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Widening of Existing Bridges – a Case Study

Elargissement de ponts existants – Etude d'un cas

Verbreiterung von bestehenden Brücken – Fallbeispiel

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SUMMARY
The increased traffic and the high costs of time and building materials have made economically beneficial to widen existing bridges simultaneously with their rehabilitation. The redesign of concrete structures introduces some problems usually not considered in the design of new structures which are succintly referred to. A practical case of widening of a bridge with calculations not available is described.

RÉSUMÉ
L'augmentation du trafic et les coûts élévés de construction ont rendent intéressants du point de vue économique la réhabilitation des ponts existants. La transformation des structures de béton existantes pose quelques problèmes qui d'ordinaire ne sont pas considérés dans la conception des nouvelles structures. Un cas pratique de l'élargissement d'un pont, dont les calculs du projet original n'étaient plus disponibles, est décrit dans ce travail.

ZUSAMMENFASSUNG
Die Durchführung von Reparaturarbeiten an vorhandenen Brücken gleichzeitig mit deren Verbreiterung hat sich als eine wirtschaftliche Maßnahme zur Lösung der Probleme, die aus der Zunahme der Verkehrsbelastung resultieren, erwiesen. Die Nachrechnung von vorhandenen Bauwerken aus Beton stellt einige Fragen, die bei der Berechnung von neuen Strukturen nicht vorkommen. Einige dieser Probleme werden dargestellt. Ein Beispiel aus der Praxis für die Verbreiterung einer Brücke, deren Berechnungen nicht mehr vorhanden waren, wird beschrieben.

1. INTRODUCTION

Traffic volume and weight have increased systematically in recent decades following an industrial and demographic development. Time has become more precious in a society where efficiency is in constant demand. Both these factors have contributed to the improvement and widening of public roads.

The ever-rising costs of workmanship and building materials have made it quite costly to demolish existing bridges in order to build larger newer ones. On the other hand, this would frequently pose the problem of transferring traffic to alternative routes for a long period of time which, in some cases, is economically ruinous. Studies of economic feasibility point out that it is beneficial to widen existing bridges simultaneously with their rehabilitation.

2. THE REDESIGN OF EXISTING STRUCTURES

In the last few decades, the design of new structures has undergone important and revolutionary developments. New techniques have come up and computerized design has taken over. The knowledge of building materials has also been widened to a large degree and new materials have been put on the market.

However, scientific investigation of the behaviour of these materials in time has not kept up to the same standards. The problems connected with pathology of structures were not widely mentioned in scientific literature before this decade. The redesign of existing structures is not yet object to any international regulations and the structural engineer faced with a practical case is more or less on his own.

Renovation of existing structures puts forward some problems usually not considered in the design of new structures. Some of these problems will next be referred to in a succint way.

2.1. Assessment of the Existing Structure

This is probably the most troublesome part of the process of redesigning a structure due to the great number of variables involved. It has to do with the degradation of the mechanical characteristics of the building materials in time, which can be very drastic if there is a high degree of steel corrosion. It also must consider the behaviour of some structural details like connections, support bearings, joints, etc.

For an efficient assessment of the structure the geometry also has to be thoroughly checked to detect possible disagreements between the reality and the initial building plans. The existing materials can be assessed through in-situ testing (ultra-sonic pulse velocity, sclerometer, cores, etc.).

2.2. Remaining Expected Life-Time

The prediction of the residual expected life-time of an existing reinforced concrete structure is a science still in its first steps. Several researchers [3] have already indicated paths for investigation, developed general philosophies on how to deal with the problem and even put forward some experimental work or mathematical models of practical cases. Nevertheless, the results have not been conclusive enough. There is a general feeling that there is a long way to go before reliable and easy to apply conclusions are reached so that the great majority of civil engineers can use them for everyday design.

The very notion of service life of a structure is not yet clear enough in the minds of engineers and builders. What happens frequently in practice is that the real life of a structure is more often dependant on economical factors than on the development of its mechanical characteristics or its durability **[1]**.

The importance of knowing the remaining life-time of a structure when it is being repaired is obvious. In a probability based design theory, the design demands are the harsher the longer that period of time is expected to be.

2.3. Interaction of Materials of Different Ages

Most techniques of repair and strengthening of existing structures resort to the addition of new materials. Some are of traditional use like plain concrete or ordinary steel. Others include gunite, plastic or metallic fibre reinforced concrete, pre-stressed steel, steel plates either glued or riveted, etc.

