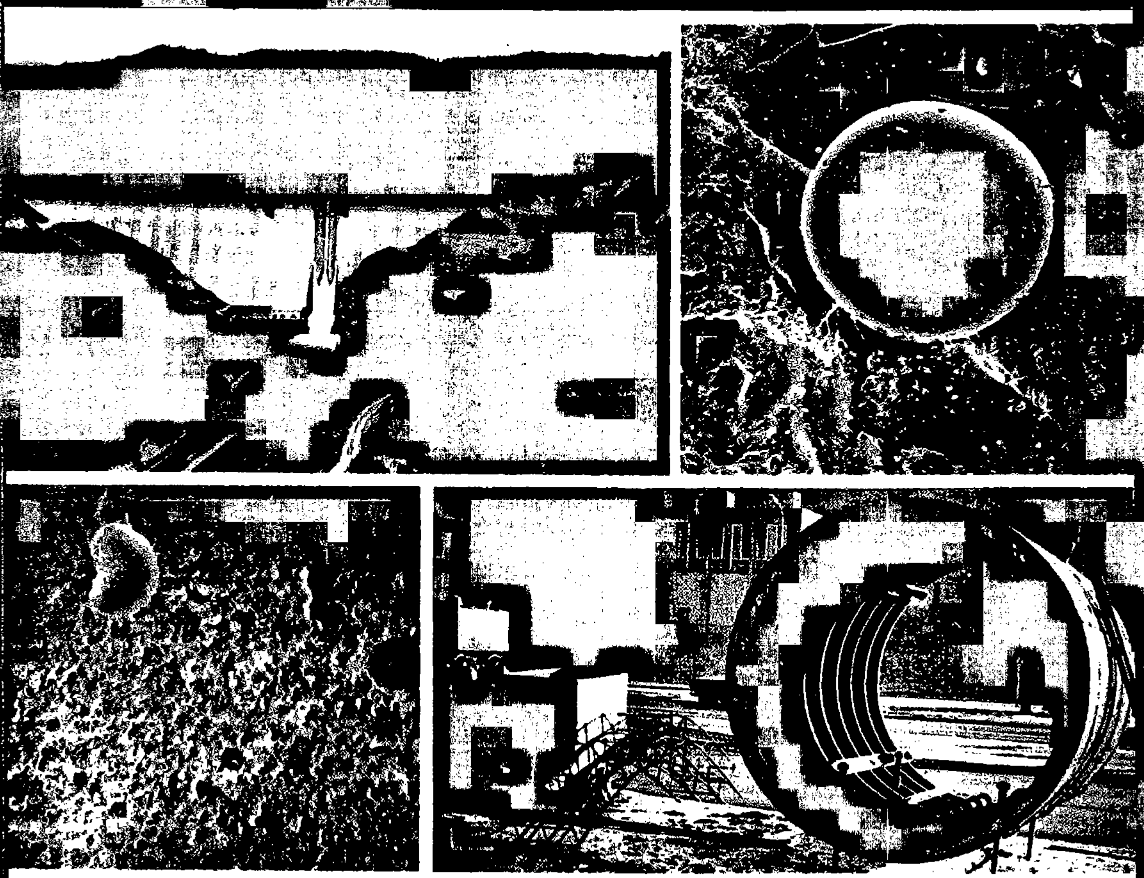
POLYMERS IN CONCRETE

International Symposium



Publication SP-58

SP 58-4

Furane Resin Concrete and Its Application to Large Diameter Sewer Pipes

By Richard A. Bareš

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

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

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

Keywords: furan resins; pipe linings; pipes (tubes); plastics, polymers and resins; resin concrete; sewer pipes.

R.A. Bareš has been closely associated with structural mechanics as well as nonhomogeneous materials for more than two and a half decades, and deeply interested in the utilisation of plastics in building for a number of years. Now Chief Research Scientist of Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences in Prague he is conserned with both research problems and the technical assistance to the building development.

INTRODUCTION

The quota of plastics used in the building industry is increasing every year. This trend is participated in considerably by the structural application of heavily filled plastics to screeds and cast floorings, protective coatings, plastering, etc. and the application of resin concretes or resin mortars. The latter - bonded filler - are granular materials whose filler acts as skeleton structure /aggregate/ and the bonding agent fills entirely or partly the remaining space in contrast to a filled bonding agent /filled plastics/ in which the solid particles are only dispersed /seggregated/ in the bonding agent /matrix/. The reason fot the ever increasing application of these materials does not rest only in the increasing knowledge /also with regard to the mechanics of materials/ and in the decreasing price of plastics due to their increasing production, but also in the increase of the assortment of plastics enabling the satisfaction of the most varied users' requirements.

Resin concretes have been investigated in the Czechoslovak Academy of Sciences since 1959. During this period valuable theoretical as well as practical knowledge and experience has been obtained. Apart from the epoxy or polyesther resin concretes widely used in the U.S.A., lately supplemented with polyurethane concretes, attention in Czechoslovakia was afforded particularly to resin concretes with furane bonding agent, especially the furfurol-furfural copolycondensate. The reason for the use of furane resins was not only their high chemical resistance and durability, but also - and primarily - the fact that the source of the initial materials fot their manufacture, timber and agricultural wastes, is very cheap and continuously reproducible by the natural process.

RESEARCH RESULTS

Properties of Furane Concrete

The optimum properties of furane resin concrete /similarly as the resin concretes with different bonding agents/ are obtained by the mixing of a well granulated filler with the bonding agent in the ratio of 1 : 7 to 1 : 12 by weight /in accordance with the filler particle size, the percentage of its porosity and the character of its surface, intensity of working, ets./

The filler is mixed first with pulverized catalyst /or catalyst on an inert carrier/ of acid reaction; afterwards the furfurol /or partial pre-condensate of this monomer/ is added and finally the furfural as a copolycondensating diluter and accelerator. A slightly elevated temperature /35 - 40°C/ for a period of 3 days ensures complete hardening; after three hours of this temperature, however, more than 50% of the final values are obtained and the further hardening proceeds, with only slight deceleration, at normal temperatures. The filler must be dry, acid-resistant and devoid of any free carbonates. The outer manifestation for polycondensation is a change of colour from light brown to black. Furane resin concrete cannot be prepared in any other colour.

The change of the density of furane resin concrete in accordance with its composition, as compared with epoxy resin and polyesther resin concretes, is illustrated in Fig. 1. The maximum relative density of all resin concretes is attained, if the bonding agent represents approximately 0.3 of the volume of the solids /filler/. Beyond this maximum the porosity begins to increase rapidly /see Fig. 2/.

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

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

For long-term structural application small creep and long term strength are of primary importance. Fig. 7 shows the changes of flexural tensile strength with the lenght of period of load application: long term strength does not exceed 50% of the short term one /curve A/. At the same the short term strength /curve B/ does not change with tiem /no self-induced ageing occurs/. However, the creep is reduced to an acceptable magnitude only for the stresses inferior to 30% of the 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 compariosn of these working diagrams and Poisson's rations the three resin concrete is shown in Fig. 8; Fig. 9 illustrates the changes of ultimate strain due to the changes of the bonding agend: filler ratio /on the same scale as in. Fig. 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 Fig. 10 and 11.

The adhesion of furane resin concrete to cement concret /or vice versa/ is lower than in the case of epoxy resin or polyesther resin concrete, and attains maximally 5 kpf/cm^2 in tension. Hoever, 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 the bond strength of the order of 10 - 25 kpf/cm^2 is no practical problem.

Furane resin concrete has good resistance to strong acids and lyes /unless they have an oxidation effect/, alyphatic carbohydrates and a number of other agents, its universality in this respect making it superior to all other resin concretes bujected to tests.

Generalization

The generalization of test results proves the justification of the hypothesis of different physical behaviour of materials of this type /non-homogeneous materials with very different properties of solid phases/ according to the type of their porosity as well as the necessity of investigating them in three separate regions: in the first region with discontinuous /closed/ porosity, in the second region which is an intermediate /transition/ region, and in the third region characterized by continuous /open/ porosity.

