributions to conceptual developments in Soil Mechanics (Pre Terzaghi era). by the author .Complementing and developing on the 1773 work of Coulomb on the wedge theory of earth pressure, Rankine in 1857 developed an innovative stress field solution that defined the active and passive states of earth pressure. The theory assumed that the soil is cohesionless, the wall is smooth and frictionless, the soil wall face is vertical, the surface of the backfill is horizontal, a planar failure surface and the resulting thrust on the wall is parallel to the surface of the backfill. His work was further developed by Bell with the innovative formulation of the Rankine Bell equation.

Since 1961, the British Geotechnical Society annually commemorates the great engineer and physicist, William John Maquorn Rankine (1820-1872), by hosting in March each year, a lecture in London presented by a distinguished soil mechanics specialist. Rankine was the Professor of Civil Engineering at Glasgow University and was one of the first UK engineers to make a significant innovative contribution to soil mechanics. The Rankine Lecture was held for the initial period (1961 to 1972) at the Institution of Civil Engineers, in London. Since 1973, the lecture has taken place at Imperial College with the lecturer for the even numbered years being from the UK, and the odd numbered tears from outside UK. The Geotechnique, Journal of the Institution of Civil Engineers publishes each Rankine Lecture together with the text of the biographical introduction of the lecturer and the vote of thanks.

Table 1 Chronological innovative developments in pre Terzaghi soil mechanics.

YEAR	*WORK OF*	*INNOVATIVE DEVELOPMENT*
1729	Belidor	Angle of repose and early ideas on earth pressures
1773	**Coulomb**	**Wedge theory of earth pressure, critical height of clay banks**
1808	Mayniel	Experimental verification of wedge theory with sands
1820	Francais	Earth Pressure and stability of slopes in clay
1840	Poncelet	Practical development of wedge theory
1846	Collin	Field observations on slips in clay slopes and shear strength of clays
1856	**Darcy**	**Permeability of sands**
1857	**Rankine**	**Earth Pressure theory**
1879	Airy	Stability of clay slopes and shear tests on clays
1885	**Boussinesq**	**Distribution of stress under loaded areas**
1908	Richardson	Flow nets in seepage problems
1911	**Atterberg**	**Concept of clay phases(liquid and plastic limits of clays and silts)**
1911	Petterson	Assumption that the surface of a slip in a cohesive soil is circular
1915	**Bell**	**"The lateral pressure and resistance of clay and the supporting power of clay foundations"**
1918	Krey	Stability of foundations, slopes and retaining walls
1922	**Fellenius**	**Swedish geotechnical commission on investigations into landslips, sampling and laboratory testing**
1925	**Karl Van Terzaghi**	Erdbaumechanik ; principles of consolidation, shear strength of clays and principles of effective stress
1943	**K.V.Terzaghi**	**"Theoretical Soil Mechanics"**
1948	**K.V.Terzaghi & R.B.Peck**	**Soil Mechanics in Engineering Practice**

Appendix 1 gives the details of the past Rankine Lectures [6]. 25 lecturers have been from the UK, 8 from USA, 4 from Canada, 3 from Australia, 2 each from France, Norway and Spain, and 1 each from Austria, Brazil, Japan and South Africa. The youngest Rankine Lecturer is probably Brian Simpson, who was 44 years old when he delivered his Rankine lecture in 1992.

3.1 Failures motivating Innovation

It is human nature, that major advances and innovations frequently precede major disasters. Hence the statements "Failures are pillars of success" and "supply meeting demand". At the beginning of the twentieth century, a number of serious railway accidents that were caused by landslides in cuttings and subsidence of embankments in Sweden, led to the formation in 1913 of the Swedish Geotechnical Commission to address those problems. Similar issues were encountered by the US Engineers during the construction of the Panama Canal, that led to the formation in the same year (1913) of the Committee of American Society of Civil Engineers which investigated a large number of soil tests and emphasized the importance of expressing the properties of soils by numerical values. Simultaneously, in Germany, active research in soil mechanics problems was stimulated by some important failures during the construction of the Kiel Canal, and then Professor Krey carried out some important work on methods of computing the pressures and resistance of earth with reference to retaining walls and on shearing resistance of soils.

3.2 Ground Movement and Zero Tolerance

Zero tolerance (no absolute movement) is sought in many engineering materials but is often only a myth in soft soil engineering. "Did it or will it move?" remains a daunting question to geotechnical engineers. The collage of scenes in Fig. 3 illustrates the need for innovative adoption of high tech solutions to monitor such movements with novel instruments.. Multidisciplinary interactions have facilitated the innovative developments of electrolytic tiltmeters, inclinometers, settlement gauges and earth pressure cells to monitor bridges, buildings, tunnels, dams, slopes, embankments etc.

