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General Considerations on Bridge Durability

Considérations générales sur la durabilité des ponts

Allgemeine Betrachtung über die Dauerhaftigkeit von Brücken

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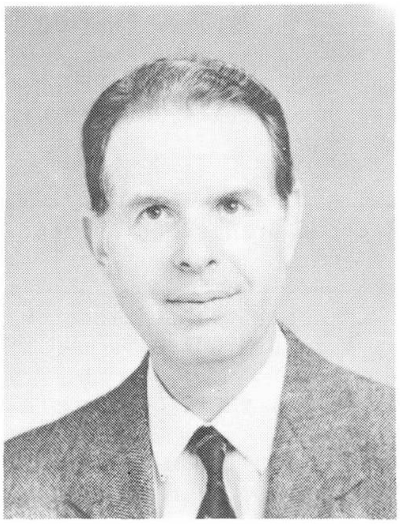

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SUMMARY

The life expectancy of bridges is somewhat variable, but economical considerations require it should be high, at least at the scale of a century. This may imply some changes in practice concerning design and contracting procedures, in order to improve quality, a condition of durability. Furthermore, the recent efforts of many countries in favour of maintenance must be further developed.

RÉSUMÉ

La durée de vie possible des ponts est assez variable, mais des considérations économiques exigent qu'elle soit élevée, au moins à l'échelle du siècle. Ceci peut conduire à des changements d'habitudes dans les procédures d'étude et de passation des marchés, en vue de promouvoir la qualité, condition de durabilité. En outre les récents efforts de nombreux pays en faveur de la maintenance devront encore être développés.

ZUSAMMENFASSUNG

Die Lebenserwartung von Brücken variiert von Fall zu Fall, sollte jedoch aus wirtschaftlichen Gründen in der Grössenordnung von 100 Jahren liegen. Diese Forderung bedingt gewisse Aenderungen der Projektierungs- und Ausschreibungsmethoden, um die Qualität, eine Grundbedingun der Dauerhaftigkeit, zu verbessern. Darüber hinaus sind die Anstrengungen zahlreicher Länder für einen besseren Unterhalt weiterzuführen.

1. ECONOMICAL CONSIDERATIONS

For bridges the concept of lifetime is of great importance, as otherwise the demands placed on public maintenance repair and replacement budgets would be too great. Bridge construction is an ancient activity of civilized societies ; as nowadays many old bridges are still suitable for service, we have been thinking for a long time that long lifetimes could be expected from bridges. Nevertheless we must admit today that the efforts of modern technology have aimed more to lower the cost of structures than to improve their durability.

An interesting report of the OECD, entitled Bridge Maintenance and dated 1981, gives some data, which we reproduce below, concerning the annual rate of bridge replacement in different countries.

Country	Rate of Bridge Replacement	Rate % per ann.
Belgium	No data. As a first approximation assume a life of 100 years	
Denmark	2-4 bridges per 1,000 at present.	0.2 to 0.4
Finland	18 bridges per 1,000 and 10 culverts per 1,000 during 1978.	1.8
France	142 bridges per year out of approx.50,000 (average for 1976, 77, and 78)	0.3
Germany	Overall replacement rate	0.6
Italy	5 motorway bridges out of 1,200 replaced during last 20 years	0.02(*)
Netherlands	1 bridge per 1,000 (due to technical obsolescence), on the State Highway System, which started in the 1930s	0.1(*)
Norway	16 bridges per 1,000 on National Roads (average of 1977 and 1978)	1.6
Sweden	Estimated at 6 bridges per 1,000	0.6
United Kingdom	Estimated at 4 bridges per 1,000	0.4
United States	3,620 out of 258,000 Federal Aid bridges being replaced over a period of 7 years.	0.2

(*) These rates relate to systems containing a high proportion of new structures

The reasons for replacement were not recorded, but some countries indicate that their rate was limited by the funds available. If we do not take into account the low rates, which concern highway system containing a large proportion of new bridges, neither the high rate, due to replacements necessitated by a change in vehicle regulations, the range appears to be between 0.2 per cent and 0.6 per cent per annum, with an exceptionnal high rate of 1.6 per annum in Norway.

