Application of Geotechniques to Urban Development with Specific Reference to United Arab Emirates

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Introduction

Geotechniques is an art of applying tools of site investigation for chracterisation of sites and evaluating the ground characteristics / geotechnical parametrs for the design of civil engineering structures.

"Unfortunately, soils are made by nature and not by man, and the products of nature are always complex."

Karl von Terzaghi, 1936

Site investigation is the process by which geological, geotechnical and other relevant information, which might affect the construction or performance of civil engineering project, is acquired.

Because of irregular deposition, soils and rocks are notoriously variable, and often have properties which are undesirable from the point of view of a proposed structure. Unfortunately, the decision to develop a particular site cannot often be made on the basis of its complete suitability from the engineering point of view. Geotechnical problems therefore occur and require an understanding of the geotechnical parameters for their solution. Site investigation is often carried out by specialists in the field of soil mechanics. Geologists with specialisation in relevance of geology to civil engineering or construction are called 'engineering geologists'.

By the first quarter of the nineteenth century, many concepts now associated with the principle of effective stress, were intuitively understood. During the twentieth century, many of the currently used geotechnical processes for the improvement of ground, such as piling, pre-loading, compaction and de-watering appear to have been used (Skempton 1960). These techniques were applied in a purely empirical manner. At the turn of the twentieth century, a series of major failures occurred which led to the works largely stemmed from Terzaghi's appreciation of the need to supplement geological information with numerical data (Terzaghi 1936).

Terzaghi (1951) argued that since there is an infinite variety of subsoil patterns and conditions of saturation, the use of the different methods of subsoil exploration cannot be standardised, but the methods themselves still leave a wide margin for improvement, as far as expediency and reliability are concerned.

The primary functions of any ground investigation and characterization process is one of the following:

- determining the lateral variability of the ground
- profiling, including determination of groundwater conditions
- locating specific 'targets', such as dissolution features or abandoned mine workings
- index testing
- classification
- parameter determination

Objectives

The objectives of site investigation can be summarized (table 1) as providing data for the following:

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Table 1: Order of events for site investigation

Geotechnical contractor	Geotechnical designers	Project design team
➢ Ground Geotechnical investigation ➢ Profiling ➢ Classification ➢ Determination of Parameters ➢ Additional ground Investigation	➢ advice on likely design issues Preliminary desk study to advise on relative geotechnical merits of different sites ➢ Geotechnical advice on optimizing structural forms and construction methods, in order to reduce sensitivity of proposed construction to ground conditions. ➢ Detailed desk study and walkover survey to produce a report giving ➢ Expected ground conditions ➢ Recommended types of foundation ➢ Geotechnical design problems needing analysis ➢ Ground investigation plan. Detailed geotechnical design	➢ Definition of project ➢ Site selection ➢ Conceptual design ➢ Detailed structural / Architectural design. ➢ Construction performance
➢ Instrumentation	➢ Comparison of actual and anticipated ground conditions assessment of new risks ➢ Geotechnical monitoring	

Site selection: The construction of certain major projects, such as earth dams, is dependent on the availability of a suitable site. Since the safety of lives and property are at stake, it is important to consider the geotechnical merits or demerits of various sites before the site is chosen.

Foundation and earthworks design: For medium-sized engineering works, such as motorways and multistorey structures, the geotechnical problems must be solved once the site is available, in order to allow a safe and economical design.

Temporary works design: The actual process of construction may often impose greater stress on the ground than the final structure. While excavating for foundations, steep side slopes may be used, and the in-flow of groundwater may cause severe problems and even collapse. These temporary difficulties, may in extreme circumstances prevent completion of a construction project, will not usually affect the design of the finished works. They must, however, be the object of serious investigation.

- ***Effects of proposed project on environment:*** The construction of an excavation may cause structural distress to neighbouring structures for a variety of reasons such as loss of ground , lowering of the groundwater table, seismicity etc. which may result in prompt legal action. On a wider scale, the extraction of water from the ground for drinking may cause pollution of the aquifer in coastal regions due to saline intrusion, and the construction of a major dam and lake may not only destroy agricultural land and game. These effects are the subject of investigation.

- ***Investigation of existing construction:*** The observation and recording of the conditions leading to failure of soils or structures are of primary importance. The investigation of existing works can also be particularly valuable for obtaining data with more certainty from back-analysis of the existing works, than from small scale laboratory tests, for use in proposed works on similar conditions.

- ***The design of remedial works:*** If structures are seen to have failed, or to be about to fail, then remedial measures must be designed. Site investigation methods are used to obtain parameters for the design.
- ***Safety checks:*** Site investigations are used to provide data to allow their continued use and behavior of major civil engineering works.

Geotechniques

The various geotechniques followed for ground characterization/ site investigation are:

- Walk over surveys of the ground and its surroundings.(use of aerial photographs and satellite imageries)
- Topographic surveys for depiction of nature of slopes
- Mapping of geological features of the area for site and project specific purposes (with or without use of satellite imageries).
- Geotechnical exploration: includes the following

i. Trial pit, Boring, Drilling etc.; using different techniques as per site and project requirements,

ii. Field/ insitu testing: as per site and project requirement, for assessments of mass properties.

iii. Laboratory tests for assessment of material properties.

iv. Interpretation of data and evaluation of parameters for the design of foundation of specific structures, stability of cut slopes etc.

v. Use of specific softwares for calculation, assessment and presentations of data. Some of these soft wares used these days are:

vi. Geologcal bore logs, plottings and development of profiles- **giNT, Winfence**

vii. Sieve analysis plottings – **Winsieve**.

viii. For Calculation and plotting – **GeoSystem** for consolidation, triaxial and direct shear tests.

ix. permeability data plottings (Falling head & packer)- **X I formats**.

x. Slope stability studies/ analysis - **PROKON, SWEDGE**

The direct method of testings are at the centre of routine ground investigation. They provide the opportunity to obtain samples for visual description and index testing.

In order to optimize the investigation, estimates of

- relative accuracy;
- relative cost;
- availability, and
- relevance to the problem should be assessed for determining the parameters.

Projects Categories with bore holes adequacy

- Isolated small structures such as pylons, radio masts, sign board structures, chimneys or small houses/ villas, where one borehole may be sufficient.
- Compact projects, such as buildings/ towers, dams, bridges or small land-slips, will require few boreholes. These will normally be deep and relatively closely spaced.
- Extended projects, such as motorways, railways, reservoirs and land reclamation schemes will require shallower, more widely spaced boreholes, but these will normally be expected to verify the depth of 'good' ground/ bed rock line. The frequency of borings on extended sites is judged on the basis of the uniformity or otherwise of the site geology and its expected soil variability.

i. The geological succession in the area.

Thin beds of limited outcrop may require closer Bore holes.

ii. The presence of drift deposits such as alluvium or glacial till, where vertical and lateral extent may require close inspection

iii. Problem areas, for example where pre-existing slope instability is suspected. The number and depth would be variable, suiting the site conditions and the design requirements.

As a rough guide to the necessary depths, determined from considerations of stress distribution or seepage, the following depths can be used.

i. Reservoirs: Explore soil to: (i) the depth of the base of the impermeable stratum, or (ii) not less than 2 x maximum hydraulic head expected.

ii. Foundations: Explore soil to the depth to which it will be significantly stressed. This is often taken as the depth at which the vertical total stress increase due to the foundation is equal to 10% of the stress applied at foundation level.

iii. For roads: Ground exploration need generally only proceed to 2 – 4 m below the finished road level, provided the vertical alignment is fixed. It is good practice to bore to at least 5 m below ground level where the finished road level is near existing ground level, 5 m below finished road level in cut, or at least one and a half times the embankment height in fill areas.

iv. For dams: For earth structures, a depth equal to one half of the base width of the dam is recommended. For concrete structures the depth of exploration should be between one and a half and two times the height of the dam. Because, the critical factor is safety against seepage and foundation failure, boreholes should penetrate not only soft or unstable materials, but also permeable materials to such a depth that seepage patterns can be predicted.

v. For retaining walls: It has been suggested by Hvorslev that the preliminary depth of exploration should be three quarters to one and a half times the wall height below the bottom of the wall or its supporting piles. Because it is rare that more than one survey will be carried out for a small structure, it will generally be better to err on the safe side and bore to at least two times the probable wall height below the base of the wall.

vi. For embankments: The depth of exploration should be at least equal to the height of the embankment and should ideally penetrate all soft soils if stability is to be investigated. If settlements are critical then soil may be significantly stressed to depths below the bottom of the embankment equal to the embankment width.

Geotechnical parameters

Geotechnical parameters are obtained by testing specimen and/or insitu testing at site which are selected to be representative of each of the soil groups defined by soil description, classification and index testing. Where soil grouping cannot be carried out, perhaps because of time or financial constraints, it is often found to be necessary to carry out much larger numbers of the more time consuming and sophisticated tests required for determining geotechnical design parameters.

Thus, if 450 mm long samples are to be taken every 1.0 to 1.5 m down the borehole in cohesive soils, every test specimen should be subjected to determinations of water content and plasticity. Where an undrained shear strength profile is required, tests should be made on every specimen of the appropriate diameter in the depth range required for the profile. For proposed spread foundations, embankments and temporary works, cuttings, these depths should not be less than the height of the cut or fill, or the width of the foundation. If soil conditions are unfavorable, piles may be required; in anticipation of this, shear strengths should then be determined to much greater depths.

Clearly, soil is normally variable, and when a two stage investigation (variation survey followed by detailed exploration) is not carried out, the only logical course is to test more extensively those specimens that are obtained.

in situ *testing is carried out when:*

i. Good quality sampling is impossible (for example, in granular soils, in fractured rock masses, in very soft or sensitive clays, or in stoney soils);

ii. The parameter required cannot be obtained from laboratory tests (for example, in situ horizontal stress);

iii. When in situ tests are cheap and quick, relative to the process of sampling and laboratory testing (for example, the use of the SPT in clay, to determine undrained shear strength).

iv. For profiling and classification of soils (for example, with the cone test, or with dynamic penetration tests).

The most commonly used test is the Standard Penetration Test (SPT), which is routinely used at 1.5 m intervals within boreholes in granular soils, stoney soils, and weak rock. Other common in situ tests (table 2) include the field vane (used only in soft and very soft cohesive soils), the plate test (used in granular soils and fractured weak rocks), and permeability tests (falling head or constant head tests used in most ground, to determine the coefficient of permeability). The physical survey is that part of site investigation which aims to determine the physical properties of the ground. These are required:

i. to classify the soil into groups of materials which will exhibit broadly similar engineering behavior.

ii. to determine parameters which are required for engineering design calculations.

