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ESTIMATE OF BEARING CAPACITY OF GYPSEOUS SOILS FROM FIELD DATA

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ABSTRACT: - This research examined field data of 84 boreholes form ten chosen sites in Salah Aldeen Governorate. The soils for these sites are granular gypseous with gypsum content (Gyp. %) ranged from 8.37-51.14%. Based on Standard Penetration Test (SPT), the N values for each chosen site were corrected for field procedures and overburden pressure effects by exploiting *NovoSPT* program to get $(N_1)_{60}$ or $N_{Cor.}$ values, where these values used later by this program for allowable bearing capacity calculations. To study the properties and illustrating the behavior of these gypseous soils, the SPSS and the Curve Expert programs were used to perform statistical analysis for the data of the chosen sites. For dry condition, it is concluded that ($N_{Cor.}$) values are increasing with (Gyp. %) after deactivating the effects of void ratio and average particles size. Also the allowable bearing capacity (q_{all}) values are observed to be increased with (Gyp. %). Based on the stresses affecting the SPT sampler, the peck et al.,1974 Equation was proved to be the reliable formula among the others Equations for calculating (q_{all}) from field N values. Depending on calibration chamber (laboratory SPT) tests results and cavity expansion theory, it is dependable to use 0.5 exponent for C_N correction Equation of overburden pressure effect.

Keywords: Gypseous soil, SPT, Allowable bearing capacity, Statistical Analysis.

1- INTRODUCTION

Soils of arid and semi-arid regions are rich with sulphates, commonly gypsum [1, 2]. Gypsum-rich soil occurs in dry lands, reflecting both of geological and climatic factor [3]. A soil is considered a gypseous soil when the gypsum percentage is enough to change or to affect its engineering properties [4].

Fattah et al.,(2008)[5] studied this problems in some Iraqi gypsiferous soils pointing out that they are problematic from both agricultural and engineering points of view. Various problems have been recognized when structures are built on them such as soil subsidence, increasing the seepage of water throughout the soil, soil softening and sulphate serious effects on concrete. Additionally slow and continuous dissolution of gypsum by seeping water through the gypsum-rich soil were thought to be important in these problems.

In general, gypseous soils are reliable for construction under dry and even under short term flow, but become problematic, collapsible and undergo large settlement under long term flooding with water [6].

For nearly all soil types, the Standard Penetration Test is commonly used for correlation with a wide range of parameters for input into routine geotechnical design calculations. The earliest use of the SPT in design was by Terzaghi and Peck in 1948[7], although at that stage in the development of the SPT it was recognized that the correlated values were estimates. It must be recognized that direct correlations are often very easy to use like Terzaghi and peck's methods in 1948[7] and 1967[8] to estimate the allowable bearing pressure for spread footings on sand [9].

The main objectives of this study were investigating the influence of Gyp.% on $N_{Cor.}$ values and later on bearing capacity calculations, examining the most reliable formula for calculating the allowable bearing capacity values base on field N values, and to establish the dependable formula for correcting N values for overburden pressure effect.

2- STANDARD PENETRATION TEST

The Standard Penetration Test is currently the most popular and economical means to obtain subsurface information. The SPT has an advantage over laboratory tests due to problems associated with disturbance of cohesionless soil. The SPT is made by dropping a free-falling hammer weighing 63.5kg (140 lb) onto the drill rods from a height of 0.76 m (30 in.) to achieve the penetration of a standard sample tube 0.45m (18 in.) into the soil. The blows number required to penetrate each 0.15m (6 in.) increment is recorded and the number of blows required to penetrate the last foot is summed together and recorded as the N value. The first 0.15m (6 in.) of penetration tends to reflect disturbed material remaining in the hole from the removal of the drill and the sampler insertion (10).

Correction factors have been proposed by various authors to account for field procedures (the type of hammer, the drill stem length, borehole diameter and the use of sampler liners). The standard blow count N_{60} can be computed from the measured N value from the following general Equation (1) (11).

$$N_{60} = N_f.C_E.C_R.C_S.C_B \tag{1}$$

where N_{60} = SPT blow count value corrected to 60% of the theoretical free fall hammer energy

N_f = field measured SPT blow count value (blows/300mm or blows/foot)

C_E = energy correction factor

C_R = rod length correction factor

C_S = sampling method (liner) correction factor

C_B = borehole diameter correction factor

For cohesionless soil another two types of corrections are normally applied to the measured SPT N values:

a- Correction due to Dilatancy

In saturated fine or silty dense or very dense sand deposits, the N value observed may be greater than the actual value because of the tendency of such materials to dilate during shear under undrained conditions. Terzaghi and Peck (1948)(7) recommended that if the observed N value is greater than15, it should be corrected for dilatation effect as

$$N' = 15 + \frac{1}{2}(N - 15) \tag{2}$$

where N = observed SPT value

N' = corrected value for dilatation effect

b- Correction due to Overburden Pressure

The overburden pressure is one of the most influential and widely known factors affecting the measured SPT value. According to (ASTM D6066-11)(12) the penetration resistance $(N_1)_{60}$ adjusted to 60% drill rod energy ratio and normalized to a 100 kPa (1tsf) stress level is calculated as follows:

$$(N_1)_{60} = C_N \times N_{60} \tag{3}$$

where:

C_N = SPT (normalization) overburden pressure correction factor

$$C_N = \left(\frac{\sigma'_{vref}}{\sigma'_v}\right)^n \tag{4}$$

where:

σ'_{vref} = reference stress level

σ'_v = vertical effective stress at test depth

n = stress exponent

for σ'_{vref} = 1tsf(≈ kg$_f$/cm^2 ≈ bar ≈ atm)

$$C_N = \left(\frac{1}{\sigma'_v}\right)^n \tag{5}$$

for n = 0.5

$$C_N = \left(\frac{1}{\sigma'_v}\right)^{0.5} \quad (6)$$

for stress unit in kPa and n=0.5

$$C_N = 9.8\left(\frac{1}{\sigma'_v}\right)^{0.5} \quad (7)$$

The Stress Exponent n is derived from chamber testing (laboratory SPT) and rely on cavity expansion theory. The exponent varies with over consolidation ratio, density, particle size, and aging of the soil [(13), (14)].

Typical values for normally consolidated clean sands used in practice today range from 0.45-0.6 . Examination of chamber penetration tests indicates that the exponent is lower in dense sands (as low as 0.4)[(14)].

The typical value used in practice is 0.5 or the square root of effective vertical overburden pressure [(15)].

3- SPT HAMMER ENERGY MEASURING SYSTEM

Some form of instrumented equipment is required to measure the energy transmitted from the hammer to the SPT drill string. The measuring system should have strain gauges for obtaining force measurements and accelerometers for obtaining velocity data. The equipment should be capable of recording and displaying the velocity and force waveforms as well as calculating energy values. The measuring system consisted of an instrumented 2-foot long AWJ drill rod section {Figure (1)} with foil strain gauges (350 ohm) glued directly onto the rod in Wheatstone bridge configuration to measure the strain, which is converted to force using the cross-sectional area and elasticity modulus of the rod. Two piezoresistant accelerometers are housed in a rigid aluminum block that is mounted to the rod. The acceleration measured by the accelerometer is integrated to obtain velocity. When the test is in progress, the beginning of the hammer blow triggers the analyzer {Figure (2)} to begin recording data. These data are continuously displayed on the screen as the force wave (from the strain gauges) and the velocity wave (from the data integration of the accelerometers). The trace of the velocity wave is scaled such that it is proportional to the force wave, the velocity is scaled at the force scale divided by the impedance Z (a property of the drill rod equal to the drill rod elastic modulus times the cross sectional area divided by the velocity of wave propagation). Four channels of data are recorded for each blow: 2 force and 2 velocity [(16)].

According to (ASTM D4633-10) [(17)] the reliable method for hammer energy efficiency measurement is performed by the integration of the product of the force and velocity records over time (Force-Velocity Method) and is referred to as EFV. For this method the transferred energy is determined by:

$$\boldsymbol{EFV} = max\left[\int F(t)V(t)dt\right] \quad (8)$$

where $\boldsymbol{F}$ = the force at time t

$\boldsymbol{V}$ = the velocity at time t

The integration begins at impact (time the energy transfer begins) and ends at the time at which energy transferred to the rod reaches a maximum value {i.e., integration over the entire force and velocity record, Figure (3)}. This method is in theory sound and requires no correction factors [(18)].

