

Recent Challenges in Geotechnical Features in Dubai, UAE

1st MYGEC

23rd-24th September 2019 – Bodrum/TURKEY

dar



Dar Al-Handasah Consultants (Shair&Partners)



Experience & Invited Speaker

An international, multidisciplinary Consultancy with expertise in Engineering, Architecture, Planning, Environment, Economics, Project & Construction Management.

Founded in **1956** and since **1970** operating in UAE:

- **5 Principal Design Offices** in Beirut/Lebanon, Cairo/Egypt, London/UK, Pune/India & Amman/Jordan.
- **Design Studio in Dubai.**
- **40 Permanent Local Offices** operating throughout the Middle East, Africa, Asia & Europe.
- **~10,000 Qualified Professionals**, including engineers, architects, town planners, environmentalists, economists, financial experts, marketing and management specialists; quantity surveyors and many others.
- Having worked with more than **950 clients** from **over 63 countries**.



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ENR 2019 TOP 225 INTERNATIONAL DESIGN FIRMS RANKING



- Ranked among the top ten consultancies by Engineering News Record (ENR) for over 30 years.

RANK 2019	RANK 2018	FIRM	FIRM TYPE
1	**	WOOD, Aberdeen, Scotland, U.K.†	In one of the most prominent success stories for this year, Dar Group placed 1 st in Africa, rising from 5 th last year. The company also ranked 3 rd in the Middle East and 6 th in the United States. By market, the Group placed 2 nd worldwide in building and 5 th in transportation.
2	4	WSP, Montreal, Quebec, Canada†	
3	1	JACOBS, Dallas, Texas, U.S.A.†	
4	2	AECOM, Los Angeles, Calif., U.S.A.	
5	5	ARCADIS NV, Amsterdam, The Netherlands†	
6	3	SNC-LAVALIN INC., Montreal, Quebec, Canada†	
7	9	WORLEYPARSONS LTD. (TRADING AS WORLEY), North Sydney, NSW, Australia	
8	8	STANTEC INC., Edmonton, Alberta, Canada†	
9	7	DAR GROUP, Dubai, U.A.E.†	
10	6	FLUOR CORP., Irving, Texas, U.S.A.†	
11	12	KBR INC., Houston, Texas, U.S.A.†	
12	16	RAMBOLL GROUP A/S, Copenhagen, Denmark†	
13	14	ARUP, London, U.K.†	
14	15	SWECO, Stockholm, Sweden	

4		MIDDLE EAST
RANK 2019 2018		Top 10 Revenue: \$5,150.7 Mil. Regional Revenue: \$10,107.4 Mil.
1	1	TECNICAS REUNIDAS
2	3	KBR INC.
3	2	DAR GROUP
4	**	CHINA ENERGY ENGINEERING CORP. LTD.
5	**	WORLEYPARSONS LTD.
6	6	SNC-LAVALIN INC.
7	5	AECOM
8	7	KHATIB & ALAMI
9	8	JACOBS
10	**	MAIRE TECNIMONT

LOCAL CODES & REGULATIONS

Location of DUBAI within United Arab Emirates-UAE



Emirates of United Arab Emirates - UAE

1. Abudhabi (largest emirate)
2. Ajman (smallest emirate)
- 3. Dubai (2nd largest emirate)**
4. Fujairah
5. Ras al-Khaimah
6. Sharjah (3rd largest emirate)
7. Umma al-Quwain

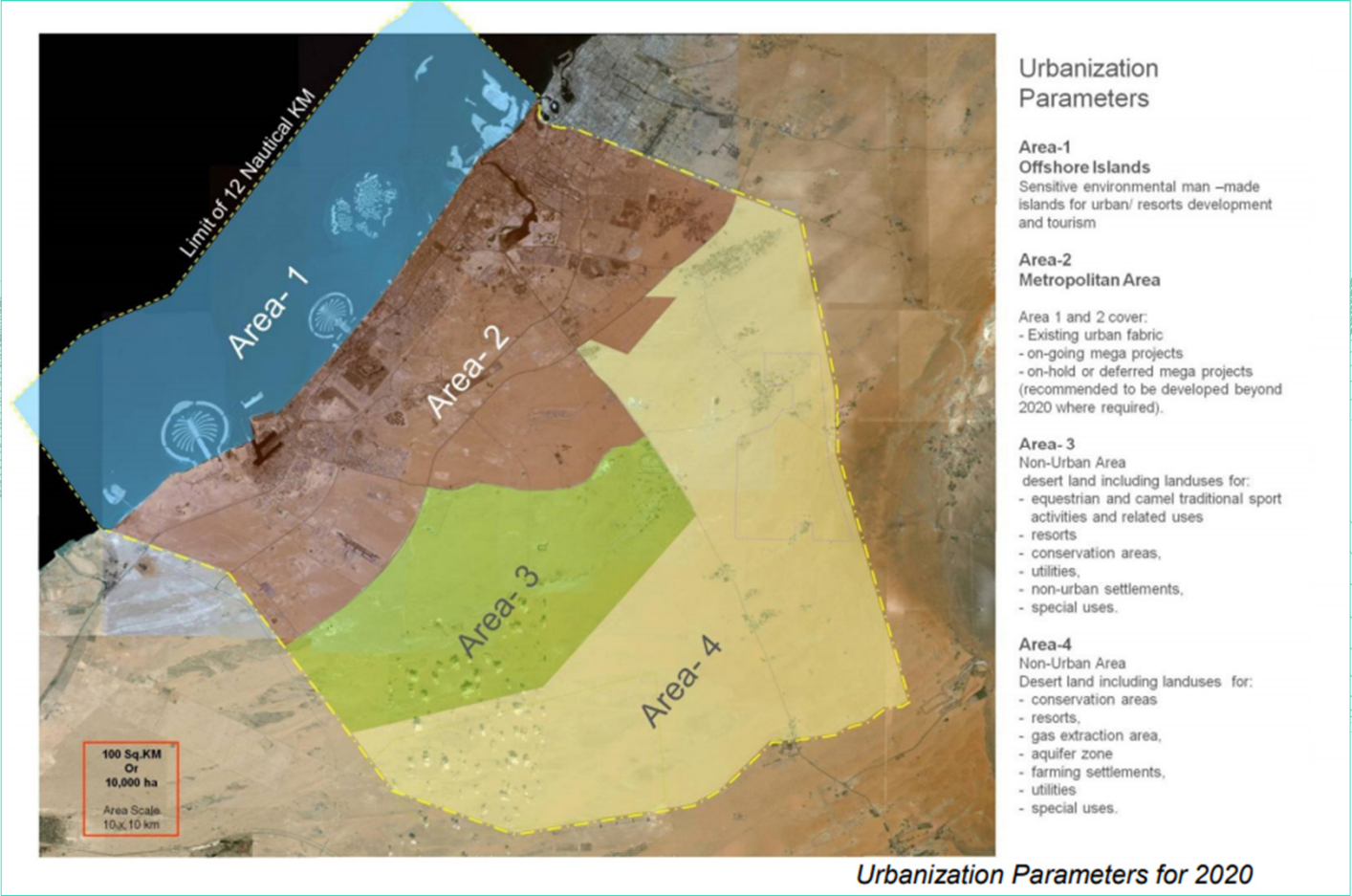
Geography: 83,600km² (total area,
including islands)
Dubai 4,114km² (~5%)

Population: 9, 630, 959 (2018 mid-year)
Dubai 3,192,275 (~35%)

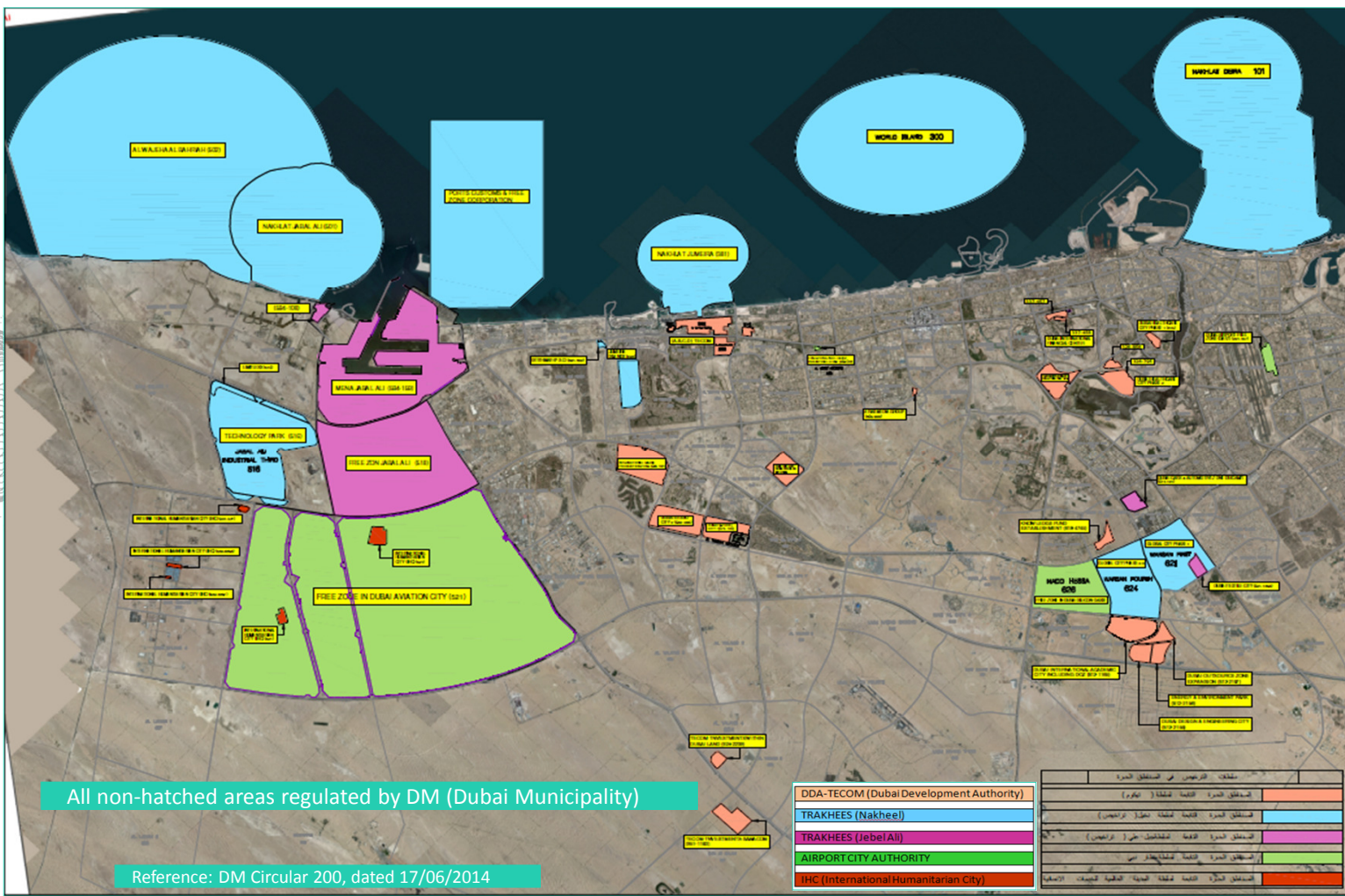
References: government.ae & data.worldbank.com



Location of DUBAI within United Arab Emirates-UAE



Regulatory Authorities



Regulatory Authorities



GOVERNMENT OF DUBAI

Structural:

- ZA-DC-REG-03 Structural Regulations for Buildings, Issued January 2008
- ZA-DC-GD-01 Traffic Safety Guidelines, Issued March 2008
- ZA-DC-REG-01 Health Safety and Environment Regulations, issued October 2007

Circular 312: proposed workshop on

Dear Customer,

Dubai Development Authority, Structural department proposes (to be announced later) on Structural design requirements. This workshop will review performance and to remove constraints/conflicts between the Development Authority (DDA), which will enhance your business and safety.

1. Geotechnical Soil Investigation
2. Excavation
3. Shoring
4. Soil Improvement
5. Piling
6. Others

to be addressed during the workshop.

Note: RSVP by submitting the form prior to 15th April, 2018



GOVERNMENT OF DUBAI

دولة دبي
دولة دبي
دولة دبي

اشتراطات اختبارات التربة والأساسات

Soil and Foundation Testing Guide

إدارة المباني

Dubai Municipality

Date : 23/7/2006
Ref : 812/02/02/1/16529

Circular No. (141)

To all engineering consultant offices, shoring work contractors and main contractors

In connection with

Procedures for licensing and execution of excavation and shoring works



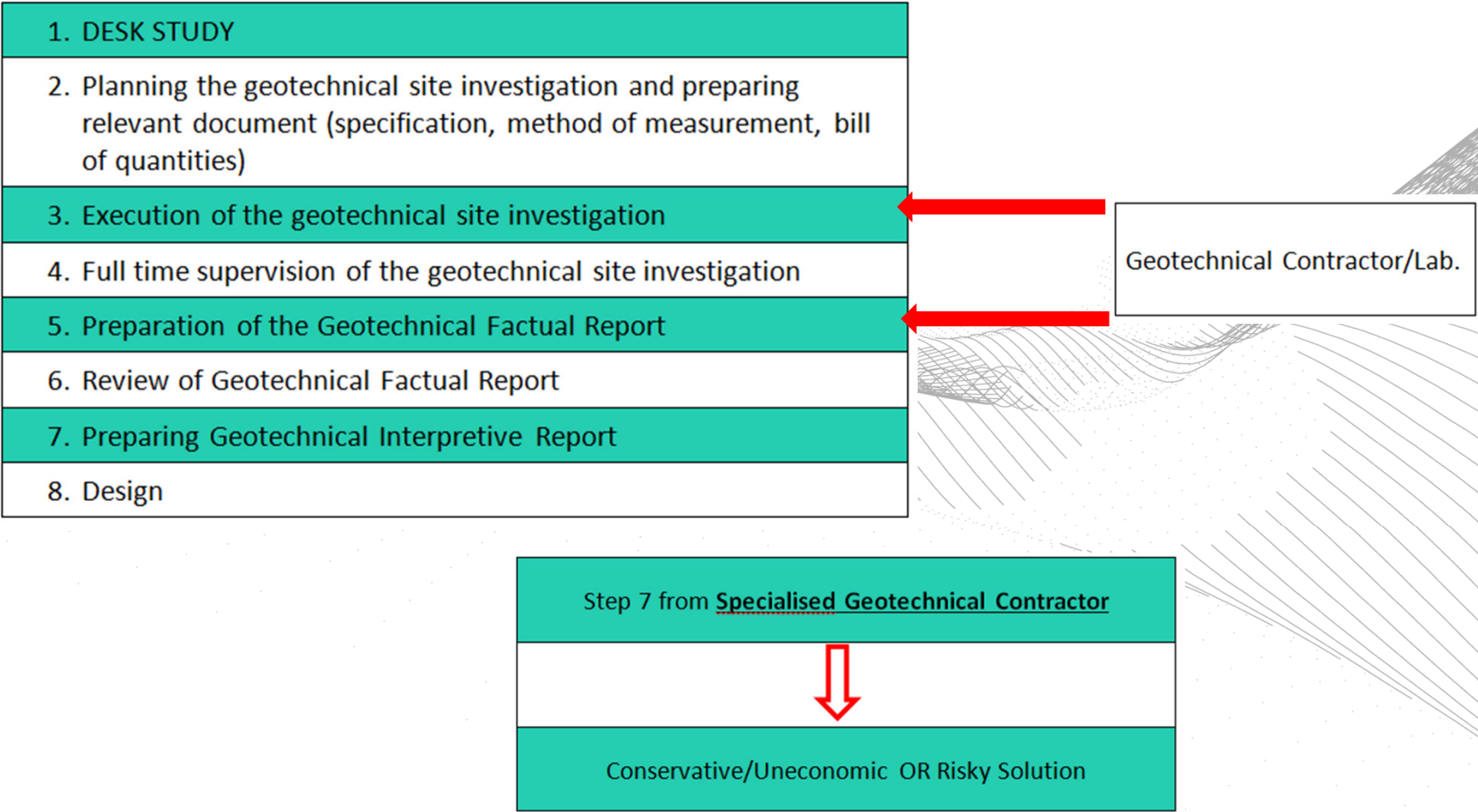
BUILDING REGULATIONS & DESIGN GUIDELINES- STRUCTURAL

