Prestressed concrete bridge design expert system

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Summary

Bridge engineering is a field where competitive tendering for non-conforming designs is very common, indicating that many inefficient structures are still being designed. The process of bridge design is a complex task because of the number of design options, the large number of design parameters and the interaction between them. It takes years of experience to develop an understanding of the design process. The design is often perceived as an iterative process of generation, evaluation and modification of trial designs. The paper describes the development of an expert system BRIDEX, for the design of prestressed concrete bridges. The philosophy is to develop a system which can take account of governing factors at an early stage in the design process, thus minimising the iterative nature of design. BRIDEX will help unravel the design intricacies and guide the designer in making decisions.

Introduction

Expert Systems appear to offer a great deal to design engineers; proponents of such systems imply that they will be able to completely automate the decision making process. Advances in computing power in the 1960s were matched by changes in the way analyses were carried out, primarily because existing analysis methods had been limited by the difficulty in solving simultaneous equations. But this revolution only affected *analysis* - it had little impact on the *design* process, except in as much as the analysis stage became faster. Indeed, it can be argued that computer analysis made design worse. Engineers no longer had to think carefully about the structures they designed. A trial structure was chosen and analysed; if it failed, modifications were made and the structure reanalysed, until it was satisfactory. It is the dearth of good design principles which motivated the authors to undertake the work described in this paper.

Novice and Expert designers

We start with an analogy with human designers. A *novice* designer, when presented with a new problem, is unlikely to know where to start. Guesses are made, more or less at random, about the structural form, and many analyses are carried out. Improvements to the structure will result from questions of the form "What if I change this a little?", which is a procedure very similar to the strategies adopted in numerical optimisation.

As the designer becomes more experienced, less and less is done by way of guesswork. The underlying principles will be understood, so that decisions can be taken without major computation. The design will now evolve, with choices being made in a logical sequence. Simple calculations will be carried out, which allow major dimensions to be chosen. This then allows further calculations, after which more dimensions can be fixed. The design progresses in this way until it is complete. At some stage in the design process, a complete analysis needs to be carried out, if only to satisfy the checking authority, but the designer does this with the expectation that the structure will be satisfactory. Good design is not iterative, so effort is not wasted. Our designer has now become an expert, and we want our expert system to mimic this way of carrying out design.

Structure of BRIDEX

A schematic representation of the architecture of BRIDEX is shown in Fig 1. BRIDEX is being developed using the Edinburgh Prolog Blackboard Shell (EPBS). The structure of BRIDEX consists of:

Knowledge base

The knowledge base of BRIDEX has two main knowledge modules for *preliminary design* (Fig 2a) and *detailed design* (Fig 2b), both of which have a number of submodules. BRIDEX is an extension of the expert system module PREDEX, previously developed by Jayasinghe (1).

Scheduler

The scheduler is the control mechanism which determines the sequence of execution of tasks based on *est*, an estimate of the usefulness of rules in the knowledge base. Rules are assigned a value of *est* which ensures that the rules are triggered, in the first instance, in the most logical sequence. Exhaustive searches involving non-optimal sequences are still possible.

User interface

A graphical interface is provided which enables selected cross section, bending moment envelopes, permissible limits on cable forces and cable layout to be presented graphically to the designer.

Implementation of the expert system

The program has been written using the principle that the computer should calculate whatever it can, and it should present to the designer any relevant limits on what the designer has to choose. The information should be presented in a logical sequence, so that the design becomes more fixed as the process continues. The designer can then make those choices in the certainty that subsequent analyses and checks will be successful.

At present, BRIDEX can design continuous prestressed concrete bridges built by *span-by-span* construction technique, which is often adopted in the case of long viaducts with relatively short spans. The superstructure is built in one direction, by means of a form traveller. As the segments are assembled in stages, progressive prestressing is carried out to provide the structural integrity and also to resist the dead load moments. The prestressing cables usually overlap in the support region. The design sequence is as follows:

- The designer specifies the basic problem parameters - total span, support positions, construction length at each stage and loads. The width of the top flange for a road bridge is governed by the number of lanes, width of lanes, width of foot path, thickness of parapet wall etc. These are normally part of design specifications and there is little scope for variation.

