Engineering Geological Appraisal of Geohazards of Duqm Area, Sultanate of Oman

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Abstract

The Duqm area in the Central Eastern Oman, is located about 600 Km SW of Muscat, the capital city of The Sultanate of Oman. Extensive developmental projects like sea port, airport, dry dock, oil refinery, Crude Oil Storage Terminals, infra-structures like roads, railway, bridges, factories, buildings and residential villas etc. are under construction or on the anvil. The area of about 9600 km^2 is fraught with geohazards assigned to the geological setup of the region. The Duqm area is marked by an exhumed / peneplaned topography with residual mounds/ hills. The Presence of the Upper Cretaceous to Lower Tertiary rocks and Quaternary sediments, pose different geo-hazards like the swelling/ expansiveness in the clays, marl and sabkha, differential settlement in loose to very loose soils/ fills and sabkha, slope failures/ rock falls from the cliffs, liquefaction etc., which drastically influence the construction of foundations for the civil engineering structures. The paper deals with the engineering geological characterisation of the geohazards in the Duqm area and the possible mitigations based on the available data from five different major projects in the area.

Key words: Engineering Geology, Geohazards, Duqm area, Oman

1. Introduction

The Duqm area (NE 40-03/07) in the Central Eastern Oman, is located about 600 Km SW of Muscat (Fig.1), the capital city of The Sultanate of Oman. Extensive developmental projects like sea port, dry dock, airport, oil refinery, factories, infra-structures like roads, bridges and buildings etc. are under construction or on the anvil. Geohazards can be relatively small features, but they can also attain huge dimensions and affect local and regional socio-economy to a large extent. Site investigations for many of the projects are under way. The engineering geological assessments for the foundation grounds has revealed geological conditions which are hazardous conditions for the civil engineering structural foundations, due to the presence of geologic materials like sabkha deposits of recent and sub-recent origin, green clays/ clay stone, marls/ chalky marls posing extensive problems of swelling/ heaving, consolidation/ settlement, solution vugs/ cavities, liquefaction and contamination etc.. The authors have carried out site investigations and geotechnical review consultancy works for certain major projects in the area. The paper gives an overview of the geo-hazardous properties of the foundation ground materials and outlines the possible mitigation measures.

Site Investigation Data: The site investigation data/ results from following tests, besides many other types, conducted at about five major projects related to infrastructure development in the area has been used in the assessments.

Field tests

i. Bore Holes - 878
ii. SPT - 4775
iii. CPT - 93

Laboratory.Test:

i. Atterberg limit -143
ii. Consolidation - 127
iii. Swell test - 102

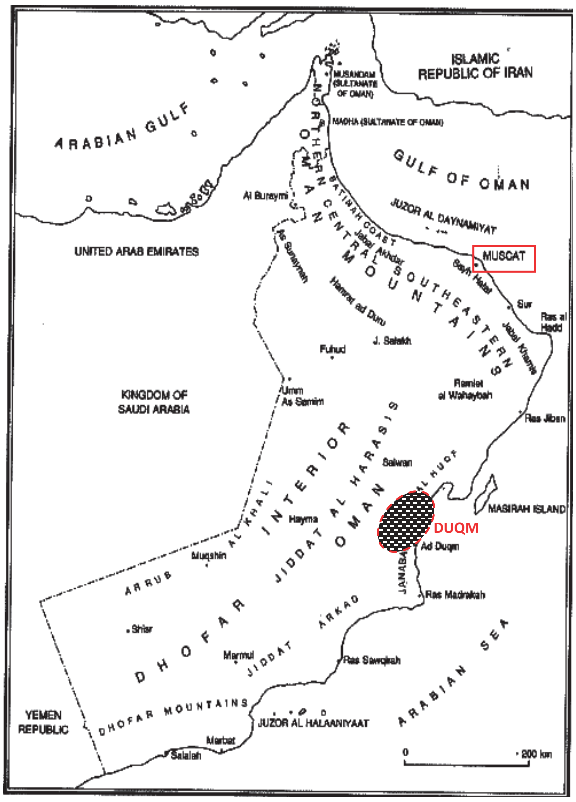

Fig. 1 Physiography Map of Oman with location of Duqm area.

