On the Need to Adjust Standards for Designing Soil Bases of Buildings and Structures from the Standpoint of Real Soil Deformation

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Abstract: The article substantiates the need to adjust standards for geotechnical designing on the base of nonlinear soil mechanics adequate to real soil deformation. Nowday all main regulatory documents for geotechnical design contains outdated formulas for calculation of soil base deformations on the base of Hooke's linear theory (model) designed for metals and other, so-called, constructive materials with strong and dense internal bonds. Correction of this unnatural situation into direction of application in geotechnical design adequate to soil nonlinear model is very important for ensuring safety and reliability of building and structures.

1 INTRODUCTION

Taking into account achievements of experimental and theoretical geotechnics it seems necessary that regulatory documents for design of soil bases of foundations clearly indicate that when designing foundations both on natural and artificial non-rock soil (hereinafter referred as to soil) must be used only adequate to soil, physically nonlinear models, main feature of which is reflection of dependence of soil stiffness (resistance to deformation) on its stress-strain state (hereinafter referred as to SSS). However, for now this is clearly indicated only at Federal Law "On Safety of Buildings and Structures" (Federal Low № 384-FZ, 2010), but design Code of Rules SP 22.13.330.2016 "Soil Bases of Buildings and Structures" (Gosstroyizdat of Russia, 2017) contains outdated provisions on calculation of soil base deformations using formulas for linear deformable materials with strong and dense ion-electronic, cementation or polymer internal bonds inherent for metals, concrete, natural stones (rock) and rubber while non-rock soils have loose internal bonds in the form of friction and cohesion, on which was definitely pointed out in 1925 year founder of International Geotechnical Society Terzaghi (Terzaghi, 1925). Such an extraordinary contradiction in main regulatory documents on geotechnical design and not only in them, but also in State Standards for determining soil deformation characteristics (GOST 20276-2012, 2013) has developed since 1950s due to a lack of information about real features of soil deformation and complete absence of technical means for complex geotechnical calculations. In fact, data on real physically nonlinear soil deformation were obtained by soviet scientist Botkin as early as 1939…1940 with using new german triaxial device for studying non-rock soils deformations – stabilometer (Botkin, 1939; Botkin, 1940). But war in USSR in 1941…1945 did not allow to complete these investigations and problems of speed restoration of destroyed structures after the war, that required accelerated development of regulatory documents for building created a situation in which it was necessary to accept Terzaghi's proposal of 1925…1943 years (Terzaghi, 1925; Terzaghi, 1961) on using during some period of time for calculation of soil deformation the theory of deformation of the simplest material in this respect – steel, namely Hooke-Young linear theory with stiffness E used in it and for metals, concrete and also for all, so called, structural materials, usually called Hooke's modulus of elasticity or Young's modulus of physically linear deformation or most often simply Young's modulus, and for soils from 1940s at incompletely correct suggestion of Gersevanov' suggestion (Gersevanov, 1948) – modulus of deformation (secant or tangent, in principle it does not

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matter). Moreover, and type of deformation (elastic, plastic, or their combination) is also not principle in this case because in formulas for soil deformations, obtained within framework of this linear theory, deformation modulus E has physical and mathematical meaning of proportionality factor between stress σ and relative deformation ε, and therefore it completely coincides with physical and mathematical meaning of Young's stiffness characteristic E. But according to numerous experimental data starting from Hooke's experiments in 1640…1670 years with metal wires and springs (Hooke, 1678), as well as subsequent studies with other materials (Bell, 1984) the theory (model) of physically linear deformation adequately reflects deformations of materials with artificially created (by melting, hydration, firing, polymerization or vulcanizing) strong and dense internal bonds, for example, in metals, concretes, ceramics or rubber; same internal bonds with similar intensive, but natural influences arose in natural stones (rocky soils). On contrary in non-rock soils internal natural bonds in form of friction and cohesion are rather weak and chaotic, that determines a much more complex nature of soil deformation compered to deformation of metals or rubber. In the case of soils it is more convenient to use more fundamental than Young's modulus E and later identified Poisson's ratio ν, stiffness characteristics, namely bulk modulus K and shear modulus G: it turned out that for dense structural materials classical (earlier) stiffness values E and ν are determined simpler and more reliably, but for soil such values are more fundamental K and G. Since both pairs reflect the same physical phenomenon, namely mechanical deformation, there is one-to-one correspondence between these pairs: $E = 3KG/(K+G)$; $\nu = 0{,}5(K-2G)/(K+G)$; $K = E/(1-2\nu)$; $G = 0{,}5E/(1+\nu)$. These relationships are derived from decomposition of total strain into volume and shape change with corresponding decomposition of total stresses. As a result, it is possible through generalized parameters of these components of stress-strain state (invariants of stress and strain tensors) to illustrate in Fig.1 and Fig.2 fundamental difference between type of structural materials deformation (physically linear deformation) and type of non-rock soils (sands and clays) deformation (physically nonlinear deformation):

Results of actual tests of specific materials and soils, schematically depicted in Fig.1and Fig.2 are the basis for derivation of so-called determining physical relationships between stresses and relative strains, supplementing general Henki's relations between stresses and relative strains, which in turn are included together with Newton's equilibrium equations, geometric Cauchy's relations between relative deformations and displacements, as well as boundary and (or) initial by time conditions in general system of resolving relations of any mechanical problem (Hooke, 1678), including geotechnical problems. For structural materials determining physical relationships according to data of numerous investigations (Bell, 1984) and to figure 1 usually

