Tier 3 – Tranche 1

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FINAL GEOTECHNICAL REPORT

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1. INTRODUCTION

Four Dining Facilities, DFAC1 – DFAC4 (Tranche 1), were commissioned by the Authority for design by KBR in early 2007. This is a report on the geotechnical aspects for this Project, which includes a desk study, ground investigation, geotechnical interpretation and geotechnical design. A drawing showing the locations of the four DFAC's within the Basra COB and four drawings showing the proposed arrangements of the DFAC's within the allocated areas are included in Annex B

2. DESK STUDY

This desk study addresses two main sources of information:

- 530 STRE (Materials) Ground Investigation Report from an investigation carried out from 21 - 24 March 2007, [Reference 1] [Annex A]
- Two papers produced by Iraqi geologists, [References 2 and 3.]

The Authority early information available comprised a 530 STRE (Materials) Ground Investigation Report from an investigation carried out from 21 - 24 March 2007, [References 1] and two papers produced by Iraqi geologists, [References 2 and 3.]

The ground investigation comprised twenty trial pits, five at each of the four sites, to depths of 2.1m. In situ testing by the Dynamic Cone Penetrometer (DCP) gave CBR values at depths of 0.8m – 1.6m of 2.9 – 8.7%. This probe was developed by TRL and calibrated for CBR's. Samples from 1m depth gave a clay with liquid limit of 51 and plastic limit of 26, i.e. clay of high plasticity. The soil profile at these trial pits is Gatch of thickness 0.3 – 1.0m overlying soft dark CLAY of high plasticity. Gatch is a local fill material and is described more fully in Section 5.1. No groundwater was encountered. The site sampling and testing showed reasonable uniformity in this top 2m.

The two papers describe the general strata of the Basra area slightly differently. Reference 2 description is as follows:

0 - 2m "Brown colour dried up like soft brick, heterogeneous."
2 – 15m "Soft clay, clay is inorganic and relatively homogeneous"
15 – 24m "Soft to stiff clayey silt containing shells and loose sand"
24 – 30m+ "Fine sand, silty sand and clay, bearing strata"

The paper Reference 3 has index characteristics. The data given for the thick soft clay layer from 2-15m are as follows:

Natural moisture content	28-38%
Liquid limit	42 – 44%
Plasticity Index	16 – 25%
Bulk density	1.8 – 1.99 gm/cm^3.
Sand	1 – 5%
Silt	53 – 63%
Clay	36 – 46%
Undrained shear strength	56 – 135kN/m^2

Groundwater is encountered in this soft clay layer. The papers describe this layer as having a “low bearing capacity” and state that it is normally consolidated.

3. EARLY DESIGN & ASSESSMENT OF GI INFORMATION AVAILABLE

Early foundation designs were for individual pad foundations supporting each column. The loading was 2300kN max column loads. A 300mm thick ground slab would be placed between the columns. The finished floor level would be broadly at existing ground level. High settlements of the pad foundations and high differential settlements between the pads and ground slab were predicted.

Subsequently as the design developed the column loads were reduced to 1200kN and a strip foundations concept introduced with 4m internal strips and 3m external strips. Loadings on the ground slab were given as 5 kN/m^2 live load and 5 kN/m^2 dead load. Also the idea of a 750mm platform of granular material laid over the existing ground was introduced. This platform had already been placed on site at these locations and for access roads at the base for drainage purposes, i.e. water is channelled to the low areas at the previous ground levels.

Using the desk study soil data and design philosophy, calculations were done for settlements and safe bearing pressure. These still gave large settlements of around 400mm and large differential settlements at the column / slab boundaries. The slab settlements are small compared to the strips.

To solve the problem of differential settlement the concept of a raft foundation was adopted. This used a load of 30kN/m^2 and gave predicted total settlements of around 200mm.

Because of the lack of full depth borehole logs, in situ characteristic data and limited test data for the soft clay layer at the site location, i.e. no undrained shear strengths (c_u) and no compressibility data (m_v and c_v), a further more comprehensive ground investigation of the DFAC locations was instructed.

4. GROUND INVESTIGATION

A ground investigation comprising sixteen trial pits, four boreholes with regular SPT’s throughout the depth and sixteen CPT’s or dynamic probes was scoped [Reference 7]. The investigation was carried out with equipment supplied by Archway Engineering in August and September 2007.