2. Geology of The Area

The geological history of the region comprises the following six main periods of sedimentary deposition separated by important tectonic or sea level changes/ eustatic events, represented by major unconformities;

The land mark events of the geologic history of the region can be enumerated as follows:

i. The Proterozoic to earliest Palaeozoic
ii. he Palaeozoic to pre-Late Permian
iii. The Late Permian to early Late Cretaceous (late Cenomanian) when the Arabian Platform developed
iv. The Late Cretaceous
v. The Early Tertiary and
vi. The Late Tertiary.

The uplift of the Arabian plate brought about vast emergence of the Arabian Platform, lasting until the early Miocene bringing with it the surface weathering and silicification. The sea persisted in the southern part/ Dhofar.

The earliest signs of the extension that resulted in the opening of the Aden Rift, and which became increasingly active from the Early Oligocene onwards, are recorded in the Dhofar margin only (Platel et al., 1992; Figs. 2&3). The southern Dhofar border that of the eastern coast between Shuwaymiyah and Duqm, gradually foundered, creating grabens and strongly subsiding basins. Initially lacustrine/ lake environments (Zalumah Formation) were followed by mixed shelf and reefal-lagoon environments (Ashawq Formation) in which tidal and clastic shoreline sediments were deposited.

Physiographically the area can be distinguished in to four regions, and is related to the distribution of the main geological units (Fig.1)

i. The most extensive natural region is the vast Jiddat al Harasis Miocene plateau in the North West with a maximum elevation of 200 m. The region is desert occupied, virtually the only vegetation being isolated clumps of thorn bushes.
ii. Extending towards SE from the above plateau is the well-developed Janabah plateau, with a, southerly-flowing drainage system called Wadi Gharm.
iii. The NE quarter of the map, is hillier- Tertiary and Mesozoic rocks are exposed concentrically around the resistant Proterozoic - Palaeozoic basement.
iv. Sabkha form fairly continuous, permanently moist, clay-sand depressions around the Precambrian massif. They occur on the soft Palaeozoic clastic rocks to the west and on an upper Cretaceous chalky sequence in the Nafun-Duqm basin. This vast ring-shaped depression is bounded to the west and south by cliffs of mainly Lower to Upper Cretaceous limestone.

The Duqm and Madraca area is at the junction of several major geologic structural domains which, however, are largely covered by the Miocene limestone forming the Jiddat al Harasis and Janabah plateau.

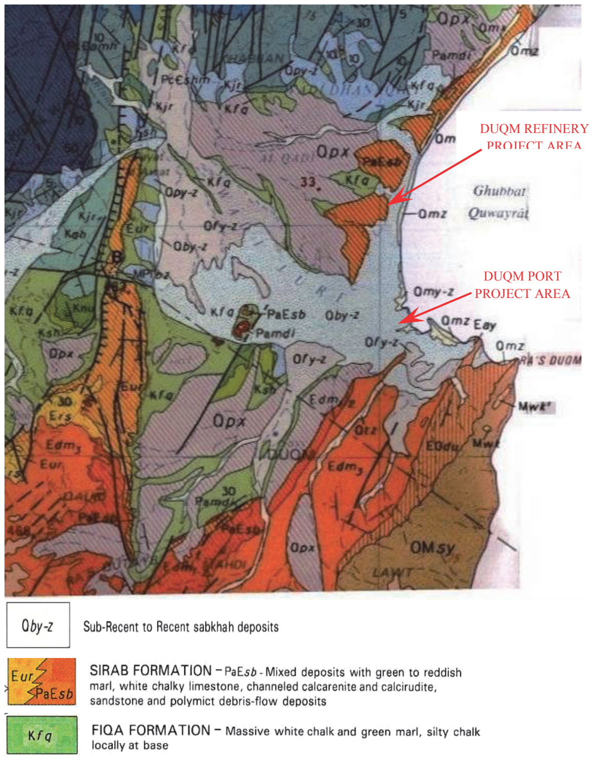

Fig. 2: Geological map of Duqm area (Platel et al., 1992)

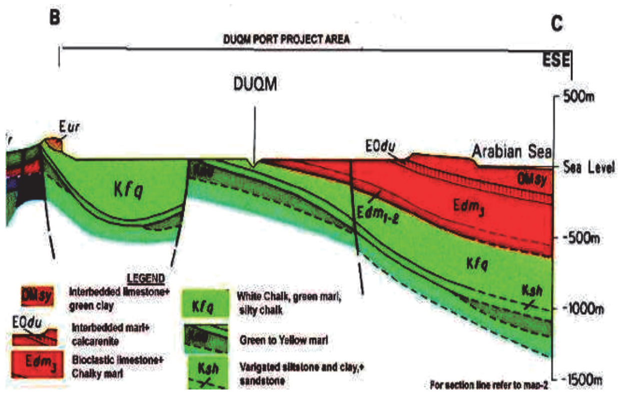

Fig. 3: Geological cross section across Duqm area (Platel et al., 1992)

3. Engineering Geological Appraisal

The 9600 km^2 area of Duqm is bounded to the east by the more or less N-S coast line of the Arabian Sea, and to the south by the near E-W northern shore of Sawqirah Bay.