- The top flange must carry local bending, which defines its thickness. In the implementation of the expert system, a simple rule defines this thickness, but this could easily be replaced by a more refined calculation.

- The overall depth of the structure is fixed by specifying a span-depth ratio. The width of the bottom flange is defined by choosing the cantilever overhang of the deck and specifying the inclination of the webs.

- The designer selects the type of top flange (reinforced or prestressed), type of web (with or without ducts) and the quality of concrete.

- The thickness of the webs and the number of webs is controlled by practical considerations, included in the implementations as a set of simple rules. The system makes an estimate of the bottom flange thickness.

- The engineer chooses the desired amount of secondary moment by specifying the *reactant moment ratio* (RMR). By definition, the secondary moment must vary linearly along the bridge span, and must be zero at the ends. It is uniquely defined by the value of M_2 at the internal supports. It is most conveniently expressed as a fraction of the hogging moment at the supports due to the dead load of the structure, as in Fig 3.

- The program analyses the structure to determine the live load moment envelopes and the dead load moments, taking account of the construction sequence. The design moments under the working load condition and the transfer condition are thus calculated by the program.
- The thickness of the bottom flange is chosen to provide adequate resistance to hogging moment at the internal supports, which is governed by the compressive resistance provided by the bottom flange. In addition, the thickness of the bottom flange should be large enough to ensure the existence of a *feasible region* in the Magnel diagram as shown in Fig 4. The system then calculates the minimum thickness of bottom flange needed, from the governing lines on the Magnel diagram. The designer then chooses the actual dimensions for the cross-section.
- The amount of prestress throughout the beam then has to be chosen, to satisfy the stresses during both the transfer and working conditions. This is governed by a number of factors. The design rationale is based on the work done by one of the authors (Burgoyne (2)). The prestressing force must lie within the limits set by the Magnel diagram and should also ensure the existence of a valid concordant profile. The program determines the limits on the prestress at critical sections, which it presents to the user. The designer chooses the actual prestressing force to be applied over each span and support regions.
- The system calculates limits on the position and angle of cable anchorages, whose actual values are then fixed by the designer.
- The determination of the cable profile can also be automated significantly using the concept of notional loads (Burgoyne(3)). The program calculates a suitable cable profile (Fig 5) which satisfies the stress limits everywhere, and which also generates the specified secondary moments.
- Based on the Magnel diagram at each stage of construction, the system suggests the amount of prestress and the cable layout to be applied at each intermediate stage.

The system can print out current values of the principal variables, and also produce plots showing the cross-section, cable profile, Magnel diagrams etc. as the design progresses.

Future of BRIDEX

It can be seen that a system like BRIDEX has immense potential in design office and academic institutions. Future developments envisaged for the system include:

1. The use of non-prismatic sections.

2. Design considerations while using other construction techniques like balanced cantilever, incremental launching etc.

3. Determination of individual cable profiles at each stage of construction.

The process described here shows how careful thought about the sequence of operations allows a system to be written which deserves the title "expert". By unravelling the design principles and accounting for the governing factors at an early stage of the design process, the whole design evolves in a logical sequence. Once such knowledge has been obtained, we will see a corresponding change in the way text books are written, and in the way the subject is taught.

References

1. Jayasinghe M. T. R.: Rationalisation of prestressed concrete spine beam design philosophy for expert systems. PhD Thesis, University of Cambridge, 1992.

2. Burgoyne C.J.: Cable design for continuous prestressed concrete bridges. *Proc. Instn Civil Engineers*, part 2, vol 85, pp 161-184, 1988.

3. Burgoyne C.J.: Automated determination of concordant profiles. *Proc. Instn Civil Engineers*, part 2, vol 85, pp 333-352, 1988.

