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Some Built Environment Research Contributing to Sustainability

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Abstract: Engineering in all forms must address global challenges of sustainability including its dimensions such as poverty, urbanisation, and climate change. The built environment is the dynamic interface between human society as it interacts and influences the ecosystem. An understanding of this inextricably linked interdependence underpins the sustainability issues relevant to Civil Engineering. Geotechnical engineering outstand the rest of the disciplines in being the most resource intensive and having an early stance in the construction process. Philosophies and definitions of sustainability, as appropriate to geotechnical engineering is punctuated with illustrations through such research studies that contribute to sustainable development. This paper is thus a technical narrative of such innovative geotechnical research focusing on the author's research career to include the modeling and assessment of the performance of a rectangular hyperbolic paraboloid shell foundation to mimic the "duck's foot" on very soft mud; innovative research on the development of rocker pipes to arrest the often unnoticed failure of utility services arising from differential settlement; industrial design and sustainable installation of thick compacted London clay surround to protect the Heathrow Express Rail link Tunnel from noxious gases entering the tunnel as it traversed through an old landfill site; Urban Heat Island studies; Hemp in rammed earth construction,; Quality control and enhancement of geo synthetic clay liners; adoption of lightweight manufactured aggregates; used vegetable oil in asphalt pavements and soil stabilization and sustainable construction through use of enzymes and light geo composites on challenging soils are presented.

Keywords: Built environment, clay liners, foundations, sustainability, urban heat island

1. Introduction

Civil engineering is a professional engineering discipline that deals with the design, construction and maintenance of the physical and natural built environment. Without it there will be no supply of clean water, roads / train networks, or sustainable energy to help save our planet [1]. Built environment, being the dynamic interface between human society and ecosystem, must therefore consider infrastructure building that is necessarily sustainable, efficient and effective. Construction and development programs should endeavour to arrest the population migration to inner cities, discouraging and disallowing unsustainable activities, having derogatory effects on nature conservation and the green environment. Research must therefore identify and develop sustainable approaches for capacity building in content, location and appropriate methodology, adapting and targeting countries and societies where this interdependence of human society and ecosystem is crucial. Civil engineering industry has indelibly set its footprint to control, modify and dominate the eco system on all development projects ranging from road networks to residential property development, engineered landfills to renewable energy initiatives and alike. This anthropocentric development being strategically important, a wide but in no way exhaustive spectrum of sustainable engineering research into materials, designs and practices are presented in this paper:

2. Sustainability in Engineering Education

In 1996, Spedding [2] remarked on the number of books, chapters and papers that use 'sustainable' or 'sustainability 'in the title but fail to define either term. However, in recent times, sustainability is generally considered as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [3].

In the UK, the importance of engineers as soldiers was recognised by the founding of the Corps of Engineers in 1717. Recognition of the contribution of engineering to civilian society came later when the Institution of Civil Engineers was formed in 1818. Civil engineering was strongly associated with the dramatic developments of the modern economy – particularly canals, bridges, lighthouses, ports and public health. In 1985, Standards and Routes to Registration (SARTOR) was published by the Engineering Council UK followed by a further document in 2003, the first version of the "UK Standard for Professional Engineering Competence" (UK-SPEC) [4]. These pointed to the social

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responsibilities in Engineering education that it must evolve to adequately address pressing global challenges such as poverty, urbanisation, climate change and sustainability. No one science or technology on its own has all the answers, and the various disciplines have to work as a team under the umbrella of sustainability to come up with the solutions against the storm that is the converging on several issues (food, water, accommodation, transport and energy) resulting from the population growth and the consequent urbanisation, and the need to decelerate climate change.

3. Sustainability - Concepts

Fig. 1 shows sustainability as the intersection of the three; social, economic and environmental with the interactions with one another defining the bearability, viability and equitability.

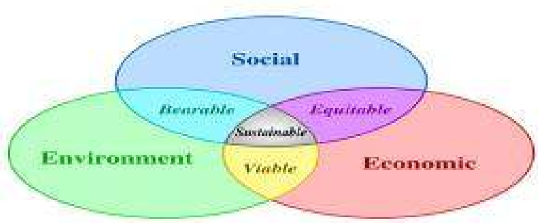


Fig. 1 Venn diagram of Social, Environment and Economic interaction in Sustainability

Historically, traditional design and construction concepts were based on technological efficiency rather than sustainability, whilst erroneously considering natural environment resources to be regenerating and infinite. The energy crisis of the 1970s aroused the need to be sustainable. It is currently construed as being the exploration into a tangled conceptual jungle where watchful eyes lurk at every bend [5]. Wilson [6] considered it as the raging monster upon the land to be population growth, and in its presence; sustainability is but a fragile theoretical construct. Weak sustainability paying little heed to depleting natural resources was content when the total capital base (natural + technological development + human) remained constant or showed signs of increase [7]. However Day [8] considered exclusively the indiscriminate uses of natural resources such as both coarse and fine aggregates have reached alarming proportions leading to even illegal quarrying (Fig. 2) of sand attracting penalties [9]. The UK Government published “Securing the future: Delivering UK Sustainable Development Strategy in 2005 [10] leading to increasing emphasis on sustainability both in industry [11] and in agriculture [12].

