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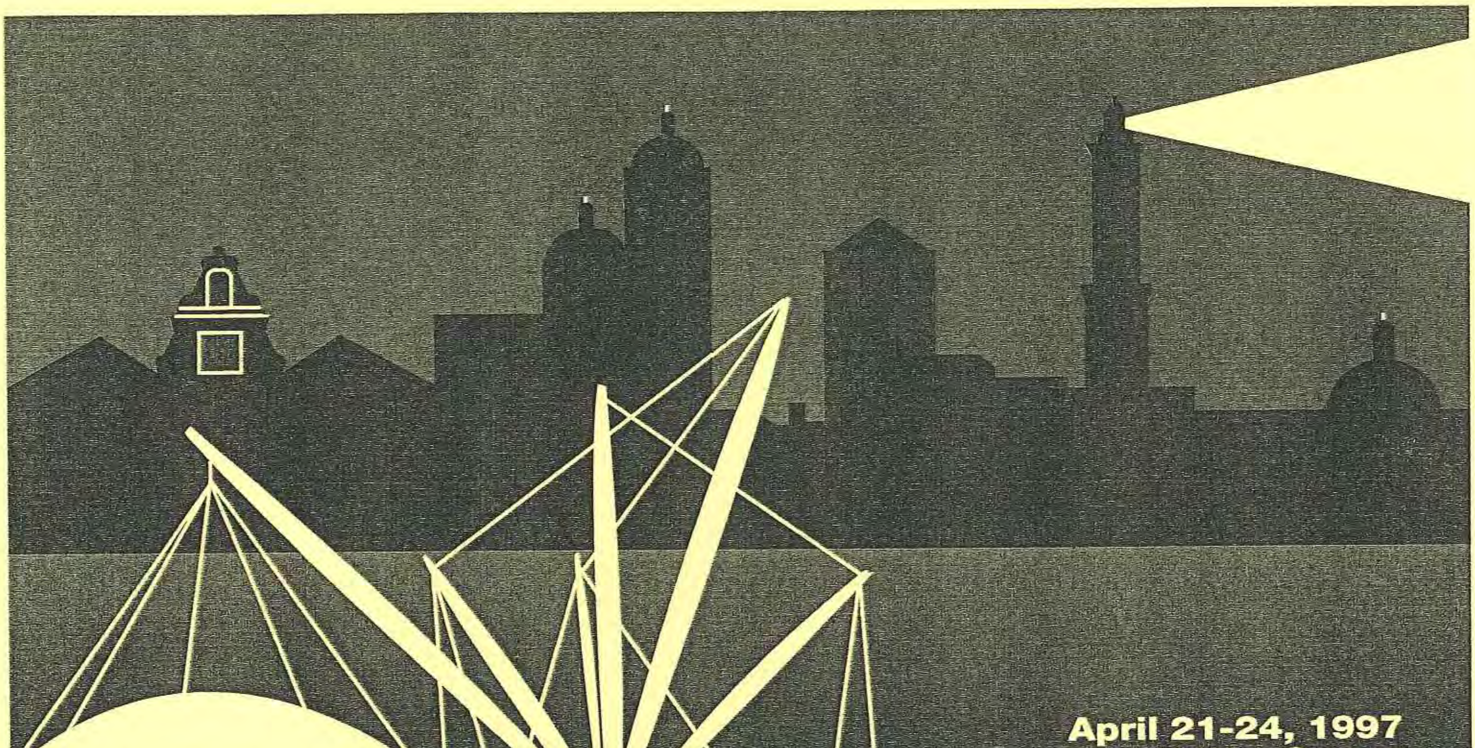

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ITALIAN ASSOCIATION FOR TRENCHLESS TECHNOLOGY

SESSION B

LARGE DIAMETER MICROTUNNELLING: COMPARISON OF DRILLING DATA OBTAINED ON THE FIELD

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SYNOPSIS

The gathering of drilling data relating to some thousands of metres of pipe laid in Italy with microtunnelling technology has permitted a study to be commenced, based on energy criteria, which aims at the "a priori" determination of the degree of difficulty of drilling in relation to the type of soil. The "specific drilling energy" parameter is determined as a concise, easily understood datum, able to summarise the most significant parameters and their relation to the characteristics of the soil traversed. A preliminary result of the study allows a summary classification of the types of soil relative to the average specific energy required in the drilling.

