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Autor: Langsoe, Henrik E. / Larsen, Ole Damgaard
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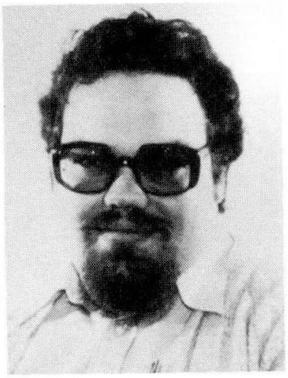
Monitoring of Structural Behaviour of Cable-Stayed Bridge

Contrôle du comportement des structures d'un pont à haubans

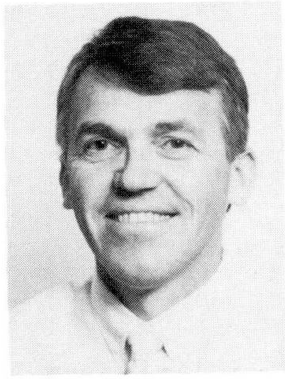
Konstruktionsüberwachung einer Schrägseilbrücke

Henrik E. LANGSOE
Civil Engineer Ph.D.
Cowiconsult, Consulting
Engineers and Planners AS.
Copenhagen, Denmark.



Henrik E. Langsoe, born 1950, got his civil engineering degree at the Technical University of Denmark. He has specialized in instrumentation and measuring techniques and has a Ph. D. degree in surveillance of structures with special reference to structural safety.

Ole Damgaard LARSEN
Consulting Engineer.
Cowiconsult, Consulting
Engineers and Planners AS.
Copenhagen, Denmark.



Ole Damgaard Larsen, born 1942, got his civil engineering degree at the Technical University of Denmark. He is presently head of the special structures department in Cowiconsult. He has been in charge of research and development studies as well as detailed design projects mainly within the bridge and offshore sector.

SUMMARY
The Faroe Bridges in Denmark, inaugurated in 1985, are permanently monitored by means of a computerbased monitoring and control system. The system checks structural conditions such as movements of the bridge superstructure at the expansion joints, rotation of the superstructure etc. The system further has a number of service functions such as monitoring the hydraulic system for torsional fixation of the superstructure and controlling the corrosive climate within the closed box girder superstructure.

RESUME
Les ponts de Faroe, inaugurés en 1985, sont surveillés en permanence par un système informatisé de surveillance et de contrôle. Le systéme contrôle les conditions structurelles telles que les mouvements de la superstructure du pont aux joints de dilatation, la torsion de la superstructure etc. Le système dispose de plus de certaines fonctions de service comme la commande du système dispose de plus de certaines fonctions de service comme la commande du système hydraulique pour la fixation rotationelle de la superstructure, et le contrôle des conditions climatiques corrosives dans le caisson fermé de la superstructure.

ZUSAMMENFASSUNG
Die Faröbrücken in Dänemark, im Verkehr seit 1985, sind permanent überwacht durch ein computerbasiertes kontroll- und Warnungssystem. Die Überwachung beinhaltet Konstruktionszustände wie u.a. Überbaubewegungen an Lagern und Brückenfugen, Trägerrotationen etc. Darüber hinaus hat das System eine Reihe von Service-funktionen wie die Überwachung des hydraulischen Systems für die Torsionsstabilisierung des Trägers und die Kontrolle des Luftklimas im geschlossenen Stahlträger.

1. INTRODUCTION

The Faroe Bridges in Denmark were built in connection with the rerouting of the E4 motorway and were inaugurated in 1985. They consist of two separate bridges, one connecting Zealand with Faroe (the ZF bridge) and one connecting Faroe with Falster (the FF bridge), cf. fig. 1, 2 and 4.

