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Reducing Power Consumption in Irrigation Systems with the Aid of a Mathematical Model for Pipe Dimensioning

The authors present a mathematical model of sizing the irrigation pipes based on the iterative computing proceeding with the minimization of energy consumption for water pumping.

It was used in this respect as a computing method the generalization of the classical concept of determining the economic diameter of the pipes. The obtainable solutions — sometimes unusual — are fully possible in practice with special economic effects.

The modern irrigation systems use underground pipes for supplying water under pressure briefly called "antennae". An antenna (Fig. 1) supplies a number of mobile sprinkler "laterals". A considerable quantity of power is consumed for pumping water into these pipes, a reason which caused thorough studies concerning the dimensioning of these pipes and eventually the finding of adequate solutions for economizing electric power and materials.

As results from the reviewing of the latest publications in the literature of speciality [1], [5], on the subject tackled in the present study, there is a permanent concern for finding ways and means for the best dimensioning of the water feed pipes, in general, and of irrigations in particular by taking into account the specific conditions in each plot-irrigation. It is also noticed that

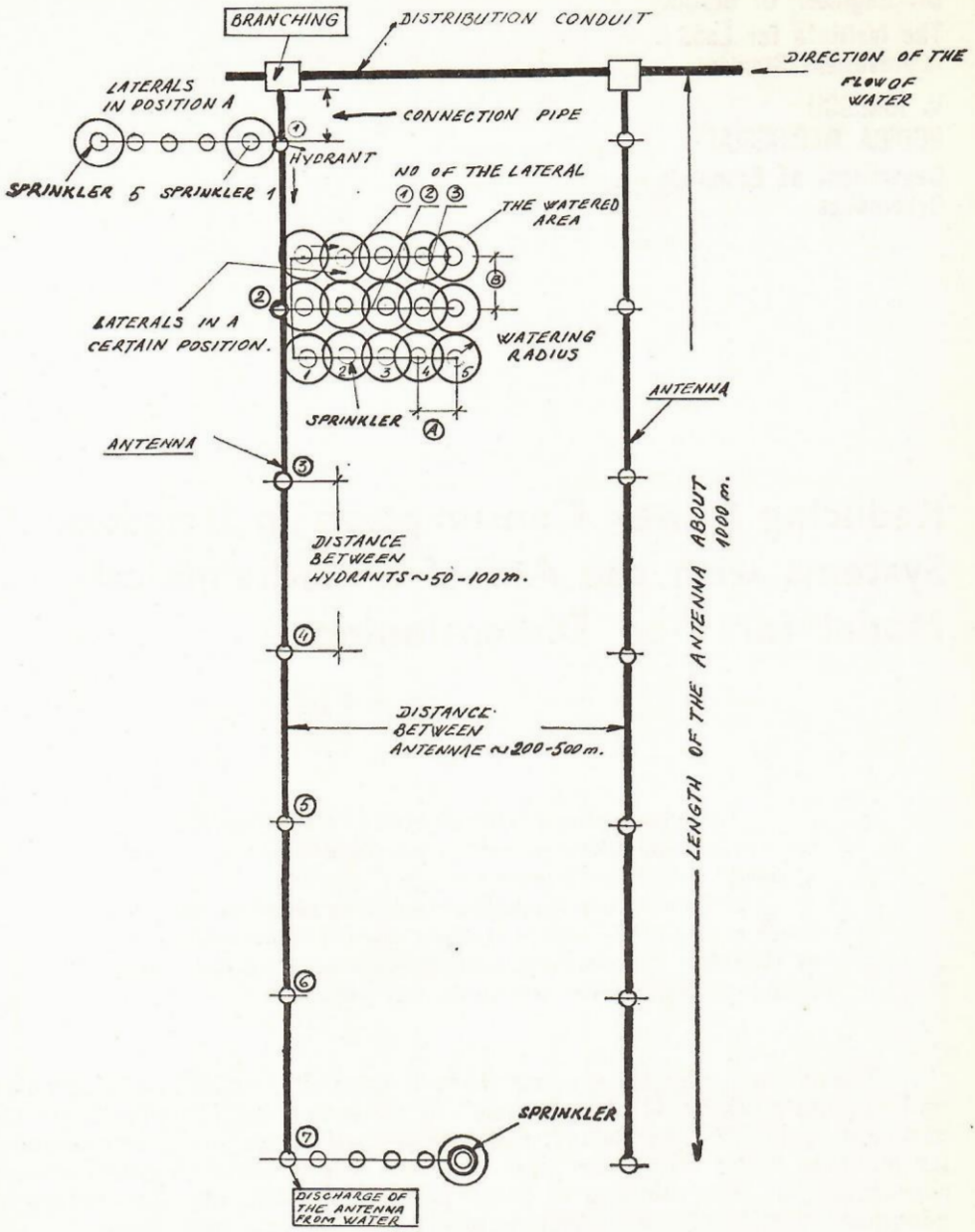


Fig. 1. – GENERAL SCHEME OF AN ANTENNA IN THE IRRIGATION SYSTEM.

not all special conditions in which an irrigation antenna is working are taken into consideration.