A rate of 0.6 leads to an assumed serviceable life of 170 years, and the rate of 0.2 raises this assumed life up to 500 years, what is obviously far too much. But this approach takes into account only an average replacement rate, which should be available for long periods. Now in all industrialised countries many more bridges were built in the last few decades than in the past, and this fact tends to lower the average age of the stock of bridges. Three examples of age distribution are shown in Figure 1, concerning the stock of bridges of two German Länder and of the United Kingdom. They show that in these regions 90 per cent of the bridges are less than 50 to 80 years old.

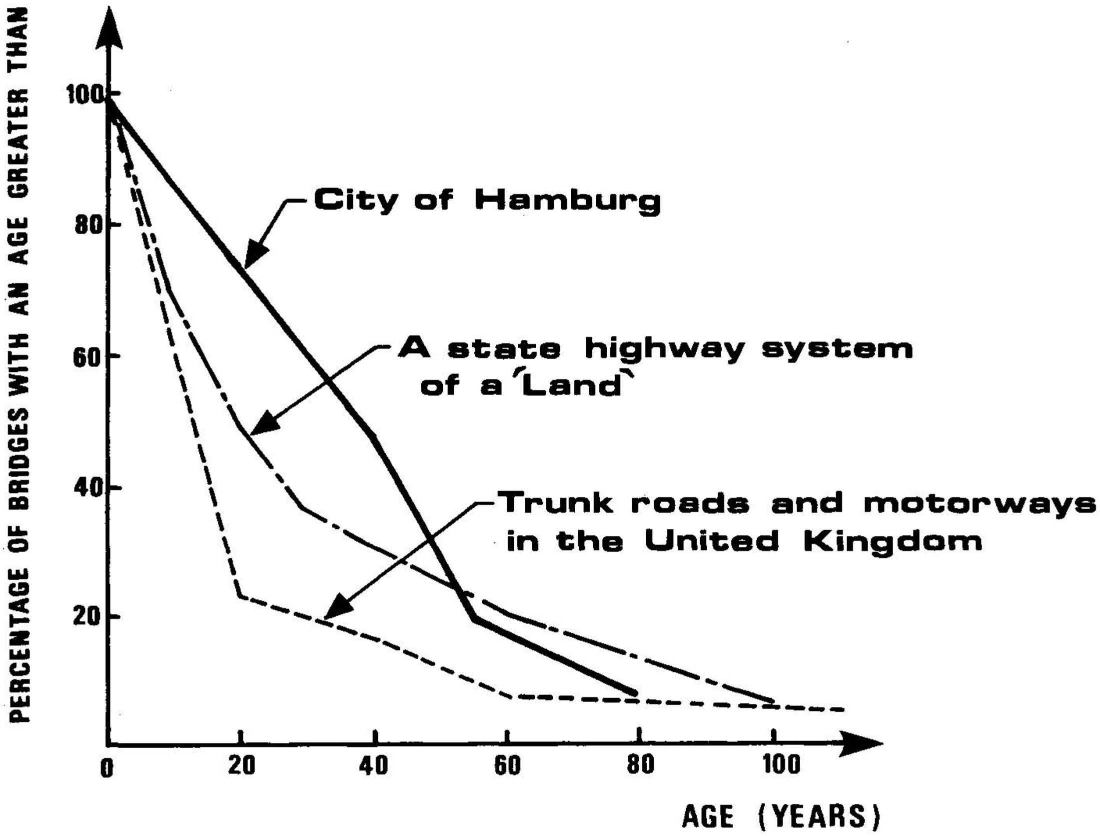

Fig. 1 : Example of age distribution

How it is possible to take into account the age distribution is well illustrated by a study of the German Land of Rhine Palatinate concerning bridge construction planning. The "bridge generation cycle" is assumed to be 60 years, and is shown in the form of a spiral in Figure 2.

