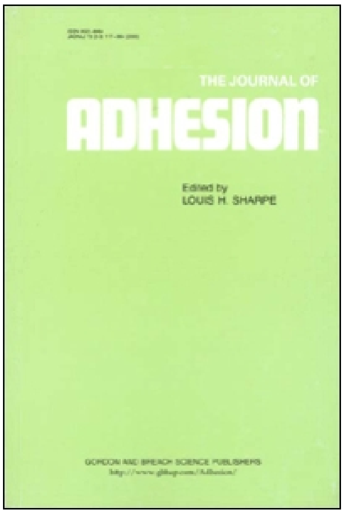

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The Repair of Concrete Structures by Injection With Epoxide Resin†

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The factors to be considered in selecting a material suitable for the repair of concrete structures are discussed. The repair work of the Zeuzier Arch Dam in Switzerland is described including the special problems encountered in this particular application and the supporting experimental programme.

KEY WORDS Application properties; cracked concrete structure; epoxy resin; field repair; mechanical properties; application properties.

INTRODUCTION

Concrete structures may be damaged as a result of inadequate design or poor fabrication such as insufficient provision of expansion joints or cracking due to shrinkage on setting. Existing structures may be damaged by overloading; for example, most bridges built in the early part of this century are now required to bear loads vastly superior to the original design.[1] Other causes of damage are seismic activity, the settlement of foundations and chemical reactions.[2] For many years the problem of cracked concrete was ignored since no effective method of repair was available.[3] However, cracks provide sources of stress concentrations and hence reduction in the strength

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of the structure, they often lead to corrosion in pre-stressed concrete and may give rise to leakage of water and other fluids.

The case which stimulated this work was the Zeuzier Arch Dam in the canton of Valais, Switzerland. This 156m. high Dam which is situated at an altitude of 1778 m. functioned perfectly normally for 21 years. The central pendulum in the Dam regularly recorded deformations in a 30×70 mm. envelope due to thermal changes throughout the year and to the variation in lateral water loads. However, in the autumn of 1978 the pendulums indicated an abnormal movement of the Dam in the upstream direction even though the Dam was almost completely full. The Dam was immediately drained but extensive investigations could only commence in the spring of 1979 due to the climatic conditions. After comprehensive examination of the structure of the Dam it was concluded that the Dam had settled 11 cm., that there was a shortening of the arch chord at the level of the Dam crest of 6 cm. and that an upstream displacement had occurred measuring 11 cm. at the Dam crest. These movements inevitably caused cracking in the Dam structure:

- an opening of the vertical construction joints on the upstream face
- cracks on the downstream face extending locally into the rock abutment
- cracks visible in the inspection galleries essentially towards the abutments.

A schematic diagram of the Dam and the crack network is shown in Figure 1. Extensive investigations as to the causes of the settlement of the Dam were conducted and their results have been published.[4] It was demonstrated that the movements of the Dam were due to a regional settlement caused by the drainage of an exploratory adit for a new motorway tunnel through the Alps. This adit was under construction a distance of 1.5 km. from the Dam and 400 m. lower in altitude than the base of the Dam. It was concluded that a repair of the Dam would be possible if a suitable agent was found. This repair operation was also stimulated by the fact that the Societe de l'Electricite de la Lienne would lose about 6M Sfr. per year by only operating as a "run of river" station rather than accumulating water in summer and generating when demand is high in winter.

