The long-term behaviour of viaducts subjected to heavy traffic and situated in an aggressive environment: the viaduct on the Polcevera in Genoa

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The Long-Term Behaviour of Viaducts Subjected to Heavy Traffic and Situated in an aggressive Environment. The Viaduct on the Polcevera in Genoa.

Comportement à long terme de viaducs soumis à un fort trafic et dans un environnement agressif. Le cas du viaduc de Polcevera à Gênes.

Langfristiges Verhalten von Brücken unter schweren Lasten und in aggressiver Umwelt. Der Polcevera Viadukt in Genua.

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SUMMARY
After a brief description of the common causes of wear to which a reinforced concrete bridge is most easily subject, the so-called wall cracks phenomenon is considered in detail and one limit case of a viaduct in Italy is described. The state of repair of the Polcevera Viaduct at Genoa (Italy) has also been examined, for which, while the static behaviour of the various members is absolutely normal, there is perplexity about the aggressivity of the local atmosphere on the concrete.

RESUME
Une brève description est faite des causes habituelles de la dégradation subie communément par un pont en béton armé: le phénomène de fissuration superficielle est décrit dans le cas particulier d'un viaduc en Italie. L'état du viaduc de Polcevera, après réparation, est examiné; si le comportement statique des différents éléments est absolument normal, il y a des doutes au sujet de l'agressivité de l'atmosphère locale sur le béton.

ZUSAMMENFASSUNG
Die üblichen Gründe der beginnenden Zerstörung, die bei Stahlbetonbrücken auftritt, werden erörtert. Es handelt sich um Risse an der Betonoberfläche, die im Falle einer Brücke in Italien beschrieben werden. Der Stand nach Wiederherstellungsarbeiten am Polcevera Viadukt in Genua wird beschrieben; das statische Verhalten der verschiedenen Bauteile ist einwandfrei; Zweifel bestehen über die schädliche Einwirkung der Atmosphäre auf den Beton.

Some decades spent in designing, directing and supervising reinforced concrete bridges constructions authorize me to express some opinions about their durability and the frequency of repeated inconvenientes which may occur in the course of time. I shall try to make a synthetic classification of such inconveniente and I shall conclude by reporting the behaviour of two structures, both built and in operation for several years, one with normal and the other with exceptional characteristics. I have chosen them amongst many other because they may arise interesting observations.

As it is well-known, a reinforced concrete bridge, apart from possible troubles due to specific static deficienses, is subject to a slow deterioration because of :

- the effect of movable loads and of the environmental action, especially on the paving, on the supporting structures, on the joints and on the finishes,
- the chemical and mechanical effects due to the metereological action on the concrete and also on the reinforcement.

We must consider, in a particular category, some special phenomena such as the appearance of diffused cracks (the wall cracks) partly due to the insufficient stretching of the concrete compared to that of the steel (when this is subjected to high unit stresses), partly to vibration caused by traffic and partly to an un uneven distribution of the reinforcements within the concrete mass.

In fact, it is well-known that normal reinforced concrete members subjected to bending and shear (especially under the effect of dynamic loads) tend to develop cracks in the course of time, even when design or technological errors must be ruled out.

Let us consider in particular the so-called wall cracks, i.e. those vertical cracks diffused almost all-over the surface of the girder and closer to each other in the intermediate areas between two adjacent supports.

Very often such cracks do not reach the main-steel reinforcements, in other words they remain small and superficial, but give rise regularly to a state of alert, to claims, and to the suspicion that there are defect which will appear in the course of time.

In other words this is a very frequent phenomenon and the positive elimination of it (in consideration of all the causes which contribute to produce it : stresses caused by external loads, by temperature changes, by shrinkage) would require us to introduce in the beam such a quantity of distributed reinforcement to jeopardize the economic conditions of the use of the structure, especially in countries where steel is particularly expensive.

In rather recent times it has been agreed to introduce the concept that the phenomenon of the appearance of cracks could be accepted as a natural behaviour of the structure, as long as it would not cause a decrease in the performance capacity of the structure, even in the long run.

Therefore, it has been agreed to proceed with a series of theoretical and experimental tests in order to find out the maximum crack width (after taking into account the various environmental circumstances) below which the structure would appear fit for service.

The aforesaid maximum values appear by now to have been specified in the codes in force for reinforced concrete structures ; therefore it should be easy, by now, to overcome the worries of the layman (followed in most cases by lawsuits and surveys) when he discovers even a small crack, which he immediately associate with the idea of the crumbling down of the structure.