Starting from the total number of bridges existing in 1918, this graph shows the number built each year between 1918 and 1947, then between 1947 and 1977. During the period 1977-2007 the bridge building programme will consist on the one hand of new structures (over 1,000), corresponding to the extension of the existing stock, and on the other hand in the replacement of bridges built between 1918 and 1947, when they reach the age of 60 years, the total number of the latter being greater than the former. Then, after 2007, the bridges built between 1947 and 1977 will progressively need replacement.

The method is interesting, although a life expectancy of 60 years seems to be a little short. Moreover, it neglects two factors : first, the deck area to be rebuilt would perhaps be a better parameter than the number of structures, as the latter includes large and small structures. Then, bridges of various ages were built with different techniques, and there is no reason to assume that different techniques lead to the same expected life.

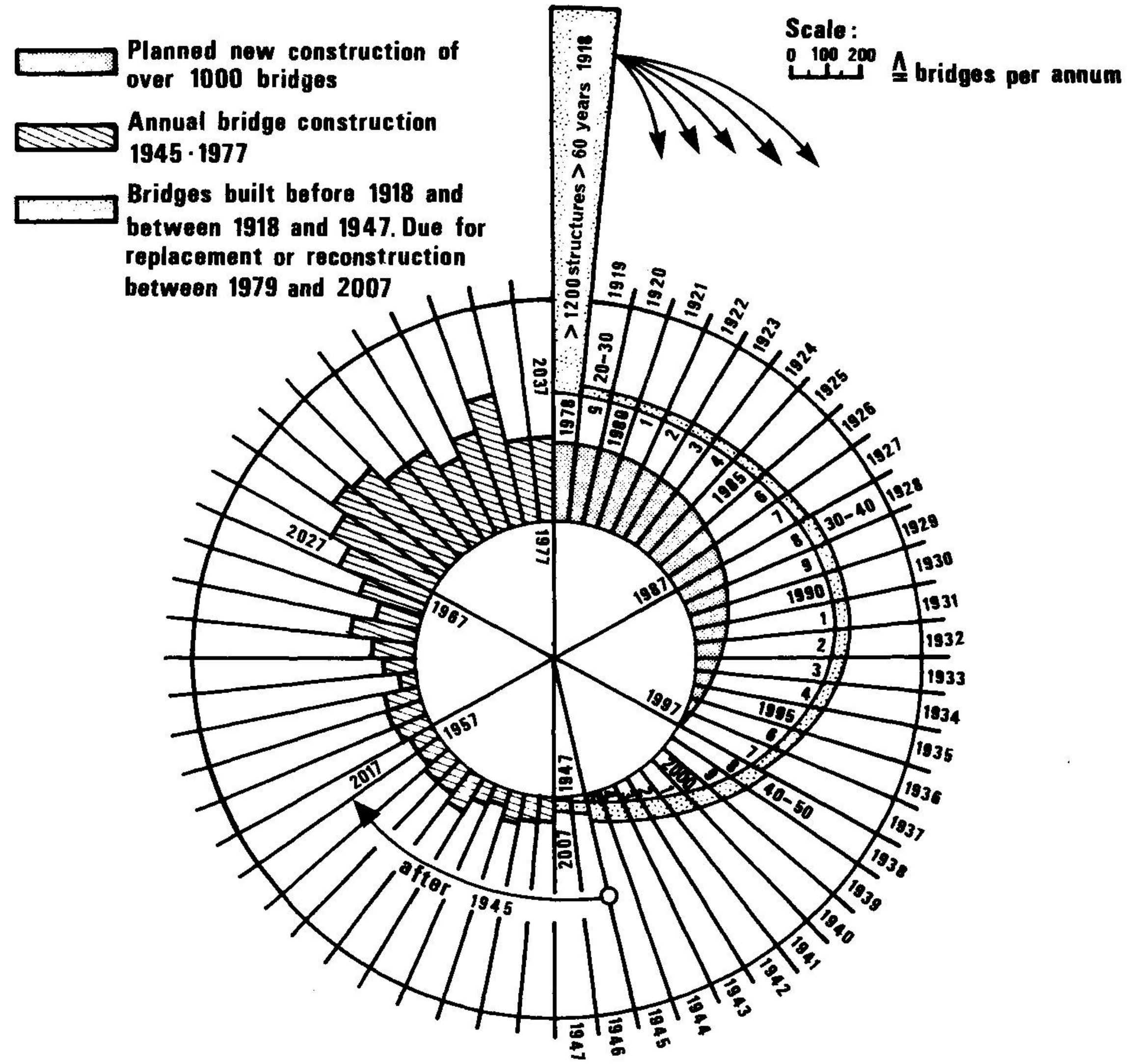

Fig. 2 : Bridge generation cycle of Rhine Palatinate Land

In France, for example, there are no detailed statistics concerning the materials of bridges and their state of maintenance, but a survey of the repair files established for financing purposes as well as the experience of local Départements make it possible to give an idea of the durability differences between techniques.

Many bridges, especially small and medium-sized in the local networks, are still masonry arches. They often have suffered from lack of maintenance, but because of their strength they often present sufficient serviceability, sometimes after some repairs. It also appeared that the foundations of the old masonry bridges on large rivers frequently were not deep enough to escape undermining, as a consequence of the technical limits imposed when they were built. But a foundation strengthening is possible, and if done, puts them in excellent serviceability.