The scope envisaged a conventional drill rig for the boreholes and SPT’s, but for practical reasons of transportation a window sampler rig was eventually used. It was appreciated at the time that this was a compromise piece of kit, which would not necessarily provide good samples for testing. However it was hoped reasonable results could be produced.

The actual investigation on site comprised six window sampler boreholes BH101, BH102, BH102a, BH201, BH301 and BH401 to a maximum depth of 20m. In addition to the exploratory holes listed above *in situ* testing was undertaken. This comprised thirty-five super heavy dynamic probes (DPSH) DP101-DP107, BH102DP, DP201 – DP207, BH201-DP, BH202-DP, DP301 – DP307, BH301-DP, BH302-DP, DP401 – DP407, BH401-DP and BH402-DP. These dynamic probes penetrated to a maximum depth of 20m.

The borehole logs and dynamic probe results are included in Annex C.

Four drawings showing the locations of the investigation points, i.e. boreholes and dynamic probes at the four DFAC areas are included in Annex B.

Laboratory tests were progressively scheduled as the investigation was carried out on site and the samples were received at the laboratory, and the tests carried out. A summary of the test results and the complete set of results are included in Annex D.

5. GEOTECHNICAL INTERPRETATION

The topography of the site was generally flat with some very shallow cross-falls. The contours demonstrating this are included on the drawings in Appendix 5.

The geology encountered in the investigation comprises Made Ground of thickness 1m overlying 15m of soft grey clay overlying compact green sands. These are broadly in agreement with the strata described in the papers, References 2 and 3. The soft clay is the alluvial deposits of the Hammar Formation of the Late Pleistocene to Recent.

5.1 Made Ground

The top stratum, the Made Ground, is the locally created fill known as Gatch. This is a material comprising a mix of clay, sand and gravel in variable quantities. Typical descriptions of the material are brownish, grey slightly sandy CLAY with little fine gravel or brownish, grey slightly clayey SAND with little fine gravel. This material was not sampled and tested in this investigation. It has been used by the MOD for the last few years at the Basra COB and is considered a suitable fill material.

5.2 Clay Layer

The main stratum is the normally consolidated soft grey clay. This is variously described as grey brown CLAY or grey silty CLAY. The clay can be regarded as normally consolidated as this is an estuarial location. The two papers, References 2 and 3, written by Iraqi academics experienced in the local soils identify the material as normally consolidated.

The index testing for this material shows typically moisture content of 34 - 41%, liquid limit 47 - 50% and plastic limit 20 - 25%, giving a plasticity index of about 25 and a plasticity classification as intermediate plasticity. There are no particle size distributions for this material. The typical bulk density is 19 kN/m^3 and dry density is 14 kN/m^3.

In situ dynamic probes with CBR correlation (as Reference 1) were carried out at the top of the clay and these gave CBR's of 4 -7 approx. at the locations of the four potential DFAC sites tested. This showed some uniformity in the top part of the clay layer. It also showed the dried out nature of the top of the soft clay layer.

Unconsolidated undrained triaxial tests were carried out and these gave undrained shear strengths of 4 - 38kN/m^2. These results are summarised in Table 1 below.

BH102		BH102A		BH201		BH301		BH401	
Depth (m)	Cu (kN/m^2)	Depth (m)	Cu (kN/m^2)	Depth (m)	Cu (kN/m^2	Depth (m)	Cu (kN/m^2)	Depth (m)	Cu (kN/m^2)
3.0	12	11.5	21	3.25	38	3.45	12	3.4	13
5.0	21			5.25	27	7.5	14	5.4	12
				10.7	10	9.0	20	11.4	7
				14.8	7	13.3	4	15.35	126
								20.55	665

Table 1: Undrained Shear Strengths of Clay Layer from Laboratory Tests

These results range from 4 – 38 kN/m^2 with an average of 15.6 kN/m^2 for fourteen results. Unfortunately these results confirmed the doubts about the equipment. They show no increase in strength with depth, there are many low results and there is some randomness in them. These results reflect the poor sampling.

It is always difficult obtaining good samples in soft and very soft clay. Factors contributing to these results in this material and location include:

- Disturbance through driving of the window sampler
- The window sampler liner method for obtaining samples is not as good as the conventional borehole sampling methods by percussion or rotary borehole methods.
- Disturbance through transportation of the samples
- Correct sealing of the samples
- Non-availability of better sampling methods such as piston samplers and block sampling

For these reasons the above undrained shear strength results are not considered reliable.