Some soils, for example clays, may readily be sampled. If good quality samples can be obtained, then laboratory testing offers the best method of determining soil and rock parameters under carefully controlled conditions. Ground is either difficult or impossible to sample and test successfully. In such cases, in situ tests are used.

Information may be obtained in situ in at least three ways

i. by using geophysical techniques; in particular, showed how seismic

Table 2: Parameters from in situ tests as per ground conditions

Test type	Parameters required							
	K_0	φ'	c_u	σ_c	E'/G	E_u	G_{max}	k
SPT		G	C	R	G	C	G	
CPT		G	C		G			
Marchetti dilatometer	G,C				G			
Borehole pressuremeter			C		G,R	C		
Plate loading test			C		G,R	C		
Field vane			C				G,C,R	
Seismic field geophysics								
Self boring pressuremeter	G,C	G	C		G,C			
Falling/rising head test								G
Constant head test								C
Packer test								R
GG = granular, C = cohesive, R = rock								

techniques may be used to obtain valuable estimates of the stiffness of the ground

ii. *by using* in situ *soil testing techniques and*

iii. by making measurements using field instrumentation

The following types of ground conditions are examples of those where in situ testing is either essential (table 2) or desirable.

- Very soft or sensitive clays: Good quality samples are hard to get.
- Stoney soils: With the possible exception of very stiff clay containing scattered gravel (for example, clayey tills) which can be sampled by careful rotary coring with either mud or polymer flush, stoney soils are almost impossible to sample.
- Sands and gravels: Sand sampling is possible (for example, using freezing techniques, or a piston sampler in a mud-filled borehole), but tends to be expensive, and to yield relatively highly disturbed samples.
- Weak, fissile or fractured rock: The strength and compressibility of fractured rock is controlled by the discontinuities (for example, joints, fissures, faults) within it.

On this basis following groups (table 3) of tests can be discerned.

i. Wholly empirical interpretation: No fundamental analysis is possible. Stress paths, strain levels, drainage conditions and rate of loading are either uncontrolled or inappropriate. (Examples: SPT, CPT.)

ii. Semi analytical interpretation: Some relationships between parameters and measurements may be developed, but in reality interpretation is semi empirical, either because both stress paths and strain levels vary widely within the mass of ground under test, or drainage is uncontrolled, or inappropriate shearing rates are used.

Table 3: Suitability of in situ and laboratory testing *Chemical characteristics* Marsland (1986) stated.

Purpose	Suitable laboratory test	Suitable *in situ* test
Profiling	Moisture content Particle size distribution Plasticity (Atterberg limits) Undrained strength	Cone test Dynamic penetration test Geophysical down-hole logging
Classification Parameter determination: Undrained strength, cu	Particle size distribution Plasticity (Atterberg limits) Undrained triaxial	Cone, DCPTU SPT , Cone Vane
Peak, effective. Residual strength, *cr' φr'* strength, *c' φ'*	Effective strength triaxial Shear box Ring shear Compressibility -Oedometer Triaxial, with small strain measurement Triaxial consolidation	Self-boring pressure meter Plate test
Permeability Chemical characteristics	Triaxial permeability pH, Sulphate content	*In situ* Geophysical / Resistivity

iii. Analytical interpretation: Stress paths are controlled, and similar (although strain levels and drainage are not). (Example: elf-boring pressure meter).

"The choice of test methods and procedures is one of the most important decisions to be made during the planning and progress of a site investigation. Even the most carefully executed tests are of little value if they are not appropriate. In assessing the suitability of a particular test, it is necessary to balance the design requirements, the combined accuracy of the test and associated correlations, and possible differences between test and full scale behavior."

The relative merits & demerits of in situ and laboratory tests can be viewed in table 4.

Advantages

Test results can be obtained during the course of the investigation, much earlier than laboratory test results Tests are carried out in a well regulated environment.

Appropriate methods may be able to test large volumes of ground, ensuring that the effects of large particle sizes and discont-inuities are fully represented. Stress and strain levels are controlled ,as are drainage boundaries and strain rates. Effective stre-ngth testing is straightforward.The effect of stress path and history can be examined.

Estimates of in situ horizontal stress can be obtained. Drained bulk modulus can be determined.

Disadvantages

Drainage boundaries are not controlled, so that it cannot definitely be known whether loading tests are fully undrained.

Stress paths and/or strain levels are often poorly controlled. Tests to determine eff-ecttive stress strength parameters cannot be

Table 4: Relative merits of in situ and laboratory testing In situ testing Laboratory testing

In situ testing	Laboratory testing
Advantages:	
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Appropriate methods may be able to test large volumes of ground , ensuring that the effects of large particle sizes and discont-inuities are fully represented.	Stress and strain levels are controlled ,as are drainage boundaries and strain rates. Effective strength testing is straightforward. The effect of stress path and history can be examined.
Estimates of *in situ* horizontal stress can be obtained.	Drained bulk modulus can be determined.
Disadvantages:	
Drainage boundaries are not controlled, so that it cannot definitely be known whether loading tests are fully undrained. Stress paths and / or strain levels are often poorly controlled. Tests to determine eff-ecttive stress strength parameters cannot be made, because of the expense and in-convenience of a long test period. Pore pressures cannot be measured in the tested volume, so that effective stresses are unknown.	Testing cannot be used whenever samples of sufficient quality and size are unobtainable, for example, in granular soils, fractured weak rock, stoney clays. Test results are only available some time after the completion of fieldwork.

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Test results are only available some time after the completion of fieldwork.

The techniques used vary widely across the world. The most common methods are augering, wash boring and light percussion drilling. This latter technique is well adapted to stoney soils, and has its origin in water well drilling techniques.

Given the relatively small sums of money involved in ground investigations, only a very small proportion of the volume of soil and rock that will affect construction can be sampled and tested. The particular methods used in any country will tend to be restricted, based on their suitability for local ground conditions.

The principal methods used worldwide are:

- Trial pitting
- Probing:
- Boring:
- Light percussion drilling;
- Power augering
- wash boring.
- Drilling:
- Open holing
- Core drilling/ wire line drilling

Drilling has traditionally been used in the more competent and cemented, deeper deposits (engineering 'rock'). It is now also widely used to obtain high quality samples of heavily over consolidated clays, for specialist laboratory testing. Probing is increasingly being used as a cheap alternative to boring and drilling. It is used as a qualitative guide to the variation of ground conditions, and is particularly valuable for profiling techniques used, are often fast, and are generally cheaper than boring and drilling, but they cannot be used to obtain samples or to install instruments. An understanding of these techniques is important not only because they represent the major element of cost in a ground investigation, and must therefore be used with care, but also because the way in which they are selected and used can have a great effect on the quality of site investigation. Drilling muds/ bentonite, polymer muds/ guargum and drilling bits etc.

Light percussion drilling

Often called 'shell and auger' drilling, this method is more properly termed light percussion drilling since the barrel auger is now rarely used with this type of equipment.

Geophysical techniques offer the chance to overcome some of the problems inherent in more conventional ground investigation techniques. Many methods exist with the potential of providing profiles and sections, so that the ground between boreholes can be checked to see whether ground conditions at the boreholes are representative of that elsewhere. Geophysical techniques also exist which can be of help in locating cavities, backfilled mine shafts, and dissolution features in carbonate rocks, and there are other techniques which can be extremely useful in determining the stiffness properties of the ground. Geophysics is rarely used in ground investigations. Various reasons have been put forward to explain this fact, including:

- Poor planning of geophysical surveys, by engineers ignorant of the techniques.
- Over optimism by geophysicists, leading to a poor reputation for the available techniques.
- Geophysics plays a vital role intermediate between geological interpretation of the ground and its structure, and the drilling of exploratory holes to confirm the presence of geological structures like faults shear zones and their properties. Geophysical

Table 5: Geophysical methods with possible application in ground investigation

Application	Comments	Possibly viable methods
Lateral variability	These techniques are best used as an aid to selecting borehole locations. Preliminary borehole information will be particularly useful in selecting the best technique. The depth investigated will generally be small (of the order of a few metres) so that these techniques will find most use on shallow, extended investigations, for example for pipelines. Microgravity is claimed to have a high success rate in cavity detection.	Ground conductivity Magnetometry Gravity Electrical resistivity
Vertical profiling	Electrical resistivity depth probing is a surface technique which utilizes curve fitting for interpretation. Therefore the sub-soil geometry must be simple. Geophysical logging of deep boreholes, for inter-borehole correlation, has been most successfully carried out using natural gamma logs. It provides additional information at relatively little extra Cost.	Electrical resistivity depth probing Natural gamma logging Seismic down-hole logging
Sectioning	Seismic tomography is a complex technique, which should be used with caution. It works best on deep sections. Its success rate in cavity detection is low. Ground penetrating radar is a shallow technique. Its technical development has been rapid in recent years, and it shows great promise for the future. Seismic reflection is best used over water, although development of shallow seismic reflection techniques may permit more land use in the future.	Seismic tomography Ground penetrating radar Seismic reflection Electrical resistivity imaging
Ground classification Stiffness determination	Both techniques are limited to classifying the ground as cohesive or non-cohesive. Seismic methods are generally successful, provided that background noise levels are low. They provide extremely valuable, and relatively cheap information on the stiffness of the ground	Electrical resistivity Ground conductivity Cross-hole seismic Up/Down-hole seismic Seismic tomography Surface wave

techniques are relatively cheap, and are highly regarded in such a speculative environment, even though they may not always be successful. (Table 5)

The solution to this difficulty is to take better geological advice during the planning of the investigation, and to maintain close geological supervision during its execution. There is a growing trend for geophysical techniques to be integrated into ground investigation in a way which is difficult for a geophysicist to understand — the geophysicist cannot readily appreciate the engineer's priorities and requirements, and may not be sufficiently familiar with the science of soil mechanics. In summary, the majority of problems arise because of:

- The expectations of engineers that all techniques will be 100% successful
- Poor inter-disciplinary understanding between engineers, engineering geologists and geophysicists
- Lack of communication, particularly with respect to the objectives of ground investigation;
- The use of inappropriate science (for example, measurements of compressional wave velocities.

Geophysical techniques can also be used for vertical profiling. The techniques can contribute very greatly to the process of ground investigation by allowing an assessment, in qualitative terms, of the lateral variability of the near surface materials beneath a site. Non contacting techniques such as ground conductivity, magnetometry and gravity surveying are very useful, as are some surface techniques (electrical resistivity traversing).

The success rate of geophysics depends greatly upon the care taken in its planning and execution. Geophysical surveys should, in general, be carried out by experienced personnel.