4- STATISTICAL ANALYSIS OF DATA

In this research, the *NovoSPT* software version 2.79-2014 was used, which is a computer program for interpretation of SPT data and correlating blow counts N to soil properties based on more than 310 from more than 70 academic researches and papers which are implemented in *NovoSPT* program along with powerful features for organizing the correlations such as statistical charts, reports, import, export data and more. Also the computer program has a wide capability of calculating soil (static and dynamic) parameters and representing them graphically with borehole depth based on several researchers selected by program's user.

Curve Expert Professional version 2.2.0-2014 is a software solution for curve fitting and data analysis. Data can be modelled using a toolbox of linear regression models, nonlinear regression models, smoothing methods, or various kinds of splines. Over 60 models are built-in, but custom regression models may also be defined by the user. Full-featured publication-quality graphing capability allows thorough examination of the curve fit. The process of finding the best fit can be automated by letting Curve Expert compare any data to each model to choose the best curve. The software is designed with the purpose of generating high quality results and output while saving time in the process.

SPSS (Statistical Package for Social Studies) version 20-2011 for Windows which is a versatile computer package that will perform a wide variety of statistical procedures was utilized in this study to relate the $N_{\text{Cor.}}$ values for each site to the influencing soil factors using multiple linear regression.

Figure (4) shows the locations of studied sites and Table (1) gives the coordinates, numbers and depths of boreholes, and code number of the sites. The boreholes of some sites were grouped into groups according to their variation of the gypsum percentage with depth (for getting the maximum possible R^2 factor for Gyp.%-depth relation) this led to get more accurate relation of $N_{\text{Cor.}}$ values (calculated by *NovoSPT* software) with influencing soil parameter (getting maximum multiple R^2 factor). For boreholes of studied sites, the Gyp.%-depth mathematical models were formulated by using Curve Expert software.

Some researchers stated that N values are influenced by the factors which are listed in Table (2) excluding the influences of field procedures. After normalization the effect of current stress level, the $N_{\text{Cor.}}$ or $(N_1)_{60}$ parameter will be used as dependent variable in the multiple linear regression Equations. Cementation and aging effects will not be included in the analysis being the studied sites locations at Salah Aldeen province belong to the same Pleistocene terrace physiographic region, also the formation of gypsum in the studied locations was from one type [(19)]. The water table level is far away from ground surface level for almost studied sites, therefore the effect of pore water will be ignored in the analysis. For soaked BS site, by utilizing *NovoSPT* software, the N values were corrected for water table presence regarding using the effective soil unit weight necessary for overburden pressure correction and exploiting the required N correction for dilation effects besides the ordinary corrections necessary for field procedures effects. The influence of uniformity coefficient is partially included in void ratio and average particles size parameters, so this effect will not be examined. The influence of particles angularity will not be examined since the soils of studied sites are of one gypseous granular type.

Consequently, the parameters that will be examined in this study are the void ratio (e), gypsum percentage (Gyp.%), average particles size (D_{50}) and fines content (F%). Being the key aim of this study was to find the effect of gypsum percentage (Gyp. %) on $N_{\text{Cor.}}$ values and later on bearing capacity calculations for granular gypseous soils.

For the examined sites, the field N data were corrected for field procedures (energy level, borehole diameter, SPT rod length and sampling method) and over burden pressure effects by utilizing *NovoSPT* software to get $(N_1)_{60}$ or $N_{\text{Cor.}}$ values, where for each borehole *NovoSPT* file, the field N values with their depths, and soil layers types with their thickness and bulk unit weight values were interred in this software to get $N_{\text{Cor.}}$ values.

For BG1 site, the SPSS software was used to relate $N_{\text{Cor.}}$ values with (e, Gyp.%, D_{50} and F%) values according to the considered factors listed in Table (2) getting Equation (9).

$$\boldsymbol{N}_{\mathbf{Cor.}} = -161.766 - 54.419(\mathbf{e}) - 0.909(\mathbf{Gyp.\%}) + 317.412(\mathbf{D_{50}}), \text{ multiple } R^2=0.90 \quad (9)$$

Equation (9) is valid for ranges {depth from 1-28 m, e from 0.55-1.01, Gyp. % from 12.3-51.63% and D_{50} from 1.21-1.44 mm}.

The percentage of fines content parameter was excluded from Equation (9) because it did not significantly predict the dependent variable ($N_{\text{Cor.}}$). The Curve Expert program was used to formulate the best models that fit the scattered data for (e-depth), (Gyp. %-depth),

(D_{50}-depth) and (γ_{Bulk}-depth) relations getting the Equations (10), (11), (12) and (13) respectively, the results of Curve Expert fitting models are shown in Figure (5).
Equations (10), (11) and (12) were back substituted in Equation (9) to get $N_{Cor.}$ Equation as a function of depth.

Curve Expert software used also to instigate the best models for ($N_{Cor.}$-e), ($N_{Cor.}$-Gyp.%) and ($N_{Cor.}$-D_{50}) relations, the analysis results revealed the Equations (14), (15), and (16) respectively.
For BG1 borehole category, γ_{Bulk} values {calculated from Equation (13) which formulated by utilizing Curve Expert software for γ_{Bulk}-depth data} were used for $N_{Cor.}$ back calculation values by exploiting *NovoSPT* software where these values will also be used later for bearing capacity calculations.

The best multiple R^2 for Equation (9) was gotten by removing the extremes from data of SPSS software. The same procedures were applied to the other sites.
The *NovoSPT* software was also utilized to calculate the (q_{all}) values for each site (after entering the calculated $N_{Cor.}$ values from SPSS Equations, bulk unit weight values calculated from Equation formulated by Curve Expert program and their corresponding depths) by using Equations of Peck et al., (1974)[20]; Parry, (1977)[21]; Bowles, (1982)[22]; and Burland and Burbidge, (1985)[23] which all were default Equations of *NovoSPT* software.

$$\boldsymbol{Void\ Ratio} = \frac{0.467296\times0.017715+0.993396(\boldsymbol{depth})^{-1.685762}}{0.017715+(\boldsymbol{depth})^{-1.685762}} \quad , R^2 = 0.98 \quad (10)$$

$$\boldsymbol{Gyp.}_{\%} = \frac{1}{0.019143+0.000971(\boldsymbol{depth})^{1.234999}} \quad , R^2 = 0.96 \quad (11)$$

$$\boldsymbol{D_{50}} = 0.709126(\boldsymbol{depth} + 18.809812)^{0.182908} \quad , R^2 = 0.91 \quad (12)$$

$$\boldsymbol{\gamma_{Bulk}} = 0.714749(\boldsymbol{depth} + 42.383476)^{0.783671} \quad , R^2 = 0.98 \quad (13)$$

$$\boldsymbol{N_{Cor.}} = \frac{338.770372}{1+(\frac{\boldsymbol{Void\ Ratio}}{0.819846})^{2.513939}} \quad , R^2=0.89 \quad (14)$$

$$\boldsymbol{N_{Cor.}} = \frac{1}{0.003398+0.000016(\boldsymbol{Gyp}.\%)^{1.436793}} \quad , R^2=0.90 \quad (15)$$

$$\boldsymbol{N_{Cor.}} = \frac{302.853174}{1+Exp(11.162903-8.883188\boldsymbol{D_{50}})} \quad , R^2=0.\ 90 \quad (16)$$

5- ALLOWABLE BEARING CAPACITY CALCULATIONS

Four default equations are used to calculate the allowable bearing capacity values by utilizing *NovoSPT* program based on N_{60} and $(N_1)_{60}$ values:

- The first Eq. by Peck et al. in 1974[20] (based on 25 mm settlement).

$$\boldsymbol{q_{all}} = 10.6(N_1)_{60} \quad \text{in cohesionless soils (valid for B<1m)} \quad (17)$$

- The second Eq. by Parry in 1977[21] (based on 25mm settlement). The allowable bearing capacity according to Parry for cohesionless soil is:

$$\boldsymbol{q_{all}} = 30N_{60} \quad D_f \le B \quad (18)$$

where N_{60} is the average SPT blow counts below 0.75B underneath footing.