The general presentation of some properties of the composite systems under investigation in Fig. 12 illustrates the qualitative change of the properties in the narrow transition /second/ region manifesting itself by the quantitative change of practically all investigated relations: density, strength and modulus of elasticity have their extremes in the second region, the ultimate strain, shrinkage and coefficient of thermal expansion suddenly change their gradients, while the coefficient of moisture expansion, porosity and absorptivity grow in this region from almost zero to their final values in the third region. The properties of the filled bonding agent /filled plastics/ differ substantially from the properties of bonded aggregate /resin concrete/, the disadvantage resting with the former, regardless of the type of bonding agent /in the experiments described in Fig. 8 the boundary between both systems lies between the mix with the bonding agent: filler ratio of 1 : 5 and 1 : 10/. For the majority of building purposes the bonded aggregates are, therefore, more advantageous, notwithstanding their economic advantages due to the lower requirements of the more expensive component /bonding agend/ in the system.

Principles of Mix 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:

- 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 its 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 $d_{max} \doteq 2 - 2.5\ d_{min}$;

- the maximum particle size of the filler should be maximally one third of the minimum thickness of the layer applied;

- before the mixing with the bonding agent the filler must be dry /the moisture content of the filler should not exceed 0.2% ot its weight/;

- river-dredged gravel-sand, clean dug sand and gravel or crushed stone or artifical aggregates /incl. expanded/ can be used as the filler; the type of filler used determines particularly the hardness, toughness, modulus of elasticity, wear resistance, thermally insulating capacity, chemical resistance, etc. of the resin concrete;

- in the capacity of microfiller ground quartz sand, fly-ash, crushed stone powder, non-expanded perlite, micro-asbestos, graphite, cocoanut powder, etc. may be used; apart from the reduction of the porosity of the filler every microfiller affords the system further specific properties;

- the particle size of the microfiller should equal or be inferior to the thickness of the layer 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 reduction 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 thicknesses of particle envelopes are far from explicit /and depend on a number of factors concerning both the bonding agent and the filler/, it is recommended to select the mean particle diameter of the microfiller within the limits of 10 and 50 microns.

Bonding Agent--The basic factor affording the resulting material its characteristic features is, naturally, the type or 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 oncrete/, i. e. the requirements imposed on its various physical properties /adhesion to the filler, relaxation, chemical resistance to UV radiation, ec./.

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 cither microvibration, heating or a combination of both methods, etc. /must be selected;

- solvents may be used in exceptional cases only and only such solvents may be used as become an integral part of the resulting matrix;

- for batching purposes the individual components of the bonding agent must be so prepared as the ensure that their quotas in the overall volume of the bonding agent may exceed 5% of weight; in the opposite case it is not possible to maintain the necessary homogeneity of the bonding agent in 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 its first phase.

APPLICATIONS OF FURANE RESIN CONCRETE

Adewuate mechanical properties, high chemical resistance and durability nad 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 in Czechoslovakia are described further on.

Resin Concrete Pipes /Pipe Cores/

For the removal of heavily aggressive /alternately acid and alkali/ 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. 13/ also dia 135 cm resin concrete pipes with a wall thickness of 4 cm were used in the period of 1963 - 1964. 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. 14/. The pipes were transported to the building site, placed on concrete foundations and clad with concrete. In this operation they served as self-supporting interior shuttering for the freshly placed concrete mix /Fig. 15/. After the joints were filled with furane resin mortar /from inside, after the setting of concrete/ the furane resin concrete core afforded effective and continuous protecion 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 next to cach other, 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 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 removal 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 ware scaled with rubber rings /Fig. 16/. 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. 17/, which were produced as follows. First a resin concrete core of 2 cm wall thickness was cast in a vertical mould /by means of vibration/; after its setting the exterior mould was removed, reinforcement was fixed and the space between the resin conrete core and a new exterior mould /of 18 cm thickness/ was filled with cement concrete /once again in vertical position/. The pipes were placed on concrete foundation blocks with laser control of positon /Fig. 18/. 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 prefabricates segments and their subsequent cladding with concrete was tried. This method proved slightly more advantageous from ehe conomic point of view.

Large - Diameter Sewers Protected with Profabricated Resin Concrete Linings

The greatest extent of application of furane resin concrete effected in Czechoslovakia so far has been its use in the construction of the new main sewer leading from the south to the north of Prague. The sewer which is under construction is scheduled for completion in 1978 when it will serve 562,000 people with a specific run-off of 420 litres per head and day, which will increase to 730 litres per head and day for 840,000 people in the year of 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 rick, 1 km in a tunnel driven in water-logged made-up ground and gravel-sand, and 4 km in an open trench. Apart from that the sewer siphons under tho 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 considered a concrete /or reinforced concrete/ structure protected with a lining of acid-resistant bricks 15 km thick /Fig. 19/, i.e. a system used successfully in Prague sewerage system for the past 70 years, However, 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. 20/.

The alternative enables a continuous conreting of the sewer. Prefabricated steel cages 3 m long /Figs. 21, 22, 23/ 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 dia. 200 cm sewer six segments are required, whilw twelve segments are used in the case of dia, 320 cm and dia. 360 cm sewer cross sections. The joints betwenn the segments are sealed with temporary rubber inserts /Fig. 24/. The whole assembly is secured with wire.

The shuttering cages with resin concrete sewer lining are placed by the cranc /Fig. 25/, if the sewer is concreted in an open trench. In tunnels they are transported on bogies /Fig. 26/. The cages are fastened to the preceding cage by two pins /Fig. 27/. After placing they are set on four adjustment screws /Fig. 23/ 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 the 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 penumatic surface vibrators mounted on the frames of the shuttering cages. The concrete is thus compacted by means of the vibrations of the resin concrete lining /Fig. 28/.

The shuttering cages are so designed as to fold on a special transport car after the completion of concrete compaction /Fig. 29/.

When the concrete has hardened, the rubber inserts are removed from the joints and the joints are sealed with of the resin concrete pipe /Fig. 30/.

To ensure good bond between cement concrete and resin concrete /in excess of 10 kpf/cm^2/ the rear /external/ face of the segments is provited with stone grit pressed into the not entirely hardened resin concrete during the production of the segments.

In tunnels this method ensured an output of as many as 193 m of sewer per month. In a trench a maximum output of 110 m per month was achieved, since - with regard to the uplift of fresh concrete - the whole sewer cross section had to be concreted in three layers. In comparison with the originally considered traditional method the construction was accelerated, on the average, 3 times in the tunnels and 6 times in the 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 duw to the introduction 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 is lower by several per cent, as a result of a lower volume of enveloping concrete and a smaller volume of carthworks required. /Fig. 19 and 20/.