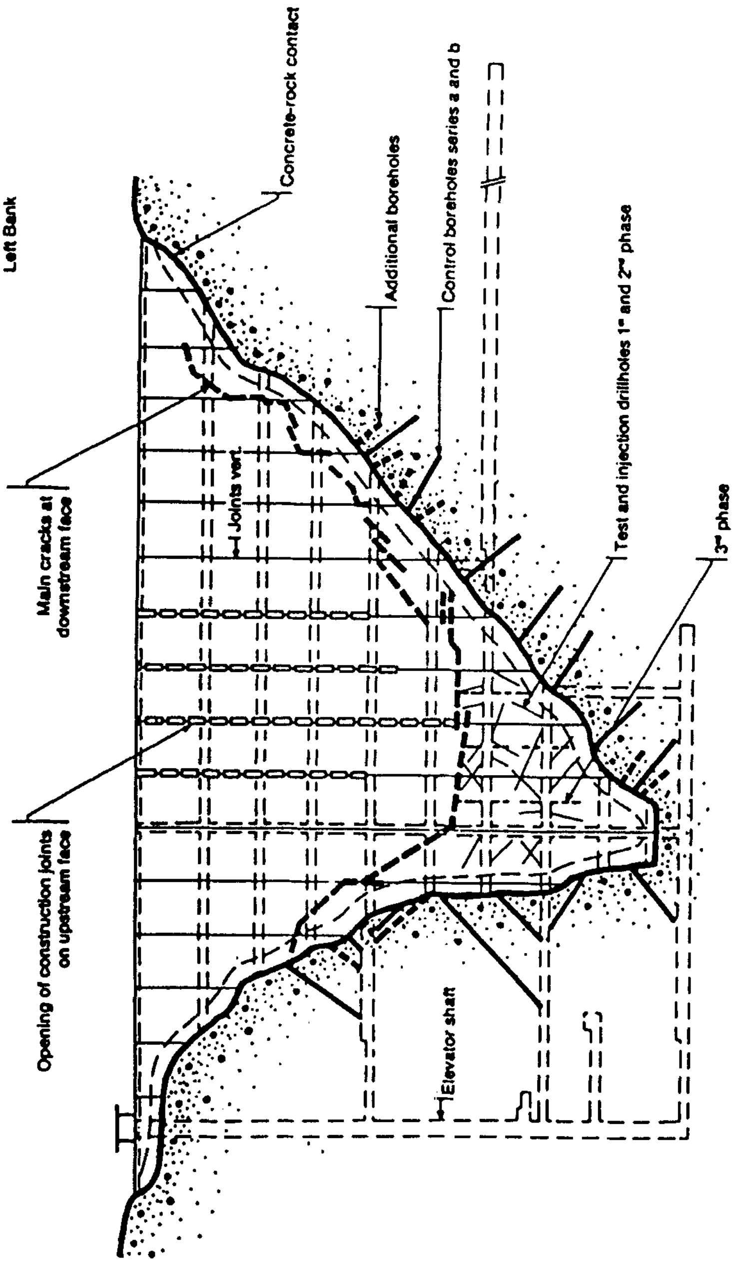


FIGURE 1 Schematic diagram of the Zeuzier Arch Dam showing the main crack network and the test boreholes (after Berchten Ref. 5).

A number of parameters had to be considered in order to select a suitable material for the repair.

- the viscosity must be sufficiently low to penetrate a network of fine cracks, in this case down to 0.2 mm. in thickness and of dimensions up to 5m. by 30m.
- the adhesion to concrete must be good even in wet conditions
- the material must have a high Young's modulus, tensile and compressive strength
- the pot life must be sufficiently long to allow injection before gelation
- the curing reaction must be possible at the working temperature of between 3 to 7°C inside the Dam which results from the altitude of 1778 m.

These requirements restricted the choice to an epoxide resin but since the properties may be considerably varied by the choice of resin and hardener chemistry, the presence of additives such as fillers and diluents, further specification was necessary. The Federation Internationale de la Précontrainte had made certain recommendations for epoxides used in construction.[5] The compressive modulus should be at least 8 GPa, the compressive strength at least 75 MPa after 7 days and the pot life a minimum of 20 minutes. On the basis of these recommendations Suiselectra Consulting Engineers asked for a resin with the following characteristics for the repair of the Zeuzier Dam:

- viscosity at 23°C: 500 mPa s
- minimum cure temperature: 5°C
- modulus of elasticity: 8 GPa
- compressive strength (min.): 60 MPa
- tensile strength (min.): 10 MPa
- bond strength to wet concrete: 3 MPa

The modulus of cured epoxide resins is always in the range of 2.5 to 3.5 GPa depending on their chemical structure. Thus, in order to increase this value it is necessary to incorporate high modulus mineral fillers in the form of particles. As a general rule the higher the volume fraction of filler the higher the modulus, the higher the viscosity of the uncured mixture and the lower the adhesive strength. Thus the quantity incorporated involves a compromise between these parameters. For this type of application typical fillers are silica flour, glass beads and barium sulphate.