In this study, we aimed at calculating the dimensioning of the irrigation antennae under real topographic conditions and under the conditions of flow and pressure characteristic of each case taken separately in the irrigation system. We also tried to obtain a solution for minimizing power and materials costs. For ensuring the optimum pressure of functioning of the sprinkler laterals fed by the antenna, we aimed, as much as possible, to eliminate the regulating terminals or the flow/pressure limits devices which are big consumers of power.

For optimization, the minimization of the following parameter was proposed

$$KAMIN = CINV + CENERG = min \tag{1}$$

where

KAMIN — represents the technical-economic parameter for comparing the variants
CINV — investments in underground pipes
CENERG — the cost of energy corresponding to the losses of charges in the pipe including the dissipation of hydrants, where the curve creates pressure higher than necessary for the functioning of the laterals.

Considering in a first approximation a 10 year period as a recuperation time, a 4% paying off per year for the pipes, a functioning time of about 1000 hours per year, the average cost of a kwh of 0.3 lei and the formula of charge losses [5].

$$J = 0.025 \frac{Q^2}{DS^{5.33} \left(\lg \frac{9150}{k}\right)^2} \tag{2}$$

where:

J represents the loss of hydraulic charge
Q — the flow (m^3/s)
DS — the standardized diameter of the pipe (m
k — the rugosity of the pipe (mm)

relation (1), by considering the symbols used in the program, becomes:

$$KMIN = 0.14\ COST\ DISH + 60 \frac{Q \cdot DISH}{DS^{5.33} \left(LOG \frac{9150}{K}\right)^2} \tag{3}$$

where:

COST represents the unitary cost of the pipe with the diameter DS
DISH — the length of the pipe between two hydrants(m)
L — the length of an antenna trunk (m)

The dimensioning of the pipes is made, in general, according to the very well known criterion of the economic diameter; the authors, however, propose the generalization of the formula for including also the particular case of the antennae in which apart from the cost of energy consumed for overcoming the charge losses in the pipe, the cost of energy losses appearing as a difference between the piezometric line created and the pressure created and the pressure effectively necessary at hydrants should also be taken into account. These additional energies at hydrants 1,2,3,4,5 and 6 in Fig. 2c either dissipate through parts, reinforcements and well known devices: hydrants, pressure reducing gears or the best functioning pressure for a qualitative sprinkler is not observed in the respective points.

In this way, the piezometric line (Fig. 2c) will go down to the CUMAX line which represents the compulsory pumping height for best sprinkler conditions.

For calculus, the notion of "lateral range" was first defined as being a field of pressure (between the CU- maximum pressure necessary for aspersion and CUF -minimum pressure) in which an aspersion lateral may be used as a determined equipment (nozzle, pipe diametre, pluviometry, length, etc.) without the watering rate applied to the extreme sprinklers should vary more than the before established one percent and considered as an inevitable error in practice.

We mention that for this, a special program for calculating the aspersion laterals (called ARITES) had been previously drawn up. The gauge of the lateral range is seen in Fig. 2c where the sigles were marked with CU and CUF. It would be ideal that the piezometric line (points CI) be found between all CU and CUF sigles on the antenna but this usually is perturbed by the relief accidents of the ground.

The following working hypotheses were taken into account in drawing up the working model:

a) the pipe — assembled undergound at the freezing depth limit of the ground by following the relief of the ground — is made up of a number of judiciously chosen diametres, which may vary from one trunk to another.

b) at equal intervals (as a rule 72 m), the hydrants are placed through which water is supplied under the watering pressure. For this, the necessary flow and pressure should be taken into consideration. Thus the water pressure should be between certain limits, namely: the minimum limit which cannot be diminished without the quality of aspersion be affected and the maximum limit which, under certain conditions, may be surpassed, but, for this a power protection and dissipation device is necessary. These limits associated to a lateral are the consequence of the fact that one and the same lateral is fed under two different pressures, according to the way in which it is placed: at the first or last hydrant (Fig. 1 the lateral in position A and in position B).

c) the flow along the antenna has a continuous variation because of the feeding of the sprinkler laterals. Generally, on an antenna and respectively on a trunk of the antenna, the flows may vary within certain limits according to the momentary position of the laterals. An average value for each trunk (Fig. 2a) is considered in the calculus. The calculus is made for an established number of laterals in all rationally possible positions.