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

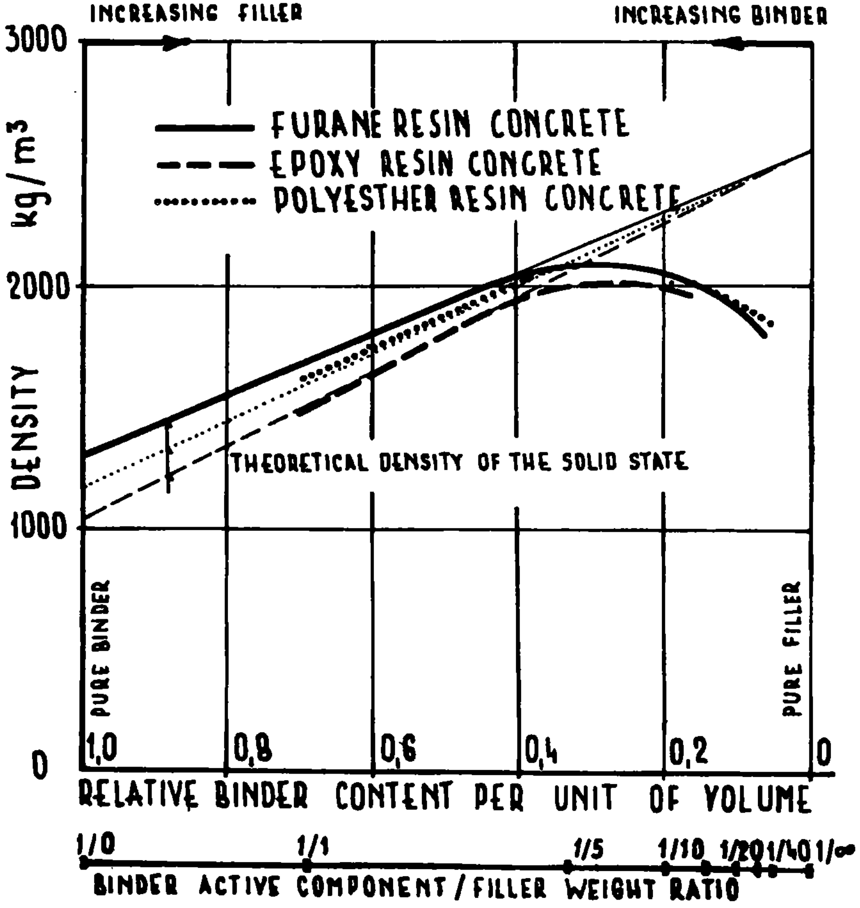


Fig. 1--Density of resin concretes plotted against concrete mix composition

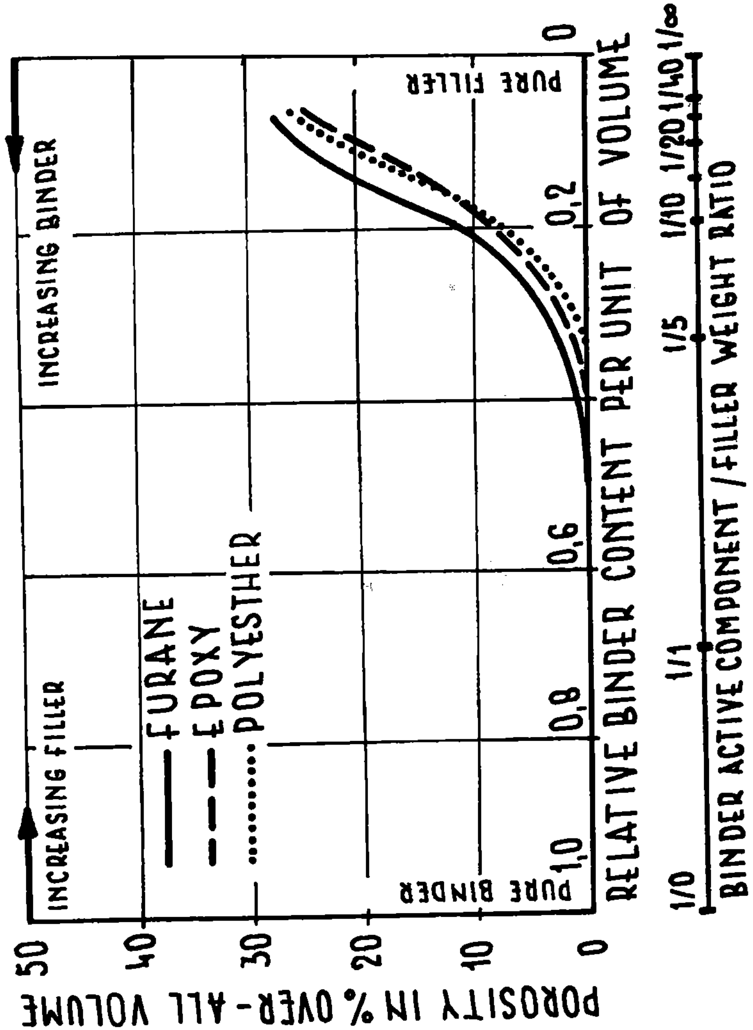


Fig. 2--Porosity of resin concretes plotted against mix composition

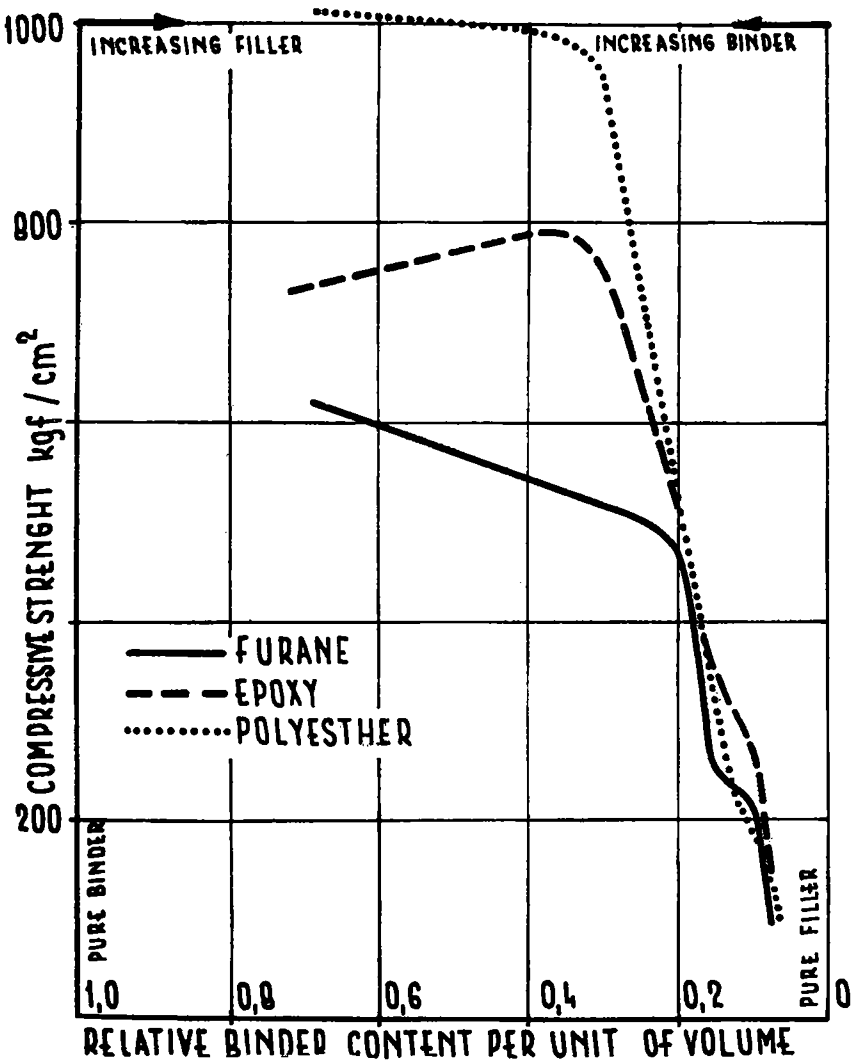


Fig. 3--Compressive strength of resin concretes plotted against mix composition

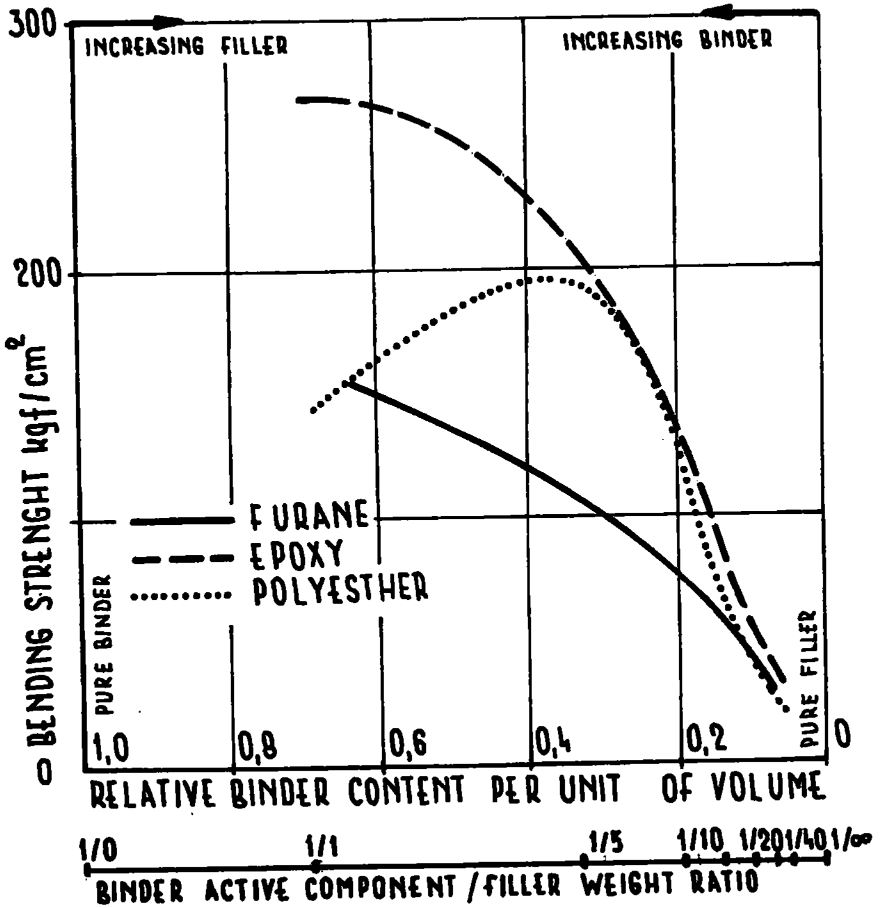


Fig. 4--Flexural tensile strength of resin concretes plotted against mix composition