MATERIALS

The principal materials used in these tests were Rodur 510 and 520, the resins selected for the repair work of the Zeuzier Dam (produced by Sika SA, Zurich). The two products have differing viscosities and can be mixed to give an intermediate viscosity appropriate to the working temperatures and the dimensions of the cracks.

REPAIR WORK ON SITE

The repair was carried out in several stages; firstly, by injection of the cracks visible on the Dam faces and in the inspection galleries. Secondly, by drilling holes 46 mm. in diameter from the inspection galleries and the Dam faces between each vertical joint perpendicular to the axis of the gallery. In total, 228,000 kg. of resin was injected into the Dam during the repair.

The epoxide resin was supplied in cans ready for mixing. The hardener component was poured directly into the can containing the resin component and the two mixed with a pneumatic tool. This procedure avoids the necessity for accurate weighing on site. The injections were carried out up to maximum pressures of 20 bars. The amount of resin injected decreased with each stage indicating the effectiveness of the treatment. Samples of the same mixes were also poured into $4 \times 4 \times 16$ cm. moulds and allowed to harden. These prisms were then labelled with the date of casting, the resin system and the location within the Dam. In addition, core samples were removed from the structure (diameter 100 mm.) in order to verify the filling of the cracks and to measure the properties of the injected concrete and the adhesion to concrete.

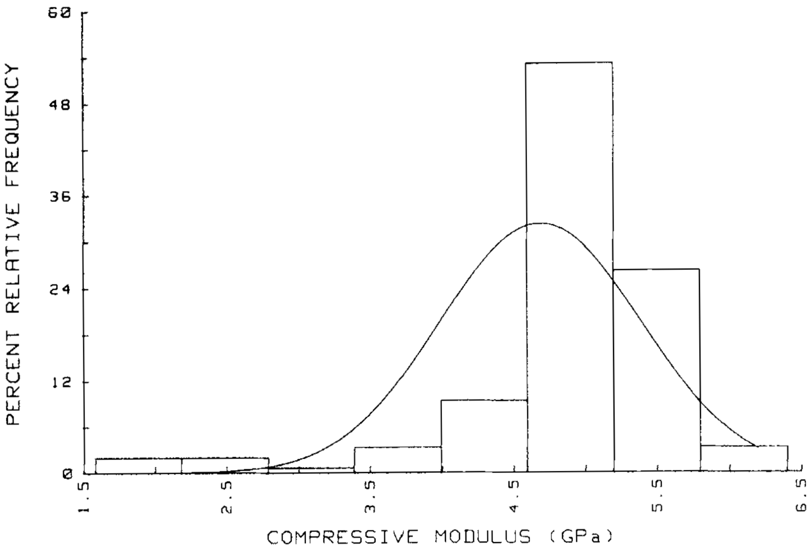
EXPERIMENTAL WORK AND RESULTS

(A) Quality control of the resin injected into the Dam

During the period 1980 to 1983 the prisms cast on site were tested. The density, compressive modulus, compressive and flexural strength were measured. Similar specimens were cast in the Laboratory for comparison. The results are given in Table I which represents data from nearly 300 specimens. It can be noted that over the three-year period there was a distinct improvement in the mechanical properties probably due to the increased experience of the employees. The values are shown in the histograms in Figure 2. In 1982 a series of low values of modulus were noted. This results from incomplete cure either due to inadequate mixing or due to leaving too much time in between the mixing and the casting. The resin component which includes the particulate filler has a density of 2.23 gdm^{-3} and the hardener of 1.02 gdm^{-3} and thus with time the two tend to separate out. One of the principal parameters which must be controlled on site is the homogeneity of the mixture since, if this is assured, the resin has reproducible properties. In