Keywords: microtunnelling, drilling data, drilling energy.

1. INTRODUCTION

From 1992 up until today more than 6000 m of horizontal axis drilling have been carried out with microtunnelling technology, mainly during the construction of gas pipelines. To achieve most of these operations, equipment with slurry material removal has been used, with both standard and rock cutting heads and with drilling diameters between 1405 mm and 1960 mm. The recording of the drilling data relating to about thirty cases, with diverse geotechnical and lithological conditions, has allowed the commencement of a theoretical study which, starting from the analysis of data relating to the soil encountered, aims to determine characteristic "energy limits" of each type of ground and which is able to provide "a priori" indications of the level of difficulty, time scales and drilling characteristics.

2. INITIAL DATA

During the drillings, summarised in Table 1, which contains the length of each course as it relates to the ground and locality [La Zazzera *et al.*, 1993], some characteristic parameters have been recorded which together allow us to reconstruct the advancement of each drilling. The parameters which have been collected with sufficient continuity to enable a comparative study are the total jacking force F at the pipe-end, the torque applied to the drilling head and the driving speed u; these parameters have been shown in a diagram relating to the drilling length. The total lithostatic pressure acting on the top of the pipe has also been noted, as has the value of the pore pressure in the zones in which the drilling was executed under the water table. Two examples are shown in figs. 1 and 2 which relate to microtunnels carried out in clayey silty soil (LBM2) [DIN18319, 1992] (Quaderna stream crossing) and in rock (FS2) (gneiss - Piano di Comi crossing).

DRILLING ZONE	GROUND ENCOUNTERED	TOTAL LENGTH OF DRILLINGS (m)
Emilia Romagna (BO)	clays, silts and fine sands	800
Abruzzo	calcareous rock	450
Abruzzo	various loose soils	570
Umbria (Orvieto)	clays	650
Lombardy (MI, PV)	fine sands	1500
Tuscany (SI, AR) and Lazio (RT, VT)	various loose soils	1000
Sicily (ME)	rock (gneiss)	650
Alto Adige (BZ)	coarse alluvial soils	500
Various	calcareous rock and quartz phyllites	160

Table 1: Italian regions where drillings have been carried out with microtunnelling technology

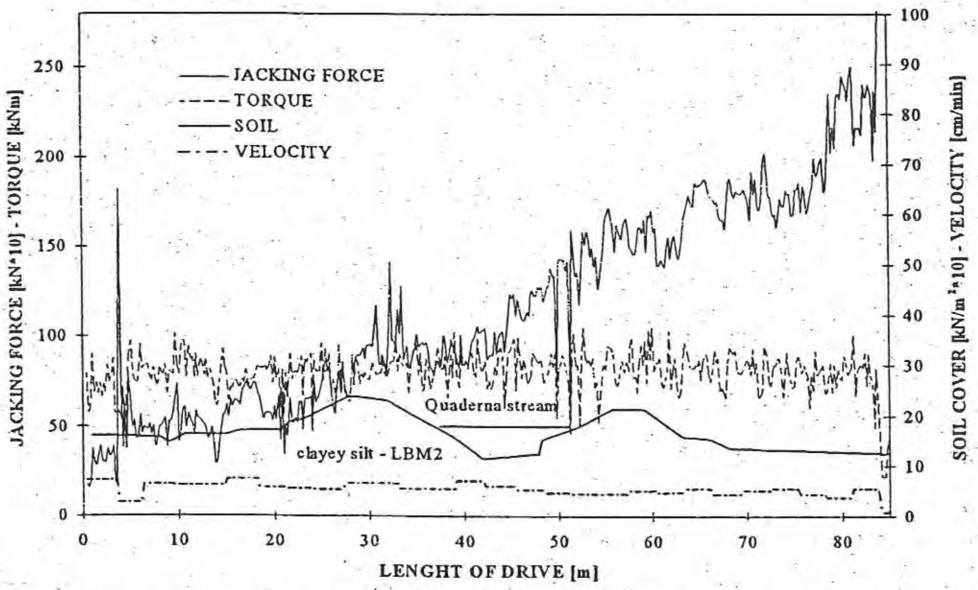

Figure 1. Variation in drilling parameters during the crossing of the Quaderna stream (province of Bologna, Emilia Romagna, 1993).

