**Zeitschrift:** IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

**Band:** 31 (1978)

**Artikel:** Computerized structural analysis of cantilever bridges

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**DOI:** https://doi.org/10.5169/seals-24928

IABSE
AIPC
IVBH
COLLOQUIUM on:
"INTERFACE BETWEEN COMPUTING AND DESIGN IN STRUCTURAL ENGINEERING"
August 30, 31 - September 1, 1978 - ISMES - BERGAMO (ITALY)

# Computerized Structural Analysis of Cantilever Bridges

Calcul statique de ponts à travées en porte-à-faux, au moyen de l'ordinateur

Computergestützte Berechnung von freitragenden Brücken

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Summary
The amount of calculations for a complete structural analysis of post-tensioned cantilever bridges is very extensive due to the stepwise construction and the live loads. The main features of a special computer programme (CoBe) for these calculations are described. Some opinions pertaining to the rational and safe use of computer programmes are put forward.

Résumé
La quantité de calculs est très grande pour le calcul statique complet de ponts construits en porte-à-faux, car il faut tenir compte des états successifs de la construction ainsi que des charges utiles. Les aspects principaux d'un tel programme spécial (CoBe) sont présentés. Quelques opinions sont émises sur l'utilisation rationnelle et sûre des programmes d'ordinateur.

Zusammenfassung
Wegen dem schrittweise ausgeführten Bau und den Nutzlasten, ist die Anzahl der Berechnungen für die Gesamtberechnung einer vorgespannten, freitragenden Brücke sehr gross. Die Grundcharakteristiken eines besonderen Computerprogramms (CoBe) werden für diese Berechnung beschrieben. Gedanken im Zusammenhang mit wirtschaftlicher und sicherer Benützung von Computerprogrammen werden unterbreitet.

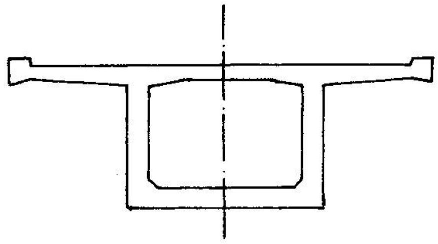
## 1. INTRODUCTION

Since 1960 about 50 bridges of the posttensioned cantilever type with spans from 60 m to 210 m have been built in Norway.

The cross section of the beam usually is a single box cell with cantilevers as shown in Fig. 1.

FIGURE 1

TYPICAL CROSS SECTION



The amount of calculations connected with a complete structural analysis of this bridge type is very extensive. The main complication compared to other bridge types is the stepwise construction which involves analysis of a series of structural systems gradually loaded and additionally influenced by creep.

Further there is considerable work connected with the calculation of the effects from mobile loads (live load).

The first bridges were calculated by hand, but for the above mentioned reasons designers soon started searching for aids that could relieve them of the greater part of the numerical calculations.

At that time (at the end of the sixties) the programmes available in Norway were for general 3-dimensional frames.

However, none of these had the possibility of calculating the step-by-step construction in a reasonable way. In addition the designer had to calculate the node coordinates, the cross section constants, the necessary load cases etc., beforehand. For these reasons it was decided to work out a special computer programme that should be able to execute all the necessary calculations in connection with a complete structural analysis of such bridges as 3-dimensional frames.

In the programme specification it was emphazised that the data for the programme input should be transfered from drawing, sketches etc. with a minimum of effort for the designer.

It was also made a point that the designer should have the possibility of giving data in more ways and with different levels of accuracy according to the purpose of the analysis.

The first version of the programme appeared in 1970, the last one in 1978.

The development of the programme has been fully sponsored by the Norwegian Highway Authority.

## 2. WHAT IS THE PROGRAMME ABLE TO CALCULATE?

First of all displacements and forces of beam and supports, but also intermediate results that may be useful for the designer.

To give an impression of the capacity and the level of automatization rendered by the programme a survey of the main input data and results is presented.

### 2.1 Reference line, system line

Parameters are given for a reference line, usually the centre line of the road or a line parallel to the centre line.

The horizontal alignment may have straight lines, circles and spirals.

The vertical alignment consists of straight lines and parabolas.

The system line is defined as a line through the centres of gravity in the beam. The distance between the reference line and this line is calculated on the basis of the cross sectional data, hence the coordinates and bearing of all the beam-nodes are determined.

### 2.2 Cross sectional constants (beam)

These may be specified by the designer or calculated in the programme on the basis of shape and dimensions of the cross sections. The cross sections are symmetrical to a vertical plane through the system line.

Otherwise they may have any shape and the dimensions may vary at random along the bridge.

### 2.3 Tendon forces/moments

Effective tendon forces may be specified by the designer or calculated in the programme based on tendon alignment, prestressing forces and parameters for losses etc. The prestress moments (load) are calculated on the basis of effective force and eccentricity of the tendon in the cross sections.

