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PLASTIC AND RUBBER WATERPROOFING IN CIVIL ENGINEERING

MATIERES PLASTIQUES ET CAOUTCHOUCS DANS L'ETANCHEITE DES CONSTRUCTIONS DU GENIE CIVIL

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RESIN CONCRETES AND THEIR USE IN WASTE WATER DISPOSAL STRUCTURES

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SUMMARY

Some research results of the investigations of the properties of various types of resin concrete were shown. Particular attention was afforded to furane resin concrete which is cheap, based on continuously available raw materials, of equivalent mechanical properties and superior chemical resistance to all other types of resin concrete used. Some main principles of its preparation were described.

Experimental research results were used as a basis for a generalization of some relations generally valid for composite materials of granular type.

Several examples of practical application of furane resin concrete to the construction of some underground engineering works in Czechoslovakia were described.

INTRODUCTION

The quota of plastics used in the building industry is increasing every year. This trend is participated in to a considerable extent by the structural application of composite systems in which at least one solid phase consists in plastics in which the solid particles are dispersed /seggregated/ in a bonding agent /matrix/ and which are most frequently used as protective coats. plasters. etc., on the other hand granular materials whose solid skeleton /aggregate/ represents the filler. while the bonding agent fills intirely or at least partly the remaining voids. These systems are usually called resin concretes, resin mortars, etc. and are generally represented by bonded filler.

Both of these groups of materials find the widest application in long-term protection of structures from the effect of water, particularly aggressive effect, i.e. in the function of insulation, while the second group retains, moreover, the structural, load-bearing function.

The Czechoslovak Academy of Sciences has been affording attention to research of these materials since 1959, a fact reported by the author on the occasion of several meetings in the past /e.g. in Liege. 1963, Paris. 1965 [1,2]. In contradistinction from other countries, Czechoslovakia afforded attention particularly to the use of those organic bonding agents which can be produced relatively easily and for whose production there are sufficient reserves of initial materials, which is the primary prerequisite for the application of thermosetting plastics to such a branch of national economy as the building industry. The quantities of bonding agents required by the building industry even in the case of introduction of most specialized productions are comparable with the quantities required by all other industrial branches put together. If these bonding agents are to meet the two principal requirements - high strength and resistance to aggressive environment - the possibilities of their selection are considerably reduced.

It was discovered that the criteria given for the selection of organic bonding agent are best met by the furfurylaldehyde - furfurylalcohol /fural-furol/ polycondensate. The principal component of this bonding agent is furfurylaldehyde /fural/ which is obtained by inexacting hydrolysis of plant /vegetable/ matter containing pentosanes, i.e. the majority of wood and agricultural waste materials. The hydrogenation of fural to furfurylalcohol /furol/, which is another basic component of the bonding agent, is not complicated, either. The quantity of raw materials can be characterized as vast and their sources have another important feature: they will not be exhausted. The relative simplicity of manufacture and the availability of initial raw materials naturally result also in the low price of the principal components of the bonding agent; on the world market this polycondensate ranks among the least expensive thermosets. The thermosetting character of the macromolecular bonding agent is practically an indispensable prerequisite for the desirable mechanical properties. With reference to the resistance to the effect of aggressive environment the fural-furol polycondensate is superior to the majority of possible bonding agents - perhaps with the excenption of fluoroplastics. It does not resist only the chlorinated and aromatic carbohydrates, ketones and oxidizing acids.

Under these circumstances it is only natural that we developed - now eighteen years ago - a combination of a traditional mineral aggregate and the selected bonding agent, a structural as well as insulating material - furol-fural resin concrete known as Berol. In a number of practical cases furane composites were then used either directly for the structures of waste water disposal facilities or for their protection.

PROPERTIES OF FURANE RESIN CONCRETE

Optimum properties of furane resin concrete /similarly as in the case of resin concrete with other bonding agents/ are obtained by the mixing of a well granulated aggregate with the bonding agent in a ratio of 1 : 7 to 1 : 12 by weight /in accordance with the size of aggregate particles, its porosity and surface texture, intensity of working, etc./.

The filler is mixed first with pulverized catalyst /or catalyst on an inert carrier/ of acid reaction; afterwards the furfurylalcohol /or partial pre-condensate of this monomer/ is added, and finally the furfurylaldehyde as a co-polycondensating diluter and simultaneously as accelerator of setting. The midly elevated temperature /35 - 40°C/ for a period of three days ensures complete hardening. However, after three hours of this elevated temperature more than 50% of inal values is obtained; further hardening proceeds, with only slight deceleration, at normal temperature. The filler should be dry, acid-resistant, and should not contain any free carbonates. The outer manifestation of polycondensation is the change of colour from light brown to black. Furane resin concrete cannot be prepared in any other colour but black.

The change of density of furane resin concrete in accordance with its composition, as compared with epoxy resin and polyesther resin concretes, is shown in Fig. 1. Maximum dens-

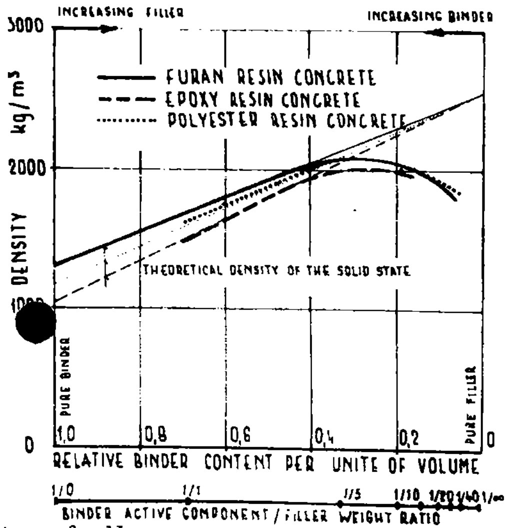

Fig.1

Density of resin concretes plotted against mix composition

ity of all resin concretes is attained, if the bonding agent represents some 0.3 of the volume of the solid phase /filler/. Beyond this maximum the porosity /overall as well as continuous/ begins to increase rapidly - which is illustrated in Fig. 2

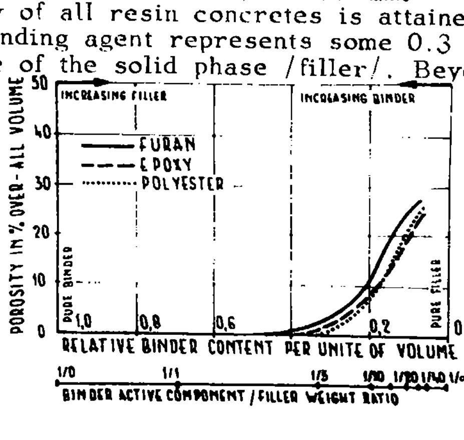

Fig.2

Porosity of resin concretes plotted against mix composition

The change of compressive and flexural tensile strengths with the changes of the bonding agent - filler ratio are shown in Fig. 3 and Fig. 4. For the bonding agent content of the order of 0.2 of the volume of the solid phase /which corresponds approximately with the bonding agent-filler ratio of 1 : 10 by weight/ the strengths of all three compared resin concretes are identical.

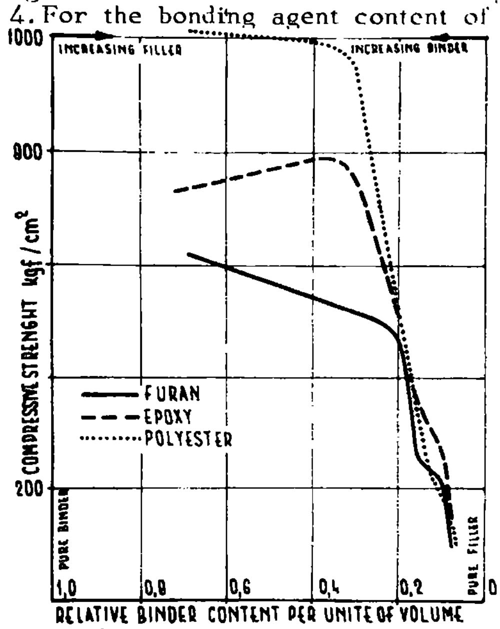

Fig.3

Compressive strength of resin concretes plotted against mix composition

The change of the modulus of elasticity corresponding with the change of the bonding agent content is illustrated in Fig. 5, Fig.6 illustrating the comparison of the coefficients of temperature expansion and linear shrinkage during hardening.