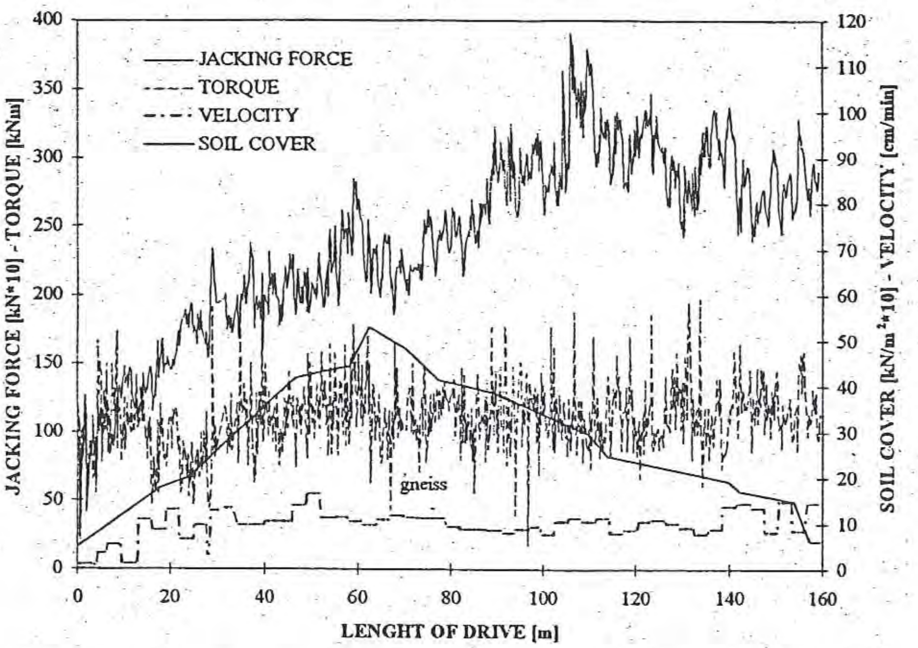

Figure 2. Variation in drilling parameters during the crossing of the Piano di Comi (province of Messina, Sicily, 1996).

In most cases the information relating to the ground encountered was limited to lithological characteristics alone, and only rarely were significant geotechnical data available, such as Atterberg limits, natural humidity, undrained cohesion of clayey soil or penetrometric resistance.

3. DATA PROCESSING

The comparison of the data available, relating to more than thirty drillings varying in length between 20 and 340 m, has immediately proved to be complex due to the large number of parameters (technological, geotechnical, executive) which are involved. The attempt to extract a concise and easily understood datum has led to the determination of the energy necessary for drilling and driving the pipes as a result of the convergence of the most significant parameters and of their relation to the characteristics of the soil encountered.
Recourse has therefore been made to an energy principle which extracts the value of the drilling and driving energy and utilises it in an expression similar to that used for vertical axis drilling:

$$E = [F + 2\pi N \cdot T/u]/A \qquad (1)$$

in which F is the jacking force at the pipe end [kN], N is the speed of rotation [rpm], T is the torque applied to the cutting wheel [kN·m], u is the driving speed [m/min] and A is the section of the cutting wheel [m^2]. This expression (1) may be used to obtain the energy required to

drill a volume unit of ground (specific energy) and then also allows a rapid comparison in the case of drillings obtained with microtunnellers of a different diameter.
Fig. 3 shows the levels of specific energy deduced from the drilling data shown by the diagram in Fig. 1, and as can be seen, these are characterised by a certain irregularity which, in some cases, can demonstrate high peak values followed immediately afterwards by extremely low values; this variation in drilling parameters depends not only on the characteristics of the soil, but also on factors related to drilling technology that are difficult to quantify, such as modifications to the lubrication system, various interruptions, technical difficulties, replacement of driving employees, etc.. Despite this irregularity, characteristic energy trends can still be distinguished, which have been interpreted with simple linear correlations (for example the one shown in fig.3).