As far as the old steel bridges are concerned, they generally support fairly well their growing old, if the painting has been renewed with sufficient frequency.

They were indeed fairly liberally dimensioned, because of the lack of knowledge in the calculation of structures, and fatigue does not seem yet to affect them. An exception, however, is to be mentioned concerning all steel bridges the deck of which is made out of little masonry arches : the latter are not waterproof and the corrosion has often strongly attacked the steel pieces supporting the deck.

Fig. 3 : Old steel bridge

Another exception, the suspension bridges : there are a little more than 200 of them in France, the major part of them being built a fairly long time ago and located in the secondary networks. Their load carrying capacity is frequently insufficient, and their maintenance condition rather poor. The collapse of one of them during the particularly cold winter of 1985 pointed out the vulnerability of the suspension bars of most of them, under low temperatures, due to the steel quality used at the time.

Fig.4 : The Sully suspension bridge

Further, the reinforced concrete bridges fall into another category. Some of those built in the first decades of reinforced concrete construction are beginning to need replacement. At that time indeed, no means of correct vibration were available, and the concrete density was insufficient. Modern concrete bridges seem to have a good behaviour, but will this last for a long time, particularly with salt aggression : we simply do not know. Many countries have suddenly encountered rather serious corrosion problems with the use of salt on roads during the winter. In France fairly high percentages of cement in the concrete used to be employed, and this

