DURABILITY OF PAVEMENT REPAIRS: POINT OF VIEW ABOUT THE ROLE OF FIBERS.

F.Grandhaie
LMDC, CR-PAM

J.L.Granju
LMDC

E.Ringot
LMDC

LMDC : Laboratoire Matériaux et Durabilité des Constructions,
Génie Civil INSA-UPS, complexe scientifique de rangueil,
31077 Toulouse Cedex, FRANCE.
CR-PAM : Centre de Recherches de Pont à Mousson,
B.P.109, 54704 Pont à Mousson Cedex, FRANCE.

ABSTRACT

The work described in this paper is part of a research program aimed at establishing the factors which give a good durability to pavement repairs made with metallic fiber reinforced concrete.

The experimental study shows that fibers, as they do not significantly reduce the shrinkage of concrete, have a positive effect by enhancing (by 15%) its relaxation and creep capacity. On the other hand, one must not ignore the indirect effects of cracking which may be of major importance. A finite elements study demonstrates that, among these effects, the stresses induced by the passage of vehicules, very dependent on the cracking characteristics, give a significant advantage to the fiber reinforced overlays.

INTRODUCTION

The work reported here is part of a general program started in late 1989 (J.-L. Granju and al (1)). Its aim is to quantify and if possible to modelize the contribution of metallic glass fibers specifically to the durability of thin concrete repairs (about 50 mm thick) cast onto horizontal concrete bases. The repairs of roads, highways and slabs are concerned.

The better durability of steel fiber reinforced repairs has been demonstrated by field experiments (G.Chanvillard and P.-C. Aitcin (2)). Fibers have a positive effect on the cracking of the repair layer and prevent its debonding. We focused our interest on the factors which could lead to the debonding. An experimental study was centered on the different length variations of the repair layer and of the base of old concrete and on their effects. It proved that fibers do not significantly change the shrinkage of concrete but have a positive effect by enhancing its relaxation and creep capacity. On the other hand, a finite elements computation was performed to study the coupled effects of cracking and mechanical loading on the stresses induced at the base-overlay interface. It showed a drastic advantage for steel fiber reinforced repairs.

EXPERIMENTAL STUDY

Fibers used

The fibers considered in this study are FIBRAFLEX fibers, produced by SEVA, France, a company of Saint Gobain Group (B. De Guillebon, J.-M. Sohm (3)). They are obtained by "melt spinning" : a thin flow of melted metal falls onto a cold spinning wheel at the contact of which it is cooled very quickly to harden into an amorphous structure. It is because of their amorphous, or glassy, nature that they are qualified as **metallic glass** fibers. The fibers obtained are shiny ribbons, a few micrometers thick, 1 to 2 millimeters wide and available in different lengths from 15 to 45 millimeters. They are flexible, have a high tensile strength as well as a strong bond with the concrete matrix and, above all, they are corrosion resistant; this quality makes them specially appropriate for repairs subjected to chemical attacks (for instance by deicing salts or by sea water or sea mist). We have chosen to carry out this work with 30 mm long fibers, which are the most common ones. Their properties are presented in table 1.

For repairs, these fibers have first been used in tunnel rehabilitation, particularly sewers, the fiber reinforced concrete being placed by shotcreting (B. Schacher (4)). Now we count several applications in slab repairs and slab coatings.

Experimentals

The tests were carried out on two types of specimens illustrated in figure 1 : simple specimens to characterize the behaviour of the repair layer alone and composite specimens representing real repairs with their two components (a concrete overlay cast onto an old concrete base).

Three concretes were considered (table 2) : a plain concrete (PC), a fiber reinforced concrete (FRC) and an unreinforced concrete (UC). Both PC and FRC were optimized using the Baron Lesage method (5) whereas UC had the same composition as FRC but without the fibers. All these concretes had in common : the same content of CPA HP cement (equivalent to the type III american cement), the same water/cement ratio, the same workability, the use of siliceous river aggregates, the use of a superplasticizer and, when required, the same fiber dosage (20 kg/m3 or 0.3% by volume). They were differentiated by the sand/gravel ratio and by the superplasticizer content. About the same strength was achieved.

