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Instrumentation and Monitoring of Norddalsfjord Bridge, Norway

Instruments de surveillance et mesures sur le pont Norddalsfjord, Norvège

Instrumentierung und Ueberwachung der Norddalsfjordbrücke in Norwegen

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SUMMARY
Norddalsfjord bridge is a prestressed, 3 span concrete bridge, with a main span of 230.5 m. As an independant check of the structural analysis and planned jacking operations, monitoring instrumentation has been installed in order to verify the safety of the bridge. Strain gauges have been used in piers and superstructure, and hydraulic jacks between abutments and superstructure. During the construction period, good agreement has been obtained between theoretical calculations and measured values.

RESUME
Le pont de Norddalsfjord est un pont en béton précontraint à trois travées continues, construit par encorbellements successifs. La travée centrale est de 230.5 m. Pour vérifier la sécurite du pont et les calculs théoriqué on a installé des instruments de surveillance. Des extensomètres à cordes vibrantes sont encastrés dans les piles et dans le tablier. Les vérins hydrauliques sont installés entre les culées et le tablier. Pendant la périodique de les calculs théoriques ont été confirmés les instruments construction de surveillance.

ZUSAMMENFASSUNG
Die Norddalsfjordbrücke ist eine dreifeldrige, vorgespannte Betonbrücke mit einer Hauptspannweite von 230.5 m. Zur unabhängigen Ueberprüfung der statischen Analyse und zur Ueberwachung der Verschiebeoperationen mit Hydraulikzylindern zwischen Widerlagern und Oberbau wurde die Brücke instrumentiert. Dehnungsmesser sind in den Pfeilern und im Oberbau installiert worden. Während der Bauperiode sind die theoretischen Berechnungen durch die Messungen bestätigt worden.

1. NORDDALSFJORD BRIDGE

Norddalsfjord bridge is a 400 m long prestressed concrete bridge near Florø in Western Norway. The bridge was opened for traffic in the end of May 1987 after less than 2 years of construction. The main span is 230.5 m, constructed in free cantilevering, and for the time being the longest span for this type of bridge in Europe. A general view of the bridge is given in Fig. 1.

The main foundations are located in sea water at approximately 10 m depth. The main span superstructure is supported by twin wall piers, which are made monolithic with foundations and superstructure. The height of the piers between foundation and superstructure is 15 m in axis 2 and 2 m in axis 3. The piers in axis 2 are flexible enough so that an expansion joint at mid span is not required. During construction temporary walls were added in axis 2. This was done in order to make a box section with the required torsional stiffness to stand dynamic wind loads in the free cantilevered state before connection to the counterweight structure near axis 1. After the temporary walls were removed, jacking to obtain rotation and translation of the completed cantilevers before establishing continuity was performed as part of the design.

The width of the bridge deck is 8 m, refer Fig. 2. The box is 13.0 m deep over the piers and 3.0 m at centre of main span. Web thicknesses vary in steps from 0.35 m at piers to 0.25 m at mid-span. The thickness of the bottom slab decreases from 0.70 m at piers to 0.22 m at mid-span.

The main span and most of the side span between axis 1 and 2 are built in free cantilevering. The other side span is built on scaffolding to the ground. The counterweight structures are constructed on sand beddings. The sand was removed when the superstructure was completed. The counterweight structures are filled with rock, and they are supported on moveable bearings in axis 1 and 4.

2. REASONS FOR MONITORING AND CHOICE OF INSTRUMENTATION

2.1 Twin wall piers

The structural analysis and calculations are based on a finite element program. The calculations showed that the stability of the foundations and twin wall piers were sensitive to the stiffness of the double piers. Besides, the double pier design was new in Norway, and the client (Public Roads Administration) decided to spend some money on extra monitoring. Strain gauges were installed in the double piers as shown in Fig. 3, mainly to give a better assessment of the structure's safety. The design aim has been to create a balanced load distribution between the twin wall piers. This has partly been obtained by vertical jacking in axis 1 and horisontal jacking of the superstructure before continuity was established.

2.2 Main span

As an extension of the instrumentation program for the piers, strain gauges were installed also in the bridge deck and the compression slab of the main span as shown in Fig. 4. The purpose of these gauges is to give information about the moment redistribution in the superstructure due to creep and change in the statical system during the structure's lifetime. The moment redistribution is a feature which is common for all concrete bridges constructed according to the free cantilever method, and additional information from monitoring instrumentation was found very desireable.