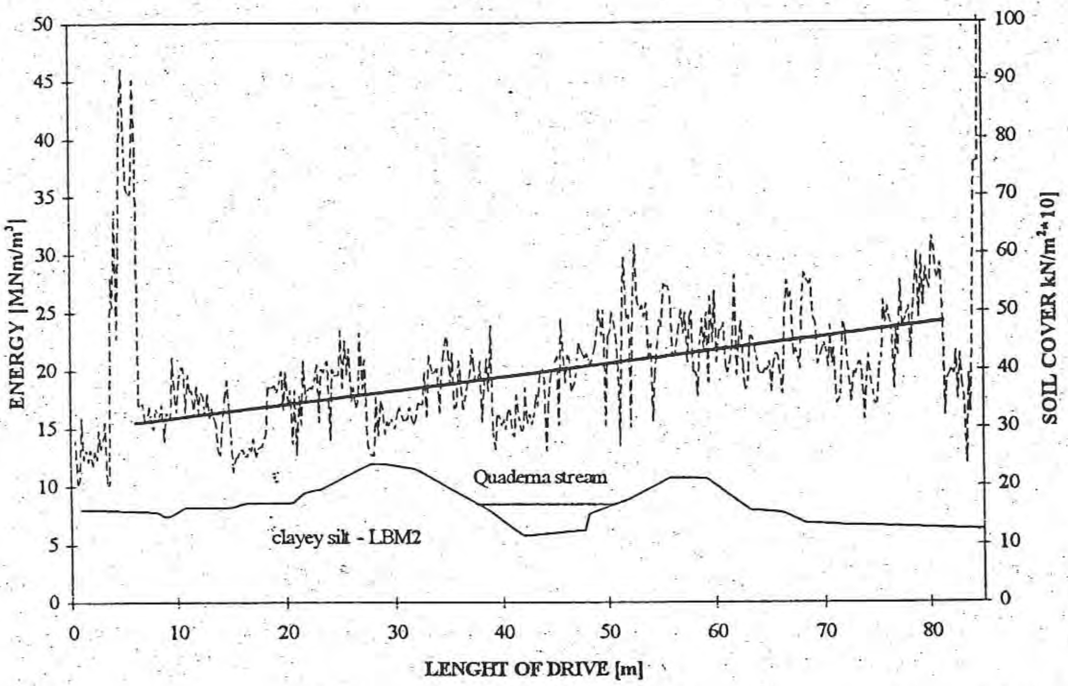

Figure 3. Specific drilling energy trends and relative linear correlation during the crossing of the Quaderna stream.

The linear correlations obtained can be interpreted physically by considering separately the intercept value of the ordinates of the segment which approximates the trend of the energy measurements and the slope of the segment itself. The intercept value, b, can be assumed as the value of the drilling energy at the machine head (initial drilling energy, entirely used to "break" the excavation face), whilst the slope, m, of the segment, which represents the variation in energy as the excavation proceeds, can be assumed as the energy necessary to overcome the tube/soil friction. The energy comparison between the different drillings is made by analysing the linear correlations relative to the energy in the first section of each diagram, a section in which the contributions of lateral friction and friction at the drilling face are easily distinguished; the same thing has been attempted on the linear sections subsequent to the first, but it has not been possible to deduce the contributions of these sections effectively (due to changes in gradient and in energy value caused by variations in lubrication and jacking methods, as well as variation in the type of soil); in such sections it would be necessary to distinguish between the jacking force at the face (Milligan *et al.*, 1996) and that at the pipe-end, as well as the jacking with relative positions and operational times of any interjack stations, to obtain a correct determination of the energy contribution due to the friction of the pipes and that due to drilling. More linear correlations relative to the type of soil have subsequently been considered, as well as determining the type of material of which the pipe is composed (steel or concrete). Fig. 4 shows, for example, the results relating to sandy soil and how in this material the drilling energy, as well as its variation, always remains very low, synonymous with both ease of drilling at the face and with low friction between the pipe and the ground; also significant is the fact that steel pipes produce greater energy figures than concrete pipes.