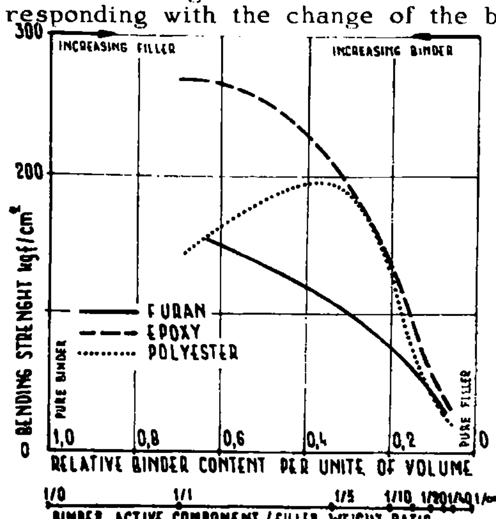

Fig.4

Flexural tensile strength of resin concretes plotted against mix composition

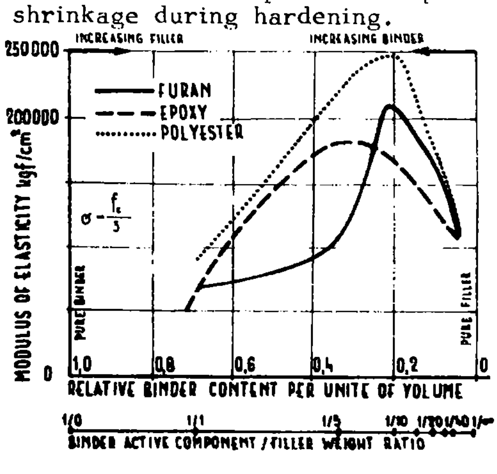

Fig.5

Modulus of elasticity of resin concretes plotted against mix composition for the stress $\sigma = \kappa/3$

For long-term structural application small creep and long-term strength are of primary importance. Fig. 7 shows the changes of the flexural tensile strength with the length of the period of load application: long-term strength does not exceed 50% of the short-term strength, At the same time the short term strength does not change with time /no selfinduced ageing occurs/.

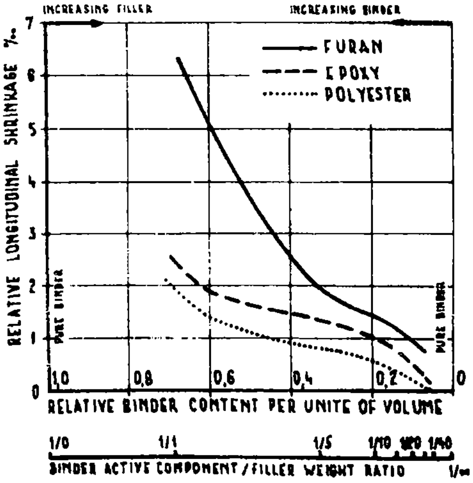

Fig.6a Coefficient of temperature expansion of resin concretes plotted against mix composition

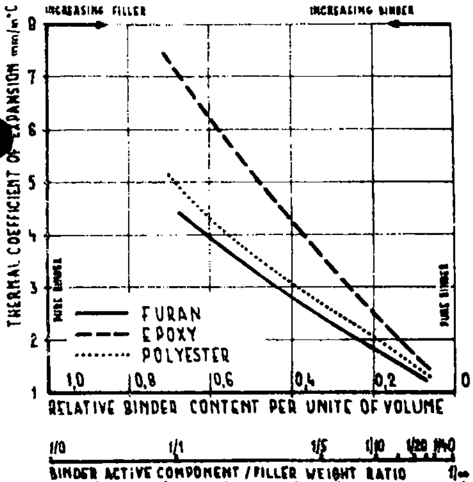

Fig.6b Linear shrinkage of resin concretes plotted against mix composition

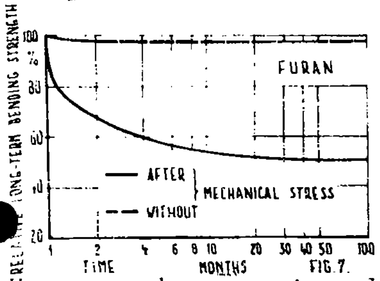

Fig.7 Relative long-term flexural tensile strength of furane concrete

However, the creep is reduced to an acceptable magnitude only for the stresses inferior to 30% of short-term strength.

For structural application also the shape of the stress/strain diagram of various mixes, the value of the Poisson's ratio and the value of ultimate strain are of importance. A comparison of the working diagrams and the Poisson's ratios of the three resin concretes is shown in Fig.8 [4], while Fig.9 illustrates the changes of ultimate strain due to the changes of the bonding agent-filler ratio /on the same scale as that of Figs. 1 - 6/.

The influence of temperature on prism strength and the ultimate volume deformation for various mix compositions /different bonding agent - filler ratios/ are shown in Figs.10 and 11.

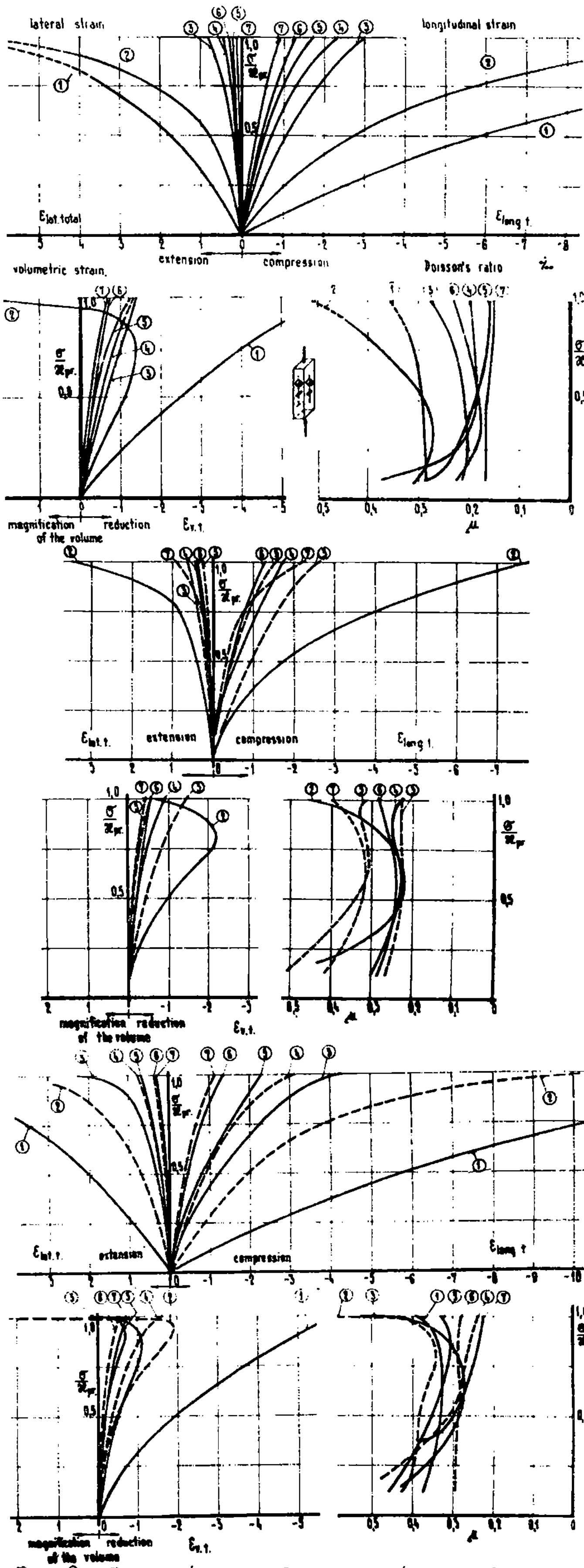

Fig.8 Stress/strain diagrams /longitudinal, transverse and volume deformation diagrams/ and Poisson's coefficients of resin concretes in dependence on mix composition.

The adhesion of furane resin concrete to -cement concrete /or vice versa/ is lower than in the case of epoxy resin or polyesther resin concretes and attains maximally 5 kpf/sq.cm. in tension. However, it can be increased considerably by a simple treatment of contact surfaces /roughening, provision of the fresh surface with sand or stone grit, coating with epoxy resin prior to concreting, etc./; to ensure a bond strength of 10 - 25 kpf/cm2 is no practical problem.

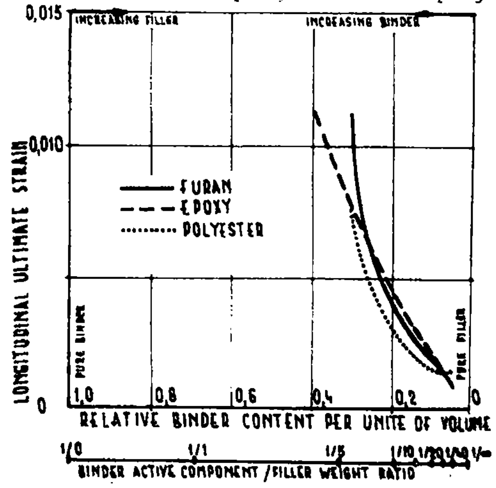

Fig.9

Ultimate strain of resin concretes plotted against mix position

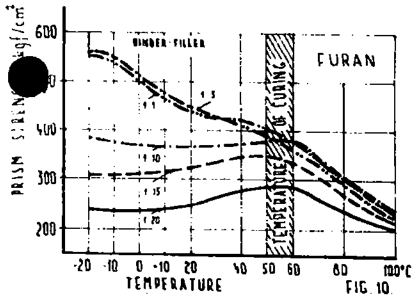

Fig.10

Effect of temperature on prism strength of furane concrete

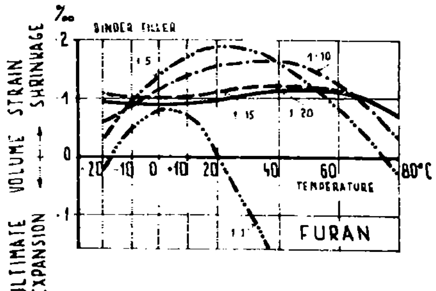

Fig.11

Effect of temperature on ultimate volume deformations of furane concrete.