The study of the determination of the aforesaid maximum crack width tends however to become ever more complex : we have noticed that it is not enough to take into account the maximum working load since we notice more and more that the agreement between the theoretical and actual behaviours of a structure is greater, especially as regards the cracking, if greater has been the investigation on the ratio between the permanent and live loads, on the period of live load permanence and especially on its fluctuating behaviour.

All this, as said beforehand, must be added to the stresses due to prevented geometrical variations under the effect of temperature changes and shrinkage.

Here, however, we must make clear an important point :
The determination of the cracking state of a structure, i.e. the determination of the extent and position of the cracks, may obviously lead us to two different conclusions : if all the cracks are hypothesis or environmental condition (cracking below a certain set limit) in such a case, at least in this respect, the structure is fit for service even in the long run. On the other hand, the structure may show crack openings exceeding the maximum value accepted in design or recognized as acceptable at the time of the survey. In this second case, as a rule, the cracks can, in the long run, cause damage to the preservation of the reinforcement because of the infiltration of humidity or other things and therefore it will be necessary to seal the wider cracks by means of gluing materials and also, in more serious cases, to cover the external surfaces by means of suitable elastomers.

The above, of course, should be done after a through survey by means or direct and indirect tests carried out in order to detect whether the cracks may have damaged the static working capacity of the structure. And, to conclude the matter of the cracks, all what has been said has of course no meaning whatsoever when the structure is subjected to prestress.

In such a case it is enough to think that, for a prestressed beam, the determination of the cracking condition has a very different meaning : in such a case it is not a question to limit cracking to acceptable values but rather to make all the necessary investigations in order to avoid cracking altogether within the limits of the assumed working conditions of the structure.

In this second case, therefore, the fact that cracks are or are not present means the absence or the presence of a defect in design or execution.

Therefore, the presence of cracks in a prestressed structure is a much rarer thing but, as a rule, a much more serious one which requires in most cases an immediate intervention.

On the other hand, in a prestressed concrete structure, the intervention against degradation phenomena caused by environmental factors on the concrete may be more important for obvious reasons, both for the necessity to protect the prestressing cables and to prevent the reduction of the resistant section of the concrete, which usually is rather small.

From all the above, which is quite well-known, the necessity arises which is felt more and more as the technique and technology for reinforced and prestressed concrete becomes more sophisticated, to keep the structures under careful observation as time goes on, to decide about possible remedial works which, in any case, must be carried out quickly and properly.

I know perfectly well that all what I have just briefly summarized is very well known by all those who deal with this subject.

However, I think it will be interesting to bring as an example some extreme cases in which first the survey and then the intervention have been or will be necessary.

The examples refer to structures built and in operation since no less than 12-15 years.

A REINFORCED CONCRETE VIADUCT SERVING A SPEEDWAY IN NORTHEN ITALY.

Of all the cases I had an opportunity to examine, the one I am going to illustrate is perhaps the most difficult to explain thoroughly : since the structure was part of an important super highway it is obvious that, besides any more or less learned considerations on the causes of the phenomena encountered, it was absolutely necessary to answer the imperative whether the structure could or could not remain open to traffic without any limitations whatsoever.

In 1967 I was charged by the Agency of the Italian National Roads with the control of the static conditions of a speed-way viaduct, designed by others, opened to traffic in 1969, consisting of dou ble independent decks (one for each traffic direction) for a total of 36 simply supported spans of average length 19.00 lm, in conventional reinforced concrete.

Figure 1 illustrates the geometry of the standard bay.