All the specimens were 500 mm long. We considered two types of simple specimens : type B, 50 mm thick (as the expected real repair overlays) and type A, 100 mm thick. The composite specimens consisted in an old concrete base onto which the 50 mm thick repair overlay was cast without any bonding agent. Two types of bases were used : unreinforced ones and other ones reinforced with steel rebars (figure 1). These rebars, located at mid-height of the bases, increase their longitudinal stiffness but not their bending one. The bases (50 mm thick) were made with the plain concrete (PC) composition and were obtained by sawing 500 mm x 100 mm x 100 mm prisms into two parts. These prisms were wet cured for 28 days at 20°C, sawed and kept during 70 days at 20°C and 60% R.H. The repair overlay was applied on their dry sawed surface after this 70 day's period. Examination of these sawed surfaces revealed that carbonation had penetrated to a depth of 0.5 mm, and that very few microcraks caused by the sawing action could be seen. This observation was done by the replica technique which permits seeing microcracks as thin as 1/10 micrometer (J.-P. Ollivier (6)).

After pouring, the specimens were cured at 20°C and 60% R.H and they were kept in the same environmental conditions after demolding. They were demolded after 24 hours and, to better approximate the field conditions of a slab repair, evaporation through all the lateral faces of the specimens was prevented by a sealing film (figure 1). The dimensional changes were measured (with an accuracy of $\pm 2\ \mu m$) between two metallic fittings installed on the end faces of each specimen as shown in figure 1.

Results

Simple specimens

In order to strictly measure the influence of the addition of 0.3% by volume of metallic glass fibers on the shrinkage of concrete one must compare FRC and UC. The results, presented in figure 2, show that metallic glass fibers reduce the measured shrinkage by 5% to 10%. This observation is in agreement with C. H. Young and J. C. Chern findings (7)(8) who studied steel fiber reinforced concretes.

From an industrial point of view it is more interesting to compare optimized concretes, that is to say PC and FRC. As it is illustrated in the figure 2, there is no significant difference in their measured shrinkage. The reduction of shrinkage due to the addition of fibers is balanced by the opposing effect of higher content of superplasticizer (9), (10).

Composite specimens

With this type of specimens, only two mixes were tested : PC and FRC.

Shrinkage induces differential length changes between the overlay and the base of old concrete which could be expected to cause the curling of the specimens. We quantified this curling by measuring the deflection at mid-length of the specimens, before any loading .

In the case of composite specimens with unreinforced bases, we measured no or insignificant curling. This implies that the overlay induces very low stresses in the base of old concrete. In addition (figure 3), the shrinkage measured on the overlay of these composite specimens between the metallic fittings 'Ac' is the same as the one measured between the corresponding metallic fittings 'As' on the 100 mm thick simple specimens. As these two types of specimens have the same geometry and the same evaporation conditions, this result implies that, at the level of the metallic fittings, the shrinkage of the overlay is not restrained by the unreinforced base of old concrete. We conclude as to the existence of a highly deformed zone in the vicinity of the base-overlay interface. We shall call it 'contact zone'(figure 4). Creep and relaxation of the hardening overlay allow this high deformation without significant stress. This contact zone develops mainly in the overlay. As it does not reach the vicinity of the metallic fittings, its height is less than 20 mm. It may as well, in a smaller extent, exist in the old concrete base. Our results indicate a larger deformation capacity (15 % more) of the contact zone for FRC than for PC (figure 5). This finding is in agreement with B.Bissonnette's results on tensile creep of concrete (unpublished data, Laval University, Québec, 1992) and with the studies of A.-M. Paillere (11) and M. El Hachem (12) on restrained shrinkage.

In the case of composite specimens with rebars reinforced bases, the stiffening effect of these bars restrains the length change of the base and increases its differential length change with the overlay. Until the 30th day, the differential dimensional variations between the overlay and the base are the same as those observed previously on composite specimens with unreinforced bases (figure 6). Past the 30th day, the shrinkage of the overlay begins to be restrained by the reinforced base. At the end of the course (500 days) a significant curling was detected, revealing the development of significant stresses at the interface. That puts in evidence the existence of a limit in the deformation of the contact zone below which built in stresses remain very low and above which they develop.

In field conditions, the length between two joints is much greater than the length of our specimens, so the development of stresses in the repair layer cannot be avoided; that usually leads to its cracking.

FINITE ELEMENTS STUDY

In field conditions, mechanical actions add their effects to the restrained shrinkage, thus the overlay is seldom crack free.