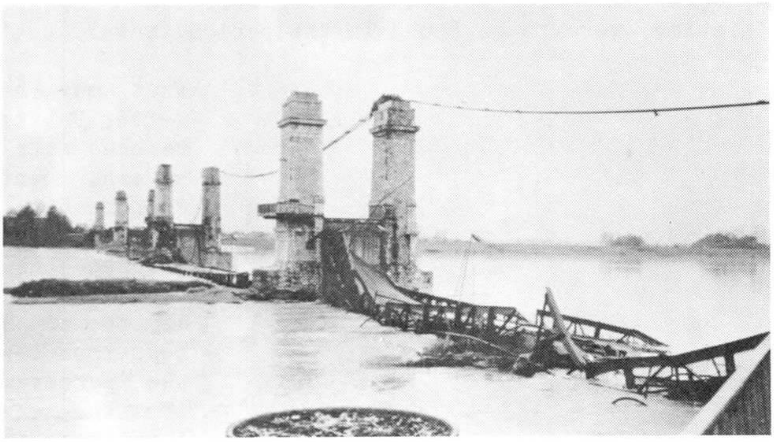

Fig. 5 : The same after collapse on Jan.16. 1985

explains perhaps the now prevailing good condition of the relatively recent concrete bridges. Nevertheless the appearance of some cases of alkali-aggregate reaction in the North of France points out a danger which up to now had not yet appeared in this country, and nobody knows whether this problem will remain limited or not in the future.

Finally, the last technique of primary importance to appear in the field of bridge construction is, of course, prestressed concrete. The first structures built in the 1950's were made out of precast in-situ prestressed beams. Many structures of this decade present lack of grouting and insufficient waterproofing, so that the tendons have been severely attacked by corrosion. It has been necessary to replace several structures of this type.

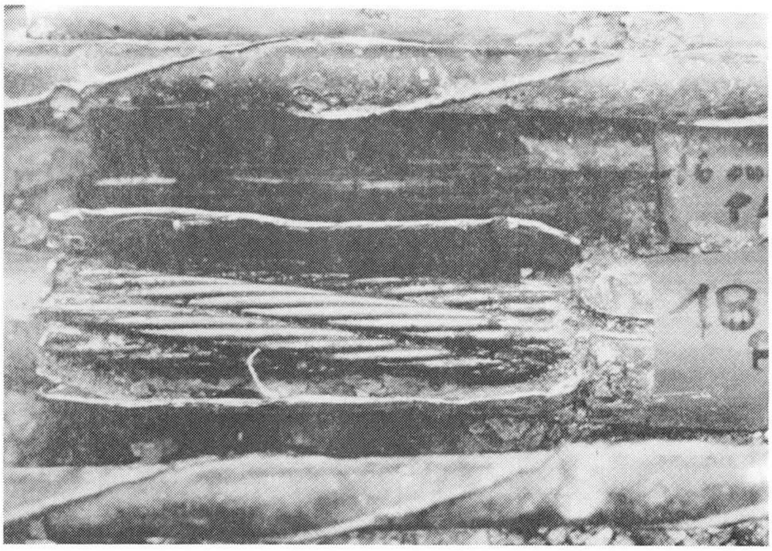

Fig. 6 : Attack of the tendons by corrosion

Another defect, which appeared in prestressed box-girders of the 1960's and the beginning of the 1970's is the lack of prestressing, due to some effects now well known. This lead to repairs by additional prestressing, which do not seem to have a noticeable effect on the life expectancy of these bridges.

Another indication concerning the life expectancy of bridges is given by following little statistics concerning 501 bridges replaced in France between 1978 and 1983. 13 of these only, all masonry bridges, were more than 200 years old and in the period from 150 to 200 years 15 were masonry bridges and 3 metal bridges. The highest densities of replaced bridges, according to their actual lifetime, were to be found in the period from 75 to 100 years.

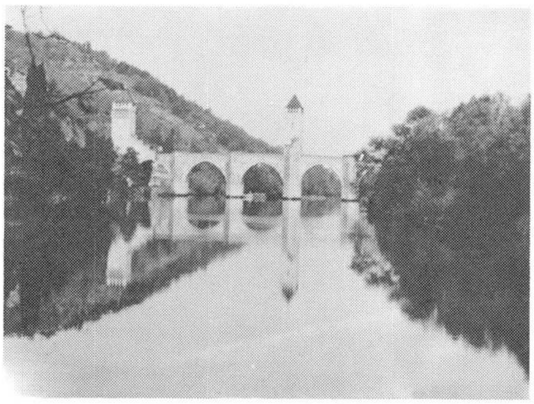

Fig. 7 : Masonry technique reached its maturity through centuries

What may be concluded from this brief survey ? The old technique of masonry reached its level of maturity through several centuries and it left some comfortable capacity margins for live load. Modern techniques have highly reduced the costs of construction, but they are developing faster and faster and a lot of bridges are built before their behaviour can be tested by time. Moreover, the increase of heavy traffic, the attacks from the environment, the use of salt spreading in winter, the growing strains allowed by codes are factors affecting durability.