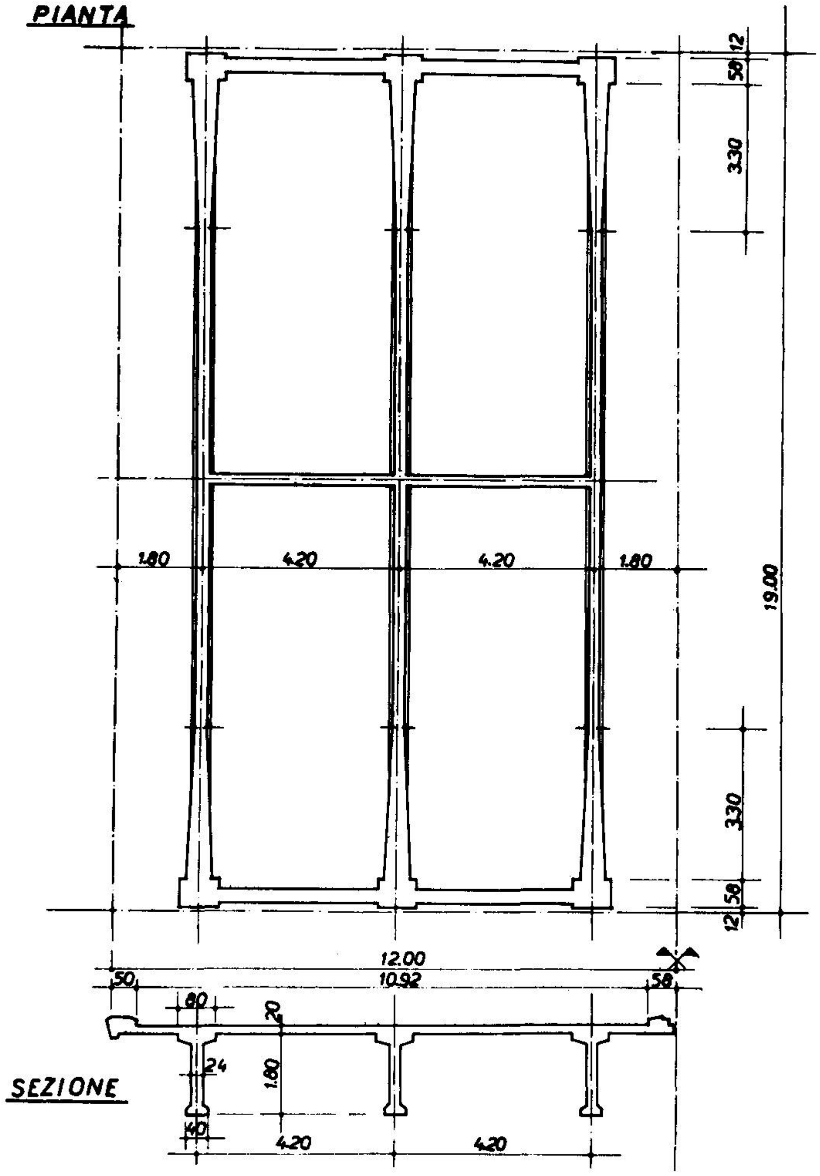

Fig. 1 - Geometry of the standard bay.

During my visit I found some superficial distress in the paving joints, some excessive crushing of the bearings (although nothing really serious) but, most important of all, that all the parallel beams of the deck showed a diffused pattern of cracks of very similar length, frequency and width on all the bays.

As an example, figure 2 shows the cracks of the external rib of bay No. 21.

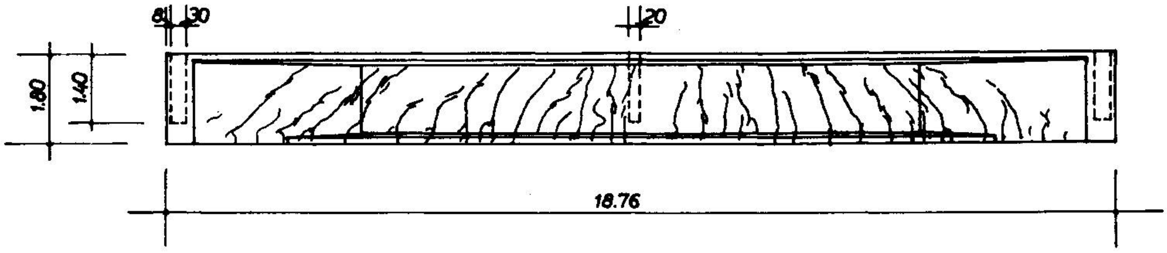

Fig. 2 - Crack pattern on the external rib of bay No. 21

As for the crack width, we can briefly conclude that the inclined cracks near the bearings of the deck reached the maximum width of 0.5 mm, while the width of all the others were between the 0.05 and 0.3 mm, with most of them being less than 0.2 mm.

Having verified and carefully inspected all that, I examined all the documentation in order to single out all the detail characteristics of the project. From that I found out :

- that the forces and the actions taken in consideration in design were in accordance with the existing regulations and with the generally accepted practice,

- that the placement of the reinforcement as resulting from design had been done in a perfect way, except for some imperfections in the positioning of the bent-up bars, which however was unimportant and could not have caused (only by themselves) the cracks I had noticed,

- that the unit stresses of the materials were not over the allowable values,

- that the characteristics strength of the materials were in accordance with those prescribed in the project,

- that the theoretical verification of the width of the crack showed that it should not have exceeded the value of 0.2 mm.