SECTION 1: GEOTECHNICAL GUIDELINES & REGULATIONS

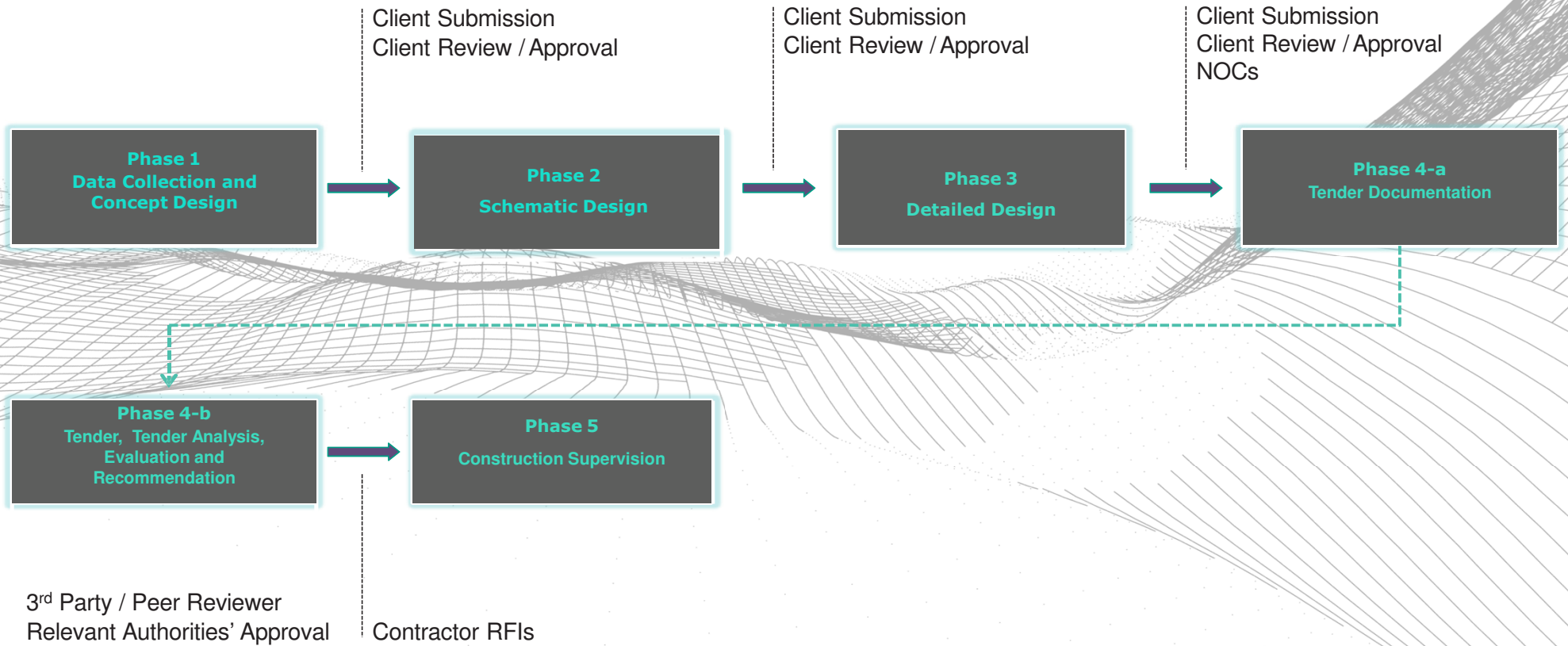
1.1	Introduction	12
1.2	Basic Guidelines For Soil Investigation Report	12
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1.3.1	Excavation Works	27
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1.4.1	Soil Improvement	36
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1.4.3	Calculation Theory	48
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1.5	Shoring Guidelines	50
1.6	Design Guidelines For Building Piles	56
1.6.1	Design Criteria For Piling Works	56
1.6.2	Points To Be Checked During Construction	59
1.6.3	Piles Testing	60

Government of Dubai traknees حكومة دبي

Geotechnical Design Procedure Followed Recently in Dubai

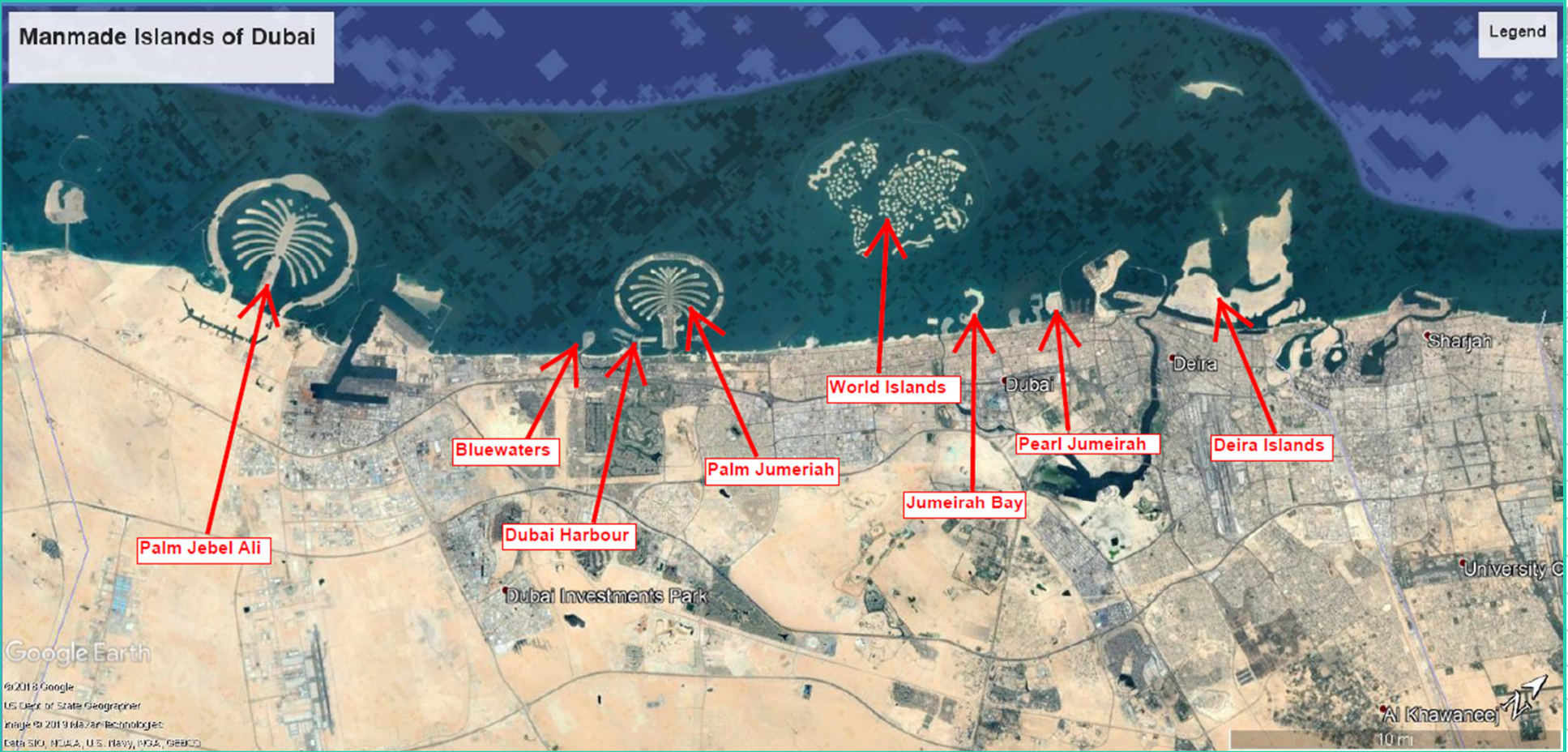


Project Phases – Design to Construction



DUBAI's GEOTECHNICAL CHALLENGES

Manmade/Artificial Islands of Dubai



Manmade/Artificial Islands of Dubai

PALM JUMEIRAH

- Construction undertaken by Dredging & Marine Contractors began in June 2001.
- By April 2002, the first 550m of breakwater was 3.0m above sea and the work on the inner palm fronds started.
- Due to tight schedule the construction of breakwater/crescent and the palm shaped island progressed simultaneously.
- Dredging technique by spraying sand precisely in a rainbow-like arch using GPS technology was used.
- 11km long and 200m wide breakwater was completed by August 2003.
- In October 2003, the land portion of the project was also completed.
- The original seabed was approximately 10.5m below sea level and the final elevation ranged between 3.5m-4.2m above sea level.
- Palm Jumeirah added an additional 78.6km of coastline to the naturally existing 72km of coast.
- Approximately 7 million tons of rock and 100 million cubic meters of sand were used.
- Following completion of reclamation, vibro-compaction work started for improvement of sprayed sand and completed in 8 months.
- A sub-sea tunnel was also built between the inner palm and outer crescent in addition to the service tunnels.

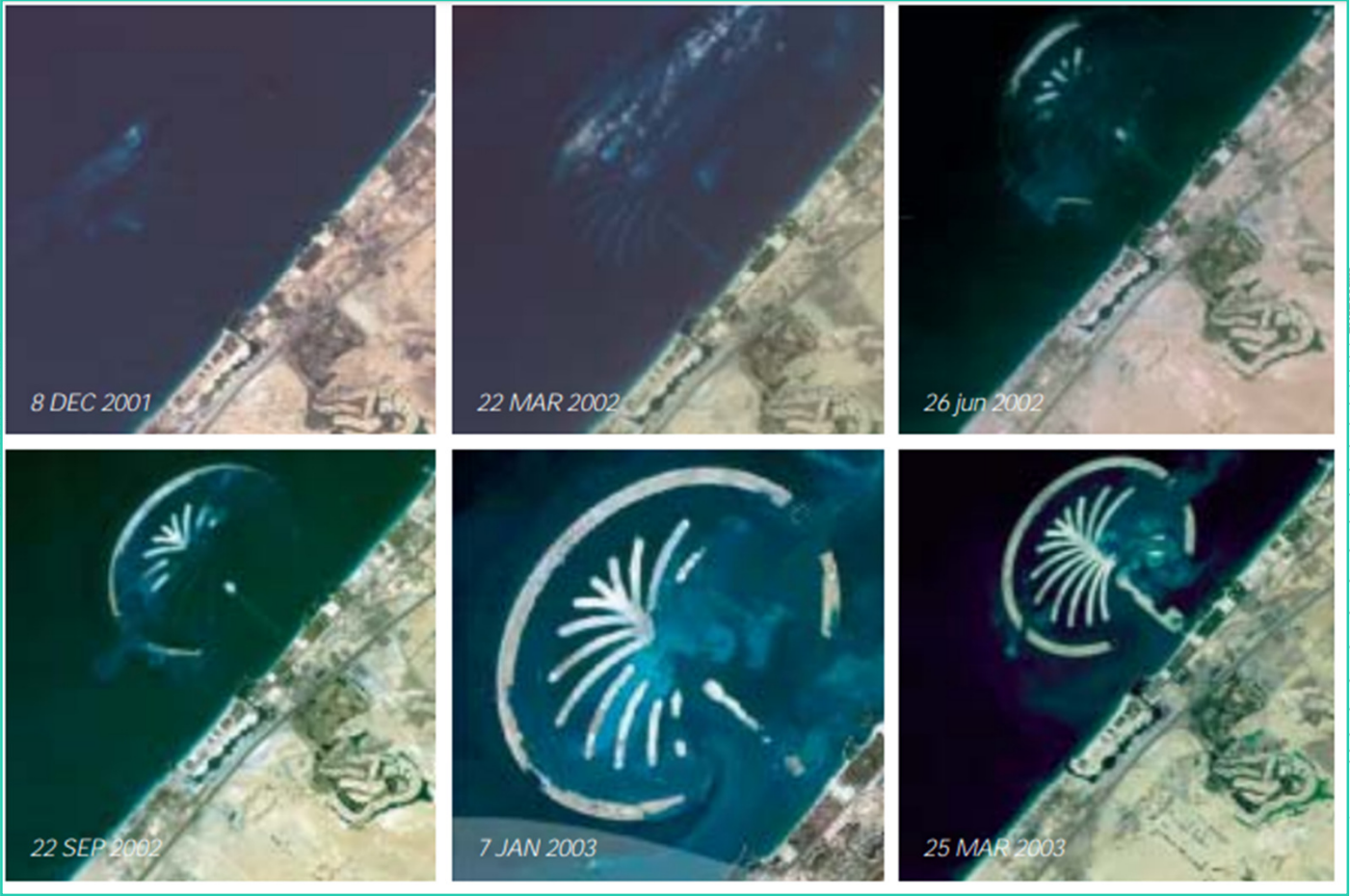
References: Jong et al, 2003 - Higgins, 2013



Manmade/Artificial Islands of Dubai



Manmade/Artificial Islands of Dubai



Manmade/Artificial Islands of Dubai

PEARL JUMEIRAH

- Constructed from Dubai sourced reclaimed/dredged sand and locally sourced rockworks.
- Sand retained along the perimeter of the development with rockwork slopes and man-made beaches (edge structures).
- Thickness of the reclamation fill varies across the site, being typically in the order of 10m-15m.
- Pre-reclamation geotechnical site investigation (off-shore) revealed that the seabed in general comprised of very weak to weak, fine to medium coarse grained CALCARENITE (CALCISILTITE in 2 boreholes), except 2 boreholes where cemented silty sand was encountered above the rock layer.
- Reclaimed material in addition to the existing granular sandy layer at the seabed subjected to post-reclamation ground improvement to improve the strength and compressibility characteristics.
- Pre-compaction geotechnical site investigation comprised of 18 boreholes and CPTu in each 50mX50m square across the project site.
- Vibro-compaction at 4.2m triangular grid spacing followed by 12ton Broons impact roller.
- Post-compaction geotechnical site investigation comprised of 2 boreholes and 3 zone load test of 1.5mX1.5m and CPTu in each 50mX50m square across the project site.
- Liquefaction analysis performed for $a=0.21g$ at the surface (2A, 0.15g at bedrock level) and minimum $FS=1.25$.

