Barettes socketed to bedrock assessment of their load capacity

La capacité verticale de fondations barrette dans les roches

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ABSTRACT

A new covered sports complex is planned to be constructed at the Asian part of the city of Istanbul. The site is an old rock quarry and later has been utilized as a landfill basin to accumulate soils and trash excavated from various locations. Main lithological unit underlain the top uncontrolled fill is, limestone, sandstone and shale at various locations and depths. The city of Istanbul is potentially under the influence area of the North Anatolian Fault – NAF of the Turkey.

The planned structure for the sports arena is a dome supported on largely spaced columns at upper levels. Maximum vertical loads as large as 1,250 tons will be transferred to foundations by means of these columns. The high seismicity of the site with very inheteregenous and poor subsoil conditions bring a big challenge for the design of foundations.

Consequently, it was decided to implement barrette foundations socketed in to the underlying bedrock in order to satisfy the imposed performance criteria. The barrettes of 0.80m x 2.80m in dimension are planned to be implemented under the each column. The socket length to be implemented within the underlying bedrock is related to the service loads and the shear resistance of socket interface. The shear resistance of the socket interface is estimated using various empirical equations utilizing compressive strength of the bedrock, in the design stage.

Osterberg test procedure has been employed for the estimation and verification of barrette capacities socketed into the bedrock. The load cell is placed at the center of the socket and specially constructed barrette has been instrumented and loaded to 2,500 tons at a early stage of the construction. The results are critically evaluated and compared with the estimated design values.

RÉSUMÉ

Un nouveau complexe sportif couvert est planifié d'être construit dans la partie asiatique de la ville d'Istanbul. Le site est une ancienne carrière de roches et a plus tard été utilisée comme un bassin d'enfouissement d'accumuler des sols excavés et des moellons. L'unité lithologique principale repose sur le remplissage incontrôlée est du grès calcaire et de schiste à divers endroits et profondeurs. La ville d'Istanbul est potentiellement en vertu de la zone d'influence du système de failles Marmara situé au sud, dans la mer de Marmara, qui est l'extrémité ouest de la faille nord anatolienne de la Turquie.

La structure prévue pour le domaine sportif est un dôme soutenu sur les colonnes largement espacés à des niveaux supérieurs. La forte sismicité du site avec les mauvaises conditions du sous-sol très inhétérogènes apportent une grande défi pour la conception des fondations.

Par conséquent il a été décidé de mettre en œuvre des fondations barrette ancrés dans la roche sous-jacente afin de satisfaire les critères de performance. Les barrettes (0.8mx2.8m) sont prévues d'être mises sous chaque colonne. La longueur d' ancrage dans la roche est lié aux charges de service et la résistance de l'interface d'ancrage. Bien que la résistance de l'interface d'ancrage peut être estimée en utilisant différentes équations empiriques.

Récemment, procédure d'essai d'Osterberg a été employé dans différents projets à travers le monde pour l'estimation et la vérification de la capacité du pieu et de barrette ancrés dans les unités lithologiques. Dans ce projet, la cellule de charge est placé au centre de l'ancrage et barrette est instrumentés et chargés de 2500 tonnes à un stade précoce de la construction. Les résultats sont évaluées et comparée avec les valeurs estimées.

Keywords: Deep Foundations, Barrette Foundations, O'Cell Test, Rock Quarry

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1 PROJECT

One of the well known sports club, through their sponsor, has decided to implement a complex project containing a covered sports arena with a capacity of eighteen thousand people, hotel, office block and shopping mall located in the Asian part of city of Istanbul, Turkey. The site is located at about 15 kilometers north of North Anatolian Fault line which is well known with its past seismic activities as shown in *Figure 1*. It is well known a segment of NAF was responsible for 1999 Golcuk Earthquake of M=7.2 that has caused large number of human casualty and great financial loss. It is also known that segment of NAF located beneath the Marmara sea will create a major earthquake of $M_w > 7.0$ in near feature; with a 67% probability within 30 years. Therefore, the earthquake resistant design of every structure, especially the ones that involve public safety such as sports arena in this complex bare at most attention to civil engineers.