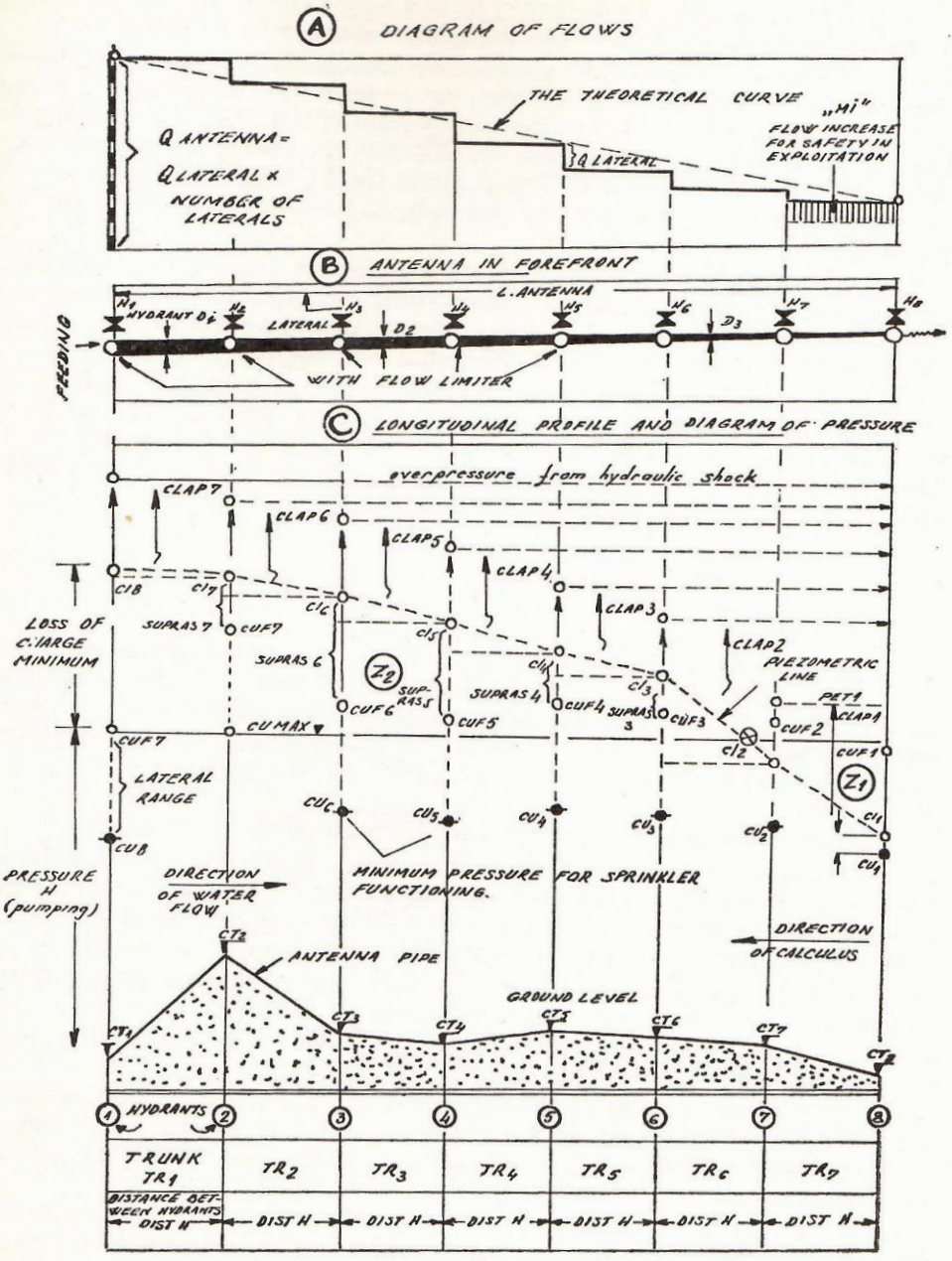


Fig. 2.- SCHEME FOR ANALYSING THE PIPES OF ANTENNA FUNCTIONING USED IN DRAWING UP THE CALCULUS MODEL.

d) The main pipe is usually fed from a single end where the branching to the distribution conduit or the pumping station is to be found.

e) Along the pipe — the piezometric curve of the hydraulic charge losses is formed. This line is set in relation to a horizontal plane corresponding to the minimum pressure of the highest hydrant (CUMAX). The piezometric line will have big slopes if placed under this line- the energy losses being even indicated; when the piezometric line is above the CUMAX line, the slope will be small in order not to increase uselessly the consumption of power by pumping.

f) Through the sudden turning off of hydrants, temporary movements may appear which can generate overpressure, sometimes very dangerous (they can break the pipes). These movements should be avoided by careful exploitation, that is the turning off should be slow (60 sec.).

g) The antennae are made of asbestos-cement pipes with a diametre of 100—400 mm and may have lengths between 200—3000 m. The program envisaged the use of other materials too (such as concrete, polyvinil, steel) whose prices may be real or conventional. In this case, solutions of pipes made up of several materials may also appear.

THE ANTES PROGRAMME

On the basis of the presented input data, a number of parameters necessary for projection are calculated: the number of trunks to be calculated, the flow along these trunks, the minimum and maximum pressure (the lateral range expressed in geodetic levels), the total investment cost, the pressure available on trunks by taking into consideration the pressure class of the pipes, etc.

Figure 3 presents the general logical scheme of the programme.