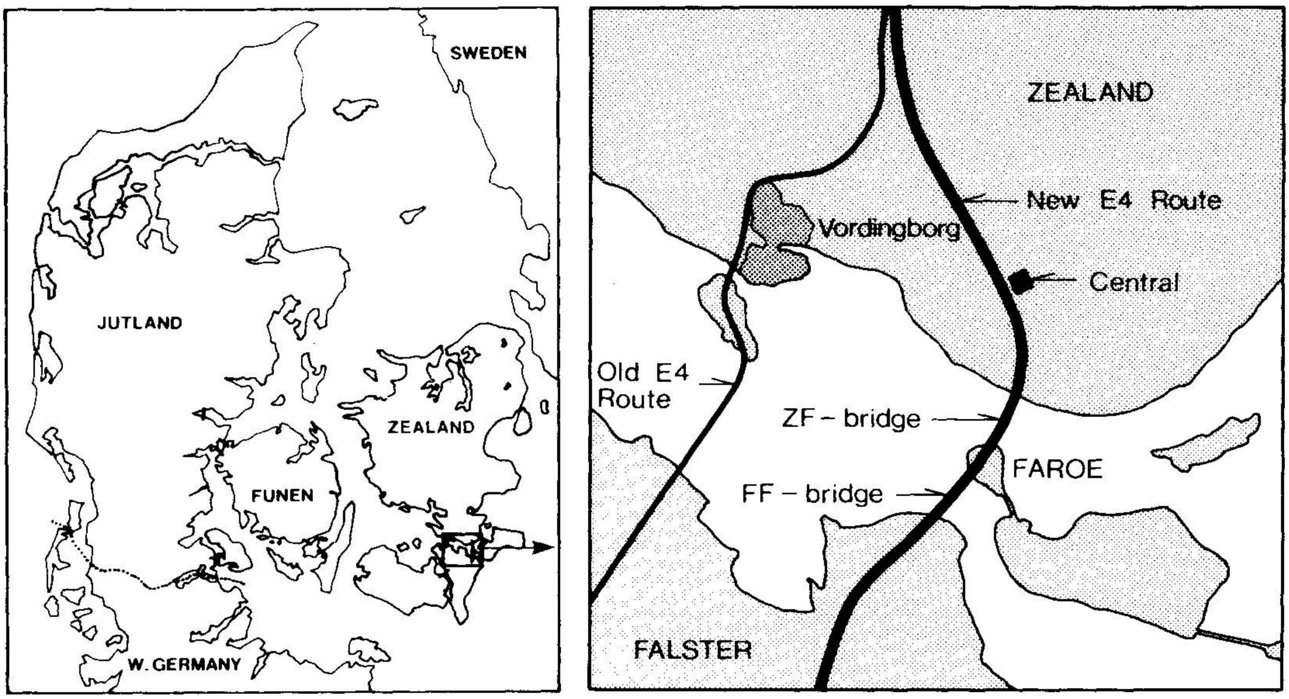


Fig. 1 Bridge location

The ZF bridge is 1.6 km long. The bridge superstructure is a continuous steel girder from coast to coast, fixated in the longitudinal direction at pier nos. 9 and 10, cf.fig. 4.

The FF bridge is 1.7 km long and the superstructure of this bridge is also continuous from coast to coast. It is fixated in the longitudinal direction at pier no. 9, cf. fig. 4. The 3 central spans of the bridge are cable stayed sections. The main span is 290m, the side spans 120m each. The cables are all located in the vertical symmetry plane of the bridge, being supported by A-shaped pylons, cf. fig 2 and 7.

A general description of the bridge project can be found in [1].

The bridges are permanently monitored by means of a computerbased monitoring and control system. The purpose is to ensure that the structure is functioning properly and to establish an optimum inspection and maintenance programme for important components. The computer central is located approximately 3 km North of the ZF-bridge, refer to fig. 1.

The present paper gives a short description of the monitoring system itself and describes the tasks of the system as well as its daily operation.