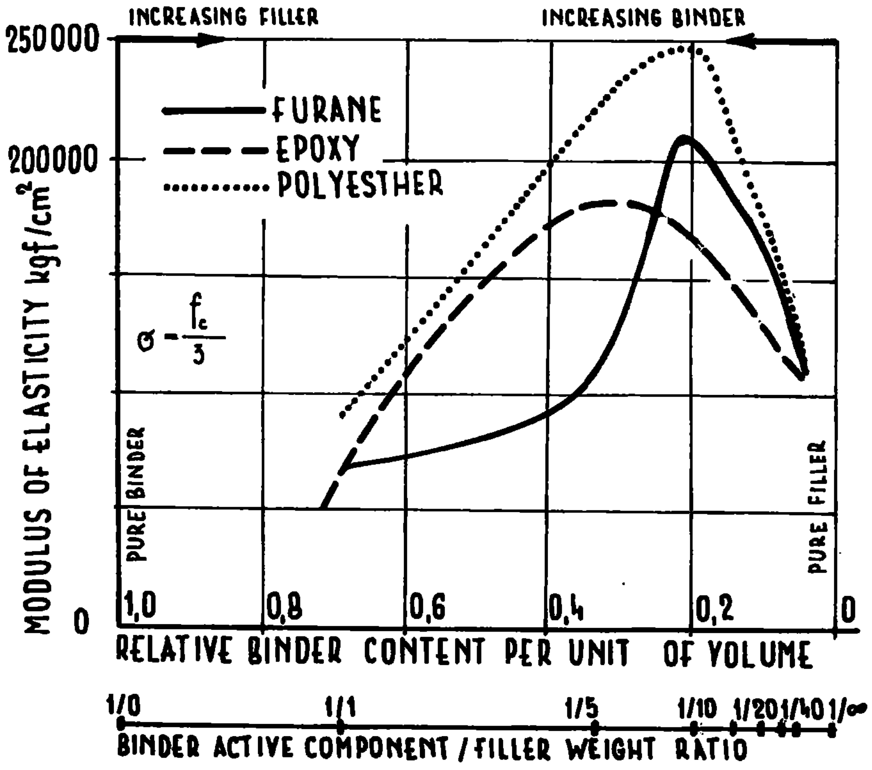


Fig. 5--Modulus of elasticity of resin concretes plotted against mix composition (for the stress of one-third strength)

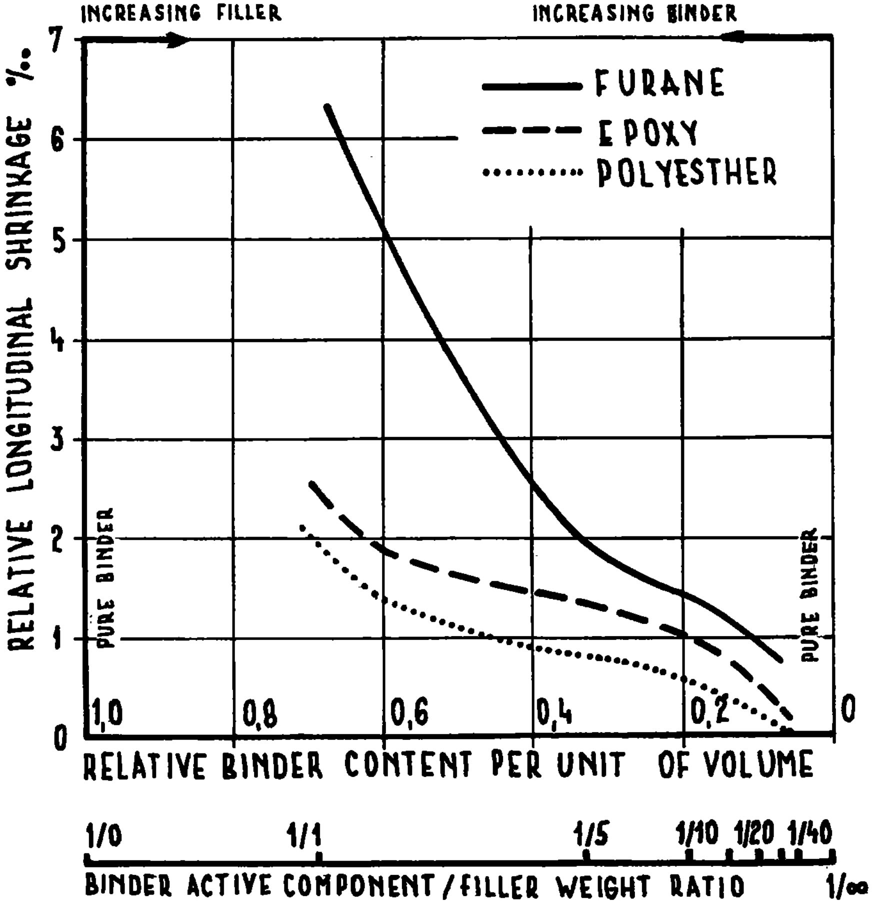


Fig. 6a--Coefficient of temperature expansion of resin concretes plotted against mix composition

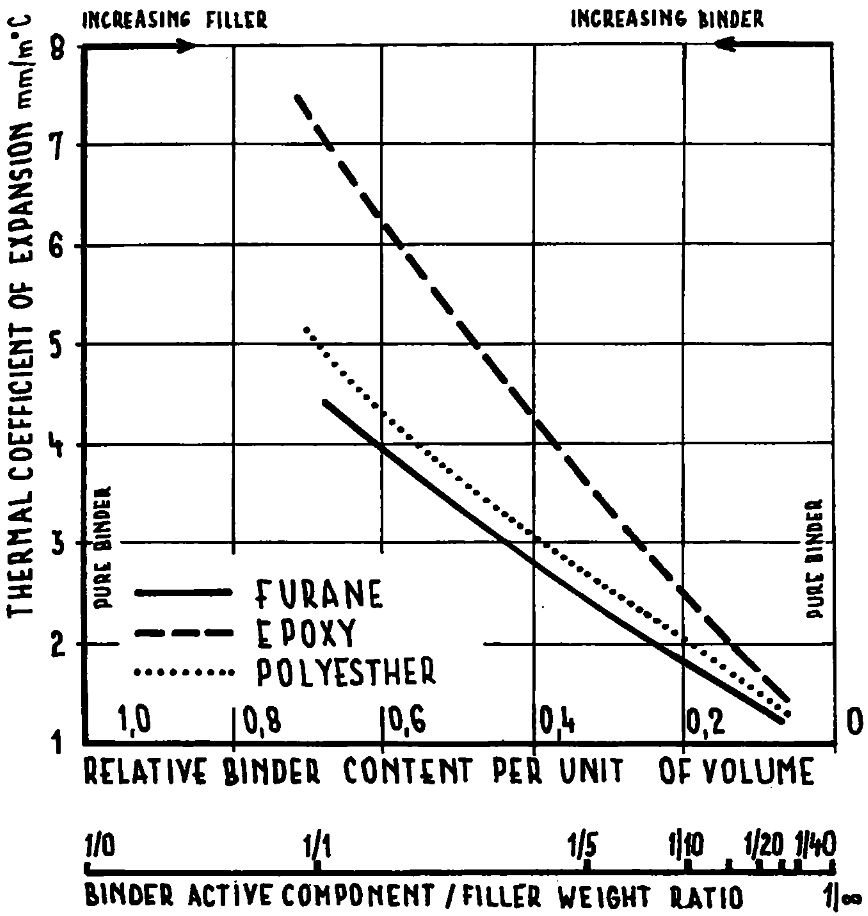


Fig. 6b--Linear shrinkage of resin concretes plotted against mix composition

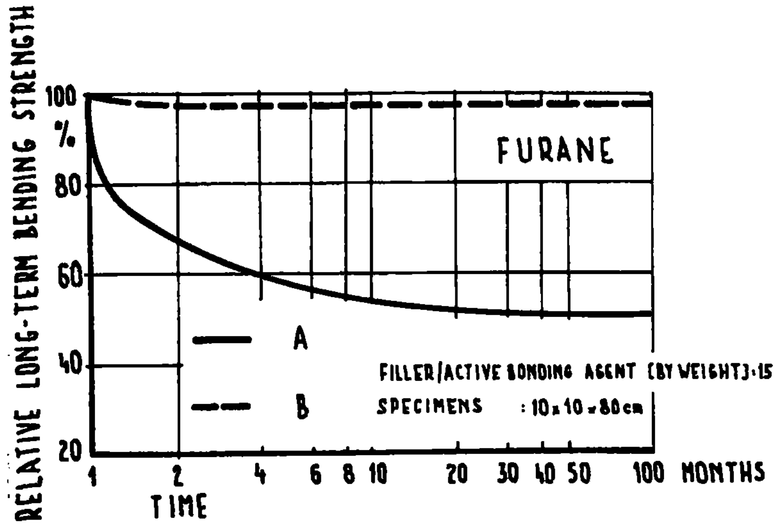


Fig. 7--Relative long-term flexural tensile strength of furane concrete. A--after exposure to mechanical stress; B--unexposed to mechanical stress