Oedometer tests for the volume compressibility tests were carried out and the coefficients of volume compressibility obtained are shown in the following table, Table 2:

Borehole	Depth (m)	Stress Range 0 - 6 kN/m^2	Stress Range 6 - 12 kN/m^2	Stress Range 12 - 25 kN/m^2	Stress Range 25 - 50 kN/m^2	Stress Range 50 - 100 kN/m^2	Stress Range 100 -200 kN/m^2	Stress Range 200 -400 kN/m^2
		m_v (m^2/MN)	m_v (m^2/MN)	m_v (m^2/MN)	m_v (m^2/MN)	m_v (m^2/MN)	m_v (m^2/MN)	m_v (m^2/MN)
BH102	3.6	*2.175*	*1.653*	*1.251*	*0.854*	0.537	0.310	
	5.4		*2.772*	*1.734*	*1.154*	0.716	0.426	0.240
BH201	3.0	*3.281*	*1.664*	*1.018*	*0.778*	0.516	0.322	
	5.1		*3.237*	*1.559*	*1.055*	0.712	0.442	0.253
	11.1			*2.665*	*1.092*	*0.614*	0.364	0.200
	15.0			*2.750*	*1.087*	*0.685*	*0.387*	0.206
BH301	3.25	*3.333*	*1.450*	*1.125*	*0.845*	0.535	0.323	
	7.3		*2.535*	*1.345*	*0.941*	*0.663*	0.396	0.229
	9.25			*2.036*	*0.936*	*0.580*	0.353	0.196
	13.15			*3.541*	*1.427*	*0.824*	0.478	0.251
BH401	3.2	*4.018*	*1.924*	*1.318*	*0.884*	0.545	0.333	
	5.2		*1.798*	*1.581*	*1.006*	0.629	0.378	0.216
	11.2			*2.400*	*1.080*	*0.677*	0.407	0.211
	15.6			*0.493*	*0.333*	*0.245*	*0.166*	0.103

Table 2: Consolidation Data from Oedometer Test Results

On inspection of the testing and test results it is noted that the results at the lower stress ranges are not representative of the behaviour at the actual depth of the soil sample, as they test the soil at stresses lower than the in situ stress. These results are shown in italics. Greater credence is given to the other values.

The dynamic probing blow count data for the clay gives useful data on the density / strength of the clay layer. It provides a "picture" of the variation with depth of in situ characteristics of the soil and approximate equivalence to undrained shear strength values.

The results are fairly uniform across the site. The blow counts show strength in the first 1.0 -1.5m reducing to a low value at the top of the soft clay layer, which then increase progressively with depth to 16m, the end of the layer, when they increase rapidly as the dense sand layer is penetrated. Typical values are summarised in Table 3 below. (DPSH *n* is the blow count for 100mm) The full results are in Annex C:

Depth (m)	**DPSH *n* Values**	**Depth (m)**	**DPSH *n* Values**
0 – 1.0	8	10.0 – 11.0	6
1.0 – 2.0	1.5	11.0 – 12.0	6
2.0 – 3.0	1	12.0 – 13.0	7
3.0 – 4.0	1	13.0 – 14.0	7
4.0 – 5.0	2	14.0 – 15.0	7.5
5.0 – 6.0	3	15.0 – 16.0	8
6.0 – 7.0	4	16.0 – 17.0	11
7.0 – 8.0	4	17.0 – 18.0	15
8.0 – 9.0	5	18.0 – 19.0	20
9.0 – 10.0	5	19.0 – 20.0	No data

Table 3: Typical DPSH n Blow Count data for Soft Clay Layer

The equivalent undrained shear strengths for clays for DPSH *n* data were obtained from the equivalence shown in the Huntley paper [Reference 5] for clays. This is the only published equivalence found. This equivalence in clay is presented in the table, Table 4, below.

DPSH *n* (for 100mm)	**Classification (as BS5930:1999)**	**Strength Cu (kN/m^2) (as BS5930:1999)**
<1	Very soft	<20
1 – 2	Soft	20 – 40
3 – 4	Firm	40 – 75
5 – 8	Stiff	75 – 150
>8	Very Stiff	150 - 300

Table 4: DPSH *n* – Strength Relationship in Clay (Huntley 1990)

SPT *N* values were given an equivalences to clay strengths by Terzaghi and Peck in 1948, and are included below in Table 5 for completeness.