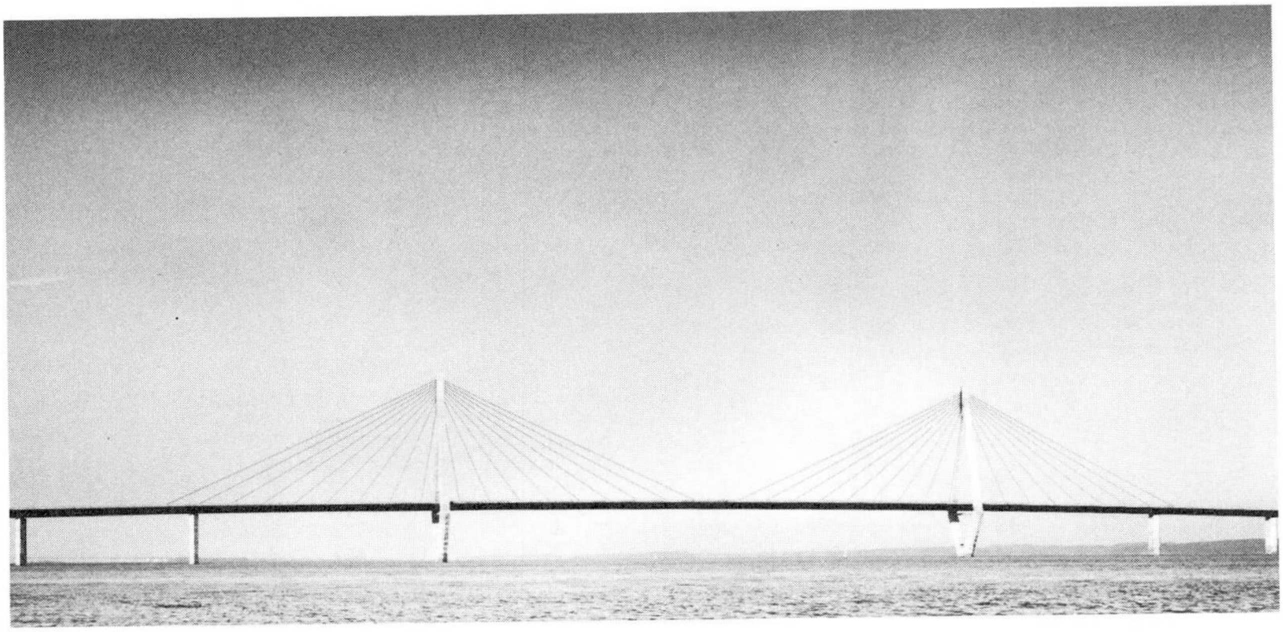


Fig. 2 Photograph of the cable stayed Faroe-Falster bridge.

2. TECHNICAL LAYOUT OF THE MONITORING SYSTEM

The principal layout of the system is a distributed process control system as shown on fig. 3:

- Two central computers in tandem operation, with automatic schwitching from one to the other in case of failure.

- Completely independent monitoring systems for each of the bridges, connected to the central by means of a common transmission line.

  Breakdown of one monitoring system does not affect the other. In case of transmission line failure or break down of the central computers each monitoring system will continue operation on its own.

- Each independent monitoring system consists of a subcentral and 3-4 substations placed in the abutments, bridge girders and pylons. In case of breakdown of a substation, the rest will continue their tasks.

- Signal input/output is controlled by the substations.

The central control room is in addition to the central computers equipped with console for communication with the operator, printer and plotters for printouts of messages, alarms, statistics and measurements.

The communication between computers and substations is based on a local area network for industrial use, modified for communication via modems.

The system has been designed with only 40% of its capacity (software as well as hardware) used. The reason for this is to make the addition of future tasks a relatively simple matter. One of the future tasks will be the monitoring of the Guldborg tunnel, which is presently being constructed 20 km from the bridge as part of the rerouting of the motorway.

3. TASKS OF THE MONITORING AND CONTROL SYSTEM

3.1 Tasks of relevance to maintenance and traffic safety.

These tasks consist of the following:

- Monitoring for malfunction in computers, substations, transmission lines and electric system (distribution boards).
- Monitoring for malfunction in illumination of bridge girders, pylons and piers in the navigation channel passing the ZF-bridge.
- Monitoring for malfunction of traffic signs.
- Monitoring for malfunction of marine lanterns and fog horn.
- Monitoring for malfunction of, or alarm from lifts and work platforms.
- Control of illumination of both bridges (on/off, intensity).
- Control of marine lanterns and fog horn (on/off).
- Control of traffic signs (on/off).
- Monitoring and control of air humidity within both bridge girders. (The inside of the girders is not painted, but protected against corrosion by keeping the air humidity within certain limits).

