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Durability Assessment from the Design Phase to Execution

Prise en compte de la durabilité du projet à l'exécution

Berücksichtigung der Dauerhaftigkeit vom Entwurf bis zur Ausführung

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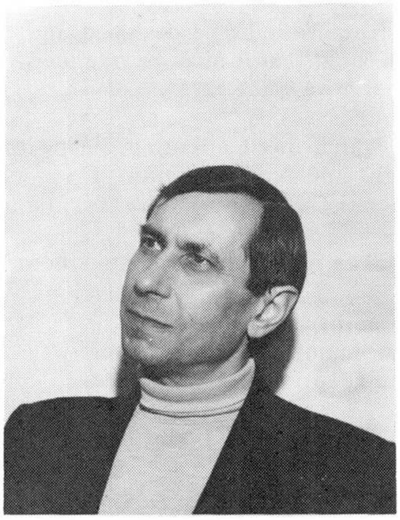

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SUMMARY

Durability assessment of bridges from the design phase, constructive measures and execution is dealt with in this article under the following four aspects: assessment of factors which affect the operational life; assessment of necessity for inspection and maintenance; assessment of necessity for adaptation or replacement; effect of construction methods on durability.

RÉSUMÉ

La prise en compte de la durabilité des ponts au niveau du projet, des dispositions constructives et de l'exécution est abordée dans cet article sous les quatres angles suivants: prise en compte des facteurs qui affectent leur durée de vie; prise en compte de la nécessité de leur visite et de leur entretien; prise en compte de la nécessité de leur adaptation ou de leur remplacement; incidence des méthodes d'exécution sur leur durabilité.

ZUSAMMENFASSUNG

Die Berücksichtigung der Dauerhaftigkeit von Brücken bei Entwurf, Ausschreibung und Ausführung wird in diesem Beitrag unter vier Aspekten diskutiert: Berücksichtigung der Faktoren, die die Lebensdauer beeinflussen; Berücksichtigung von Inspektion und Unterhaltung; Berücksichtigung der Notwendigkeit ihrer Umbaues und Entfernung; Einfluss der Baumethoden auf die Dauerhaftigkeit.

1. INTRODUCTION

Throughout its operational life, a structure must fulfil its functions, with an acceptable probability, without incurring excessive investment or maintenance expenses, without its operation being interrupted except for short periods for maintenance (usual or specialised), repairs, or even strengthening or changes and lastly without suffering notable damage with regard to safety and comfort of users and third parties.

To obtain these objectives, the structure must be designed and built with an initial adequate quality. It should be emphasised that it must be operated with the same concern for quality, which unfortunately is not always the case.

I shall try to review four points which merit attention during the first two stages of the life of the structure, i.e. "design" and "construction", if we wish to obtain the abovementioned objectives meaning a "satisfactory durability" for the structure.

Three of these points should be taken into account at the structure design stage:

- factors which can affect its durability;
- the requirement for supervision, maintenance, even repair;
- the necessity of replacing it and adapting it.

The fourth point deals with both the design and construction phase as it concerns the effect of construction methods on durability.

My report will be oriented towards concrete bridges (reinforced concrete and prestressed concrete) and metal bridges. The construction principles I shall discuss are, of course, applicable "mutatis mutandis" to other engineering structures.

2 - REPORT

2.1 - Assessment at design phase of factors which may affect the structure durability

2.1.1 - General

At the design phase, all the external factors should be listed and classified which might have major unfavourable effects on the durability of the future structure during its service phase but also during construction. Afterwards, this is taken into account in the choice of structure type, certain construction specifications, calculation, quality of materials to use, various protection systems....

It is possible to separate factors having a "negative influence on durability" into two categories:

The first category lists the factors which can cause major structural disorders or even ruin the structure. Generally their actions are sudden.

The second category lists factors which downgrade the structure by attacking the component materials. Generally, the disorders appear slowly. However, when they have reached a certain magnitude, they also lead to major structural disorders and ruin the structure.

2.1.2 - List of factors in the first category

We refer here to accidental occurences or else factors whose effect can be equivalent to those of accidental occurences. We can mention:

- earthquakes;
- tropical cyclones;
- impacts due to road vehicles - Figure 1 or rail traffic, boats or even aircraft;
- fires and explosions;
- broken piping;
- slippage;
- landslides and avalanches;
- mining subsidence;
- local, general or regressive under mining;
- floods;
- human error....