"Torre Pendente Di Pisa" (Leaning Tower of Pisa – Fig. 4) is one of the seven wonders of the Medieval World. It is also a classic case study for soft soil engineering. Located in Pisa, Italy (4.3° N, 10° E), the tower is 60m high with 8 stories. It weighs14,700 tonnes and lent at 3.99° S with the seventh cornice overhung about 4.5 m. Construction of the tower commenced in 1173 with the placement of the first foundation stones (heavy) of Marble and Lime. Unknown to the architect, this area had once been a large river delta, thus comprising of alternating sequences of beds of soft lacustrine deposits (best described as a "bed of jelly", comprising of highly compressible soft clays and silty sands) making the area unsuitable for large and heavy buildings. For varied reasons, the construction was abruptly stopped twice, and it was therefore not completed until about 1370.

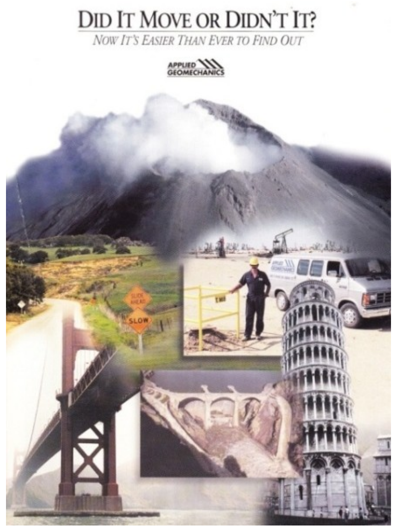
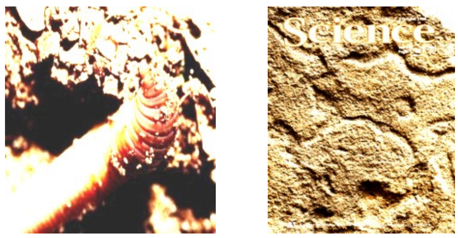


Fig. 3 Did it move or didn't it ? – Now it's easier than ever to find out [6].

Prediction surveys carried out in the 1990s suggested that it would collapse by the middle of the 21st century. Futile restoration attempts made the situation worse. The English Engineer and Professor of Geotechnical Engineering (Imperial College, London) came up with an innovative solution of soil extraction, which is a technique of creating many little tunnels to cause a controlled form of subsidence. The augers ran slowly extracting about 100 litres of earth per day from beneath the tower's foundation in a systematic way dictated daily by Professor Burland. This technique aptly mimics the natural burrowing of earth worms, which with time have left evidence marked indelibly on stone (Fig. 4).



a) Earthworm b) Worm burrows

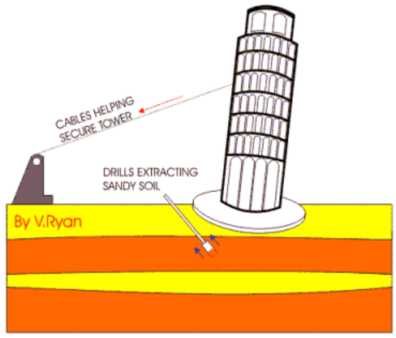
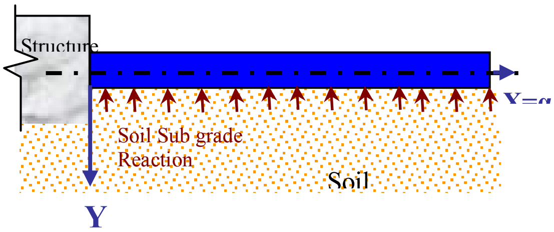
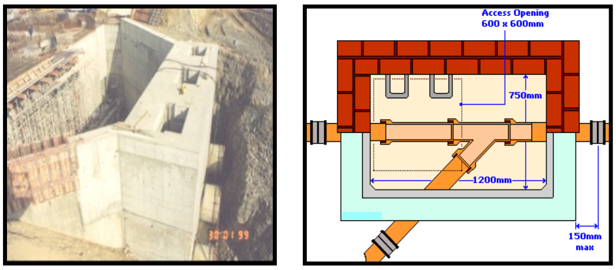


Fig 4. Soil Extraction Technique for Restoration of Tower of Pisa [7].