Have done all this, it was necessary - of course - to answer the basic question whether and to what extent the structure, was damaged with respect to its functional capacities, and especially if its safety coefficient had to be regarded as unduly decreased.

The answer to the above question would permit to reach a decision on whether a strengthening of the structure was necessary or a protective action was sufficient so as to avoid that the crack ope -

nings, with the time going on, would damage the internal reinfor cement.

We have preferred to subordinate such important decision to a se cond stage of investigation carried out to establish :

- the causes of the cracking phenomenon, in order to see whether it would have been possible to eliminate them to avoid a further degradation,

- the assestment of the performance conditions by means of a series of tests.

As for the first research (the determination of the causes of such an important cracking phenomenon), we found out after a long series of studies that many factors had occurred accidentally at the same time which could explain the cracking.

The most important of them may be listed as follows :

- the very small ratio beatween the beam width and their height,

- the use of a cement which had not been seasoned long enough in silos, with a consequent increase of the shrinkage value.
The faulty performance of the bearings with consequent temperatu re stresse arisen in the structure.

- Very heavy and fast traffic : the structure is located near an important marble production centre,

- the imperfect position of the bent-up bars for shear reinforce ment.

As for the second question, i.e. whether and to what extent the safety of the structure was effected, we have carried out a series of tests organized as follows :

a) Test of three bays chosen amongst those showing more cracks, with a static load equal to 120 % the maximum design value.
Period of stay of the load : 24 hours.
Determination of the variation of the geometry of the deck and of the size of the cracks. Reversebility characteristics of the above variations. Determination of the average apparent elastic modulus.

b) Testing of the same three bays by means of a vibrating apparatus (vibrodine) for the determination of the dynamic behaviour characteristics and consequent determination, by other means, of the apparent elastic modulus of each deck.

In short, the results of the tests have been the following :

The three tested bays have shown a practically identical behaviour, with almost unnoticeable "dispersion". Such behaviour has appeared to be stable and reversible, not showing any signs of deteriora - tion and unelastic deformations.

The deflections and deformations of the structures have appeared to be realiably estimated by means of an elastic calculation model, assuming a modulus of elasticity equal to about 300,000 kg/cm2 and with begligible residual deformations. In particular, with regards to dynamic tests, the values of elasticity modulus obtained from the comparison between the fundamental experimental frequencies and those calculated theoretically appear to be practically identical to those resulting from the static tests.

Finally, the behaviour of the structures under the dynamic impulses shows a satisfactory level of integrity of the entire assembly. Obviously, after having considered all the above results, we reached the conclusion that it was sufficient to apply coats of various substances (elastomers) on the external surfaces in order to prevent the reinforcements to be reached and damaged by air through the cracks.

I repeat that I wanted to quote this case (to be regarded as rather emblematic) amongst so many other ones, because here a through study has prevented to make recourse to unnecessary and costly interventions or, even worse, to demolition or structural repairs.

May be it will be useful that the experts explain to the laymen that the cracks in a reinforced concrete beam are, within certain limits, a normal phenomenon and should not be considered as the warning sign of a coming disaster.

THE VIADUCT ON THE POLCEVERA, FOR THE GENOA-SAVONA SPEEDWAY.

I shall deal now with one of the biggest reinforced concrete structure built and in operation for more than ten years, which appeares to be surrounded by a particularly aggressive environment.

The viaduct on the Polcevera in Sampierdarena (Genova) marks the junction between two of the most important italian speed-ways, i.e. the Genoa-French Border and the Genoa-Po River valley, crossing a valley in a heavily built-up area with civil and industrial buildings and also including, besides the Polcevera river by a series of very important railway yards.

Therefore, the structure in the whole may be regarded as an example of a big infrastructure within a thick urban and industrial network.

The structure may be subdivided into a main viaduct and four approach lines, the latter being arranged in different ways, altimetrically and planimetrically.

The main viaduct has the following theoretical spans :

- one 43.00 m span
- five 73.20 m spans
- one 75.313 m span

- one 142.655 m span
- one 207.884 m span
- one 202.50 m span
- one 65.10 m span

The spans, of such a different length, find their conceptual link in a series of prestressed concrete decks, all of the same span 36.00 m long, simply supported by a series of special systems, amongst which we may distinguish the following two different basic types :

- The system supporting the amsller spans, consisting of two inclined piers connected at the top by a double cantilever girder of variable length. The whole in reinforced concrete, carried by a foundation raft which in turn rests on drilled piles 110 cm in diameter of a length variable up to 40.0 m.