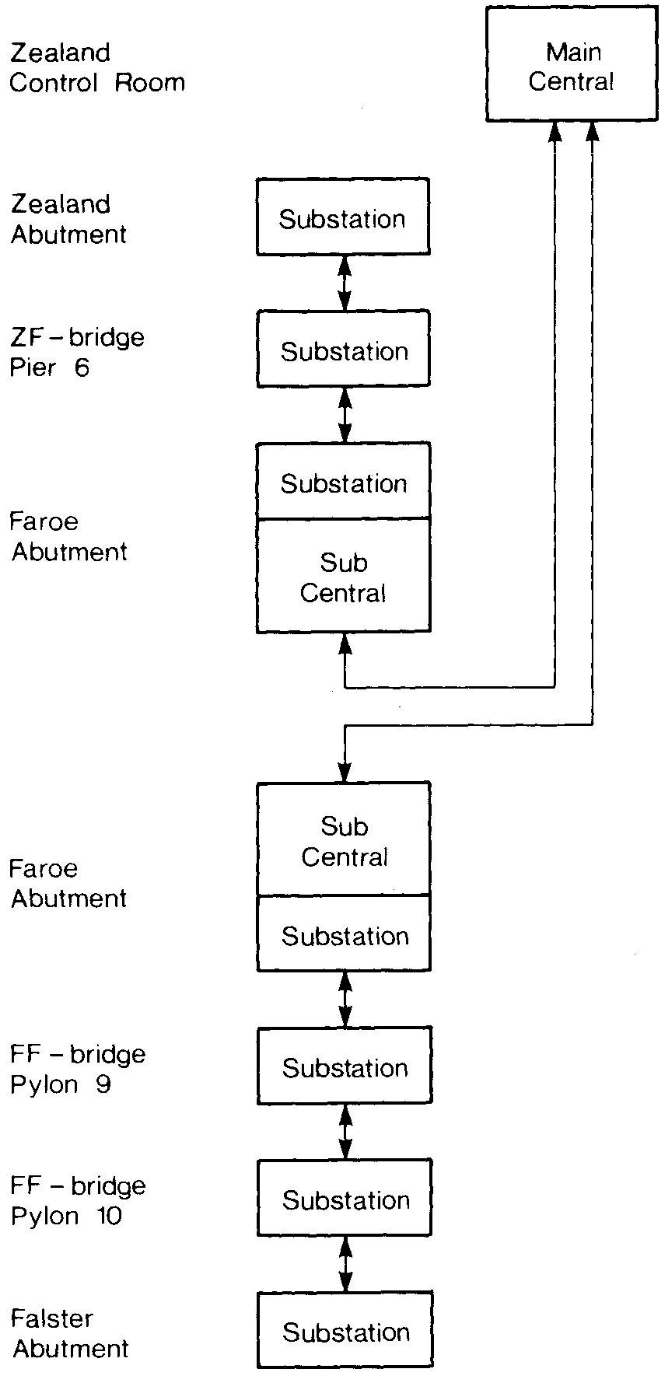


Fig. 3 Principal layout of monitoring system.

These tasks are more or less trivial and will not be commented further upon.

3.2 Tasks of relevance to structural safety.

These tasks, which are summarized on fig. 4, consist of the following:

1 Monitoring of oil pressures in the hydraulic pendulums at the pylons combined with monitoring of the transverse inclination of the bridge superstructure.

2 Monitoring of the displacements of the bridge girders at the abutments.

3 Inclination transducers were installed during the building period, for use during construction of the bridge girder. It is planned to connect these tranducers to the monitoring system.

4 Monitoring of the inclination of the anchor piers in the ZF-bridge has been planned, but not yet installed.

Since these tasks are special to the Faroe Bridges, they will be further described in the following.

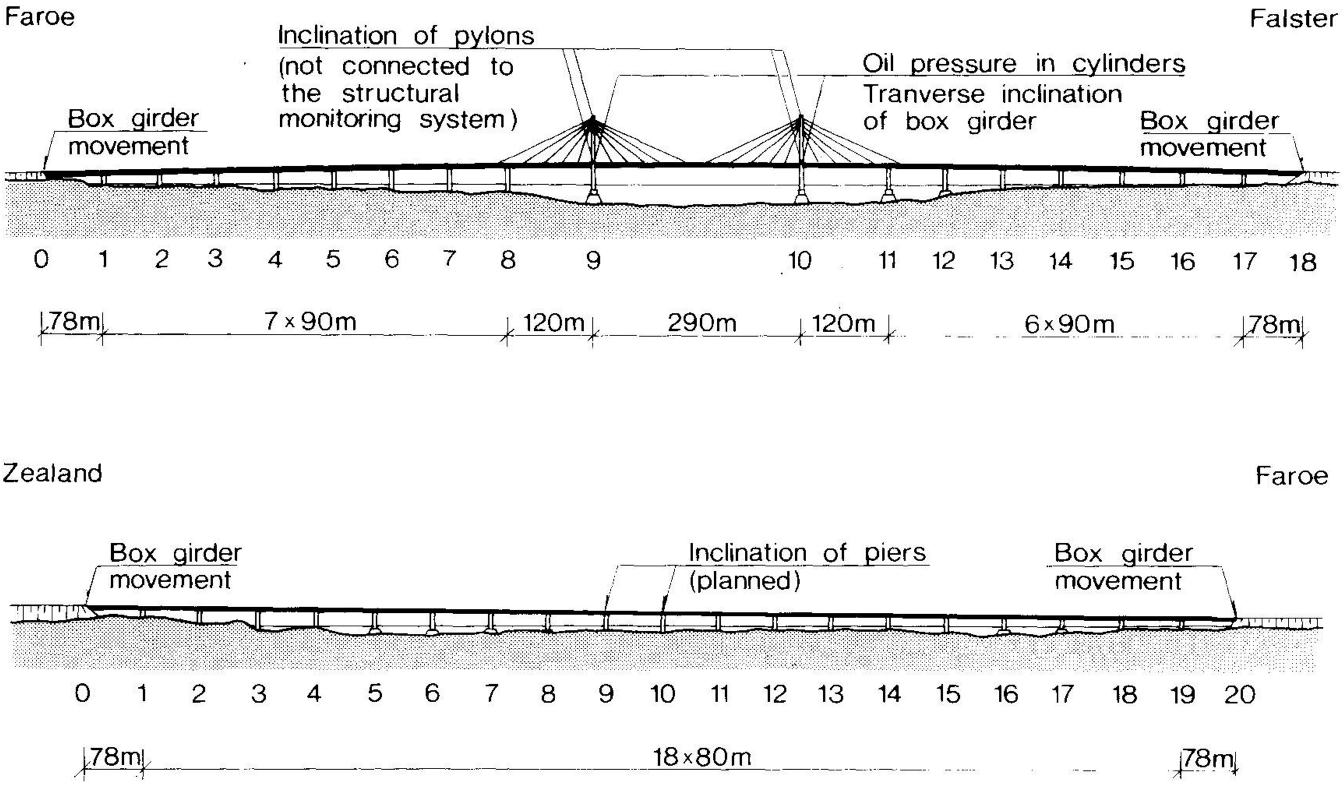


Fig. 4 Monitoring of structural parameters with relevance to safety.