- The third Eq. by Bowles in 1982[22] based on Meyerhof (based on 25mm settlement).The allowable bearing capacity based on the SPT N value according to Meyerhof is:

$$\boldsymbol{q_{all}} = \frac{N_{60}}{F_1}K_d \quad B \le F_4 \quad (19)$$

$$\boldsymbol{q_{all}} = \frac{N_{60}}{F_2}\left(\frac{B+F_3}{B}\right)^2 K_d \quad B > F_4 \quad (20)$$

where $\boldsymbol{K_d} = 1 + \frac{D}{3B} \le 1.33$, for SI units F_1=0.05, F_2=0.08, F_3=0.30, F_4=1.20 and N_{60} is the average SPT blow counts from 0.5B above to 2B below the foundation level.

- The forth Eq. by Burland and Burbidge in 1985[23] (based on 25 mm settlement).

$$\boldsymbol{q_{all}} = 2540(N_{60})^{1.4}/(10^{T}\ B^{0.75}) \quad (21)$$

where N_{60} is the average SPT blow counts to a depth of $B^{0.75}$ below footing and T=2.23 .

6- DISSCUSSION OF THE RESULTS

The *NovoSPT* software was efficient program for correcting the field N values of the studied sites for field procedures and overburden pressure effects to get $N_{Cor.}$ or $(N_1)_{60}$ values where these values were used later by this program for (q_{all}) calculations based on $(N_1)_{60}$ and N_{60} parameters using four default methods by this software.

For all selected sites, the statistical analysis results {listed in Table (3)} of the field data revealed that the Curve Expert models of the gypsum percentage and void ratio are decreasing with depth while the average particles size and bulk unit weight are increasing with depth. The gypseous soils behavior of gypsum percentage decreasing with depth belongs to its formation. It is known that during the downward movement of water, a gypsum-rich horizon in the deep soils layers could be developed. The outcomes of a rising movement of salt-loaded brine are exterior gypsic and salic horizons in the top soil layers. The decreasing of the void ratio with depth is related to soil formation, where soils are formed by weathering process of parent rocks then transportation, redisposition and consolidation of the disintegrated products in horizontal layers. Accordingly the deepest soil layers will be of heavier unit weight than the top layers for the overburden pressure of upper layer. The soil profiles of almost all sites were towards increasing the average particles size with depth, where the top layers were silty-sand to gravel-sand-silt mixtures to gravel-sands mixtures.

As illustrated in Table (4) for BG1 site SPSS model summary, the effect of fines content was excluded from {$N_{Cor.}$-(e, Gyp. %, D_{50} & F.%)} SPSS multiple linear regression model. The chosen SPSS model was No.3 {$N_{Cor.}$- (e, Gyp.% & D_{50})} which has the highest adjusted multiple R^2 as well as the significant F value was less than 0.05 for statistical confidence interval 95%. This statistical result were confirmed by the site report data of being the fines content for BG1 did not show clear trend with depth. This trends was examined for all other chosen sites.

For these studied sites, the trends of soil parameters (e, Gyp. % & D_{50}) with depth are clear from the sings of multiple linear regression coefficients of SPSS $N_{Cor.}$-(e, Gyp. % & D_{50}) Equations.

To formulate $N_{Cor.}$-depth relation, the SPSS {$N_{Cor.}$-(e, Gyp.% & D_{50})} Equation were substituted by (e-depth), (Gyp.%-depth) and (D_{50}-depth) Curve Expert models, this offers the advantage of data continuity for comparison among the studied sites as shown in Figure (6) which illustrates that the compound effects of void ratio, gypsum percentage and average particles size effects on $N_{Cor.}$ variation with depth.

The SPT causes dynamic failure of the soil, and so penetration resistance should be a function of the friction effective angle $Ø'$ and effective stresses operational at the time of the test. The $Ø'$ is a function of stress level, grain size distribution, particle angularity, void ratio (expressed in terms of relative density), and for dry gypseous soil samples the high $Ø'$ of the gypsum particles themselves led to higher Ø in dry gypseous soil samples. Although problematic nature of gypseous soil for their complex and unpredictable behavior as well as the SPT characteristics of being it considered as gross values or trends and cannot be interpreted as accurate determinations for any specific case, it can be inferred from Figure (7) that the existence of high gypsum percentage results in high $N_{Cor.}$ values after deactivating the effects of e and D_{50} factors in SPSS {$N_{Cor.}$-(e, Gyp. % & D_{50})} Equations.

Figure (8) illustrates the 3D Curve Expert mathematical models results for {$N_{Cor.}$ values-Influencing Factors-Depth} relations for site BG1, where in each one of the 3D Curve expert results there was an individual influencing factor (void ratio or gypsum percentage or average particle size) related to $N_{Cor.}$ values and depth. It can be revealed from this Figure that the (e & Gyp. %) values were decreasing with increasing $N_{Cor.}$ values with depth increasing while the D_{50} values were increasing with $N_{Cor.}$ values with depth increasing. The same behavior for the other sites can be seen from the results listed in Table (3).

For the previous sites, based on $(N_1)_{60}$ and N_{60} parameters, the calculated allowable bearing values by utilizing *NovoSPT* software are illustrated in Figures (9)-(12). Where in these Figures it can be seen that the (q_{all}) values obtained by the first (q_{all}) Equation (depending on $(N_1)_{60}$ parameter) are the lowest among the (q_{all}) values obtained by other Equations, where these equations are depending on N_{60} values which are uncorrected for overburden pressure effect (N values increasing with increasing overburden pressure). For granular material, SPT N value are proportional to the confining stress, therefore, the stress normalization is essential to convert the measured N value to a representative value (N_1) that would be measured when vertical stress equals 1 tsf or (100 kPa).

As shown in Figure (6) for soaked site BS, the variation of $N_{Cor.}$ with depth is fairly the minimum among the other sites, being gypseous soils are usually very stiff when they are dry, especially for the cementation of soil particles by offered by gypsum, but exhibit sudden losses in strength accompanied with excessive compressibility when they are in contact with water.

7- CONCLUSION

Based on the results obtained, the following concluding remarks can be withdrawn:

a. The measurement of the energy transfer efficiency of SPT hammer prior to perform site investigation is essential for accurate field N records.

b. For granular material, SPT N value are proportional to the vertical effective stress, therefore, the stress normalization is essential to convert the measured N value to a representative value (N_1) that would be measured when vertical effective stress equals 100 kpa (1 tsf). Accordingly the Peck et al., 1974 formula {$(N_1)_{60}$ dependent parameter} is more reliable equation than other equations for allowable bearing capacity calculations based on field N values.

c. The effect of gypsum percentage on allowable bearing capacity values is obvious, where sites of low gypsum percentage have the lowest allowable bearing capacity values, while for sites of high gypsum content give highest allowable bearing capacity values.

d. The stress exponent n is derived from calibration chamber (laboratory SPT) testing results and depends on cavity expansion theory. The exponent varies with density, particle size, over consolidation ratio, and aging of the soil. The typical stress exponent n value used in practice is 0.5 for stress normalization of overburden pressure effect.

e. The effect of soaking will cause reduction in soil shear strength accompanied with extensive settlement, therefore when loading is applied for gypseous soil, the loading must be limited and a high factor of safety may be considered.

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Table (1): Description; Coordinates; Boreholes Nos. and Depths; and Coded Nos. for the studied sites in Salah Aldeen Province

Item No.	Sites Descriptions	Boreholes		Coordinates		code No.
		Nos.	Depth m	N	E	
1	Gas Power Generation Plant/Baiji	(4,6,10,11,71&75) (1,5,16,18,22&23) (8,9,14,17,19,21,74,77&7)	30	35º02′12.3″	43º31′32.8″	BG1 BG2 BG3
2	Al-Dour General Hospital	(9&19) (3,7,8,10,12&13) (1,2,5,14,15,17&18)	20	34º26′43″	43º47′44.5″	DG1 DG2 DG3
3	Samarra General Hospital	(2,16&18) (10,12,13,14&17)	20	34º12′08″	43º53′08″	SG1 SG2
4	Tikrit Olympic Stadium	(6,9,10,15&16) (5,7,11,13&14) (2,3,4,8&12)	20	34º37′39.2″	43º37′41.7″	OG1 OG2 OG3
5	Al-Dhahia Primary School/Al Shirqat	(1,2,3)	10	35º27′00.8″	43º24′48.8″	DH
6	Al-Harery Primary School/Al-Dour	(1,2,3)	10	34º34′31.5″	44º21′52.3″	H
7	AI-shaqi Primary School/Al-Ishaqi	(1,2,3)	10	34º02′42.4″	43º59′24.3″	I
8	Diesel Power Plant/ Baiji (Soaked Site)	(1,2,3,5,6,7&9)	15	35º01′10″	43º30′10.3″	BS
9	Residential Tikrit Gate	(1,2,8,9,13&17)	10	34º33′43.4″	43º41′01.6″	R
10	Al-I'zza Primary School/Al-Dour	(1,2,3)	10	34º22′53.1″	44º27′29.7″	Z