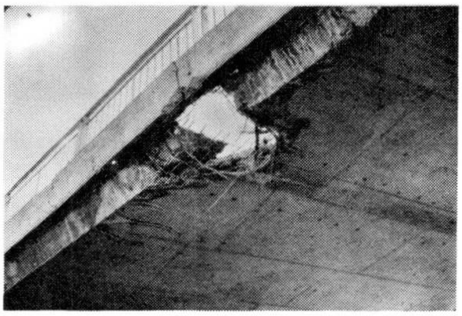

Fig. 1

To illustrate my report here are three typical examples:

. The first example is that of the new cable stayed bridge in TJORN (Sweden) whose pylons were installed on the banks necessitating a central span of 366 m. This structure is designed to protect the deck and pylons from boat impacts. This structure replaces a metal arch bridge with 278 m span destroyed on 18 January 1980 by a ship which collided with the arch near one of the abutments outside the shipping lane where theoretically it should have been sailing.

. The second example is that of a bow-string metal bridge in BELGIUM which was destroyed on 14 August 1985 in about ten minutes due to a fire which broke out after an explosion of a gas pipe attached underneath the deck.

. The third example concerns the tipping over, during the construction phase, of a bridge balance beam built with successive cantilevers using prefabricated segments. The balance beam was resting on two wedges forming simple supports and safety was provided by the unsymmetrical counterweights and the order of installing the segments. A human error led to reversing the fitting process which caused the static balance to be broken. This accident has led the French government to impose stability regulations for balance beams enabling the static balance to be verified and secondly resistance of all structural elements (deck section, provisional support equipment, pile shaft, foundation...).

2.1.3 - List of factors in the second category

This refers to factors which might attack the different materials used in building bridges and their accessories (screed, bearing fittings, pavement joints...). These different factors may be classed according to their origins under the following headings:

- actions exerted by the environment
  - . sea air;
  - . industrial atmospheres;
  - . either natural or industrial water, soft or hard;
  - . certain soils.

- climatic influences developed by:
  . sun;
  . frost and thaw;
  . rain often containing aggressive agents due to pollution;
  . wind....

- influences exerted by the different living organisms:

  . man (pollution, vandalism...);
  . animals (defecations, underground passageways...);
  . vegetal (effects produced by growth of plants);
  . micro-organisms such as certain bacteria....

- influences exerted by traffic:

  . earthwork machines;
  . HGVs;
  . exceptional convoys.....

- influences exerted by materials or their components on one another:

  . certain cements reacting with certain aggregates;
  . ordinary steels corroding after contact with stainless steels.

The different factors mentioned above cause damage to materials by the following main processes:

- chemical and physico-chemical reactions. For instance, carbon dioxide causes carbonation of concrete coating the reinforcement which leads to depassivation of steels and corrosion).

- electrochemical reactions (for instance in the presence of water containing salts which form an electrolyte, the richer sections of a steel part will take on the role of a soluble anode compared to the more heterogeneous parts which take on the function of the cathode. A corrosion will result - Figure 2).

- physical reactions (for instance at low temperature metal materials have a reduced deformability which can lead to brittle phenomena in the case of impact or presence of nicks - Figure 3).

- mechanical reactions (for instance, repeated loads on a structure can lead to fatigue phenomena).

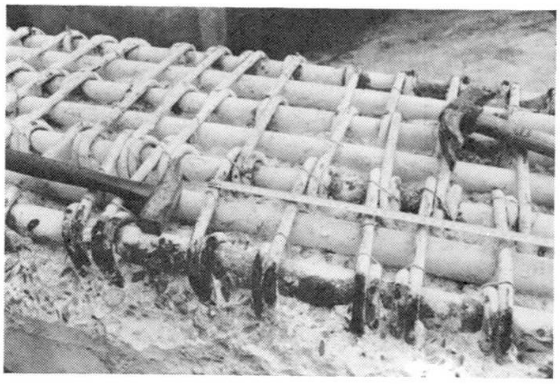

Fig.2

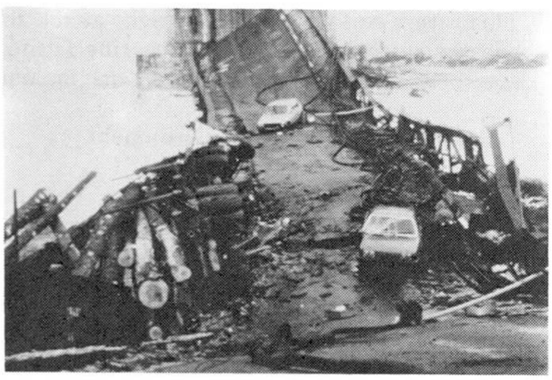

Fig. 3

To illustrate what I am saying, here are two typical examples which show the measures and precautions to take in the fight against certain factors which cause damage to materials.