References: Alzaylaie & Abdelaziz, 2015



Manmade/Artificial Islands of Dubai

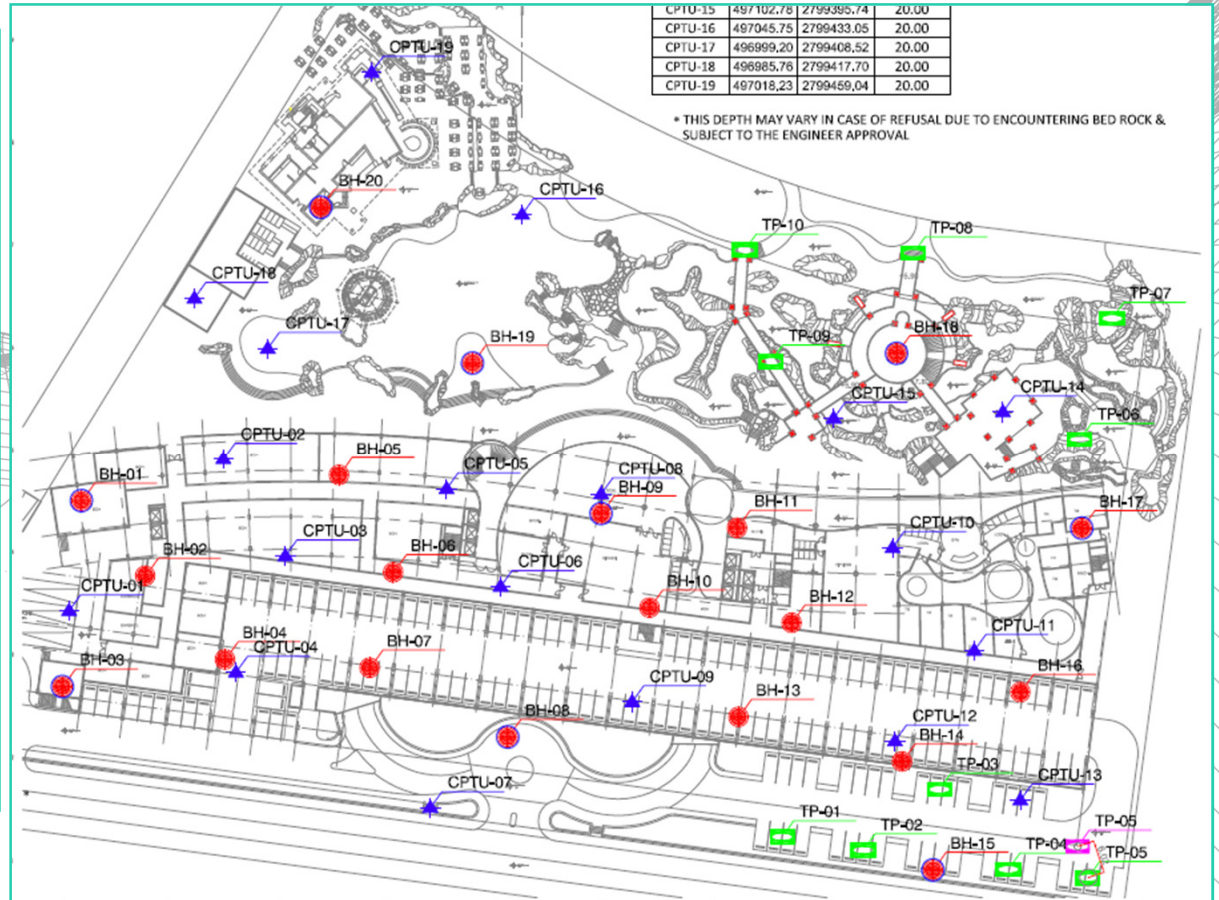


Manmade/Artificial Islands of Dubai

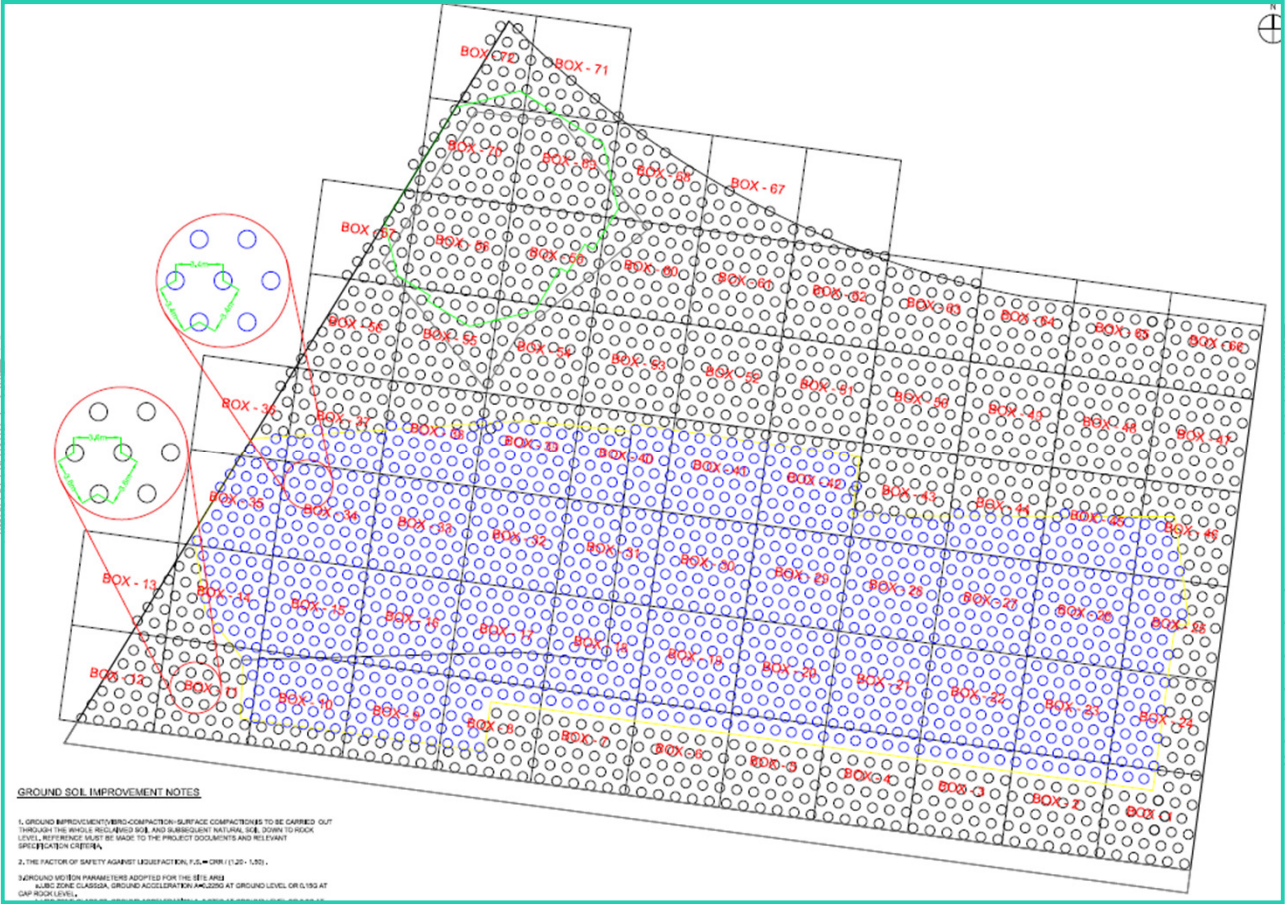
- G+9 building.
- Thickness of the reclamation fill varies across the site, being typically in the order of 18m-21m.
- Pre-compaction geotechnical site investigation comprised of 20 boreholes (20m-40m deep) and 19 CPTUs to the refusal, 3 downhole seismic tests in 40m boreholes.

Elevation (m) DMD	Strata Description
+3.50 to -15.50	Fill comprising of SAND, SILT & GRAVEL with shells and shell fragments.
-15.50 to -36.50	Very weak locally extremely weak CALCARENITE/SANDSTONE locally imbedded by sand & gravel

- Vibro-compaction at 3.4m and 3.6m triangular grid spacing (2B & 2A seismic zones, respectively) followed by dynamic compaction.
- Post-compaction quality control tests comprised of CPTUs in each 20mX20m square, plate load tests and filed density tests across the project site.



Manmade/Artificial Islands of Dubai



Manmade/Artificial Islands of Dubai

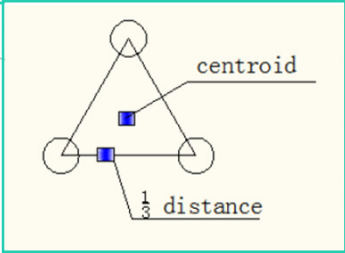
GROUND MOTION PARAMETERS ADOPTED FOR THE SITE ARE:

- a. UBC ZONE CLASS: 2A, GROUND ACCELERATION $A=0.225G$ AT GROUND LEVEL OR $0.15G$ AT CAP ROCK LEVEL.
- b. UBC ZONE CLASS: 2B, GROUND ACCELERATION $A=0.275G$ AT GROUND LEVEL OR $0.2G$ AT CAP ROCK LEVEL.

FOR ACCEPTANCE CRITERIA, REFERENCE MUST BE MADE TO THE PROJECT RELEVANT SPECIFICATION (SPECIFICATION SECTION 312050 - GROUND IMPROVEMENT SECTION 2.4), WHICH COVERS THE CODE REQUIREMENT FOR THE TWO CONSIDERED SEISMIC ZONES (I.E, 6.0 MPA (SEISMIC ZONE: 2A) AND 8 MPA (SEISMIC ZONE 2B) WEIGHTED AVERAGE OF THE TIP RESISTANCE PROFILE FOR THE POST COMPACTION CPT

The improvement target (average) values for the CPT versus depth shall be as per the following criteria/table (with no point falling below the values in parenthesis), provide achievement of 6.0 MPa (Seismic Zone: 2A) and 8 MPa (Seismic Zone 2B) weighted average of the tip resistance profile for the post compaction CPT.

Elevation	CPT (Mpa)	
	Average	Minimum
(+3.4 DMD) to (+1.00 DMD)	Up to 6	(up to 4)
(+1.00 DMD) to (-2.00 DMD)	6	(4)
(-2.00 DMD) to (-6.00 DMD)	8	(6)
(-6.00 DMD) to (-11.00 DMD)	10	(8)
(-11.00 DMD) to Top of Rock	11	(9)



Ground Improvement Techniques

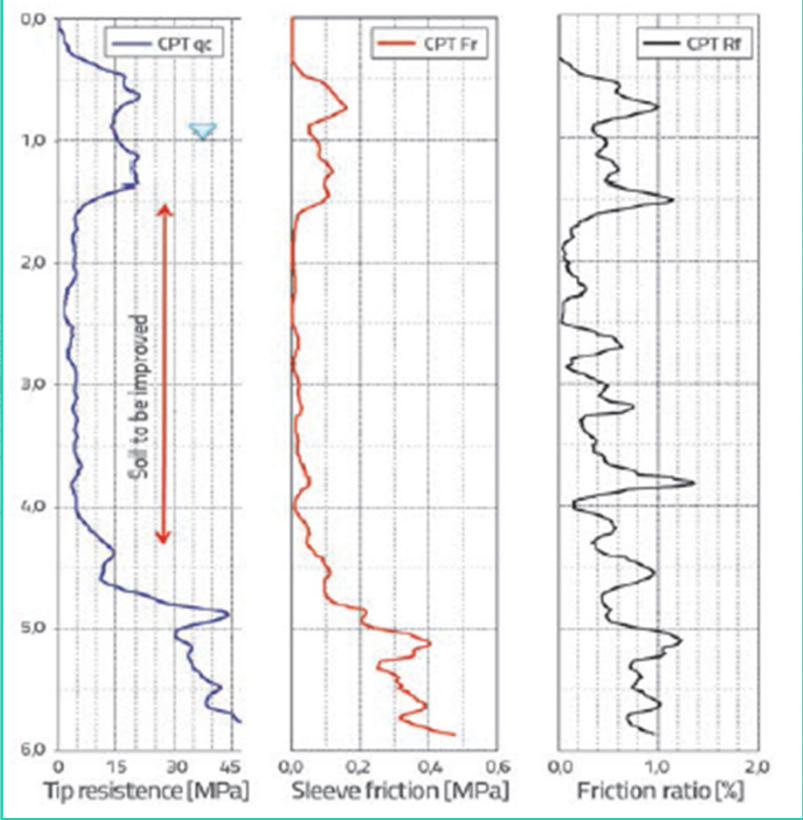
Jumeirah Park - Rapid Impact Compaction

- 134 villas.
- In some areas of the project site, loose to very loose fine to medium grained sand layer at 1.0m-4.50m below the existing ground level.
- Groundwater level at 0.5m-2.0m below the existing ground.
- 9ton hammer to be dropped from 0.3m-1.2m onto a 1.5m diameter steel patent foot.
- A top-down compaction process compared to Dynamic compaction which is a bottom-up process.
- Effective depth is 4.0m-6.0m.
- 1 CPT at each villa footprint before compaction.
- Shallow groundwater can act as a hydraulic barrier reducing the effective transfer of energy to the soil. To reduce build-up of pore water pressure, 4 well points in the vicinity of each villa were installed.
- 2 villas for trial areas.
 - Sequences 1 & 2 considered as 1 pass. 1 CPT carried out after each pass. After 3 passes, the project design criteria were met.
- Seismographs placed at 8.5m away from compaction points to measure the peak particle velocity (PPV).
- PPV of 50mm/s causes damage to reinforced or framed structures as Building Research Establishment. PPV measured as 20mm/s.