TABLE I
Properties of resin samples cast on site and in the laboratory

Place/ Material	Density $g\,dm^{-3}$	Flexural modulus GPa	Flexural strength MPa	Compressive strength MPa
Site 1980 (510)	—	3.80 ± 0.61	—	54.7 ± 3.4
Site 1980 (510/520)	—	5.33 ± 0.2	—	—
Site 1982 (510)	2.02 ± 0.01	4.93 ± 0.05	35.1 ± 2.2	88.5 ± 1.6
Site 1982 (510/520)	1.88 ± 0.05	3.62 ± 0.4	29.5 ± 1.5	66.8 ± 2.9
Site 1983 (510)	1.97 ± 0.02	5.08 ± 0.5	36.0 ± 0.6	90.4 ± 0.7
Lab. 1981 (510)	1.93 ± 0.02	4.88 ± 1.6	41.9 ± 3.5	97.7 ± 3.6
Lab. 1982 (510)	2.00 ± 0.01	4.69 ± 0.11	50.5 ± 3.0	88.8 ± 2.5
Overall mean	1.97 ± 0.01	4.89 ± 0.06	35.8 ± 0.6	87.8 ± 0.9



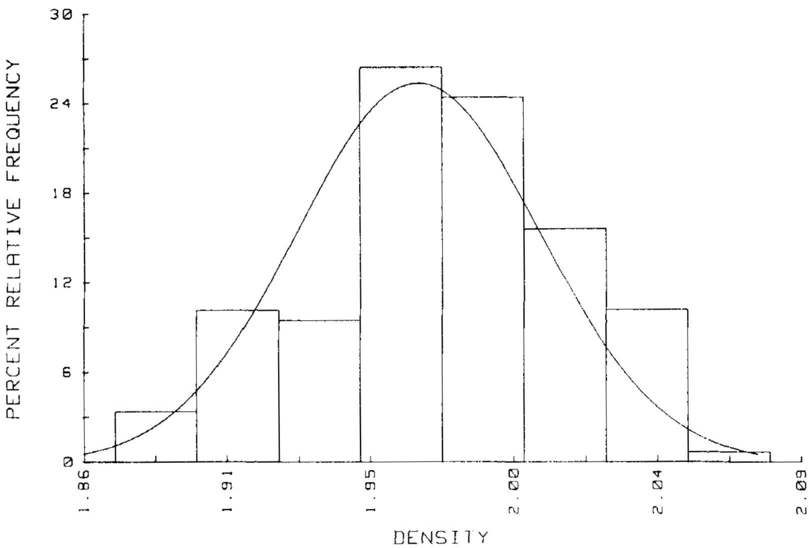
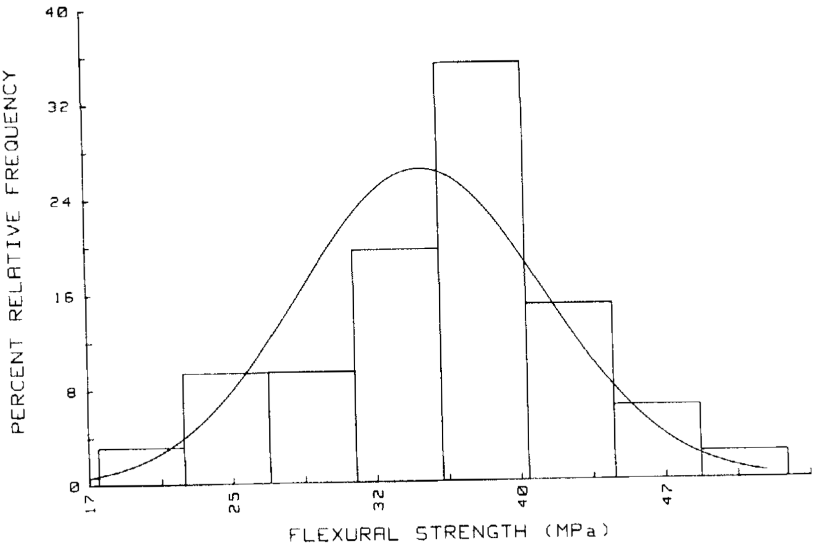