- The balanced system for the main spans. Such system consists of a three-span continuous girder resting on four supports, with two end cantilevers giving support to the above said 36.00 m beams. The two external support of the three-span girder are provided by the anchorages of two prestressed stay-cables passing over a mast (sospension tower) located on the axis of the system. The mast top is 90.00 m above the ground and about 45.00 m over the roadway deck.

Each balanced system consists of :

1. A reinforced concrete ribbed foundations raft resting on drilled piles 150 cm in diameter.

2. A special reinforced concrete trestle consisting of four "H" shaped bents laid side by side and connected to each other by cross elements. The tops of the trestle give elastic supports to the deck girder.

3. A mast, or suspension tower ("Antenna") made up of four inclined legs with adequate connections in both directions (longitudinal and transversal) so as to form a true and proper frame, but such as to keep independent the tower itself from the trestle-deck sistem.

4. A continuous deck-girder of prestressed concrete, of cellular type, with top and bottom slab and six longitudinal ribs, resting on the trestle referred to under paragraph 2. The connection between the deck and the stay-cables is achieved through a stiff cross girder, also in prestressed concrete, whose projections on each side of the deck provide the anchorage of the two stay-cables passing over the top of the mast at an elevation of 9,000 m above ground. Later on, concrete shells were poured around the cables ; the function of these shells, as it is known, is, besides protecting the steel, also to reduce the cable elongation at the passage of moaving loads because the shells themselves have been prestressed.

Figure 3 - General view of the structure.

The work has been completed in 1966 and was regularly opened to traffic in 1967. Since then it underwent a series of controls about its state of preservation.

Essentially, it has been ascertained that the structure stands the very neavy traffic to which it is continuously submitted without signs of deterioration or static unadequacy.

The balanced systems are behaving in a regular way and obviously, as far as they are concerned, we must not worry about cracks because we deal with structures the parts of which are practically all in compression under the effect of external loads or prestressing.

Some slight cracks of a very small size (much below 0.2 mm) have been noticed in the secondary connecting cross elements - which obviously had not been prestressed - and which were surely due to the vibration caused by the traffic.

On the other hand, no cracks are noticed on the horizontal elements of the secondary unprestressed "V" piers.

This, evidently, is due to a sufficient distribution of the reinforcement within the concrete and to a non-exceptional shrinkage of the concrete.