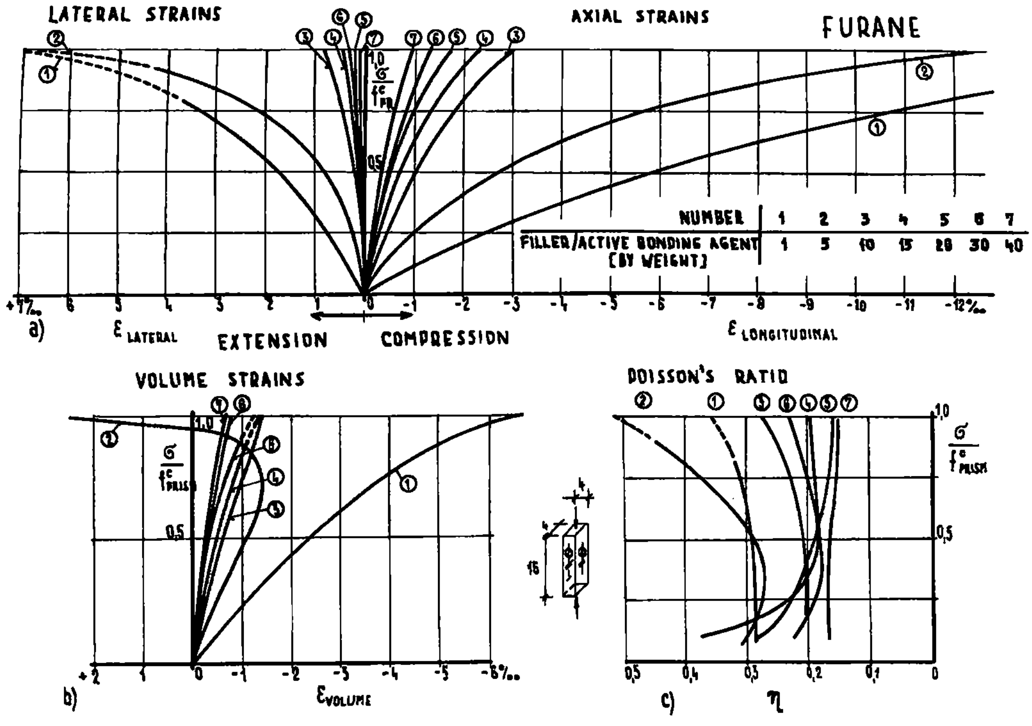


Fig. 8a--Stress-strain diagrams; longitudinal, transverse, and volume deformation diagrams; and Poisson's coefficient of resin concretes in dependence on mix composition

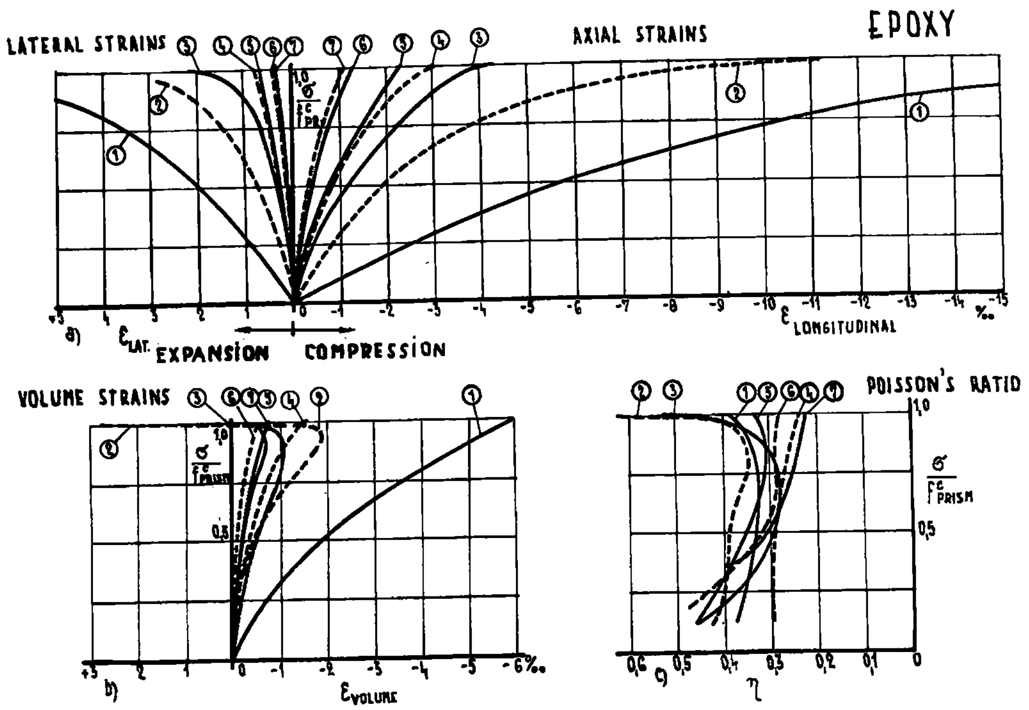


Fig. 8b--Stress-strain diagrams; longitudinal, transverse, and volume deformation diagrams; and Poisson's coefficient of resin concretes in dependence on mix composition

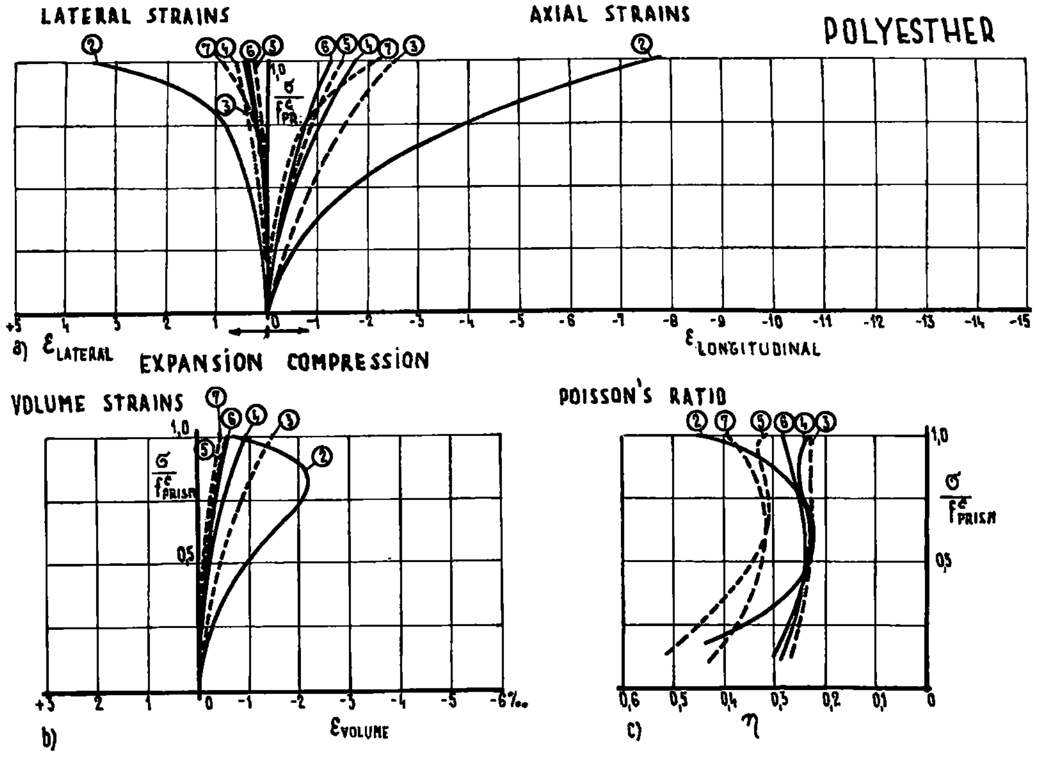


Fig. 8c--Stress-strain diagrams; longitudinal, transverse, and volume deformation diagrams; and Poisson's coefficient of resin concretes in dependence on mix composition