. first example concerns the fight against water which is the main enemy of bridges especially as its effects are aggravated by thawing salt and the frost-thaw process. The designer must conceive the structure in order to:

- evacuate water by giving a bridge a longitudinal slope of at least 0.5% or better 1% (attention should be paid to top and low points where the water can stagnate) and a transversal slope of 2% or better 2.5%;
- avoid the water stagnating on the different bridge elements (mouldings, head rail of bridge railing, supports or piles and abutments) by providing these with slopes and arrangements such as flaps, water bars, gutters to guide the water outside;

- prevent the water from penetrating in the deck by protecting the whole surface with a sealing course. The deck itself can be self-protected by wide cantilevers;

- design solid, simple shapes which provide a minimum area open to aggression and which enable correct installation of concrete;

- provide the use of strong sheets for a metal deck and make sure that the beam ends are protected against drains and condensation;

- use air entrainers to improve the resistance of concrete to frost-thaw (the characteristics of the bubble network should generally be as follows: the spacing coefficient $\leq$ 200 um and the volume $\geq$ 25 mm^{-1}).

The second example concerns the choice of protection procedures against corrosion and warranty periods which apply within the scope of French public works contracts.

With regard to painting, there are different warranty periods concerning anti-corrosion and secondly the appearance (separation, pealing and blistering - changing colour - change in surface film) according to the following three parameters:

- firstly: classification of structures into three categories according to minimum thickness of elements ($\geq$ 8 mm, $\geq$ 4 mm, < 4 mm);
- secondly: surface preparation conditions (degree of stripping or scraping and brushing);
- thirdly: the protection system used in the three categories A, B and C. (Systems A benefit from an approval with control).

Furthermore, the warranties take into account exposure conditions. They are applicable to the following structures:

- overhead structures in country, urban or industrial and coastal atmosphere;
- structures submerged in soft water, sea water and aggressive water.

Certain structures are excluded which give rise to special research:

- structures located inside or immediately leeward of industrial or chemical complexes;
- structures in tropical atmosphere;
- structures submerged and protected by hot galvanising with electrolytic zinc plating.

2.2 - Assessment at design stage for the necessity of monitoring, service or even repair of structures

2.2.1 - General

During its existence, a structure must undergo maintenance work or even repairs. To carry out these maintenance operations in good time the structure must be monitored.

Therefore, a note must be made at the design phase of all sections of the structure which must be monitored in order to make them accessible for inspection in total safety, and secondly the sections which must be maintained or even repaired in order to make these operations easy to execute.
Furthermore, when the structure is completed it must be officially handed over to the manager by the chief consultant accompanied either by a visit and maintenance file if the structure is complex or large, or otherwise, a simple manual.

These two documents describe the monitoring actions and their frequency, specifying in what conditions and with what precautions maintenance or repair work should be carried out.

Normal bridges which cross over a road or are located at a low height above the ground are generally accessible by simple methods (ladder, scaffolding, platform on vehicle, inspection platform). The necessity of the inspection and service therefore has an influence on the design. However, access should be provided to the tops of piles and springers of abutments, bearing fittings and drainage and water discharge devices.

For the other structures, i.e. normal bridges with difficult access (over water, inaccessible overhanging ground, railway) and exceptional structures (suspension bridges or cable stayed bridges, box plate girder bridges, arch bridges). The necessity of inspections and maintenance influences their design and vice versa as the rest of my report shows.

2.2.2 - Effect on the deck design

. It is generally preferable to provide separate decks to support motorway pavements or assimilated in order to be able to execute maintenance operations wihtout traffic.

. The access to the outside of the deck can be provided by means of specialised commercially available machines such as electric foot-bridges if the following main measures are taken:

- the central space between two paired decks must allow clearance of the suspension column of the foot-bridge if the horizontal penetration of the foot-bridge is less than the deck width;
- the deck height must be adapted to the vertical penetration of the foot-bridge;
- the pavements, if they are wide, must allow the foot-bridge carrier vehicle to circulate (absence of high curves and fragile slabs);
- the lateral obstacles such as lamp posts and overhead traffic signs are to be avoided.