FIGURE 2 Histograms of density, modulus, flexural and compressive strength for resin samples cast on site during the repair.



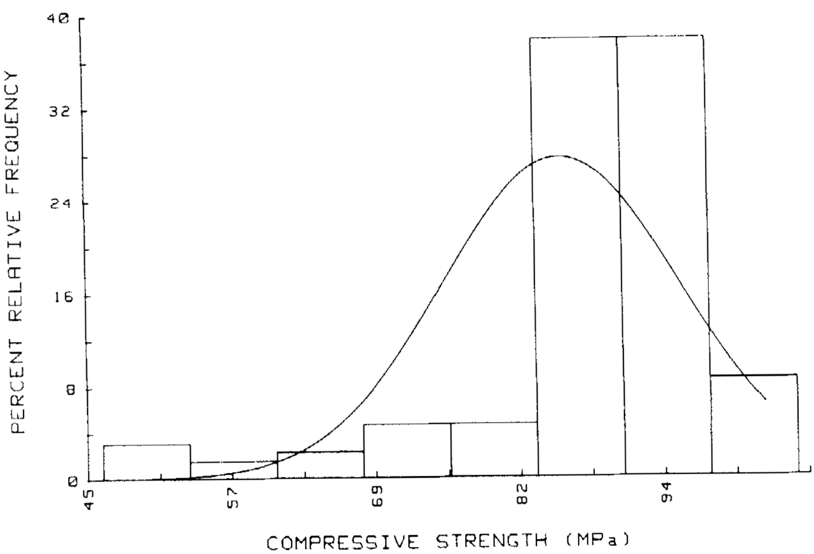


FIGURE 2 *(continued)*

Figure 3, the mechanical properties of the Rodur have been compared with the density; there is some correlation between density fluctuations and the modulus and compressive strength.

(B) Verification of the properties of Rodur

The properties measured were the density, viscosity, the pot life, filler content, flexural strength and the bond strength to wet concrete. The viscosity was measured using a Rheomat 30 turboviscometer. Following the practice of the resin manufacturer, the pot life was taken as the time for a mixture of 1 kg to rise in temperature from 20 to 40°C. The filler content was measured by burn off tests at 400°C. The bond strength to wet concrete was obtained by using $7 \times 7 \times 16$ cm blocks of concrete which were submerged in tap water for 7 days. After alignment in aluminium jigs the resin was poured into the glue line (1.5 mm) and the samples immediately re-immersed in water. After 7 days cure under water the samples were ruptured in four-point bending. The results of these tests are given in Table II.

(C) Cure of resin at low temperatures

It was necessary to establish whether the cure of the resin was still possible at temperatures as low as 0°C, especially in thin layers. The cure reaction being exothermic accelerates the reaction and cure time is strongly dependent on the volume of the mixture. For these tests the resin, hardener and steel moulds were pre-cooled to 0°C. Mixing, casting and curing were carried out at this temperature. The flexural modulus and strength were measured after 1000 h cure at 1°C. These 1 mm thick samples gave values of 3.85 GPa and 40.8 MPa respectively. This indicated that curing was possible at low temperature and in layers of thickness comparable to the cracks in the Dam. The evolution of flexural modulus with cure time at 5°C for 4 mm. thick samples is given in Figure 4. Under these conditions the gelation time is approx. 24h. and the mechanical properties reach plateau values after 600 h. The final values are in good agreement with those measured for the large prisms (*cf* Table II).