Furane resin concrete has a good resistance to strong acids and lyes /unless they have an oxidizing effect/, alyphatic carbohydrates and a number of other agents. Its universality in this respect makes it superior to all other resin concretes subjected to test.

RESIN CONCRETE AS A COMPOSITE SYSTEM

With reference to material mechanics resin concrete is a composite multiphase system with markedly different mechanical properties of the two fundamental solid phases - the bonding agent and the filler. A role of considerable importance is played in these systems by the possible presence of the fluid phase - liquid or gaseous. Every property of this composite material is the function of [4] :

- the property of the bonding agent: the property of the bonding agent represents a certain limit of the corresponding property of the composite material which can be exceeded only in such an inner state of stress of the system as is particularly favourable with regard to the property under consideration;
- volume representation of the bonding agent in the system: the volume representation of the bonding agent represents a measure of the influence of the property of the bonding agent on the properties of the system;
- porosity of the filler : the ratio of the volume of the bonding agent to the volume of the voids of the filler in the material determines the degree of cohesion or at least the density of the system; on porosity also the state of stress under external load depends;
- mechanical interaction between the bonding agent and the filler in dependence on the conditions of the origin of the material: the conditions of hardening of a composite material determine the combination of properties brought about by the volume quotas of bonding agent and filler, i.e. the primary inner state of stress of the system;
- mechanical interaction of the system with the environment: the relation between the system and the ambient environment is decisive for the origin of secondary inner state of stress in the system.

The application of this functional dependence is determined by the location of the respective system in the whole region of composite materials, determined by the volume representation of filler and bonding agent, the basic phases, in the overall volume of the solids-the sum of solid phases - of the system. The region of composite materials is thus divided into three intervals [5] with different application of the afore mentionde functional dependence.

The first of these three intervals is the interval of <u>filled bonding agents</u>. In the systems of this interval the filler, whether granular, lamellar or fibrous, is seggregated in the bonding agent which forms the matrix of the system.

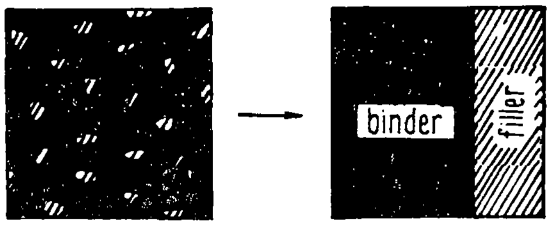

Fig.12

Systems of the third interval--bonded fillers

With the exception of the cases when the bonding agent phase is porous in itself and is, therefore, the bearer of the porosity of the matrix, the systems of this interval may be considered as compact /Fig. 12/.

The last, third, interval, on the other hand, is the interval of <u>bonded fillers.</u> The skeleton of the systems of this interval consists in aggregate filler whose particles are bonded by the bridges of the bonding agent. Since the bonding agent does not by far suffice to fill all the voids of the aggregate filler, every system of this type is characterized by an open interior volume. The composite materials ranking to this interval, have always continuous porosity /Fig.13/.

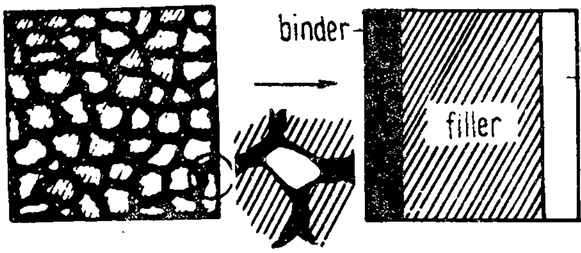

Fig.13: Systems of the third interval - bonded fillers

The second, intermediate, interval, which is most complicated from the viewpoint of mechanics, is the interval of transition systems, a fact suggested by its very location in between the two marginal intervals. The systems of this interval are characterized by aggregated filler and porosity varying - from the beginning to the end of this interval - from zero over discontinued porosity /closed interior volume/ to continuous porosity /Fig. 14/.

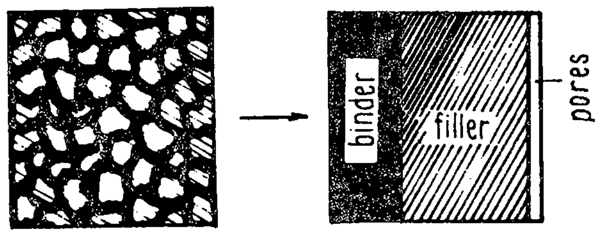

Fig.14: Systems of the second /transition/ interval - bonded fillers

The mechanical behaviour of composite materials in these three intervals of their volume composition is considerably different. If we should schematize graphically the definition of the intervals over an axis "all bonding agent--pure filler" /Fig.15a/, we can follow the differences - in analogous representation - from the very origin of the systems due to the setting of the bonding agent. /Fig.15b/.

By means of the fundamental mechanical properties /Fig. 15c - f/ - with the same representation - it is possible, moreover, to illustrate the influence of the fluid phase in the system. The systems, particularly those of the third interval react mostly markedly to the exchange of the gaseous phase for the phillic liquid phase /phillic with regard to the inner surface of the system/. Since the fillers, but particularly the bonding agents of concrete bonded materials are not usually non-polar, we can simply speak of water and the interaction of the systems with the humidity of ambient environment. The influence of humidity on the systems of particularly the third interval is so marked that it requires /analogously with the thermal physical parameter - Fig. 15g/ the introduction of the moisture physical parameter /Fig. 15h/

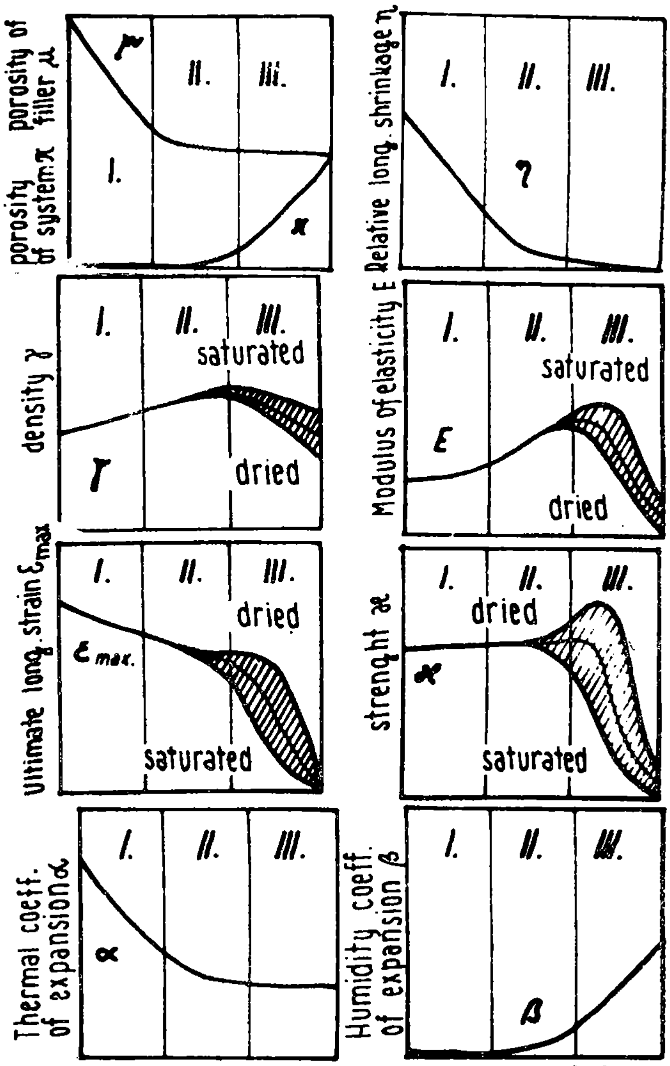

Fig. 15a-h : Schematic representation of the change of properties of composite materials in the three basic intervals according to the volume representation of bonding agent in the solid phase of the system

SOME PRINCIPLES OF RESIN CONCRETE PREPARATION

Filler

One of the principal factors influencing the quantity of bonding agent required /and - consequently - all resulting properties/ is the correct selection of the filler.

The principles of this selection include:

- the filler must consist of /at least/ three gradings incl. the microfiller in accordance with the so-called discrete granulometric curve /gap-grading/ so as to ensure minimum porosity;
- the gaps between the individual gradings must be at least two to four times as large as the diameter of the particle of the lower grade;
- the extent of every grade should lie within the limits of $d_{max} = 2 - 2.5\ d_{min}$;
- the maximum particle size of the filler should be maximally one third of the minimum thickness of the layer applied;
- the filler must be clean, it must contain 7 - 10% of microfiller with particles below 0.05mm.

and must be resistant to the effect of the components of the bonding agent;
- before the mixing with the bonding agent the filler must be dry /the moisture content of the filler should not exceed 0,2% of its weight/;
- river-dredged gravel-sand, clean dug sand and gravel or crushed stone or artificial aggregates /incl. expanded aggregates/ may be used as filler; the type of filler determines particularly the hardness, toughness, modulus of elasticity, wear resistance, thermally insulating capacity, chemical resistance and other properties of resin concrete;
- in the capacity of microfiller ground quartz sand, fly-ash, crushed stone powder, non-expanded perlite, microasbestos, graphite, coke powder, and similar materials may be used; apart from the reduction of the overall porosity of the filler every micro filler affords the system further specific properties;
- the particle size of the microfiller should equal or be inferior to the thickness of thelayer of the bonding agent enveloping the particles of the basic filler grade; the observation of this rule ensures the most effective compaction of the system, the maximum reuction of the necessary amount of the bonding agent required and the best workability of the mix. However, since the results of the determination of the thinckness of particle envelopes are far from explicit /and depent on a number of factors concerning both the bonding agent anf the filler/, it is recomanded to select the mean particle diameter of the microfiller within the limits of 10 and 50 mikrones.