Sustainable land-use initiative is an umbrella title under which zero carbon land-use, biodiversity conservation, soil management, woodland management and crafts, water management, composting, reconnecting with nature, sustainable agriculture, environmental economics, land rights and other factor that help a worthwhile perception of land and the landscape. Human behaviour within the landscape is determined by their way of life and upbringing and these needs to be revisited within the initiative. Human impact on environment can be mathematically represented by the PAT formula;
I = P x A x T ,where I is environment impact, P the population, A, the affluence and T the technology.

Saturday, 28 January, 2012 | THE BRUNEI TIMES | A11

BIMP-EAGA | NEWS

Prize offered for arrest in illegal quarrying

COTABATO CITY, PHILIPPINES

NORTH Cotabato Governor Emmylou Talio-Mendoza announced on Friday a P50,000 reward for information leading to the arrest of people engaged in illegal sand and soil quarrying in the province.

Mendoza said she hoped the reward would entice residents to help the provincial government identify people involved in illegal quarry operations in the province and officials abetting their activities. Soil shoveled out from hillsides is called mountain mix and is used in road rehabilitation or construction as well as for landfill.

Their nefarious days would soon cease with the launching of the cash reward system to those who can provide 'A-1 information for their arrest, she said.

Mendoza said tipsters can simply contact her office and if the information turns out to be correct, the reward would be given.

The provincial government would reward a tipster or any concerned citizen P50,000 in cash after verification of truthful information relayed to the Office of the Provincial Governor, she said.

Mendoza said illegal quarrying was a serious problem in the province because of soil erosion and landslides.

Philippine Daily Inquirer/ANN

Fig. 2 Recent news article on illegal sand / soil quarrying in Philippines [9]

System’s approach to strong sustainability is the arduous task of achieving a compromising balance between the three E’s – economy, environment and equity [13], which are often in conflict between themselves as shown in Figure 3. Economic aspirations have to be reconciled with the growing imperative of environment protection to minimise the conflict through resource abuse from equity. Concurrently, ill effects of climate change become more visible and the calls for action become louder and more numerous.

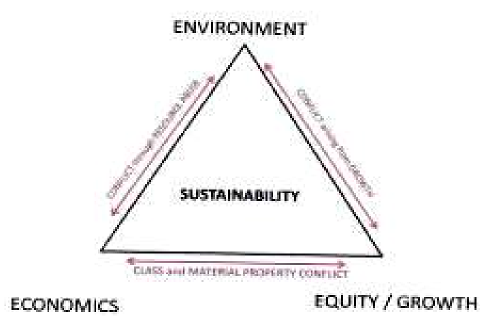


Fig. 3 Systems approach of balancing the three E’s in sustainability [13]

4. Sustainability – Historical Built Environment Perspective

Parthenon (Fig. 4) – the apotheosis of ancient Greek architecture (490 BC) is a monument for sustainability. During the past 2500 years, it has been rocked by earthquakes, set on fire, shattered by exploding gunpowder, looted for its stunning sculptures and defaced by misguided preservation efforts. The ancient Athenians built the Parthenon within a decade. Restoration project is in its 35th year!!. The ancient Greek builders had secured the marble blocks together with iron clamps fitted into the carefully carved grooves. Molten lead was then poured over the joints to provide earthquake resistant design and protect the clamps from corrosion. The Parthenon's base was 23,028 square feet (2139.4 m^2) and its 46 outer columns were some 34 feet (10.36m) high.

In 1999, the Millenium Dome (Figure 5) was constructed in UK to mark the dawn of the new millenium. It was intended to be a celebratory, iconic, non-hierarchial structure offering a vast flexible space. The building formed a key element for the future development of Greenwich Peninsula. The building itself was remarkably inexpensive (GBP 43 million) for groundwork, perimeter wall, masts, cable net structure and the roof fabric. The Dome is constructed on a brownfield site and was fundamental to the delivery of a safe and sustainable development. Special challenges met were cost, risk and potential liability, but with it opportunities for bringing derelict land back into beneficial use, remediating the contamination and enhancing the environment

The WISE (Welsh Institute for Sustainable Education) building (Figures 6 & 7), is a part of the Centre for Alternative Technology in Machynlleth, Wales is a further monument for sustainable construction. This is the largest "deep green" eco-building in the UK to date. Construction costs were within a GBP 7 million budget. This has a 7m high rammed earth wall, making it the largest earth wall construction in UK. The walls are 250 mm thick lime hemp cladding. Amidst other sustainable initiatives it has an inbuilt 40kW Solar thermal array and compost loos for ecological sanitation.