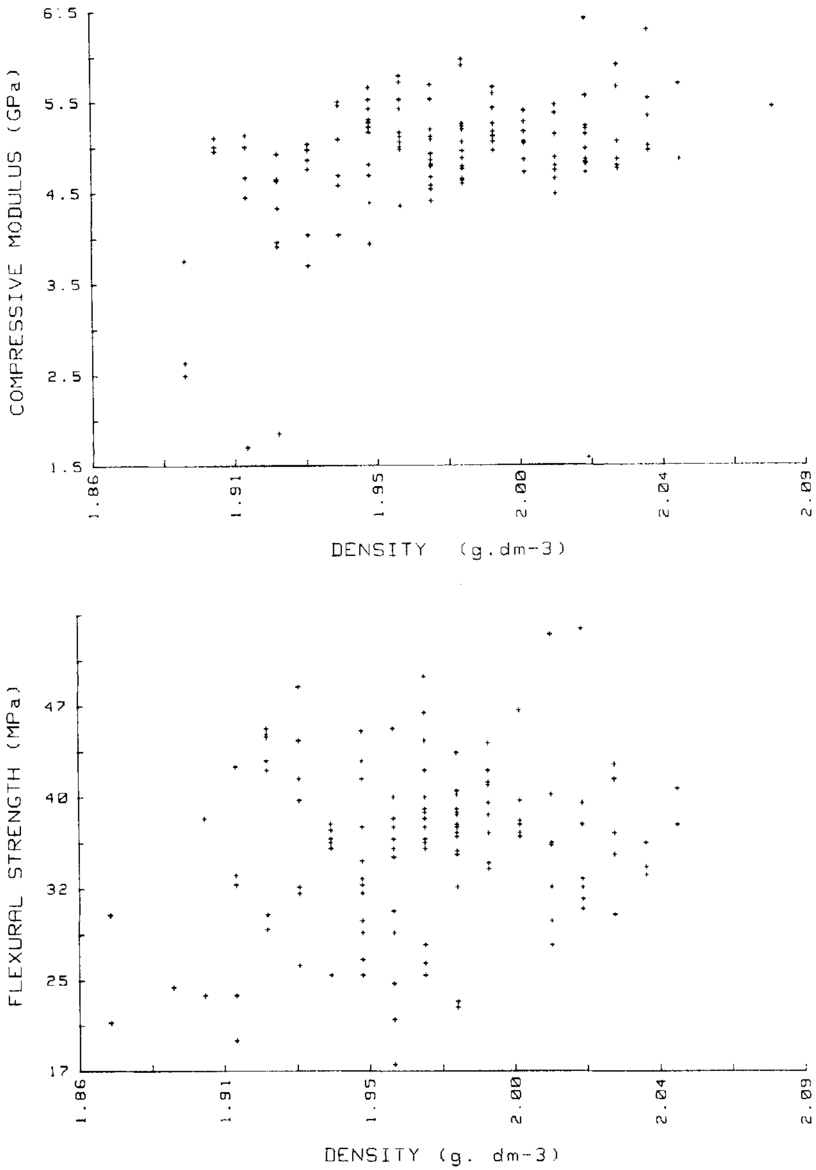
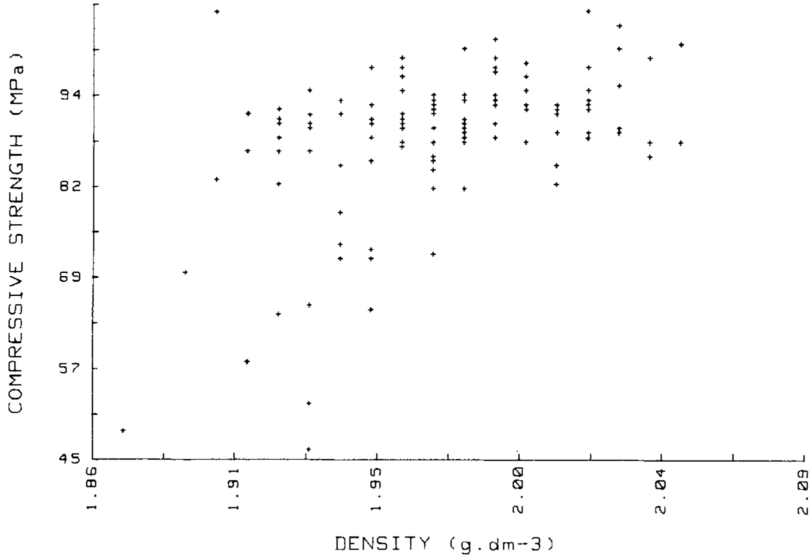