The presence of anti-noise shields requires the use of certain specific models of electric foot-bridges.

In the cases where usual inspection and maintenance machines cannot be used a special foot-bridge should be provided under or over the structure or else longitudinal fixed foot-bridges.

Special equipment is used for the large cable stayed bridges.

. Access inside the deck (for box girders) requires the presence of openings of sufficient dimension to enable personnel and maintenance equipment to pass through for installation or replacement of structures of utility companies (water pipes, electrical cables).

These openings must not be accessible to the public. Therefore, they are blocked off with doors, grids or trap doors which lock with a key. In addition, there must be no danger to the maintenance personnel and they should not adversely affect the structure durability. Consequently, manholes under pavements are formally advised against due to risk of accident and their doubtful watertightness. Furthermore, openings made in the piles and deck should be proscribed due to risks of falls from a great height.

Inside the deck, as far as possible, a sufficient space should be reserved to allow personnel to pass through. The passageways should be free of all obstacles or else these should be indicated by white paint and/or a local reinforcement of lighting.

In line with the spaces, or bridge parts there should be ladders or stairways plus openings for the passage. Figure 4.

It is desirable to light up the inside of the deck (20 to 25 lux). This signal lighting can be completed by headlamps provided the necessary sockets are reserved. The power supply can be either from the mains or a power plant.

The different sections of the structure must be indexed and oriented (numbering of segments and bearings, differentiation between upstream and downstream...).

2.2.3 - Effects on the design of bearings (piles and abutments)

Most of the recommendations on access, circulation and lighting in the decks apply to the bearings.

. Access to the outside of the piles can be provided by means of a suspended platform with a foot-bridge or more simply using a scaffolding provided the top of the pile has a small wall where the scaffolding suspension brackets can be secured.

. Access inside the hollow piles is from fire ladders intersected by stairs and if necessary a hanging scaffolding.

. The bearing supports must be designed to allow adjustment and changing of bearing fittings. It is desirable to have a minimum free height of 0.15 m to be able to install jacks and safety wedges where necessary.

With regard to large size supports and all those located at a considerable height, the free height must be increased (by 0.40 m to 0.80 m or even more) to allow the workers to operate in the space located between the top of the deck and the bearing supports - Figure 5.

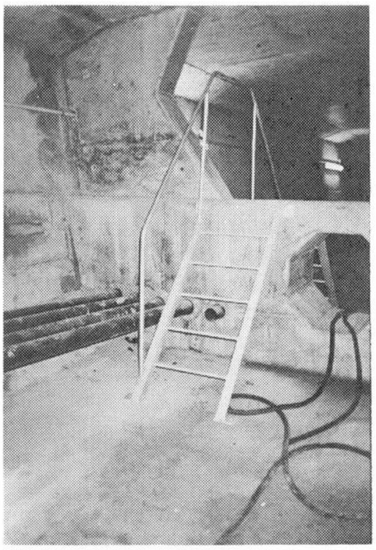

Fig.4

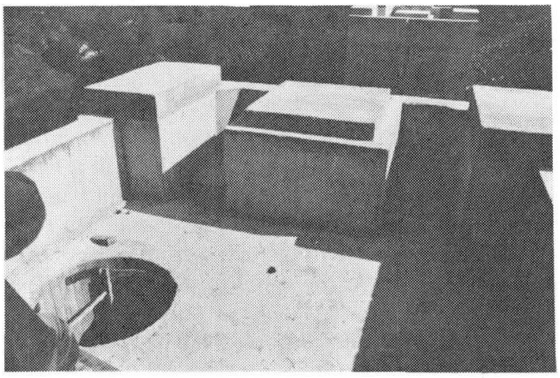

Fig.5

. With regard to the abutments, it is advisable to provide brackets at the end of the deck and on the parapet to provide a sufficient space between the two elements. This facilitates access for cleaning and maintenance (unblocking discharge pipes, renewing paint) and secondly ventilation of this damp zone as the expansion joints only provide a perfect seal in rare cases.

. Drainage and discharge of water from the bearings must be designed to be easily maintained. The water down pipes must have the most direct route possible and be accessible. For instance, with regard to abutments, it is preferable to discharge water by prefabricated ducts installed on the embankments rather than embed the pipes in the ground. In fact, pipes break under the consolidation of embankments with all the damaging consequences on the behaviour of the latter and the pavement.