Fig. 4 Parthenon (490 BC) – Sustained Earthquake Resistant Design

Fig. 5 Millenium Dome, UK completed in 1999

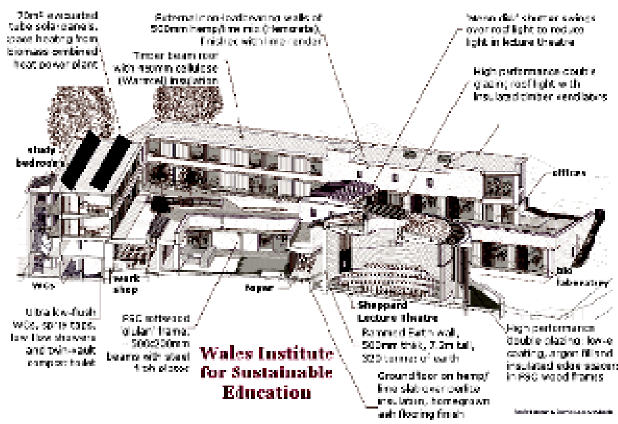


Fig. 6 Layout of Welsh Institute for Sustainable Education

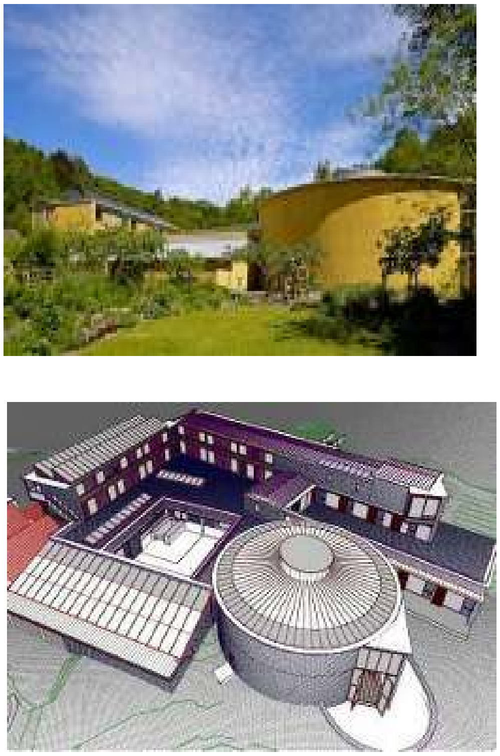


Fig. 7 Welsh Institute for Sustainable Education completed in 2008

Fig. 8 Typical Wattle and Daub construction

In the traditional wattle and daub construction, wattle is used to lay the groundwork for walls both inside and outside a house. Once the wattle structure is made it is covered with daub, a puddle plaster like mixture of clays, mud, plant fibres and animal dung. After the daub has set the walls are white lime washed to make the dwelling place more weather resistant, brighten and cool it.

Docklands Campus buildings (Figures 9 and 10) of the University of East London, UK are a further example of sustainable construction. This forms a part of the London Docklands regeneration program. The first phase of the Campus development was completed in 2000 and was awarded the 2001 Building of the year for energy efficient design with eco friendly roof design. The hardcore used in foundations was reprocessed from the Brownfield material on site. Some of the buildings opened in 2006 featured recycled prefabricated construction. Student Village opened in 2007 was designed to minimise the wastage of energy for heating and the water usage.

Fig. 9 Sustainable Architecture of the Dockland Campus buildings of University of East London, UK

UEL further initiated the scheme of free hire of cycles for staff and students to promote sustainable transport which is now adopted all over London. There exists areas such as Pulau Ketam, to some a “yesterday’s island” where the only means of permitted transport is bicyclesOn the other hand emerging countries such as Vietnam, have motor cycles and scooters taking over the roads both unsustainably and unsafely. Sustainable inner city transport is a highly desirable initiative particularly in level formations such as in Oxford, Cambridge, Amsterdam.

The rapid pace of urban development and population growth makes good buildable land scarce, causing the geotechnical engineers to venture into the challenges associated with road and building construction on unfavourable and challenging ground conditions.

Fig. 10 New Technology blending with Old Dock land environment & free healthy bicycle transport

Additional to the introduction of urban heat island effects, most road construction projects will modify the run off patterns in the area which then requires efficient and sustainable urban drainage schemes to prevent consequential flooding of the area. The volumes of waste generated by the population increase necessitates strict waste management practices with appropriate recycling initiatives and well engineered landfills rather than incineration to minimise groundwater and atmospheric pollution. Thus geotechnical projects interfere with many social, environmental and economic issues, and improving the sustainability of geotechnical processes is extremely important in achieving overall sustainable development [14]. However, despite the inadequate knowledge of the influence of a geotechnical process on the ecological balance of the surrounding area, in many global project planning and design, the financial motivations [15] dominate the geotechnical engineering profession resulting in a traditional neglect of the more important environmental and societal planning issues. Environmental Geotechnics Indicators (EGIs) proposed by Jefferson et al [16] comprised of a set of 76 generic indicators and 12 technology specific indicators for ensuring the sustainability of ground improvement methods. The output from the system is based on a point score system that ranged from 1 (harmful) to 5 (significantly improved construction practice). Failures are generally considered as the pillars of success. Classic geotechnical failures such as that of the Tacoma Narrows Bridge disaster, Leaning Tower of Pisa, Highland Towers Failure etc have all contributed sustainably valuable data on what went wrong and how such can be avoided.