The calculus starts from the terminal to the initial trunk and is continued from hydrant to hydrant until the end. The part of the pipe between the first hydrant and the antenna branching to the feed pipe is calculated separately with another programme (SAMO — the Best Management Scheme).

At the beginning, the diameter of the first trunk is calculated whose charge loss must lead to the satisfaction of equations (3) and (4):

$$Cl_{(i)} \geqslant CU_{(i)}, \quad \forall\, CI \text{ and } \forall\, CU \tag{4}$$

where CI represents the geodetic level (i) of the piezometric line of hydrant (i). If only one of these equations is satisfied one proceeds to the seeking of another diameter or to using a pipe made of another material until an adequate solution is found.

Within the seekings, one calculates also the value P of the overpressure resulting from the temporary movement occuring following the sudden turning off of hydrants:

$$P = 2\rho \frac{L.V.}{T} \tag{5}$$

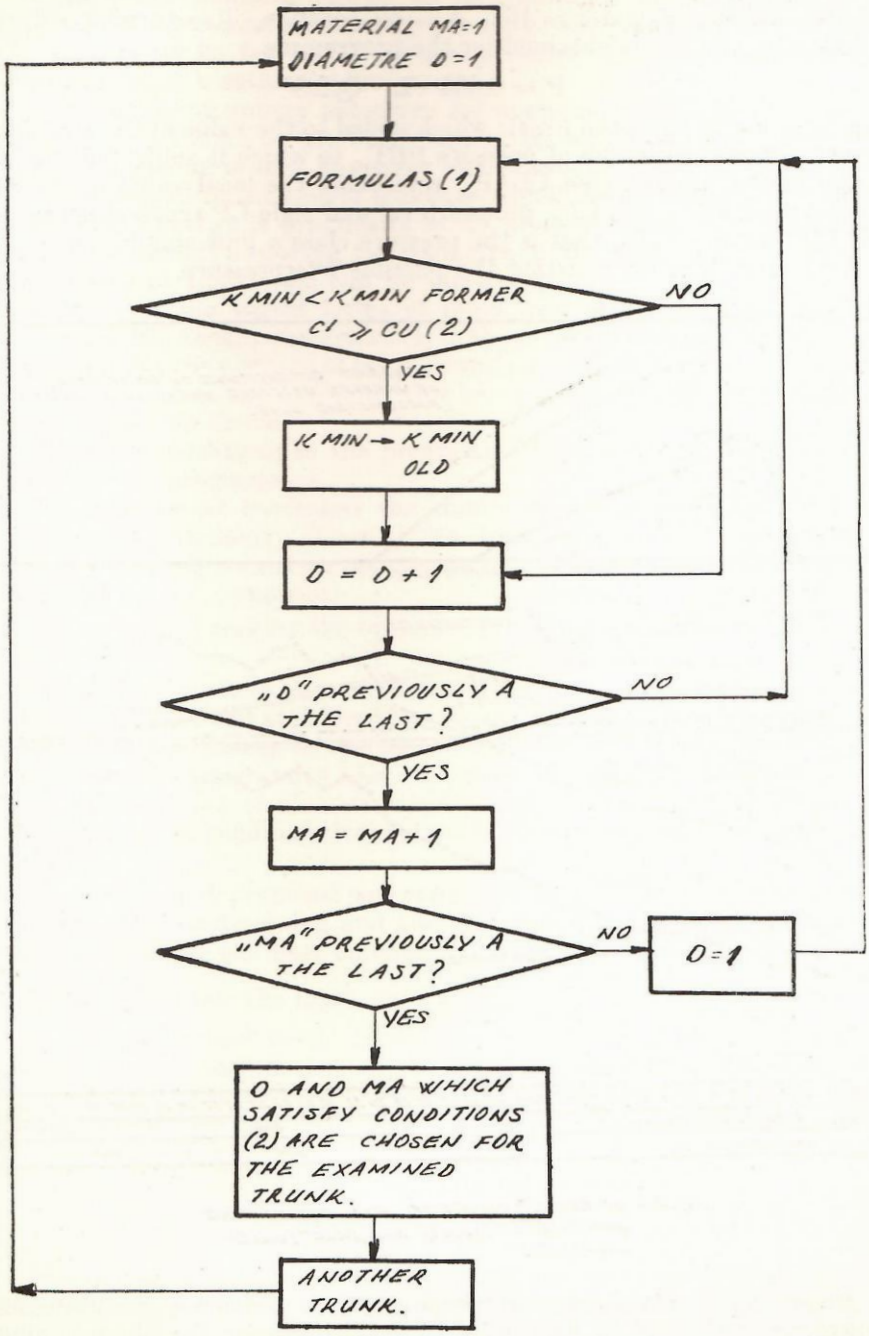


Fig. 3. - GENERAL LOGICAL SCHEME OF ANTES PROGRAMME.