Bonding Agent

The basic factor affording the resulting material its characteristic features is, naturally, the type and modification of the bonding agent which influences also the workability and, consequently, the minimum quantity required in the system. The correct selection of the bonding agent is dictated by the future exploitation of the material /resin concrete/, i.e. by the requirements imposed on its various physical properties /adhesion to the filler, relaxation, chemical resistance, resistance to UV radiation, etc/.

It holds that

- on the basis of its viscosity the mixing equipment as well as the equipment for the working of the placed material /according to the type of resin either microvibration, heating or a combination of both methods, etc./ must be selected;
- solvents may be used in exceptional cases only and only such solvents as become an integral part of the resulting matrix;
- for batching purposes the individual components of the bonding agent must be so prepared as to ensure that their quotas in the overall volume of the bonding agent may exceed 3% by weight; in the opposite case it is not possible to maintain the necessary homogeneity of the bonding agent in actual practice;
- the batching of the individual components of the bonding agent must ensure the life of the mix of at least 30 minutes; the setting should proceed slowly, particularly in the first phase.

APPLICATIONS OF FURANE RESIN CONCRETE

Adequate mechanical properties, high chemical resistance and durability and relatively low price predetermine the fields of application of furane resin concrete: pipe lines for aggressive liquids, protection of tanks, reservoirs and other structures exposed to chemical attack, etc. Some applications, particularly to the pipe lines of various purposes, carried out in Czechoslovakia, are described further on. In comparison with traditional technology the labour requirements were reduced approximately to 25%, financial economy amounting to about 30%.

Resin Concrete Pipes /Pipe Cores/

For the disposal of heavily aggressive /alternately acid and alkaline/ waste water from a big chemical works beside traditional concrete sewer protected by several layers of plastics foils and coatings and a lining of acid-resistant bricks /Fig.16/ also dia. 135 cm resin concrete pipes with a wall thickness of 4 cm were used in the period of 1963-1964 [1,3]. These pipes of furane resin concrete were produced in vertical position in a dual mould provided with effective vibrators. The length of the pipes was 300 cm /Fig. 17/. The pipes were transported to the site, placed on concrete foundations and clad with concrete. In this operation they served as self-supporting interior shuttering for the fresh concrete mix /Fig.18/. After the joints have been filled with furane resin mortar /from inside, after the setting of concrete/ the furane resin concrete core affords affective and lasting protection against the effects of aggressive waste water to the concrete of the pipe.

The inspections of this work, where the conventional and the modern parts serve the same purpose in the same conditions side by side, were made after two, five and ten years of exploitation. So far the furane resin concrete part has shown no defects, while the brick-lined part was slightly disturbed after five years of service and failed entirely after ten years and required full reconstruction.

Concrete Pipes with Inner Lining of Resin Concrete

In another part of the same work furane resin concrete was used for the disposal of chemically aggressive waste water in a different manner. Concrete pipes produced by spinning by the TUBECO system were provided with an inner lining of furane resin concrete 2 - 3 cm thick, applied to the inside of the pipes in the process of spinning under simultaneous rolling. The joints between the individual pipes were sealed with rubber rings /Fig. 19/. This method of production is under further consideration.

Reinforced Concrete Pipes with Resin Concrete Cores

In the construction of one of the main sewers serving a new housing estate in Prague dia. 180 cm reinforced concrete pipes 200 cm long with furane resin concrete cores were used /Fig. 20/, which were produced as follows:

First a resin concrete core with walls 2cm thick was cast in a vertical mould /by means of vibration/; after its setting the exterior mould was removed, reinforcement was placed and fixed and the space between the resin concrete core and a new exterior mould /18cm thick/ was filled with cement concrete/ once again in vertical position/ and vibrated. The pipes were placed on concrete foundation blocks with laser control of position /Fig.21/. Their joints were pointed with resin concrete mastic from inside and the whole pipe line was grouted with thin concrete to a height of about one third of the pipe diameter. In this project also the method of assembly of resin concrete cores from prefabricated segments and their subsequent cladding with concrete was tried. This method proved slightly more advantageous from the economic point of view.

Large-Diameter Sewer Protected with Prefabricated Resin Concrete Lining

The greatest extent of application of furane resin concrete effected in Czechoslovaia so far has been its use in the construction of the new m in sewer leading from the south to the north of Prague. The sewer is scheduled for completion in 1978 when it will serve 562,000 people with a specific run-off of 420 litres of waste water per head and day, which will increase to 730 litres per head and day for 840,000 people in 2000. The sewer is designed for a flow of 20.44 cu.m per sec., its clearance varying from dia. 200 cm to dia. 360 cm over a length of 11,300 m. Of this overall length 5.5 km pass in a tunnel driven in firm rock, 1 km in a tunnel driven in waterlogged made-up ground and gravel sand, and 4 km in an open trench. Apart from that the sewer siphons under two water courses. The required life expectancy is 80-100 years. The construction began in 1972. It is a highly exacting project both technically and in time.

The original design considred a concrete /or reinforced concrete/ structure protected with a lining of acid-resistant bricks 15 cm thick /Fig. 22/, i.e. a system used successfully in Prague for the past 70 years. However,

Fig.22: Originally intended sewer design

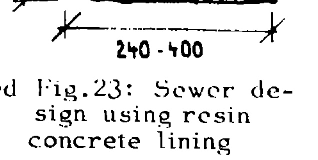

Fig.23: Sewer design using resin concrete lining

considerable labour requirements and a shortage of specialists proved a stumbling stone of this process. From the number of other methods available it was decided to accept the alternative replacing the brick lining with a lining of resin concrete 2 cm thick used as "lost" shuttering of the concrete sewer /Fig.23/.

This alternative enables a continuous concreting of the sewer. Prefabricated steel cages 3 m long /Figs. 24, 25, 26/ are lined with resin concrete segments prefabricated in a special plant. The segments 149 cm long and 90 - 100 cm wide are produced by vibropressing in the curvatures required by the cage cross section. Their weight varies between 60 and 70 kg. In the case of a dia. 200 cm sewer six segments were required, while twelve segments were used in the case of dia. 320 cm and dia.360 cm sewer cross section. The joints between the segments were sealed with temporary rubber inserts /Fig. 27/. The whole assembly is secured with wire.

The shuttering cages with resin concrete sewer lining are placed by a crane /Fig. 28/, if the sewer is concreted in an open trench. In tunnels they are transported on bogies /Fig. 29/. The cages are fastened to the preceding cage by two pins /Fig. 30/. After placing they are set on four adjustment screws /Fig. 31/ which are used for their accurate alignment. In the tunnels they are fixed by means of another four screws against the vault to secure them against uplift during concreting. The concrete is cast in sectors comprizing 2 - 3 cages /6 - 9 m long/. In tunnels the concrete is placed by means of compressed air pumps and compacted by type CIFA pneumatic surface vibrators mounted on the frames of the shuttering cages. The concrete is thus compacted by means of vibrations of the resin concrete lining/Fig.31/.

The shuttering cages are so designed as to fold on a special transport car after the completion of concrete compaction /Fig.32/.

When the concrete has hardened, the rubber inserts are removed from the joints and the joints are sealed with epoxy resin mortar. This also ensures perfect monolithicization of the resin concrete pipes /Fig. 33/.

To ensure good bond between cement concrete and resin concrete /in excess of 10 kpf/cm2/, the rear /external/ face of the segments is provided with stone grit, pressed into the not entirely hardened resin concrete during segment manufacture.

In tunnels this method ensured an aoutput of as many as 193 m of sewer per month. In an open trench a maximum output of 110 m per month was achieved, since - with regard to the uplift of freshly placed concrete - the whole sewer cross section had to be concreted in three layers. In comparison with the originally considered tradidional method the construction was accelerated, on the average, three times in the tunnels and six times in open trenches. The brick lining in a tunnel required 98.1 manhours/m, while the resin concrete lining required only 29.4 manhours/m. The economy of labour requirements due to the application of the new method amounted to 70%. The same economy was achieved also in the trenches.

In spite of the high price of resin concrete the overall costs per 1 m run of the sewer were lower by several per cent, as a result of a lower volume of envelopingconcrete and a smaller volume of earthworks required /Figs.22 and 23/.

Furane resin concrete was used also for additional structures /inspection chambers, branch-off pipes, etc./. In actual construction no difficulties have arisen so far and the construction proceeds according to schedule.