5. Sustainable Lessons from Nature

Human alienation from nature can arise in unintentional damage being inflicted upon the natural environment and consequently has a boomerang effect. Fig. 11 illustrates the external and internal views of the workings of the termite building.

Fig. 11 The external and internal views of a termite mound

Most termites are social insects that are present in discrete mounds, hills or nests and access remote food resources via covered runways or galleries. [17] The termites have an effective way of bringing stone free, fine grained soil to the surface. Termite mounds can be extremely numerous, and can even reach 10m in height. [18]. Termites deliberately move soil into large mounds or 'termitaria'. These structures contain runway, shelters and sheeting, and are cemented together with faeces, saliva and undigested wood fibres [19] Termite mounds, and the soil immediately below, are commonly enriched in many nutrients, even precious metals (Figure 12). Termite mounds [20] studied had enormously high zinc, gold and silver contents. They were underlain at 10- 25 m by rock rich in these metals, pointing not only to the enriching tendencies of termites but also to their extreme depth of burrowing. These hills / mounds stand the test of time and extreme weather condition and give indications of the validity and the possibility of using appropriate enzymes for soil stabilisation. Figure 12 shows the analysis of the materials collected from the vicinity of a termite hill. Tests are being carried out with other commercial enzymes and that of Probase Chemical stabiliser to evaluate the efficacy of the stabilisation of soils. Microorganisma – fungi and bacteria – are the major source of soil enzymes, while plants and animals are also contributory sources of soil enzymes.

Extension of this thought process leads to the development of manufactured lightweight aggregates, a greatly needed and desired sustainable construction material. The UK Government has for sometime been concerned about the sustainability of mineral extraction and carefully monitors the amount of aggregate that is used and its sources. Table 1 shows the likely quantity of aggregate to be used in England until the year 2016. The table shows how alternative materials are becoming a very significant contributor to the overall aggregate requirements [22].

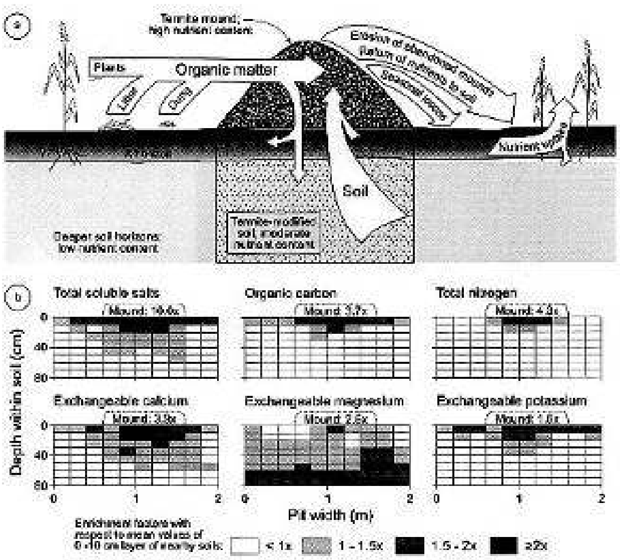


Fig. 12 Relationship of Termite Mounds with Soil fertility below and near the Mounds [21]

Manufactured aggregates have been produced for more than 70 years from such materials as clay, shale, slate and slag, and more recently from pulverised-fuel ash (PFA). This facility enables large-scale feasibility testing to be carried out on aggregates designed and manufactured using a wide variety of waste materials. Current developments in the science and technology of thermal processing now enable aggregates to be designed and manufactured from various combinations of resource materials, such as:

- residues from bio-degradable materials
- municipal solid wastes
- industrial and by-product ashes
- reclaimed argillaceous and granular materials
- demolition and construction-derived wastes

The processing technology (Fig. 13) enabled aggregate to be designed and produced to meet specific market applications (Fig. 14) thus allowing natural aggregates to be substituted by manufactured aggregates of superior technical performance at a competitive cost. This project aims to significantly reduce the disposal of both hazardous and non-hazardous wastes to landfill. By using materials perceived as wastes as resources for aggregate manufacture, this project has demonstrated a sustainable waste management policy in support of Waste Strategy 2000 by:

- reducing waste to landfill and developing new waste management techniques
- conserving non-renewable resources
- conserving the natural environment
- lowering construction costs

Fig. 13 Diagrammatic View of the Plant for Aggregate Manufacture [22]