Instrumentation

Soil instrumentation is a complex and rapidly evolving field of study. The amount of instrumentation used in site investigation depends on the type of investigation being carried out. In practice the amount of instrumentation used in routine pre-design site investigation is very limited and normally consists only of pore water pressure measuring devices. The main parameters which may require measurement are displacement, strain, stress and force; pressure in the form of pore water pressure will be the most frequent measurement because of the relative importance of this parameter in geotechnical design.

The primary requirement of any instrument is that it should be capable of determining a required parameter, such as water pressure, or displacement, without leading to a change in that parameter as a result of the presence of the instrument in the soil

i. Standpipes and standpipe (Casagrande) piezometers: The simplest form of pore pressure measuring device is the observation well or standpipe. The standpipe piezometer accounts for the majority of piezometer installations in site investigations, primarily because it is relatively simple to install.

However, there are a variety of precautions that must be taken if a really good piezometer installation is to be made. First, the seals are to be effective, then backfill to the borehole should be well tamped down.The standpipe and Casagrande or standpipe piezometer are the two devices in most common use in site investigation but they are not suitable for some applications, particularly where it is not possible to read the water level in the standpipe from directly above, or where water pressure responses to relatively rapid load changes must be measured. The other piezometers are hydraulic and pneumatic pressure gauges etc.

ii. Displacement measuring techniques measure the vertical movements and settlements with extensometers and settlement gauges. The mercury filled settlement gauges are the sophisticated versons used these days.

Quality assurance

Quality assurance is 'All those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements of quality'. In other words, quality assurance concerns the management of an organization to meet agreed quality objectives. In itself it does not guarantee that a service is of the necessary quality for a given job, but attempts to meet predetermined standards by approaching the work in a systematic manner. In this sense it simply represents good management practice. Quality systems comprise several levels of activity (Fig. 2).

i. Quality policy: The overall quality intentions and direction of an organization as regards quality, as formally expressed by top management.

ii. Quality management: That aspect of the overall management function that determines and implem-ents the quality policy.

iii. Quality system: The organizat-ional structure, responsibilities, proced-ures, processes and resources for implementing quality management.

iv. Quality control: The operational techniques and activities that are used to ful-fill requirements for quality.

In the UAE, quality management systems and practices are being implemented in the ground investigation industry. They are standardized as per ISO/IEC 17025:2005, international Acreditation Service (IAS), ASTM & BS standards(5750:1987, 5930; 1999) relevant for different techniques and tests. Dubai Municipality Acreditation Centre (DAC) does regular audits as a part of monitoring system.

Foundation Types adopted in Urban Development

A building foundation transmits loads from buildings and other structures to the earth. Geotechnical engineers design foundations based on the load characteristics of the structure and the properties of the soils and/ or bedrock at the site. In general, geotechnical engineers: 1) estimate the magnitude and location of the loads to be supported; 2) develop an investigation plan to explore the subsurface; 3) determine necessary soil parameters through field and lab testing (e.g., consolidation test, triaxial shear test, vane shear test, standard penetration test); and 4) design the foundation in the safest and most economical manner.

The primary considerations for foundation support are bearing capacity, settlement, and ground movement beneath the foundations. For heavier structures or softer sites, both overall settlement relative to unbuilt areas or neighboring buildings, and differential settlement under a single structure, can be of concerns. Of particular concern is settlement which occurs over time, as immediate settlement can usually be compensated for during construction. Ground movement beneath a structure's foundations can occur due to shrinkage or swell of expansive soils due to climatic changes, frost expansion of soil, melting of permafrost, slope instability, or other causes. All these factors are to be considered during design of foundations.

In areas of shallow bedrock, most foundations may bear directly on bedrock; in other areas, the soil may provide sufficient strength for the support of structures. In areas of deeper bedrock with soft overlying soils, deep foundations are used to support structures directly on the bedrock; in areas where bedrock is not economically available, stiff "bearing layers" are used to support deep foundations instead.

The foundation types adopted in urban development works are as follows:

Shallow foundations

Shallow foundations are a type of foundation that transfers building load to the very near the surface, rather than to a subsurface layer. Shallow foundations typically have a depth to width ratio of less than.

Footings

Footings (often called "spread footings" because they spread the load) are structural elements which transfer structure loads to the ground by direct areal contact. Footings can be isolated footings for point or column loads, or strip footings for wall or other long (line) loads. Footings are normally constructed from reinforced concrete cast directly onto the soil, and are typically embedded into the ground to obtain additional bearing capacity.

Slab/raft foundations

A variant on spread footings is to have the entire structure bear on a single slab of concrete underlying the entire area of the structure. Slabs must be thick enough to provide sufficient rigidity to spread the bearing loads somewhat uniformly, and to minimize differential settlement across the foundation. In some cases, flexure is allowed and the building is constructed to tolerate small movements of the foundation instead. For small structures, like single family houses, the slab may be less than 30cm thick; for larger structures, the foundation slab may be several meters thick.

Slab foundations can be either slab-on-grade foundations or embedded foundations, typically in buildings with basements. Slab-on-grade foundations must be designed to allow for potential ground movement due to changing soil conditions.

Deep foundations

Deep foundations are used for structures with heavy loads when shallow foundations cannot provide adequate capacity, due to size and structural limitations. They may also be used to transfer building loads past weak or compressible soil layers. While shallow foundations rely solely on the bearing capacity of the soil beneath them, deep foundations can rely on end bearing resistance, frictional resistance along their length, or both in developing the required capacity. Geotechnical engineers use specialized tools, such as the cone penetration test, to estimate the amount of skin and end bearing resistance available in the subsurface.

There are many types of deep foundations including piles, drilled shafts, caissons, piers, and earth stabilized columns. Large buildings such as skyscrapers typically require deep foundations. For example, the Jin Mao Tower in China, Burj Al Arab, Burj Dubai, Al Burj etc in Dubai, use tubular steel piles about driven to a depth of +80 m to support its weight.

In buildings that are constructed and found to undergo settlement, underpinning piles can be used to stabilize the existing building.

Lateral Earth Support Structure

Retaining wall

A retaining wall is a structure that holds back earth. Retaining walls stabilize soil and rock from down slope movement or erosion and provide support for vertical or near vertical grade changes. Cofferdams and bulkheads, structures to hold back water, are sometimes also considered retaining walls.

The primary geotechnical concern in design and installation of retaining walls is that the retained material is attempting to move forward and down slope due to gravity. This creates soil pressure behind the wall, which can be analyzed based on the angle of internal friction and the cohesive strength (c) of the material and the amount of allowable movement of the wall. This pressure is smallest at the top and increases toward the bottom in a manner similar to hydraulic pressure, and tends to push the wall forward and overturn it. Groundwater behind the wall that is not dissipated by a drainage system causes an additional horizontal hydrostatic pressure on the wall.

Gravity walls

Gravity walls depend on the size and weight of the wall mass to resist pressures from behind. Gravity walls will often have a slight setback, to improve wall stability. For short, landscaping walls, gravity walls made from dry stacked (mortar less) stone/ gabbions or segmental concrete units (masonry units) are commonly used.

Earlier in the 20th century, taller retaining walls were often gravity walls made from large masses of concrete or stone. Today, taller retaining walls are increasingly built as composite gravity walls such as: geosynthetic or steel reinforced backfill soil with pre cast facing; gabions (stacked steel wire baskets filled with rocks), crib walls (cells built up log cabin style from precast concrete or timber and filled with soil) or soil-nailed walls (soil reinforced in place with steel and concrete rods).

For reinforced soil gravity walls, the soil reinforcement is placed in horizontal layers throughout the height of the wall. Commonly, the soil reinforcement is geo-grid, a high-strength polymer mesh, that provide tensile strength to hold soil together. The wall face is often of precast, segmental concrete units that can tolerate some differential movement. The reinforced soil mass, along with the facing, becomes the gravity wall. The reinforced mass must be built large enough to retain the pressures from the soil behind it. Gravity walls usually must be a minimum of 50 to 60 percent as deep (thick) as the height of the wall, and may have to be larger if there is a slope or surcharge on the wall.

Cantilever walls

Prior to the introduction of reinforced soil gravity walls, cantilevered walls were the most common type for taller retaining wall. Cantilevered walls are made from a relatively thin stem of steel reinforced, cast-in-place concrete or mortar masonry (often in the shape of an inverted T). These walls cantilever loads (like a beam) to a large, structural footing; Sometimes cantilevered walls are buttressed on the front, or include a counterfort on the back, to improve their stability against high loads. This type of wall uses much less material than a traditional gravity wall. Cantilever walls resist lateral pressures by friction at the base of the wall and/or **passive earth pressure**, the tendency of the soil to resist lateral movement.

Excavation shoring

Shoring of temporary excavations frequently requires a wall design which does not extend laterally beyond the wall, so shoring extends below the planned base of the excavation. Common methods of shoring are the use of **sheet piles** or **soldier beams and lagging**. Sheet piles are a form of driven piling using thin interlocking sheets of steel to obtain a continuous barrier in the ground, and are driven prior to excavation. Soldier beams are constructed of wide flange steel H sections spaced about 2-3 m apart, driven prior to excavation. As the excavation proceeds, horizontal timber or steel sheeting (lagging) is inserted behind the H pile flanges.

In some cases, the lateral support which can be provided by the shoring wall alone is insufficient to resist the planned lateral loads; in this case additional support is provided by walers or tie-backs. Walers are structural elements which connect across the excavation so that the loads from the soil on either side of the excavation are used to resist each other, or which transfer horizontal loads from the shoring wall to the base of the excavation. Tie-backs are steel tendons drilled into the face of the wall which extend beyond the soil which is applying pressure to the wall, to provide additional lateral resistance to the wall.

Slope stability

Slope stability is the analysis of soil covered slopes and its' potential to undergo movement. Stability is determined by the balance of shear stress and shear strength. A previously stable slope may be initially affected by preparatory factors, making the slope conditionally unstable. Triggering factors of a slope failure can be climatic events, that can make a slope actively unstable, leading to mass movements. Mass movements can be caused by increase in shear stress, such as loading, lateral pressure, and transient forces. Alternatively, shear strength may be decreased by weathering, changes in pore water pressure and organic material.

United Arab Emirates (UAE)

The United Arab Emirates (In Arabic-Dawlat Al-Imarat al-'Arabiyah al-Muttaidah) is a Middle Eastern federation of seven states situated in the southeast of the Arabian Peninsula in Southwest Asia on the Persian Gulf, bordering Oman and Saudi Arabia. The seven states, termed emirates, are Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaimah, Sharjah, and Umm al-Quwain (Table 6).