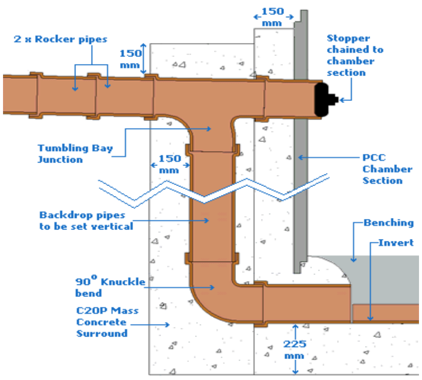
Soil-pipe interaction studies leading to settlement of pipelines is not new. Nevertheless, pipeline failures still occur due to differential ground movements between a heavy yielding structure and a pipeline firmly connected to it [8]. Such differential movements induce excessive stress concentrations in the pipeline. Plastics pipes fail as a consequence of such movements, though their flexibility can make them less vulnerable than rigid pipes.



a) Schematic Problem



b) Intake tower Power Station and domestic manhole



c) Provision of rocker pipes at vulnerable pipe joints

d) Swivel Rocker joint assembly

Fig. 5 "Rocker Pipe" provision to alleviate differential ground settlement induced Pipe failure [8].

By treating the pipelines as beams on elastic foundation, the magnitude and location of the maximum bending moments arising from yielding of the heavy structure can be determined. The provision of rocker pipe (Fig. 5) joints that facilitates a permissible rotation help to redistribute the bending moments to acceptable levels and thereby alleviate distress in the pipeline. Fig. 5(c) illustrates an innovative Swivel Joint assembly, with a rotational capability of 360^0 and an angular deflection of 15^0 from its axis, combined with the provision for longitudinal expansion/contraction.

3.3 Micro scale ground movements – shear? / drainage channel ?

In the latter half of the twentieth century the electron microscopes were developed as a powerful tool enabling the study of fabric of soils beyond the optical microscope magnifications. Fig. 6 (note 40 micron scale marker) illustrates preferential orientation of kaolinite clay particles that were observed [9] along the edge of a pore water channel. This later promotes shear / separation forming the basis for the formation of fissures in over - consolidated clays such as London Clay.

Innovative methods of photographic Fourier analysis of electron micrographs to quantify preferred orientation and also observations of initial cementation in clay – shale formation are presented in the thesis [9]. Innovative testing utilising emerging electronic transducers enabled research study geochemical and micro structural changes with high pressure consolidation of clays to simulate deep burial. [10]

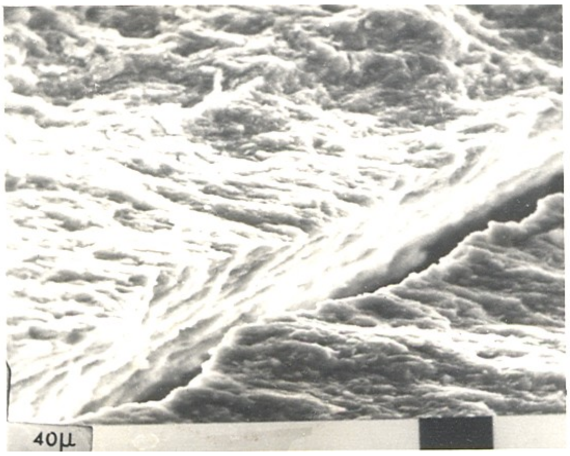


Fig. 6 Scanning Electron Micrograph of preferential orientation of clay particles initially along drainage channels dissipating excessive pore water pressures [9].

The usual assumptions that soil is a isotropic, elasto-plastic, continuous medium were being examined in Cambridge University and elsewhere to develop a critical state approach to mechanics of soil behaviour. A new energy equation was proposed, which was well supported by experimental evidence, from which a stress-strain relationship is developed for virgin and lightly over consolidated clays [11]. The unified soil mechanics theory is in itself an innovation that helped to establish both deformation and proximity to failure. Thus the latter half of the 20th century saw the proliferation of constitutive models based on plasticity, with attempts to comprehend the more complex behaviour forms such as hysteresis and anisotropy, cyclic ratchet ting and liquefaction, creep and ageing. Unfortunately, only a few models have been able to match comprehensive test and field data. Those that did match accurately represented a wide range of behaviour often related to dozens of parameters which had to be selected by curve-fitting.