SPT *N* (for 300mm)	Classification (as T & P 1948)	Strength Cu (kN/m^2) (as T & P 1948)
<2	Very soft	<12
2 – 4	Soft	12 – 24
4 – 8	Medium	24 – 48
8 – 15	Stiff	48 – 96
15 – 30	Very Stiff	96 – 194
>30	Hard	> 194

Table 5: SPT *N* - Strength Relationship in Clay (Terzaghi & Peck, 1948)

These two tables help give approximate equivalences of DPSH *n* and SPT *N*. It is noted Terzaghi and Peck appeared to assign a more conservative (and lower) value to the shear strength, i.e. the definitions of “soft”, “stiff”, etc. vary slightly.

The DPSH results do indicate a broad almost linear increase in shear strength with depth. This certainly seems logical as the clay would progressively compress as further layers were deposited. This increase in strength is also referred to in the papers, References 2 and 3.

A linear increase of undrained shear strength with depth of normally consolidated clay is also referred to in text books such as Simons and Menzies, Reference 6, who quote Bishop and Henkel’s results presented in their 1962 paper, for which the relationship is $c_u/p' = 0.3$. Similarly Skempton (1957) proposed $c_u/p' = 0.11 + 0.00037PI$ where PI is the plasticity index. For our situation where PI = 25% , $c_u/p' = 0.2$.

Using these two relationships undrained shear strength ranges at 5m depth are 15 – 20 kN/m^2 and at 10m depth are 24 – 30 kN/m^2.

These relationships give shear strength values significantly lower than the DPSH equivalence, implying a conservative approach should be used in interpreting these data.

In this investigation testing of the in situ condition in soft clays is considered to give more logical undrained shear strength values (although high) and variation with depth than those values obtained in the laboratory.

Where recordings were made, groundwater was found be at about 2m bgl.

Testing of pH value and sulphate content has been undertaken within the site. Results identify pH values between 6.2 – 7.0 and sulphate content to be between 0.3 – 1.3g/l, within the clay at depths of up to 5m. There is no data for soils near the surface. Assuming the clay material is consistent any buried concrete within the clay should be designed for Design Sulphate Class DS-1, with an ACEC Class AC-1 as defined by BRE Special Digest 1 [Reference 4], i.e. the non-sulphate resisting condition. Sulphate tests on the Gatch are advisable.

Based on the data in this section the parameters for the design in this clay layer are as follows:

Geotechnical Design Parameters

Bulk density = 19 kN/m^3

Liquid limit = 25

Plasticity index = 25

Undrained modulus = 10MN/m^2 .

Undrained shear strength = 20 - 75kN/m^2 (from DPSH Results)
(Conservative low values are used in the calculations)

Coefficient of volume compressibility, m_v, = 0.8 – 0.3m^2/MN.
This varies with in situ pressure, i.e. depth. In this case the higher value is near the surface, which reduces with depth.

There is no need for any effective stress parameters. The undrained analysis is considered the primary factor dictating soil behaviour under loading.

5.3 Sand Layer

The third stratum starting at 15m – 17m bgl and continuing to depth is a dense fine sand or sandy clay, typically described as a greenish grey clayey SAND or a silty sandy CLAY. The PSD tests in the material (at the upper levels of the stratum) show the material as a clay and a sand. However there is no need to quote any parameters for this layer as the dynamic probes identify a dense to very dense sand or stiff to very stiff clay, and in any case at that depth the loadings will have little effect on the material.

6. GEOTECHNICAL DESIGN / CONCLUSION

The applied load is a reinforced concrete raft of size 62m x 44m with an applied load of 30kN/m^2. This slab is placed on top of the current ground level, i.e. on top of the 1m added Made Ground (Gatch).

A check on the safe bearing pressure, q_s, using a conservative undrained shear strength of 20kN/m^2 for the entire clay layer gave a value of 45kN/m^2. It should be noted the safe bearing pressure increases with time, as moisture is squeezed out and consolidation occurs.

The immediate settlement is worked out using the Janbu method with the modulus E_u of 10MPa based on a conservative E_u/c_u correlation and an undrained shear strength of 40kN/m^2. This gives a settlement of 40mm.

The consolidation settlement is calculated for layers with reducing coefficient of volume compressibility, m_v, values from test data, 0.8 - 0.45m^2/MN. This gives a settlement of 275mm. The total estimated settlement is in the region of 320mm.

The calculations are included in Annex E.

7. REFERENCES

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