A finite elements calculation shows that the cracking of the overlay modifies the stresses induced at the base-overlay interface by the passage of vehicules.

In a plain concrete overlay the cracks are wide and develop through its whole depth. Such a crack can be modelized by a cut through the overlay. In contrast, in a steel fiber reinforced overlay, the cracks are thinner and more numerous, their openings are restrained by the fibers and many of them do not develop on the whole depth of the overlay. G.Chanvillard and P.-C.Aitcin (2) observed, on a 5 year old metallic fiber reinforced repair of a motorway in Quebec (CANADA), that most of these cracks develop on less than half the depth of the overlay. Such a crack through which fibers go on transmitting efforts, probably prolongated by a highly deformed zone, was modelized by a slice of the overlay of lower elastic modulus. According to the the size of the finite elements considered for the calculation, this slice was taken 50 mm wide. We assumed its modulus equal to 1/3 of the one of the uncracked overlay. This is a pessimistic hypothesis which supposes that the typical crack in the fiber reinforced overlay develops through about the 2/3 of its depth.

The calculations were carried out on a bidimensional model, comparing the pavement to a strip resting on an elastic support with the assumption of plain strains. As we were interested by the stresses caused by the passage of the wheel of a vehicule, creep or any viscous behaviour was not to be considered. Consequently the elastic calculation was convenient.

We considered a slab 200 mm thick (a 50 mm thick overlay on a 150 mm thick base) resting on a compacted subgrade with a 100 MPa/m modulus of reaction. Considering the case of hardened repairs, we chose the same elastic modulus for the base and the overlay : 3.5 GPa. A perfect bond was assumed between of them both.

In front of and behind the wheel the upper layer of the slab is in tension, we studied the case of the crack located in the zone of maximum tension. With our hypotheses, it is about 1.50 m away from the axis of the wheel.

These hypotheses and the results of the calculation are presented in the figure 7. They show that :

- In the case of PC overlays (fully developed crack), the passage of a vehicule induces sharp extra stresses at the interface : in particular shear a stress τxy and debonding a tensile stresse σy. This association of shear and tensile stresses is very detrimental. Further calculations showed that, when debonding has begun, these extra stresses then are applied at each end of the debonded zone. Their amplitude is not sensitively altered and they make debonding going on.

- In the case of FRC overlays the extra stresses are drastically reduced. They are divided by a factor of 5 in the case of our pessimistic hypothesis, probably much more in usual cases. This has a beneficial effect for the durability of repairs.

CONCLUSION

The addition of fibers to the overlay concrete does not affect its shrinkage and only enhances (by 15%) its relaxation and creep capacity. Often, that will not be enough to prevent the cracking of the overlay but, in all cases, it will change the characteristics of this cracking.

One must not ignore the indirect effects of cracking which may be of major importance. Among them are the stresses induced at the base-overlay interface by the passage of vehicules. Finite elements calculation prove a definite advantage of the steel fiber reinforced overlays. Well developed cracks, met in plain concrete overlays, induce sharp debonding stresses. By limiting the opening and development of cracks, steel fibers have a very beneficial effect : they drastically reduce these debonding stresses.

Metallic glass fibers, by their efficiency to control the cracks during the first stage of their opening and to provide high I_5 and I_{10} toughness indexes (13)(14), seem specially suitable for this purpose.

ACKNOWLEDGMENTS

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Table 1. Characteristics of the fibers.

Name :	FIBRAFLEX
Nature :	Amorphous metallic alloy, $(Fe, Cr)_{80}(P,C,Si)_{20}$
Length :	30 mm
Width :	1.6 mm
Thickness :	30 μm
Specific surface :	10 m^2/kg
Density :	7.2
Tensile strength :	2000 MPa
Elastic modulus :	140 000 MPa
Corrosion resistance :	rustproof

Table 2. Characteristics of the concrete mixtures for 1 m^3.