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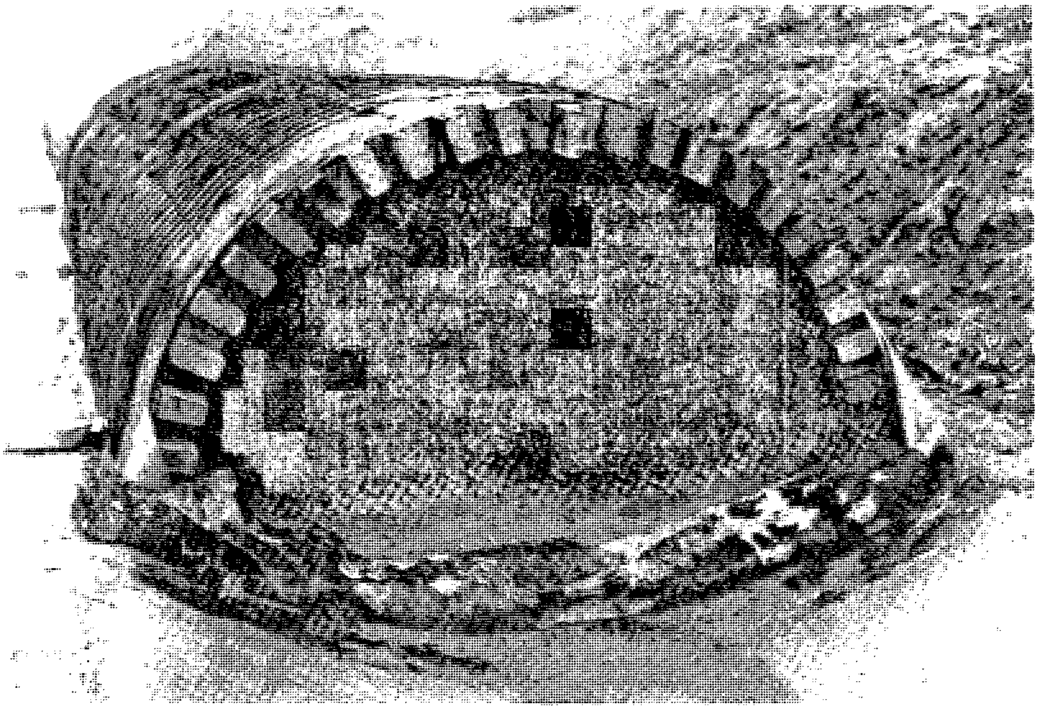

Fig. 16 : Sewer of conventional design.

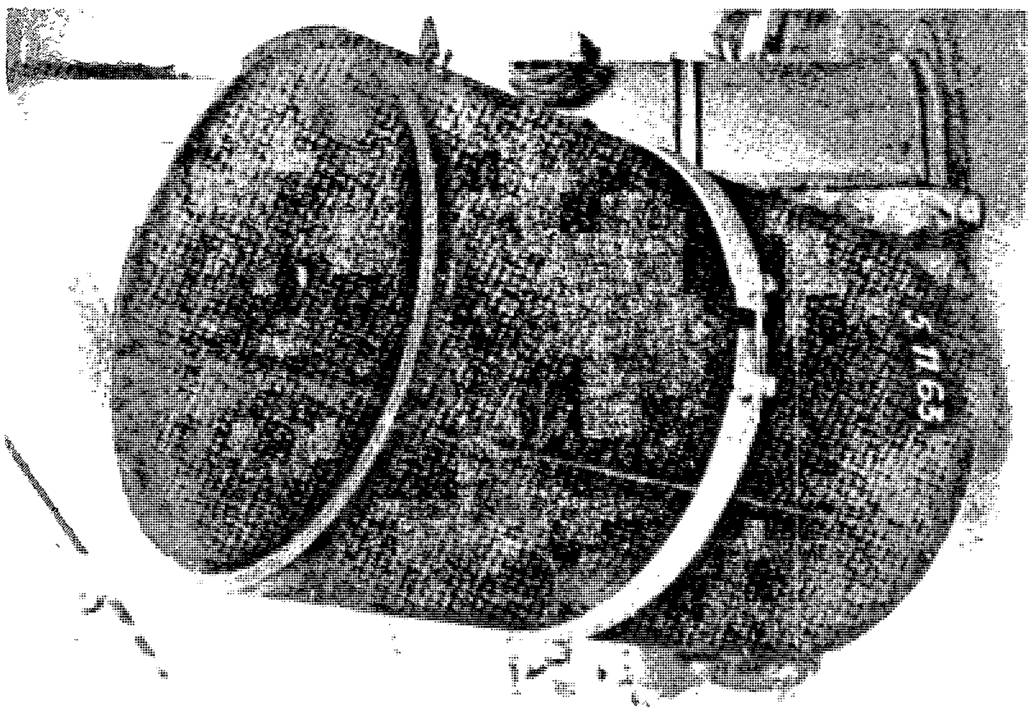

Fig. 17 : Dia. 135 cm pipe core of furane concrete.

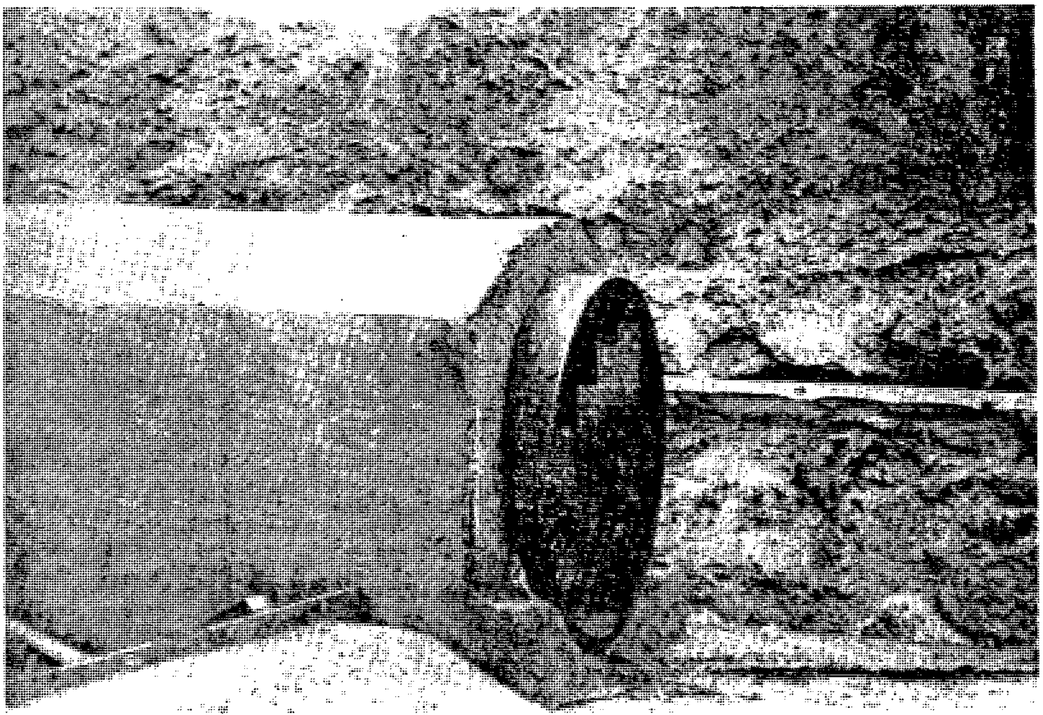

Fig. 18 : Waste water piping of self-supporting resin concrete pope cores.

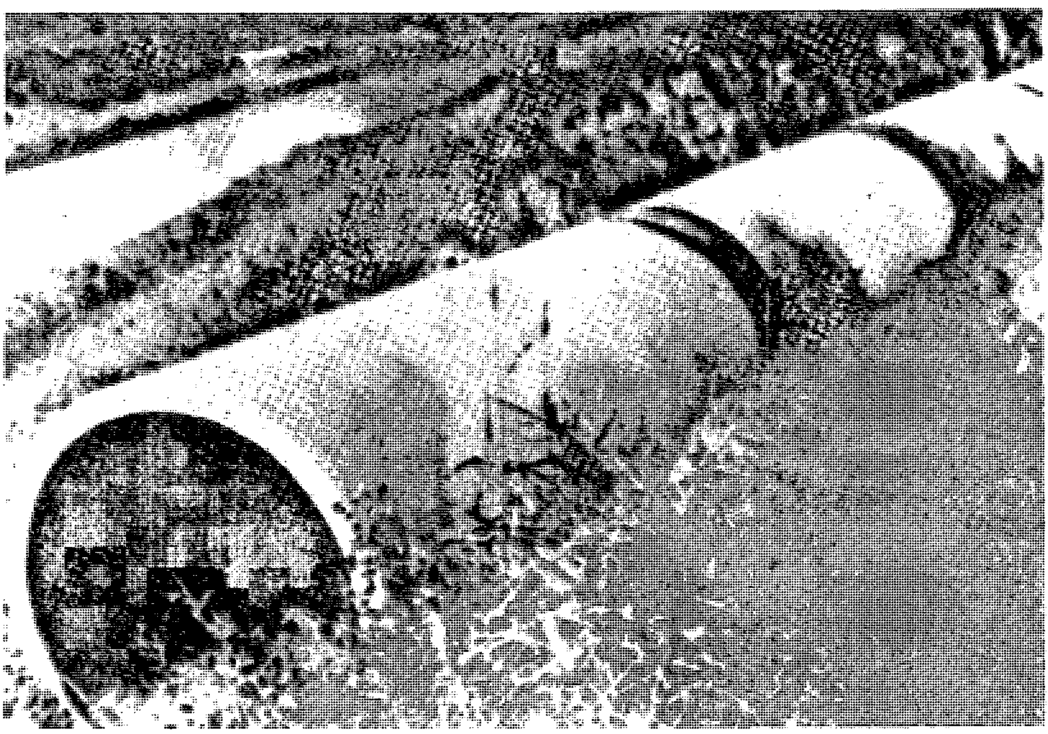

Fig. 19 : Waste water piping of spun concrete pipes with resin.