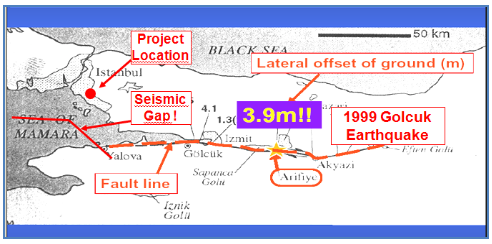

Figure 1. Location of NAF.

The subject of this paper is the foundation design of sports arena which is about 100 meters in diameter dome structure as shown in *Figures 2 and 3*.

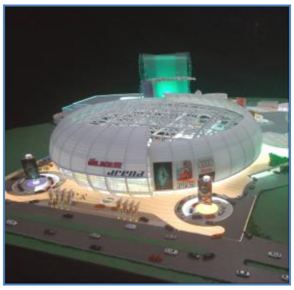

Figure 2. Ulker Arena Project.

Figure 3. Ulker Arena Project Typical Section.

2 SUBSOIL CONDITIONS

Site is an old rock quarry later being used as landfill and has been filled with trash and the excavated surplus material obtained from the various construction sites within the city. Consequently, the depth of bedrock from existing ground surface beneath the uncontrolled fill is quite variable and unpredictable underlain the sports arena. Therefore, a systematic subsoil investigation programme was implemented having one boring at each structural column locations. The length of borings was specified as having minimum coring of ten meters within the underlying bedrock. Consequently, maximum boring length of 65.0 meters were realized at the bottom of the cross valley. The thickness of the uncontrolled fill located above the bedrock was quite variable, reaching to a value of as high as 50.0 meters. As expected, it is determined that the fill has contained all kinds of debris transported to the site and was quite loosely packed having various size void spaces. As a result, the uncontrolled fill is very susceptible to vertical displacements due to the further wetting of the formation. Further, the hydraulic conductivity of the fill is quite large due to its loose state of placement. As determined from the corings, the bedrock is very inheterogeneous in lithology and mechanical properties. Main lithological units observed were sandstone, siltstone, shale and very infrequently weak limestone.

3 MECHANICAL PROPERTIES OF BEDROCK

Systematic core samples have been taken from the bedrock in each boring have been tested under uniaxial compression to determine unconfined compressive strength in the laboratory. The variation of uniaxial compressive strength, UCS-q_{ucs} with depth is quiet variable as expected due to the in heterogenity in lithology and the depth of the bedrock. Based on the laboratory results, there is a distinct increase in UCS with depth from the existing ground surface. The results could be modeled for design purposes as below according to depth of bedrock:

Table 1. UCS values according to the depth of bed rock.

d_b, m	UCS, MPa
0-15	2.5
15-25	5.0
25^+	7.5

4 STRUCTURAL SYSTEM AND FOUNDATIONS

Dome structure is carried out by means of 208 rectangular columns having circular symmetry as seen in *Figure 4*. Outside column loads, maximum value of 1250 tons, are much larger compared to central column load value of 350 tons.

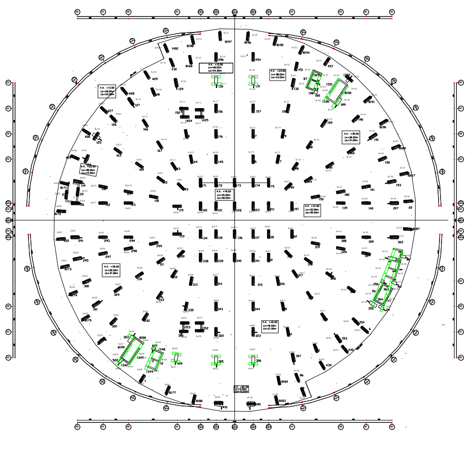

Figure 4. Layout of Barrette Foundations.