Mixture		PC	FRC	UC
Cement	(kg)	400	400	400
Water	(l)	180	180	180
Gravel 5-12.5 mm	(kg)	1116	932	932
Sand 0-5 mm	(kg)	839	839	839
Fibre	(kg)	0	20	0
Superplasticizer	(l)	2.7	4.2	4.2
28 day strength	(MPa)	51	52	54

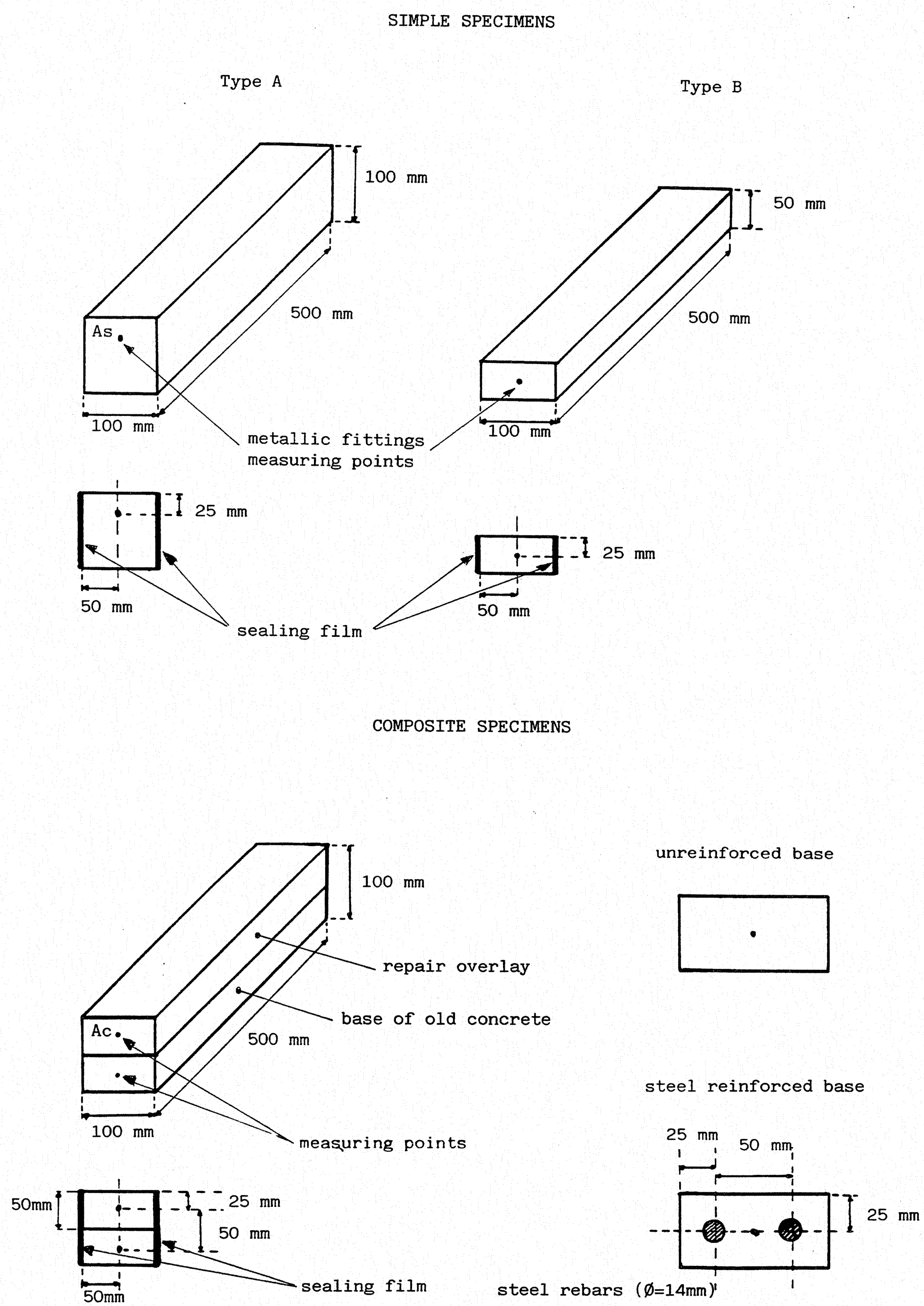


Figure 1. Characteristics of the specimens.