The design using these materials, even the more recent ones, poses no special difficulties as there is a wide range of experimental work on them. The main problem is to guarantee that the new added materials are securely fastened to the pre-existing element. In theory, if the connection were perfect, the design of the strengthened element would assume a monolithic functioning. In practice, that is not necessarily so. To account for this uncertainty, some procedures may be used **[2]**: use higher safety factors for the added materials; assume only a certain degree of monolithic behaviour; design the adherence surface and the associated connecting rivets, bolts or embedded stirrups. In either case, investigation is needed in order to put forward some practical design recommendations.

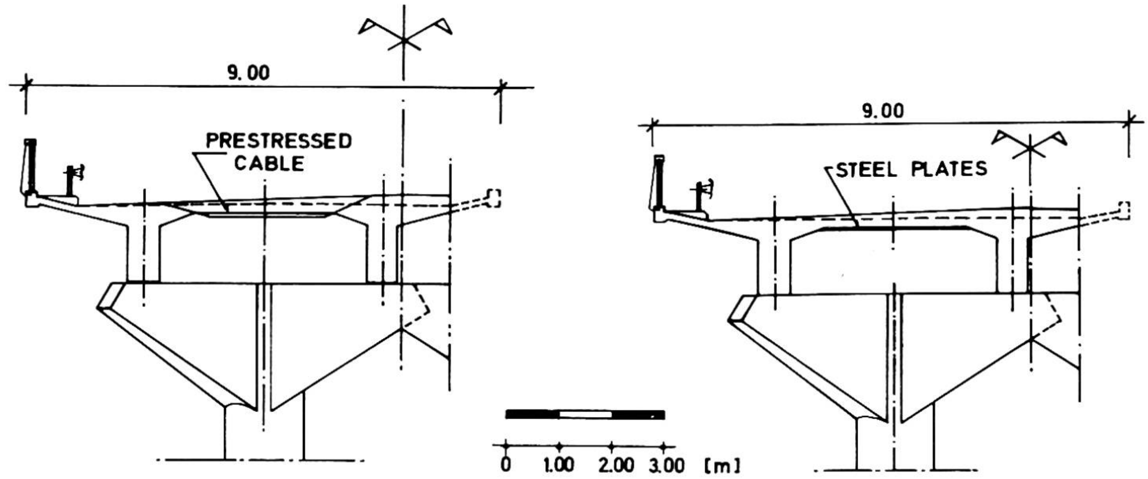
2.4. Force Effects Redistribution within the Structure

The distribution of force effects within a hyperstatic structure depends on the relative values of the stiffness of each element. The addition of new materials to the pre-existing elements changes its stiffness and has consequences in the distribution of force effects in the structure as a whole. The same happens if new structural elements are included in the previous structure.

The evaluation of the new stiffness of the elements is in itself a difficulty as it depends on the assessment of the existing materials at the time of the repair work and on the interaction of materials of different ages.

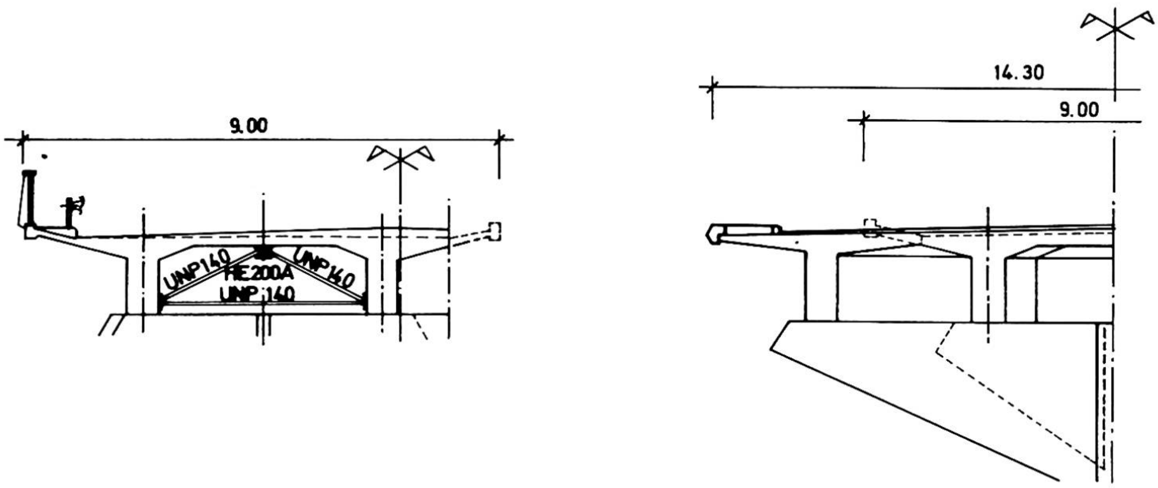
The design force effects for the strengthened structure can only be obtained through an incremental analysis of the loading taking into account which structure sustains which part of the loading.