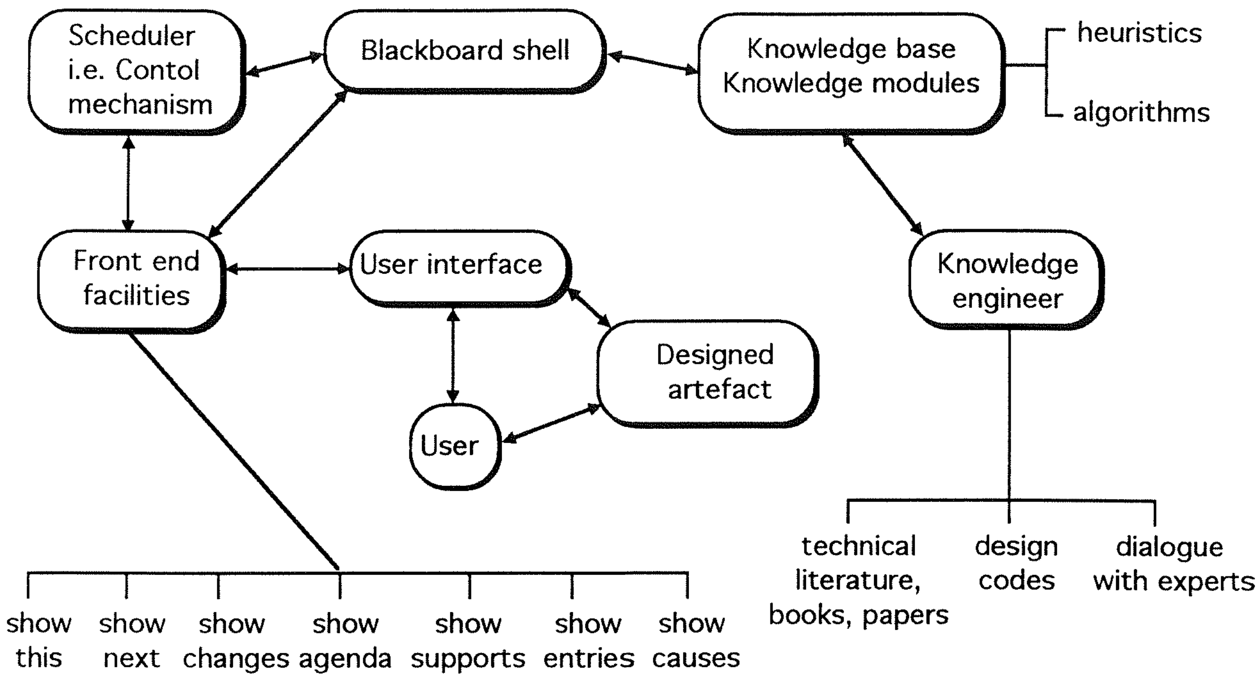

Figure 1. Architecture of BRIDEX

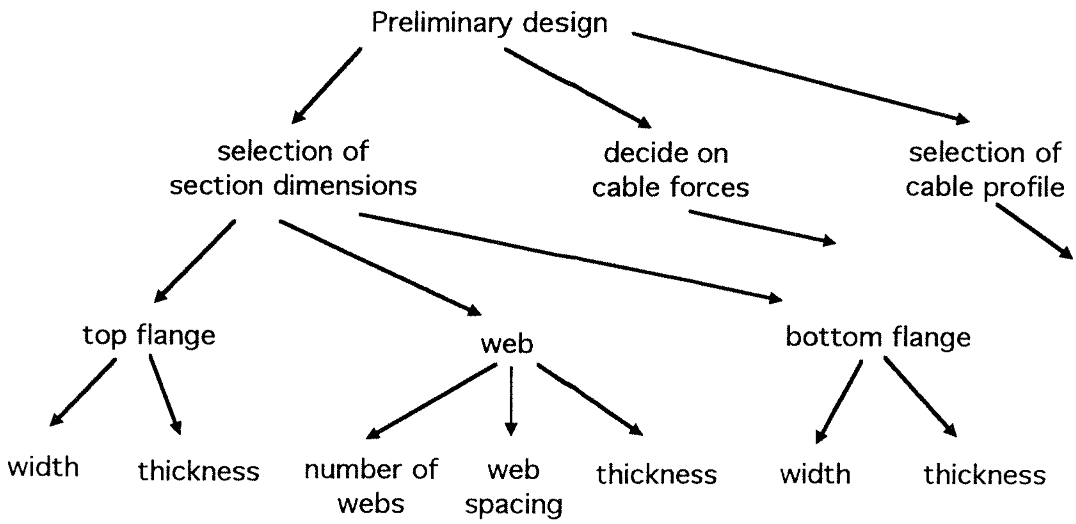

Figure 2a. Module for preliminary design

