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THE CALCULATION OF FOUNDATION GIRDERS IN EQUIVALENT ELASTIC SEMISPACE

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Abstract. *The paper presents the concept of foundation girder calculation based on equivalent elastic constants corresponding to foundation stiffness, distribution of soil layers, soil consolidation effects, loading type, size and distribution, foundation depth, excavation unloading, etc. Results of calculation of simple beam with two consoles, for classical method of calculation and calculation based on equivalent semi-space are analyzed in this paper.*

1. INTRODUCTION

In modern civil engineering we can often meet structures whose calculation boils down to the calculation of foundation girders in elastic semi-space, which imposes the need for their detailed study with the aim of a more authentic calculation and greater economy. These structures are usually various kinds of housing and industrial object frames, retaining walls, crane paths, tanks, etc.

Superfoundation structure load is transmitted onto the soil through the foundation, which brings about the appearance of stresses known as soil resistance or react ional load in the contact surface. Therefore, soil resistance is determined by the mutual reaction, that is interaction, of the soil and the foundation. The influence of its size and distribution upon the foundation internal forces, as well as upon the foundation dimensions and the adopted armature, is crucial. This is the reason for paying special attention to determining the foundation-soil interaction in foundation girder designing, which is in practical issues most often reduced to the calculation of contact pressures vertical components, where friction and adhesion between the foundation and soil on contact surface are neglected.

The size and shape of the soil resistance diagram under the foundation girder depend on a number of parameters which are divided into two groups:

– parameters coming from the object: foundation stiffness conditioned by its cross

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section, superfoundation structure stiffness, foundation depth, intensity and mutual relation between constant and periodical loading, the size of horizontal object loading and the presence of dynamical effects, the appearance of cracks in the concrete which brings about the redistribution of loads, and the presence of joints in the structure.
- parameters coming from the soil: soil deformational characteristics, soil type, number of layers and layer slope, the appearance of calculation tension stresses in contact surface, consolidation effects, the effect of underground water level variations and the influence of neighbouring objects.

For the time being, there are not any such methods of foundation girder calculation, nor is there a soil model which would take into consideration all the effects mentioned above.

2. DEFINING THE PROBLEM OF FOUNDATION GIRDER CALCULATION

In solving the problem of foundation girders, we start with the elastic line differential equation of a constant cross section girder

$$EI\frac{d^4w}{dx^4} = [p(x) - q(x)]B$$

where these stand for

EI - girder stiffness upon bending (for a constant cross section girder it is $EI = const$)
$w(x)$ - vertical movement of girder axis points (girder slope) in arbitrary section x
B - foundation girder width
$q(x)$ - base resistance in section x
$p(x)$ - external active loading in section x

As far as base is concerned, various idealized models of loaded soil responses can be introduced into the calculation. In order to describe soil mechanical characteristics as authentic as possible, modern soil models (elasto-plastic, visco-elastic, visco-plastic) allow that soil deformational parameters are changeable when the soil stress condition changes, and they also take into consideration time-conditioned effects. However, these models are very bulky, complicated even in the simplest cases of loading and at present they are not used for everyday needs, but only in theoretical and research investigations.

For everyday designing needs, foundation girders are most often calculated as elastic base foundations. Most often used soil elastic models are the following:
- Winkler's model,
- isotropic elastic semi-space model, and
- two-parameter models (Filonenko-Borodich, Hetenyi, Pasternak, Vlasov and Leontiev).

Unlike the elastic environment, to which the above models refer, real soil as an objectively non-linear material does not have constant indication sizes of deformability, nor does it have constant physical characteristics such as porosity, density and humidity. Hence, constitutive equations should be always set up anew in accordance with stress condition changes and soil deformations dependent on loading constellation and time lapse. In other words, the so-called soil elastic constants are, for a given soil, changeable according to loading attributes and time. Besides, instead of semi-space (as it is usually represented), soil is often a combination of two or more layers, with mutually different indicators of elasticity for the remaining conditions which are the same.

Therefore, in order to obtain an at least approximate image of real soil behaviour using the models based on elasticity theory, elastic parameters should be determined so as to contain in themselves as many as possible mentioned parameters, which influence the foundation-soil interaction. One of the ways to achieve this is to define the equivalent elastic semi-space whose elastic constants would be determined in such a manner that they would contain some of the said effects. From the practical aspect, it is most convenient to determine the equivalent semi-space relationship $E/(1-\nu^2)$ because it is this relationship of the mentioned constants that acts in all soil elastic models.

Due to the increasing use of computers, this sort of calculation, which includes a huge calculation apparatus, nowadays becomes achievable. Namely, the application of computer technology and adequate numerical methods helps to build the procedure for calculating foundation girders in equivalent elastic semi-space, which would also take into consideration those effects that standard elastic base calculation methods do not contain.

3. Procedure for determining equivalent semi-space elastic constants

Procedure for determining equivalent semi-space elastic constants, which refer to a particular soil consolidation condition, will be given successively, step by step.

Step 1

Elastic constants initial values are determined by taking average values of the elasticity module given by the assignment for *Epoc*, i.e. Poisson's subgirder soil layers co-efficient for *Vpoc*. Then the reaction soil resistance is determined by any of the foundation girder calculation methods, where for the base one of the described elastic models is chosen.

Step 2

On the basis of obtained reaction loading in girder dividing points, the distribution of vertical stresses in the soil under those points is calculated. Using any of the distinguished methods such as, for example, Stein Brenner's method based on Boussinesque's solution of elastic semi-space problem, or Midline's method performs soil stress calculation.