3.2.1 Oil pressure i hydraulic pendulums and inclination of bridge girder.

At the pylons, the bridge girder is free to move in the vertical direction, but fixed against rotation in order to give the girder sufficient torsional stiffness. This is done by the use of interconnected oil filled cylinders as shown on fig. 5.

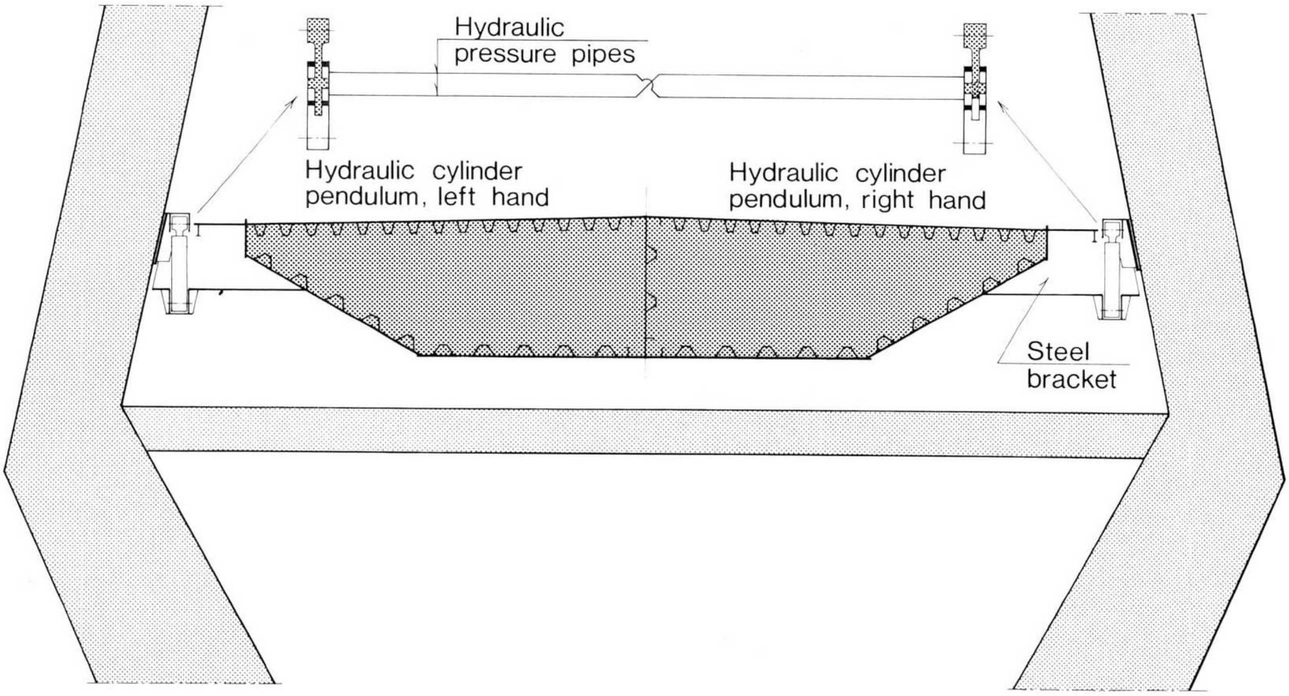


Fig. 5 Arrangement of hydraulic pendulums for torsional fixation of bridge superstructure at pylons.