The technology of the current 21st century includes fast particle size analysis using lasers which discriminate from nano size through to 0.04 microns to 2.5mm, $400 digital cameras which record 3.3 million pixels per picture, optical microscopes with fast computerised image processing which can recreate three-dimensional microstructures, and facilities for lab-bench X-ray, computerised tomography CT scan, and MRI. New innovative agenda should be to observe and quantify soil microstructure as it changes under load, and to establish reasonably economical methods of routine evaluation which usefully supplement conventional test data

Fig. 7 Biogenic fragments in Mexican City clay [12].

Fig. 7 illustrates the constituents of an organic soil that points to a very complex particulate mechanics problem. The mechanical behaviour of granular / particulate materials depend on particle morphology. Sand, with its unique sedimentalogical character is a typical granular material. The uniqueness of these characteristics is due to the fact that sand particles feature a wide range of shape and size distributions, which solicit further research. Various testing methods are adopted to relate the micro-structural properties of the particles with the overall mechanical response of the material. Particle shape is a key factor affecting the mechanical properties of granular materials. Modern techniques using microscope and interferometer are useful approaches for particle shape and roughness quantification. Scanning electron microscope (SEM) is a relatively expensive and complex device, therefore various alternative techniques such as the digital microscope shown in Fig. 8 produce images with sufficient quality for the purpose of observing and analyzing the grain shape profile.

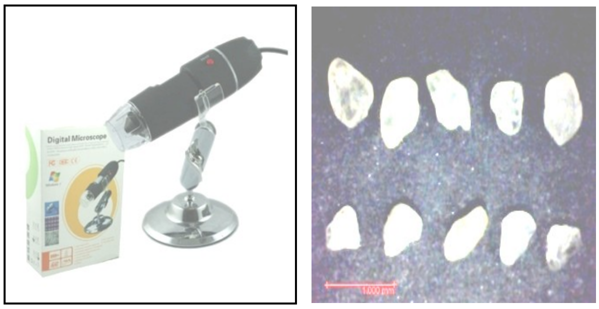
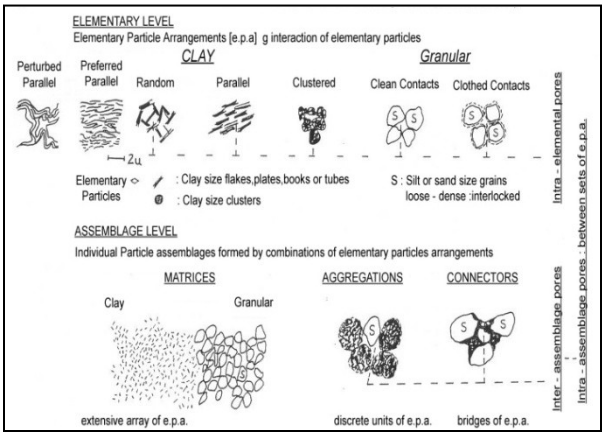


Fig. 8 Digital Microscope for shape quantification [13,14,15].

Shape and roughness of specimens of glass beads have been observed to influence the mechanical response of specimens of glass beads in terms of compressibility, stiffness and strength [16]. Combination of shape parameters such as circularity, roundness, sphericity, aspect ratio and compactness impose a significant effect on the dilatancy of sand samples [17]. The classical Mitchell's elementary particle arrangement classifications [18] have been innovatively and usefully extended to accommodate a variety of soil fabrics found in coarse and fine grained soils (see table 2 [19]

Table 2 Micro fabric classification [19]



The various micro fabrics (see Fig. 9) can be viewed with the development of powerful electron microscopes.

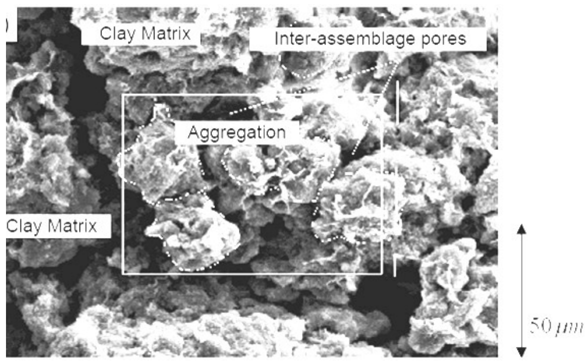


Fig. 9 Clay matrix, aggregation and inter assemblage pores.