The gas-fired high-temperature (over 1100^{0}C) rotary Trefoil kiln is at the heart of the facility. The name Trefoil relates to the internal shape of the kiln, which unlike conventional cylindrical kilns, is similar to a three-leaf clover. This shape, when rotated, allows a bed of pellets to gently cascade from leaf to leaf with every revolution of the kiln to ensure even distribution and mixing. Table 2 gives a summary of results from relevant tests carried out on 3 different manufactured aggregates and natural pea gravel. The three manufactured aggregates reported represent just a few possible variations in the type and proportions of raw feed that can be used. The manufacturing process makes A, B and C to be spherical in shape

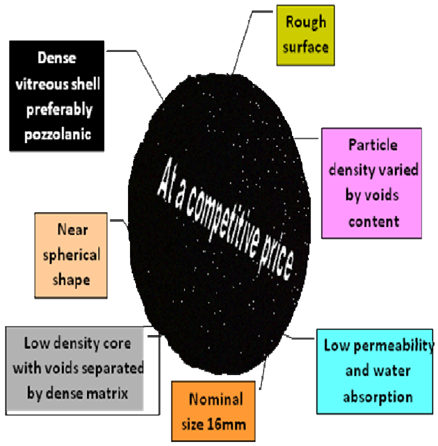


Fig. 14 Manufactured Lightweight Aggregate [22]

The spherical shape promotes self-compaction and is an ideal fill for pipe surrounds. Furthermore the spherical particles pack to give a relatively higher porosity and consequently a lower density. The firing during manufacture produces a lightweight aggregate with specific gravities in the order of 1.6 – 1.7, comparably lower to that of the natural aggregate. Despite the distinct differences in the surface roughness of the natural aggregates and the manufactured aggregates, the angles of friction observed were also similar. The modulus of elasticity for the manufactured aggregates was observed to be slightly less but is of the same order as that of the pea gravel.

A basic design philosophy for the original Cakar Ayam System was proposed by Professor Sedyamto through his understanding and quest to appreciate lessons from mother nature.(Fig. 15) [24]. The unique design of pipes prevents the soil inside to be displaced by the counter pressures generated within. A further lesson from nature is to study the mechanism behind the interaction of shell structure of the Ducks Webbed feet. (Fig. 16) Mathematical modelling leads it to the simple form of a Rectangular Hyperbolic Parabaloid Shell which will then be like a thin shell tent roof. The forces developed with the bending of the shell will be taken by the edge beams at the quadrants as tensile forces. This structure benefits from both its initial preformed curvature as well as its light weight. It is accepted that the construction form work etc will not be just that straightforward as seen in Fig. 17

A case for Recycling with used tyres is being revisited and utilised by the Construction and Plant Growth Faculty at the University of Cambridge, UK.

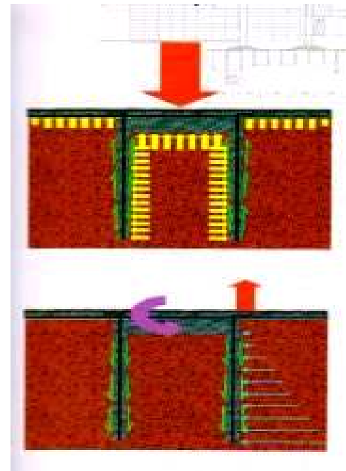


Fig. 15 Cakar Ayam Construction System [24]

Fig. 16 Duck's webbed feet

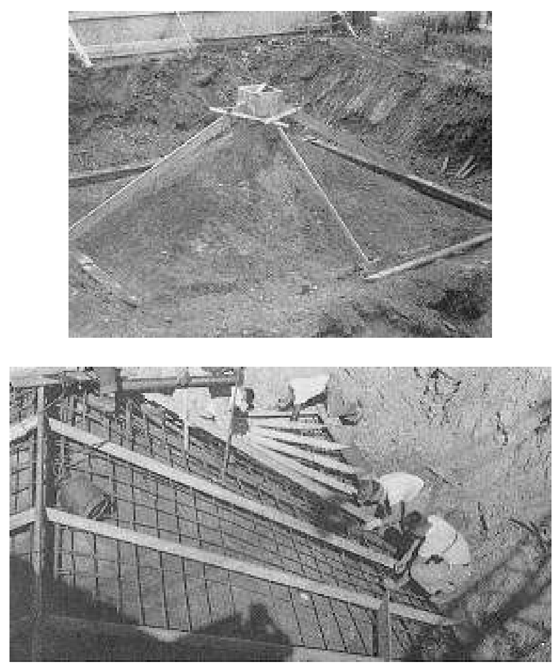


Fig. 17 Rectangular Hyperbolic Paraboloid Shell Foundation

Fig. 18 Retaining Wall with Recycled Tyres

A retaining wall similar to the one shown in Fig. 18 was being studied to provide an acoustic and visual screen to hide external mechanical plant. In total around 600 tyres were being used