Nevertheless most of the initial defects of a new technique are later overcome. Moreover, modern structures do not necessarily require complete reconstruction, because the foundations, piers and abutments can usually be retained. Thus, while some existing bridges may need replacement after 40-60 years, a design life of the order of 100 years is generally considered to be attainable by modern structures.

2. THE CHALLENGE OF THE DESIGN

New techniques and innovation tend surely to lower construction costs in high proportions, and make it possible to have more ambitious construction programmes, with a fixed possible expenditure. But the audacity of the innovator must be accompanied by an equal prudence. As an example the five bridges built on the Marne River by Freyssinet in 1949, which were among the very first prestressed bridges, are nowadays in good condition, while some other prestressed bridges built later required rather substantial repairs, as we just have seen.

The experience from many repairs shows that some additional but limited expense during the building period would have later saved heavy expenses. Moreover, repairs are not always able to restore to the structure its normal life expectancy. One might say, as a figure of speech, that one dollar wrongly saved in the design generates ten dollars needlessly spent on site, and that ten dollars wrongly saved during construction generates hundred dollars of extra repairs during the lifetime of the structure.

So the challenge to the designer consists in avoiding false economies, while saving all what is possible through technical progress and skilled design. Intelligent design indeed is quite different from blind application of technical prescriptions or rules. It is fairly difficult because the designer has to think of many things : general design, detailing, possibilities of future disorders, accessibility for inspection and repair, etc. In the case of a somewhat innovative structure, he must imagine how this one will be working and find appropriate calculation models.

Usually the owner of a future structure chooses a particular designer, consultant or official, according to proficiency criteria, which he cannot always appreciate with a certain accuracy, or he even selects him according to quite other criteria, for example the amount of the required fee or the geographical proximity. In our opinion, this way of acting ought to change somewhat. The importance of good design for the bridge durability does not suffer to emphasize other criteria without sufficient regard to professional skill.

For some years now in France, and for fairly large structures, of course, we usually choose two or even more designers who will work together, splitting the whole task between themselves under the direction of one of them. This makes it possible to benefit from the specific experience and proficiency of several designers. It also allows one to make two and even several complete designs for a given bridge. So it is possible to test by the competition between contractors which is the better structure from the economical point of view, and to promote progress with all the required care. Design fees indeed are very small, compared with the benefits to expect from better designs.

Another solution equally used is for the owner choosing another consultant than the one in charge of the design in order to advise him, i.e. in fact to propose to the designer improvements to the design. We are convinced that the greater technical difficulty of large modern bridges is a valid reason to give greater care to obtaining a better design, as much in its main features as in all its details. Durability is at this price.

3. THE CONTRACTS

For contracts the same balance as for design is to be kept between security, which is a condition of durability, and risk, which is the counterpart of technical progress. A source of progress consists in allowing the contractor to present some alternate features to the design, in order to adapt it to his own equipment and building methods, or even in some cases to propose an alternative. The alternate features permitted by the competition rule may be more or less extended, but in our opinion it is desirable to leave a margin to the contractor, considering the importance of building methods in modern bridge design.

The counterpart of this intervention of the contractor must *not* be a reason to reduce the requirement of proficiency and skill concerning the main designer. On the contrary, it is necessary to have the detailed design proposed by the contractor entirely verified and recalculated by the consultant. Quality and durability require this care in the perfecting of the design.

We have concentrated on the quality of the design, but a similar effort is to be made to use the quality assurance methods in the whole building process. The professions of construction are not yet aware enough of the necessity of improving their working methods, as it is now being done in industry. This ought to be even more obvious for bridges, the life expectancy of which is much longer than for industrial products.