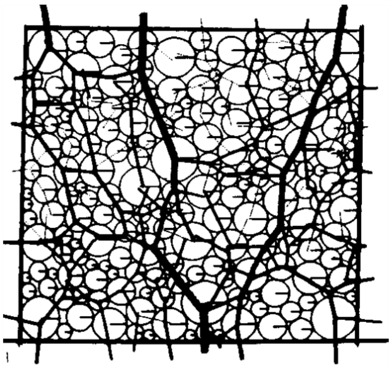


Fig. 10 Stress as a network of contact forces [12].

Such views of the micro fabrics raise questions on the load transfer mechanisms within a particulate medium. Research by de Josselyn de Jong and Verruijt who did a photoelastic analysis of glass balls have shown that the major stress is carried in strong load paths through chains of particles which happen to enjoy favourable contact normals. Fig. 10 shows the contact force response at a given instant due to a moderate vertical compression; the thickness of the contact force lines indicates their magnitude. These strong load paths switch around suddenly as the deviatoric stress is increased, so that many particles may take turns in carrying an unfair proportion of the overall load.

The behaviour of the particulate response based on computer software simulations (see Fig.11) can improve the understanding and establish some linkage between continuum parameters by monitoring the evolution of microstructure during soil testing / loading. Discrete Element Modelling (DEM) with the PFC3D program to simulate crushable grains by forming regular agglomerates of elementary spheres, and bonding them have ben carried out by Robertson [20]. Fig. 10 shows the computer simulation of the crushing of such agglomerate. Observations indicate that the grain initially split into two on a vertical diametral plane, and then split again when the applied force came to bear on the right-hand hemisphere. It is proposed that brittle fracture of grains or asperities is the essential precursor to the grain rearrangement that is described as soil plasticity. Physical testing which involves shape and roughness quantification from simple and innovative tools also provide good estimates of the strength characteristics based on the physical properties and applied loading.

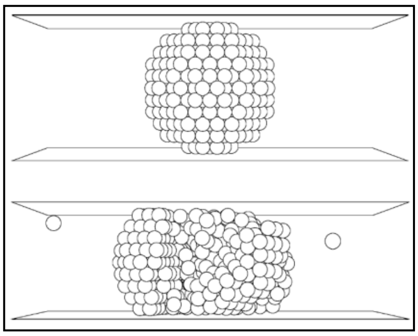


Fig. 11 Agglomerated modeling crushable grains [20].

The evolution of information technology catalysed the modern mathematical developments related to particle mechanics. Developments of Plaxis can be traced back to 1974 for the program of research on finite element analysis at Delft University of Technology. Commercialisation and utilization of geotechnical software has advanced, proliferated with user friendly approaches such as those of GeoStru Software. Workiing with GeoStru is more than just buying software. But it enables a team of professionals beside you willing to share their knowledge and experience for a wide variety of geotechnical problems. New applications are being developed for mobile devices Tablet and SmartPhone using Android and windows phone operating systems.

4. Innovations in Geotechnical Engineering

The aim of geo engineering research and technology innovation must provide in both the short and long term s knowledge and understanding that will enable problem solving and projects to be done with more certainty, faster, cheaper, better, and with proper respect for sustainability and environmental protection.

The uncertainties about the ground conditions poses the greatest element of risk to most civil engineering projects. The Mackintosh Probe development was prompted by the principles enunciated by Hvorslev [21] and adopted later by European Group Subcommittee [22]. The total number of blows (R) required for a specified standard pointer to penetrate a distance of 30 cm when driven by a small 5 kg hammer falling vertically through a fixed height of 30 cm. The Mackintosh probe test is adopted as a JKR Probe test to determine “safe pressure” P kN/m^2 given by a correlation equation (1) for soils with R>40 (stiff) soils.

$$P = (2860+550(R-40)^{1/2}) \times 0.04788 \qquad (1)$$

For softer soils (R<40); P is obtained from referring to Charts supplied by JKR. These relationships have been further modified in the quest to determine soil penetration resistance with its dependence on soil moisture and the geological age of raised bed deposits in Vietnam [23].

Soil sampling and testing is a progressive area of development in geotechnical engineering. It must be borne in mind that in all cases, only a minute fraction of the total soil mass is investigated. If for example, in the case of 10m spaced boreholes with one 50 mm sample being tested every second meter, then only 1/1,000,000 th of the total volume of soil will be investigated [24].

Innovative geophysics applications in geotechnical engineering is still underutilized, principally due to poor understanding and communications of the process by which meaningful geophysical information techniques is obtained [25, 26].