Table (2): Influence of gypseous granular soil properties on penetration resistance [9 & 25]

Factor	Influence	Reference
Gypsum content	Gypsum appears as an intercept in Mohr Coulomb failure envelope which is denoted by c. The appearance of a higher Ø in dry gypseous soil samples is due to the high Ø of the gypsum particles themselves (which is about 45 to 75°).	Petrukhin and Arakelyan (1985)
Void ratio	Decreasing void ratio increased penetration resistance.	Marcuson and Bieganousky (1977a)
Average particles size	Increased average particles size gives increased penetration resistance.	Schultze and Menzenbach (1961)
Fines content	The presence of fines tends to reduce SPT N value of sands.	Tokimatsu and Yoshimi,(1983)
Coefficient of uniformity	Uniform soil exhibit lower penetration resistance	DIN4094, Part 2
Pore water pressure	Dense fine soils dilate to increase penetration resistance. Very loose fine soils may liquefy during testing.	Terzaghi and Peck (1948)
Particles angularity	Increased angularity gives increased penetration resistance.	Holubec and D'Appolonia (1973)
Cementation	Cementation increases penetration resistance.	DIN4094, Part 2
Current stress level	Increased vertical stress gives increased penetration resistance, Increased horizontal stresses gives increased penetration resistance.	Dikran (1983)
Age	Increasing age leads to increased penetration resistance.	Skempton (1986)

Table (3): All Studied Sites ($N_{Cor.}$, e , Gyp.% , D50 & γ_{Bulk})
Curve Expert Software Calculated Parameters at Different Depths

Item No.	Studied site group	Depth considered m	Calculated $N_{Cor.}$ values from SPSS Eqs.	Parameters calculated from Curve Expert software mathematical models			
				e	Gyp.%	D_{50},mm	γ_{Bulk} ,kN/m^3
1	BG1	0.5	124	0.99	51.14	1.22	13.59
		1.0	128	0.98	49.72	1.22	13.72
		1.5	131	0.98	48.20	1.23	13.84
		2.0	134	0.97	46.67	1.24	13.96
2	BG2	0.5	117	0.98	43.61	1.21	13.34
		1.0	122	0.97	42.19	1.22	13.62
		1.5	126	0.96	40.77	1.22	13.88
		2.0	129	0.95	39.35	1.22	14.12
3	BG3	0.5	119	0.97	39.85	1.26	13.88
		1.0	122	0.97	37.50	1.27	13.92
		1.5	126	0.96	35.34	1.27	13.98
		2.0	129	0.95	33.39	1.28	14.08
4	DG1	0.5	90	0.92	49.57	1.42	14.21
		1.0	94	0.91	47.91	1.73	14.27
		1.5	99	0.90	46.23	1.98	14.33
		2.0	102	0.90	44.53	2.21	14.39
5	DG2	0.5	83	0.91	35.90	1.25	14.31
		1.0	90	0.90	34.67	1.59	14.37
		1.5	97	0.89	33.23	1.93	14.42
		2.0	104	0.89	31.70	2.28	14.48
6	DG3	0.5	94	0.92	29.42	1.51	14.07
		1.0	100	0.92	27.79	1.95	14.15
		1.5	107	0.91	26.26	2.35	14.23
		2.0	111	0.91	24.81	2.74	14.31
7	SG1	0.5	73	0.96	37.49	1.31	13.86
		1.0	82	0.94	35.91	1.43	13.98
		1.5	90	0.93	33.62	1.57	14.10
		2.0	100	0.92	30.89	1.72	14.23
8	SG2	0.5	82	0.93	29.36	1.04	14.09
		1.0	88	0.92	26.79	1.30	14.21
		1.5	95	0.92	24.45	1.52	14.34
		2.0	102	0.91	22.31	1.72	14.46
9	OG1	0.5	54	0.98	38.37	1.36	13.66
		1.0	65	0.96	34.29	1.52	13.92
		1.5	75	0.94	30.64	1.70	14.17
		2.0	85	0.92	27.38	1.90	14.39
10	OG2	0.5	48	1.00	30.83	0.65	13.64
		1.0	60	0.97	28.98	1.31	13.85
		1.5	75	0.95	26.41	2.00	14.06
		2.0	88	0.92	23.55	2.71	14.26
11	OG3	0.5	44	0.99	19.95	0.34	13.26
		1.0	54	0.97	18.23	0.60	13.62
		1.5	63	0.95	16.66	0.87	13.94
		2.0	73	0.92	15.22	1.15	14.23
12	DH	0.5	77	0.96	29.20	0.31	14.19

		1.0	85	0.95	27.24	0.91	14.29
		1.5	94	0.93	23.73	1.69	14.46
		2.0	105	0.91	19.79	2.55	14.69
13	H	0.5	87	0.98	16.77	1.30	13.70
		1.0	92	0.95	14.68	1.72	13.97
		1.5	99	0.93	12.86	2.23	14.23
		2.0	105	0.91	11.26	2.81	14.47
14	I	0.5	126	1.00	52.56	0.69	14.29
		1.0	129	0.98	50.11	0.74	14.41
		1.5	134	0.97	47.87	0.78	14.55
		2.0	134	0.95	45.83	0.82	14.68
15	Soaked BS	0.5	58	1.10	21.21	0.68	16.39
		1.0	63	1.07	20.29	0.74	17.00
		1.5	66	1.05	19.50	0.80	17.38
		2.0	71	1.03	18.18	0.85	17.66
16	R	0.5	90	0.95	12.69	0.18	13.55
		1.0	104	0.91	10.85	0.97	13.98
		1.5	116	0.88	9.78	1.79	14.38
		2.0	124	0.85	9.02	2.52	14.75
17	Z	0.5	46	0.97	8.37	1.31	13.99
		1.0	56	0.97	7.20	1.34	14.24
		1.5	63	0.97	6.32	1.35	14.49
		2.0	66	0.96	5.63	1.36	14.72

Table (4): SPSS Models Summary for BG1 BHs Category

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	Sig. F Change
1	0.938[a]	0.880	0.876	13.702	0.880	205.777	0.000
2	0.945[b]	0.893	0.885	13.217	0.012	3.095	0.090
3	**0.954**[c]	**0.911**	**0.900**	**12.283**	**0.018**	**5.261**	**0.030**
4	0.954[d]	0.911	0.896	12.519	0.000	0.027	0.870

a. Predictors: (Constant), Void Ratio.

b. Predictors: (Constant), Void Ratio, Gypsum Percentage %.

c. Predictors: (Constant), Void Ratio, Gypsum Percentage %, Average Particles Size .

d. Predictors: (Constant), Void Ratio, Gypsum Percentage %, Average Particles Size ,Fines Content.

Figure (1) Instrumented Safety Hammer (after MDT , 2001)

Figure (2) SPT Analyzer (after MDT, 2001)

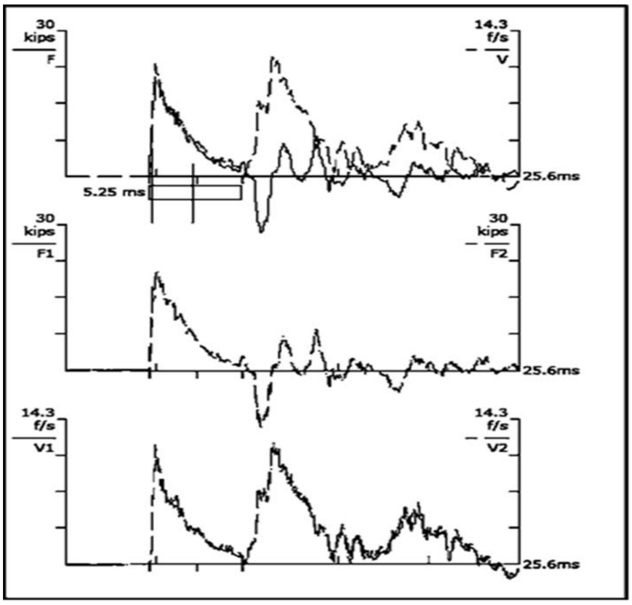


Figure (3) Example Force- and Velocity-Time Measurements for SPT (ASTM D4633-10)