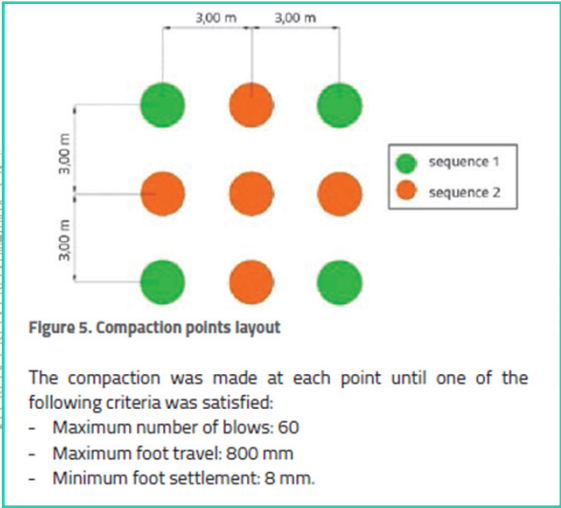
Reference: Tarawneh & Matraji, 2014

Ground Improvement Techniques

Depth [m]	R.L. [m DMD]	Log	Description of strata	N
1,00	3,460	▼	Medium dense, brown, silty, gravelly, fine to medium, gypsiferous, siliceous carbonate SAND. Gravels are fine to medium of gypsiferous, siliceous calcarenite.	15
				16
1,30	3,160	☼☼☼	Brown, slightly silty, very sandy, fine to medium GRAVEL of gypsum crystals.	4
2,00	2,460		Loose, brown, slightly gravelly, silty, fine to medium, gypsiferous, siliceous carbonate SAND.	6
4,00	0,690		Loose becoming medium dense, brown, silty, gravelly, fine to medium, gypsiferous, siliceous carbonate SAND. Gravels are fine to medium of gypsiferous, siliceous calcarenite.	9
				11
				10
				11
5,15	-0,690		Medium dense becoming dense, brown, silty, fine to medium, siliceous carbonate SAND.	19
				32
6,00	-1,540		Medium dense, brown, silty, very gravelly, fine to medium, siliceous, carbonate SAND. Gravels are fine to coarse of gypsiferous, siliceous calcarenite.	30
				28
			Snd of the borehole at 6,00 m	
R.L. - Reduced level; DMD - Dubai Municipality Datum; N - number of blows				

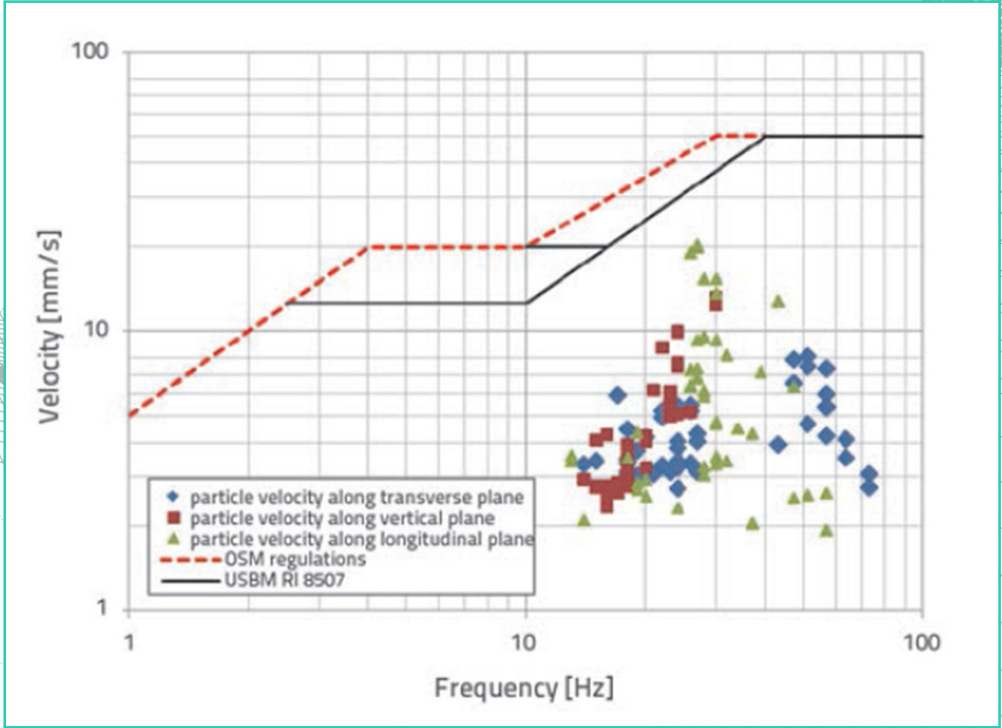
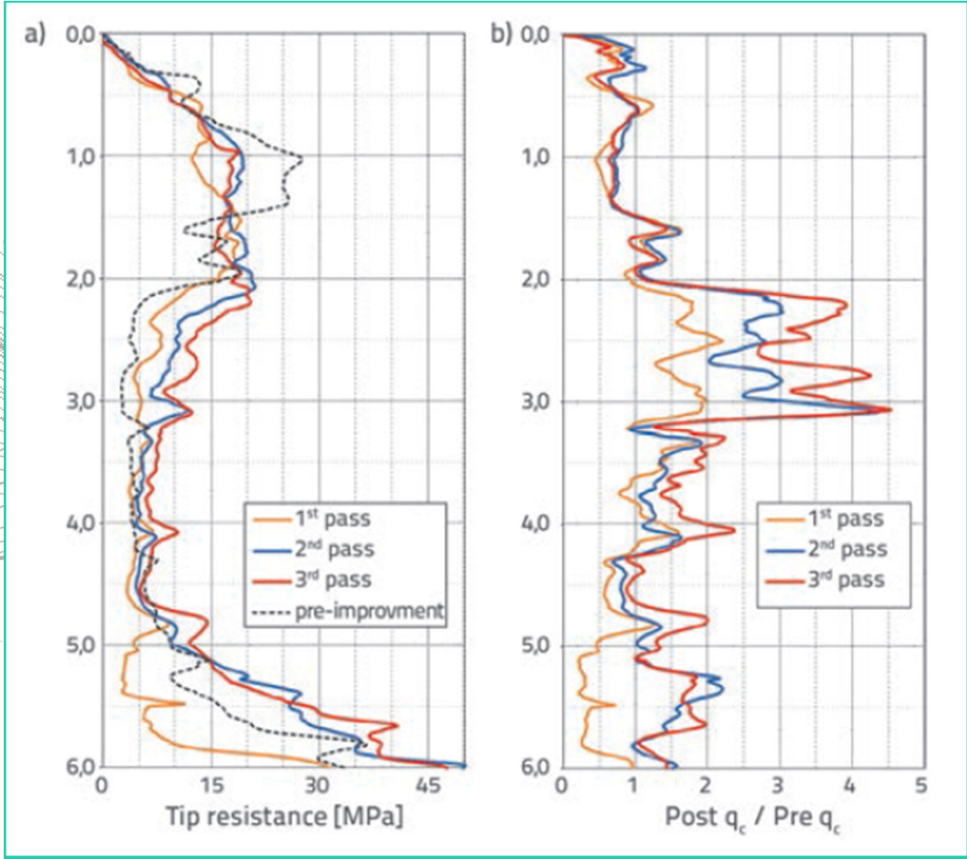


Ground Improvement Techniques



Point	Coordinates		Date	Time	Total blows	Final set [mm]	Final depth [m]	Ave fall [mm]	Total energy [kNm]
	East	North							
1	483460	2770184	23.10.2013.	14:31:43	17	8	0,553	1130	1728,6
2	483456	2770179	23.10.2013.	14:32:42	21	8	0,207	1176	2223,5
3	483452	2770174	23.10.2013.	14:33:34	13	8	0,118	1164	1362,1
4	483448	2770170	23.10.2013.	14:34:30	19	8	0,186	1175	2008,5
5	483445	2770165	23.10.2013.	14:35:24	18	8	0,182	1155	1870,8
6	483441	2770160	23.10.2013.	14:36:24	18	8	0,196	1147	1858,2
7	483437	2770156	23.10.2013.	14:37:19	20	8	0,213	1159	2086,1
8	483433	2770151	23.10.2013.	14:38:19	23	8	0,258	1143	2366,2
9	483429	2770147	23.10.2013.	14:39:41	21	8	0,205	1147	2168,5
10	483425	2770150	23.10.2013.	14:41:02	15	8	0,147	1110	1499,1
11	483429	2770155	23.10.2013.	14:41:50	16		0,199	1132	1630,1

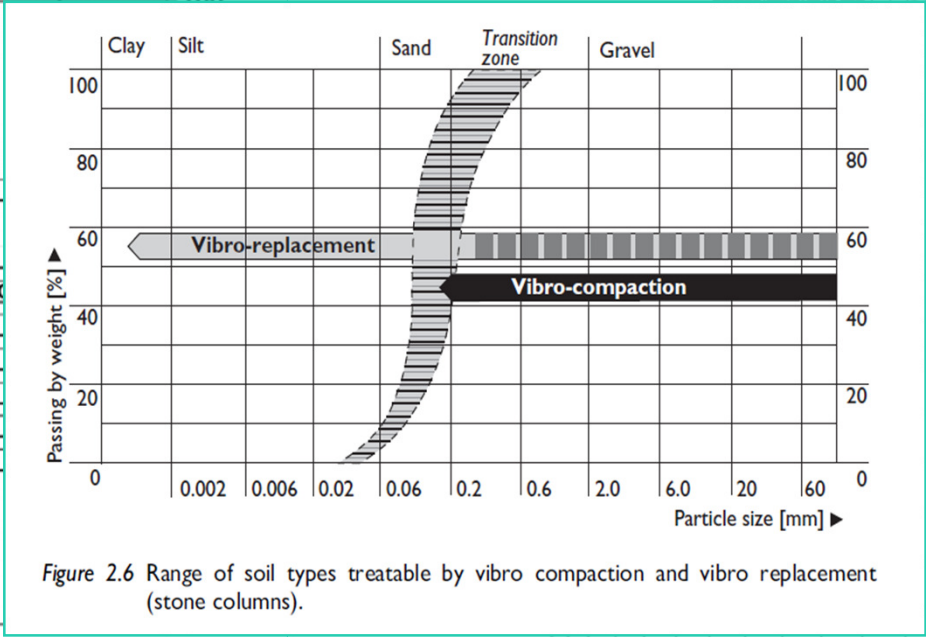
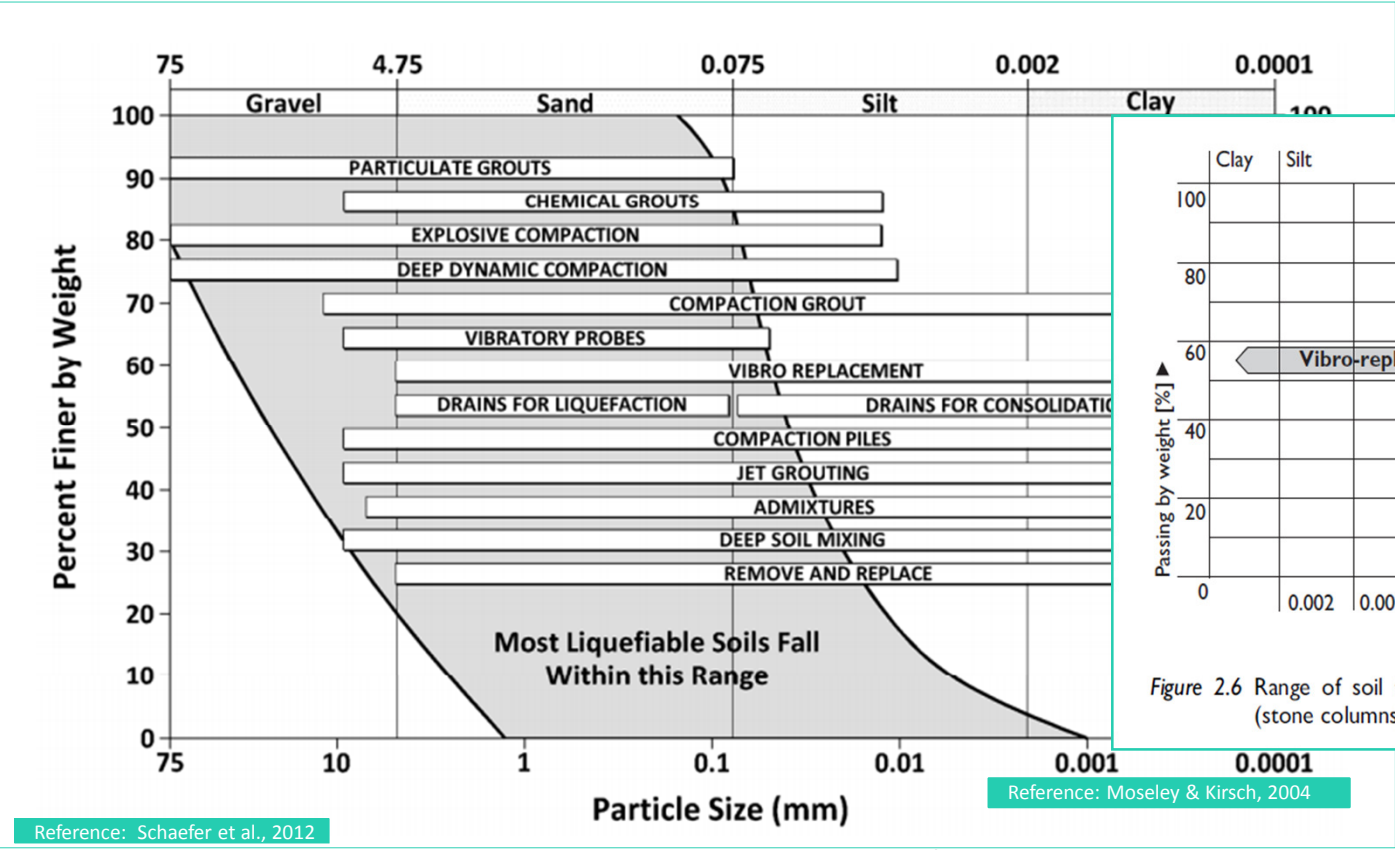
Ground Improvement Techniques