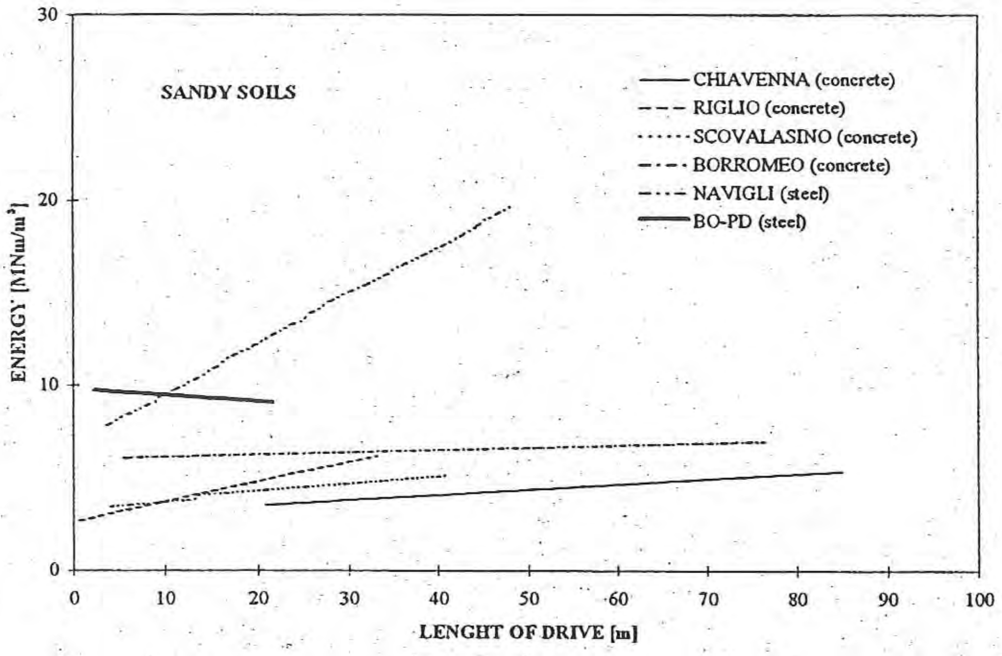

Figure 4. Linear correlations representing the specific energy of drillings performed in sandy soil.

The data relating to all of the types of soil encountered has then been collated in a single graph; the summary has been compiled by utilising the intercept value (abscissa) and of the angular coeff. (ordinate) of the linear correlations. Fig. 5 reproduces this table, with a subdivision of the elements depending on the type of soil to which they relate.

4. INTERPRETATION OF RESULTS

When observing the results obtained, some significant conclusions immediately appear evident, which partly confirm what is already known from operational experience.

One can point out the following:

