A RAPID TECHNIQUE to DETERMINE ALLOWABLE BEARING PRESSURE

Semih S. Tezcan[-1]*, Zuhal Ozdemir*[-1]*, Ali Keceli*[-2]*, and Aykut Erkal*[-1]

Adress: [1-]Bogazici University, Bebek, Istanbul, Türkiye

[2-]Istanbul University, Beyazit, Istanbul, Türkiye.

E-mail: tezokan @ superonline. com

Key words: Bearing capacity, shear wave velocity , shallow foundations, allowable bearing pressure, seismic technique.

ABSTRACT *Based on a variety of case histories of site investigations, including extensive bore hole data, laboratory testing and geophysical prospecting, an empirical formulation is proposed for the rapid determination of allowable bearing capacity of shallow foundations. The proposed expression corroborates consistently with the results of the classical theory and is proven to be rapid, reliable and safe. It consists of only two soil parameters, namely, the insitu measured shear wave velocity, and the unit weight. The unit weight may be also determined with sufficient accuracy, by means of another empirical expression, using the P-wave velocity. It is indicated that once the shear and P-wave velocities are measured insitu by an appropriate geophysical survey, the allowable bearing capacity may be determined rapidly and reliably through a single step operation. Such an innovative approach, using the seismic wave velocities only, is considerably cost and time-saving, in practice.*

INTRODUCTION

Professor Schulze (1943) [1], a prominent historical figure in soil mechanics and foundation engineering in Germany, stated that "For the determination of allowable bearing pressure, the geophysical methods, utilising seismic wave velocity measuring techniques with absolutely no disturbance of natural site conditions, may yield relatively more realistic results than those of the geotechnical methods, which are based primarily on bore hole data and laboratory testing of so-called undisturbed soil samples ".

Since that time, various significant contributions have been made to solving geotechnical problems by means of geophysical prospecting. The P-wave velocities, for instance, have been used to determine the unconfined compressive strengths and modulus of elasticity of soil samples by Coates (1970)*[2]*. Hardin and Black (1968) *[3]*, and also Hardin and Drnevich (1976) *[4]*, based on extensive experimental data, established indispensable relations between the shear wave velocity, void ratio, and shear rigidity of soils. Similarly, Ohkuba and Terasaki (1976) *[5]* supplied various expressions relating the seismic wave velocities to weight density, permeability, water content, unconfined compressive strength and modulus of elasticity.

The use of geophysical methods in foundation engineering has been extensively studied also by Imai and Yoshimura (1976) *[6]*, Tatham (1982)*[7]*, Willkens, et.al. (1984)*[8]*, Phillips, et. al. (1989)*[9]*, Keceli (1990) *[10]*, Jongmans (1992) *[11]*, Sully and Campanella (1995)*[12]*, and Pyrak-Nolte, et.al. (1996) *[13]*. Campanella and Stewart

(1992) *[14]* determined various soil parameters by digital signal processing, while Butcher and Powell (1995) *[15]* supplied practical geophysical techniques to assess various soil parameters related to ground stiffness. A series of guidelines have been also prepared in this respect by the Technical Committee TC 16 of IRTP, ISSMGE (1999) *[16]*, and also by Sieffert (2000) *[17]*. Turker (2004) *[18]*, based on extensive case studies, supplied an explicit expression for the allowable bearing pressure, using shear wave velocity. Massarsch (2004) *[19]* determined deformation properties of fine-grained soils from seismic tests.

In this presentation, typical empirical expressions have been proposed for the rapid determination of the allowable bearing pressures in soils, 'soft' and 'hard' rocks. This is actually an extension of an earlier publication by the writers *[20]*, presenting a theoretical background for the formulation and also introducing a number of refinements, including the correction factors for the foundation size.

The insitu measured shear wave velocity, as a single field index, represents the real soil conditions, much more effectively and reliably than the insitu or laboratory tested shear strength parameters. In addition to geophysical refraction seismic survey, there are several other techniques of measuring the shear wave velocity at site as discussed by Stokoe and Woods (1972) *[21]*, Tezcan et. al. (1975) *[22],* and Butcher, et.al.(2005) *[23]*. Insitu measured shear wave velocity reflects the true photograph of the soil, containing the contributions of void ratio, effective confining stress, stress history, shear and compressive strengths, geologic age etc. As will be seen later in this study, the shear wave velocity enables the practicing engineer to determine the allowable bearing capacity in a most convenient, economic, reliable and straight forward manner.