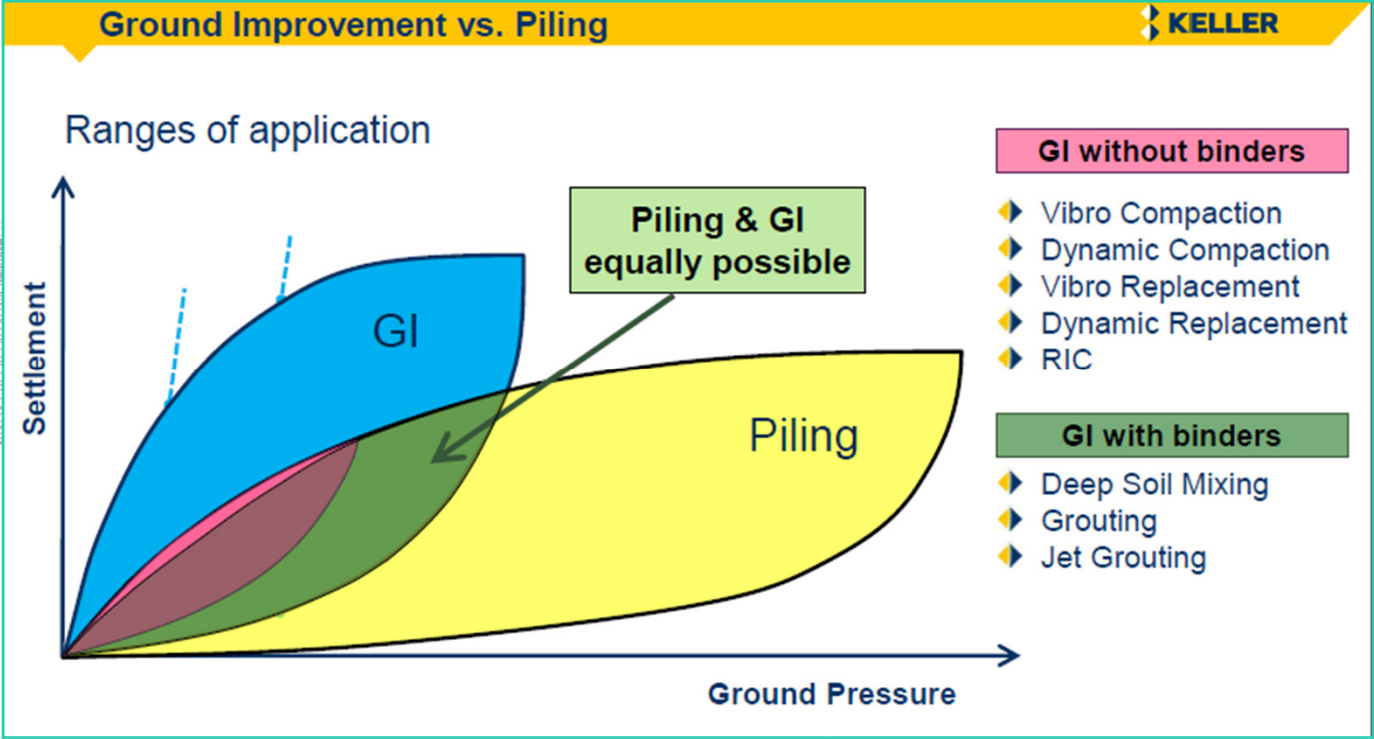
Ground Improvement Techniques



Ground Improvement Techniques



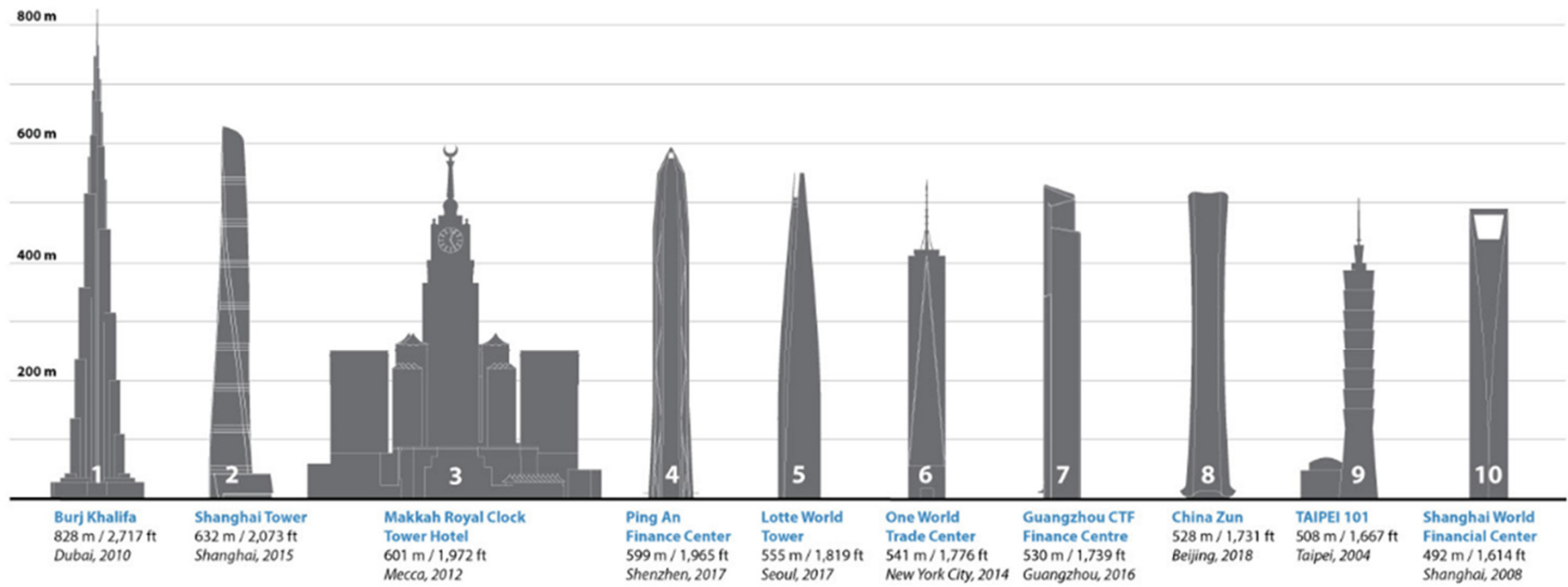
Ground Improvement Techniques



High-rise Buildings/Skyscrapers of Dubai

1. Height to Architectural Top

...the architectural top of the building, including spires, but not including antennae, signage, flagpoles or other functional-technical equipment.⁵
 This measurement is the most widely utilized and is employed to define the CTBUH rankings of the "World's Tallest Buildings."



www.skyscrapercenter.com/buildings



High-rise Buildings/Skyscrapers of Dubai

Tallest Building (by 2019)	<u>Burj Khalifa</u> (828m)(2010)
150m + Buildings	190 Completed (Global: 4,819) 52 Under construction
First 150m + Building	<u>Burj Al Arab</u> (321m) (1999)
300m + Buildings	22 Completed (Global: 148) 13 Under construction
Global Ranking	#4 in the World by no. of 150m + completed building #1 in the World by no. of 300m + completed building (Shenzen/China 11, New York/USA & Guangzhou/China 10)
Regional Ranking	#1 in Middle East by no. of 150m + completed building
Country Ranking	#1 in UAE by no. of 150m + completed building
Most Common Function	52% Residential
Most Common Material	94% Concrete

High-rise Buildings/Skyscrapers of Dubai



Burj Khalifa Construction Timeline	
January 2004	Excavation started
February 2004	Piling started
March 2005	Superstructure started
June 2006	Level 50 reached
January 2007	Level 100 reached
March 2007	Level 110 reached
April 2007	Level 120 reached
May 2007	Level 130 reached
July 2007	Level 141 reached world's tallest building
September 2007	Level 150 reached world's tallest free-standing structure
April 2008	Level 160 reached world's tallest man-made structure
January 2009	Completion of spire Burj Khalifa tops out
September 2009	Exterior cladding completed
January 2010	Official launch ceremony

www.burjkhalifa.ae/en/

High-rise Buildings/Skyscrapers of Dubai



www.burjkhalifa.ae/en/

High-rise Buildings/Skyscrapers of Dubai

Geotechnical Site Investigation	
Phase 1 (1 st June - 23 rd July 2003)	➤ 23 boreholes (30.0m-140.0m), ➤ 40 <u>pressuremeters</u> in 3 boreholes, ➤ 4 piezometers.
Phase 2 (7 th – 25 th August 2003)	➤ 3 new geophysical boreholes with Cross-hole & tomography geophysical surveys between 3 new and 1 existing boreholes.
Phase 3 (16 th September - 10 th October 2003)	➤ 6 boreholes, ➤ 20 <u>pressuremeters</u> in 2 boreholes, ➤ 2 piezometers.
Phase 4 (to assess the difference in core quality)	➤ 1 borehole, ➤ Cross-hole geophysical test in 3BHs, ➤ Down-hole geophysical test in 1BH.
Sophisticated Lab Tests	➤ Stress path <u>triaxial</u>, ➤ Resonant column, ➤ Cyclic undrained <u>triaxial</u>, ➤ Cyclic simple shear ➤ Constant normal stiffness direct shear.
Subsurface Stratigraphy	➤ Complex & highly variable, ➤ Medium dense to very loose granular silty SANDs, ➤ Very weak to weak calcareous SANDSTONE interbedded with very weakly cemented sand ➤ <u>Gypsiferous</u> fine grained SANDSTONE/SILTSTONE, ➤ Weak to moderately weak CONGLOMERATE/CALCISILTITE
Groundwater	➤ ~ 2.50m below existing ground level, i.e. +0.0m DMD.
Poulos, 2009/2015	

BURJ KHALIFA
➤ 163 <u>storey</u>, 828m high, super tall tower with a podium development at its base. ➤ Founded on a 3.7m thick raft supported on bored piles, 1.50m diameter & 47.45m long (@-7.55m DMD) for tower (in total 196 piles) and 0.65m thick raft (increased to 1.0m at column locations) supported on 0.90m diameter & 30.0m long (@-4.85m DMD) for podium (in total 750 piles)(piled raft on deep deposits of carbonate soils & rock). ➤ Minimum center-to-center spacing of tower piles is 2.5D. ➤ Analysis of block movement (piles + soil/rock) carried out for vertical, horizontal and overturning cases. ➤ <u>Static Load Tests</u>: 7 Preliminary - Strain gauges along pile - 2Xworking load for tower and 3.5-4.0X for podium - Only 4.0X working load shows failure – no mobilization of any significant end bearing resistance for the applied test loads 8 Working (1.5Xworking load) ➤ <u>Dynamic Load Tests</u> on working piles: 10 for tower and 31 for podium. ➤ Design governed primarily by tolerable settlement rather than allowable bearing capacity. ➤ Settlement measured during construction smaller than those predicted which are 45mm-62mm.
Reference: Poulos, (Coffey Geosciences, Peer Reviewer), 2009/2012

High-rise Buildings/Skyscrapers of Dubai

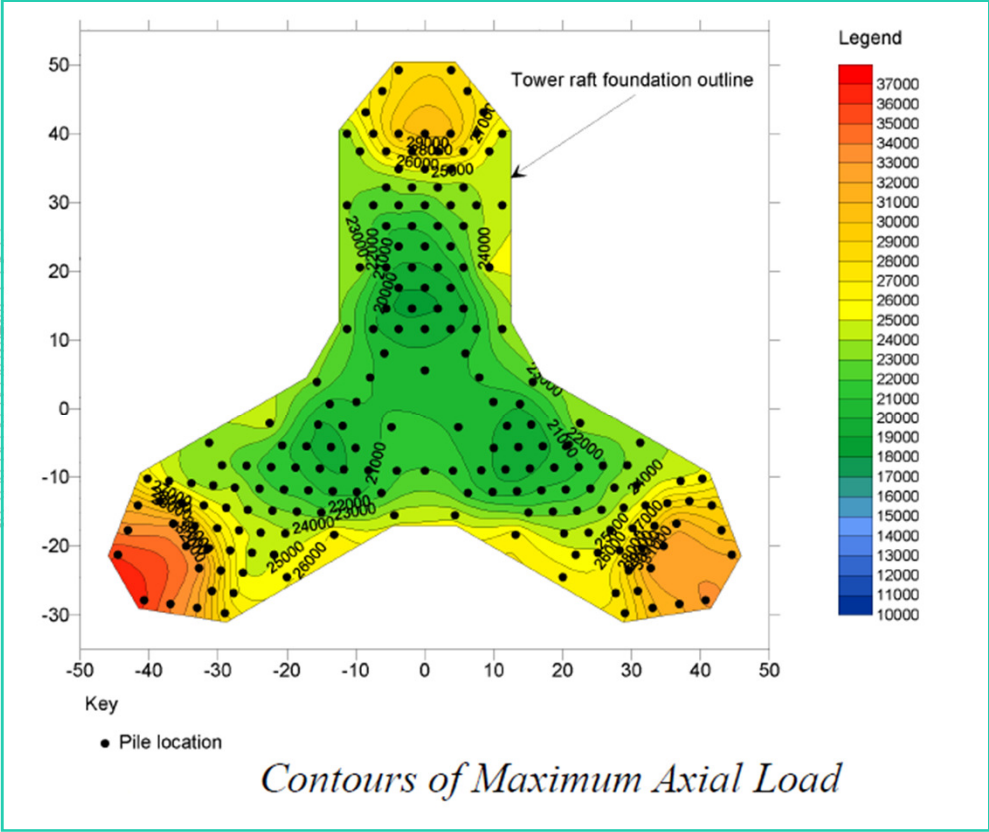
Summary of Pile Load Test Results – Axial Loading

<i>Pile Number</i>	<i>Working Load MN</i>	<i>Max. Load MN</i>	<i>Settlement at W. Load mm</i>	<i>Settlement at Max. Load mm</i>	<i>Stiffness at W. Load MN/m</i>	<i>Stiffness at Max. Load MN/m</i>
TP1	30.13	60.26	7.89	21.26	3819	2834
TP2	30.13	60.26	5.55	16.85	5429	3576
TP3	30.13	60.26	5.78	20.24	5213	2977
TP4	10.1	35.07	4.47	26.62	2260	1317
TP5	10.1	40.16	3.64	27.45	2775	1463
TP6	-1.0	-3.5	-0.65	-4.88	1536	717