For values: ρ water = 102, T = 60 seconds, T = turning off time, the following relation is obtained for the programme

$$P = 0.004 \cdot L \cdot Q/DS^2 \qquad (6)$$

where V = the water speed (m/s); which added to the value of the piezometric curve $CI_{(i)}$ gives the value of pressure $PET_{(i)}$ to which it subjected the trunk and the entire antenna-pipe. $CLAP_{(i)}$ represents the local value of the difference between $PET_{(i)}$ the $CT_{(i)}$ ground level and sigle CP represents the difference $PET(max) - CT_{(i)}$ that is the pressure class a pipe should have under the local conditions for resisting the possible overpressure.

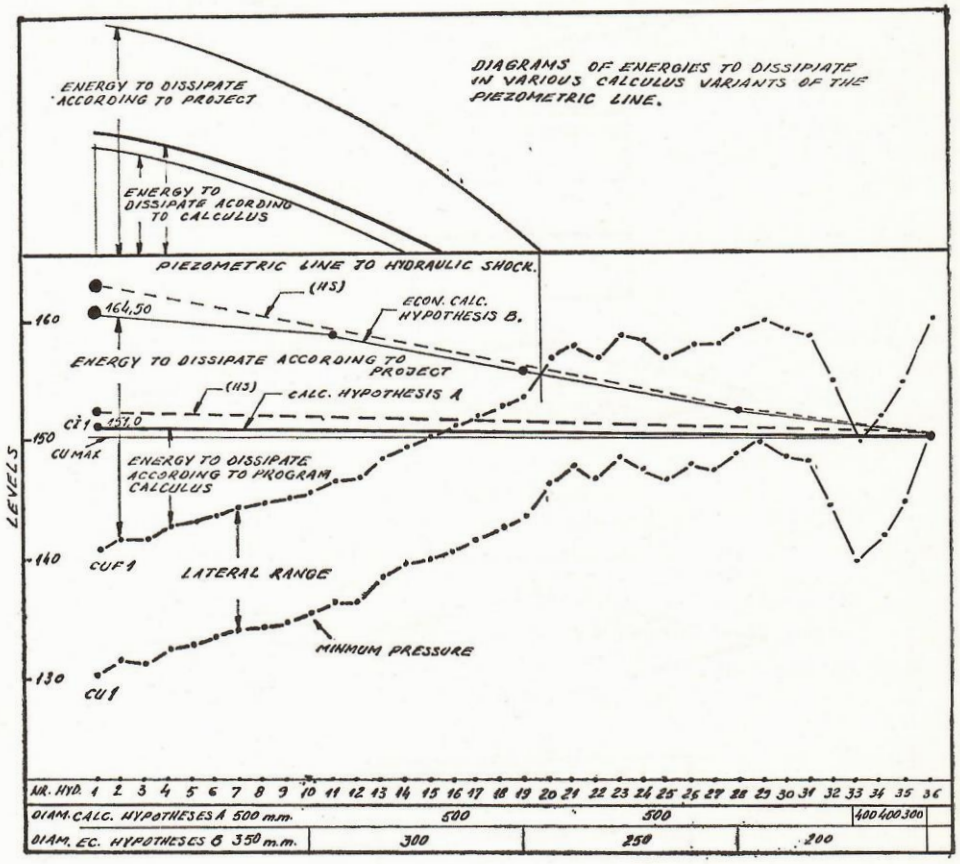


Fig. 4.- GENERAL STRATEGY FOR CALCULATING „EXPENSIVE" (case 1) AND „FREE" (case 3) ENERGIES.

Figure 4 presents the way in which a certain position of the piezometric line towards the CUMAX horizontal line will influence the dimensioning of the antenna. The position of the piezometric line to CUMAX is important because:

— the water pumping energy up to CUMAX is an obligation of the functioning of the antenna; this energy cannot be diminished because the sprinkler laterals must be fed under certain pressure H(Fig.2) for ensuring the implementation of a rational pluviometry;

— the pumping energy necessary for overcoming the charge losses and which is above CUMAX is the only element on which we can intervene by calculus for reducing it to a necessary and economical minimum.

It results that in the case of trunks at which the piezometric line is under CUMAX — the energy is practically of no price and it can be dissipated in order to considerably reducing the diametre of the pipes, and the admitted classical speed of 1.5—2 m/s can be surpassed.

Because of the varied forms of relief, this is not always possible.

There exists a main constraint (4) in the program ensuring the optimality of results, namely the position of the piezometric curbe above the minimum pressure to be ensured at the hydrants, this being solved by the costs of electric power as was shown above.

The other conditions in the programme have a minor character within the various subprogrammes.

The programme envisaged the minimum speed constraint (0.5 m/s).

For most judiciously choosing the design solutions, the lists with the diametres of the pipes existing on the market, of various materials are put at the disposal of the computer.

The scheme of seeking the optimum pipes and diametres is presented in Fig. 5.

The seeking is made from diametre to diametre (a discontinuous method) calculating KAMIN and satisfying the above relations 3 and 4 and keeping the smallest KAMIN, passing to the second material and further until the list is exhausted. The programme also envisages the overseeing (eventually the limiting) of the choice of diametres and /or of materials, but, it allows and/ or the obtaining of genuine solutions, such as the pipes made of several types of materials.