6. Sustainability in the Unseen Geotechnics

The end use of geotechnics research and design is often in the subsurface, without glory in being unseen and often unknown, but yet so important. "Out of sight out of mind" can be exploited to cover inefficient and unsustainable development. Dealing with contaminated land, design of buried utilities and sustainable landfill design are such issues. Unknown to some engineers in the developed world, are the Bakau Piles popularly used in Far East; Malaysia and Singapore to primarily support small box culverts etc. The Bakau Pile is essentially the untreated trunk of a tree, with branches trimmed off Bakau wood which grows in mangrove areas, and are much more weather resistant than bamboo. Its performance and durability is particularly favourable when installed below ground water level and these have in some instances, survived over centuries when embedded in clayey soil. These piles are 75mm in diameter and 5m long. Extensions of the piles are attached using a metal sheath and nails, and are rarely installed for lengths of over 10m. As a guide the load carrying capacity is circa 1 metric tonne per pile. Bakau Piles (Fig. 19) are useful and cost effective for specific applications such as temporary roads and excavations. Challenging ground conditions from Peatlands are a nightmare to civil engineers. In addition to the usual very high (acidic) ground water, untoward characteristics for peat soils are high water content (>200%), high compressibility, high organic content (>75%), low shear strength (5-20 kPa), low bearing capacity (<8 kN/m^2) and high shrinkage [25,26]. Timber logs have are used as a log mattress over soft soil in road construction (Fig. 20).

Fig. 19 Preparation and stock piling of Bakau

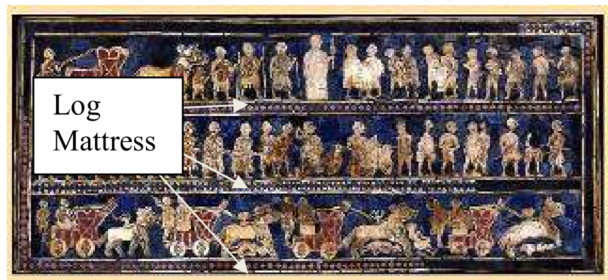


Fig. 20 Illustration of the use of wooden logs as a means of stabilising road

Soil-pipe interaction studies leading to settlement of pipelines is not new and pipeline failures still occur due to differential ground movements between a heavy yielding structure and a pipeline firmly connected to it. Such differential movements induce excessive stress concentrations in the pipeline{27,28]. Plastics pipes fail as a consequence of such movements, though their flexibility can make them less vulnerable than rigid pipes. The provision of rocker pipe joints that accommodate a permissible rotation helps to redistribute the bending moments to acceptable levels and thereby alleviate distress in the pipeline.(Fig. 21)

The construction and performance details of a compacted London clay surround that was designed to prevent any leachate or methane penetrating a stretch of the cut and cover box section tunnel of the London Heathrow Express Rail Link (Figures 22, 23). The barrier was constructed of London clay excavated from the concurrent bored tunnelling operations on adjacent sites [29]. aboratory investigations carried out on the compacted London clay indicated that it was possible to design the clay surround to function as a barrier protecting the structure from the ingress of leachate.

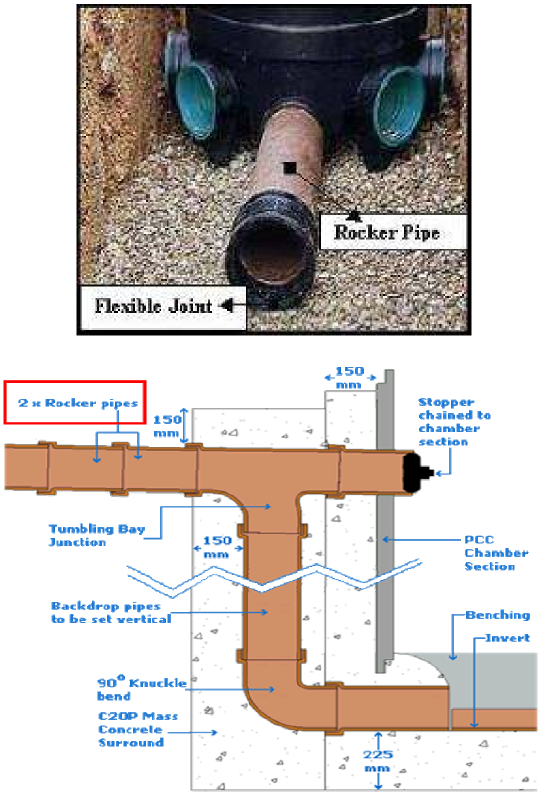


Fig. 21 Rocker Pipe solution to alleviate differential settlement induced domestic pipe failure