The Duqm area manifests an exhumed/ pene-planed topography with isolated residual mounds or low ranges of hills. The topography manifests the classic case of wind erosion. The different geologic materials differentiated in the area influencing the engineering structure foundations are discussed below:

Photo 1: Classic wind erosion and piedmont deposits at the foot hills

3.1 The piedmont deposits

The softer/ weaker inter beds of marls and chalks exposed on the cliff faces are eroded sub-horizontally along the bedding by wind action, creating overhangs (Photo 1) of the relatively resistant overlying dolomitic limestone's which eventually collapse in the long run to accumulate at the foot hills/ cliff toes as piedmont deposits (Photos 1&2). These constitute assorted gravel and boulder size rock fragments strewn in a sandy silty matrix. The piedmont deposits are differentiated as ancient, sub-recent and recent depending on their degree of compaction/ cementation.

3.2 Alluvial fans deposits

The present-day wadis/ valleys bear the recent bed loads of cobbles and coarse-grained, poorly sorted, unconsolidated sands accumulated mostly after the Pleistocene glaciation. These sediments are incised by 1- 2 m into the older alluvial deposits or more deeply into the substratum.

Photo 2: Typical photograph showing the manifestations of wind erosion in the Duqm port area with Shuwayr Formation, underlain unconformably by the green marls/ clays of Duqm Formation at the foot hills. Formations dipping SE (into the hill) by 20 – 30°.

3.3 Beach sand, recent coastal dunes and aeolian sand veneer.

These include the most recent, coarse-grained, coastal deposits of marine origin constituting mainly the beach deposits as well as those deposits derived from them. All these deposits are sandy, very white, fine to medium-grained, and comprises mainly of highly fragmented bio-clasts with a small amount of quartz grains varying much with the nature of the rocks forming the beaches.

3.4 The Sabkha deposits

The whole of the periphery of the pre-Late Permian Basement is marked by a series of more-or-less closed depressions on the soft Late Palaeozoic Formations which butt against the Mesozoic homoclinal scarps. These are filled by numerous sabkha deposits which vary considerably in size, Abu Tan in the north and those of Wadi Jurf to the west open eastwards to the coastal sabkha of Duqm.

In the Duqm port project area extensive deposits of coastal sabkha are noticed (Photo.3) overlying the white chalk, green marl, silty chalks of the late Mesozoic's/ late cretaceous Fiqa Formation of Aruma Group. The low lying areas (tidal flats) are masked by extensive deposits of sub-recent sabkha. The +3 m thick sub-recent sabkha, covering about 20 % of the area, are loose to medium dense ('N' value of < 30).

Photo 3: Exposure of sub-recent sabkha in excavations - Port area

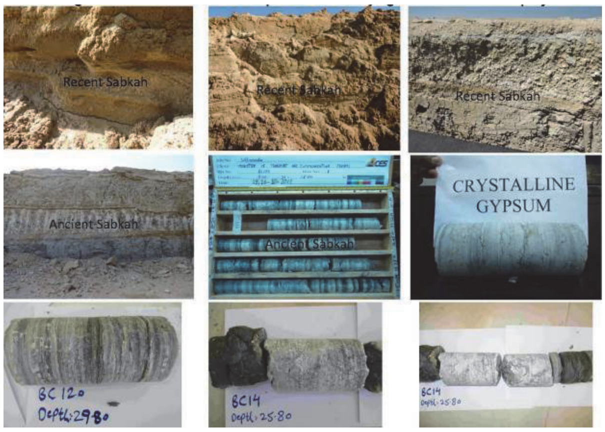

Photo 4: Exposed sections and in cores recent & sub-recent sabkha in Port area

They comprise of clay-silt deposits and fine-grained brown-yellow sand with small gypsum crystals, brought in by storm, rain flows along the wadis/ valleys and by run-off eroding adjacent slopes as well as by wind during dry phases. The aeolian silt is trapped by almost permanent moisture of the sabkha.