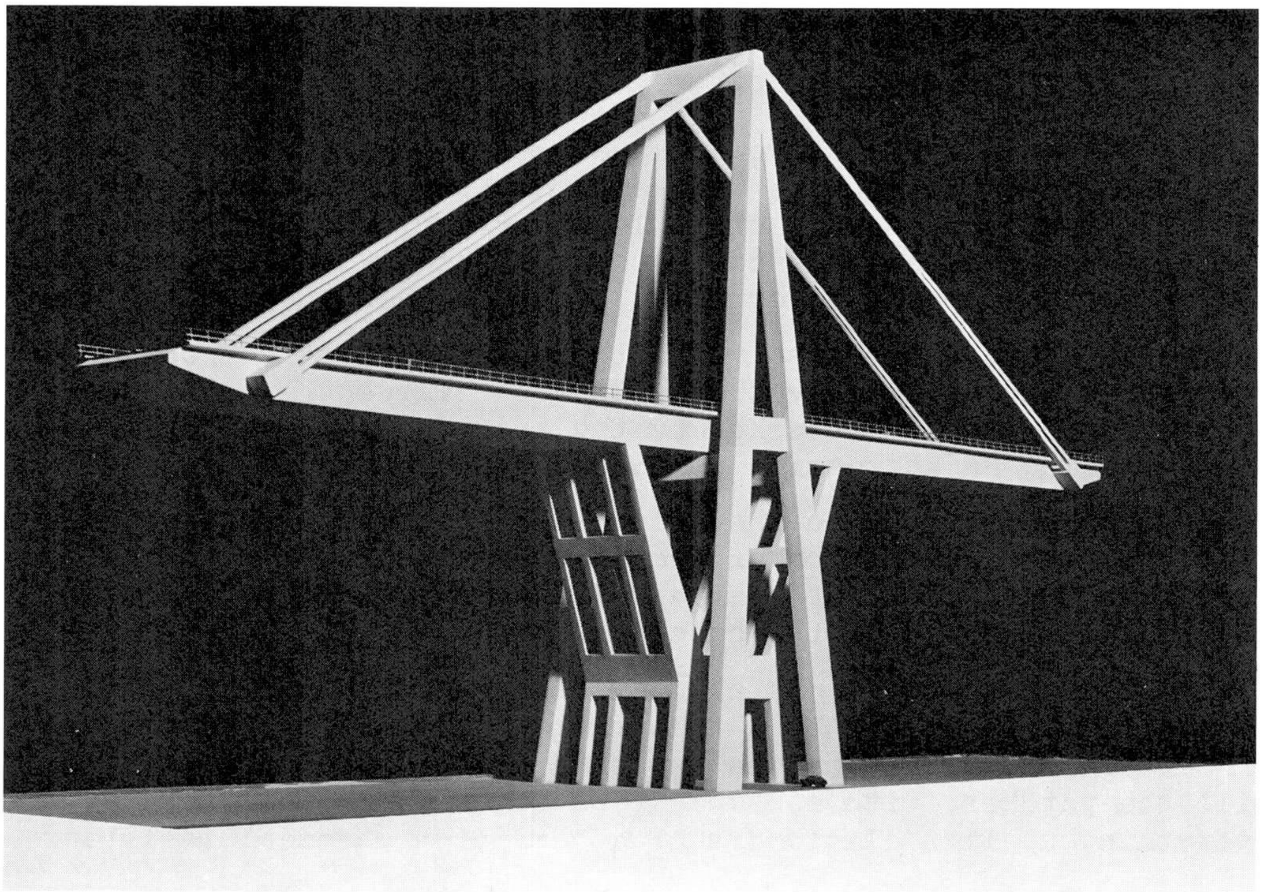

Figure 4 - Photo of the model of a balanced system.

Certainly, in this case, the behaviour of the structure is so different from that we have seen in the vuaduct given as first example that it confirms for the latter the influence of a series of concomitant causes, as it has already been pointed out.

On the other hand, the atmospheric aggressiveness is what represents a definitely negative environmental condition for this structure.

It appears that the structure is struck directly by the marine winds (the sea is about 1 km away), which are canalized in the valley crossed by the viaduct.

Therefore it is a highly saline atmosphere which also finds, on his ways before reaching the viaduct, a curtain of fumes from the chimneys of steel mills and therefore becomes saturated with highly noxious vapours.

In the whall structure, besides some small imperfections of execution which caused some small rust spots to appear on isolated areas due to insufficient end cover of reinforcement, the project has carefully placed within the concrete all steel elements, except, of course, the cadmium-lined plates of the bearings for the simply supported girders.

All these plates have been literally corroded in little more than five years by the extreme aggressiveness of the atmosphere and had to be substituted, with rather complicated processes, with stainless steel elements.

We must think about what would have been the maintenance costs if, instead of a structure made entirely of concrete, a steel solution had been adopted or at least if the solution of the stay-cables embedded in a concrete shell under compression, and therefore not subject to cracking, had not been adopted.

Furthermore, in these last years the external surfaces of the structures and especially those exposed towards the sea and therefore more directly attached by the acid fumes of the chimneys, start showing an aggression phenomenon of a chemical origin.

This is obviously due to the production of soluble salts resulting from the combination of the acids of the fumes with the free lime of the concrete : the well-known loss of superficial chemical resistance of the concrete itself.

I thinck that sooner or later, may be in a few years, it will be necessary to resort to a treatment consisting of the removal of all traces of rust on the exposure of the reinforcements, to fill the patches, with epoxidic type resins and finally to cover everything up with elastomers of a very high chemical resistance.

In conclusion, to sum it up, I wanted to point out with the two examples illustrated above (chosen as border cases amongst many other ones) that, for reinforced concrete structures destined to stay outside, their preservation in the course of time - besides any trouble due to static insufficiency - is subordinated not only to the protection of the reinforcement and therefore the big worry about the effects of cracking, but also to the aggression of the external surfaces of the concrete and this is particularly important under special environmental conditions.

It is also suitable in this case to provide some protection over the external surfaces of the structures in order to increase their chemical resistance and, if necessary, the mechanical resistance to abrasions.

This is especially true for the big infrastructures for which the following interventions will entail at the end very heavy burdens.