2.3 - Assessment at the design stage of the necessity for adaptation and replacement of a structure or part of a structure

2.3.1 - General

In the case of bridges, these problems are initially raised for all equipment accessories (bearing fittings, pavement joints...) whose durability is considerably less than that of a bridge. The replacement or adaptation of these different elements is part of the specialised maintenance which has just been mentioned in the second point of my report. Therefore I will not bring up these problems again.

Apart from the equipment accessories, the problems of adaptation or replacement of a structure or one of its parts occurs for instance:

- for "strategic" structures for which the interruption of traffic flow is difficult to envisage;
- for structures whereby certain structural sections have a life which is probably quite less than that of the remaining structure or for structures whose life is reduced;
- for structures intended to be duplicated or enlarge or submitted to higher loads;
- for structures subjected to relatively unknown rheological phenomena.

2.3.2 - Some examples of structure adaptation

First example: It is rare to meet owners who, prior to start-up of a project research on a bridge, have precise ideas on the future of the structure. However, this does exist and was the case for the MECHELLE bridge project in Nancy which perfectly illustrates my arguments.

This structure, completed in December 1987, currently crosses the lake of the MECHELLE and the MEURTHE. It was designed to be used as an interchange for a future ring road which would use the current bed of the MEURTHE which would be transferred to the lake and made navigable.

This future adaptation led to three projects being studied:

- the project of the current bridge which has two lanes over part of its length and then three lanes;

- the project of an enlarged bridge to three and four lanes respectively;

- the project of the interchange bridge with creation of a crossroad on pile number two - Figure 6.

Furthermore, two piles had to be designed to the right of the lake capable of taking the impacts from boats.

Example two: In France for the last fifteen years, major structures in prestressed concrete have been designed to receive a complementary prestressing and an additional prestressing. The complementary prestressing is provided to be used during the construction phase. For this purpose, empty ducts are reserved to house the prestressing reinforcements if checks reveal insufficient prestressing (excessive friction, breakage of wires, wiring errors). If the empty ducts are not used, they are injected with a grouting compound when construction is completed.

Additional prestressing is planned to be used during the operational phase. Reserved spaces are made in line with the spaces to allow passage and fixture of external prestressing reinforcements to the concrete. This addition prestressing is installed if monitoring proves this necessary.

2.3.3 - Some examples where structure or structural sections are replaced

First example: Experience has shown that certain types of structures can have shorter lives than other equivalent structures when maintenance is neglected, and when aggressive agents (ice clearing salts, industrial waters) are present in the zone affecting the structure.

This may be the case for metal tubes too, the recommendations and state of the art developed by the Central Laboratory for Bridges and Highways (L.C.P.C.) and the Roads and Highways Engineering Department (S.E.T.R.A.) advise providing an extra template of about 15 cm in order to allow repair by the sheathing technique or shotcrete.

Second example: In France over the last few years external prestressing of concrete has been used in certain major structures usually in combination with internal prestressing of concrete.

Currently, this external prestressing can be removed and replaced. For this purpose, the prestressing reinforcements are arranged under a double tubing in line with deflectors and fixtures - Figure 7.

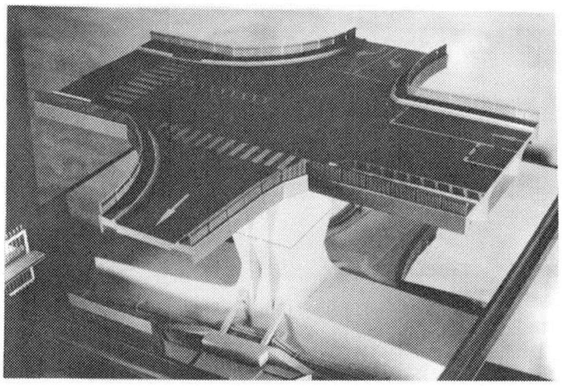

Fig.6

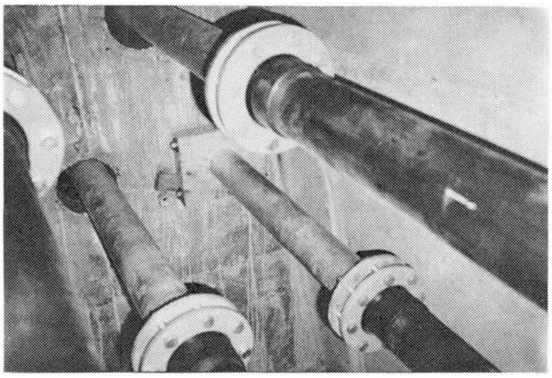

Fig.7

2.4 - Effect of construction methods on structural durability

2.4.1 - General

The construction method used for a structure often dictates the structure type and special construction arrangements although certain types of structures are less sturdy than others and certain building measures make the structures more sensitive to aggressive actions. Therefore, it is possible to say that construction methods have a certain influence on the durability of structures.