The UAE, rich in oil and natural gas, has

Table 6 : Details of UAE

Emirate	Capital	Area km²	Population calc. 2007
Abu Dhabi	Abu Dhabi	67340	1465 431
Ajman	Ajman	259	260492
Dubai	Dubai	3885	1469330
Fujairah	Fujairah	1166	118933
Ras al-Khaimah	Ras al-Khaimah	1683	191753
Sharjah	Sharjah	2590	656941
Umm al-Quwain	Umm al-Quwain	777	59 098
United Arab Emirates	Abu Dhabi	82,888,	

become highly prosperous after gaining foreign direct investment funding in the 1970s. The country has a relatively high Human Development Index for the Asian continent, ranking 39th globally, and having the 5th highest GDP per capita in the world according to the CIA.

Before 1971, the UAE were known as the Trucial States or Trucial Oman, in reference to a nineteenth-century truce between Britain and several Arab Sheikhs. The name Pirate Coast was also used in reference to the area's emirates in the 18th to early 20th century.

The United Arab Emirates is situated in Southwest Asia, bordering the Gulf of Oman and the Persian Gulf, between Oman and Saudi Arabia; it is in a strategic location along southern approaches to the Strait of Hormuz, a vital transit point for world crude oil. The United Arab Emirates was formed from tribally organized Arabian Peninsula sheikhdoms along the southern coast of the Persian Gulf and the northwestern coast of the Gulf of Oman. The area became Islamic in the 7th century (Fig. 3).

The UAE lies between 22°50' and 26° north latitude and between 51° and 56°25' east longitude. It shares a 530-kilometer border with Saudi Arabia on the west, south, and southeast, and a 450-kilometer border with Oman on the southeast and northeast. The land border with Qatar in the Khawr al Udayd area is a source of ongoing dispute. The country's exact size is unknown because of disputed claims to several islands in the Persian Gulf. The largest emirate, Abu Dhabi, accounts for 87 percent of the UAE's total area (67,340 square kilometers). The smallest emirate, Ajman, encompasses only 259 square kilometers (Fig. 4).

The Portuguese controlled the area for 150 years in which they conquered the inhabitants of the Arabian peninsula. Later, portions of the nation came under the direct influence of the Ottoman Empire during the 16th century.

Environmental concerns

Climate

The climate of the UAE generally is hot and dry. The hottest months are July and August, when average maximum temperatures reach above 48° C (118° F) on the coastal plain. In the Al Hajar al Gharbi Mountains, temperatures are considerably cooler, a result of increased altitude. Average minimum temperatures in January and February are between 10°C (50°F) and 14°C (57°F). The average annual rainfall in the coastal area is fewer than 120 mm (5 in), but in some mountainous areas annual rainfall often reaches 350 mm (14 in). Rain in the coastal region falls in short, torrential bursts during the summer months, sometimes resulting in floods in ordinarily dry wadi/ valley beds. The region is prone to occasional, violent dust storms, which can severely reduce visibility.

Natural hazards: frequent sand and dust storms

Environment- current issues: lack of natural freshwater resources being overcome by desalination plants;

Desertification; beach pollution from oil spills.

Economy

The GDP per capita is currently the 14th in the world and 3rd in the Middle East after Qatar and Kuwait as measured by the CIA World Fact book, or the 17th in the world as measured by the International Monetary Fund; while at $168 billion in 2006, with a small population of 4 million, the GDP of the UAE ranks second in the CCASG (after Saudi Arabia), third in the Middle East — North Africa (MENA) region (after Saudi Arabia and Iran), and 38th in the world (ahead of Malaysia).

General geology of UAE

The ancient sea, once covering the whole region of UAE, rose and fell, influenced by major world climatic changes, and deposited its sediments for at least 500 million years. The layer of rocks thus formed is in places several kilometers thick and deep down, in pockets of this ancient sea-bed, processes of decomposition have created oil and gas reserves providing the means for man to transform the modern landscape. Earth movements folded and tilted these once horizontal layers during the mid-Tertiary, creating in the process scenic mountains such as Jebel Hafit. This, and several other outcrops, including Jebel Howayyah (popularly known as 'Fossil Valley', near Al Ain) have been formed by erosion of an arched fold of sedimentary rocks.

Cutting deep into the sedimentary series, erosion has exposed Upper Cretaceous ('Simsima') limestone; the remains of an offshore reef, where forms of sea-life once flourished.

An interesting feature which observers sometimes find difficult to explain is the existence of various rocks and minerals in the midst of a limestone series. These may consist of lavas, gypsum of various colours, hematite iron ore and mauve or green shales. Origins of these are clearly separate from the biotic limestones.The explanation lies in the upsurges of salt deposits from beneath the limestone layers: extreme pressure on these, caused by overlying rocks, squeezed them up towards the surface through weakness planes or cracks, dragging with them rocks from deep within the crust, sometimes from 6,000 meters down. When the salt rock pierces the surface it is quite rapidly eroded, depositing the boulders and debris it has brought up with it. Current examples of this phenomenon is seen at Jebel Dhanna, Sir Bani Yas, Das, Zirku and on several other islands.

Unlike the Asir mountains along the Red Sea coast of Saudi Arabia and Yemen, which have dominated the landscape for hundreds of millions of years, the Hajar range is a relatively recent phenomenon, only 15 to 20 million years old. It is a geologically distinct feature, separate from the sabkhas and deserts.

The tall N – S trending mountains on the east, forming a natural boundary between Oman and UAE, are of great interest since they offer a relatively rare opportunity to examine oceanic rocks, such as basalts, lavas and oozes, formed at the site of a mid-oceanic ridge more than seventy million years ago (Lower Tertiaries).

During the Cretaceous period the movement of oceanic plates resulted in this segment of the earth's crust being dragged towards Arabia and eventually being pushed onto the edge of the peninsula. Great pressures were clearly involved in the process, altering crustal rocks and lavas into green-grey ophiolites and dark brown gabbros which we see today on the majestic craggy peaks south of Dibba and Masafi. At first this movement did not necessarily entail uplift of the oceanic rocks above sea-level, and they did in fact form a new sea-bed on top of which other sediments were deposited. This may be observed from the road to Hatta, and through Jebel Faiyah, where Upper Cretaceous limestones are resting on top of an older sea-bed of lavas.

Today's scenery is primarily a relic of the Ice Age during which a much wetter climate resulted in large rivers tearing down the mountains, cutting into their sides, and carrying vast quantities of gravel, pebbles and boulders. Once washed out, they formed huge alluvial fans, filling up the valleys and extending on to the surrounding plains. Since then, sun and wind have continued to weather rock surfaces while flash floods can still result in alluvial deposits.

The rocks of Permian, cretaceous and quaternary age are exposed in the main land. The autochthonous sediments of quaternary age are mostly confined towards the north eastern part of the country. Most of the rock in the sabkah desert reach is the deep to shallow sea bed deposits characterized by the gravely calcareous siltstones with capping of polymictic conglomerates. The depth of the gravelly siltstones is established up to +150 m. The allocthonous sedimentary group of rock like limestone of Permian to Cretaceous age is associated with the ophiolite suit of rocks. The coastal hill ranges on the eastern part of the country are occupied by the allocthonous basic flow/ ophiolite suit of rocks of cretaceous age. The rocks are intensely folded, faulted / thrusted and subsequently injected with the basic, acidic and calcareous intrusive. The dense flow rocks are of basaltic to dunitic to gabbroic to amphibolitic in composition, with olivine rich pockets (Herzburgite).

Urban developments in UAE

The UAE is becoming a hub for urban developmental activities, of the world. Some of the media reactions are as below:

- Demand for property in the United Arab Emirates is growing faster than developers can build. That's pushing up property sale and rental prices - the average cost of buying in Dubai is 6, 500 dollars a square meter.
- They range from a 95 billion dollar beach front project to a proposed one kilometer high tower.
- Expressions like 'global credit crunch' and 'recession' are mentioned at this year's Cityscape property exhibition but nothing has yet dampened the scale of new developments and it's showcasing.

For the construction of the above categories of structures a sound evaluation of the ground conditions is very much essential, for a proper design of the foundation. As per the law of the land the requirement of the geotechnical exploration/ investigation is mandatory for getting clearances for the design and construction of any proposed project. The Dubai Municipality has the sole authority for quality control and monitoring.

Over 35 geotechnical laboratories are operating in Dubai to cater to the needs of the construction industry and providing geotechnical services like drilling/ boring and testing of material, insitu testings, interpretations and reporting etc.

The geotechniques deployed, based on the general ground conditions for the determination and evaluation of foundation design parameters in the UAE are as follows:

Typical ground characteristics in UAE

Based on the geological setup and the ground characteristics the UAE can be classed in to four typical zones:

i. The Main Land

ii. Eastern hill ranges

iii. Eastern coastal range and

iv. The western coastal belt

The mainland is typically the gently undulating deserts, with an elevation difference of 2 to 65 m and covers about 70 % of UAE area, Under the 2 – 12 m thick aeolian sand, the inter bedded sequence of Permian calcareous arenaceous and argillaceous units, with inter beds of conglomerates, are noticed up to an established depth of 150m. A 0.5 to 2 m thick

Table 7: Deployment of geotechniques

Geotechnique	Material type	Project
Walk over surveys and mapping	-	For the reclaimed islands for detection of features like sink holes, water logging areas rock out crops etc. In slope stability problems. Canal projects
Trial pits	soil	For all categories of projects as per requirements for utitlity detections, bulk sampling of soil for contamination testing, field tests like plate load tests etc.
Boring/ drilling	Soil & rock	In all categories of projects as per requirements like field tests
Field tests (in bore holes):		In all projects for foundation assessment
Standard Penetration Tests (SPT)	soil	Villas, roads, resorts, towers/ buildings, metro projects, reclaimed lands etc.
Cone Penetration Tests (CPT)	soil	Towers, Multi storied buildings, in soils of reclaimed areas.
Resistivity Surveys	soil	Towers, buildings, determine thickness of soil, depth to bed rock etc.
Down hole seismic logging	Soil and rock	Deep foundations in rock for towers.
Cross hole seismic logging, cross hole tomography.	rock	High tower foundations in rock.
Permeability– Falling head Permeability– Packer tests	soil rock	In soils for multistoried buildings, towers, reclaimed lands etc. In rock for multi storied buildings/ tower projects, canals water storage projects etc.
Pressure meter tests	Soil & rock	For deep foundations in soil and rock for high rise buildings/ tower structures etc.
Plate load tests	Soil & rock	On soil and rock for specific projects like high rise building/ towers
Block shear tests	rock	
Laboratory tests: Soil		
Sieve analysis, moisture content, particle and bulk density, direct shear, triaxial and consolidation for cohesive soils, chemical tests- chloride, Sulphate, carbonate and pH, swell tests for swelling clays, proctor & CBR, organic matter etc. Contamination testing.	soil soil & water	In general for all projects depending on the soil condition and categories.
Laboratory tests: Rock		
Moisture content, density, specific gravity, direct shear test, triaxial test, chemical tests- chloride, sulphate, carbonate and pH, redox potential, electrical Resistivity, UCS, Modulus, point load.	rock	For deep and shallow and deep foundations for high rise build-ings, towers, industries.

crystalline gypsum/ anhydrite beds/ layer is noticed at shallow depths and as inter beds at varying depths. The rocks are unweathered to distinctly weathered (class A-C) at depth. Inter-beds of destructured (class D) rock mass are noticed at depth.