Summary of Pile Load Tests – Preliminary Pile Testing

<i>Pile No.</i>	<i>Pile Diam. m</i>	<i>Pile Length m</i>	<i>Side Grouted ?</i>	<i>Test Type</i>
TP1	1.5	45.15	No	Compression
TP2	1.5	55.15	No	Compression
TP3	1.5	35.15	Yes	Compression
TP4	0.9	47.10	No	Compression (cyclic)
TP5	0.9	47.05	Yes	Compression
TP6	0.9	36.51	No	Tension
TP7A	0.9	37.51	No	Lateral

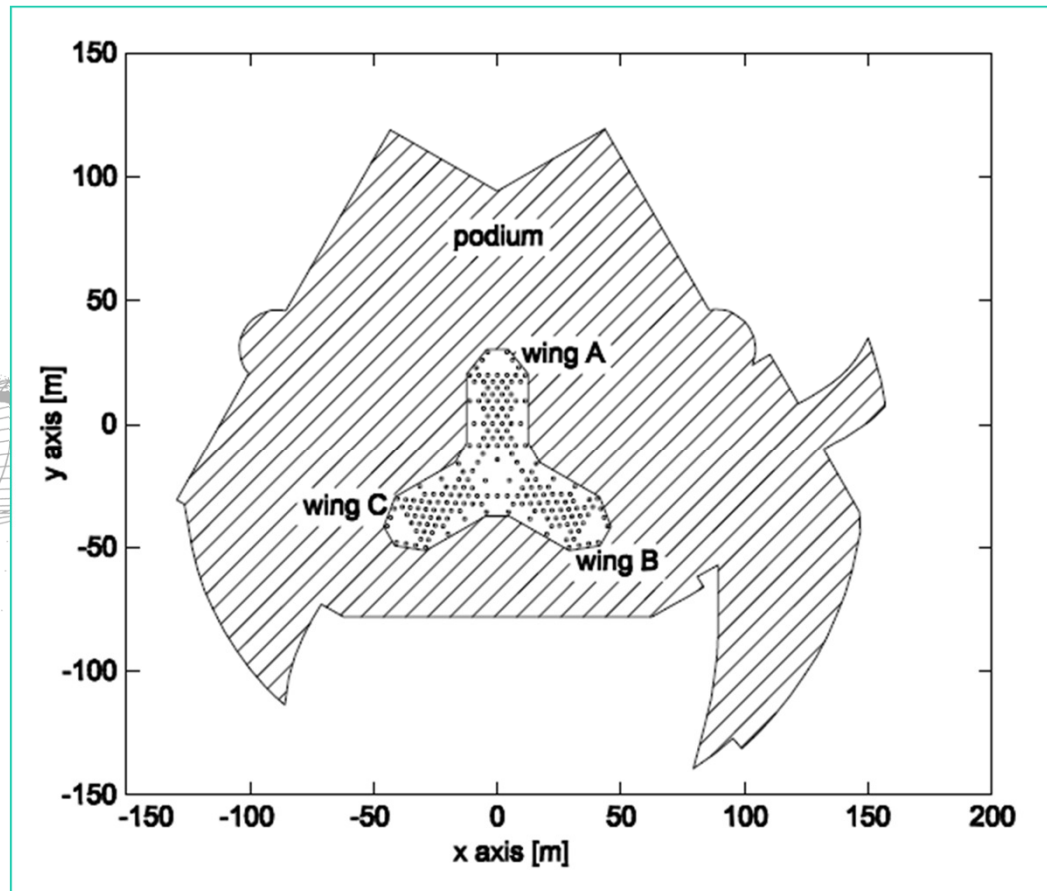
High-rise Buildings/Skyscrapers of Dubai



Computed Settlements from Analyses			
Analysis Method	Loadcase	Settlement mm	
		Rigid	Flexible
FEA	Tower Only (DL+LL)	56	66
REPUTE	Tower Only (DL+LL)	45	-
PIGLET	Tower Only (DL+LL)	62	-
VDISP	Tower Only (DL+LL)	46	72

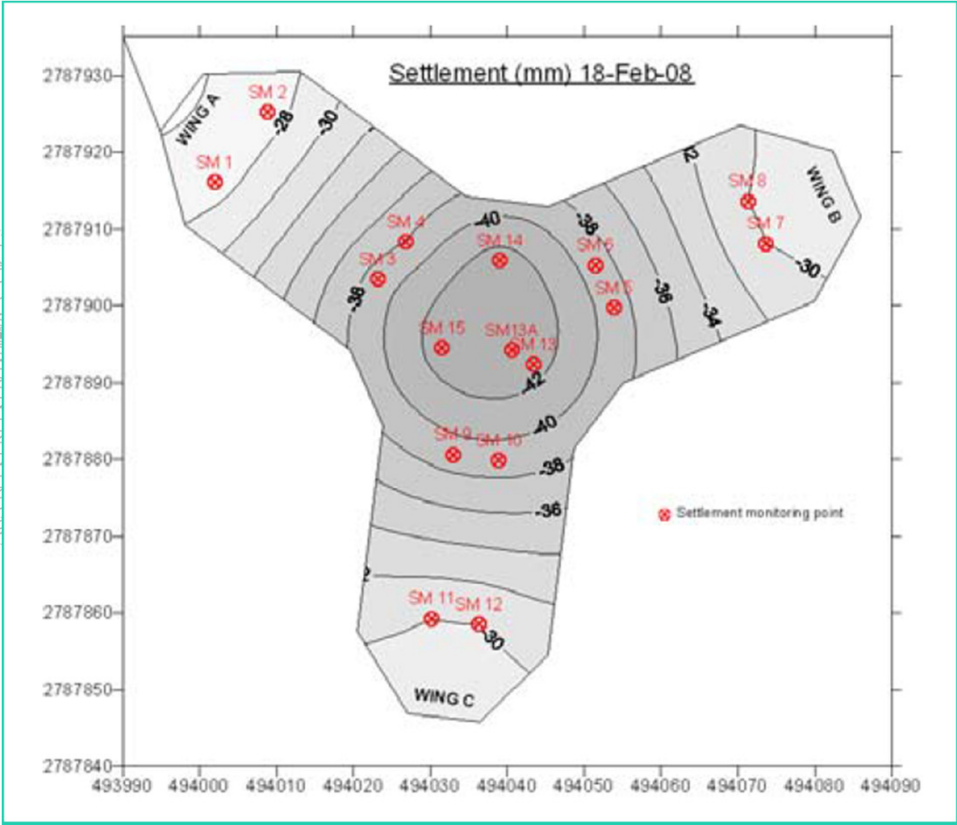
Reference: Poulos, (Coffey Geosciences, Peer Reviewer), 2009/2012

High-rise Buildings/Skyscrapers of Dubai



Reference: Poulos, (Coffey Geosciences, Peer Reviewer), 2009/2012

High-rise Buildings/Skyscrapers of Dubai



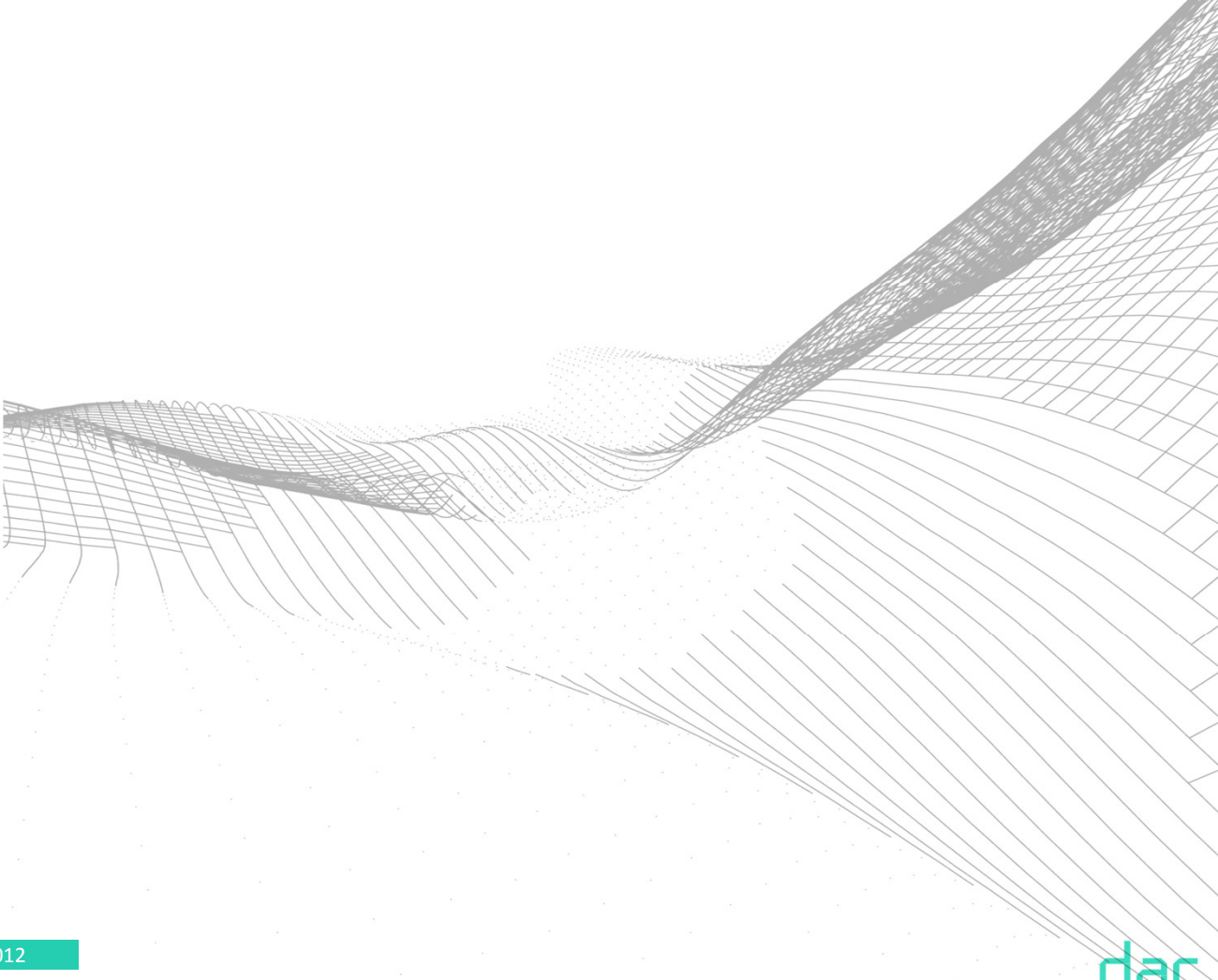
Reference: Poulos, (Coffey Geosciences, Peer Reviewer), 2009/2012

High-rise Buildings/Skyscrapers of Dubai

	Stratum name and age	Typical lithological description, features
Up to 20m thick	Holocene sands and silts	Aeolian, marine, intertidal and sabkha sediments associated with the Holocene sea level maximum.
Up to 25m thick	Pleistocene "white" calcarenite Ghayathi Fm	Off white to grey homogeneous to cross bedded (occasionally shelly and oolitic) weak calcium carbonate rich sandstone – often seen in relict "zeugen" ² outcrop, with a distinct cross bedding (interbedded with/or replaced by conglomerate and/or sandstone in places)
Up to 7m thick	Pleistocene red sandstone and conglomerate (?Ghayathi Fm)	Red-brown, occasional cross bedded, gypsiferous quartz sandstone/aeolianite; (interbedded with/or replaced by conglomerate and/or sandstone in places)
Up to 60m thick	Mio-Pliocene Barzaman Fm	Cemented and pedogenically altered wadi conglomerates comprising: • Polymictic clast-supported brown conglomerate (palaeo-wadi gravels) • Matrix supported polymictic white conglomerate (duricrust formed on gravels) • White carbonate siltstone/marl (few or no visible clasts) mostly composed of a dolomite-palygorskite rich rock • Breccia – comprising clasts (mainly of the carbonate siltstone) within a palygorskite-dolomite matrix Rare "gravelly sandstone" also occur, probably representing relict "inter-fluve" sediments between wadi channels
Up to 25m thick	Miocene thinly bedded to laminated marls and limestones Fars Group	Thinly bedded/laminated to thick bedded white, red-brown and greenish grey carbonate siltstone and marl, with thin inter-beds of polymictic conglomerate

Macklin et al., 2012

Tentative stratigraphic scheme for coastal Dubai



High-rise Buildings/Skyscrapers of Dubai

SECTION: 4 STRUCTURAL DESIGN GUIDELINES - STEEL STRUCTURES

4.2.2 SEISMIC LOADS

1. UBC 1997, Volume 2, 'Structural Engineering Design Provision Division IV 'Earthquake Design'
2. Seismic zone shall be considered as per Dubai Municipality latest Circular and Trakhees-CED evaluation.

SECTION: 1 GEOTECHNICAL GUIDELINES & REGULATIONS

- 1.2.32 Cyclic stress ratio (CSR) induced in the soil due to earthquake shall be estimated considering Richter Magnitude $M=6.0$, (Amplification Factor = 1.5) and ground motion parameters as follows:
 - UBC zone class: 2A, ground acceleration $a=0.225g$ at ground level or 0.15g at cap rock level.
 - UBC zone class: 2B, ground acceleration $a=0.275g$ at ground level or 0.2g at cap rock level.
- 1.2.33 Calculation of cyclic resistance ratio (CRR, soil "strength") based on in-situ test data from SPT (Seed & Idriss) or CPT method (1996 NCEER workshop on Liquefaction Evaluation).
- 1.2.34 Evaluation of liquefaction potential by calculating the factor of safety against liquefaction from the earthquake load and soil strength.
- 1.2.35 $[F.S. = CRR / (1.2-1.5) CSR]$. There are a potential for liquefaction if the F.S. less than unity, the layer is susceptible to liquefy and the ground densification or mitigation measures are needed.
- 1.2.36 Estimation of liquefaction induced settlement.

1.4.2 SAFETY AGAINST LIQUEFACTION

The hydraulic fill, loose, fine and saturated sands may subject to liquefaction (significant loss of strength due to buildup pore water pressure and subsequent deformation in some locations under the cyclic loading of earthquakes).