There are two parking levels located beneath the structure. Foundations of columns socketed into the bedrock were considered suitable based on the encountered subsoil conditions and seismicity of the site. Cast-in situ barrette foundations are chosen to be implemented for this purpose. Barrette dimensions were designed as 0.80 m by 2.80 m. Under each column one barrette is located having total of 208 number of barrettes as foundation system. Barrettes were connected with a structural reinforced concrete mat at the top. Due to inheterogenity in bedrock conditions and due to no redundancy of foundations each barrette was designed based on the maximum column load of 1250 tons. Barrettes have offered various advantages compared to cast-in situ conventional circular piles in this specific project. First, it was possible to utilize one single barrette under each column carrying maximum service load of 1250 tons. Rectangular configuration having possibility of placement of foundations with circular symmetry offered the possibility excellent behavior of foundations under seismic loadings. Having circular symmetry in foundations, no torsional moment is expected to be created under earthquake loadings regardless of the direction of the seismic shaking. Further, utilizing both hydraulic grab and reversed circulation cutter technology used in barrette construction offered the confidence and comfort of obtaining desired socket lengths within the bedrock. At last, for the same section barrette offers 35% larger frictional surface compared to circular piles. In this case each barrette area is Ab=0.8x2.8 =2.4 m2, equivalent pile diameter is deq=1.69 m, skin area of barrette for unit length is asb=7,2 m2/m and skin area of pile is asp=5.3m2/m yielding to ratio of asb/asp= 1.35.

5 DESIGN OF BARRETTES

Considering structural system, subsoil conditions and high seismicity of the site, barrettes were designed based on skin friction only. In order to limit the vertical displacements under static and earthquake loadings socket skin friction only within the bedrock is considered. Low skin friction through the uncontrolled fill is neglected in estimation of vertical load capacity. Ultimate socket load through the bedrock, Q_{sult} is estimated from;

$$Q_{sult} = A_s \cdot f_{sult} \tag{1}$$

Where A_s=socket area which is given as A_s=p.L_s where p=perimeter of the barrette which is 7.2 m and L_s is the socket length; f_{sult} is the ultimate unit skin friction developed along the socket. Based on the previous studies, f_{sult} could be estimated from;

$$f_{sult} = \alpha \cdot q_{UCS}^{\beta} \tag{2}$$

Where, α and β are correlation coefficients recommended by various authors and q_{UCS} is the uniaxial compressive strength of the bedrock along the socket length. Therefore ultimate skin load, Q_{sult} will be equal to:

$$Q_{sult} = \alpha \cdot A_s \cdot q_{UCS}^{\beta} \tag{3}$$

Using factor of safety FS, the safe load will be;

$$Q_{Ssafe} = \frac{Q_{sult}}{FS} = \frac{\alpha \cdot p \cdot L_s \cdot q_{UCS}^{\beta}}{FS} \tag{4}$$

Considering that the minimum socket length of barrettes are estimated based on the maximum service load, Q_{ser} (MPa), the socket length, L_s could be estimated from Qs_{safe}=Q_{ser}, i.e.

$$L(m) \geq \frac{Q_{ser} \cdot FS}{\alpha \cdot p \cdot q_{UCS}^{\beta}} \tag{5}$$

In this relationship, p= 2(0.8+2.8) = 7.2m, FS=2, therefore;

$$L(m) \geq \frac{Q_{ser}}{3{,}6 \cdot \alpha \cdot q_{UCS}^{\beta}} \tag{6}$$

Table 2, summarizes different α and β values recommended by various authors and, range of estimated average values of f_{sult} (MPa) are 0.49, 0.82 and 1.12 respectively for bedrock depth ranges of 0-15 m, 15-30m and 30^+ m.