Length of tendons, elongations during tensioning and effective forces/moments are intermediate results presented in the output if wanted.

Effective forces/moments are introduced as loads for the structural analysis.

### 2.4 Stepwise construction

To describe the variable time, structural system and load relationship the designer may specify the following activities:

- activate beam segments.
- " prestressing tendons.

- activate dead load.
- introduce, move and remove travellers.
- introduce/remove supports/hinges.
- execute structural calculations.
- move the point of time and calculate the effects of shrinkage and creep during the preceding period.

Displacements and forces can be printed out at any point of time.

To save time the designer has the possibility to use the LOOP-concept enabling him to specify series of activities in a very short way.

The results (displ. and forces) from the different points of time are added and saved for later use.

The programme may of course also calculate bridges which are not stepwise constructed.

## 2.5 Live loads

The live loads for bridges are specified by various National Bridge Load Codes.

Although such Standard Live Loads have more or less different compositions they have one common denominator: The loads have to be positioned in such way that the maximum effect on the sectional forces is obtained.

To this end the programme will calculate influence lines, search for the dimensioning load position and compute the maximum (or minimum) effect in accordance with the rules of the specified Standard Loading.

Thus the designer may receive results from hundreds of load cases by giving only a few lines of Live Load input (type, magnitude of loads and position of lanes).

At present the programme can handle Live Loads set out in the Internordic Standard Loadings for Highway Bridges, however, if required any Standard Loading can be built into the programme.

## 2.6 Combination of results

The Norwegian Bridge Code defines three combinations of loads:

1: ordinary loads.

2: dead load + prestressing + extraordinary loads.

3: ordinary + extraordinary loads.

The following loads are defined as ordinary:

- dead load.
- prestressing.

- creep.
- shrinkage.
- water pressure.
- earth pressure.
- standard live load.

The following loads are defined as extraordinary:

- wind pressure.
- temperature.
- brake forces.
- ice pressure.
- collision forces.

The different loads may be of the following types:

- ordinary/extraordinary.
- permanent/transient.
- independant/alternative.

Two limit states are defined:

- serviceability limit state.
- ultimate limit state.

With different load factors for the different load combinations/ load types/limit states it is easily understood that the number of calculations connected with the combinations of loads may be quite extensive.

However, the programme carries out these combinations in a speedy and reliable way and presents the results in well arranged tables.

## 3. FURTHER DEVELOPMENTS

In connection with projects in development countries some additional features will be added to the programme in the near future:

- the possibility of having all texts in English.
- British Standard Highway Live Loads.
- earthquake response calculations.

A logical extension of the programme would be to include the calculation of the necessary capacities of the beam sections. This has not been done until now because of the rapid change and national variations of the design rules.

## 4. RATIONAL USE OF THE PROGRAMME

A necessary precondition for the rational use of this and other computer programmes is that the designer should have an understanding of the underlying theory and its implications to such an extent that he in principle could have done the calculations himself.

Rational use also means that the designer will estimate the most critical features beforehand and will compare these with the computed results. The estimates may be carried out on the basis of more or less exact formulas or based on modifications of similar existing structures.

Such procedure will have more advantages:

- errors in data and/or programme can be detected and corrected at an early stage prior to possible serious consequences.

- the basis of the estimate may be improved which in turn leads to fewer computer runs, faster design and less cost.

When the programme is used in this way the risk of serious errors is minimized, the designer is relieved of timeconsuming and costly numerical calculations and the effects of changes in the structural system can be fast and economically calculated.

It is on the other hand quite clear that computer programmes may be misused.

Poor understanding, time-pressure and the absence of adequate checking are the main reasons for miserable results, however, these conditions would also jeopardize the calculations if they were carried out in the old manner.

During the design period it may also sometimes be observed that extensive calculations are run after only small changes in the structural system. This is due to lack of understanding and experience on the hand of the designers and should be prevented by proper supervision.

The supervision of computer-calculations may in most cases be limited to checking the structural system, loads and the reasonableness of the results. If the supervisor is unacquainted with the programme or the structure is complicated he may carry out his own calculations either by hand or by mean of another computer programme. The clear documentation of the structural system, loads and results obtained by the use of a computer programme is in every case of great value to the supervisor.

## 5. CONCLUSION

General computer programmes do not always suit the designers need for calculating assistance. If there is sufficient know-how and capacity available, the development of a special programme may be a possible solution to the problem.

The advantages of making programmes "in house" are several:

- the programmes may be well adapted to the problems in such a way that a high degree of automatization is obtained.
- changes in the specifications may be built in when required.
- the application is simpler and safer because people with intimate knowledge of the programmes are readily available.

The disadvantages are mainly the high costs involved in programme development and maintenance.

Rational and safe use of well suited computer programmes relieves the designer of timeconsuming, tedious and costly numerical calculations and leads to faster and safer design at a lower cost.

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