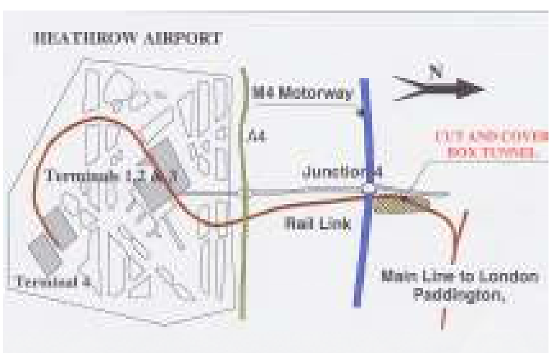


Fig. 22 Layout of Heathrow Express rail Link (0.5 km of cut and cover section in disused landfill site) [29]

Field monitoring using magnetic extensometer gauge measurements indicate that the settlements are lower than that predicted by the laboratory tests. Strict site control was necessary to ascertain the conditioning of the London Clay waS in accordance with the design specifications. The technology was pro sustainability in minimising transport of contaminated soil elsewhere and meeting all necessary safety requirements.

Geosynthetic clay liners (GCLs) are an innovative and sustainable construction material that has been developed over the last two decades.

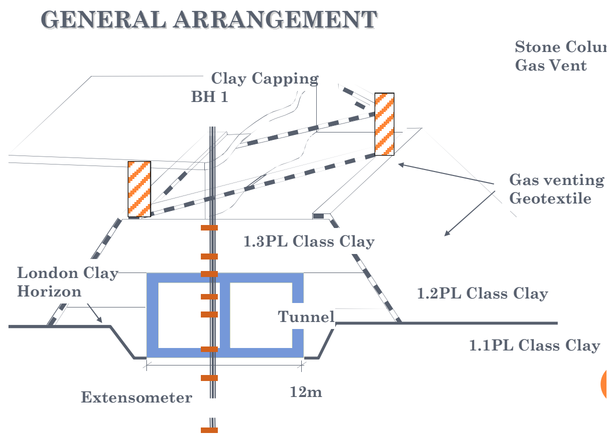
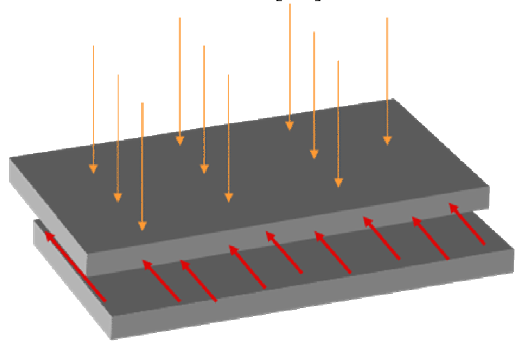


Fig. 23 Design of Compact Clay Liner Surround [29]



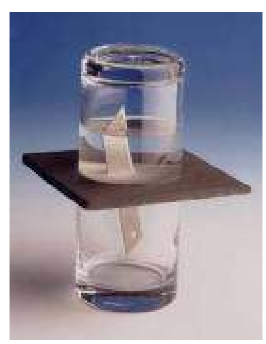


Fig. 24 Factory Prehydrated Geosynthetic Clay Liner [30]

These composite matting comprise of bentonite with two covering geosynthetics. GCLs are now being popularly specified as “leachate retaining” or “water proofing” membranes within the geo-environmental construction industry (Figure 25 The predominant (approximately 75-90% by weight) clay mineral in bentonite is the three-layered (2:1) clay mineral montmorillonite[30,31,32]. High quality bentonites need to be used in the GCL manufacture. The sodium montmorillonite’s characteristic high swelling capacity, high ion exchange capacity and the consequently very low hydraulic conductivity provides the basis for the sealing medium in GCLs. The bentonite in the manufactured GCLs are either in an air dried granulated / powdered form or have been factory prehydrated to a moisture content beyond its shrinkage limit and vacuum extruded to enhance its performance.

7. Further Innovative Sustainable Built Environmental Research

Sustainable development has become a key ideal which must be translated into the real world, leaving scientists and engineers confronted with meeting demanding tasks of far-reaching environmental, economic and social objectives. Products must be developed that can be manufactured in environmentally acceptable ways with minimum consumption of energy and raw materials, while maintaining as favourable and ecological balance as possible. Global drivers have led the construction industry to consider the use of recycled and waste materials to aid sustainability. A key area of development is in the use of alternative binders for asphalt. Innovative research into the development of technical knowhow for blending of bitumen with vegetable oil(both virgin and used) to produce a range of equivalent penetration grade binders. [33]

Hemp is being researched to assess its performance as an alternative sustainable thermal insulation material. Also mixed with lime, they are performing well as thermal insulating walls.[34,35]