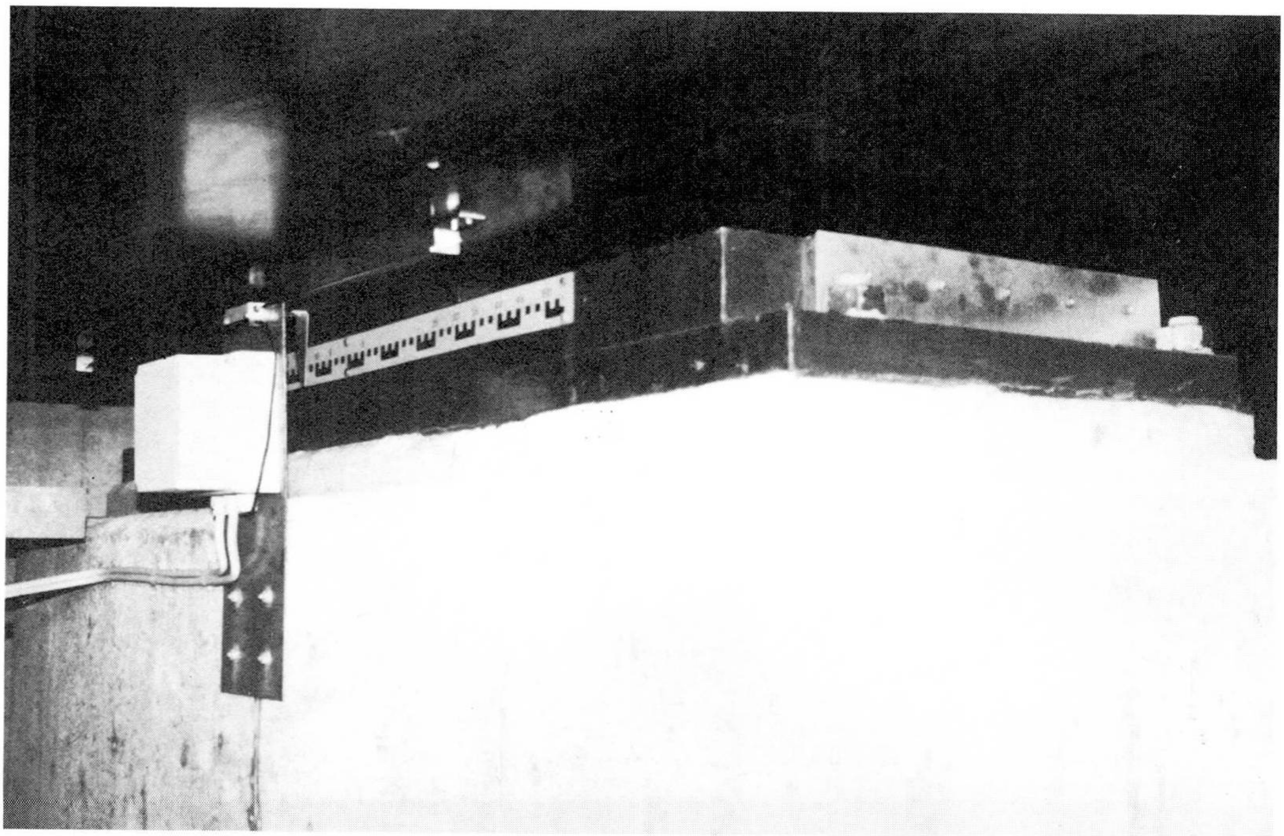


Fig. 6 Photo of displacement transducer at abutment.

In order to check the functioning of the cylinders and to measure the effect of excentric loading of the bridge deck, pressure sensors are installed in each cylinder.

The system can malfunction in two ways. Rupture can occur resulting in immediate loss of oil pressure and consequently the superstructure will experience a critical decrease in torsional rigidity. This is detected directly by means of monitoring the oil pressures in the hydraulic pendulums.

In case of uneven load distribution on the cylinders, however, too large inclination of the bridge girder in the transverse direction can result from leakage of oil past the pistons in the cylinders. This will not necessarily show on the oil pressures, but is detected by means of inclinometers located within the bridge girder.

In case of low or high oil pressure or too high inclination, an alarm massage is printed in the control room.

3.2.2 Girder displacements at abutments.

The expansion joint movements at the abutments can become very large for both bridges because of the continuity of the bridge superstructure. Allowance is made for a total travel of up to 1 m at each abutment.

In order to follow the movements in relation to box girder temperature, displacement transducers have been installed at the abutments, see fig. 6.

The computer registers

- The position of the box girder at each abutment. If a girder end is outside the allowable interval, an alarm message will be given in the control room.

- The accumulated travel at each abutment. This gives useful information upon the wear of the bearings and is of importance for the determination of inspection intervals and perhaps the initiation of special maintenance works.