To mitigate liquefaction hazards, soil improvement is required and its efficiency shall be ensured from CPT readings pre and post-tests, (ASTM D 5778 or BS 1377: Part 9: Test 3.1 Amd 8264-95 and SSMFE test Procedure for Cone Penetration Test (IRTP) - 1989 and updated 1997). The pre CPT shall be carried out every 900 m2 maximum or as per project specs and the results to be compared with the post compaction CPT results for the same area as per Fig. (1.31). The locations of post CPTs shall be selected at the central points and/or at one third the maximum distance between the improved points. Proper weighted average for near and far tested points should be considered.

For deep foundations, the achievement of 6.0 MPa (Seismic Zone: 2A) and 8 MPa (Seismic Zone 2B) weighted average of the tip resistance profile for the post compaction CPT is an accepted criterion of the compaction efficiency.

High-rise Buildings/Skyscrapers of Dubai

Location	Seismic Zone	Location	Seismic Zone
Bahrain		Laos	
Manama	0	Vientiane	1
Bangladesh		Lebanon	
Dacca	3	Beirut	3
Brunei		Malaysia	
Bandar Seri Begawan	1	Kuala Lumpur	1
Burma		Nepal	
Mandalay	3	Kathmandu	4
Rangoon	3	Oman	
China		Muscat	2A
Beijing	4	Pakistan	
Chengdu	3	Islamabad	4
Guangzhou	2A	Karachi	4
Nanjing	2A	Lahore	2A
Qingdao	3	Peshawar	4
Shanghai	2A	Qatar	
Shengyang	4	Doha	0
Taiwan		Saudi Arabia	
All	4	Al Batin	1
Tihwa	4	Dharan	1
Wuhan	2A	Jiddah	2A
Xianggang	2A	Khamis Mushayf	1
Cyprus		Riyadh	0
Nicosia	3	Singapore	
India		All	1
Bombay	3	South Yemen	
Calcutta	2A	Aden City	3
Madras	1	Sri Lanka	
New Delhi	3	Colombo	0
Indonesia		Syria	
Bandung	4	Aleppo	3
Jakarta	4	Damascus	3
Medan	3	Thailand	
Surabaya	4	Bangkok	1
Iran		Chiang Mai	2A
Isfahan	3	Songkhla	0
Shiraz	3	Udon	1
Tabriz	4	Turkey	
Tehran	4	Adana	2A
Iraq		Ankara	2A
Baghdad	3	Ismir	4
Basra	1	Istanbul	4
Israel		Karamusul	3
Haifa	3	United Arab Emirates	
Jerusalem	3	Abu Dhabi	0
Tel Aviv	3	Dubai	0
Japan		Viet Nam	
Fukuoka	3	Ho Chi Minh (Saigon)	0
Itazuke AFB	3	Yemen Aran Republic	
Misawa AFB	3	Sanaa	3
Naha, Okinawa	4	ATLANTIC OCEAN AREA	
Osaka/Kobe	4	Azores	
Sapporo	3	All	2A
Tokyo	4	Bermuda	
Wakkami	3	All	1

High-rise Buildings/Skyscrapers of Dubai

THE TOWER at DUBAI CREEK HARBOUR

- 100m taller than Burj Khalifa, i.e. 928m (for now!),
- Ground-breaking ceremony in October 2016,
- 473 barrettes, to a maximum depth of 72.0m, set under the tower itself (145) and the two cable stay anchor blocks, completed in July 2017,
- Concrete placement for 19.0m thick multi-layered raft/pile cap began in September 2017.

Reference: www.soletanchefreyssinet.com - industry-me.com



High-rise Buildings/Skyscrapers of Dubai

**36,300
TONNES,
A RECORD
TEST LOADING**



High-rise Buildings/Skyscrapers of Dubai



High-rise Buildings/Skyscrapers of Dubai



Height: To Tip
306.4 m / 1,005 ft
Height:
Architectural
306.4 m / 1,005 ft
Height: Occupied
263.1 m / 863 ft



Floors Above Ground
73
Floors Below Ground
5
of Elevators
7
Top Elevator Speed
8 m/s
Tower GFA
111,000 m² / 1,194,794 ft²
Development GFA
111,000 m² / 1,194,794 ft²
of Apartments
495
of Parking Spaces
623

High-rise Buildings/Skyscrapers of Dubai

CAYAN (INFINITY) TOWER

- The world's tallest twisting tower,
- In May 2006, enabling work began,
- On 7 February 2007, the diaphragm wall with anchors and corner bracing constructed for basement excavation (~22.0m deep), which held back the marina, collapsed and flooded the entire site.
- *"One day we noticed there was suddenly some seepage happening in the wall. Luckily, somebody noticed it. We gave the order to evacuate immediately. After we evacuated, maybe within 30 minutes, the collapse happened. There were no casualties."*
- The project resumed construction in July 2008.
- Cayan Tower inaugurated with fireworks accompanied with laser light display on the tower on 10 June 2013.

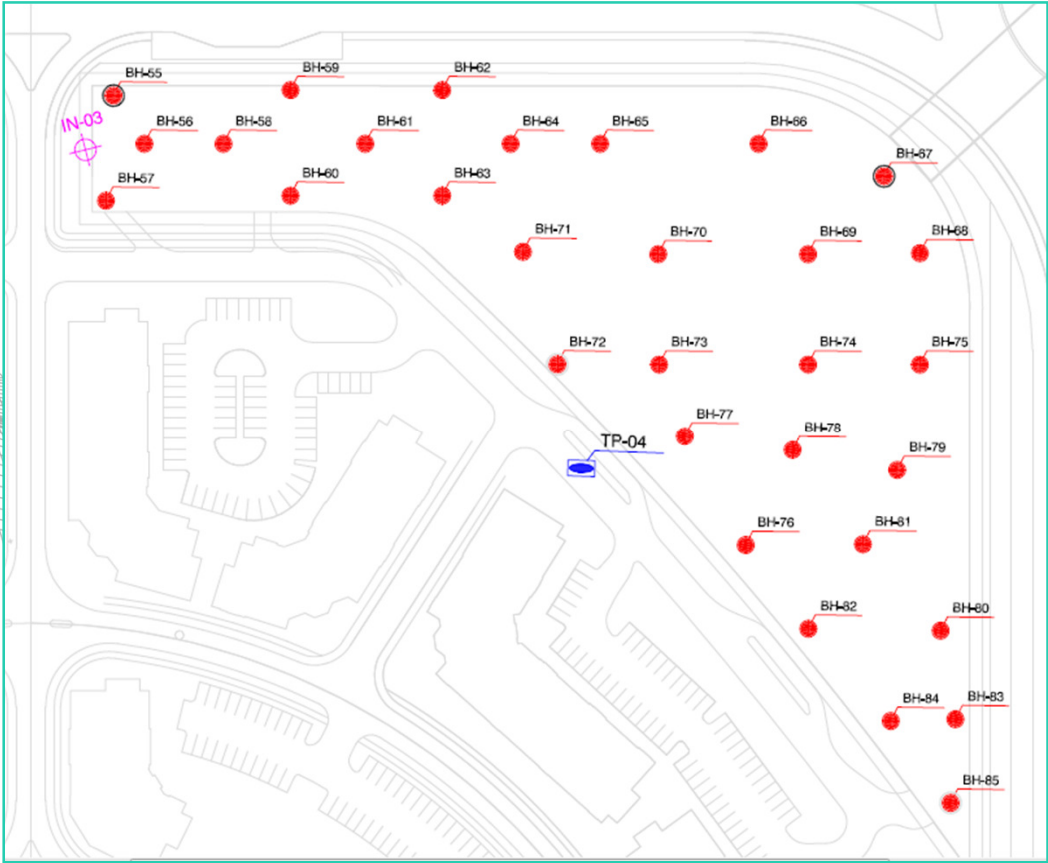
Reference: www.constructionweekonline.com



High-rise Buildings/Skyscrapers of Dubai

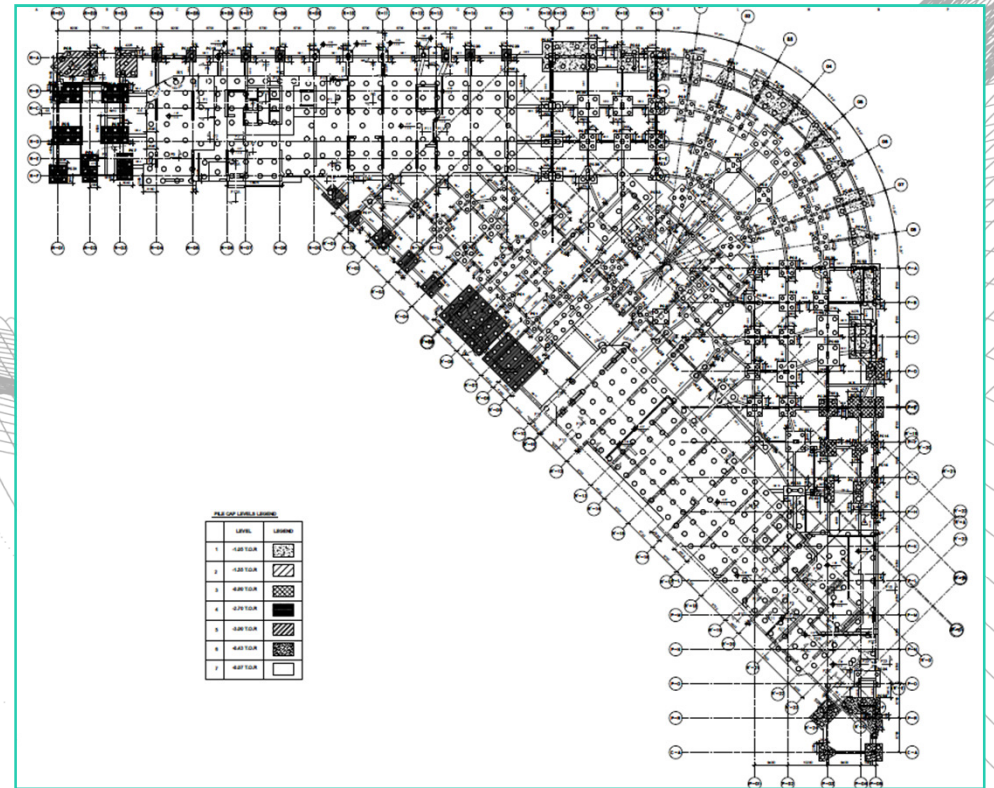
MIXED USE COMPLEX-TWIN TOWER DEVELOPMENT

- Two 37 storey, each containing apartments with balconies, two floors featuring a variety of retail outlets, a clubhouse housing a dedicated rooftop gym, tennis court, large 25-metre swimming pool, kids' pool and a poolside and also parking spaces.
- 560 piles with 1.0m & 1.2m diameter, having rock socket lengths of 4.0m-20.0m.
- 2 preliminary static load tests on piles instrumented by strain gauges along the shaft.
- Preliminary test results used for refining/redesigning of piles by enhancing rock parameters.
- 6 Static load, 28 Dynamic load, 56 Sonic logging, 56 Caliper and 560 Integrity tests.

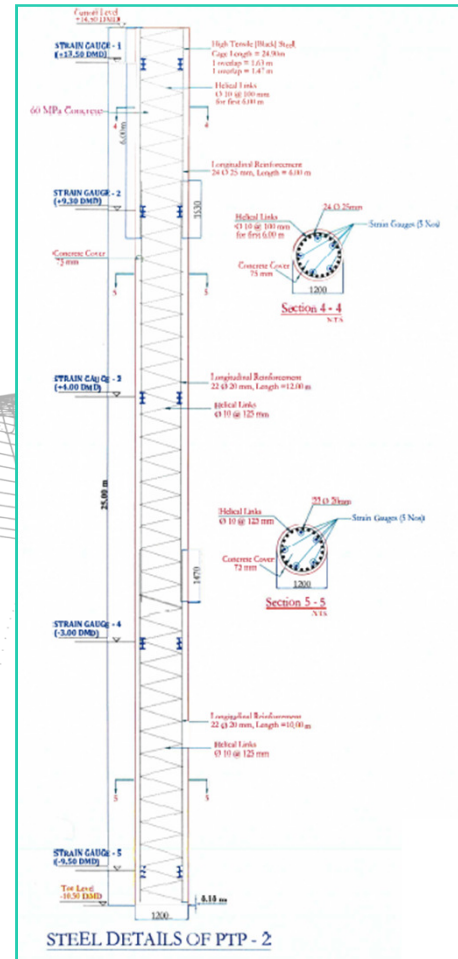
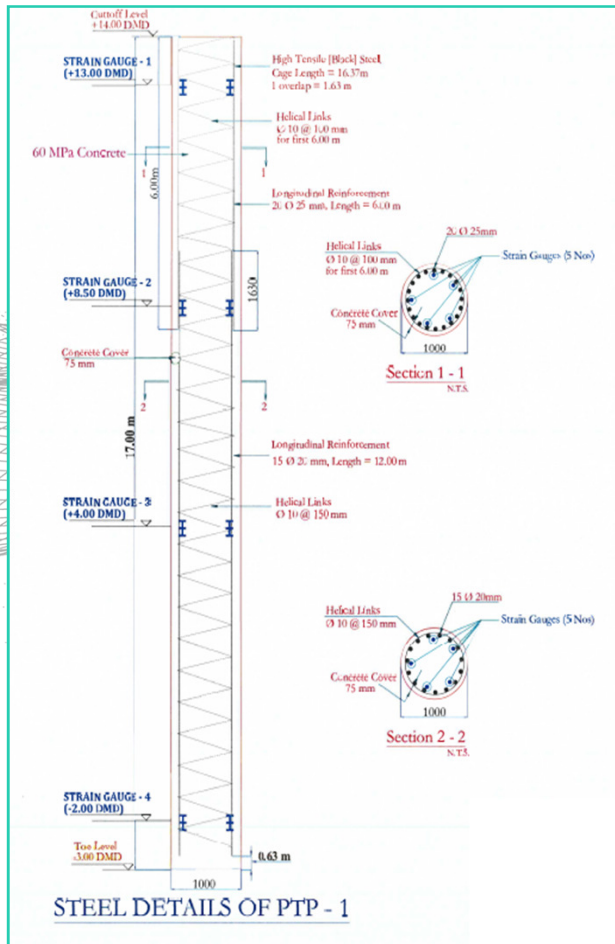