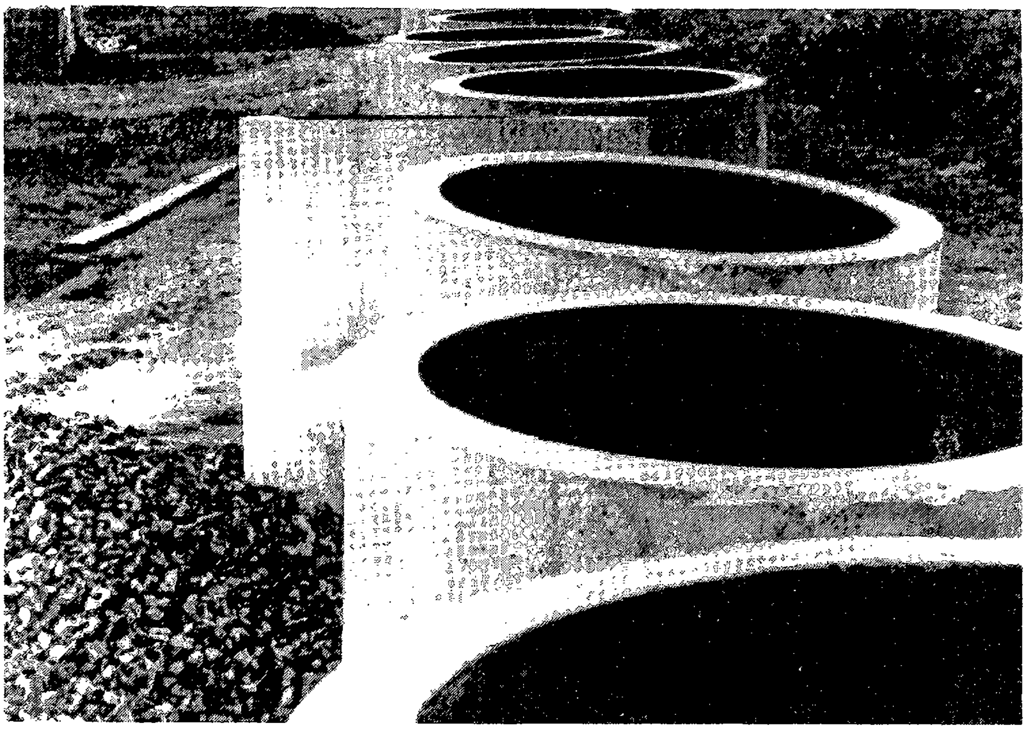

FIG. 20 : Dia. 180 cm reinforced concrete pipes with resin concrete cores.

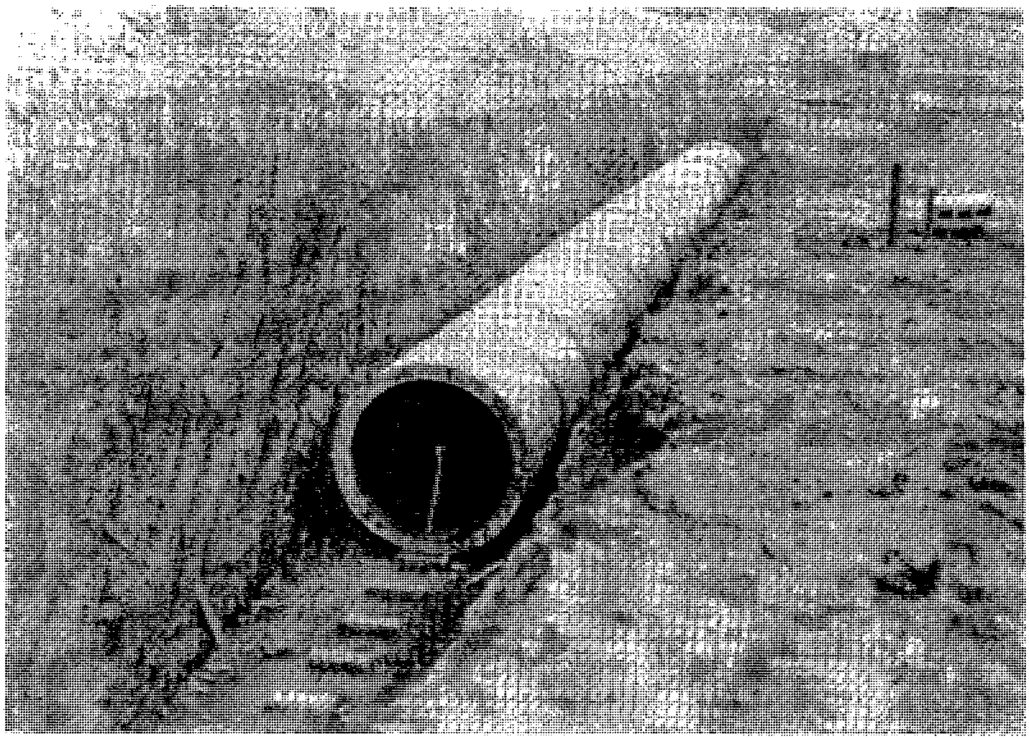

Fig. 21 : Sewer of R.C. pipes shown in Fig. 20.

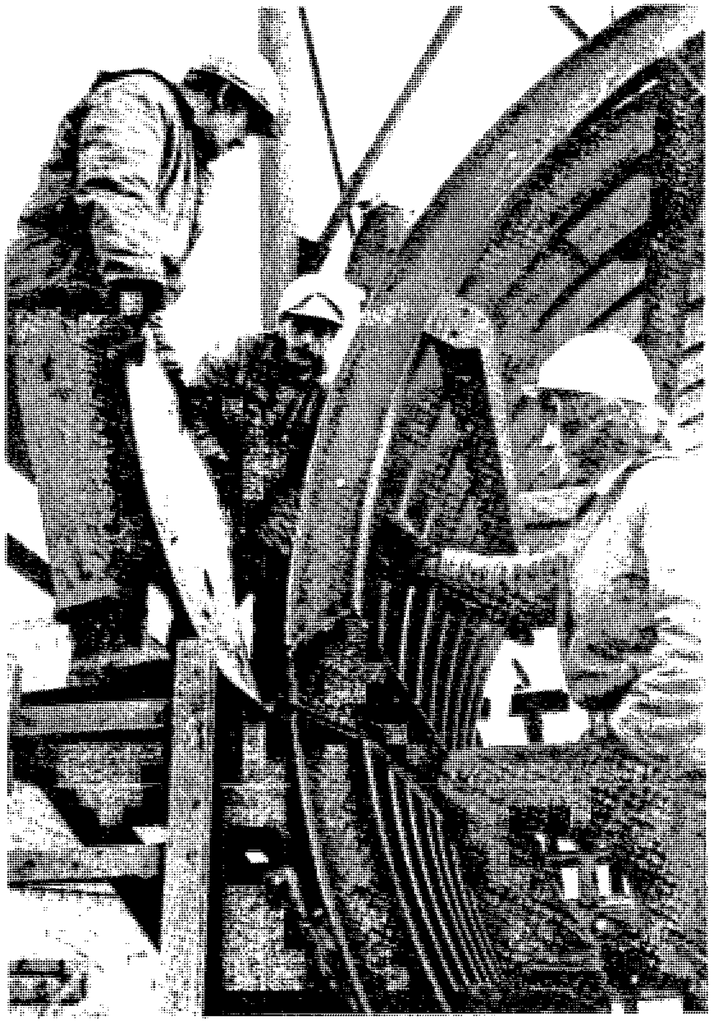

Fig. 25 : Placing of resin concrete segments
on steel shutering cages.