THEORETICAL BASIS FOR THE EMPIRICAL EXPRESSION

The most general format for the allowable bearing pressure , q_a , under a shallow foundation with depth H from the surface, may be assumed to be compatible with the weight of the soil column above the foundation base and therefore may be expressed as

$$q_a = \gamma H / n \qquad (1)$$

where, γ = unit weight *(kN/m³)*, n = factor of safety. The foundation depth, H, may be replaced by the product of V_s = shear wave velocity and the time parameter, T, as;

$$H = V_s T \qquad (2)$$

which is substituted in *Eq.1* to yield

$$q_a = \gamma V_s \; T / n \qquad (3)$$

A typical 'hard' rock formation, for which the essential parameters are available, will be used to calibrate the above expression. Namely, q_a = *10 000 kN/m²*, γ *=35 kN/m³* , and $V_s = 4\ 000$ *m/sec*. Assuming a safety factor of $n = 1.4$ for 'hard' rocks, the time parameter is obtained as $T = 0.10$ sec, from *Eq.3*, as follows:

$$q_a = 35\ (4000)\ T / 1.4 = 10\ 000 \quad kN/m^2 \tag{4}$$

Therefore, the allowable bearing pressure, acquires the general form of

$$q_a = 0.1\ \gamma\ V_s\ / n \tag{5}$$

For various soil *(rock)* types, the factors of safety, as well as the allowable bearing pressures, are given in *Table 1*.

Table-1. Factors of safety, *n*, for soils and rocks[1]

Soil type	V_s **– range** *(m/sec)*	n	q_a *(kN/m²)*
'Hard' rocks	$V_s \geq 4\ 000$	$n = 1.4$	$q_a = 0.071\ \gamma V_s$
'Soft' weak rocks	$750 \leq V_s \leq 4\ 000$	$n = 4.6 - 0.0008\ V_s$	$q_a = 0.1\ \gamma V_s / n$
Soils	$750 \geq V_s$	$n = 4.0$	$q_a = 0.025\ \gamma V_s\ \alpha$

[1] Linear interpolation is made for 'soft' weak rocks with $750 \leq V_s \leq 4\ 000$ *m/sec*.

EFFECT OF FOUNDATION WIDTH

It is determined by Terzaghi and Peck (1967) *[24]* that the width of footing has a reducing influence on the value of allowable bearing pressure. Therefore, a correction factor α is introduced into the formula, for 'soils' type formations only, as shown in the third line of *Table 1*. The proposed values of this correction factor, for different foundation width *B*, as deduced from *Fig. 54.4* of *Ref. [24]*, are as follows:

$$\begin{aligned} \alpha &= 1.00 && \text{for } (0 \leq B \leq 1.20 \text{ m}) \\ \alpha &= 1.13 - 0.11\,B && \text{for } (1.2 \leq B \leq 3.00 \text{ m}) \\ \alpha &= 0.83 - 0.01\,B && \text{for } (3.0 \leq B \leq 12.0 \text{ m}) \end{aligned} \tag{6}$$

COEFFICIENT OF SUBGRADE REACTION

The shear wave velocity may also be used to determine k_s= coefficient of subgrade reaction, d= total settlement and E= modulus of elasticity as follows:

$$k_s = 40\ q_f \qquad (kN/m^3) \tag{7}$$

$$d = q_f / k_s \qquad (m) \tag{8}$$

$$E = H\ k_s \qquad (kN/m^2) \tag{9}$$

$$q_f = n\ q_a = 0.1\ \gamma V_s \qquad (kN/m^2) \tag{10}$$

in which, q_f = bearing pressure at failure, H= the layer thickness for which the modulus of elasticity is required. The empirical expression in *Eq.7* is given by Bowles (1982) *[25]*. Substituting *Eq.10* into *Eq.7*, we obtain

$$k_s = 4\ \gamma V_s \qquad (kN/m^3) \tag{11}$$

It is seen from *Eq.8* and *Eq.11* that, the maximum settlement is permanently set to $d = 0.025\ m$, as should be the case for all shallow single or strip footings.