High-rise Buildings/Skyscrapers of Dubai

Vicinity of BH No.	Approximate Elevation DMD (m)	Strata Description
58, 60, 61, 63, 64 & 65 (Tower 1)	14.00 to 9.00*	Brown, slightly silty SAND
	9.00 to 6.50	Very weak to weak, massive locally thinly laminated, brown to reddish brown, fine to medium grained, SANDSTONE locally interbedded by SAND & CONGLOMERATE
	6.50 to 4.50	Weak to moderately weak, massive, brown to reddish brown speckled dark grey and offwhite, fine to medium grained, CONGLOMERATE locally interbedded by CALCISILTITE
	4.50 to -11.50	Weak locally very weak, massive, offwhite locally speckled dark grey and reddish brown, fine to medium grained, CALCISILTITE locally interbedded by CONGLOMERATE
	-11.50 to -17.50	Weak locally very weak, massive, brown to reddish brown speckled dark grey and offwhite, fine to medium grained, CONGLOMERATE locally interbedded by CALCISILTITE
55, 56, 57, 59, 62, 66 to 75, 78, 79, 83 & 85 (Podium)	Below -17.50	Weak locally very weak, massive, offwhite locally speckled dark grey and reddish brown, fine to medium grained, CALCISILTITE locally interbedded by CONGLOMERATE
	14.50 to 13.00	FILL comprising of sand, gravel with rare concrete and wooden pieces / SAND
	13.00 to 9.00**	Brown, slightly silty to silty, slightly gravelly to gravelly, fine to medium SAND locally interbedded by CALCARENITE
	9.00 to 7.00	Very weak to weak locally moderately weak, massive locally thinly laminated, brown to reddish brown, fine to medium grained, SANDSTONE locally interbedded by SAND
	7.00 to 4.50	Weak to moderately weak, massive, brown to reddish brown speckled dark grey and offwhite, fine to medium grained, CONGLOMERATE locally interbedded by SANDSTONE & CALCISILTITE
76, 77, 80, 81, 82 & 84 (Tower 2)	Below 4.50	Weak locally very weak, massive, offwhite locally speckled dark grey and reddish brown, fine to medium grained, conglomeratic CALCISILTITE locally interbedded by CONGLOMERATE
	14.50 to 14.00	FILL comprising of sand and gravel of various rock types / SAND
	14.00 to 9.50	Brown, slightly silty, fine to medium SAND
	9.50 to 7.00	Weak to moderately weak locally very weak, massive, brown to reddish brown, fine to medium grained, SANDSTONE locally interbedded by SAND and CONGLOMERATE
	Below 7.00	Weak locally very weak, massive, offwhite locally speckled dark grey and reddish brown, fine to medium grained, conglomeratic CALCISILTITE locally interbedded by CONGLOMERATE



High-rise Buildings/Skyscrapers of Dubai



High-rise Buildings/Skyscrapers of Dubai

FATIMA DE LA CERNA



WHAT'S YOUR VIEW? COMMENT ONLINE @CWMIDDLEEAST



The cost of playing it safe

The regional construction industry's practice of oversizing is not only a bane to sustainability initiatives, but also an obstacle to efforts to reduce project costs

Reference: www.constructionweekonline.com/

High-rise Buildings/Skyscrapers of Dubai

Jagath Gunawardena, Dubai Chamber's senior manager for projects and building development, and the champion of its sustainability agenda, said that one of the measures the organisation implemented to improve the building's efficiency was to address the problem of oversized mechanical, electrical, and plumbing (MEP) components.

The issue of oversizing is not uncommon, and is not limited to MEP – attend any conference or seminar on energy efficiency and it's bound to come up, with sustainability and energy-management experts pointing out that consultants are guilty of over-specifying because they buffer or round up their measurements in the design stage, to avoid the risk of undersizing. This fear of making a mistake, it must be noted,

In the field of geotechnics, a 'better safe than sorry' attitude has resulted in over-dimensioned foundations in the UAE, something that was noted by Prof Rolf Katzenbach, director of the Institute and the Research Laboratory for Geotechnics at TU Darmstadt, and Prof Harry Poulos, senior consultant at Coffey, during a recent geotechnics conference held in Dubai.

Reference: www.constructionweekonline.com/

High-rise Buildings/Skyscrapers of Dubai



WHAT LIES BENEATH

With the number of high-rise structures in the GCC increasing, is the construction industry doing enough to keep abreast of developments in geotechnics? *Fatima de la Cerna* reports



“[Geotechnics] is very important now, especially with the growing number of high-rise buildings.”

Merei Mohammed, DCCA



“In Dubai [...] there has been a tendency to be overly conservative with designs.”

Prof Harry Poulos, Coffey

20 CONSTRUCTION WEEK MAY 27 - JUNE 2, 2017

“Nearly all foundations in Dubai and the rest of the emirates are heavily over-dimensioned.”

Prof Rolf Katzenbach, TU Darmstadt



Piled Raft Foundations (Combined Pile-Raft Foundation-CPRF)

In many cases it has become an economic necessity to install piles beneath a raft not because a lack of bearing capacity of the foundation but because the settlement of the raft is excessive. Such usage of piles was first termed by Broms (1976) as “settlement reducing piles”.

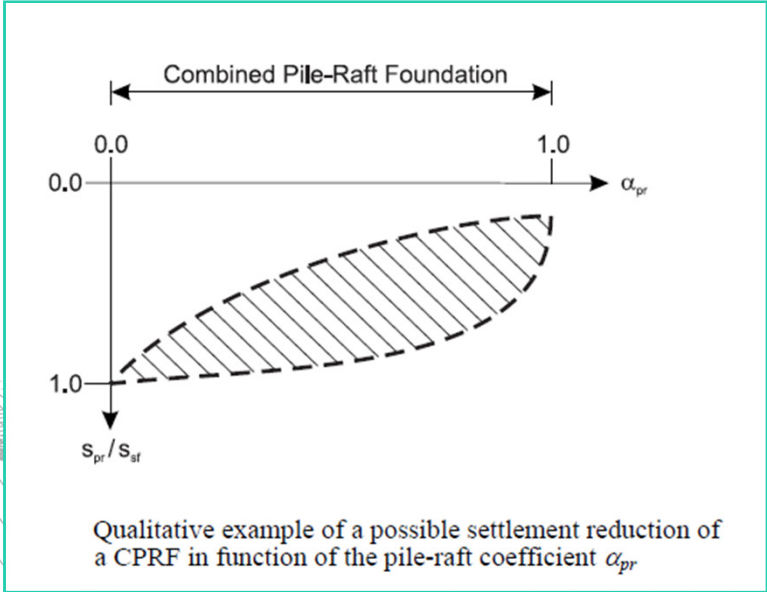
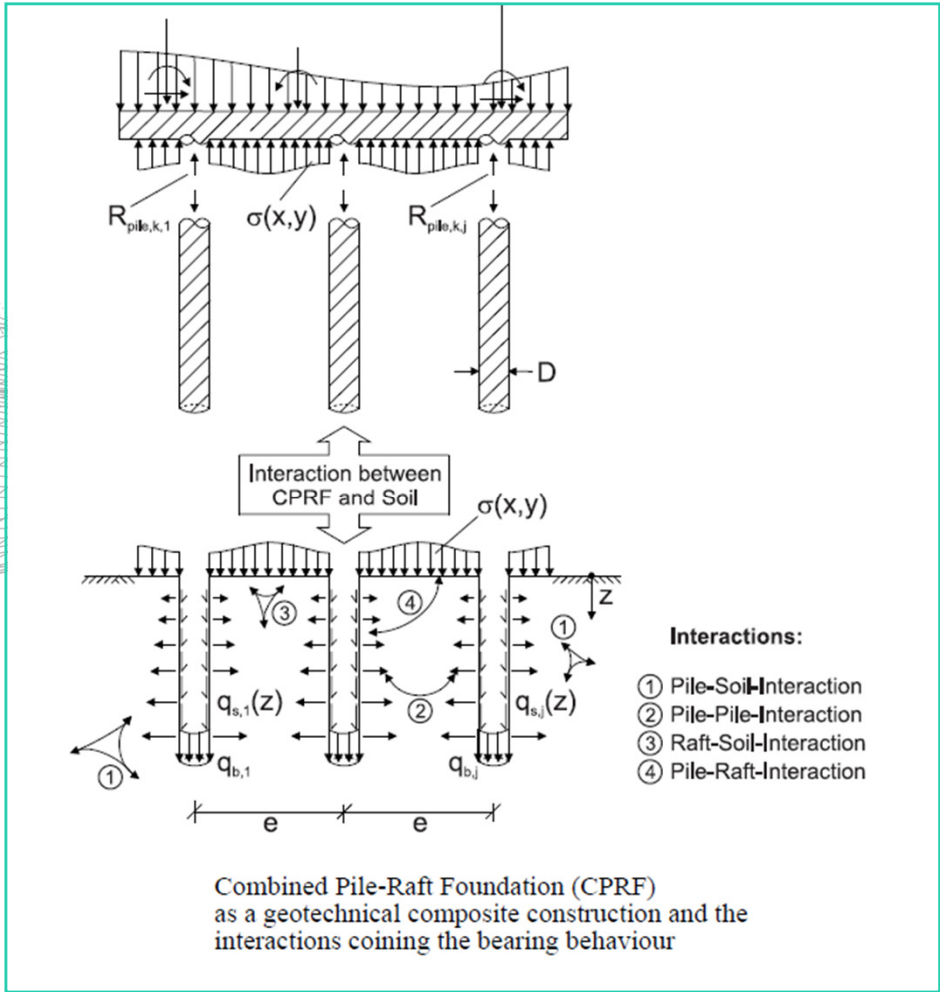
Wide use of pile foundations all over the world has made piling an important branch of geotechnical engineering. Gradually, the concept and usage which was coined as “settlement reducing piles” transformed into a much wider definition of “piled rafts” where “load sharing” between piles and raft has become as important as limiting settlements. Several methods of analysis of piled raft foundations have also been introduced by several authors, but it appears that predicting foundation behaviour is still an area worth to study.

Randolph (1994) has defined clearly three different design philosophies with respect to piled rafts:

- (a) the ‘conventional approach’, in which the piles are designed as a group to carry the major part of the load, while making some allowance for the contribution of the raft, primarily to ultimate load capacity
- (b) ‘creep piling’, in which the piles are designed to operate at a working load at which significant creep starts to occur, typically 70–80% of the ultimate load capacity; sufficient piles are included to reduce the net contact pressure between the raft and the soil to below the preconsolidation pressure of the soil.
- (c) differential settlement control, in which the piles are located strategically in order to reduce the differential settlements, rather than to reduce the overall average settlement substantially.

In addition, there is a more extreme version of creep piling, in which the full load capacity of the piles is utilised: that is, some or all of the piles operate at 100% of their ultimate load capacity. This gives rise to the concept of using piles primarily as settlement reducers, while recognising that they also contribute to increasing the ultimate load capacity of the entire foundation system.

Piled Raft Foundations (Combined Pile-Raft Foundation-CPRF)



$$\alpha_{pr} = \frac{\sum_{j=1}^m R_{pile,k,j}(s)}{R_{tot,k}(s)}$$

Reference: Katzenbach & Choudhury, 2013

Piled Raft Foundations (Combined Pile-Raft Foundation-CPRF)

Favourable and unfavourable circumstances for piled rafts

The most effective application of piled rafts occurs when the raft can provide adequate load capacity, but the settlement and/or differential settlements of the raft alone exceed the allowable values. Poulos (1991) has examined a number of idealised soil profiles, and has found that the following situations may be favourable:

- (a) soil profiles consisting of relatively stiff clays
- (b) soil profiles consisting of relatively dense sands.

In both circumstances, the raft can provide a significant proportion of the required load capacity and stiffness, with the piles acting to 'boost' the performance of the foundation, rather than providing the major means of support.

Conversely, there are some situations that are unfavourable, including:

- (a) soil profiles containing soft clays near the surface
- (b) soil profiles containing loose sands near the surface
- (c) soil profiles that contain soft compressible layers at relatively shallow depths
- (d) soil profiles that are likely to undergo consolidation settlements
- (e) soil profiles that are likely to undergo swelling movements due to external causes.

Reference: Poulos, 2001



Are We Overdesigning? – A Survey of International Practice

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 ISSMGE Secretariat |
  Corporate Associates |
  08-08-2019

A joint initiative by:

Corporate Associates Presidential Group (CAPG),
 Young Members Presidential Group (YMPG),
 Technical Committee TC205 (Safety and Serviceability), and
 Technical Committee TC304 (Risk).

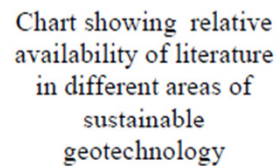
1. MOTIVATION

At the XVI Danube European Conference (Skopje Macedonia, June 2018), the question was raised “Are we overdesigning?”. Although the question originated from the Asian Region, it is valid internationally where different countries and users of various testing techniques or design codes tend to follow local practice for geotechnical design.

This survey is intended to assess the consistency of calculation models and design methods for a variety of geotechnical structures and, where possible, to compare the results with full-scale tests and reliability analyses.

4. PRESENTATION OF RESULTS

The initial results of the survey will be presented at the Asian Regional Conference in Taipei, October 2019. A detailed analysis of the results will be presented at the ISSMGE International Conference in Sydney 2021.



SUSTAINABILITY in GEOTECHNICAL ENGINEERING

- Use of recycled or secondary materials like asphalt pavement and cement stabilized quarry fines as pavement bases,
- Use of recycled glass-crushed rock blends for pavement sub-base,
- Recycling of shredded scrap tires as a light-weight fill material,
- Use of pulverized fly ash to improve the thermal properties of energy piles,
- Use of alternate materials like lignosulfonate promoting surface vegetation and natural subsurface fauna for soil improvement,
- Beneficial use of otherwise hazardous coal and fly ash in geotechnical constructions,
- Bio-engineered slope,
- Recycled mixed glass and plastic for segmental retaining wall units,
- Use of solar powered prefabricated vertical drains,
- Improvement of the mechanical & hydraulic properties of soil using in-situ soil bacteria through bio-mineralisation & bio-polymerisation,
- Reuse & retrofitting of existing foundations,
- Use of underground space for housing and facilities,
- Use of energy related geo-structures like energy piles, wind turbine foundations, and foundations for oil and gas drilling operations.
-

dar

A wide-angle, nighttime photograph of the Dubai skyline. The image shows a dense cluster of skyscrapers, many of which are illuminated with various lights. The Burj Khalifa is prominent in the center. In the foreground, a curved waterfront promenade with palm trees and lights runs along a body of water. A small, brightly lit boat is visible on the water. The overall scene is a vibrant display of urban architecture at night.

Thank you