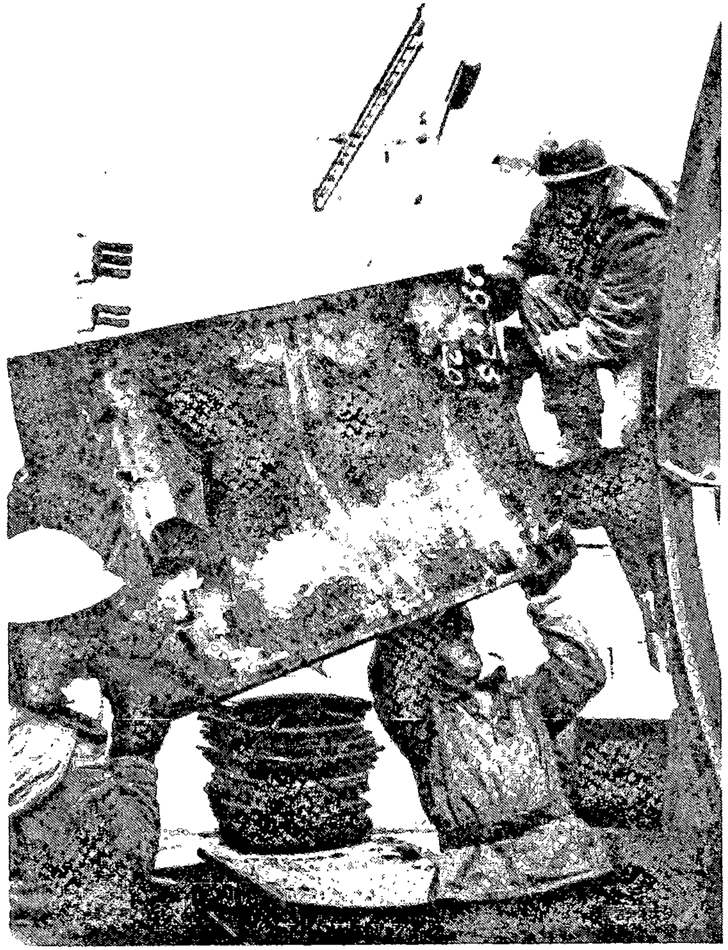

Fig. 24 : Placing of resin concrete segments
on steel shuttering cages.

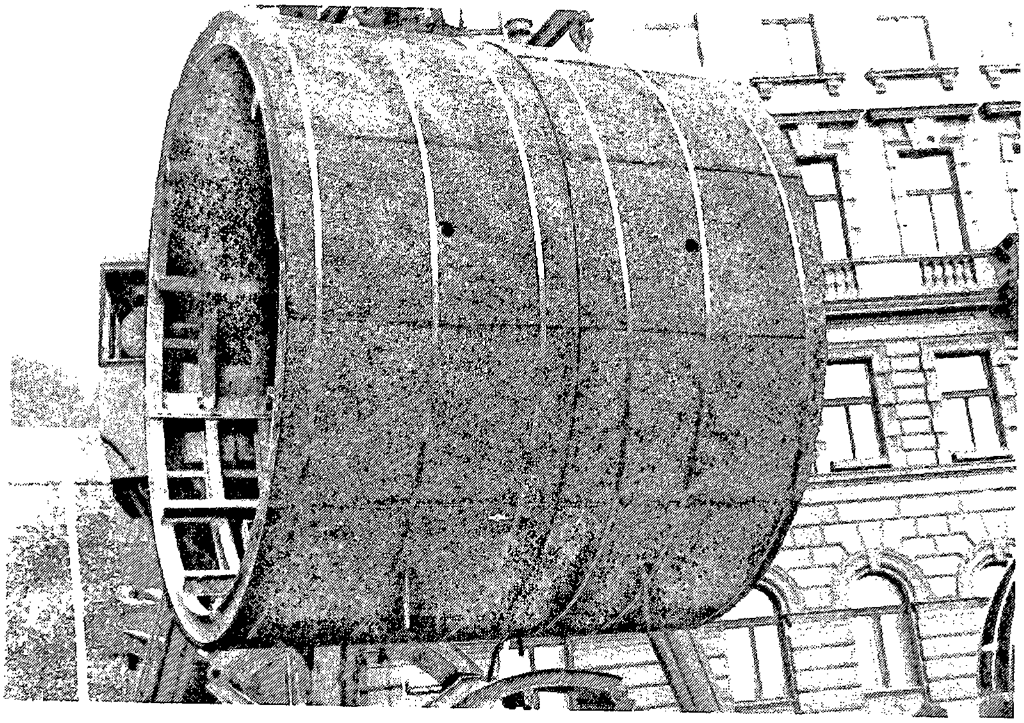

Fig. 26 : Placing of resin concrete segments on steel shuttering cages.

Fig. 27 : Temporary joint sealing with soft rubber preformed inserts.

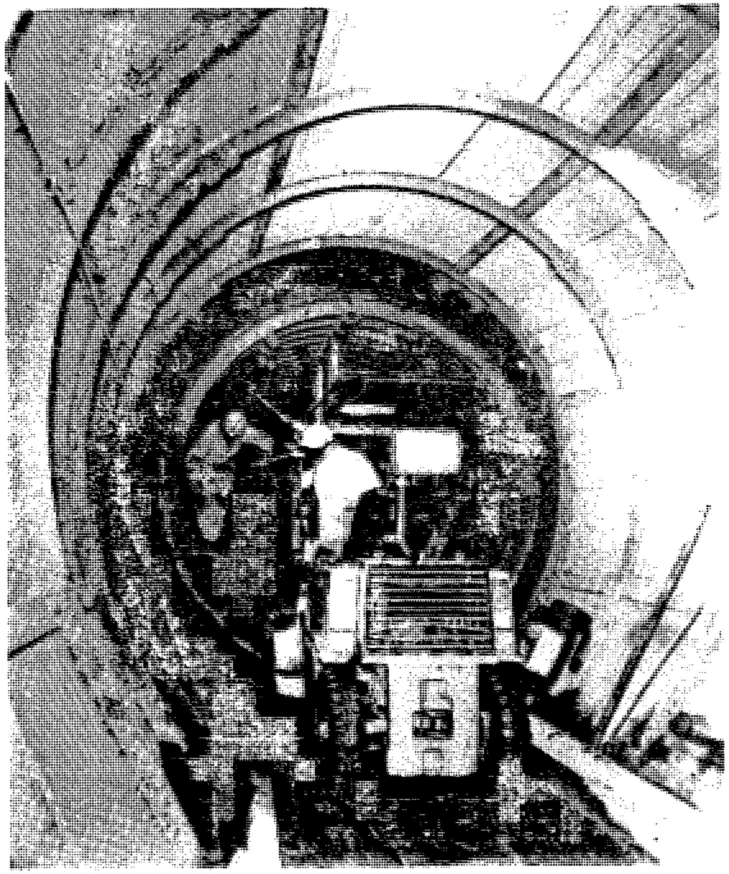

Fig. 29 : Placing the cages in the tunnels.

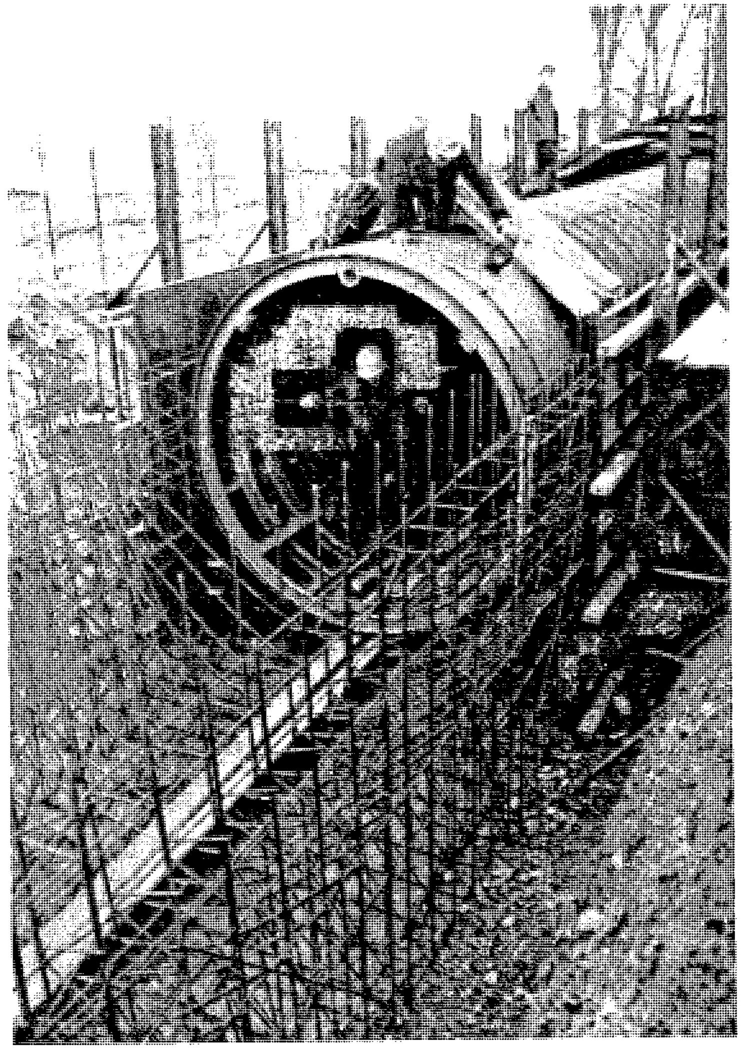

Fig. 28 : Placing clad shuttering cages into trenches.