ESTIMATION OF UNIT WEIGHT

There is a direct relationship between the average unit weight γ, and the P-wave velocity of a soil layer. Based on extensive case histories of laboratory testing by the writers *[20]*, a convenient empirical relationship is proposed as follows:

$$\gamma_p = \gamma_o + 0.002\ V_p \tag{12}$$

where, γ_p = the unit weight in kN/m^3 based on P-wave velocity, V_p = P-wave velocity in *m/sec*, and γ_o = the reference unit weight (kN/m^3) values given as follows:

$\gamma_o = 16$ *for loose sandy, silty and clayey soils,*

$\gamma_o = 17$ *for dense sand and gravel,*

$\gamma_o = 18$ *for mudstone, limestone, claystone, conglomerate, etc.,*

$\gamma_o = 20$ *for cracked sandstone, tuff, graywacke, schist, etc.,*

γ_o = 24   *for hard rocks.*

The unit weights calculated by *Eq.12*, are in excellent agreement with those determined in the laboratory. In the absence of any bore hole sampling and laboratory testing of soil samples, the above empirical expression provides a reliable first approximation for the unit weights of various soils, once the in-situ measured P-wave velocities are available. In fact, the speedy evaluation of unit weights, prior to any soil sampling, enables the practicing engineer to calculate the allowable bearing capacity q_a , readily from *Eq. 5*. As an example, consider a soft clayey soil layer of *H=15 m* beneath a shallow foundation with insitu measured seismic wave velocities as V_s *= 200 m/sec*, and V_p*= 700 m/sec*, the various soil parameters, which are also verified by conventional geotechnical methods are calculated as follows:

Eq.12	γ	=	γ_o + **0.002** V_p	=	16	+	=	17.4	kN/m^3
					0.002(700)				
Eq.11	k_s	=	**4** γV_s	=	4(17.4)200		=	13 920	kN/m^3
Eq. 9	**E**	=	**H** k_s	=	15 (13 920)		=	208 800	kN/m^2
Eq.10	q_f	=	**0.1** γV_s	=	0.1(17.4)200		=	348	kN/m^2

	n	=	**4** ---		(since, V_s < 750 m/sec, see Table 1)				4
Eq.10	q_a	=	q_f / n	=	348 / 4		=	87	kN/m^2
Eq. 8	**d**	=	q_f / k_s	=	348 / 13 920		=	0.025	m

CASE STUDIES

The allowable bearing pressures have been determined, at more than 120 construction sites in and around the Kocaeli Province in Turkiye, using both the conventional method recommended by Terzaghi and Peck (1967)*[24]*, and the seismic method as proposed herein. The results of both methods are illustrated in a comparative fashion in *Fig.1.* The stability and consistency of the results by the seismic method proposed herein are clearly visible.

CONCLUSIONS

1. The shear wave velocity is a single and most powerfull soil parameter representing a family of geotechnical soil conditions, ranging from compressive strength to void ratio, from shear rigidity to cohesion etc,

2. Extensive bore hole and laboratory testing would no longer be needed if the shear and P-wave velocities are measured, as accurately as possible, right under the foundation level. Then, the allowable bearing pressure, the coefficient of subgrade

reaction, as well as the approximate value of the unit weight are rapidly determined, using relatively simple empirical expressions.

3. The results obtained from seismic method are more stable, consistent and reliable when compared with those of the conventional method, as already demonstrated by more than 120 case studies *(Fig.1)*.

ACKNOWLEDGEMENT

The writers gratefully acknowledge the technical support and encouragement, as well as the constant and ample supply of field data for the case studies by Mr. Mustafa Cevher, Chief Geophysical Engineer, Municipality of the Greater City of Kocaeli, Turkiye.