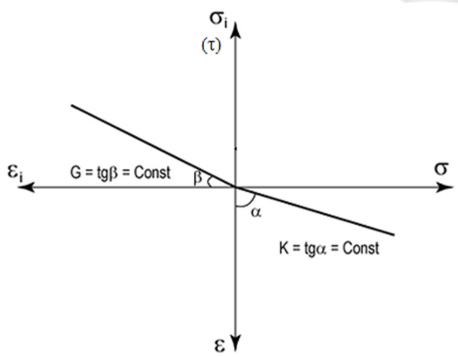

Figure 1: Physically linear deformation of structural (metals, concretes, ceramics, plastics, rubber) materials and rocks (K = const, G = const): ε - invariant of volume part of total relative strain; ε_I – invariant of form change of total relative strain; σ , MPA and σ_I , MPA – stress invariants corresponding to these parts of total relative strain; K – bulk modulus, MPA; G – modulus of shape change modulus – shear modulus, MPA.

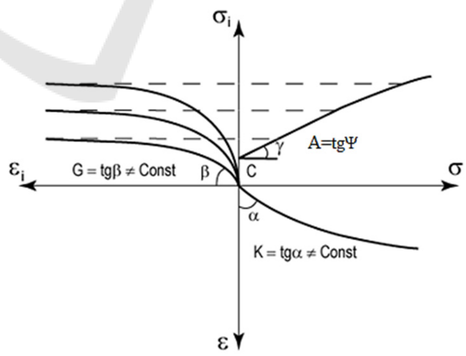

Figure 2: Physically nonlinear deformation of non-rock (sands and clays) soils (K ≠ const, G ≠ const) : designations are the same as in Figure 1.

have a very simple form: K = const; G = const and therefore E = const and ν = const. This type of deformation with constant coefficients between parameters (values) of various kinds of deformations and parameters (values) of various kinds of force actions is called physically linear. But for soils according to Botkin's studies (Botkin, 1939; Botkin, 1940) and subsequent similar studies (Lomize, 1959; Kopeikin, 1977) as well as to figure 2 even optimal kind of determining physical relationships have much more complex form than in the case of physical linearity: for bulk modulus $K = \sigma/\varepsilon = \sigma^{1-\propto}/A0 \neq const$ and for shear modulus $G = \sigma I/\varepsilon I = (\sigma u - \sigma i)/B = (A\sigma + C)/(B + \varepsilon i) \neq const$ (Here $\sigma u = A\sigma + C$ – strength condition for non-rocky soils according to Mises and Botkin (Mises, 1928; Botkin, 1940); σ, σi, ε, εi – parameters-invariants of SSS; A, B, C, A0, α –constants of determining physical relationships. The presence in determining physical relationships with constants of variable parameters ov SSS determines complex type of deformation with changing during loading ratio between parameters (values) of various types of deformations and parameters (values) of various types of force effects, and therefore having, according to figure 2 curvilinear graphical form of these relationships. Of course, substitution in design of complex real nonlinear) deformation of soil base with SSS-dependent stiffness by an extremely simplified nominal for soil linear deformation with constant stiffness is dangerous with serious deformations or even collapses, an example of which due to such miscalculation is shown at Fig. 3.

Figure 3: Collapse of industrial building due yo incorrect prediction of column foundations settlements.

Nowday it is clear that to ensure safety and reliability of objects they must be designed taking into account actual physically nonlinear deformation of soil base – the supporting bearing element of the structure. But in addition to complex type of soil base deformation, which is different with materials deformation, soil has another important feature – natural origin with complex formed over a long geological period its structure and stress affecting stiffness. In USSSR application of physically nonlinear soil model for geotechnical design began to study since 1959 year (Lomize, 1959; Kopeikin, 1977), implemented in adoption in 1985 in SNiP 2.02.01-85 * (Ministry of Regional Development of Russia, 2017), and then in the Federal Law № 384-FZ (Article 16) (Federal Low № 384-FZ, 2010) and in SP 22.13330.2016 (paragraphs 5.1.11, 5.1.12, 5.3.3) (Gosstroyizdat of Russia, 2017) the requirements to use of a physically and geometrically nonlinear soil model in geotechnical design. At the same time, firstly, physically linear model (Hooke-Jung model) is not mentioned at all in the Federal Law, and in SP 22.13330.2016 the formulas corresponding to it remained as a relic due to the unpreparedness of designers, builders and engineers - geologists. But such a situation, as noted above, confuses designers, which often leads to serious accidents. To resolve this contradiction, it is necessary to concentrate in a separate Appendix all points of SP 22.13330.2016, reflecting the provisions of the theory of linear deformation (the theory of a linearly deformable medium) with a warning that they do not comply with the requirements of paragraph 5.11 of this SP (Gosstroyizdat of Russia, 2017) and Federal Law No. 384-FZ (Technical Regulations on the Safety of Buildings and Structures) (Federal Low № 384-FZ, 2010).At the same time, it is necessary to indicate in a separate Appendix, with subsequent addition, physically nonlinear soil models that meet the requirement of paragraph 5.1.12 (Gosstroyizdat of Russia, 2017) on verification of the model, indicating soil parameters necessary for determining and methods for their determination(laboratory or in-situ tests). It is necessary to determine real values of parameters A, B, C, A0, α from results of in-situ static tests with the simplest scheme and least disturbing natural state of soil: at present only pressure meter and bearing circle plate are such tests (Alekhin, 1982).

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