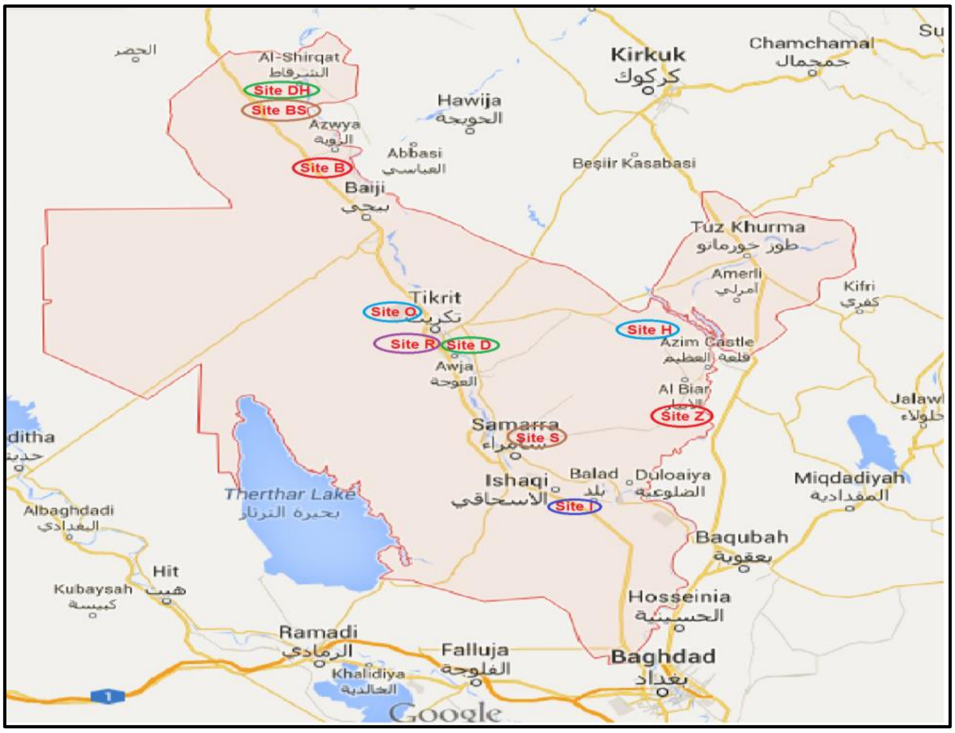
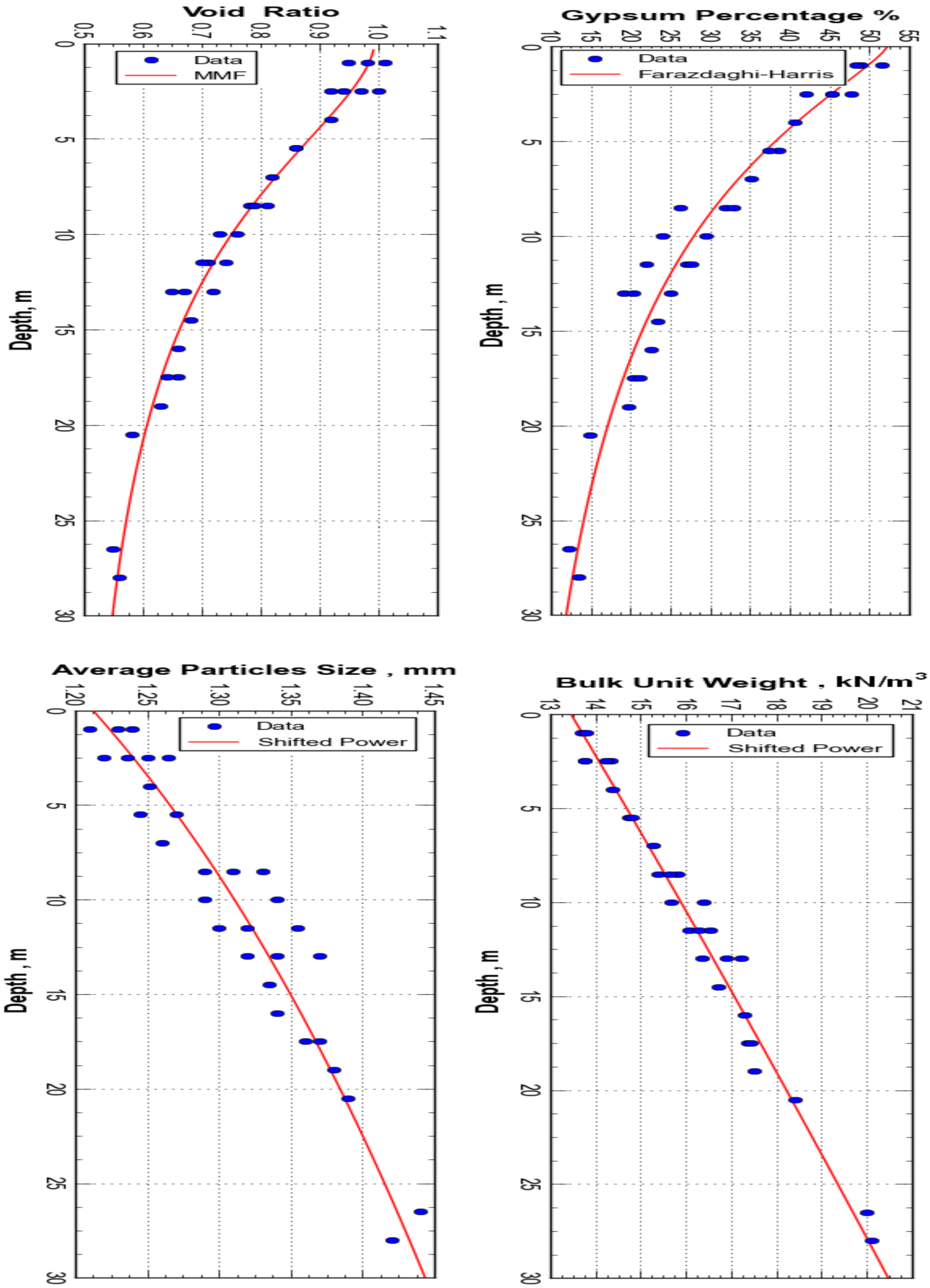


Figure (4) Sites Location, Image from Google Earth

(a) (b)



(c) (d)

Figure (5) Results of (e-depth), (Gyp. %-depth), (D_{50}-depth) and (γ_{Bulk}-depth) Curve Expert Fitting Models for BG1 Boreholes Category