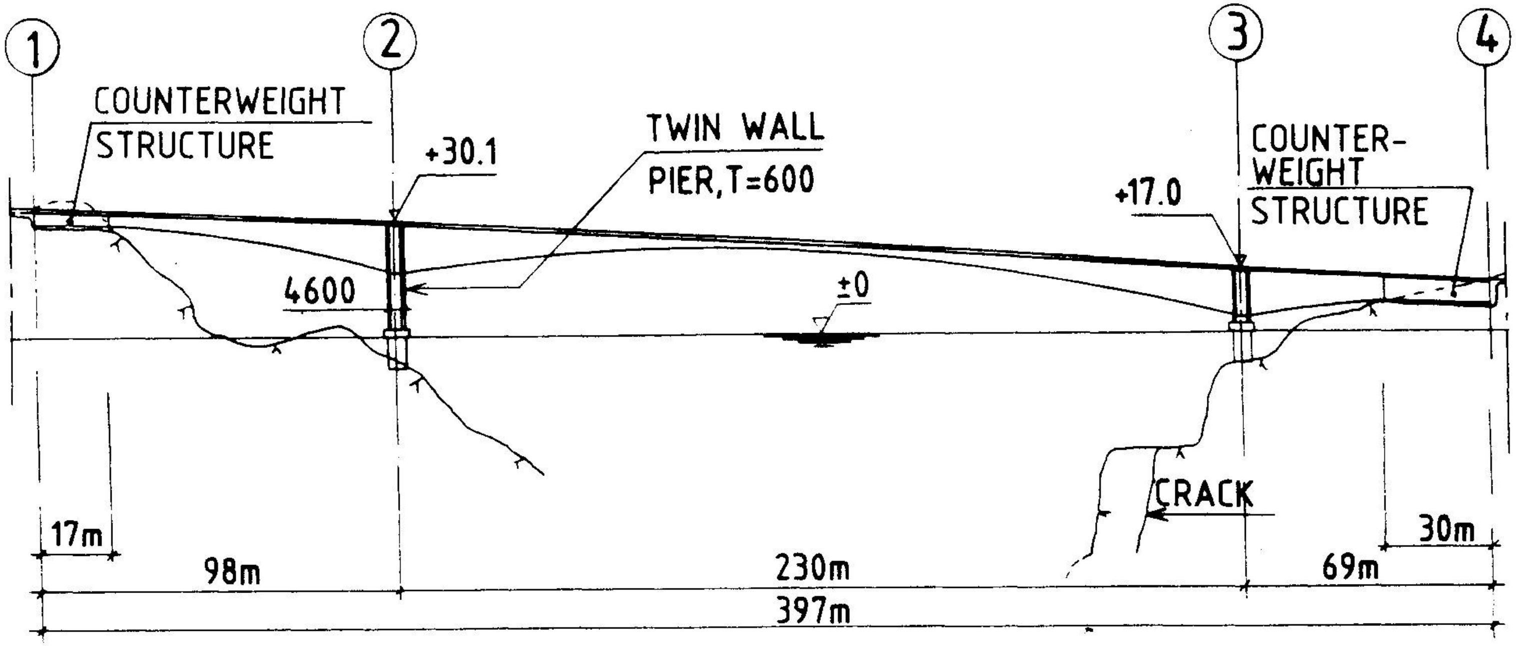


FIG. 1. NORDDALSFJORD BRIDGE. ELEVATION