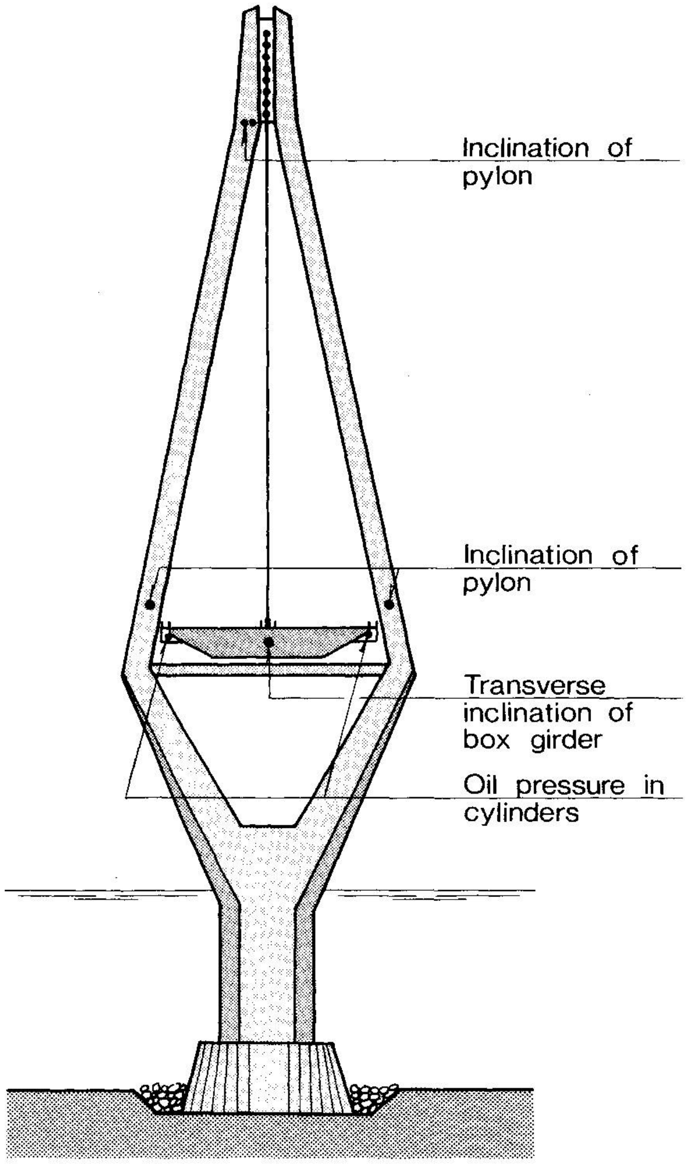


Fig. 7 View of pylon with instrumentation.

3.2.3 Inclination of pylons.

Inclination transducers have been installed in both pylons in two levels as shown on fig. 7. They are presently set up for manual measurements, but can be connected to the monitoring system if time should prove it nescessary.

The inclination of pylon 9 gives a direct measure of the horizontal differential force from the two cable planes.

As the transducers are of the wibrating wire type, they provide an excellent long term stability. Therefore, they are very well suited for monitoring the long-term stability of the pylons. Fig. 8 shows one of the inclinometers.

3.2.4 Inclination of anchor piers in ZF-bridge.

It is planned to use the inclination of the the anchor piers in the ZF bridge to monitor the horizontal force on them from the bridge girder, just as the inclination of pylon 9 could be used as such an indicator for the FF bridge.
Such equipment has however not yet been installed.

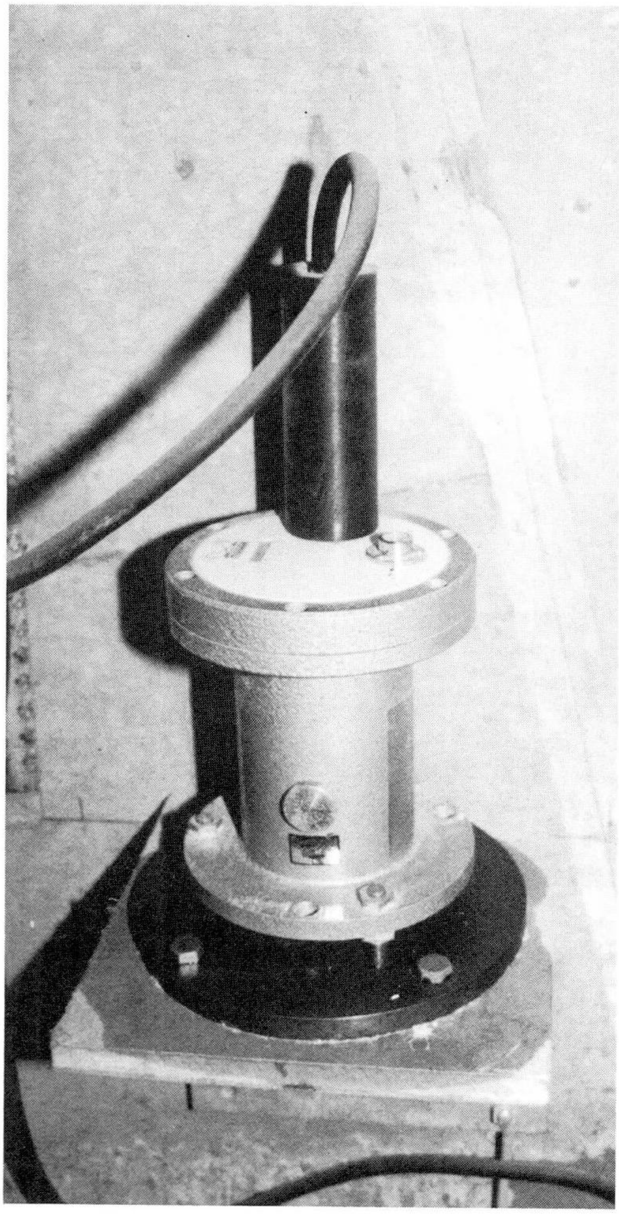


Fig. 8 Photo of an inclinometer (protective shield removed).