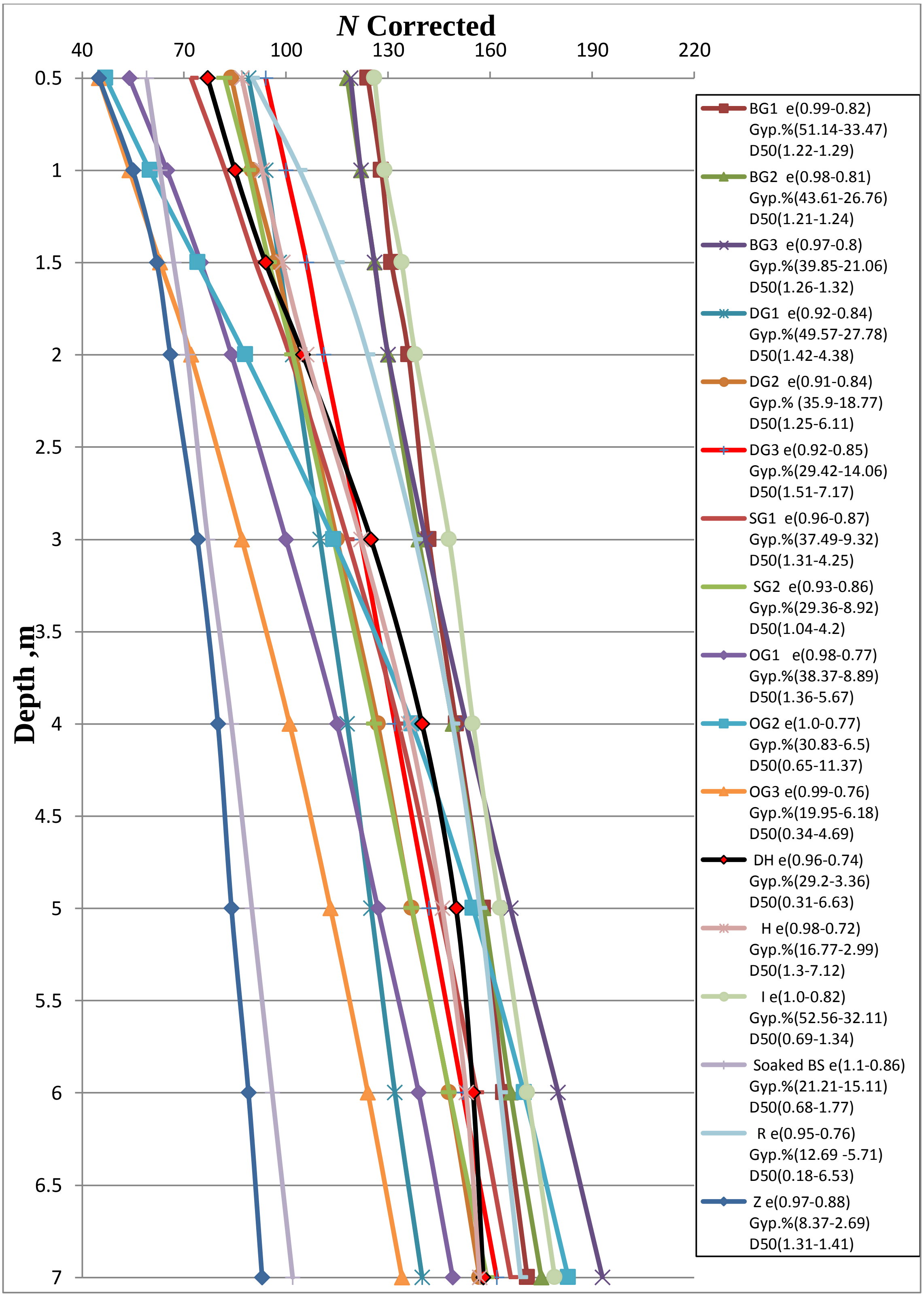


Figure (6) Studied sites SPSS $N_{Cor.}$-depth (from 0.5-7m) relations with their corresponding (e, Gyp.% and D_{50}) parameters ranges

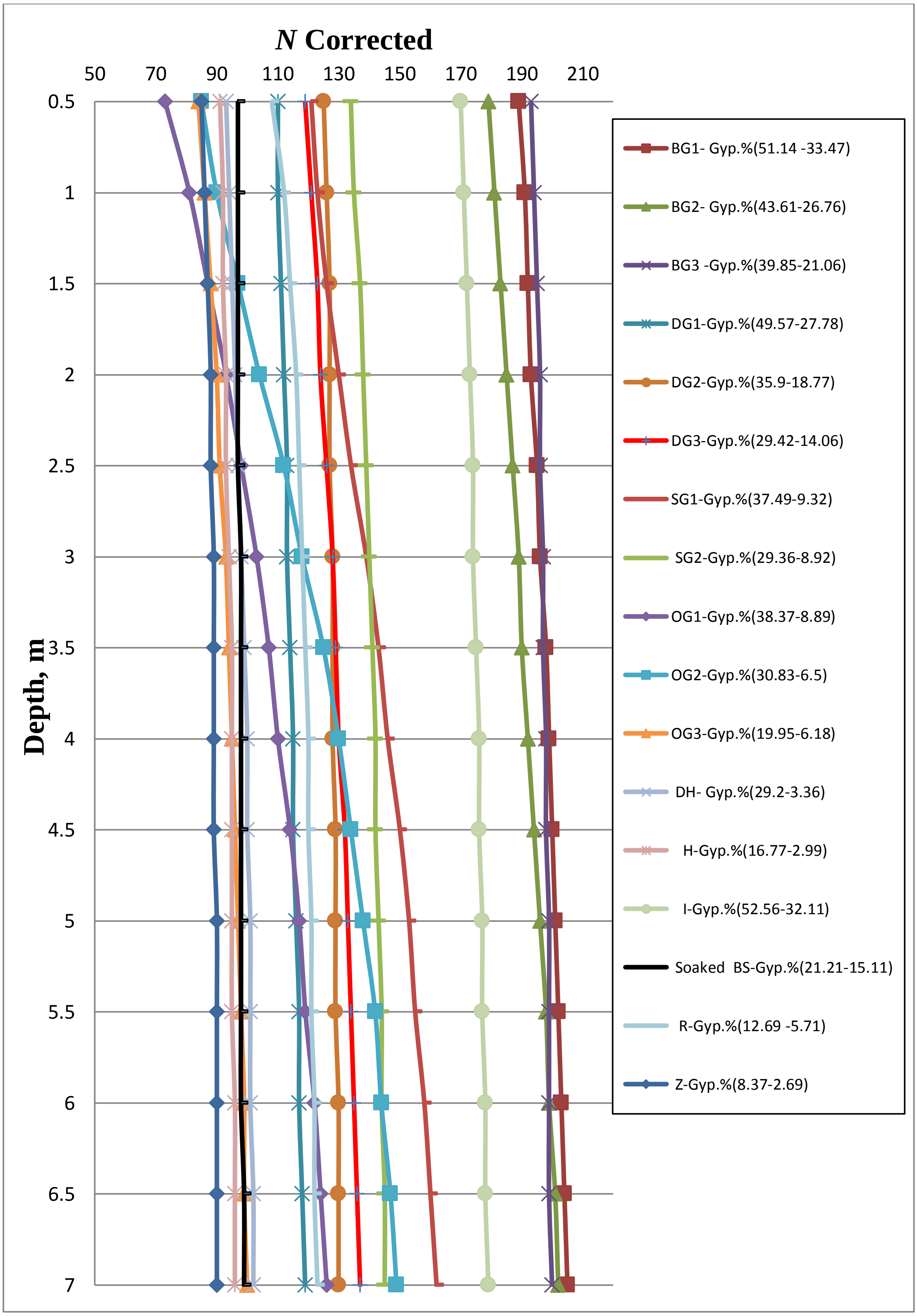


Figure (7) Studied sites SPSS $N_{Cor.}$ -depth (from 0.5-7m) relations at constant (e=0.86 and D_{50} =1.4mm) parameters with their corresponding Gyp.% variations