5. Innovations in Soft Soil Engineering

A variety of innovative methods (Dynami Compaction, Vibro Compaction, Vibro replacement, Vibro flotation, Jet grouting, Pressure grouting, soil cement stabilisation, soil lime stabilisation, drainage vegetation and geotextiles) have been adopted to improve the natural weak ground in order to increase the density, shear strength and load bearing capacity, and reducing settlement. Advantages of innovative soft soil stabilization need to be rapid and use technology familiar to most civil engineering contractors, yielding a "value added" product to be used in bulk fill economically and with versatility. Cement and its derivative have been used for a long time. The use of cement and lime has been particularly suited in highway earthworks. Recent experimental progress, since 1997, focuses on innovative applications of protein engineering and chemical modification. Some of these include peroxidases, phospholipase, cellulose, phytase, luciferase, bacterial proteases, and others [27]. Innovative thought is provoked in pointing to the engineering prowess of the "termite engineers" in the construction processes of their all weather proof termite mounds (see Fig.12).

Fig. 12 Termite Mounds and Termite Engineers.

Soil roads are constructed for low traffic volume areas as access roads in rural areas and as estate roads. Innovative methods, adopting artificial intelligence techniques are proposed with the view of providing a proper design guide lines ensuring quality design guide lines for soil road construction [28].

Fig. 13 illustrates an ancient soil road stabilisation technology adopted by the Sumerians who used wooden logs placed laterally to allow construction of roadways over very soft soils. Such techniques are still used for temporary access roads. Alternative but related techniques are the development and manufacture of geotextiles, tensors, geowebs etc to improve the bearing capacity of soft soils. A "weight credit" technique of using light weight fill material in embankments is a further promising and innovative technology.

Applications of lightweight construction materials enable the design and construction in challenging, difficult and demanding scenarios. However, these traditional materials and in particular the conventional concrete is characteristically heavy (~2400 kg/m^3) in self-weight, causing it to be a major proportion of the total structural loading. As a consequence, foam concrete has been developed as a preferred form of lightweight concrete. This foam concrete, though not strictly to be cellular, can yet be classified as a weight reducing cellular concrete. Foam concrete has a variably induced distribution of air voids throughout the paste or mortar, while "no-fines" concrete or lightly compacted concretes also contain large, irregular voids.

Fig. 13 Road in Ur , circa 2500 BC (Adopted from http:// semerianshakespeare.com/mediac/).

Fig. 14(a) shows the use of expanded polystyrene blocks as lightweight fill material in areas that are prone to give differential settlement. These however are so light that are affected by rising water ground levels and deteriorate with acidic ground water, and are attacked by rodents. Construction materials with enhanced stiffness as in sandwich panels, large portable structures and floating foundations are examples of such materials. The advent of cellular structure technology has actively introduced innovation and enabled design and construction, meeting engineering requirements such as in the construction of the body of air crafts. An alternative geocomposite cellular mat (GCM) is proposed innovatively,These are porous, permitting water to rise and be stored in its pores with ease. The cellular structure helps in the sharing of the highway load while the mat structure negates any differential settlement. [29]. The use of these in challenging peat soil ground [30] is being explored.

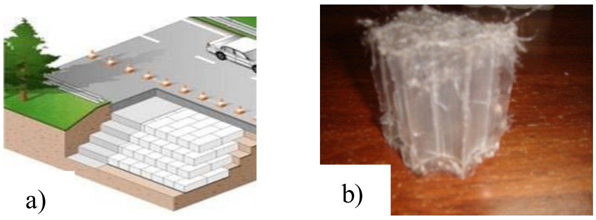


Fig. 14 a) use of EPS blocks b) view of a GCM (Source http://www.acfenvironmental.com/geofoam.html).

Stabilisation of contaminated material with cementitious inorganic binders is regarded as an established technique. Bentonites are being used as a filler in a wide variety of geosynthetic clay liners (GCL), which are only 5 to 6 mm thick but are reported to be equivalent to over 3 m of compacted clay liners which demand human resources and transport of fill soils. These are used as contaminant barriers and also as waterproofing liners. The efficacy of contaminant barriers depend on the clay mineralogy, the manner of its placement and the construction placement history of the liner. The inappropriateness and geotechnical deficiencies in using granular / aggregated bentonite have been shown to produce non uniform swelling which promotes undesired contaminant migration. The innovative development and manufacture of factory prehydrated GCLs have addressed issues of non uniformity and weaknesses on wet and dry conditions. Fig. 15 demonstrates that such prehydrated clay cake mats can also resist leakage that can arise due to accidental construction damage.