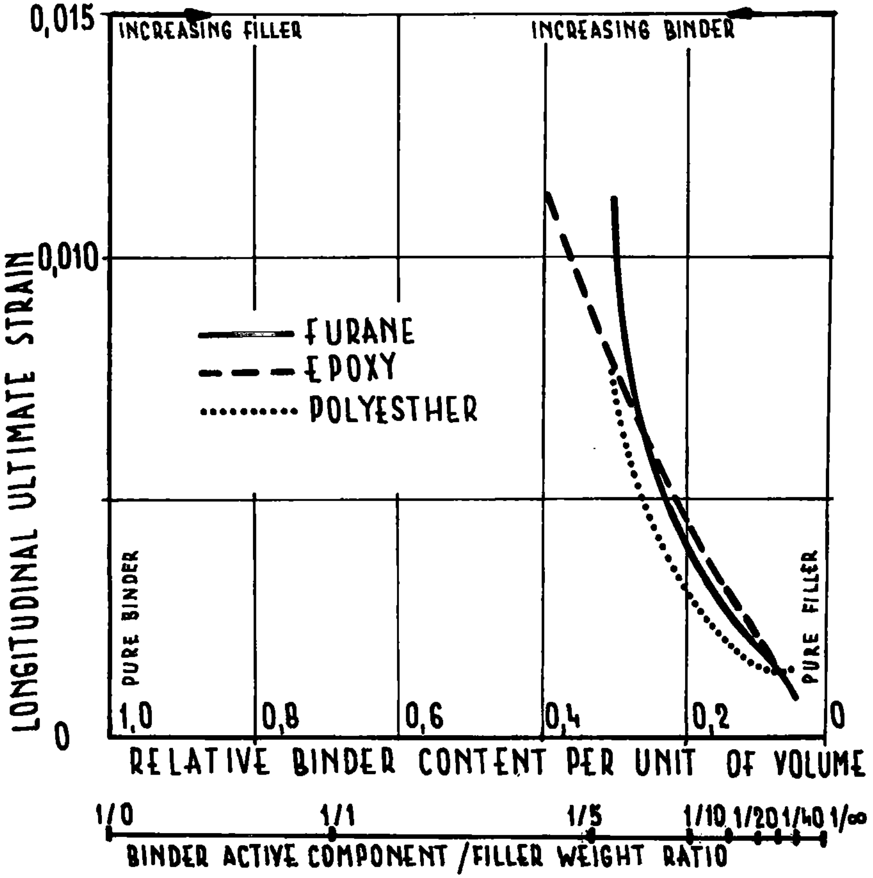


FIG. 9

Fig. 9--Ultimate strain of resin concretes plotted against mix composition

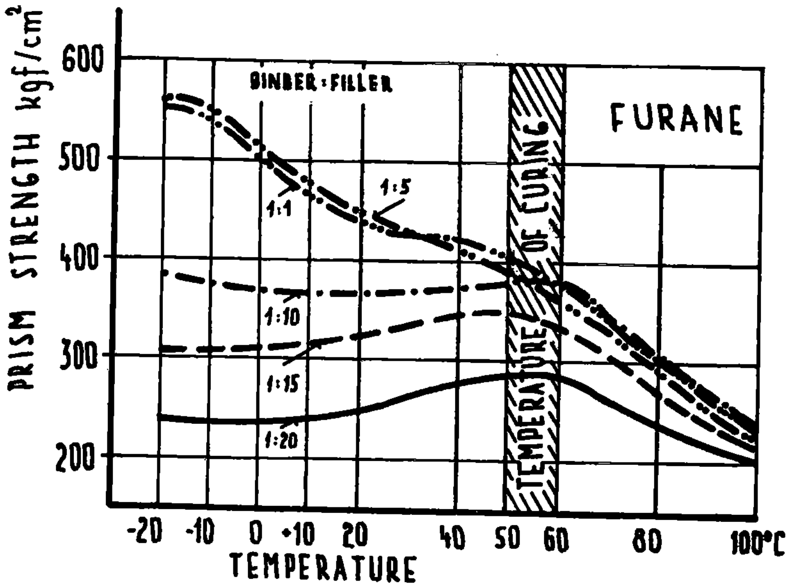
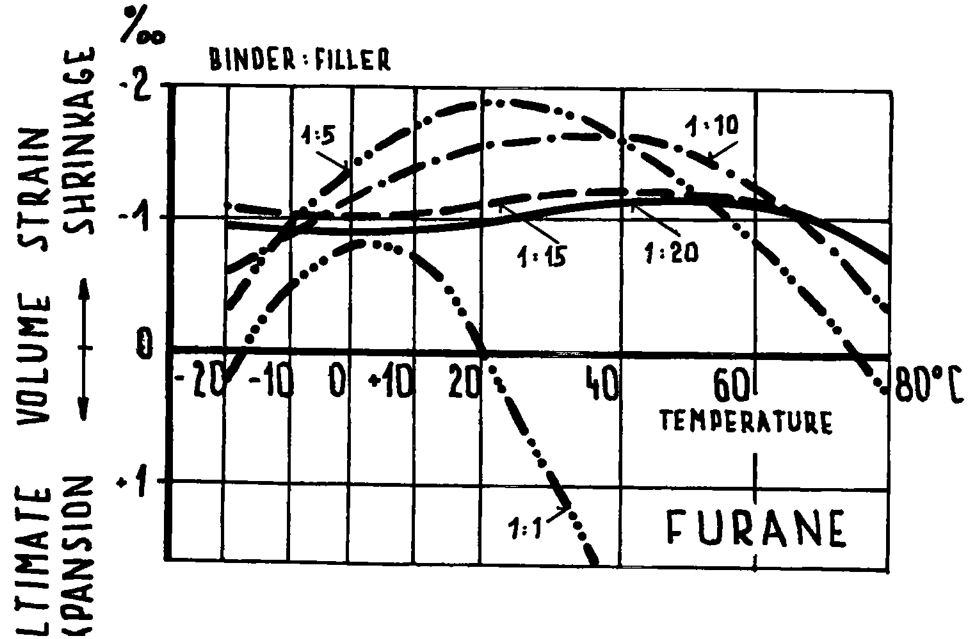


Fig. 10--Effect of temperature on prism strength of furane concrete



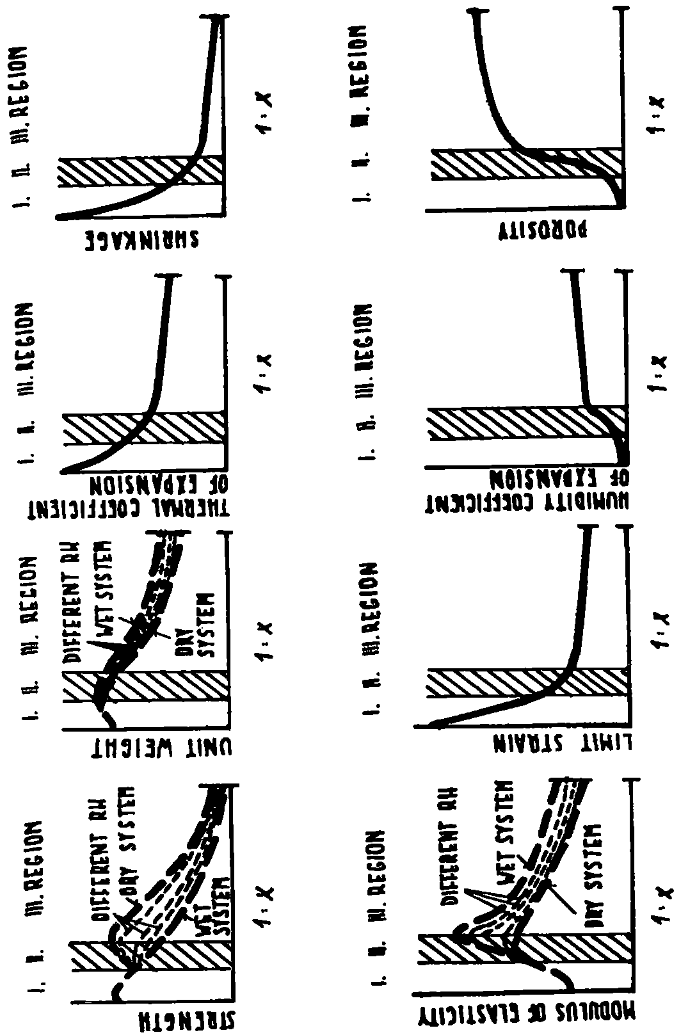


Fig. 12--Schematic representation of some properties of resin concretes as composite systems plotted against mix composition. Region 1--filler binder; Region 2--transition region; Region 3--bonded filler