Most of the high rise buildings/ tower projects, Arabian canal, pipeline projects, Asia-Asia hotels and resorts, Bawadi project etc are located in this zone. The typical geotechnical characteristics of the main land are discussed below:

The standard penetrations (fig.6) are loose to medium dense (N= 10 -50) to a depth of 6 – 8 m bgl, below which very dense (N>50) destructured weathered (class D) rock mass is noticed up to depths of 10 – 15 m.

The underlying A – C class of rock mass are weak to very weak in strength (fig. 7 and 8).

The rock mass permeability is < 10 lugeon in an average (fig.9).

The eastern hill ranges are defined with steeply rising conical to curved peaks. The drainage system is structure controlled. The mid tertiary basic flow rock like gabbros, dunites, amphibolites and olivine rich ophilitic suit of rocks are exposed with steep easterly dips of 30 – 45°. The older Permian limestones are exposed as outliers within the flow rocks. The flow layers are differentiated with highly weathered klinkery, vescicular tops. The flow rocks are a good source for aggregates, road base material amrock/ rip rap material. The lime stones are of good grade and cater to the cement plants in the area.

The eastern coastal belt between the foot hills and the sea have relatively gentler slopes towards the sea, and occupied by thick (established up to 25 m depth) gravely to bouldery (mostly of basic rocks) sand of quaternary/ ice age. The area has a top soil cover of 2 – 3 m thickness of recent sediments of mostly fine silt, deposited during the sea level changes. The gravelly to bouldery sand formation is very dense (N>50) but highly permeable. A number of pipeline, desalination & power plant projects are designed for structural foundations, cutoffs in the material.

The western coastal belt is gently sloping towards the Arabian gulf sea and is covered with beach sediments of fine sand. Recent sediments of fine silt are noticed to a depth of 8 – 10 m locally, which were deposited due to the eustatic/ sea level fluctuations. The calcareous sandstones are noticed to a depth of 15 – 20 m under lain by the gravely calcareous silt stones. A distinct layer of Very dense (N>50) Class 'D' sandstone is noticed under the recent sediments and as interbeds with in the bedrock are noticed at depth.

A number reclamation projects like palm Jumairah, Plam Jebel Ali, World islands, Marjan Islands, many tower projects, promenade and jumairah garden city etc. are under construction or constructed in the area/ zone.

The developmental projects in the UAE

The various categories of developmental projects under construction or on the anvil are as follows:

- Buildings, Villas, small houses, Resorts Spa's and Marinas.
- Roads and highways Rapid transit system/ metro railways.
- Multi storied Buildings/ Tower structures
- Reclamations in the Arabian gulf and gulf of Oman
- Canals and related developments in the deserts/ main land.
- Development of rock quarries for aggregates, amrock, rip rap stones/ blocks etc.
- Desalination & power plants, Cement and glass plants / industries.
- Oil and Gas pipeline projects/ pipe line diversion projects

Construction of buildings and villas are in thousands. The mandatory investigations are done for each villa and building. The eastern and western coastal belts of UAE (Dubai, Rasal Khaima, Fujairah and Umal Quwain) are dotted with developments of sea resorts, spas and marinas. The geotechnical investigation report is mandatory for obtaining clearance for construction from Municipalities of respective states. A number of sea resorts with marinas and spas are developed/ constructed on the coasts of Fujairah, Rasal Khaima, Umal Quwain and Dubai. All these constructions require geotechnical investigations to determine and evaluate the ground characteristics for the design of structures.

Special mention here is about the Asia- Asia hotel, Bawadi. Bawadi is an ambitious tourism project that was launched on May 1 2006 by Sheikh Mohammed bin Rashid Al Maktoum, Prime Minister and Vice President of the United Arab Emirates and Ruler of Dubai.

The project being managed by Tatweer will cost AED 200 billion. It will be located on a 10 km strip at Dubailand and comprise 51 hotels with 60,000 rooms, theatres and shopping malls. The first hotels are expected to open in 2010, with the remainder complete by 2014. Bawadi will also be the world's biggest shopping area. Total retail space will be in excess of 40 million square feet.

Roads, highways and flyovers are constructed in hundreds. 12 lane roads are constructed in Dubai to meet the traffic congestions. Geotechnical investigations are done for the roads, flyovers, bridges, sign posts, cross over's, interchanges etc.

Dubai Metro: The Dubai Metro is a driverless, fully automated metro network which is under construction in the United Arab Emirates city of Dubai. The Red and Green Lines are under construction, and further lines are planned. These first two lines will run underground in the city centre and on elevated viaducts elsewhere. The Dubai Metro will be the longest fully automated rail system in the world when it opens in 2009.

Red Line: 50 kilometres line with 35 stations from Jebel Ali Port, the American University in Dubai, through the city centre to Al Rashidiya.

Green Line: 20 kilometres line with 22 stations from Festival City, through the city centre, Dubai International Airport Terminal 2 and the Airport Free Zone.

Proposed

- **Blue Line**: 47 kilometres line along Emirates Road, exact route currently unknown.
- Purple Line: 49 kilometres line along Al Khail Road, meant to be an express route between Dubai International Airport and Al Makt-oum International Airport.

The Dubai Metro will be operated by Serco under contract to the Dubai Roads & Transport Authority. Dubai Municipality Public Transport Department expects the metro to carry 1.2 million passengers on an average day, Bus routes and stops will be organised around the backbone provided by the metro system. Taxi stations and park-and-ride facilities will be included in key Metro stations.

Ground works began in February 2006, centered around the 52.1km Red Line. In August 2006 a second contract worth US$.12bn was awarded to the MHI consortium for building the 17.6km Green Line, intersecting with Red Line at two stations.

Underground sections in the city centre are on the Red Line. Elsewhere, trains will run on elevated viaducts, the design and aesthetics developed specifically to enhance the urban architecture along its corridor. In no location will tracks cross highways, ensuring full mode segregation. A key objective is to minimize the impact on road traffic and on city life during the works. All stations, elevated or underground, will feature platform screen doors for passenger safety and facilitating full air conditioning.

Table 8: List of important Skyscrapersin dubai.

Skyscraper	Height	Expected Competition
1. *Burj Dubai*	705m	2008
2. Burj Al Alam	484 m	2009
3. Ocean Heights	460 m	2010
4. Princess Tower	414 m	2009
5. Marina 101	412 m	2010
6. 23 Marina	395 m	2008
7. Emirates Park Tower 1 & 2	395 m	2009
8. Elite Residence	380 m	2010
9. Infinity Tower	372 m	2009
10. Almas Tower	360 m	2007
11.The Torch	345 m	2008
12. Al Sharq Tower	342 m	2009
13. Rose Tower	333 m	2006
14. Al Durrah Tower II	330 m	2008
15. Infinity Tower	330 m	2009
16.Al Yaquob Tower	330 m	2008
17. The Skyscraper	330 m	2008
18. The Index 2	328 m	2008
19. Four Seasons Dubai Festival City	320 m	2009
20. Ocean Heights 1	310 m	2008
21. Burj Dubai Lake Hotel	306 m	2008
22. Ahmed Abdul Rahim Al Attar Tower	301 m	2007

The geotechniques applied were boring, drilling, SPTs, CPTs, extensive laboratory tests, electrical resistivity survey, pump out tests, plate load tests, down hole seismic logging etc.

Multi storied Buildings/Tower Structures

Dubai is one of the most beautiful cities in the world, it can be considered as a World Wonder.

Dubai skyscrapers *of over 300 m (978 ft), which are under construction, are shown in the following table.*

Burj Dubai: *The world's tallest building - Burj Dubai - reaches 705m and it's still growing. The statistics are almost as spectacular as the view.*

This is Burj Dubai and, once again, the editors of the Guinness Book of Records have got to rewrite the chapter on buildings. This is not simply the tallest structure in the world; it smashed the tallest building record a year ago and, this April, it overtook the world's tallest antenna.

Now it has gone one further. As of this week, Burj Dubai - meaning 'Dubai Tower' - has officially become the tallest man-made thing ever.

From its 2,257ft (688m) peak, you do not merely view the entire Gulf state of Dubai. On a good day, you can see 100 miles away into sunny Iran. and the Burj Dubai has not stopped growing.

It already boasts 160 floors and the developer, Emaar, is adding new ones at the rate of around one per week. Its eventual height remains a secret in order to confuse any rival constructors.

'Only a handful of senior designers know the final idea,' says project director Greg Sang, adding that Dubai's ruler, Sheikh Mohammed Al-Maktoum, is also in on the plot. Every tool is attached to its user by a lanyard and safety codes are rigidly enforced among all 5,000 construction workers. Thus far, the project has claimed two lives. New Zealand-born Greg, 42, has built several skyscrapers, including an 88-storey tower in Hong Kong.

But the developers point out that this building is made from heavyduty concrete, whereas the World Trade Centre, which collapsed after the 9/11 attacks of 2001, was a steel frame. The supporting pillars have been designed with a 'long-wave' effect to absorb any earthquake activity along the Iran/Iraq fault line. The foundations drop 150ft (46m) below ground and the three pronged 'footprint' of the building replicates the design of a desert flower.

The Burj Al Arab- Arabian Tower (the world's costliest hotel) designed to resemble a billowing sail, the hotel soars to a height of 321 metres, dominating the Dubai coastline. Construction of Burj Al Arab began in 1994. It was built to resemble the sail of a dhow, a type of Arabian vessel. Two "wings" spread in a V to form a vast "mast", while the space between them is enclosed in a massive atrium.

At night, it offers an unforgettable sight, surrounded by choreographed colour sculptures of water and fire. This all-suite hotel reflects the finest that the world has to offer.