Table 2: Estimation of Unit Socket Skin Resistance

References			**f_{sULT}, Mpa Depth**		
Method	α	β	0-15m	15-25m	>25m
Horvath and Kenny (1979)	0.21	0.50	0.33	0.47	0.58
Carter and Kulhawy (1988)	0.20	0.50	0.32	0.45	0.55
Williams et al. (1980)	0.44	0.38	0.61	0.79	0.91
Rowe and Armitage (1984)	0.40	0.57	0.67	1.00	1.26
Rosenberg and Journeaux (1976)	0.34	0.51	0.54	0.77	0.95
Reese and O'Neill (1988)	0.15	1.00	0.38	0.75	1.13
Meigh and Wolski (1979)	0.22	0.60	0.36	0.58	0.74
$fs_{ult-avg}$, (Mpa)			0.49	0.82	1.12

Under these circumstances, if the average unit socket skin friction values are utilized in estimation of minimum socket lengths, the values of L_s=7.0 m, 4.2m and 3.1 m are determined based on the depth of the bedrock from the ground surface. At most of the barrette locations the depth of the bedrock is greater than 15 m, as a result utilization of a specific single value of L_s=5.0m > 4.2m is considered to be on the safe side for design purposes.

6 CONSTRUCTION OF BARRETTES

Mechanical and hydraulic grabs are utilized in excavation of uncontrolled fill located at the top. Using bentonite slurry, special precautions were taken to prevent the seepage of the slurry through the surface skin area of the each segment towards the loose uncontrolled fill. Later, cutters of Bauer BC-30 and MBC-30 are utilized with reverse circulation using bentonite slurry to excavate the bedrock in order to achieve the required socket length of 5.0 meters. The reinforcement cage is prepared outside according to its structural design and later lowered into the excavated segment of each barrette. The segment containing bentonite slurry and cage is concreted using classical tremie procedure. The specification related to bentonite slurry usage TS EN 1538/2001 is strictly followed during construction of barrettes in order to ensure the concrete quality within the barrettes.

7 BD-SLT/O-CELL TESTING

The estimated vertical load capacity of a barrette constructed with 5.0 m socket length is tested using BD-SLT/O-CELL procedure in order to verify the design load and estimate the vertical displacement under the service load. The test barrette has 0.8mx2.8m dimensions having an average length of 30.0m with a maximum test load of 2500 tons. Load cells are located in the middle of the socket length, and 2x700 tons load cells are used in testing. In addition sixty strain-gauges at ten different elevations are used in order to measure the skin friction distribution along the skin of the barrette with depth. The configuration of testing is given in *Figure 5.*

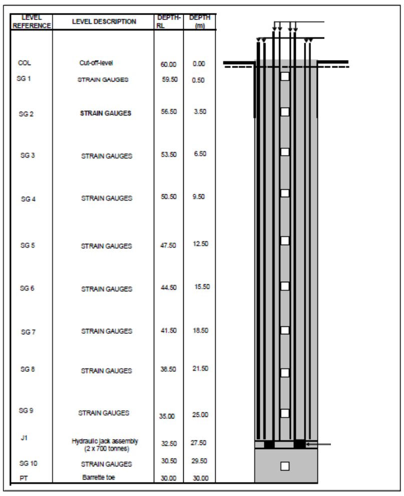

Figure 5. Configuration of testing.

Test is conducted according to ASTM D 1143-81 and loading up to 2500 tons are achieved in two consecutive steps. Load vs displacement relations are obtained by three direct measurements at top of the barrette, load cell top and load cell bottom as given in *Figure 6*.

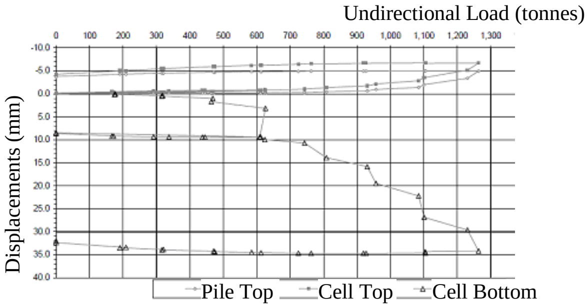

Figure 6. Load vs displacements.