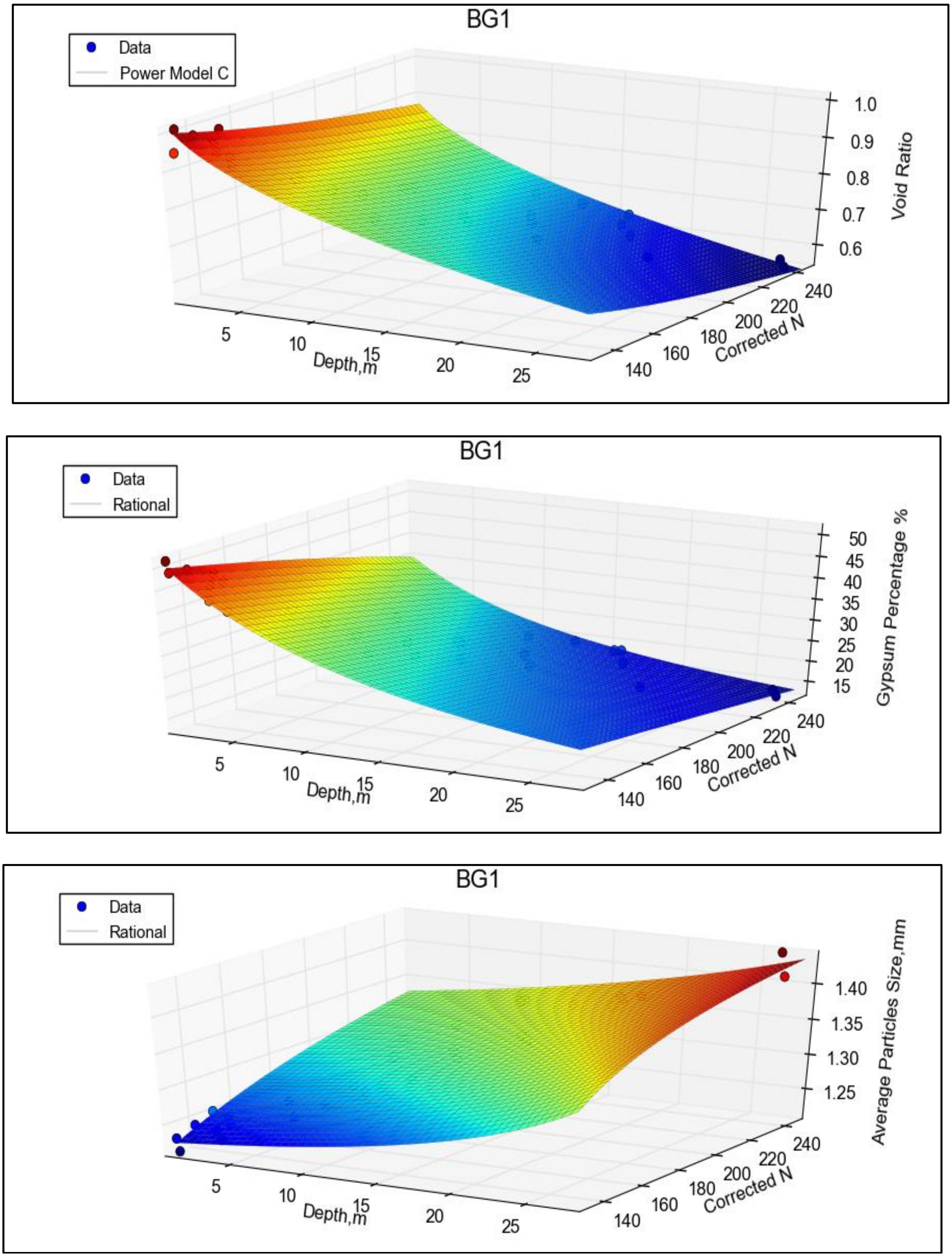


Figure (8) 3D Curve Expert Fitting Models Results of $N_{Cor.}$-Influencing Factors-Depth for BG1 Boreholes Category

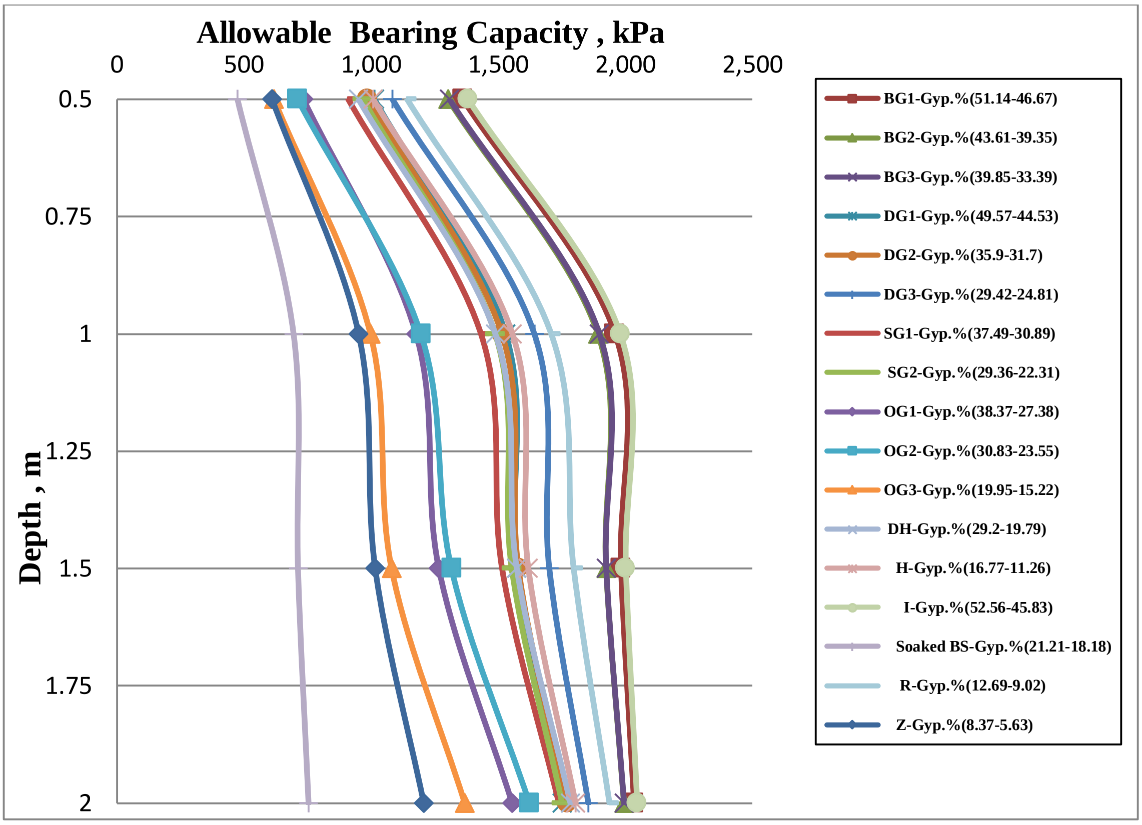


Figure (9) Studied Sites Depth-q_{all} Values by Bowles, 1982 with their Gyp. % Range

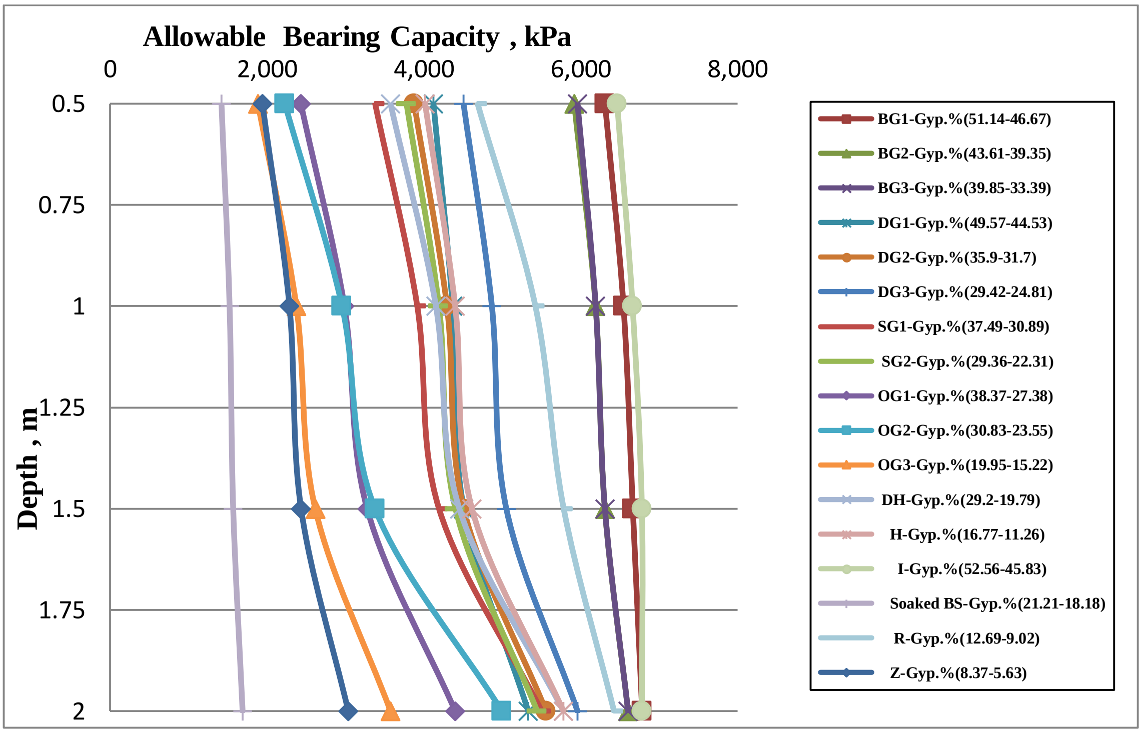


Figure (10) Studied Sites Depth-q_{all} by Burland & Burbidge, 1985 with their Gyp. % Range