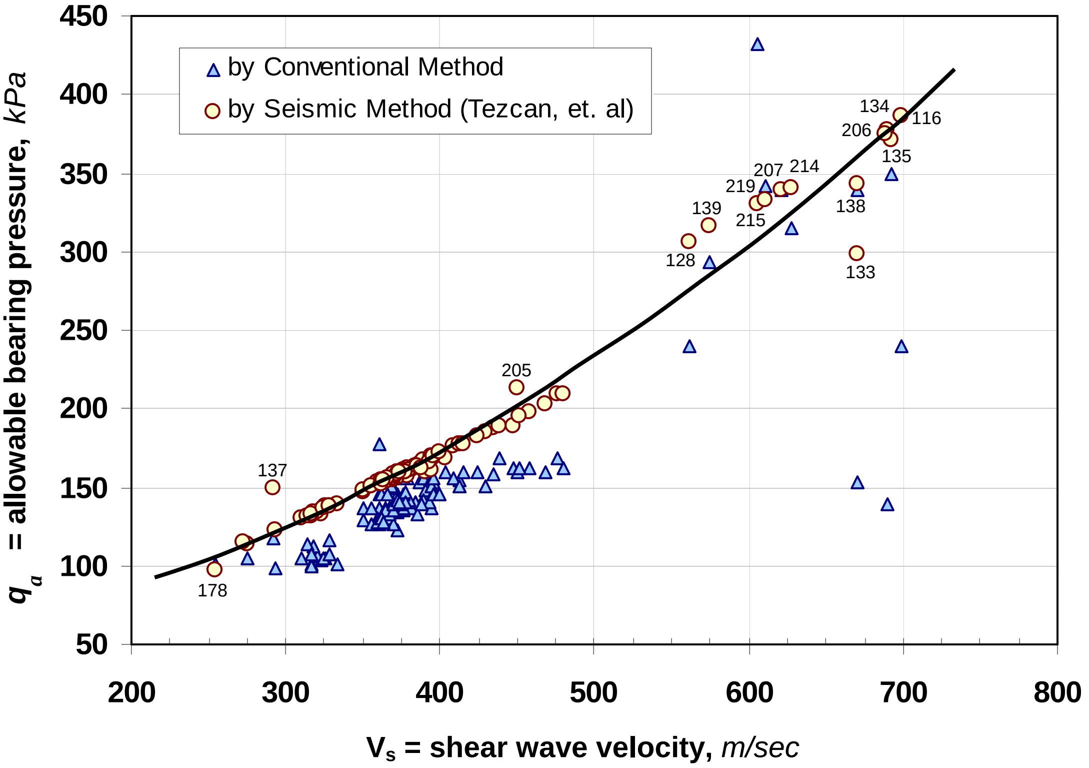

Figure-1. Comparison of Conventional and Seismic methods

(From a data base containing 123 case studies in and around the Kocaeli Province, 2004-06)

REFERENCES

Schulze, W.E., (1943) **Grundbau**, Deutsche Forschungsgesellschaft für Bodenmechanik, 7th ed., B.G. Taubner Publishers, Leipzig, Germany. Also available: Technical University of Istanbul, Issue 48, No DK624-15, Uçler Printing House, Istanbul, Turkiye.

Coates, D.F., (1970) **Rock Mechanics Principles**: Mines Branch Monographs, No. 874.

Hardin, B. O., and Black, W.L., (1968) Vibration modulus of normally consolidated clays, **Journal of the Soil Mechanics and Foundation Division**, ASCE, Vol.94, No. SM2, pp.353-369.

Hardin, B.O., and Drnevich, V.P., (1972) Shear modulus and damping in soils. **Journal of the Soil Mechanics and Foundation Division ASCE**, Vol. 98, No. SM7, pp.667-692.

Ohkubo, T., and Terasaki, A., (1976) Physical property and seismic wave velocity of Rocks. OYO Corporation, Japan.

Imai, T., and Yoshimura, M., (1976) The relation of mechanical properties of soils to P and S- Wave velocities for soil ground in Japan. **Urana Research Institue**, OYO Corporation.

Tatham, R.H., (1982) V_p / V_s and lithology. **Geophysics**, 47:336-344.