However, this statement should be moderated as the durability of a construction is also strongly influenced by the quality of the design and by the quality of execution. Consequently, the method for awarding study contracts and assigning works have also a certain influence on the durability of structures.

Therefore one can conclude that certain construction methods may have a negative influence on the durability of a structure, especially if certain precautions and certain constructive arrangements are not taken at the design phase and the execution phase or even management of the latter.

To illustrate my arguments I am going to deal with a few methods for building concrete bridges which make use of concreting in situ and prefabricated concrete.

2.4.2 - Construction on scaffolding and simulated techniques

First example: Structures poured in situ generally have a good behaviour in time except when the execution process leads to "slicing" the structure due to multiple repeated concreting in the longitudinal direction and in the transversal direction.

In such a case, shrinkage and differential creep appear in the form of cracks and in addition, the restart surfaces are weak points through which water and aggressive agents can penetrate.

Second example: construction by successive cantilevers with segments poured in situ on mobile rigs is a delicate technique for the following reasons:

- the multiplying of concreting restarts especially when the segment is concreted in several stages;
- deformation of rigs during concreting can lead to concrete cracking which starts to set especially at the level of the joints between segments;
- tensioning of prestressing reinforcements on fresh concrete can initiate diffusion cracks;
- the effects of redistributing stresses by deferred deformations (effects of creeping) are important due to the young age of the concrete....

2.4.3 - Prefabrication and associated techniques

First example: we refer to reinforced concrete bridges composed of prefabricated contiguous beams linked by spacers poured in situ. The current state of decks, about forty years old, in relation to the very satisfactory state of bearings shows what can be achieved without top slab and waterproofing layer - Figure 8.

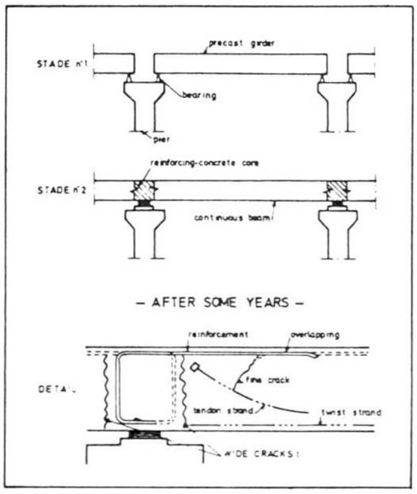

Fig.8

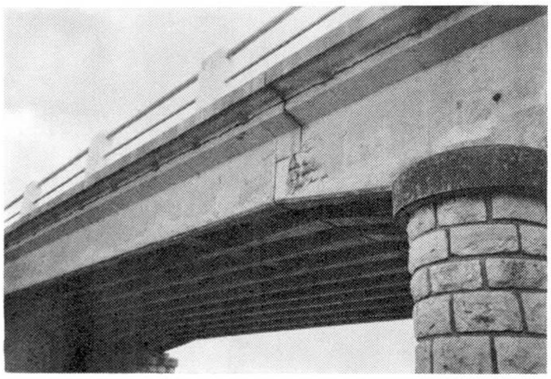

Fig.9

Second example: the assembly of prefabricated jointed elements interspersed with prestressed is a technique well developed which provides satisfaction. If the bonding film is eliminated at the joints, this causes the concrete to crack in line with the hard points through which the stresses pass preferentially. If the waterproofing layer is also eliminated, water and aggressive agents infiltrate by the cracks and cause disaggregation of the material by corrosion of reinforced concrete strengthenings.

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Third example: a certain number of small continuous structures have been built using prefabricated beams in prestressed concreted linked by a reinforced concrete core poured in situ in line with intermediate bearings. Effects of hindered delayed deformations (creepage and shrinkage) were not taken into account in design.

The current operating mode for these bridges leaves much to the imagination - Figure 9.

3 - CONCLUSION

Assessment of durability problems for a specific structure from the design phase through to execution should avoid both the premature appearance of major disorders or even its total damage, and secondly the transformation of the structure into a permanent repair site as is the case for instance for certain cathedrals whereby renewal is a never ending job much to the dismay of the owners.