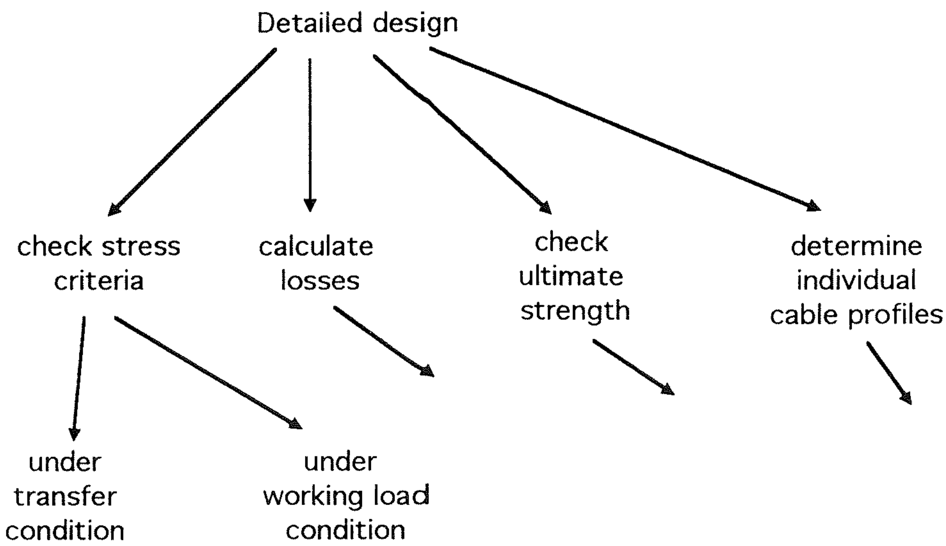

Figure 2b. Module for detailed design

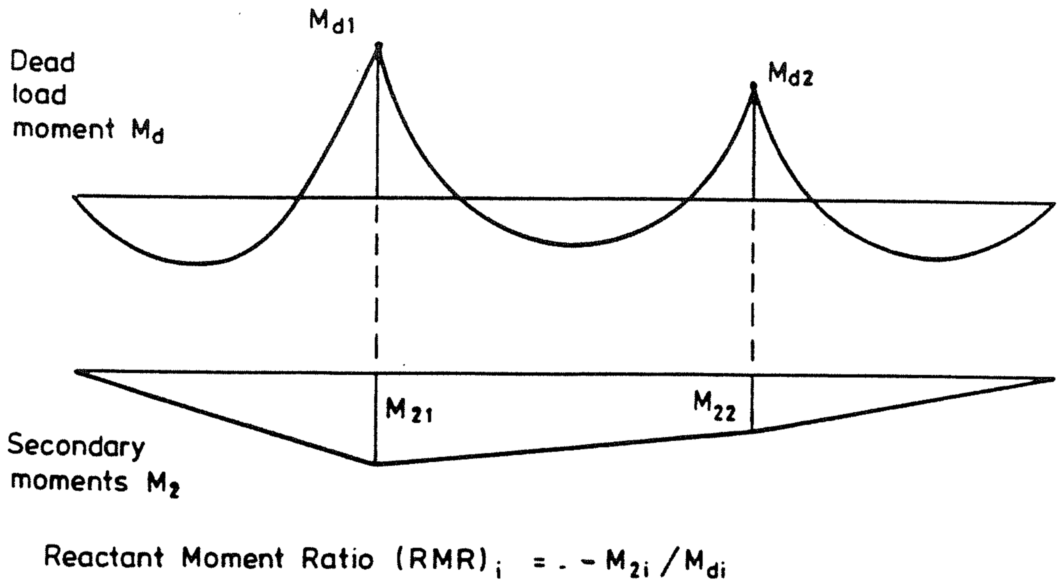

Figure 3. Calculation of reactant moment ratio (RMR)