4. SMALL BRIDGES

Each small structure cannot be designed with the same luxury of care as with large structures. Nevertheless small bridges are much more numerous than the large ones, and the asset they constitute is higher. Therefore, the problem of their durability is as important as for the latter. Moreover, the contractors who build small structures generally are less skilled than those who build the large bridges.

So the major point concerning small bridges is simplicity : simplicity of design, simplicity of building. This is the best guarantee of their durability. A good solution to obtain this simplicity consists in standardizing them. Prefabrication may accompany this standardization. This last solution is used for example in Belgium, and in the cold countries, for obvious reasons of climate.

In France both the economical conditions and the climate make it possible to build small structures with cast in-situ concrete. So the major part of the standardized small bridges is composed of slab decks. Their design is quite simple and fast, due to the fact that the calculation of the standard slabs is made at low price in a special public office using specific computer programs.

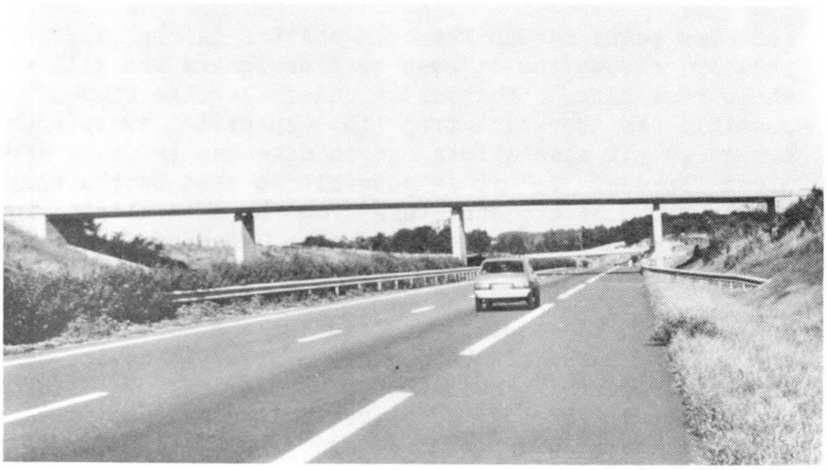

Fig. 8 : Simplicity of the slab deck for common bridges

These slabs are very strong structures, since in more than twenty years thousands of this type of bridge have been built, and their durability appears to be excellent.

5. BRIDGE MANAGEMENT

The different countries are now more aware of the necessity of promoting bridge inspection and maintenance policies, in order to obtain sufficient durability of this considerable asset. Prevention is more efficient and less expensive than subsequent repairs. Bridge inspection rules and bridge inspection manuals have been developed in several countries. Another step will consist in developing a bridge management system in order to obtain the best efficiency of public repair expenditures.

But an important aspect of maintenance concerns the inspection equipment. Large progress has been done in this field, but much more still remains to be done. For example, testing the load carrying capacity of reinforced concrete bridges by calculation would require further progress, in order to be able to detect the diameter and the location of all reinforcing bars. Devices exist nowadays, which can detect some details of the reinforcement, but not all the desirable ones.

6. CONCLUSION

It is now the moment to conclude this brief survey of some general aspects concerning bridge durability. The latter is an essential requirement for bridges perhaps even more for them than for other products of human activity, because the considerable asset they represent cannot be replaced very quickly, due to limitations of public budgets.

Now it seems that the main efforts of technical progress up to the present have tended to reduce the cost of construction. Without renouncing this purpose, it will be necessary in the future to bring an equal care to quality, which is an essential factor of durability. Taking into account the greater complexity and boldness of modern bridges, this may imply some change in enginering practice concerning design and contracting procedures. Finally, the better care now brought to maintenance certainly must be more developed.

Examining all these points is the object of the present Symposium. I hope it will come up to the participants' expectations.

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