Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)
1994 Elsevier Science B.V.

Technical Note: Statistical estimates of soil cutting resistances for excavating robots

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Abstract

The paper deals with the problems of forecasting specific forces, acting on operating devices (blades and buckets) of excavating robots in the course of soil cutting (digging), by means of statistical mathematical methods. Correlations between the soil cutting resistance and soil strength have been obtained by statistical processing of the author's experimental data. On the basis of these, a single scale of soil cutting and soil digging resistance is formulated. These resistance values are recommended for use in the calculations for excavating robots and other equipment.

ESTIMATING METHOD

Excavating robots are applied in conditions where information on the soil physics and mechanical properties is limited. This makes the calculation of the forces acting on the operating devices difficult to calculate. Therefore, it is necessary to define correlations between soil cutting resistance and soil strength, the latter being more readily determined. These correlations have been obtained by statistical processing of the author's experimental data. In this, the processing required preliminary division of the cutting device in four groups:

1- wide blades 2- narrow blades 3- cutting edge perimeters 4 - buckets

The soil strength is estimated according to the number of dynamic densimeter impacts C, where this has the following parameters:

length of round tip driven into soil	-	10 cm
tip area	-	1 cm^2
impact energy	-	10 J

Sufficient correlation was established between the number C and other characteristics of the soil strength: compression resistance σ_o , tension resistance σ_t and soil specific cohesion C_o (in MPa).

Values are as follows:

$$\sigma_o = C / 30, \qquad C_o = 0.008\, C \qquad \text{and} \qquad \sigma_t = 0.2\, \sigma_o .$$

Usually in calculations, specific soil cutting resistances K are used that are the forces acting on a unit cross sectional area of soil shaving. These values of K are strength estimates of the soil.
It is interesting to now consider the relationships we have between common soil strength values and the specific cutting resistances for each of the four groups of operating devices shown in figure 1.
There is a classification of soil strength on the basis of the number of dynamic densimeter impacts C (Zelenin S classification). This is founded on the progression:

$$\bar{C}_i = \bar{C}_1 \, x \; 2^{i-1}$$

where i is the category of soil and $\bar{C}_1$ is the middle number of impacts for the first soil category.
There is thus the following scale:

i	1	2	3	4	
$\bar{C}$	3	6	12	24	etc.

In correlation analysis of specific soil cutting resistance K and the soil strength analogous model used:

$$\bar{K}_i \;=\; \bar{K}_1 \, x \; j^{i-1}$$

where $j \leq 2$, because cutting resistance may be disproportional to the soil strength.
In the case where the cutting process is associated with the formation of a soil prism, an additional resistance occurs. After calculations, the following equations are obtained:

for wide blades $\bar{K}_i = 0.033 \; x \;\; 2^{i-1}$

for narrow blades $\bar{K}_i = 0.466 \; x \;\; 1.7^{i-1}$

for cutting edge perimeters $\bar{K}_i = 0.036 \; x \;\; 2^{i-1}$

for buckets $K'_i = 0.091 \; x \;\; 1.7^{i-1}$

where $K\,(K')$ is in MPa.

These equations allow us to define probable ranges of values for the specific cutting and digging resistances and their middle values. Thus the single scale of soil cutting and soil digging resistances for blades and buckets is formed as shown in Table 1.

Figure 2 shows the corresponding graphs of correlations for "soil cutting resistance vs soil strength". From this, it is possible to conclude that the specific soil cutting (and digging) resistances for wide blades and buckets are located in dispersion $\sigma_o - \sigma_t$ according to :

$$\sigma_o > K\,(K') > \sigma_t$$

The nearer value of $K(K')$ is to the value of σ_t, the more rational is the structure of the operating devices. At the same time, the values of K for narrow blades , as shown in figure 1-position 2, exceed σ_o. The values K and K' represented in Table 1. are recommended for use in calculations for excavating robots and other equipment.