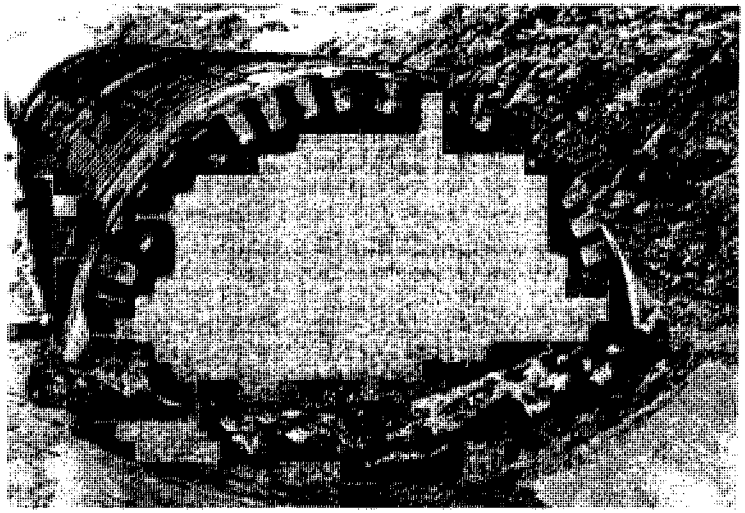
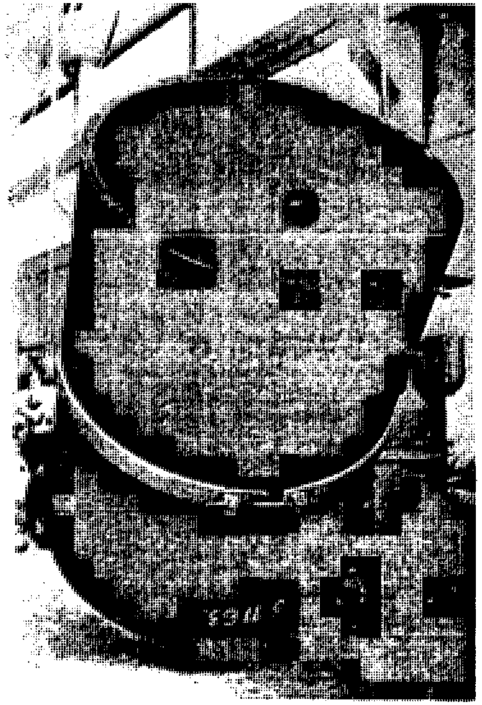


Fig. 13--Sewer of conventional design



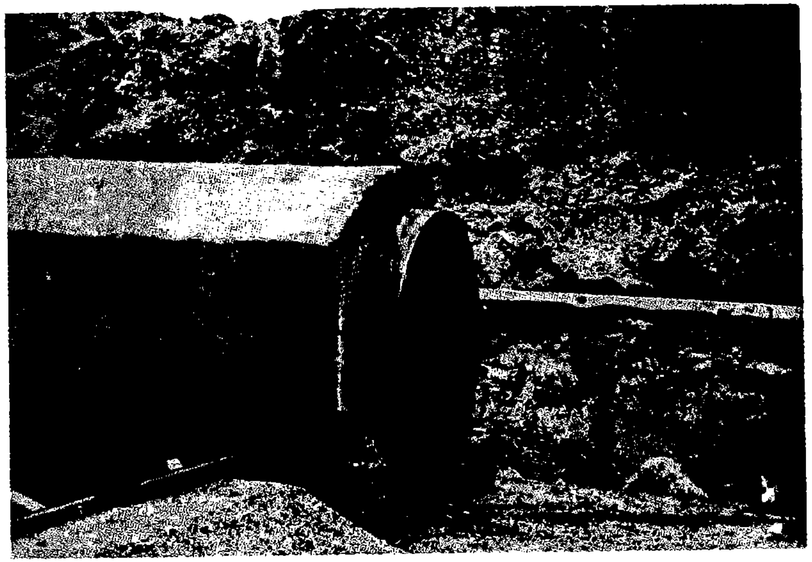


Fig. 15--Waste water piping of self-supporting resin concrete pipe cores

Fig. 16--Waste water piping of spun concrete pipes with resin concrete lining

Fig. 17--180 cm diameter reinforced concrete pipes with resin concrete cores

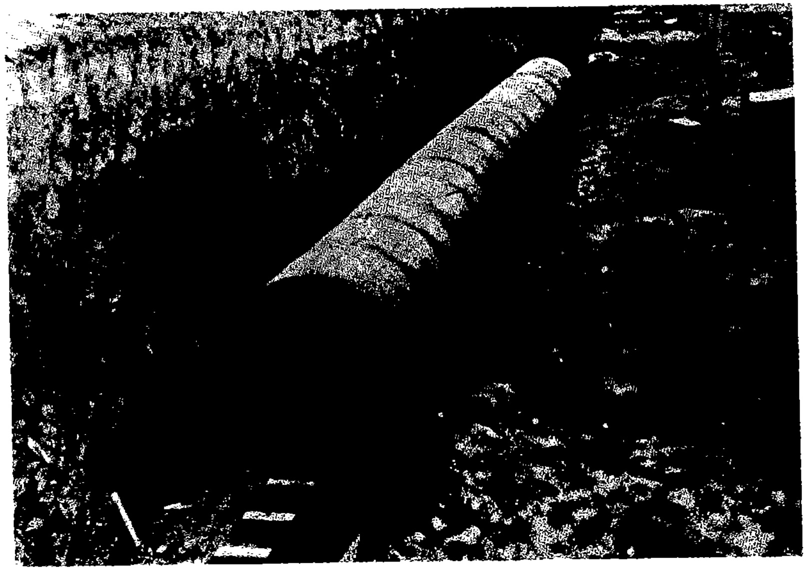


Fig. 18--Sewer of reinforced concrete pipes shown in Fig. 17

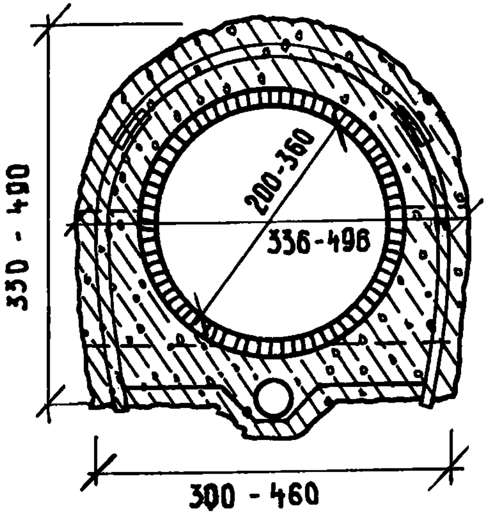


Fig. 19--Originally intended sewer design

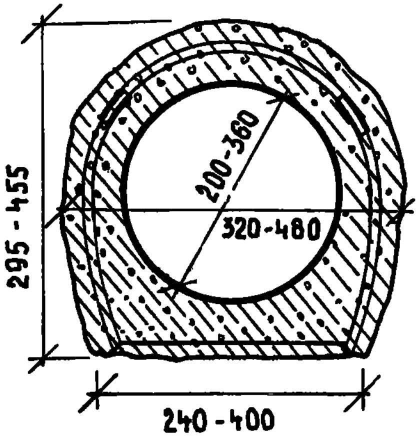
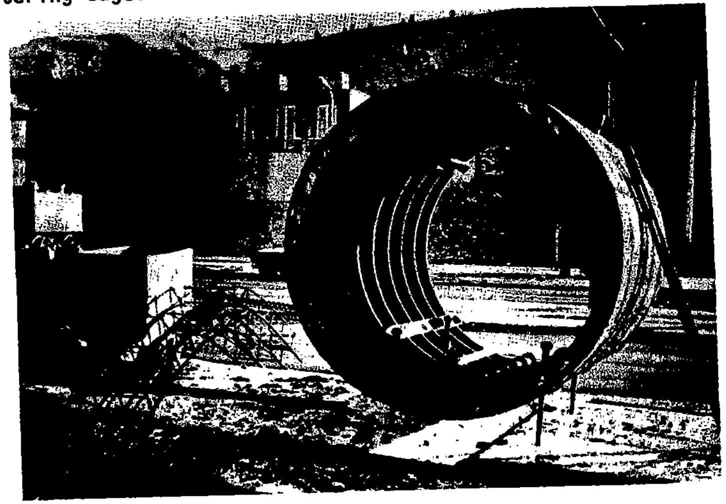