Using the procedure recommended by Osterberg, real load-displacement relationship for the case of barrette loaded at the top is estimated in *Figure7*.

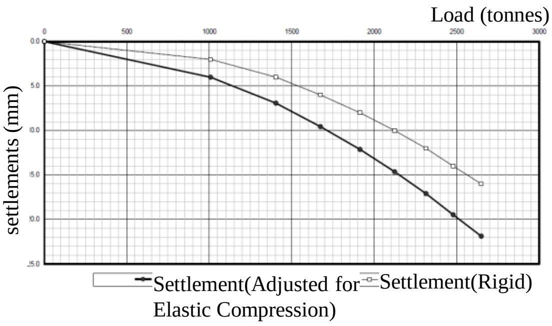

Figure 7. Settlements vs Load.

Variations of skin friction depth the skin at various loading steps are presented in *Figure 8*.

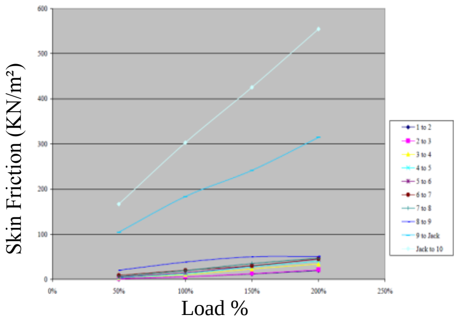

Figure 8. Skin Friction vs Load (%).

From the test, the following results are obtained;

Average unit skin friction mobilized in fill;
$f_{smob(fill)} \sim 20kPa$
Average unit skin friction mobilized in bedrock;
$f_{smob} \sim (300-550)kPa = (0.30-0.55)MPa$
Vertical displacement under service load;
$\delta \sim 5.8mm$
Vertical displacement under maximum test load;
$\delta \sim 19.8mm$

It is seen that, average unit skin friction mobilized value of 0.55 MPa is in good agreement with the safe average value of 1.12/2=0.56 MPa estimated in *Table 1.*

Further, the vertical displacement of barrette under service load were limited with a value of $\delta = 5.8mm$ which is well below the vertical limiting displacement imposed by performance design criteria.

8 CONCLUSIONS

- Barrette foundations interms of their constructability in most difficult subsoil conditions to originally designed elevations offers confidence and comfort in foundation design.
- Utilization of mechanical and hydraulic grabs in sedimentary formations and cutters with reverse circulation in bedrock allows the possibility to construct the barrette foundations with optimum time, cost and effort. On the contrary, even very high capacity rotary piling may have great difficulty in drilling hard rocks in order to achieve designed socket lengths.
- Performance criteria i.e. allowable displacement of the planned structure controls the allowable vertical loads of the barrettes. In this specific project, utilization of 5.0m socket length in bedrock was sufficient to support the maximum column load of 1250 tons with factor of safety value of 2, and the resulting vertical displacement under the service load was limited with 5.8 mm based on the O'Cell testing.
- It is shown that estimation of vertical capacity of barrettes socketed in rocks could be made using uniaxial compressive strength of the bedrock employing empirical equations to estimate the value of unit skin friction along the socket length at design stages.
- A successful application of BD/SLT O-CELL test has been utilized in verification of barrette design i.e. estimation of socket length and prediction of vertical displacement under service load.
- No redundancy design by means of utilization of one barrette under each column, offered the possibility of optimum and cost effective design of foundations.
- Placement of barrettes following circular symmetry in radial directions has resulted in an optimum configuration of foundations against rotational forces around the vertical axis that will be subjected during earthquake.

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