Furthermore cation exchange capacity (CEC) differences in Sodium and Potassium montmorillonite have to be considered [31]. Field application of the preferred prefabricated GCL as encapsulated embankment / tunnels demonstrates its multifaceted use [32,33].

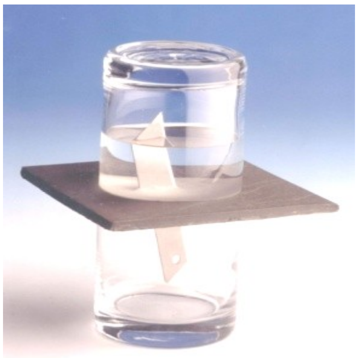


Fig. 15 Demostration of the instantaneous swell healing of an accidental damage.

6. Future Challenges needing Innovative Solutions

Geo-mechanics is therefore riven with uncertainty and without the benefit of prior experience, and innovations which may need to be tailored to the ground conditions. Notwithstanding the newness of the technology used in construction, there is no possibility of making a few prototype structures rior to the production run; Civil Engineering has generally got to work first time Reducing construction costs particularly in challenging ground conditions js essentially desirable, but sustainable and environmentally friendly building developments is equally important. Owners, developers, designers, researchers and contractors need to interact more closely than previously with focused goals to develop innovative, cost-effective, low risk, and environmentally sustainable engineering solutions.

The difficulties regarding the sampling ,characterisation and testing will persist these natural materials and emerging landfill material.. Perhaps as a result, design methods which may seem to depend on theoretical principles and mechanical properties are often actually based on *empirical* correlations and previous experience. On the other hand, the industry is rapidly developing new technologies (soil nailing, deep mixing, electro kinetics, bio-remediation, tunnel boring, pipe jacking etc) which must be optimised

7. Conclusions

Sustainable research and innovative development contribute to economic and social benefits while protecting the ecological support systems are a worthwhile challenge. Engineers have a duty to provide a service in a manner consistent with the standard of professional care contributing to sustainable development.

As a concluding request, a quote from Joyce Wycroff', the co founder of the Innovation network [34] is given below, modified slightly replacing the *I*s to *We*s, emphasizing the values of collaboration. Thus,

“We see possibilities and we must show up;
We have fun and we get energized;
We question and we open the space for learning
We multi sense and we remember;
We do and we understand;
We reflect and integrate and we can share with others;
We apply to real life and we get results.

Go forth with hope and seek the glories of the mind. Create value for your learning, teaching, research and industrial projects by applying innovative thinking and ideas.

Acknowledgements

The author is grateful to all his past and present research students and colleagues for their contributions to this paper.

References

[1] ASTM D1883-05. *Standard test method for california bearing ratio (CBR) of laboratory-compacted soils*. ASTM International, West Conshohocken, PA, (2005).

[2] ASTM D4429-09a. *Standard test method for CBR (california bearing ratio) of soils in place*. ASTM International, West Conshohocken, PA, (2009).

[3] AASHTO T193. *Standard method of test for the california bearing ratio*. American Association of State Highway and Transportation Officials, USA, (2003).

[4] BS1377-4. *Methods of test for civil engineering purposes*. British Standard, 1990.

[5] Wolfe, B.J. The city terminus extension of the Charing Cross Railway. *Proc., Institution of Civil Engineer,* (1868).

[6] Applied Geomechanics, Did it move or didn't it?, www.geomechanics.com, (2013).

[7] Ryan, V. The leaning tower of Pisa, www.technologystudent.com, (2002).

[8] Wijeyesekera, D.C., and Reginold, J.T. Rocker pipes – a solution for differential settlement induced distress in pipelines. *Proceedings of 6th International Pipeline Conference, Calgary, Canada,* (2006).

[9] Wijeyesekera, D.C. *Artificial gravitational compaction of clays*. PhD Thesis, Imperial College, London, United Kindom, (1975).

[10] Wijeyesekera, D.C., De Freitas, M. H., and Clarke, B.A. Apparatus for comprehensive study of the deep

burial and exhumation of sediments, *American Journal of Science,* (1978).

[11] Roscoe, K.H., Schofield, A.N., and Thurairajah, A. Yielding of clays in states wetter than critical, *Geotechnique*, Volume 13(3), (1963) pp. 211-240.

[12] Bolton, M.D. The role of micro mechanics in soil mechanics, *CUED – Soils/ TR 313 September 2000,* also presented at *International Workshop on Soil Crushability,* Yamaguchi University, Japan, (1999).