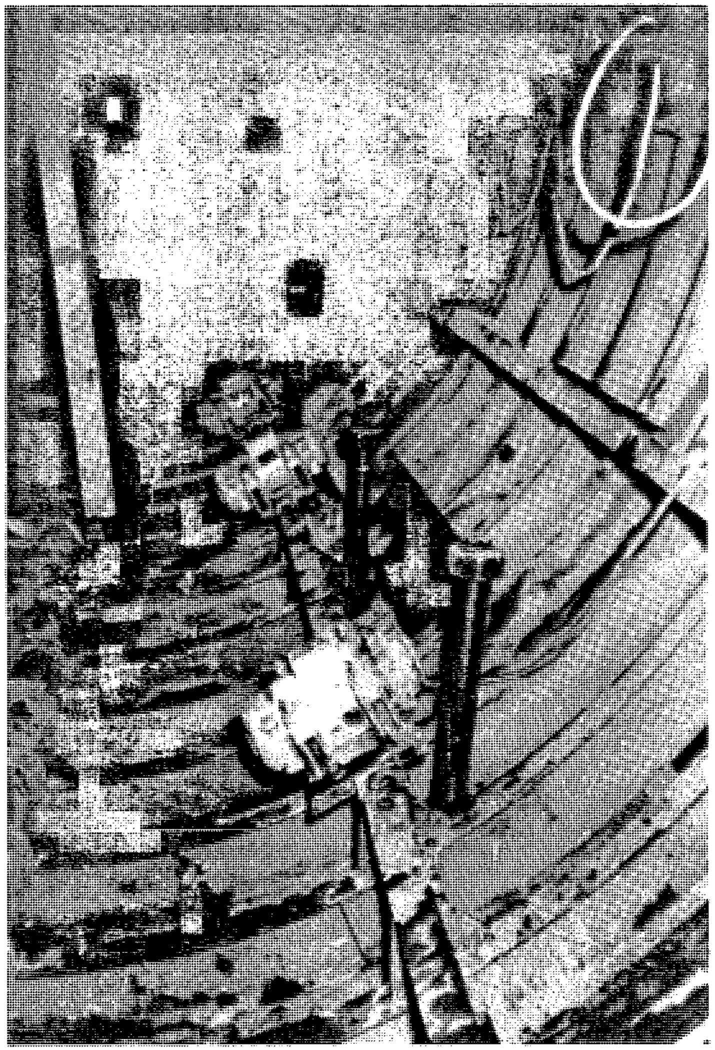

Fig. 31 : Mounting of the cages on adjustement bolts and fastening of vibrators.

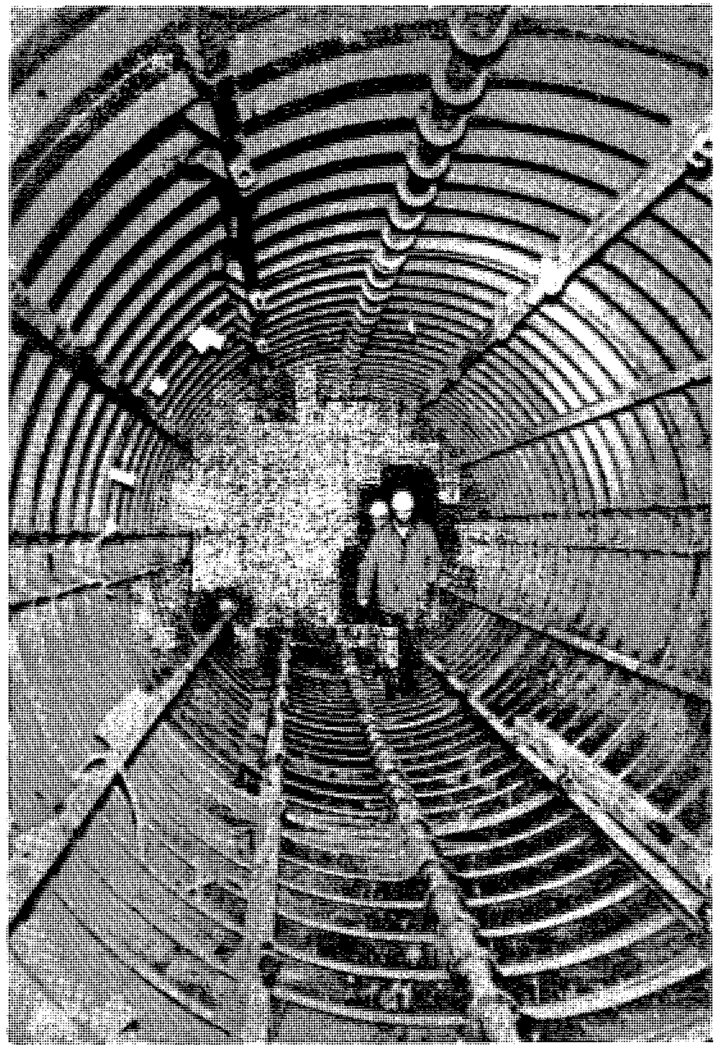

Fig. 30 : A row of placed and connected cages.

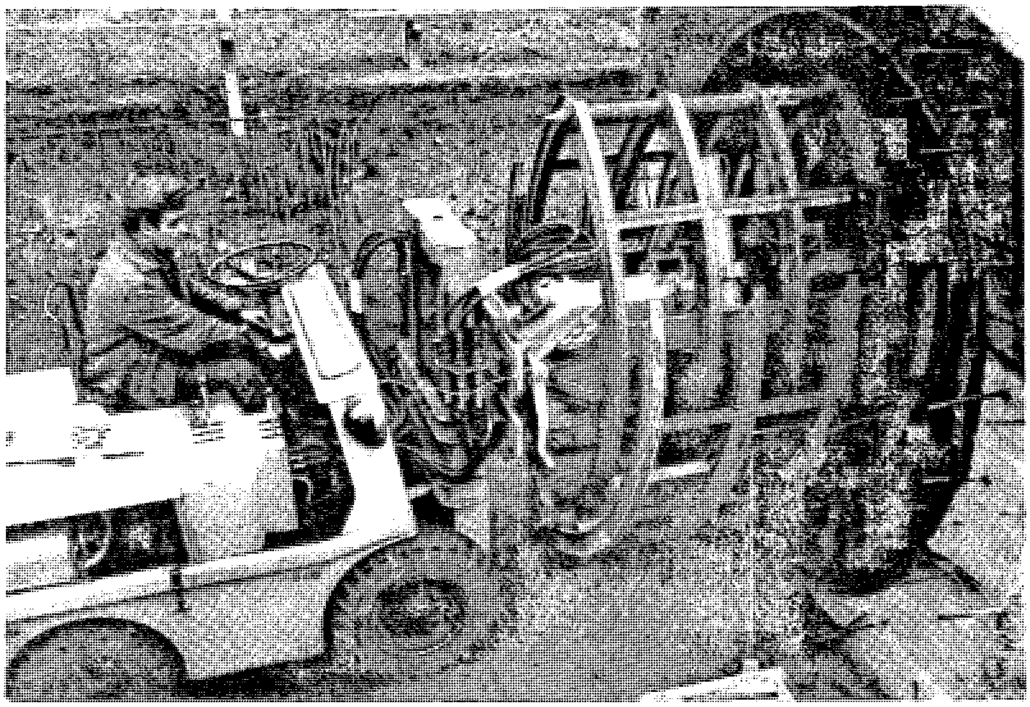

Fig. 32 : Removal of folded steel cages from the completed sewer.

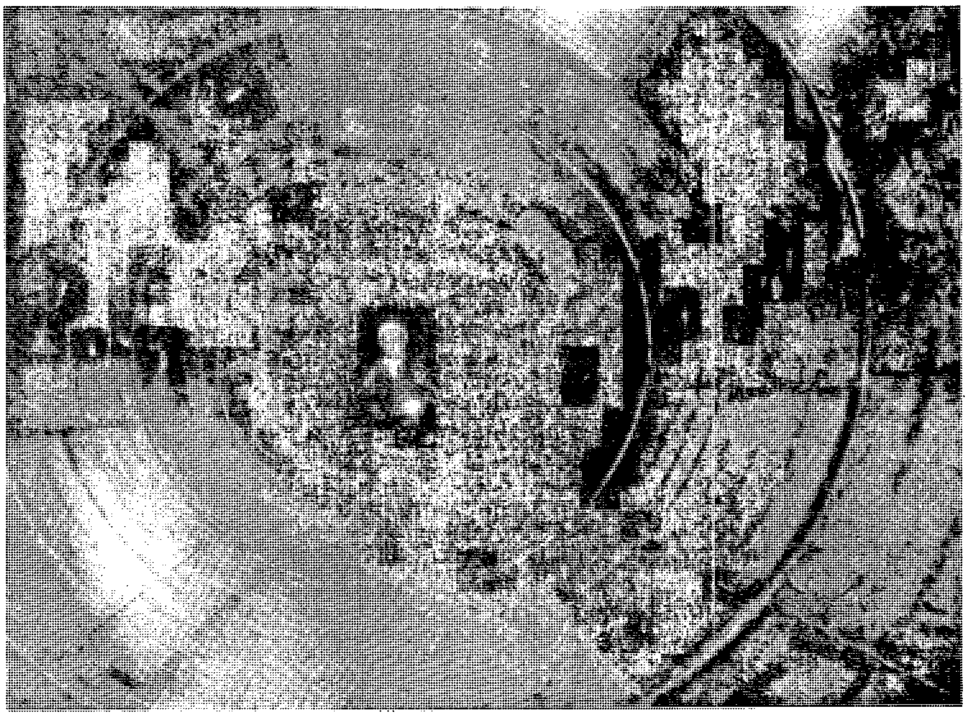

Fig. 33 : Completed sewer.