The programme proposed was conceived so as to be used both as a unitary programme for designing and also integrated into deck programmes necessary for choosing the best management scheme.

In the first case, the input data are:

— CT the ground level; SUMQ — the flow of a lateral; NRAR-the number of laterals to function on the antenna; the lateral RANGE; MI — safety coefficient in case that more than a lateral have met at the last hydrant; DISH — the distance between hydrants; LANT — the length of the antenna.

RESULTS, DISCUSSIONS

Figure 6 presents by way of comparison the results of the calculus of an antenna with the aid of the ANTES programme (hypothesis A) and the manual calculus in which diagrams were used for establishing the economic diametre (hypothesis B). To this end, a more difficult case was deliberately chosen.

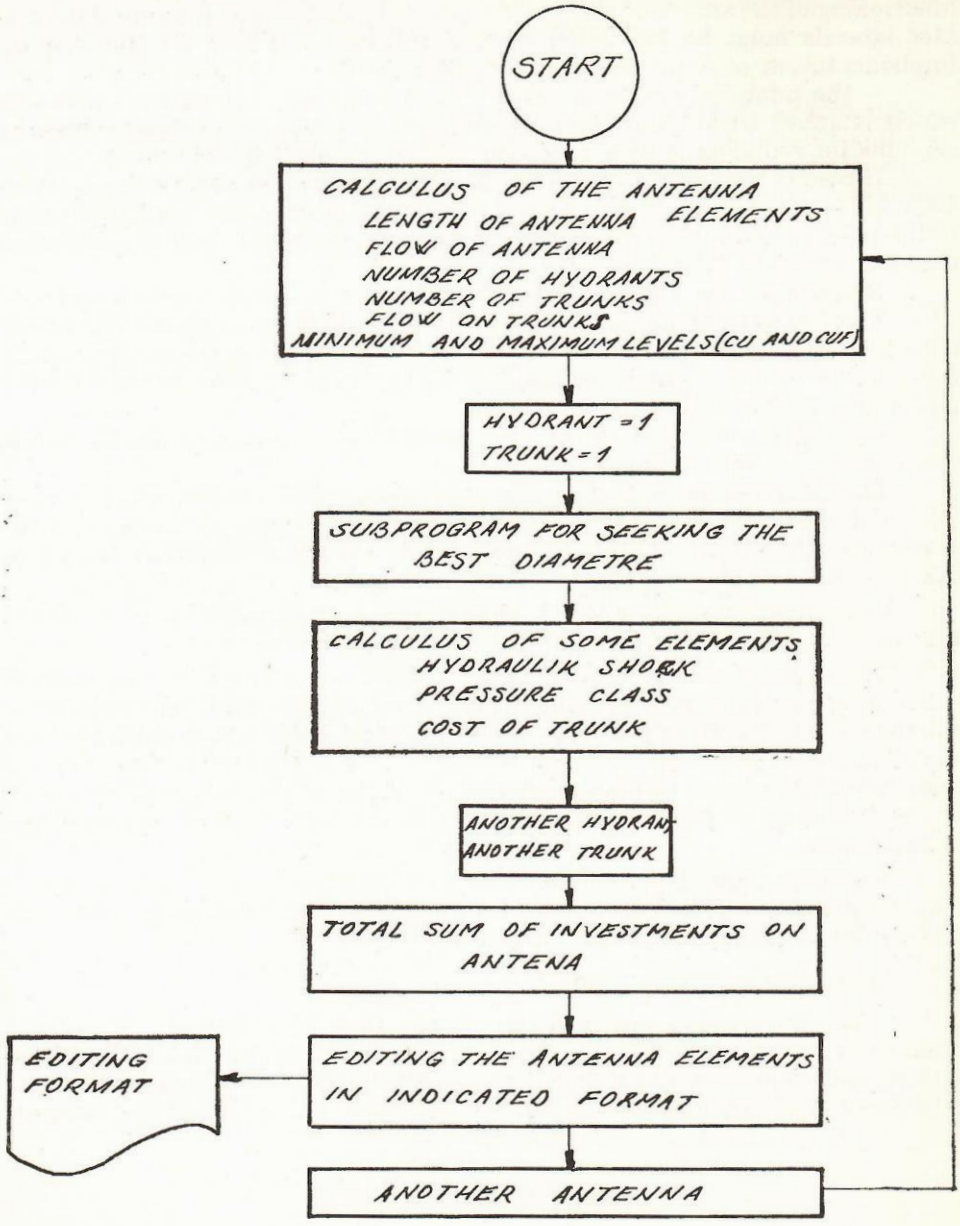


Fig. 5.- SCHEME FOR SEEKING THE BEST TYPE OF PIPES.

It is noticed in Figure 6 that:

1. The water pumping level is of 151.0 m in hypothesis A of dimensioning with the ANTES programme and of 164.50 m in hypothesis B of calculating with the economic diametre.