Fig. 20--Sewer design using resin concrete lining

Fig. 21--Placing of resin concrete segments on steel shuttering cages

Fig. 22--Placing of resin concrete segments on steel shuttering cages



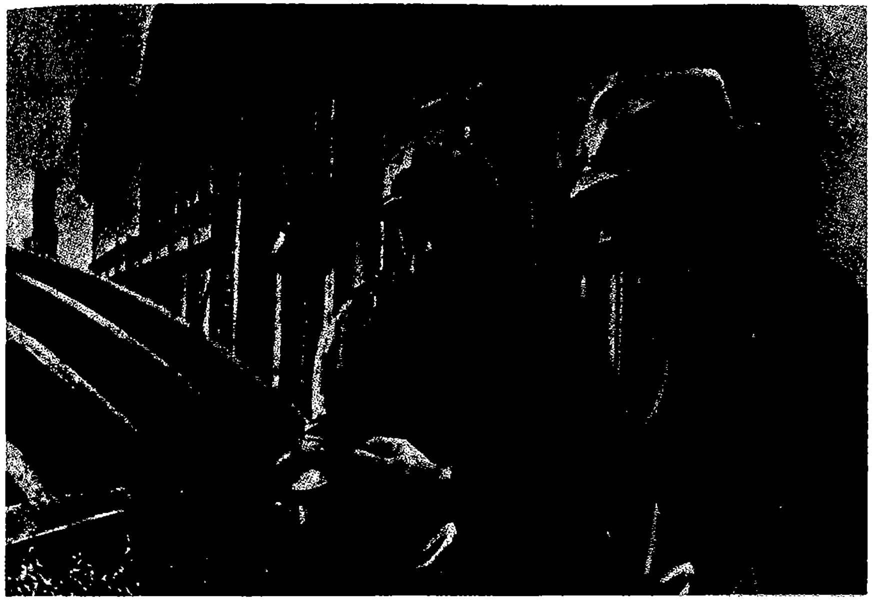
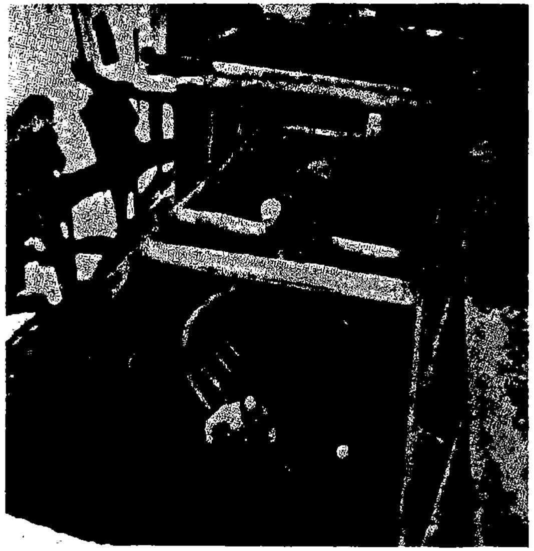


Fig. 24--Temporary joint sealing with soft rubber preformed insert



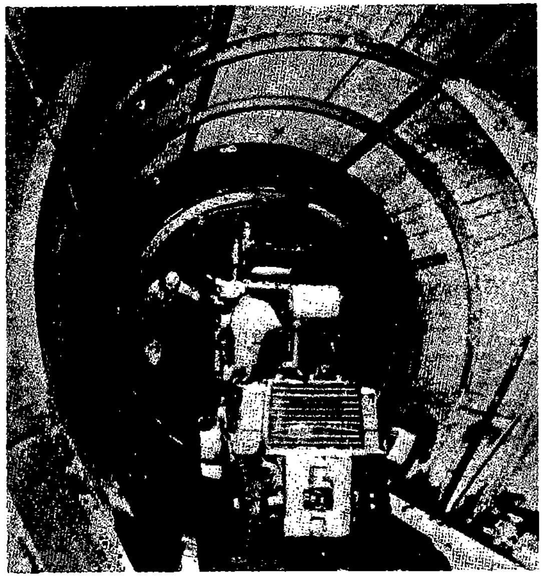


Fig. 26--Placing the cages in the tunnel

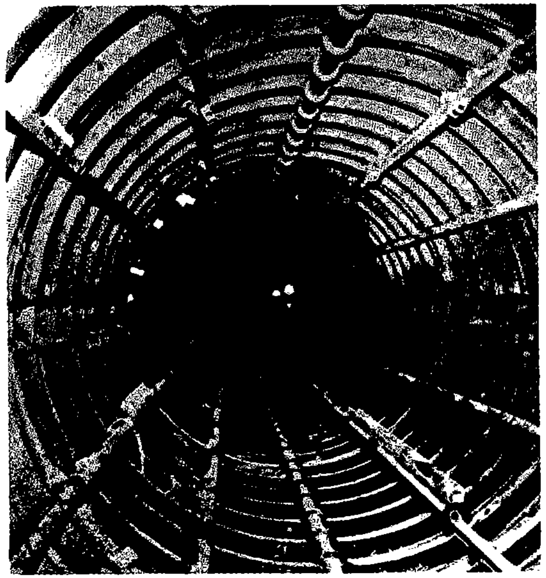


Fig. 28--Mounting of the cages on adjustment bolts and fastening of vibrators

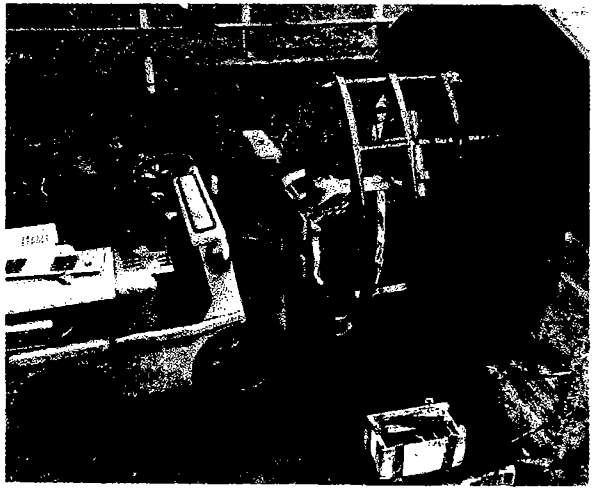


Fig. 29--Removal of folded steel cages from the completed

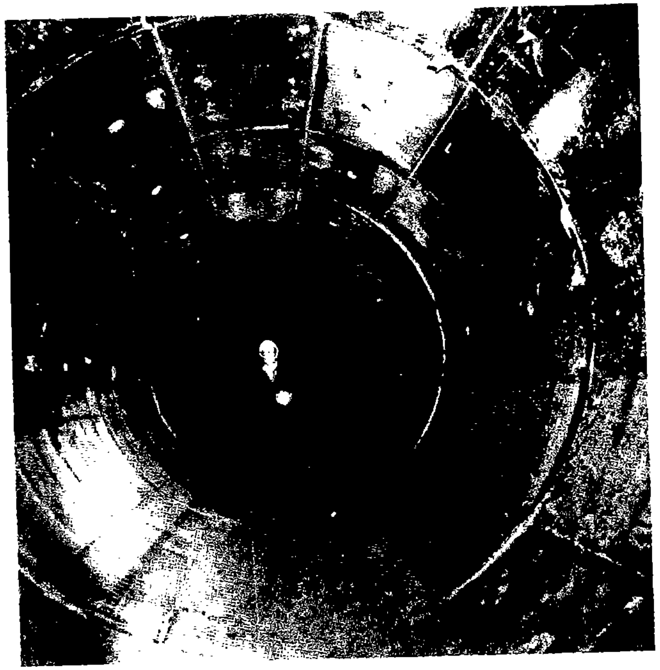


Fig. 30--Completed sewer