Middle soil strength, $\bar{C}$			
3	6	I2	24
For wide blades (Fig.I, position I)			
0,0II-0,044 [I)] 0,033 [2)]	0,055-0,088 0,066	0,I00-0,I65 0,I32	0,I76-0,374 0,264
For narrow blades (position 2)			
0,20I-0,58I 0,466	0,690-0,988 0,792	I,08I-I,598 I,347	I,679-2,990 2,290
For cutting edge perimeters (position 3)			
0,0I2-0,048 0,036	0,060-0,096 0,072	0,I08-0,I80 0,I44	0,I92-0,408 0,288
For buckets (position 4)			
0,039-0,II3 0,09I	0,I35-0,I93 0,I55	0,2II-0,3I2 0,263	0,328-0,584 0,447

I) Probable range of values;
2) Middle values.

Table 1. Statistical values of specific soil cutting and soil digging resistances (MPa)

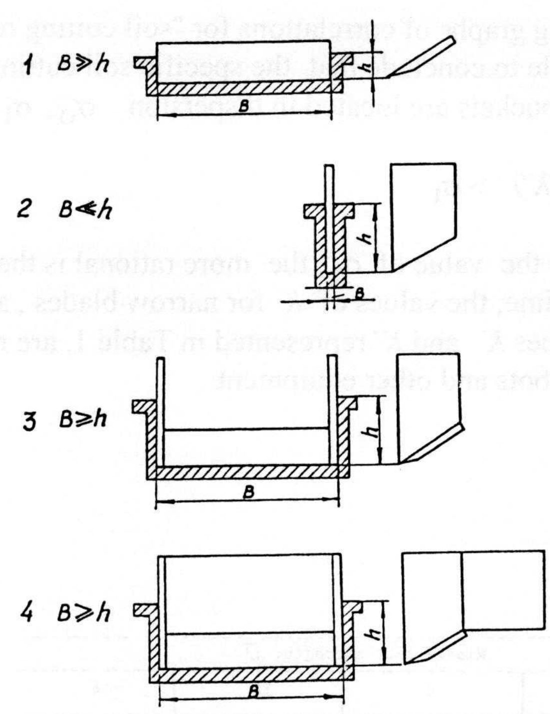

Figure 1. The group of four operating devices of excavating robots:
B is the width of the blade (bucket) and h is the depth of cutting (digging)

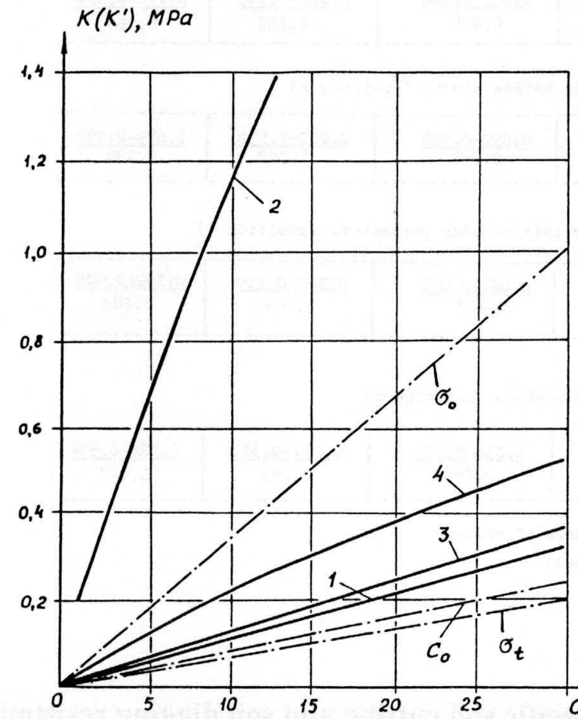

Figure 2. Correlation graphs: "soil cutting (digging) resistance - soil strength"
1 is for wide blades, 2 is for narrow blades, 3 is for cutting edge perimeters and 4 for buckets.