FIGURE 3 Properties of resin samples cast on site during the repair.



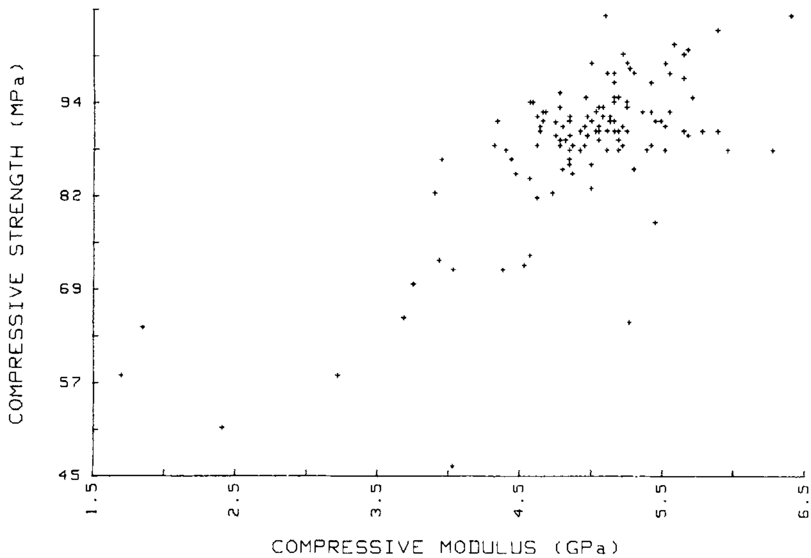


FIGURE 3 (*continued*)

TABLE II
Properties of Rodur 510

Density	(g dm^{-3})	2.02
Viscosity of uncured mixture	(mPas)	2500
Pot life/20°C/1 kg	(min)	57
Filler weight ratio		1:1.6
Compressive strength		
10 d. at 20°C	(MPa)	88.8
Flexural strength		
10 d. at 20°C	(MPa)	50.5
42 d. at 1°C	(MPa)	40.8
Flexural modulus		
10 d. at 20°C	(GPa)	4.69
42 d. at 1°C	(GPa)	3.85
Bond strength to wet concrete	(MPa)	3.00