Willkens, R., Simmons G. & Caruso, L., (1984) The Ration V_p / V_s as a discriminant of composition for siliceous limestones. **Geophysics**, 49(11) 1850-1860.

Phillips, D. E., Han, D. H. & Zoback, M. D., (1989) Empirical relationships among seismic velocity, effective pressure, porosity, and clay content in sandstone. **Geophysics**, 54:(1) 82-89.

Keçeli, A. D., (1990) Determination of bearing capacity of soils by means of seismic methods *(in Turkish)*, **Geophysical Journal**, Ankara, Turkiye, 4, 83-92.

Jongmans, D., (1992) The application of seismic methods for dynamic characterization of soils. **Bulletin of International Association of Engineering Geology**. 46:63-69.

Sully, J. P. & Campanella, R.G., (1995) Evaluation of in situ anisotropy from crosshole and downhole shear wave velocities measurements. **Geotechnique**, 45(2):267-282.

Pyrak-Nolte, L. J., Roy, S. & Mullenbach, B., l., (1996) Interface waves propagated along a fracture. **Journal of Applied Geophysics**, (35):79-87.

Campanella, R.G. and Stewart, W.P. (1992) "Seismic cone analysis using digital signal processing for dynamic site characterization", **Canadian Geotechnical Journal**, Vol.29, No.3, June 1992, pp.477-486.

Butcher, A.P. and Powell, J.J., (1995) Practical considerations for field geophysical techniques to used assess ground stiffness. **Proc. Int. Conf. on Advances in Site Investigation Practice**, ICE London, March 1995. Thomas Telford, pp 701-714.

IRTP, 1999:ISSMGE Technical Committee TC16 Ground Property Characterization from In-situ Testing, (1999) International Reference Test Procedure (IRTP) for the Cone Penetration Test (CPT) and the Cone Penetration Test with pore pressure (CPTU). *Proc. XIIth ECSMGE* Amsterdam. Balkema. pp 2195-2222.

Sieffert, J. G., and Bay-Gress, Ch, (2000) Comparison of the European bearing capacity calculation methods for shallow foundations. Geotechnical Engineering, Institution of Civil Engineers, Vol. 143, pp. 65-74, England.

Turker, E., (2004) Computation of ground bearing capacity from shear wave velocity, Continuum Models and Discrete Systems, Eds. D. Bergman, et. al., Netherlands, pp. 173-180.

Massarsch, K. R. (2004) Deformation properties of fine-grained soils from seismic tests. Keynote lecture, International Conference on Site Characterization, ISC'2, 19-22 Sept. 2004, Porto, 133-146.

Tezcan, S. S., Ozdemir, Z., and Keceli, A., (2006) Allowable bearing capacity of shallow foundations based on shear wave velocity, **Journal of Geotechnical and Geological Engineering**, 24: pp. 203-218, DOI 10.1007 / s.10706-004-1748-4, Netherlands, Springer, www.springerlink.com.

Stokoe, K. H., and Woods, R.D., (1972) Insitu shear wave velocity by cross-hole method, **Journal of the Soil Mechanics and Foundation Divison**, ASCE, Vol. 98, No.SM5, pp.443-460.

Tezcan, S. S., Erden, S. M., and Durgunoğlu, H. T., (1975) Insitu measurement of shear wave velocity at Boğaziçi University Campus, **Proceedings of the International Conference on Soil Mechanics and Foundation Engineering**, Vol. 2, April 1975, pp. 157-164, Istanbul Technical University, Istanbul, Turkey.

Butcher, A.P., Campanella, R.G., Kaynia, A.M., and Massarsch, K. R., (2005) Seismic cone downhole procedure to measure shear wave velocity. A guideline prepared by ISSMGE TC10, Proceedings of the International Symposium on Geophysical Testing in Geotechnical Engineering, May, 2006, Osaka, Japan.

Terzaghi, K., and Peck, R.B., (1967) **Soil Mechanics in Engineering Practice**. 2nd ed., John Wiley&Sons, London.

Bowles, J.E., (1982) **Foundation Analysis and Design**, 3rd ed., McGraw-Hill Book Company, New York.