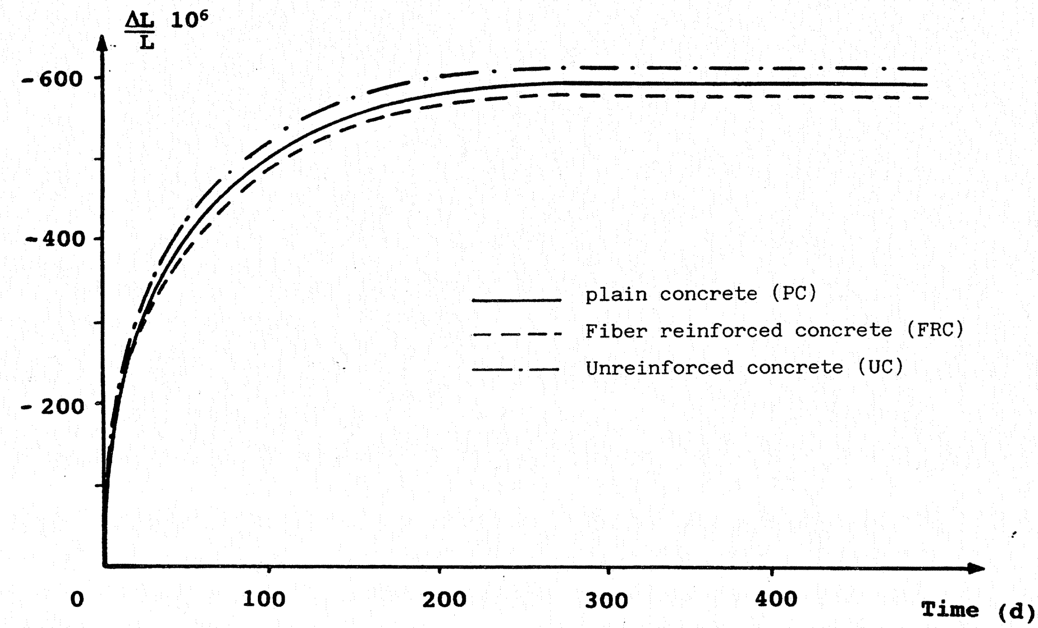


Figure 2. Dimensional variation of shrinkage measured on simple specimens type B.

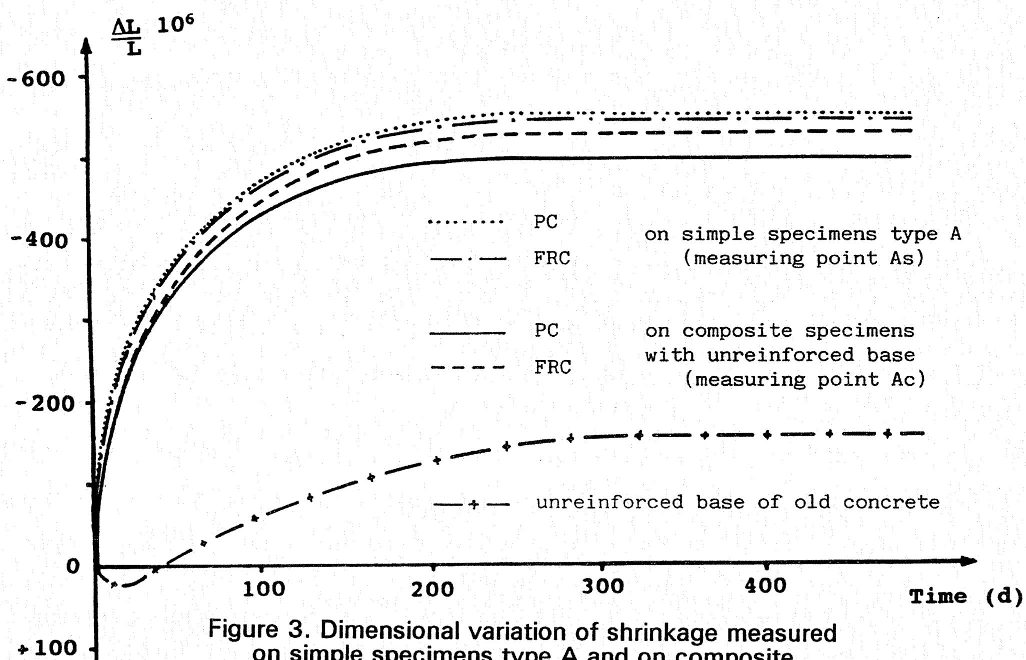
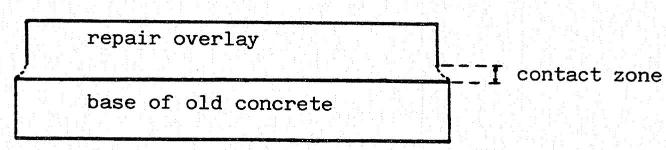


Figure 3. Dimensional variation of shrinkage measured on simple specimens type A and on composite specimens with unreinforced bases.