Several features of the hotel required complex engineering feats to achieve. The hotel rests on an artificial island constructed 280 meters offshore. To secure a foundation, 230 40-meter deep concrete piles were driven into the sand.

Engineers created a surface layer of large rocks, which is circled with a concrete honey-comb pattern, which serves to protect the foundation from erosion. It took three years to reclaim the land from the sea, but less than three years to construct the building itself. The building contains over 70,000 cubic meters of concrete and 9,000 tons of steel.

Inside the building, the atrium is 180 meters (590 ft) tall. During the construction phase, to lower the interior temperature, the building was cooled by one degree per day for over 6 months. Burj Al Arab characterizes itself as the world's only "7-star" property, a designation considered by travel professionals to be hyperbole. It is the world's tallest structure with a membrane facade and the world's tallest hotel (not including buildings with mixed use) and was the first 5-star hotel to surpass 1,000 ft (305 m) in height.

Dynamic Towers: And now a new star is rising. Dubai's Dynamic Tower (fig.17), the first skyscraper in the world that actually changes shape. Each floor moves independently of others causing the building to look dramatically different, and that too in a very organic way. The technology behind this kind of construction will be key for green buildings lined with solar panels that twist and turn towards the sun. In order to keep things cooler, perhaps floors will keep rotating at a certain speed so no one side spends too much time in direct sunlight. The possibilities are numerous before we even get to the pure architectural interest that the Dynamic Tower presents.

So, when you talk about the **Dynamic Tower** coming up in the UAE, perhaps the noteworthy part of the story is not merely the tower's ability to shift its shape, but the shift of influence and innovation this structure represents. A shift in the balance of power.

Sama Dubai Towers located in the Lagoons area of Dubai. The architect inspired by the flames of a candle, designed the towers in the shape of flames (fig.18).

It will be a dizzy little addition to "The Lagoons" business district. Designed by Thompson, Ventulett, these four towers will be completed in mid 2010. Even though this is to be completed within 24 months, there is very little info about this building. Some of the features are:

- The towers will range from 57 to 94 floors in height, the tallest topping off at 400 meters.

- The tenants will be a healthy potpourri: apartments, hotels, restaurants, shopping
- They are supposed to represent candlelights (which they do)

What's hard to understand is how tall these buildings are. They are being built near the airport, so their height is restricted, but they are still giant. That tall one is almost as tall as the Empire State Building.

Dancing Towers is a three tower project being built among the commercial towers in Dubai Business Bay, located on Sheikh Zayed Road next to Burj Dubai Downtown. The tower was designed by Iraqi-born female architect Zaha Hadid. Dancing Towers form the centerpiece of the Business Bay and consist of one office, one apartment and one hotel tower. The three towers share a common podium featuring retail, restaurants and related amenities. The office and hotel towers are connected at the base, while the hotel and apartment towers are connected at the top. The three towers will also be connected together at its top, to share a panoramic restaurant with views of the Dubai Creek and Business Bay. Expected Completion in 2009.

Al Burj: Nakheel plans to build the world's tallest tower, at over a dizzying one kilometre high,joining the ranks of companies in the region furiously trying to achieve the same feat.Nakheel Harbour and Tower will be a 270 hectare development, stretching between phase two of Ibn Battuta shopping mall and the 75-kilometre Arabian Canal.

The one-kilometre-high tower will be the centre-piece of the area.The tower will have more than 200 floors and will take an estimated 500,000 cubic metres of concrete to construct. Reinforcing bars used in the tower's construction could stretch from Dubai to New York, if laid end-to-end. The building is so tall that it will experience five different microclimatic conditions from top to bottom. Architect: Pei Partnership Architects. Materials to be used- glass, steel, concrete, reinforced.

Land Reclamation projects

A number of land reclamation and development projects are under construction in the whole of UAE in the Arabian gulf and the gulf of Oman along the shores of Dubai, Ras Al Khaima, Umal Quwain and Fujairah.

The Palm Jumeirah: The first of the Palm Islands to be launched, Palm Jumeirah represents one of the most exciting property developments of all time. This man-made island, off Dubai's popular coastline will cover an area of 7 million square meters and is surrounded by a 12 kilometre-long crescent shaped breakwaters. Over 220 kilometres of beach front will be offered on Palm Jumeirah.

The Palm will offer residents a choice of some 2,000 villas from exclusive

Signature Villas to beachfront Garden Villas and Town Houses

In addition there are 2,500 luxury apartments in a variety of styles and surroundings. Visitors and residents to Palm Jumeirah will be spoilt by the world-class hotels on the trunk and crescent of the Palm, the 220 boutique shops and restaurants on the famous Golden Mile, two marinas, spas and other first class facilities

The Crescent is 12 kilometres long and surrounds the island, acting as a breakwater. This breakwater has been designed by international specialists and is able to withstand a fourmetre wave. The Crescent on Palm Jumeirah will be one of the most desirable hoiday destinations in the world, featuring 22 boutique hotels, each with its own theme

The Crown of the Palm consists of seventeen fronds. Each of the fronds provides residents a fabulous beachfront home in private surroundings. Buyers can choose from a wide range of different styled themed properties, ensuring that this is truly their dream home.

The Trunk of the Palm will be home to some of the most luxurious apartments in the Dubai property market. At nearly half a kilometer wide, it will act as the central point of the palm Jumeirah with theme parks, marinas, shopping malls and restaurants. It will also feature a monorail system for the convenience of residents and guests.

Marina Village Apartments

Oceana is a major apartment project on the Palm Jumeirah. Located on the trunk of The Palm comprises of seven buildings. Each building comprises of 1, 2 and 3 bedroom apartments offering owners spacious living accomodation, high quality finishes and panoramic views to the garden, beach and marina.

Dubai Water front: Located on the western shores of Dubai, Waterfront will transform 1.4 billion square feet of empty desert and sea into an international community – for an estimated population of 1.5 million, i.e.

twice the size of Hong Kong Island. Waterfront is being developed on the last 15km of natural coastline in Dubai and will provide more than 70 km of coastline in total, including the development of 23% of Dubai water front- master plan the Arabian Canal. Waterfront's location ensures it is easily accessible on a local, regional and international basis. Waterfront will comprise a wide variety of residences, commercial districts and industrial areas, with a number of major tourist attractions and leisure amenities that are expected of a city for more than a million people. In addition to the high-end residential and business properties, Waterfront will also provide a range of affordable housing for Dubai's working community.

Waterfront is on a track to become a landmark sustainable city founded on resource efficiency, social equity, and economic prosperity. Energy and water conservation are achieved through integration of utilities in dedicated utility centres, where process streams are interlinked and waste is transformed into energy to power the city.

The world- Islands: The World is a man-made archipelago of 300 islands constructed in the shape of a world map and located 4 kilometres

(2.5 miles) off the coast of Dubai, Arab Emirates. Palm

Islands. Like the other artificial island projects, The World is built primarily using sand dredged from the sea. It was developed by Nakheel Properties and was originally conceived by Sheikh Mohammed bin Rashid Al Maktoum, the ruler of Dubai [*| In-line.WMF. The World is one of several artificial island projects being constructed in Dubai, others being the :

Al Marjan Island

Al Marjan Island is an offshore island tourism development being built in the south-west of Ras Al Khaimah. The US$ 1.8 billion (AED 6.6 billion) project will be located close to the Al Hamra Fort hotel and Al Hamra Village, approximately 27 kilometers (17 miles) from the city's center.

Al Marjan Islands will comprise of five man-made coral shaped islands, covering over 2.7 million square metres (29 million square feet) and extend approximately 2 kilometers (1.24 miles) into the Arabian Gulf. It will contain 10 major hotel sites, 50 large villa sites, a marina and marina village, and a water theme park. Land reclamation of Al Marjan Island is expected to be finished by the end of 2007 and the development was masterplanned by Halcrow International.

'Marjan Island is indeed a magnificent feat of engineering envisioned by the RAK Investment Authority under the patronage of the Government of Ras Al Khaimah. Only 45 minutes from Dubai International Airport and 15 minutes from RAK International Airport, La Hoya Bay Residence is the perfect location for either a permanent home, a weekend get away or a wise investment.

Al Marjan Island Sub-Developments

The Gateway - commercial and residential development being built in five phases to

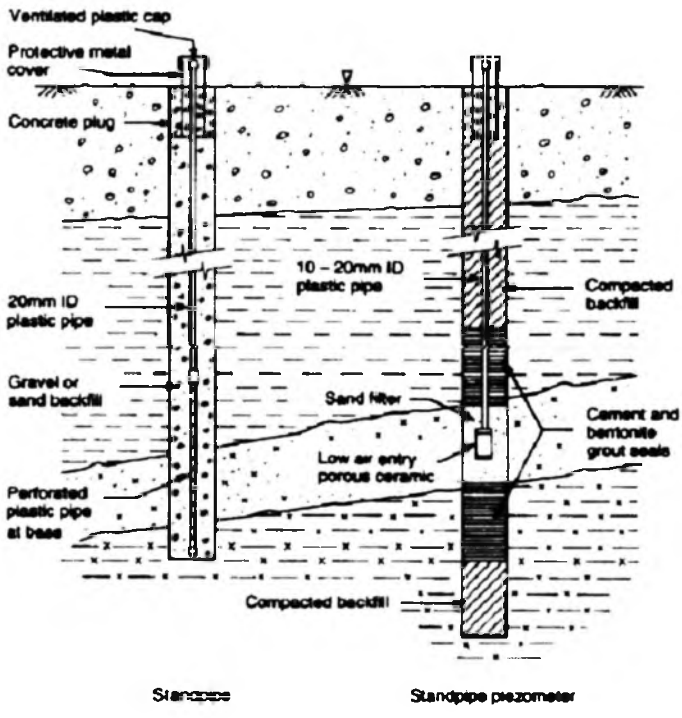

Fig. 1: Standpipe and standpipe (or Casagrande) piezometer.

Fig. 2: Relationships of quality concepts (BS 5750: part 0: section 0.1: 1987).