2. On nearly all the length of the antenna in the B calculus hypothesis, one must proceed to installing energy dissipators — respectively by reducing pressure from the piezometric line to CUF level, whereas in hypothesis A this dissipation is reduced to the minimum possible by calculus and it is represented by the area comprised between CUMAX and the line uniting the CUF pressure. This appears more clearly in the graph above in Figure 6.

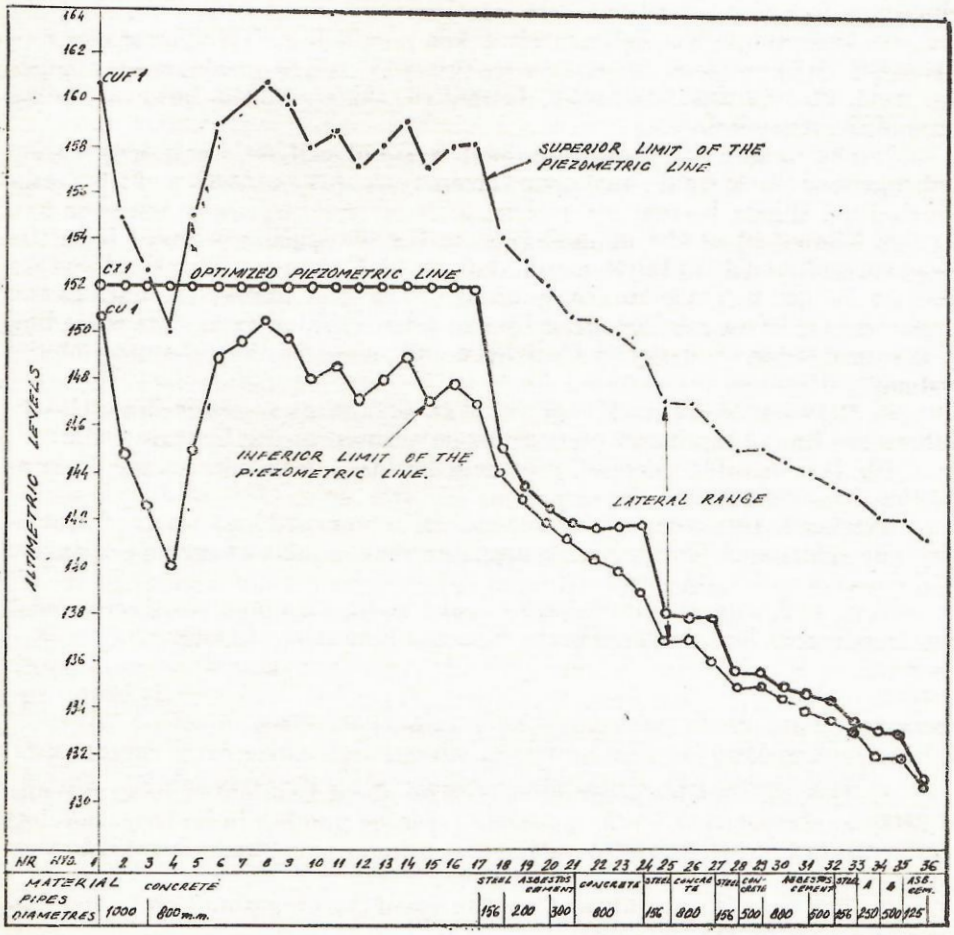


Fig. 6. — RESULTS BY WAY OF COMPARISON OF THE DIMENSIONING OF AN ANTENNA.

3. The line of overpressure in the two calculus hypotheses is different due to the different speed appearing in hypothesis B and as such, it appears more endangered.

4. The diametres are different, namely bigger in hypothesis A than in B, as a result of the way of dimensioning. This fact will influence the investment of the work which will be bigger. Considering that energy is saved, these diametres are only apparantly uneconomical in comparison with hypothesis B.

Diametres smaller than those considered to be economical in the B calculus hypothesis are obtained in case of the antennae at which the piezometric line develops under the CUMAX line.

5. The diversification of the diametres on trunks is made in a much more varied way with the local ground conditions in hypothesis A than in hypothesis B. This leads to the remark that each antenna is a particular case which requires and has its own best solution.

6. An example was deliberately taken in which a single list of concrete pipes (BEGRA) was used. In other cases (Fig. 6) in which a wider range of pipes was used, the solution was better diversified, the execution, however, being more difficult to find.

7. The range of the resulting diametres and materials is largely varied and suprises at first sight; but, upon the analysis of the evolution of the piezometric line, things become very clear.

8. The effect of the minimization of the dissipating pressure from the piezometric line (CI) to the line of maximum CUF pressure is noticed and we shall be obliged to place an energy dissipater only at hydrant 5, since in the other cases exists a selfregulation by the game of diametres. This is leading to a considerable economy of electricity and increases the reliability of the system.

9. Between hydrants 17 and 36 (Fig. 6), the piezometric line closely follows the line of minimum pressure to be ensured to the hydrants (C).