Figure 4. Deformation of the composite specimens with unreinforced bases after the shrinkage of the overlay.



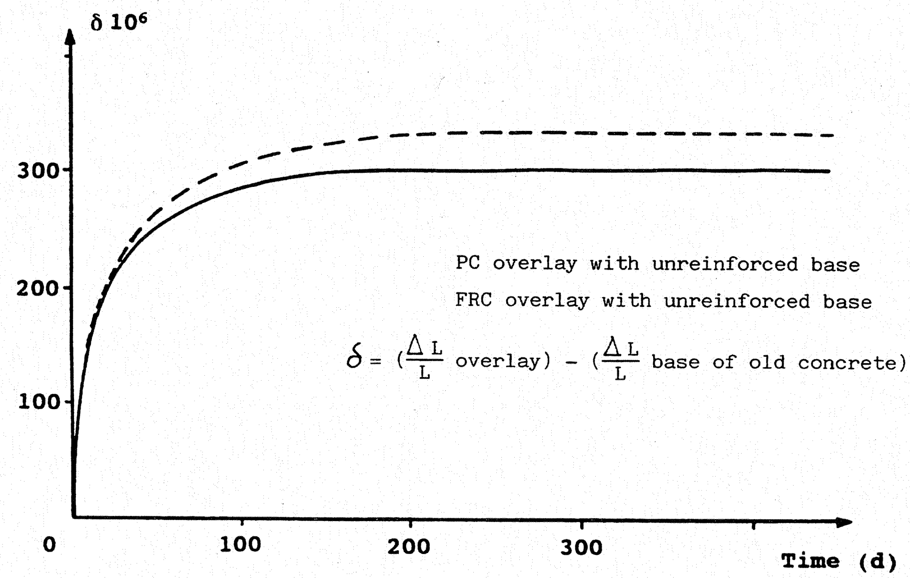


Figure 5. Deformation of the contact zone, comparison of the FRC and PC overlay.

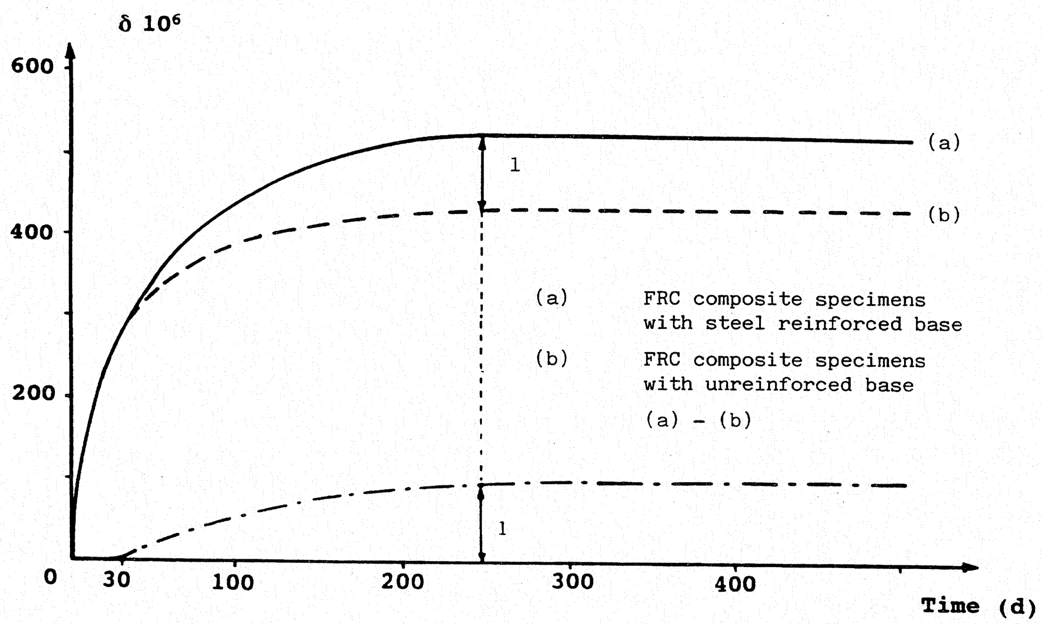


Figure 6. Influence of the stiffness of the base of old concrete on the differential dimensional variations between the fiber reinforced overlay and the base of the old concrete.