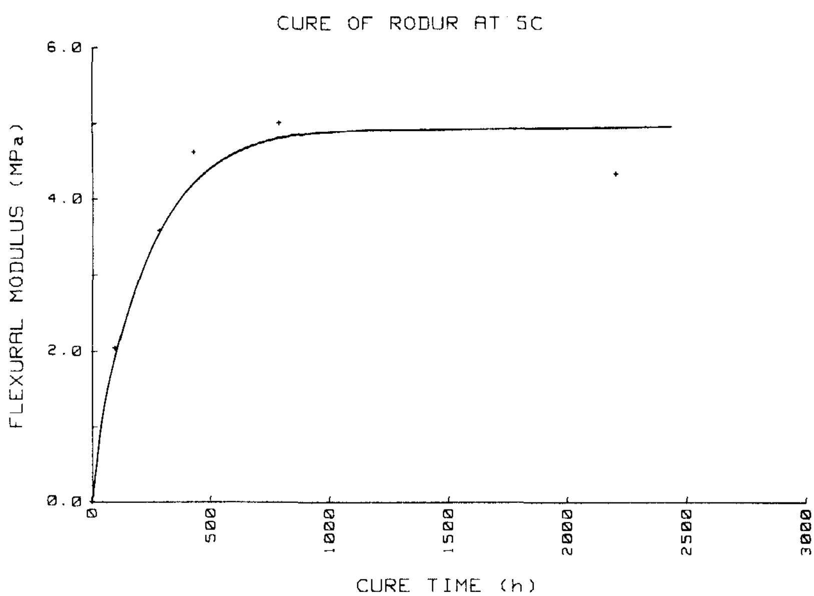


FIGURE 4 Flexural modulus as a function of cure time at 5°C.

DISCUSSION

The experience gained on site and the tests carried out in the Laboratory have indicated that an epoxide resin such as the Rodur system can be used to repair concrete structures such as the Zeuzier Dam. Removal of core samples showed that even cracks down to 0.2 mm. in width were penetrated. Thus, a viscosity of up to 2500 mPas is suitable even for a network of very fine cracks. The Federation de la Précontrainte recommended that epoxide resins in construction should have a modulus of 8 GPa. However, this is extremely difficult to achieve taking into account the viscosity requirements and the low cure temperature in this particular application. Their recommendation for compressive strength and tensile strength (75 MPa and 10 MPa respectively) may be obtained easily since most epoxide resins have properties superior to these values.

A factor of considerable importance in the repair of such a large scale structure is when injections should take place. It has been suggested that cracks should be injected when they are completely open, that is in the early morning or in winter.[6] This may be valid for isolated cracks but not for extensive repair work in a structure such as a Dam. If injections are performed in such conditions tensile stresses develop when the structure re-heats and this could result in new cracking on the opposite face on the Dam. In addition, injection pressures must be carefully controlled especially in the final stages of the repair. Excess pressures could also induce new cracks in the structure. In the Zeuzier Dam supplementary gauges were installed with valves to cut off the resin flow in order to avoid this problem.

The repair of the Zeuzier Dam required consideration of the climatic conditions in the Alps and, in particular, this area. Access to the Dam for the purposes of the repair was possible just from June to September or October each year. The repair of the Zeuzier Dam was completed in 1984.[7] The instrumentation in and around the Dam has been considerably increased by installing dilatometers, piezometers, strain gauges and remote reading seismometers and thermometers in order to measure rapidly and very accurately the behaviour of the Dam. The seismometers are so sensitive that it is claimed they can detect movements caused by the wind on the ridge of the Rohrbachstein some 1500 m. above the left bank of the Dam. The Swiss Government has approved a refilling programme over a period of 6 years. If the behaviour of the Dam during the refilling procedure continues to be completely normal the maximum storage will be reached again in 1988, ten years after the original incident.

References

1. F. Hugenschmidt, "Strengthening of existing concrete structures with bonded reinforcements", Ciba Geigy, Basle, Sept. (1981).
2. Ann. Inst. Tech. Bat. Trav. Pub. No. 366 Nov. 1978 Chap. VI "Principales applications des résines synthetiques dans les domaines du bâtiment".
3. R. W. Gaul and E. P. Smith in *Epoxies with Concrete* Amer. Concrete Inst. SP-21 (1968), p. 29.
4. Wasser, Energie, Luft, Special issue for the Int. Congress on Large Dams, Rio de Janiero, 74 (3), 1982.
5. Federation Int. de la Précontrainte, "Proposal for a standard for acceptance tests and verification of epoxy bonding agents for segmental construction, March (1978).
6. P. Wolf, Ann Inst. Tech. Bat. Trav. Pub. No. 349, April (1977), "Les injections de résines utilisées pour réstituer leur monolithisme aux structures fissurées ou caverneuses".
7. A. R. Berchten, Int. Congress on Large Dams, Lausanne, 1985, "Repair of the Zeuzier Arch Dam in Switzerland".