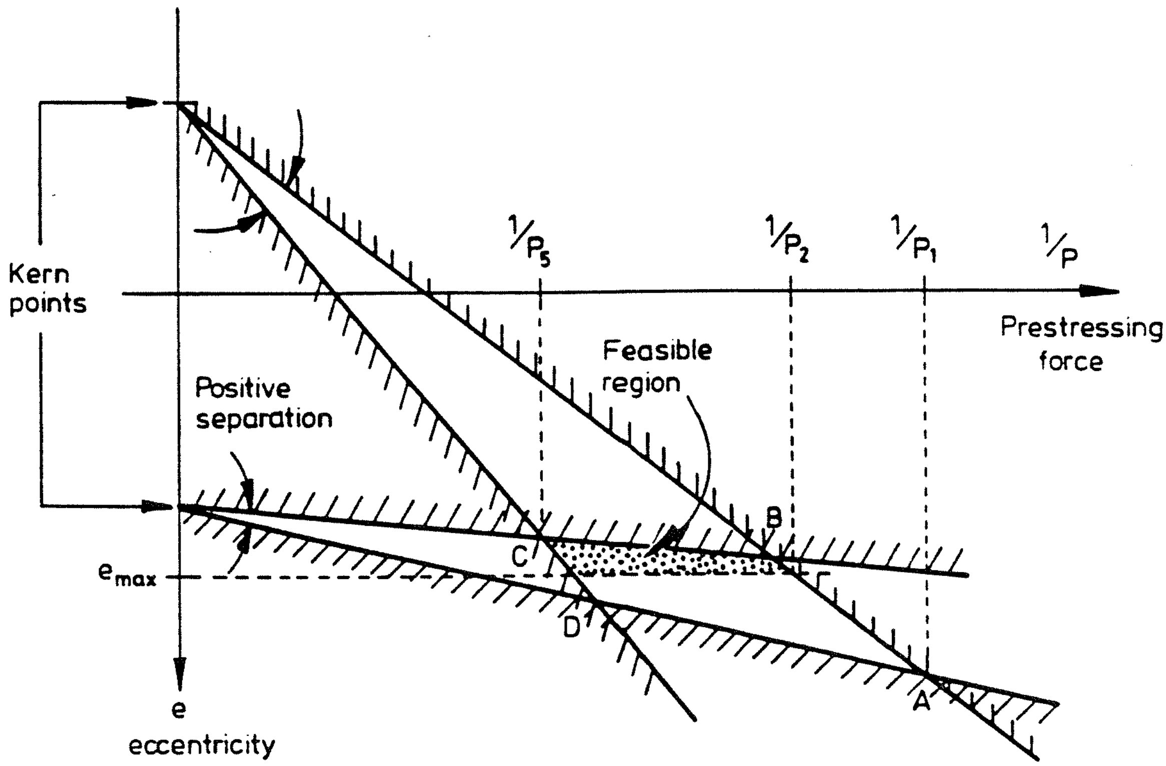

Figure 4. Magnel diagram

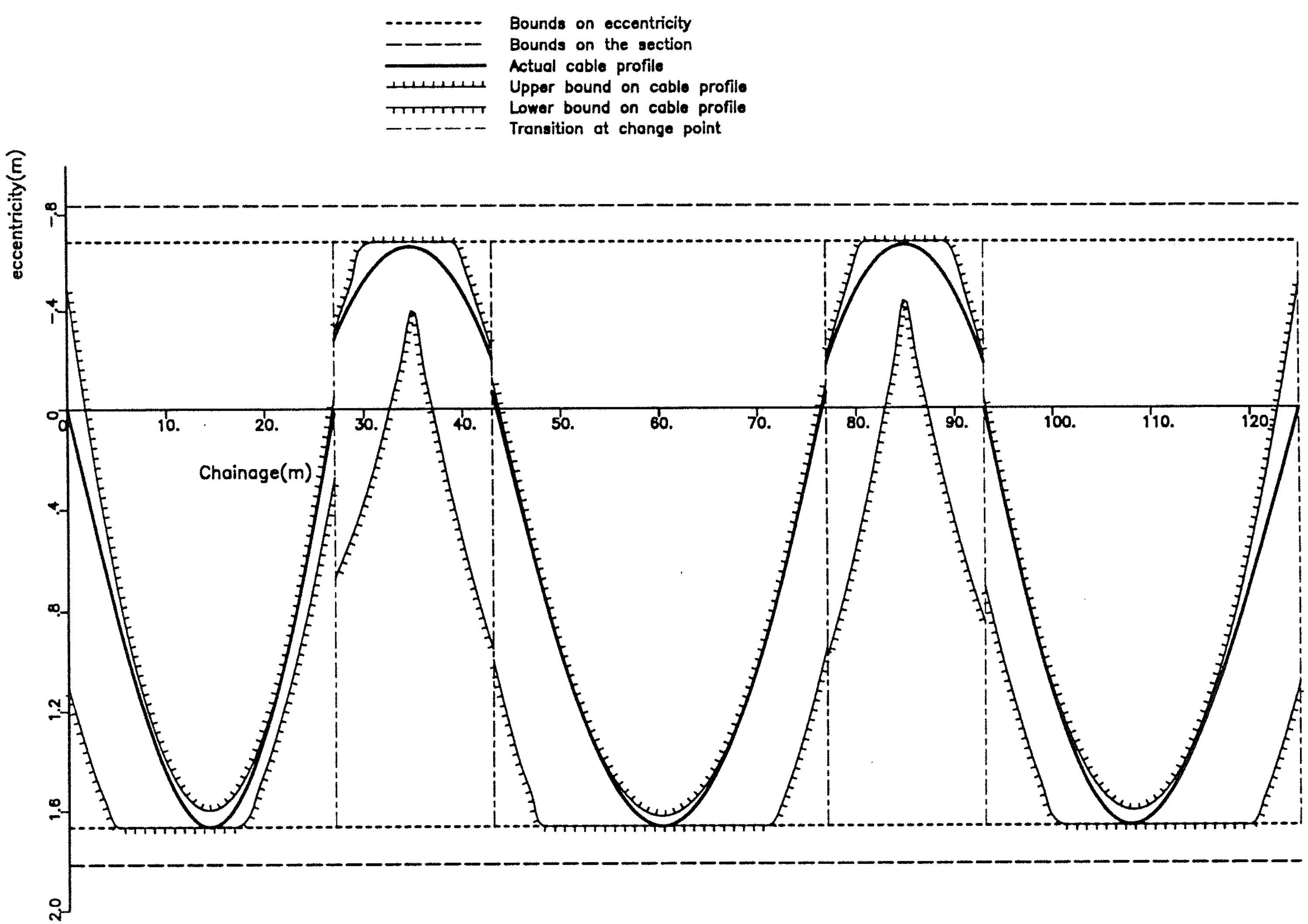

Figure 5. Typical program output showing the automatically generated cable profile within the required bounds, for a 3-span beam. The discontinuties occur at cable anchorage positions.