Step 3

On the basis of the known vertical stress, cohesive soil settlements are calculated by means of applying the method of integration of vertical movements along the vertical lines under the girder dividing points. Non-cohesive soil settlements are determined by some of the methods used for settlement calculation in such soils, and here it is most often Schmertmann's method or Buisman De Beer's method.

Total settlement under each dividing point equals the sum of cohesive and non-cohesive soil settlement. The described settlement calculation procedure for one girder dividing point is repeated for all dividing points.

Step 4

By equalizing every dividing point settlement with Gorbun-Posadov's solution for elastic semi-space settlement, the value of equivalent semi-space initial relationship $E/(1-\nu^2)$ is obtained for every point. By getting the average value of the obtained values of the relationship $E/(1-\nu^2)$ between all points, average value of this relationship for equivalent semi-space under the whole girder is obtained. It now contains in itself all the effects used in the settlement calculation (loading type, size and distribution, all relevant layers characteristics, foundation depth, excavation unloading, etc).

Step 5

By comparing the initial and the obtained value of $E/(1-\nu^2)$ relationship, the question whether the calculation procedure should be repeated or not is answered. If the difference between the initial and final value of $E/(1-\nu^2)$ relationship is bigger than the value given prior to calculation, one should go back to step 1 and do the whole calculation again; if the difference is smaller, the procedure ends. In this way, final values of equivalent elastic constants are obtained, on the basis of which another foundation girder calculation is performed, but this time final values of equivalent elastic constants.

Using the same iterative procedure performs the calculation of equivalent elastic constants, which correspond to the soil stress condition after partially performed soil consolidation. Settlement values in dividing points, which now correspond to the same percent of total settlements, represent the only difference.

GREDA is an adequate programme written for foundation girder calculation using the described methodology. Its incoming data are arbitrarily given loading and soil layer distribution under the girders. Girder shape can be either rectangular or different type of reversed T section. Programme outcoming data consist of the distribution of soil resistance, girder slope, transversal forces and bending moments along the foundation beam. Hence the programme enables rapid identifying of equivalent semi-space elastic characteristics corresponding to the given distribution of soil layers and the given loading constellation. It also makes possible the beam calculation by adopting some of the mentioned soil models as a base.

4. EXAMPLE

This example analyzes the case of a simple beam with two consoles, calculated using the method of finite differences; Flamant's solution for homogenous, isotropic and elastic semi-space was adopted as a soil. In order to illustrate the suggested calculation procedure, the effect of given loading in the girder upon the value of soil elastic constants, and in that way upon the value of bending moments, will be examined.

Beam dimensions, material characteristic, and the given loading are shown in picture 1.

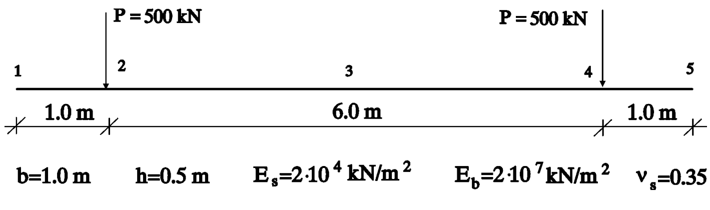

Fig. 1. Given beam and base characteristics

The beam is initially calculated by applying the classical method of finite differences, where elastic constants from the assignment were used. Then, the foundation girder was calculated using the equivalent elastic constants, which correspond to the given loading constellation. Comparative results are shown in picture 2, and values of bending moments in characteristic girder points are given in table 1.

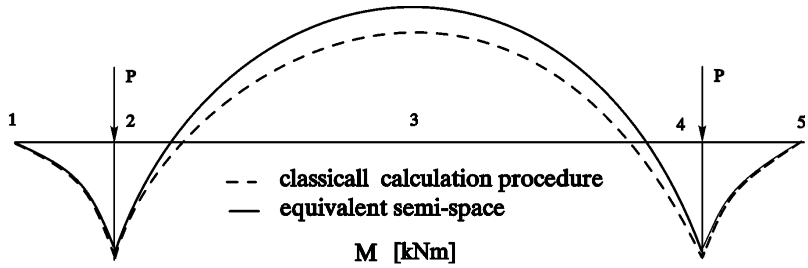

Fig. 2. Comparative diagrams of bending moments for a beam with two consoles and different calculation methods

Table 1. Comparative results of beam bending moments for different calculation methods

Calculation type	M_2[kNm]	M_3[kNm]
Classical method	169.73	-157.63
Equivalent semi-space	162.12	-194.54

5. CONCLUSION

Foundation girder calculation performed by the classical procedure and the method of equivalent elastic semi-space indicates considerable changes of static effects in the girder depending on the adopted elastic constant values. The calculation of foundation girder with equivalent elastic constants corresponding to the given loading constellation results in somewhat smaller moments under the concentrated forces (the difference is 7.61 kNm) and in considerably larger field moments (the difference is 36.91 kNm or 23.41%). The observed phenomenon has a great practical significance because it points out that in structural design of foundation girders appropriate soil elastic characteristics must be taken care of for the given beam characteristics and the given loading constellation.

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PRORAČUN TEMELJNIH NOSAČA NA EKVIVALENTNOM ELASTIČNOM POLUPROSTORU

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U radu je predstavljen koncept prora~una temeljnih nosa~a zasnovan na konstantama ekvivalentnih poluprostora odgovaraju}ih krutosti temelja, rasporedu slojeva tla, efektima konsolidacije tla, vrsti, veli~ini i rasporedu optere}enja, dubini fundiranja, rastere}enju usled iskopa itd. Na kraju su analizirani rezultati prora~una grede sa prepustima u slu~aju da je greda ra~unata klasi~nim postupkom i na osnovu proračuna ekvivalentnog elasti~nog poluprostora.