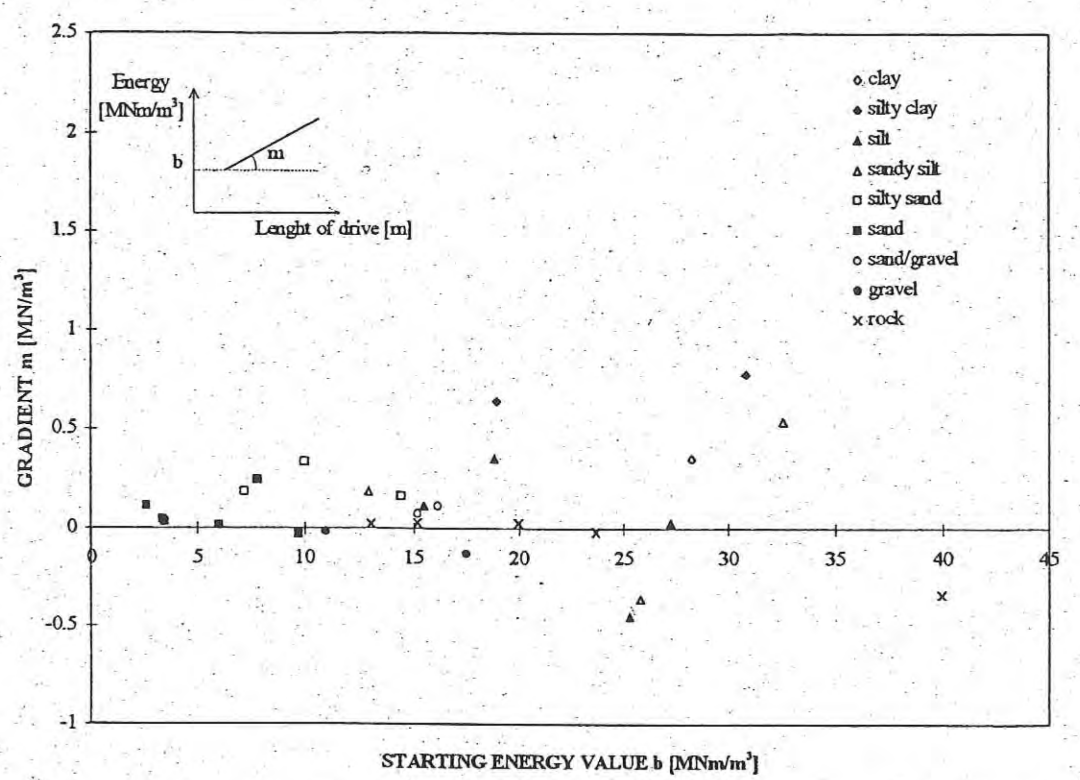

Figure 5. Table containing the linear correlation parameters of the specific energy of all the drillings analysed.

- the sands appear to be the material easiest to drill, characterised by low energy values and by low increases in energy: energy levels less than 15 MNm/mc and slope less than 0.5 MN/mc;
- gravelly sands and gravels have an average drilling energy value (between 10 and 20 MNm/mc and a slight increase (<0.2 MN/mc);
- rocky soil has a very variable drilling energy (from 10 to 40 MNm/mc) and very slight increase (<0.1 MN/mc);
- silts have average/averagely high drilling energy values (energy between 10 and 35 MNm/mc) and variable increases lower than 1.00 MN/mc;
- clays have average/averagely high drilling energy values, quite similar to silts (energy between 15 and 30 MNm/mc) with quite steep increases (between 0.4 and 0.8 MN/mc).

On the basis of the above, we can reasonably attempt to subdivide the energy graph into homogeneous zones characterising the individual types of soil (fig.6) and to give, as a preliminary result of this drilling energy characterisation, a classification of the difficulty of drilling in various types of soil (fig.7). This classification, based on the average drilling energy value in a 50 m section of drilling, determines clay as the most onerous material, in energy terms, for the installation of microtunnels and equates silt with rock in the middle of the list; sand comes out as the "winning" material by far.