Having no or very little run-off, the depressions give rise to the repeated formation of salt and gypsum crusts over a thickness of several centimetres leading to the characteristic surficial appearance of blistered, dark brown soil with large polygonal mud cracks. Deposition of these sediments in the area has been taking place since at least the Late Pleistocene.

Relatively compact/ consolidated/ very dense (N>50) ancient deposits of sabkha/ Gypsum associated with the clays are noticed in the bore holes (photo. 4). These are noticed at a depth range of 10 - 25 m (below El. -20 m). The Duqm Formation has enclosures of saccharoidal gypsum as large nodules and laminations/ beds (Photo 4). The thickest bed is noticed to be about 2 m (Photo 6).

3.5 The Clays & Marls

The clays / marls noticed in Duqm area are of late Mesozoic to tertiary age and belong to two different formations - the greenish marls/ clay stones of Fiqa Formation of late cretaceous age and Yellow marls and shales are of Dammam Formation of early tertiary age which are extensively exposed (Photos 5&6) or underlying the piedmonts (Fig. 4), in the Duqm area by virtue of their low angle easterly dips and the easterly downthrown blocks (Fig. 3). The Calcarenites and calcirudites of Shi'nzi Formation of Aruma Group are found overlying the clays in the higher reaches.

Photo 5: Clays in exposed sections and bore holes - port area

Photo 6: Green clays associated with Ancient sabkha in sections and bore hole cores- port area

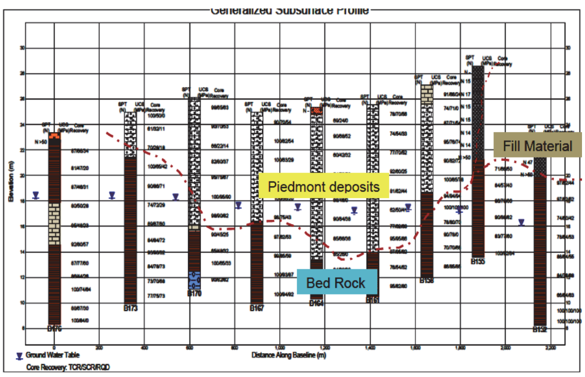

Fig. 4: Geological sections showing the bed rock / green clays at depth underlying the piedmonts.

The clay deposits show extensive variations in mineralogy - high kaolinite, a low illite content. The green clays of Duqm Formation has predominance of palygorskite and lesser content of illite- smectite. The green clays are expansive/ swelling in nature due to the presence of inter-layered illite- smectite (Platel et al., 1992).

3.6 The Limestones

The other formation of Dhofar Group is the Shuwayr Formation, which are dominantly exposed in the Duqm area on the higher reaches of the residual hills. The formation consists of interbedded white bioclastic, reefal limestone with corals, dolomitic laminated limestone and green to reddish clay and black dolomite at the top (Photo 7). The limestones trend in N – S direction with gentle dips of 10 – 15^{o} towards SE (i.e. towards the sea). The limestones are weak friable with high porosity.

Photo 7: Limestone with characteristics at Duqm

3.7 Sand stones and conglomerates

These are early Tertiary rocks- arenites, bioclastic rudites which are dominantly weak to extremely weak in nature (UCS <5Mpa). These overlie unconformably the late cretaceous marls, clays/ green clay stones. The thickness of the formation varies from 1.5 to +100 m with gentle easterly dips of 10– 12^{o} ie. towards the coast.

4. Potential Geohazards

A geohazard is a geological state that may lead to widespread damage or risks. These can be relatively small features, but they can attain huge dimensions and affect local and regional socio-economy to a large extent (e.g. tsunami).

The geohazards can be evaluated systematically by the risk and/or event frequency (chance of occurrence) and risk level (severity). However, a simpler scheme was followed by the authors for the process of geo-risk evaluation and determining necessary actions according to the evaluation of likely hazard by examining the likely influence, associated risks and consequences on the proposed foundation of the structure in the light of safety and performance. Accordingly, geo-risks are classified into 3 main classes:

- **Low-hazard** conditions exist where the likely consequences of occurrence is small and tolerable, or the probability for significant occurrence is low.
- **Moderate-hazard** conditions exist where the likely occurrence is undesirable but the probability of occurrence is low.
- **High-hazard** conditions exist where the likely occurrence is undesirable and the probability of occurrence is high.