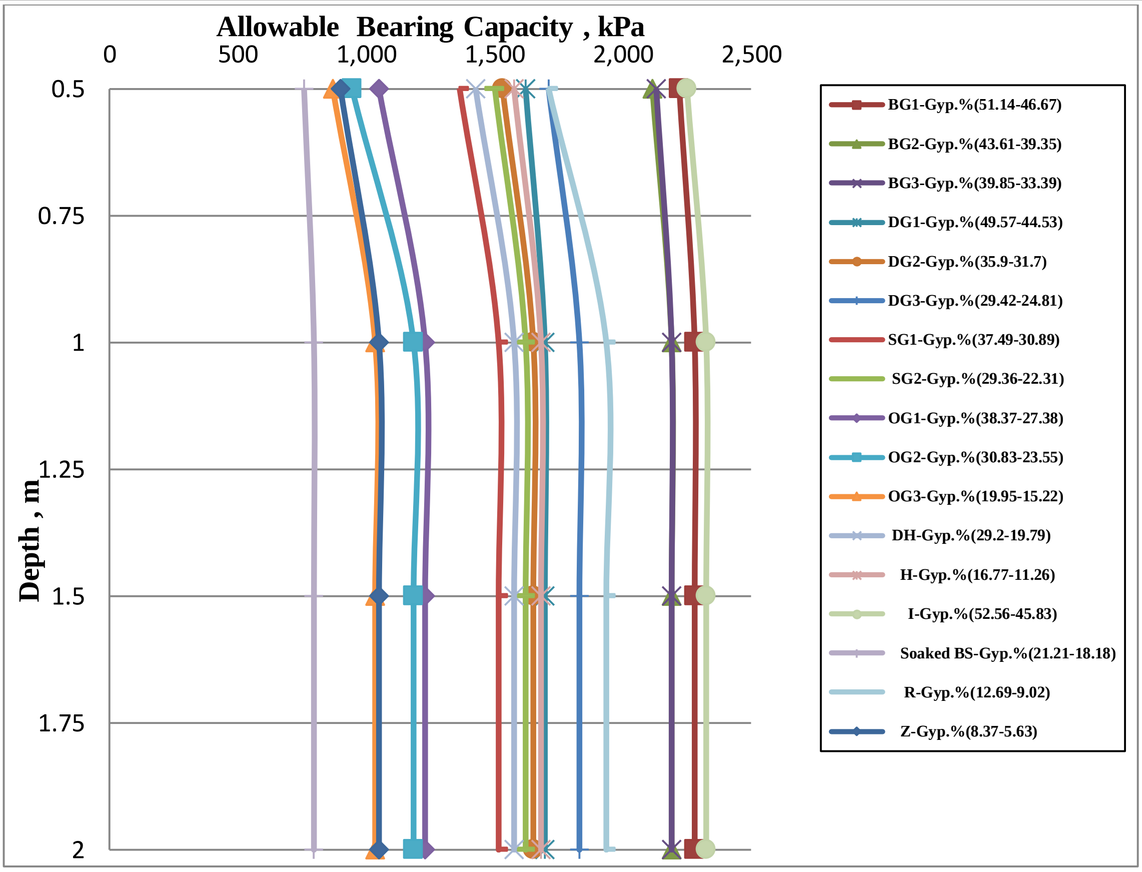


Figure (11) Studied Sites Relation of Depth-q_{all} by Parry, 1977 with their Gyp. % Range

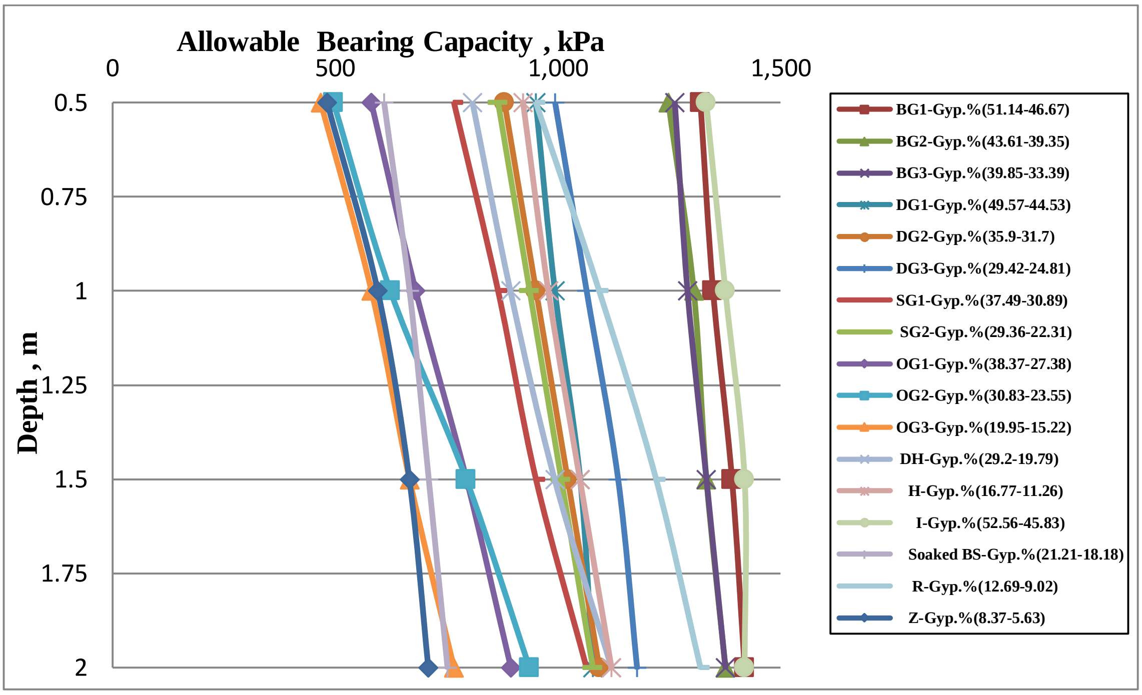


Figure (12) Studied Sites Relation of Depth-q_{all} by Peck et al., 1974 with their Gyp. % Range

قابلية تحمل الترب الجبسية إعتماداً على الفحوص الحقلية

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الخلاصة

هذا البحث يدرس نتائج الفحوص الحقلية لـ 84 حفرة إختبارية من عشـرة مواقع تم إختيارها في محافظة صلاح الدين. طبيعة التربة لهذه المواقع كانت حبيبية جبسية بنسبة جبس تراوحت بين 8.37−51.14 %.

إعتماداً على فحص الإختراق القياسي الحقلي فإن قيم فحص الإختراق القياســـي تم تصحيحها لكل موقع تأثير إجراءات الحفر الموقعي بالإضافة إلى تأثير الإجهاد الفَعَّال بإســـتخدام برنامج *NovoSPT* للحصول على قيم فحص الإختراق القياسي المصححة $N_{Cor.}$ أو $(N_1)_{60}$ حيث إن هذه القيم تم إســتعمالها لاحقاً بهذا البرنامج لغرض حساب قابلية التحمل المسموح. لغرض دراسة خواص وتوضيح سلوكية هذه الترب الجبسية تم إستخدام برنامجي SPSSو Curve Expert

لغرض إجراء التحليل الإحصائي للبيانات الحقلية لهذه المواقع التي تم دراستها .

في الحالة الجافة للتربة الجبسية إعتماداً على التحليل الإحصائي للبيانات الحقلية للمواقع التي تم إختيارها فقد تم الإستنتاج بأن قيم $N_{Cor.}$ تزداد مع نسبة الجبس بعد تحييد تأثيري نسبة الفجوات ومعدل حجم الحبيبات. كذلك لوحظ بأن قيم قابلية تحمل التربة المسموحة (q_{all}) تزداد أيضاً مع نسبة الجبس.

إعتماداً على الإجهادات المؤثرة على آخذة نماذج فحص الإختراق القياســـي فقد تبين بأن معادلة Peck et al.,1974 بالإمكان الإعتماد عليها لتخمين قابلية تحمل الترب الجبسـية المسموح من بين المعادلات الأخرى المستخدمة لحساب قابلية التحمل من قيم فحص الإختراق القياسـي. بالرجوع إلى نتائج فحوص حجرة المعايرة (فحص الإختراق القياسي المختبري) و نظرية توســـع الفجوة فقد إتضح بأن من المعتمد إستعمال مقدار أس 0.5 لمعادلة تحييد الإجهاد الفَعَّال (C_N)عــن تأثير وزن طبقات التربة فوق مستوى فحص الإختراق القياسى .

مفاتيح الكلمات: الترب الجبسية ,فحص الإختراق القياسي , تحمل التربة المسموح ,التحليل الإحصائي.