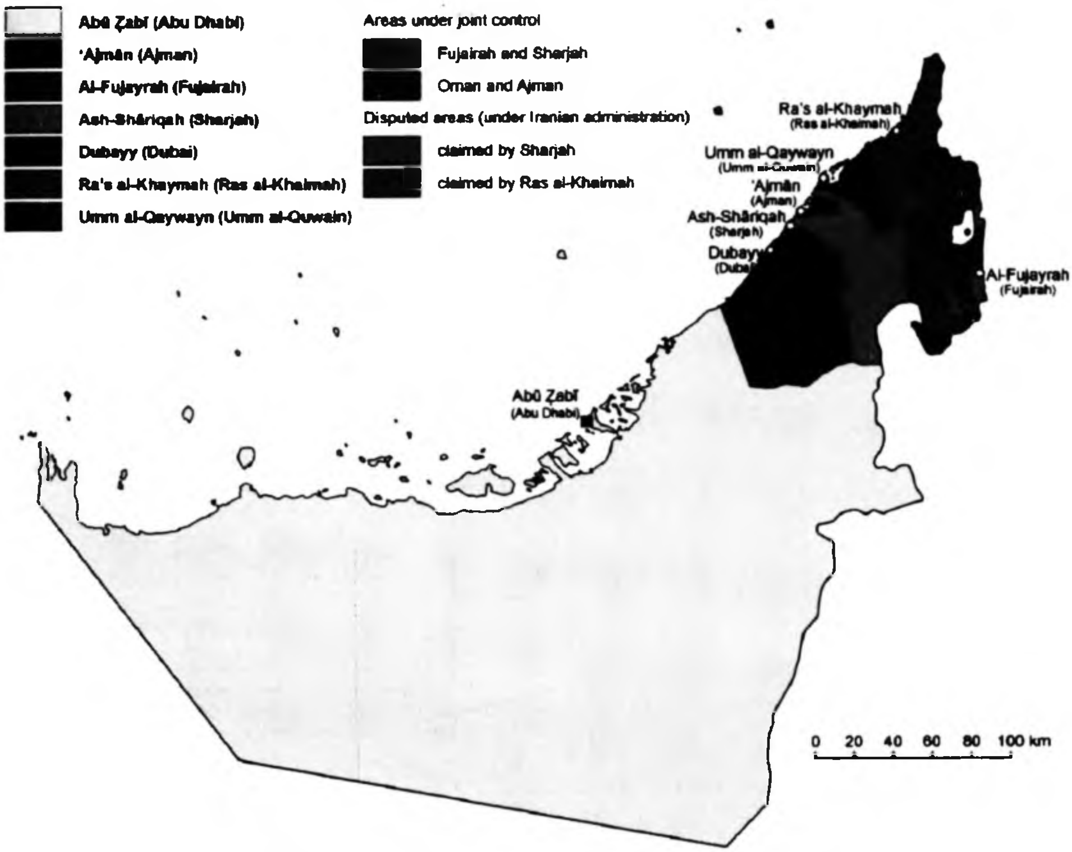

Fig. 3: Regional setup of UAE

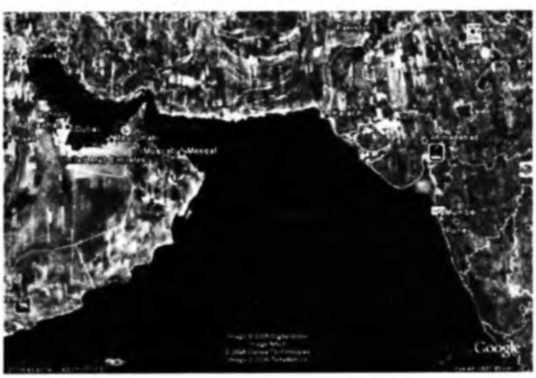

Fig. 4: Administrative setup of UAE

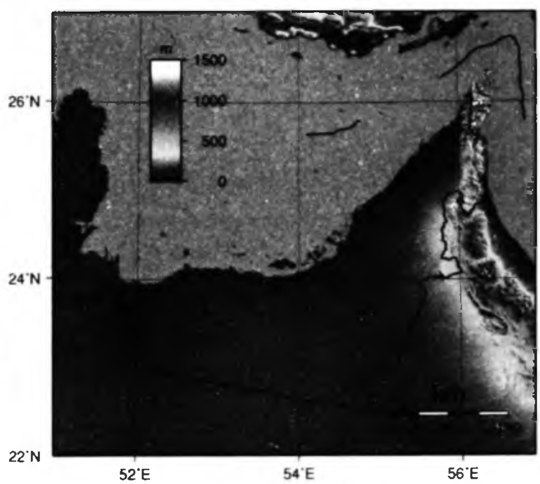

Fig. 5: Topography of UAE

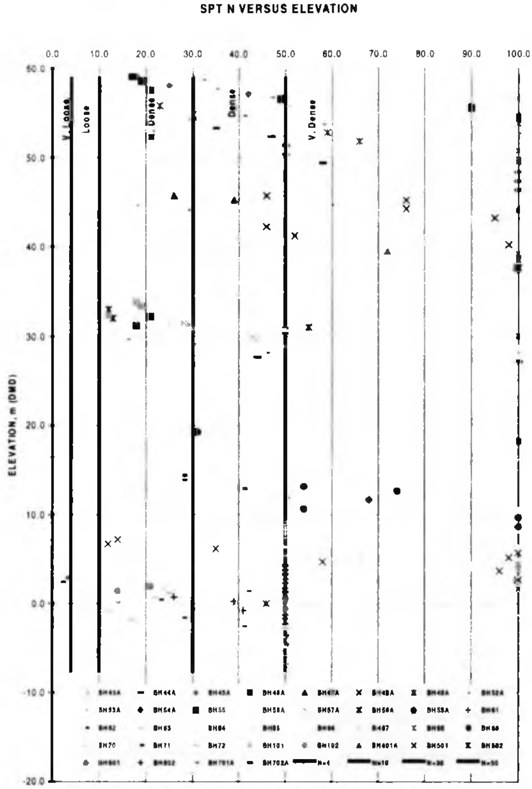

Fig. 6: Typical Standard penetrations in Soil of main land

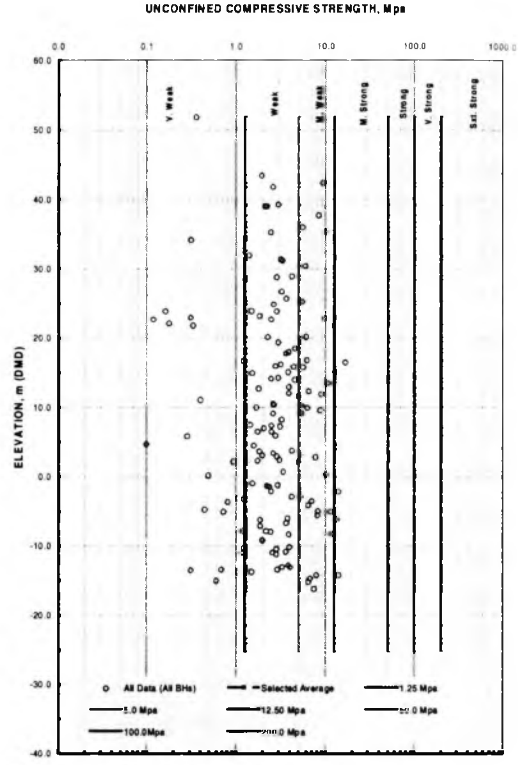

Fig. 7: Typical UCS in rock

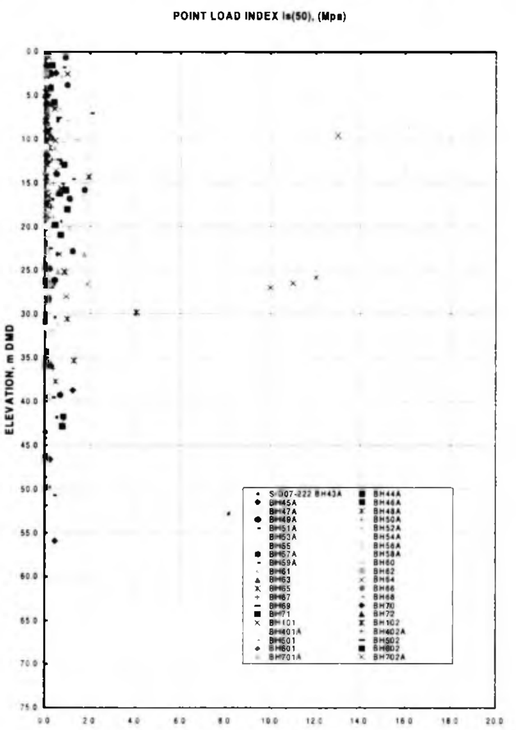

Fig. 8: Typical point load index

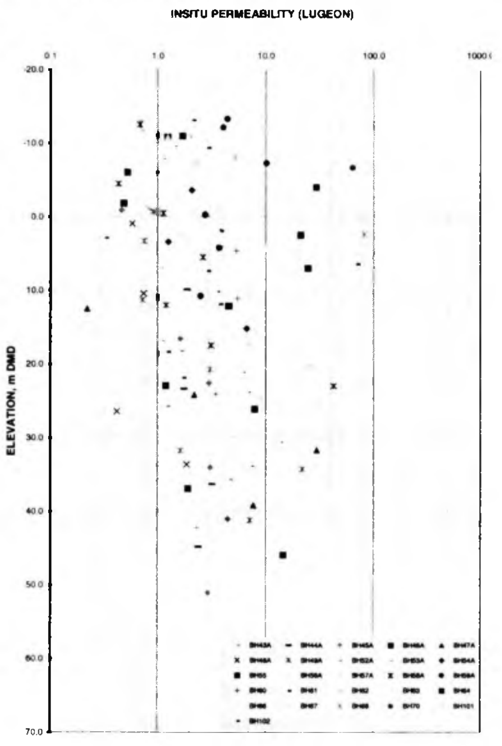

Fig. 9: Typical permeability in rock mass

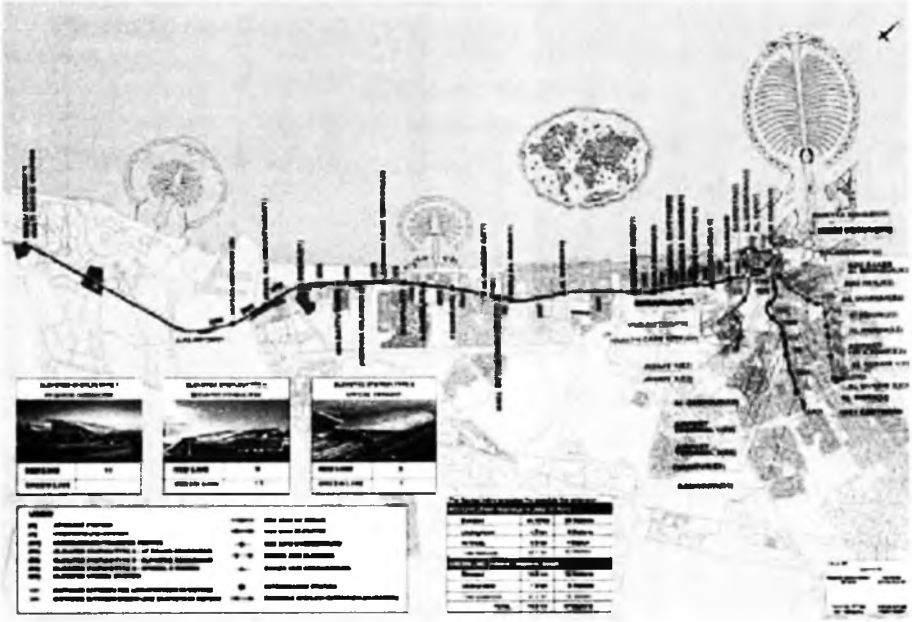

Fig. 10: Layout of Metro project

Fig. 11: Metro under construction

Fig. 12: Metro on trial run

Fig. 13: Burj Dubai under construction.