Based on the identified geological setup/ composition of the site, the nature, properties of the different components and GW conditions the following potential hazards/ challenges, in order of dominance, could be identified in the Duqm area.

- Soft and weak Sabkha Soils
- Swelling potential of clay marls
- Collapse potential of surfacial dry soils.
- Liquefaction potential and seismic effects.
- Scour and erosion.
- Thick engineered fill embankments supporting main/ heavy structural foundations.
- Side slope Stability & protection of high Earth embankments with Engineered fills.
- Rock slope stability issues.
- Subsurface Cavities / Karst
- Contamination of site soils / GW

Each of the above risks is discussed to assess its frequency/ chance of occurrence and severity such that an evaluation of the importance / significance of the hazard is established with necessary remedial / precautionary considerations.

4.1 Soft and Weak Sabkha Soils

The SPT, CPT and consolidation test results conducted for several samples of Sabkha materials has confirmed that the material existing in varying thickness from few meters to about 10 m (Fig. 5), in few areas, is identified as Loose (N=10) to Medium Dense (N=<30).

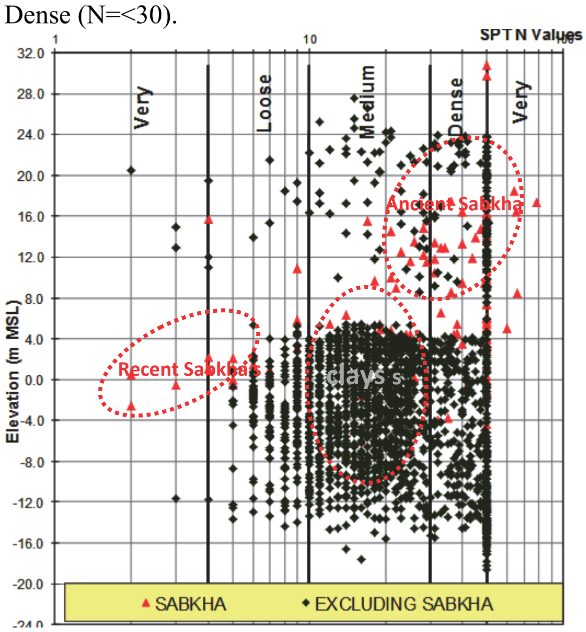

Fig. 5: Plot of SPT vs Depth

The CPT test is relatively an accurate and reliable assessment method and measurements that are used to establish the shear strength and stiffness of the soil. Some of the most commonly used assessment methods of Engineering parameters for fine grained soils from CPT tests are briefly outlined below.

Robertson et al (1986) and Robertson (1990) stressed that CPT-based charts measured on disturbed soil samples are predictive for soil behavior type (SBT), grain-size distribution and Atterberg limits (Fig. 7). Fortunately, soil classification criteria based on grain-size distribution and plasticity often relate reasonably well to in-situ soil behaviour and hence, there is often good agreement between USCS-based classification and CPT-based SBT (e.g. Molle, 2005).

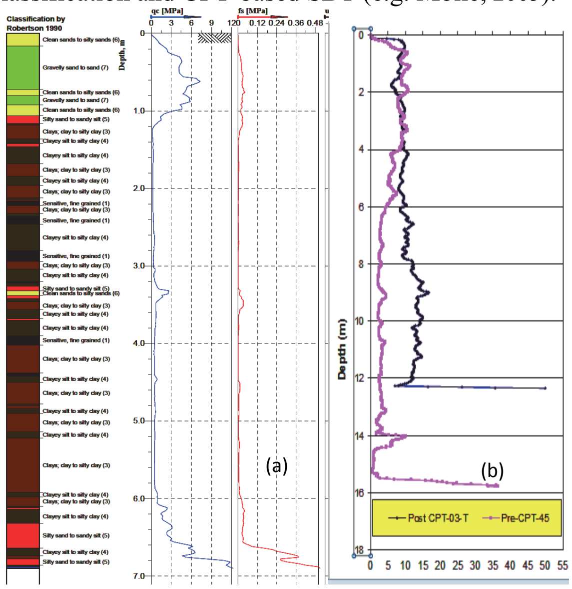

Fig. 6: Typical CPT plots showing (a) qc, fr & soil type with depth (b).degree of ground improvement in fills.

The shown SBT (Fig.7) and CPT results (Fig. 6a) is a typical result of the CPTs' conducted in the port and refinery project areas. The result shows the Sabkha material extends to about 7 m below EGL at this location and is composed mainly of Clays, silty clays, with sandy soil on the top.