4. OPERATION OF THE MONITORING AND CONTROL SYSTEM.

The system performs automatically the tasks mentioned in section 3. Automatic control can however at any time be overridden manually. This gives the possibility of

- Enabling a special test mode for the system.
- Controlling all installations manually, which is important during maintenance and repair of the installations.
- Controlling all measurements, e.g. starting printing of selected data on plotter etc.

Fig. 9 gives a view of the control room.

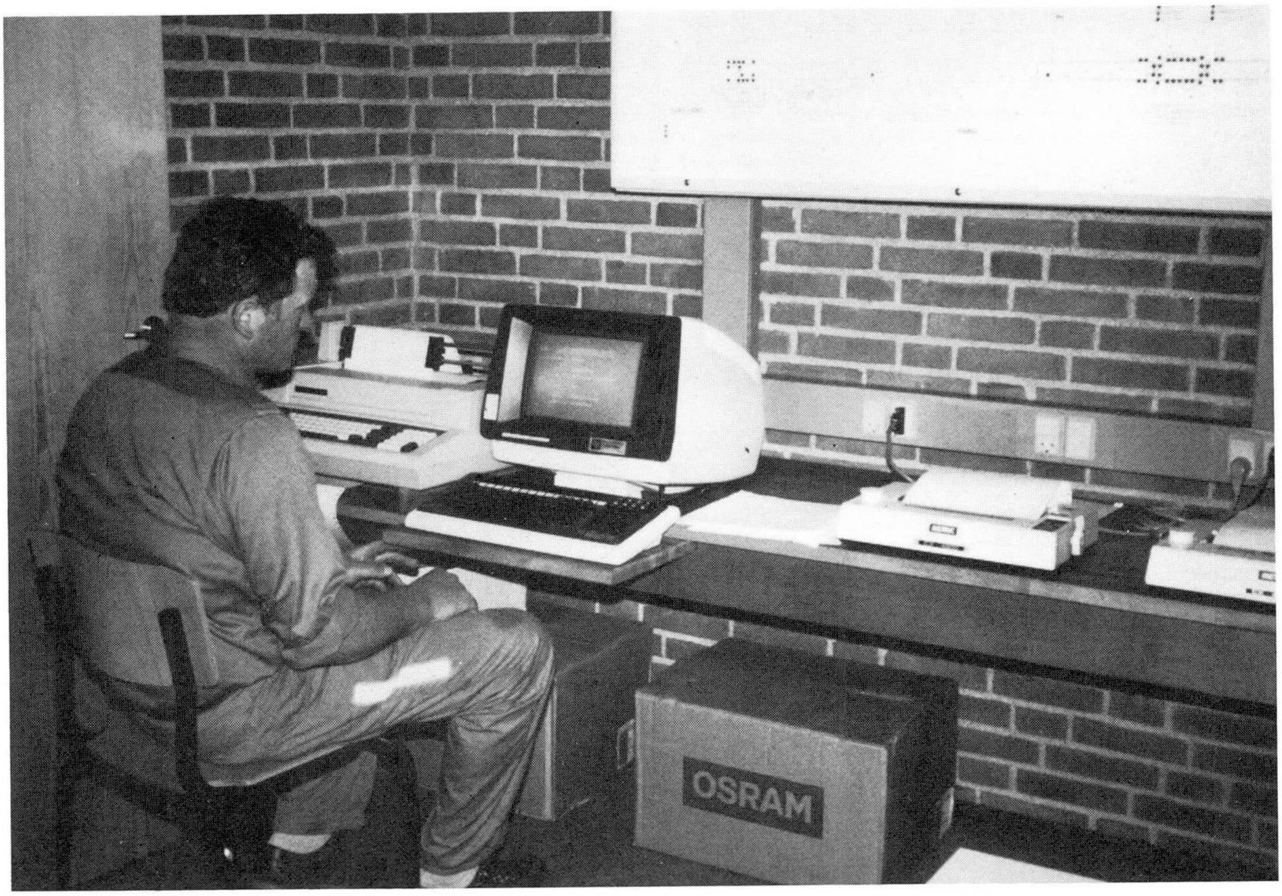


Fig. 9 Control room.

5. EXPERIENCES.

The system has at present been in service for two years. Experiences from use of the system from start-up time till now are however sparce, since some initial technical problems have had to be overcome.

The system is at present working to its best, and there is no doubt that it will fulfill the expectations to it.

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