The rapid growth of worldwide urbanization arouses concerns on Urban Heat Island (UHI) effects particularly within areas where the population density is high. Road pavements are necessary facets of urbanization and have important localized environmental effects; absorbing heat during the day and radiating it back out at night time contributing to significant localized temperature increase. Furthermore social and ecological effects are felt in terms of heat related illness and breakdown of sensitive environmental systems leading to derogatory contribution to global warming. Due to the large area covered by pavements in urban areas, they are an important element to consider in the heat island migration. The temperatures of the pavements depend on the percentage composition of the solar energy, and the pavement material's thermo physical properties such as solar reflectance (albedo), thermal conductivity, and thermal emittance. Installation of green roofs, cool pavements and increasing tree and vegetation cover are some of the strategies being adopted to reduce the urban heat effects. Preliminary field monitoring of the urban heat island levels within an array of different pavement materials are being conducted on 5 test pavement bays constructed at an Aggregate Industries (UK) site. The temperature distribution within the test bays were data logged continuously for the field analysis. The heat flow characteristics through the pavement constituents, including thermal energy input and output are evaluated and assessed. Innovative systems to reduce such temperature variations in order to extend life of the asphalt pavements as well as the possibility of harnessing the UHI as an energy source are explored. [36]

8. Conclusions

Sustainable research and innovative development contributing to economic and social benefits while protecting the ecological support systems are a worthwhile challenge. Engineers have a duty of care to provide a service in a manner consistent with the standard of professional care contributing to sustainable development. Built Environmentalists must make sustainability a key issue in their multi dimensional approach in planning design and construction. Geotechnical engineers as they develop their profession through research nand development, must go beyond the concept of "covering up", both literally and metaphorically, as their successes / failures will influence sustainability. Sustainability must start from the grass roots, from home, to school, to work place to the market place. Simply, it means;

- Minimal consumption of all natural resources
- Reuse or recycling of all wastes
- No polluting or emitting of wastes beyond what ecosystems can breakdown and harmlessly recycle naturally
- Total reliance on clean, renewable energy technologies.

Dynamism of the evolutionary process of research, vastness of the subject "sustainability", and the brevity as this review had to be, the author hopes that it has conveyed an idea of the prospect, responsibility and fruitfulness of geo environmental sustainability research. A Variety of sustainable examples were presented with the hope that there will be an ever increasing number of persons who will endeavour to adopt sustainable practices in their daily living. So, let us all keep sustainability's true meaning and apply it to our living. This will encourage us to have a longer view, work harder and not settle, Too much is at stake.

Acknowledgements

True to the context of sustainability, the author is thankful to the present conducive environment to living, hoping that there will be no abuse of it to the detriment of the future generations. The author is immensely grateful to many of his past and present research students and colleagues who have both inspired and contributed sustainably to this research.

Table 1 National And Regional Guidelines For Aggregates Provision In England, 2001 - 2016 (Million Tonnes) [23]

	Guidelines for land-won production		Assumptions		
New Regions	Land-won Sand & Gravel	Land-won Crushed Rock	Marine Sand & Gravel	Alternative Materials	Net Imports to England
South East England	212	35	120	118	85
London	19	0	53	82	6
East of England	256	8	32	110	8
East Midlands	165	523	0	95	0
West Midlands	162	93	0	88	16
South West	106	453	9	121	4
North West	55	167	4	101	50
Yorkshire & the Humber	73	220	3	128	0
North East	20	119	9	76	0
England	1068	1618	230	919	169

Table 2 Summary of Geotechnical Properties of the Aggregates tested [22]

PROPERTY	AGGREGATE SAMPLE TESTED			
	A	B	C	D
Description	Standard Aggregate Mix: 45% OC, 45% PFA, 10% SS *	Dredge Mix: 45% DM, 20% PFA, 20% ISSA, 10% SS, 5% FA*	Filter Cake: 50% PGW, 45% CMDW, 5% RG*	Natural Flint pea gravel
Colour	Brown	Dark brown	Grey	Various brown black white
Specific gravity	1.7	1.62	1.64	2.55
Mean dry density (kG/m^3)	820	775	695	1440
Mean void ratio	1.082	1.085	1.362	0.772
Mean porosity (%)	52	52.1	57.7	43.6
Shape	Spherical	Spherical	Spherical	Angular
Effective size (mm)	6.05	4.92	5.02	7.85
Median size(mm)	8.85	7.76	9.75	9.74
Uniformity coefficient	1.55	1.78	2.33	1.33
Coefficient of curvature	1.05	0.96	0.9	0.97
Aggregate crushing value (%)	38	54	51	19
Dry density after crushing test (kG/m^3)	2411	1837	1503	6156
Strain at 400kN load (%)	34.4	42.9	46.8	23.4
Durability loss with dry abrasion (%)	2.7	4.6	3.7	0.2
Durability loss after slaking in fresh water (%)	1.99	7.87	1.19	0.49
Durability loss after slaking in sea water (%)	1.3	6.74	1.42	0.88
Angle of friction (°)	38	41	40	39
Modulus of elasticity (MPa)	65	52	48	95

* Abbreviations; CMDW:- Construction material and demolition waste (particulate), DM:- Dredged material, FA:- Fly ash, ISSA:- Incinerated sewage sludge ash, OC:- overburden clay, PFA:- Pulverised fly ash, RG:- Recycled glass (particulate), SS:- Sewage sludge

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