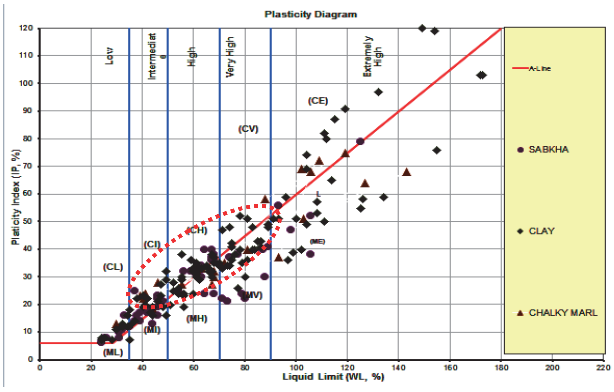

Fig. 7: Plot on Plasticity diagram (A line chart).

Based on different calculation methods and the CPT –SBT data correlation the interpreted design parameters for the project sites are as follows:

Su = 10 kpa, φu = 0.0

M = 1.5 Mpa, and E is <1.0Mpa

(*Where Su*=undrained shear strength, *φu*=undrained friction angle; , *M*= Constrained modulus; *E*= Stiffness/ elastic modulus)

Consolidation parameters are also given as the soil is NC type, with Cc = 0.25 - 0.40; e0 = 0.75 - 2.0,

The properties of the encountered Sabkha soils indicate to be highly hazardous and cannot be used directly to support the structure foundation, because of the extremely weak bearing resistance and the very high settlements and long term movements. Accordingly the footing ground treatment / Engineering solutions proposed for the foundations are site specific (Table 2).

4.2 Swelling potential of clay & marls

The principal cause of expansive clays is the presence of swelling clay minerals such as montmorillonite and smectite, illite. Differences in the period and amount of precipitation and evapo-transpiration are the principal factors influencing the swell-shrink response of a clayey soil beneath a building. Poor surface drainage or leakage from underground pipes also can produce concentrations of moisture in clay. Trees with high water demand and uninsulated hot process foundations may dry out clay causing shrinkage.

The potential for volume change in clay soil is governed by the amount of clay minerals present, it's initial moisture content, initial density/ void ratio, it's microstructure and the vertical stress. The susceptible soils include most of the Mesozoic and Tertiary clay formations in Duqm area. Generally speaking, the older formations are less susceptible to swell than the younger ones.

Engineering problems related to expansive soils have been reported in many countries of the world, but are generally most serious in arid and semi-arid regions (Duqm area is classified as Arid region). Consequently, many engineered structures suffer severe distress and damage .

Two modes of swelling in clay soils may be distinguished, namely inter-crystalline and intra-crystalline swelling. Inter-particle swelling takes place in any type of clay deposit irrespective of its' mineralogical composition, intra-crystalline swelling on the other hand is characteristic of the smectite family of clay minerals and montmorillonite in particular.

Table 1: Classification of swell potential (Bell & Culshaw 2001).

LL (%)	PL (%)	Initial (insitu) suction (kPa)	Potential swell (%)	Classifi-cation	Duqm Range
< 50 50 -60 >60	< 25 25 – 35 >35	<145 145 - 385 > 385	<0.5 0.5 – 1.5 > 1.5	**Low** **Marginal** **High**	**High**

Generally kaolinite has the smallest swelling capacity amongst the clay minerals and nearly all of its swelling is of the inter-particle type. Illite may swell by up to 15 % but intermixed illite and montmorillonite may swell some 60 to 100 %.

Empirical methods are used for the assessment of swelling potential based on void ratio, natural moisture content, liquid and plastic limits (Table 1) and Plasticity Index (PI) ranges (Table 2).

The activity chart (Fig.8), proposed by Van Der Merwe (1964), frequently has been used to assess the expansiveness of green clay and Chalky Marls.