10. It is possible to adopt other solutions too, from case to case, by proceeding in at least two ways:

Version 1. Introduce into the computer a more reduced range of diametres, the solution thus obtained being more monotonous as regards diversity of diametres and materials.

Version 2. Consider the solution given by the computer as a refinement and these results be considered in the design as indications to follow.

PRACTICAL ASPECTS

1. The run of such a programme lasts for about 10 minutes for an antenna of 2500 m, respectively for 20 antennae (average number in an irrigation lot) will last for about three and a half hours using a medium-sized IBM computer.

2. The economies resulting from the use of the programme cover the running expenses on the computer.

3. Considering the results hard to foresee which might appear in the dimensioning of antennae even for an experienced designer, it is advisable to use the programme as frequently as possible.

4. The programme can be used also for antennae constructed at present and on which functional changes are desirable, to be made, namely to increase (decrease) the number of laterals, their flow, feeding pressure, etc.

5. A special economic effect of this sort of calculus results from the fact that it removes the use of irrigation terminals or of reinforcements — pressure and /or flow limiters. These devices, besides their high cost and a useless consumption of power are easily defectible and reduce the safety level in the exploitation of the antennae.

THEORETICAL CONSEQUENCES

1. The economic diametre should be considered for each case separately in connection with the local conditions of functioning of the pipe — the principle being in essence correct but not sufficiently general for special cases, such as the antennae. The calculus proposals existing in the literature of speciality (the Riebeck-Labye method, etc.) suffer from this point of view.

2. A number of hypotheses were made in the calculus model, linked with the functioning system and which are unanimously recognized by specialists, but which should be more carefully tested under conditions of laboratory with an adequate control apparatus, such as:

a) the distortion of the pipes and joints; b) the improvement and modernization of the type of branching and hydrant according to rational hydrodynamic considerations; the practical increase of the minimum speeds admitted on pipes for various categories of water; d) the automation of the turning off and turning on of hydrants by radio in the event of special installations (a manual or mechanical operator, or at a big number of mobile laterals, fixed installations); e) the rational methods of provisional ringing of the antennae with the pipes of the sprinkler lateral (Fig.1) and the division into fragments of the antennae with "on-line" installed valves; f) turning off — turning on systems of the hydrants in keeping with the conditions of exploitation and unconcordance with the hydrodynamic phenomena; g) studies on the reliability of the antennae equiped with and without pressure regulating devices; h) the behaviour of some new materials for pipes, especially plastics (polyvinyl, polyethylene, fiberglass, etc.) which have a low fabrication price; i) the study of the control apparatus system and the checking of the working antennae in connection with their tightness, the evolution of rugosity, the resistence to pressure, etc.

3) Based on adequate studies from which some of the above mentioned suggestions were given, the simulation model can be further developed for giving ampler answers to designing, exploitation and research.

CONCLUSIONS

A mathematical model of dimensioning for the irrigation antennae is proposed by taking into consideration the simulation of the functioning conditions specific of these pipes.

The objective function is represented by the minimization of investments in the pipe and of costs of power to dissipate at some hydrants by eliminating to the maximum the use of pressure and/or flow limiters.

The model allows the choice of diametres and materials after interchangeable catalogues.

The calculus hypotheses taken into consideration are the same as in the case of the classical calculus — but laboratory researches are also necessary for finding out some possible minor phenomena yet unkonwn.

The model can be used in various fields of activity in the I.F. branch and may be connected with other programmes on the computer, with a view to optimizing other major objectives: management schemes, plots, irrigable areas, zones which can be modernized, etc.

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REDUCTION DE LA CONSOMMATION D'ENERGIE DES SYSTEMES D'IRRIGATION A L'AIDE D'UN MODELE MATHEMATIQUE POUR DETERMINER LES DIMENSIONS DES CONDUITS

Les auteurs présentent un modèle mathématique pour déterminer les dimensions des conduits d'irrigation, construit sur un procédé itératif de calcul en minimisant la consommation d'énergie nécessaire au pompage de l'eau. On a utilisé pour cette méthode de calcul la généralisation du concept classique pour la détermination du diamètre économique des conduits. Les solutions pouvant être obtenues — parfois insolites — sont parfaitement réalisables dans la pratique et ayant des effects remarquables.

СНИЖЕНИЕ РАСХОДА ЭНЕРГИИ В ОРОСИТЕЛЬНЫХ СИСТЕМАХ ПРИ ПОМОЩИ МАТЕМАТИЧЕСОЙ МОДЕЛИ РАСЧЕТА РАЗМЕРОВ ТРУБ

Авторы настоящей статьи представляют математическую модель расчета размеров оросительных труб, основанную на итеративном способе расчета с минимизацией расхода энергии для перекачки воды. Для этого в качестве метода расчета было применено обобщение классического понятия определения экономичного диаметра труб. Получаемые решения — иногда необычные — вполне осуществимы на практике с особыми экономическими эффектами.