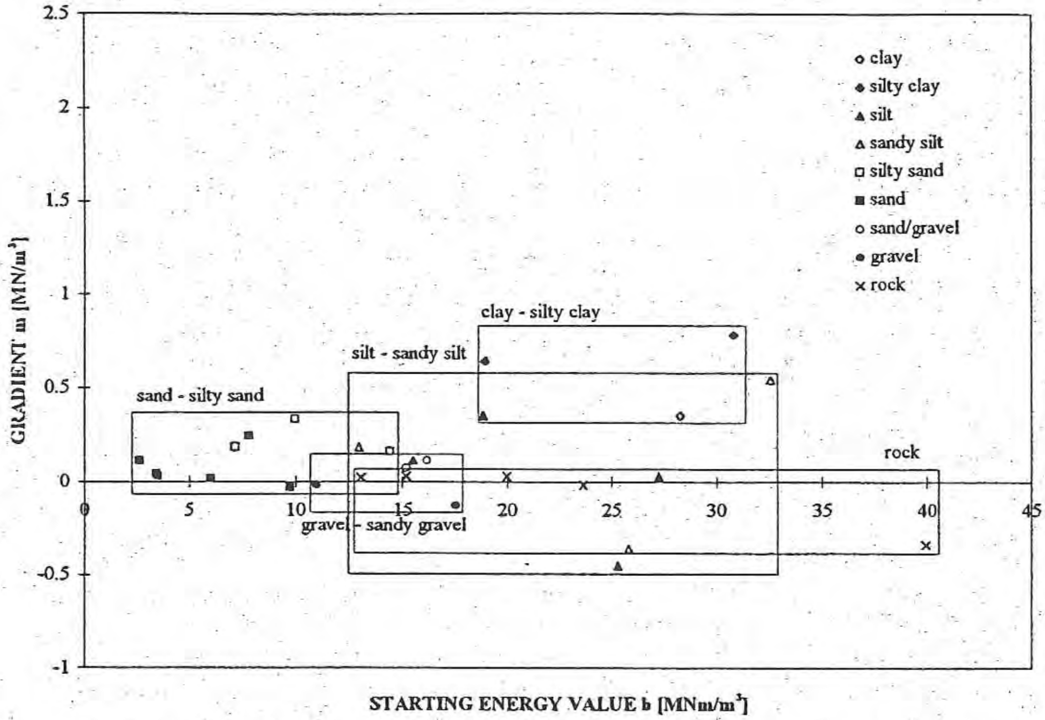

Figure 6. Subdivision into zones characterising the individual types of soil of the specific drilling energy collation table.

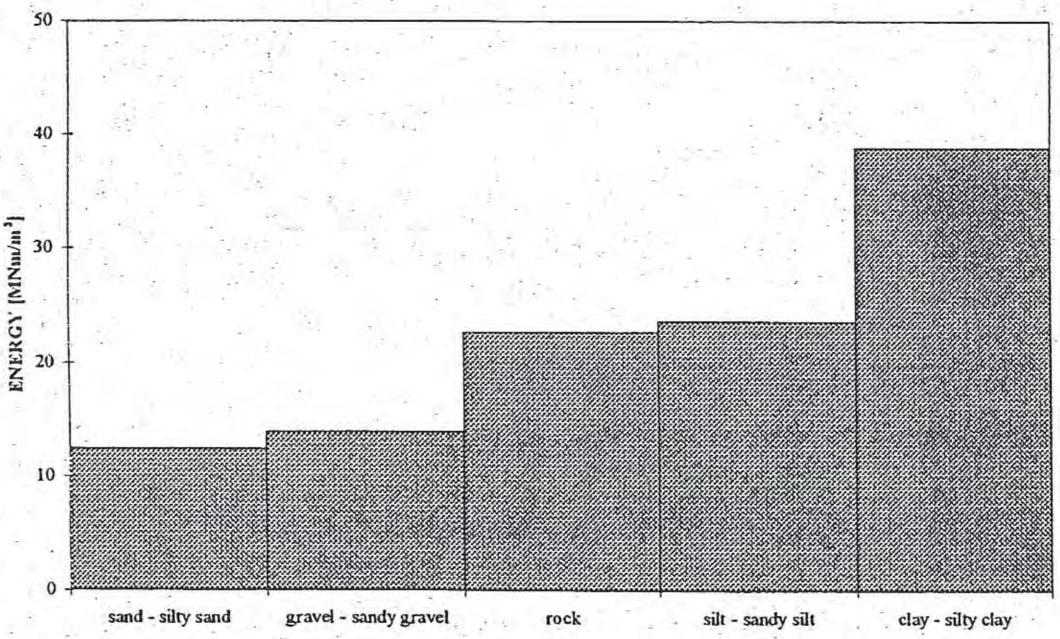

Figure 7. Energy-based classification for the difficulty of drilling in various types of soil.

5. CONCLUSIONS

From the results of the study conducted, it appears possible to determine in the "specific energy" a concise and significant parameter which represents the difficulty of drilling in relation to microtunnelling.

The comparative analysis of the drilling data of a considerable number of pipes installed with the microtunnelling method in Italy, has allowed the determination, on the basis of the energy approach examined, of which types of soil are, on average, more or less onerous.

This result could, suitably interpreted and if necessary combined with other classifying criteria [Toepfer, 1992; Becker, 1995], supply a "preliminary approach" method in the estimation of costs and difficulty of drilling with microtunnellers in soil of different characteristics.

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