The dynamic characteristics of the structures are also affected by the repair work. In particular, the fundamental frequency usually increases which may lead to an increase of the seismic coefficient.



1st Solution (Road axis changes): DYWIDAG 20F strand cables spaced 0.50 m in the longitudinal direction anchored at the top of the slab. The anchorages are to be sealed with epoxy mortar.

2nd Solution (Road axis changes): steel plates with 2800x250x4 spaced 1.00 m in the longitudinal direction glued and riveted to the concrete.



3rd Solution (Road axis changes): metallic frames spaced 2.00 m in the longitudinal direction on top of which rests a HE200A beam. The frames are connected to the longitudinal beams through plates riveted to the concrete.

Final Solution (Road axis constant): thickening of existing slab and introduction of additional ordinary steel reinforcement over the longitudinal beams.

Fig. 1 Alternative systems for widening the deck of a rural bridge and simultaneously strengthen the existing slab

3. A CASE STUDY - WIDENING OF A RURAL BRIDGE

3.1. Problem Description

A particular rural bridge had to be widened from 9.00 m to 14.30 m due to an increase in traffic. The existing bridge had been designed in the early sixties according to the National Design Code in use at the the time **[4]**. The actual Code **[5]** foresees traffic loads substantially higher than the ones considered in the original design. The seismic loads have also been increased according to more modern theories.

3.2. Assessment of the Existing Bridge

Description of the structure - the existing structure consisted of a bridge deck monolithic with two longitudinal beams which were supported by two intermediate circular collumns and the abutments. It has shallow foundations supported by a high bearing capacity soil.

Initial design calculations - they were missing but final drawings of the structure were available.

Building materials - the concrete, over 20 years old, showed no important signs of degradation whatsoever and there were no external symptoms of steel corrosion. To assess the existing materials, in-situ non-destructive testing was used: sclerometer and cores. Conservative values for materials properties were used in the design.

Structural safety - a preliminary analysis of the existing bridge deck showed that only the slab deck needed strengthening according to the new Code forces. This was confirmed in the final design.

Remaining service-life - it was considered that the time already passed since the building of the bridge was to be deducted from the normal design service-life of a new structure.

3.3. Design Solutions

To widen the bridge, two basic hypotheses were considered, related to changing or keeping the road axis. In the first situation, the widening of the deck would be all done to one side. This would involve the demolition of the pedestrian passage-way and the building of the remaining deck supported by an additional beam which would rest on two extra intermediate columns. The outside look of the bridge would not change.

To account for the increased loads in the existing deck three different solutions for slab strengthening were studied: one with the introduction of pre-stressed steel, the second using steel plates glued with epoxy and riveted on both ends and a last one using a three-dimensional metallic frame (Fig. 1).

The other situation led to a solution where the widening of the deck was done symmetrically to both sides. Two extra longitudinal beams had to be built and the existing columns were significantly thickened which changed the outside look of the bridge. The existing bridge deck slab had to be thickened to account for the transversal sloping of the road which made it possible to avoid an external system of strengthening by using additional reinforcement. The columns foundations were enlarged. Due to traffic conditions, this last solution was adopted.

3.4. Design Methods

New force effects were taken into account to conform with the new road traffic loads and the new code on earthquake design. An incremental study of the loading of the structure was done to estimate force effects distribution both in the new elements and the pre-existing ones.

The sections were considered as monolithic. To guarantee such functioning of the old and new materials all common surfaces are to be pick-axed, blown free of all particles or dust and plastered with a suitable epoxy formulation. On vertical or inverted surfaces the new concrete is to be shotcreted.

4. CONCLUSIONS

In this paper a contribution to the analysis of the redesign of existing bridges was presented. Special attention must be paid to the following subjects: degradation of building materials with time and ways of preventing it; techniques of in-situ structural evaluation; criteria as to when a structure is to be considered as obsolete; force effects redistribution; more appropriate safety factors for the design of structures with new and old materials.

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