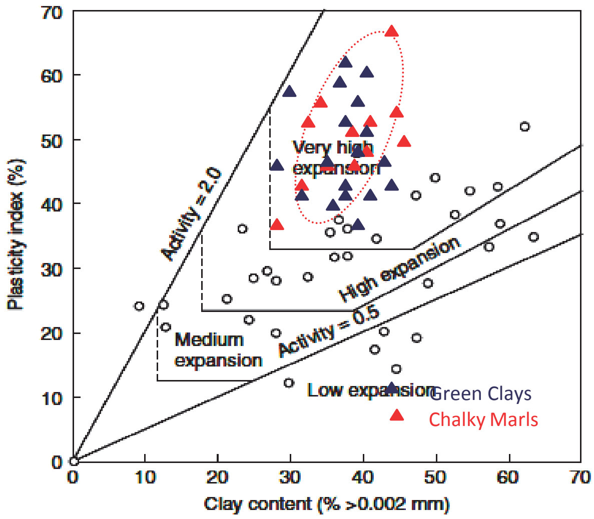

Fig. 8: Activity chart with results of Duqm Area

The results of Atterberg limits (Index Parameters) classify the bed rock (Marls) as follows (Table 2):

Table 2: Swelling range(after Bell and Culshaw, 2001).

Plasticity Index (%)	Potential Vol. Change	Duqm Range	Remarks
> 35 22 – 48 12 – 32 < 18	Very High High Medium Low	**30 – 147** **-** **-** **-**	**High to Very high Swell**

- Potential for volume change: **High to v High**
- Degree of Expansiveness: **High to v high, and high activity**
- Swell potential: **High**

The results of few Oeodometer Swell Pressure tests, of the sabkhas, green clays and marls show a very high volume change reaching up to 18 % with a swelling pressure up to 627 kN/m^2 (0.627 Mpa). This necessarily calls for a hazard mitigation process for the foundations of the structures (Table 3).

In-situ inundated plate load tests were conducted inone of the sites on the marls to have a more reliable assessment of swelling behavior of the marl rock at the proposed foundation levels. The tests were conducted with a pressure range of 50 to 200 kPa have given a swell pressure range of 80 – 170 kPa with a heave of 1 – 5 mm (0.2%) corresponding to the active zone of 3 m. The marls under inundation have shown settlements of 0.5 to 8.0 mm under high pressure of 200 kpa.

4.3 Sub-surface cavities

The karst process is an erosion by groundwater. The encountered subsurface materials include Marl and chalky marls and limestones which are generally susceptible to solution activity. However, the large number of drilled boreholes did not indicate presence of such large solution features that are typically indicated by loss of drilling fluid and sudden drop of drilling rods, which is not reported in any of the boring logs, although limited water loss (up to 45%) was indicated in several boreholes. This was mainly related to fractured nature of the bedrock, indicated by the retrieved core samples.

4.4 Thick Earth Fills

The proposed grading of sites involves the construction of deep earth fill embankment that would eventually support the proposed structure foundations.

(1) Suitability of Fill Material: Practically any non-organic insoluble soil may be incorporated in an embankment when modern compaction equipment and control standards are employed.

(2) Types of Fill: The proposed fills are of controlled nature, placed in thin layers with prescribed compaction during placement.

(3) Influence of Material Type: The following soils are difficult to use economically.

- Fine –grained soils may have insufficient shear strength Or excessive compressibility.
- Clays of medium to high plasticity
- Plastic soils with high natural moisture
- Stratified soils' may require extensive mixing with borrow material.

4.5 Contamination

The suitability of the proposed backfill material are examined against the following criteria:

- *Contamination:* Soils proposed for structural fills shall be free of contamination, which may be hazardous to public health and the environment
- *Water soluble solids*: Water soluble salts content shall be very limited, typically less than 2%.
- Suitability for final engineering performance in accordance to the project requirements (support structural foundations).

The main risk of settlement is considered due to the above mentioned parameters. Strict QC / verification tests are the main feature to mitigate such hazards.

Soil Water Solubility: In arid areas, the soil may contain soluble soil particles such as halite. Deposits of halite can form in salt playas, sabkhas and Salinas. These soluble soil particles are dense and hard enough to carry the overburden pressure. But after the infiltrations of water into the ground two types of settlement can occur:

- The water can dissolve away the soluble minerals resulting in ground settlement.
- The collapse of the soil structure due to weakening of salt cemented bonds at particle contacts, and

The property of the soil is assessed by conducting Collapse potential and Conventional Oedometer tests. The later test is not considered suitable due to the difficulty in obtaining un-disturbed samples.

4.6 Liquefaction Potential and Seismic Effects

Liquefaction is used to describe a situation of significant loss of strength due to build-up of pore water pressure and subsequent deformation of loose, fine, saturated sands under the dynamic process of cyclic loading during the earthquakes.

Two major areas within the Port of Duqm were constructed by hydraulic sand fill method, dredged from the adjacent sea,bed up to a thickness of 15-18m.