Fig. 14: Burj Dubai in shape

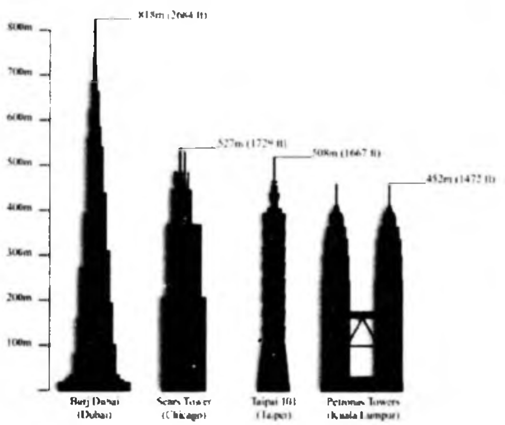

Fig. 15 : Status of Burj Dubai in the world

Fig. 16: Burj Al Arab


Fig. 17: Dynamic Towers


Fig. 18 : Sama Dubai Towers


Fig. 19: The Dancing Tower

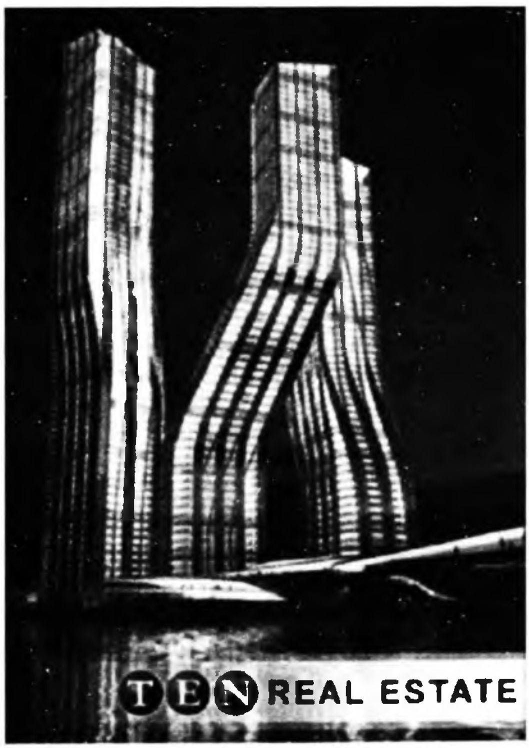

Fig. 20: The Al Burj Tower


Fig. 21: Palm Jumeirah

Fig. 22: Dubai water front

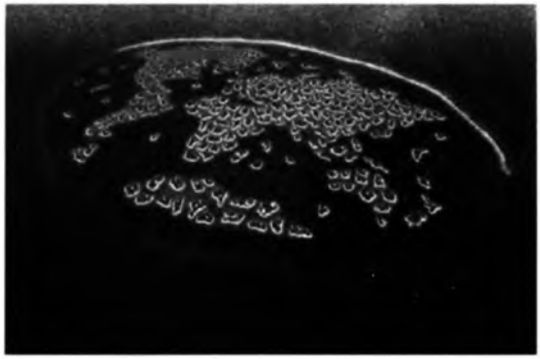

Fig. 23: The world – Islands

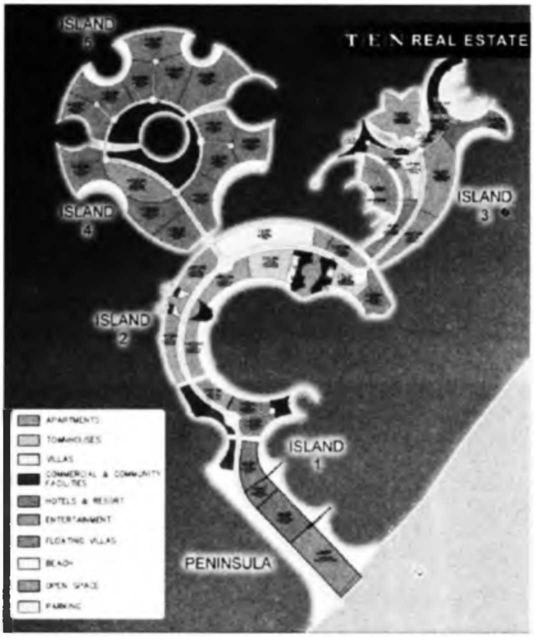

Fig. 24: Al Marjan Island

accomodate 50 thousand residents to be complete by 2012.

Arabian Canal

The Arabian Canal will be world's longest man-made canal, at 75 km long. The excavation of the Arabian Canal will start near the Dubai Marina area flowing inland around the massive area for planned Jebel Ali International Airport and wind its way to enter the sea once again at the outer end of Palm Jebel Ali. Dubai Waterfront forms the first phase of the larger Arabian Canal effort.

Fig. 25: Dredging for forming the island

The Arabian Canal will give rise to some truly unbelievable developments even by Dubai property standards. The delta forms the base from which Dubai Waterfront will extend several kilometers out into the sea, far beyond Palm Jebel Ali. The Palm Jebel Ali will form about a fifth of the massive reclaimed component of the project. The Dubai Waterfront took two years to plan and is bigger than Manhattan and Beirut in size. The first phase of the project will concentrate on building Madinat Al Arab, a downtown type metropolis.

The site is characterized by typical sabkah desert topography with sand dunes and intervening low land areas. The exploratory bore hole logs indicate a top thin cover of aeolian sand under which a distinct polymictic conglomerate bed of 0.50 – 4.0 m thickness is encountered. Underlying the conglomerates unweathered to distinctly weathered (Class A/C) calcareous siltstones and locally calcisiltite are noticed to an explored depth of +150 m. Interbeds of 0.20 – 4.5 m thickness, of partially to destructured (weathering class B – D) weathered conglomerates, silt stone calcareous sandstone are noticed at various levels. The beds are sub-horizontally disposed with low dips of 2 - 10°. The water table in the area varies from 1 – 10 m bgl.

Dubai promenade

The project is a mixed use development as follows:

The Dubai Promenade project site is located within the Dubai Marina development at south west of the channel entering Dubai Marina. The general site location is shown in the following photograph, which shows parts of Palm Jumeira Island. The significant features of the project are:

The Channel Towers project consists of three towers of different heights ranging from 181 – 200 m, with 44 to 49 stories.

The Icon Hotel: Is a wheel shaped building with 40 storey sitting on top of a 4 storey podium containing the car parking, services and other facilities. The project consists of tower, wings and podium at different levels.

The Marina Towers: The Marina Towers consists of two 48 storey towers and one 44 floor tower.

The Beach Towers: The Beach Towers consists of two 55 storey towers.

The Boutique Hotel: A 200 key hotel with 17 storeys.

The Office Tower: The Office Tower Consists of 14 storeys above a Podium.

A 4 Storey Podium: The podium joins all the above buildings, except for the Icon Hotel which has its own dedicated podium. Contains car parking, service tunnel and other services that are shared by towers. The Podium top is landscaped and provides the primary entry to the parking for retail and tower visitors and an optional entry point for the Tower residents.

The Promenade Retail Link: The Retail Link consists of around 26,000m^2 of retail end amenities.

The Amphitheatre: An amphitheatre with approx. 300 seats, forms an integral part of the hard and soft landscaping of the Pier. The space offers possibilities for different kinds of venues such as: shows, outdoor cinema, small concerts. It can also be used as an exhibition space.

Private and Public Spaces: The development is divided into two different access zones, one which is for residents alone and one which is accessible to the general public.

A detailed investigation for the complete features was carried out to assess the parameters for foundation designs, deploying various geotechniques, discussed earlier.

Jumeirah garden city is an environmentally green city Jumeirah Garden City is the proposed name of the redevelopment of the area behind the Sheikh Zayed Road/Trade Centre, between the World Trade Centre roundabout and Al Safa park. It involves demolition of existing housing in the Al Wasl and Satwa Areas. Eviction notices were served to residents at the beginning of 2008.The developer is the Meraas Investment Company.

The geotechnical investigations for the villas, tower , canals gardens etc. were carried out deploying specific geotechniques. Bore holes up to 150 m have been drilled to explore the ground.

Reclamation on the Fujairah coast line : Reclamation works are on in the gulf of Oman for developing resorts with marinas and spas to promote tourism. One such Resort is Mina Al Fajer Project which is under constructed on the terraced hills with a sea view, with a marina and spa in the reclamations.

The assessments for foundation, reclamations and slope stability were assessed through different geotechniques for the design evaluation.

Conclusions

There is a long list of things that were unimaginable until they were done in Dubai, including the world's largest indoor ski slope with its own ski lift, the largest man made islands in the world. The upcoming underwater hotel marks yet another exciting marvel for tourists and visitors. What makes this all possible. Many assume Dubai's economy is supported purely by oil and that if it weren't for oil, everything in the state would be unsustainable. Well, consider that over 70% of the UAE's GDP comes from non-oil sources such as Tourism and Finance.

Fifty per cent of the world's supply of cranes are now at work in Dubai on projects worth $100 bn, twice the World Bank's estimated cost of reconstructing Iraq and double the total foreign investment in China, the word's third-largest economy. The amount of architectural innovation stemming from the increasingly audacious projects being pursued in Dubai is staggering.

Many ask, where does this madness end? The question is sometimes motivated by the assumption that this grandiose must obviously be unsustainable, and geotechniques play a major sustainable role in its' technicalities.

But there is also a downside to the glistening towers that soar above the shopping malls, the six lane highways and the world's only seven-star hotel with suites that can cost $50,000 (£28,000) a night. More than 2,500 workers at the site of the world's tallest building, the 800 m Burj Dubai, went on strike last week in a country where striking and unions are illegal.

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References

From different sources on the internet, personal communications and unpublished reports.