δ = (Δl/l overlay) - (Δl/l base of old concrete)

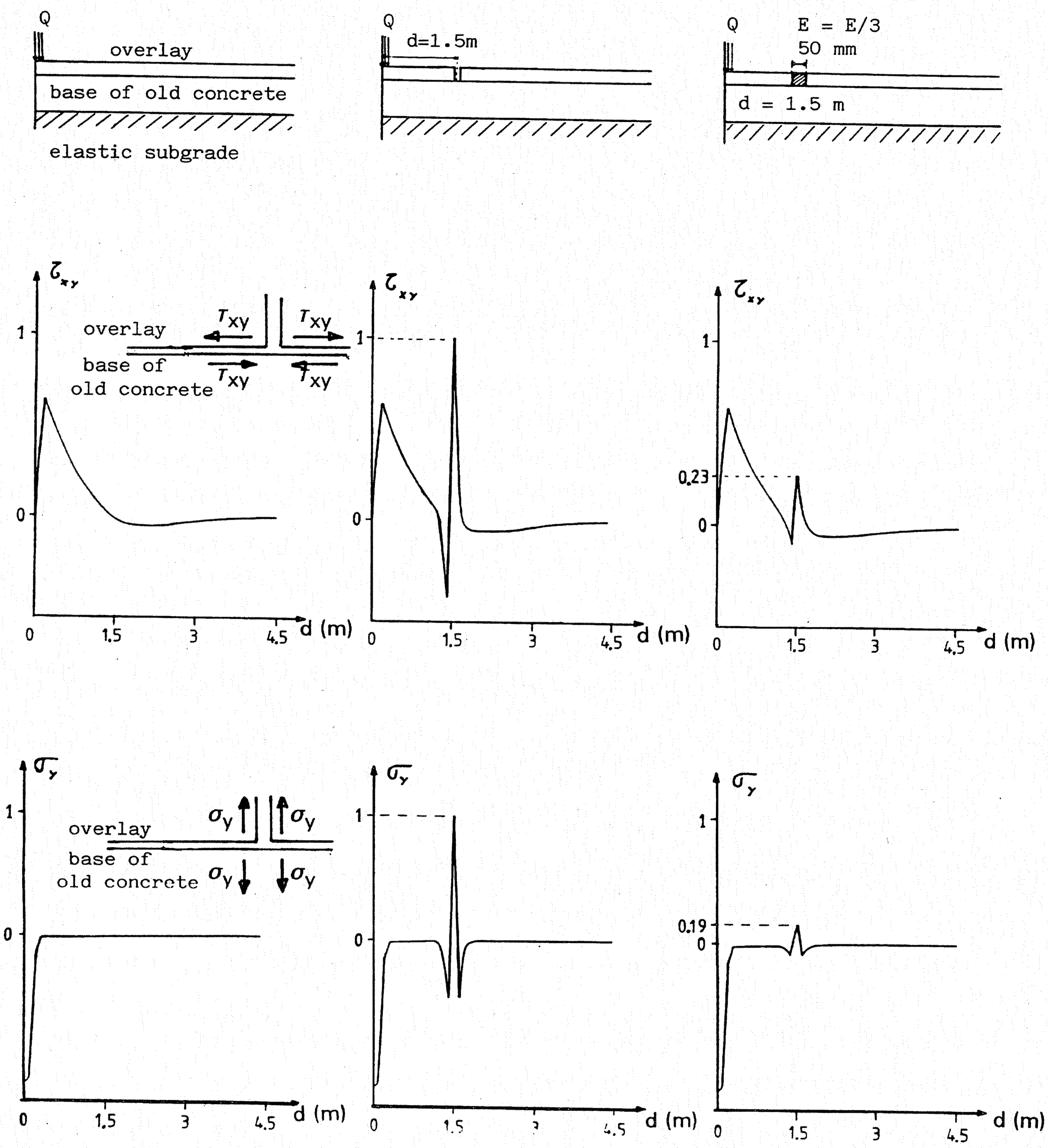


Figure 7. Hypotheses and results of the finite elements study.