The site investigation included SPT (Standard penetration tests). The obtained Nspt profiles from many test borings revealed the ground to be medium dense in general, loose to very loose pockets.

Hydraulic fills of silty sands typically form high hazardous materials in terms of susceptibility to liquefaction, (although Duqm area is classified with relatively low seismic hazard potential), and high deformations under monotonic /static loading. This is related to its weak micro structure as the fine grained content tend to form bridges and bind the sand grains; in zones of honey-combed like structure; leading to noticeable heterogeneous stiffness and strength (fig.6b).

Based on Martin & Lew (1999), "preliminary screening for liquefaction" was carried out. Since the GWT exists at deeper depth with respect to the upper thin sandy soils encountered, which means these sandy soils are not susceptible to liquefaction. On the other hand, the very weak Sabkha soils with Clay and Sandy Silts existing in other areas of the site are considered not liquefiable due to their nature of plasticity.

Liquefaction assessment for the site was conducted according to Youd & Idriss (1997) with specialist software based on Nspt results for quantitative assessments and design of deep compaction options.

4.7 Side Slope Stability and Protection of Earth Fill Embankments:

Protection of side slopes from the effects of earthquake, scouring and undermining by the tidal waves, streams etc. is another major feature which requires adequate attention.

4.8 Stability of Natural and Rock cut slopes

The cliffs of interlayered and interbedded rock pose hazards of rock falls and slides due to:

- The collapse of overhangs created by the erosion of the softer interbeds by wind action (photo. 2&7),
- Sliding failure along adverse planes.

The cliffs are potential hazards during the earthquakes. A systematic study of the discontinuity data and analysis can help designing a safe cut slope angle and identify the requirement of slope support / protection measures.

5. Mitigation plan

Mitigation and prevention are paramount, through improved understanding of geohazards, their preconditions, causes and implications. Particularly, in

Montane regions, natural processes can cause catalytic events of a complex nature. The continued multi-disciplinary investigation into the occurrence and implications of geohazards, in particular, lead to site specific mitigation studies, to establish relevant prevention mechanisms (Table 3).

The remedial or treatment options / actions are categorized accordingly under two main strategies:

5.1. Reduce the Hazard

To propose actions / options that will control the consequences of occurrence of the hazard within tolerable and controlled limits.

5.2. Avoid the Hazard

Propose solutions that will not be affected by the likely hazard, such as use of deep piles to mitigate settlement of foundation soil.

A mitigation plan for the various geohazards in Duqm area based on the level of Geo-risks mentioned above is given in the following Table 3.

6. Conclusions

The Duqm area covering over 9600 sq. Km is on the anvil of large constructions on relatively weak grounds conditions fraught with geohazards. Adequate measures need to be taken during every stage of the project to identify the site specific hazard and mitigate them with suitably designed measures, in order to have a trouble free designed life of the structures.

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Table 3: Summary of mitigation plan for the Geo-risks to engineering structures in Duqm area

Geohazard	Structure type	Geo Risk Level	Mitigation Measures
Sabkha deposits	Roads/ fill embankment, villas/ buildings etc.	**High**	*Limited thickness(< 4 m):* Removal of sabkha and fill back with engineered fill material
			Thick deposits (+4 m) : Ground improvement- pre-loading technique Deep foundations- stone columns, soil mixing, Geopier / RAP, micro piles etc.
Expansive clays	Roads	**High**	Excavate by about 1 – 1.5 m and fill back with engineered sandy fill material. No contact with water or flooding.
	Buildings, other structures like tanks etc.	**High**	Deep foundations micro piles, bored piles, with suspended slabs,
Solution cavities	Embankments / heavy structures	Low	Selective grouting of foundation.
Soluble salts	Embankments & other structures	Low	Excavate and replace collapsible soils with engineered fills.
Slope stability & Scour effects	Earth Embankment side slopes	Low to **Moderate**	Design Side slope angles. Surface protection with suitable measures like grouted pitching, concrete slabs, soil nails, mesh reinforced shotcrete, geogrids etc. with efficient surface drainage at top & toe and across the side slope.
Natural or rock cut slopes	Structures close to the slope, safety requirements	Low	Slope protection measures shotcrete, rock bolts, mesh.. and efficient drainage
Liquefaction- / Compressibility of hydraulic sandy fills	Roads, service lines, structure foundations	**High**	Foundation soil stabilisation/ ground improvement, strict QC