[13] Alvin John Lim Meng Siang, Devapriya Chitral Wijeyesekera and Adnan Zainorabidin. Effect of particle grading size and shape on density, dilatancy and shear strength of sands. *Malaysian Journal of Science,* Volume 31(2), (2012), pp. 161-174.

[14] Alvin John Lim Meng Siang and Devapriya Chitral Wijeyesekera. Effect of Particle Morphology of sand on the relationship between shear strength and dilatancy characteristics, *Electronic Journal of Geotechnical Engineering,* Volume 18, (2013).

[15] Alvin John Lim Meng Siang, Devapriya Chitral Wijeyesekera Lim Sin Mei. Innovative laboratory assessment of the resilient behavior of materials (rigid, elastic and particulate). *Procedia Engineering,* Volume 53, (2013), pp. 156-166.

[16] Cavarretta, I.. *The influence of particle characteristics on the engineering behaviour of granular materials*. PhD Thesis, Imperial College University of London, (2009).

[17] Brooke, M.R.C. *The influence of grain shape on dilatancy*. PhD Thesis*,* Univerisity of Arizona, (2008).

[18] Mitchell, J.K. *Fundamentals of soil behavior*. John Wiley and Sons, (1993).

[19] Collins, K., and Mc Gowan, A. The form and function of microfabric features in a variety of natural soils, *Geotechnique*, Volume 24 (2), (1994) pp. 223-224.

[20] Robertson, D. *Computer simulations of crushble aggregates.* PhD Thesis, Cambridge University, (2009).

[21] Hvorslev, M.J. Subsurface exploration and sampling of soils for civil engineering purposes. *Report of ASCE, U.S. Army Engineer Experiment Station,* Vicksburg, (1949).

[22] European Group Subcommittee, (1968).

[23] Pham Van Quang, Per-Erik Jansson and Le Van Khoa. Soil penetration resistance and its dependence on soil moisture and age of the raised beds in the Mekong Delta, Vietnam, *International Journal of Engineering Research and Development*, Volume 4 (8), (2012), pp. 84-93.

[24] Broms, B.B. Soil Sampling in Europe: State-of-the-art. *ASCE, Journal of the Geotechnical Engineering Division,* GT1, (1980), pp. 65-97.

[25] Whiteley, R.J. Reducing tunneling risks with seismic imaging, *Proc. Underground Construction*. London, (2003), pp. 585-594.

[26] Mohd. Hazreek Zainal Abidin, Rosli Saad, Fauziah Ahmad, Devapriya Chitral Wijeyesekera and Mohd Faizul Baharuddin. Geophysical methods in civil engineering applications. *Proc. of Malaysian Technical University International Conference,* Batu pahat, Malaysia, (2011).

[27] O'Fagain Ciaran. Enzyme stabilization – recent experimental progress. *Enzyme and Microbial Technology*, Volume 33, (2003) pp. 137-149.

[28] Sin Mei lim, Devapriya Chitral Wijeyesekera and Ismail Bakar. Critical overview of laboratory assessment for the use in soil road design. *Soft Soil Engineering International Conference,* Kuching Sarawak, Malaysia, (2013).

[29] Tuan Noor Hassanah Tuan Ismail, Devapriya Chitral Wijeyesekera, Aimi Nadia Mohd Yusoff. Improvement of soft soil stiffness using geocomposite cellular mat, *Soft Soil Engineering International Conference,* Kuching Sarawak, Malaysia, (2013).

[30] Adnan Zainorabidin, Chitral Wijeyesekera, Ismail Bakar and Mohd Idrus Masirin. Geotechnical characteristics of peat soils through the fabric and micro-structure perspectives*, Proceeding of the 8th International Conference on Geotechnical and Transportation Engineering*, Sabah, Malaysia, (2010).

[31] Wijeyesekera, D.C. Use and performance of bentonite in geosynthetic clay liners. Keynote Paper of International Conference on Geoenvironmental Engineering, Singapore, (2003).

[32] Wijeyesekera, D.C., and Mohd Masirin, M.I. Innovative encapsulated pavements*, Internationale Fachmesse*, (2007).

[33] Wijeyesekera, D.C**.,** O'Connor, K. and Salmon, D.E. Design and performance of a compacted clay barrier through a landfill. *Engineering Geology*, Volume 60(1-4), Special issue on Geoenvironmental Engineering, pp. 295-306, (2001)

[34] Hattori, R., and Wycoff, J. Innovation DNA . *Talent Development*, Volume 65(1), 2002.