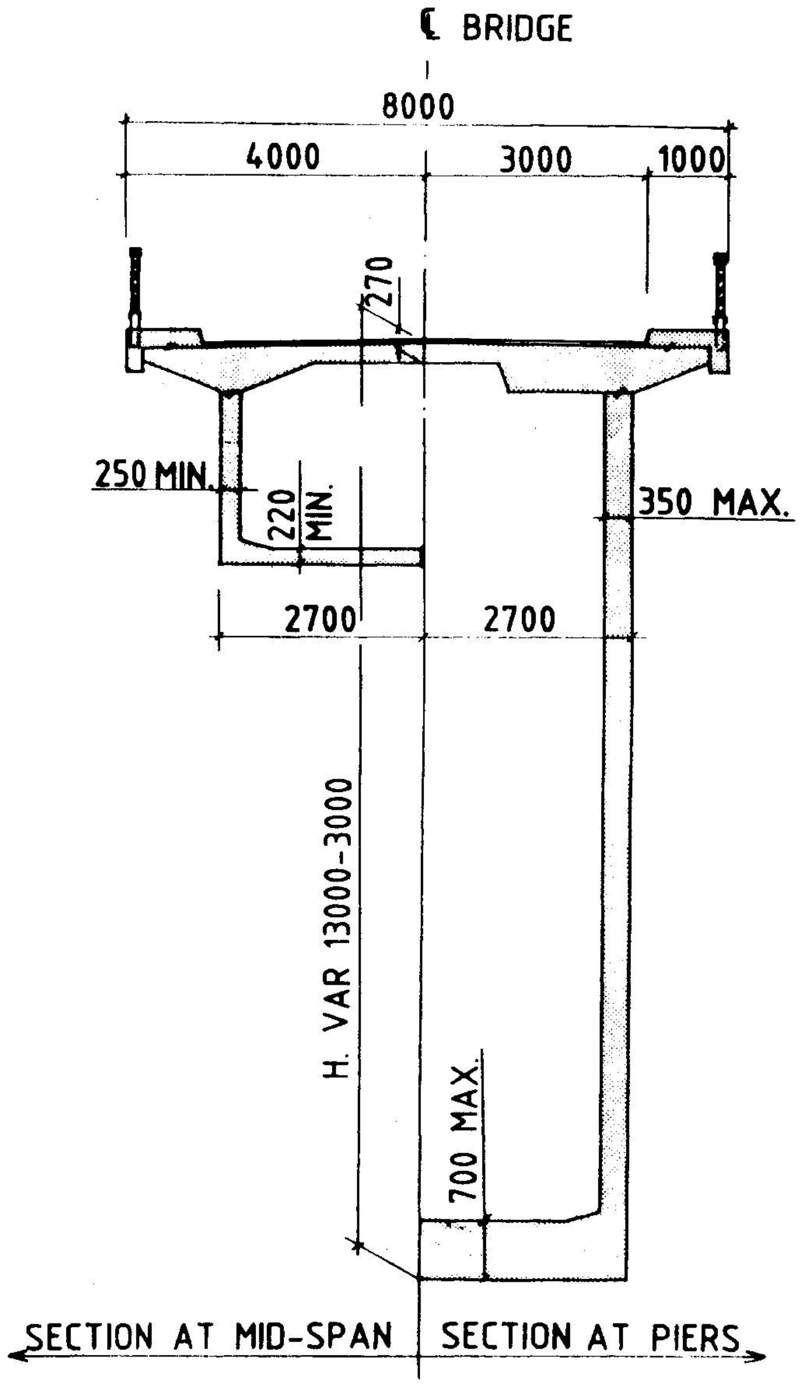
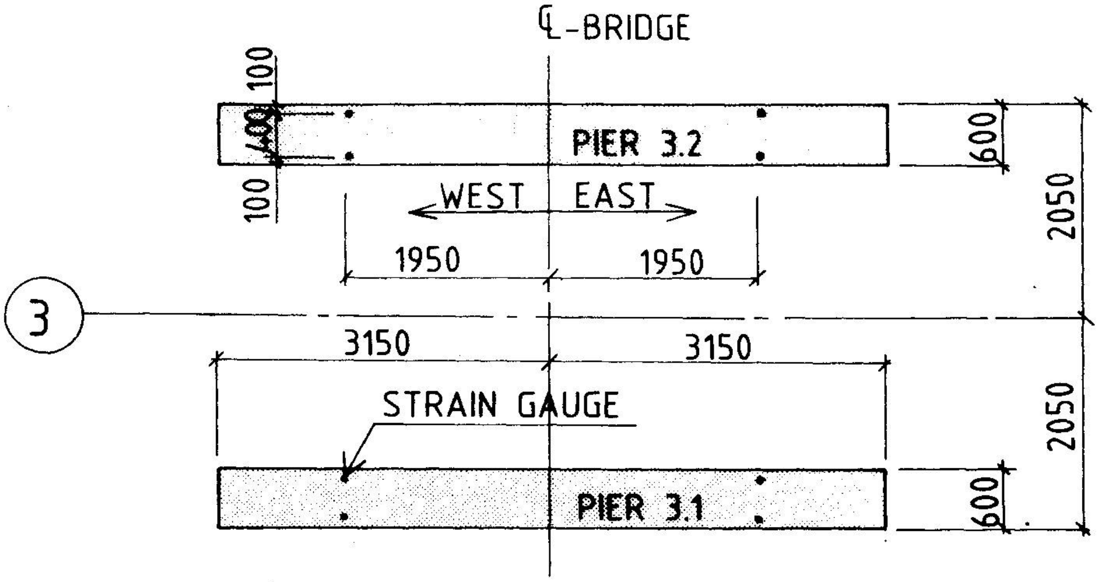
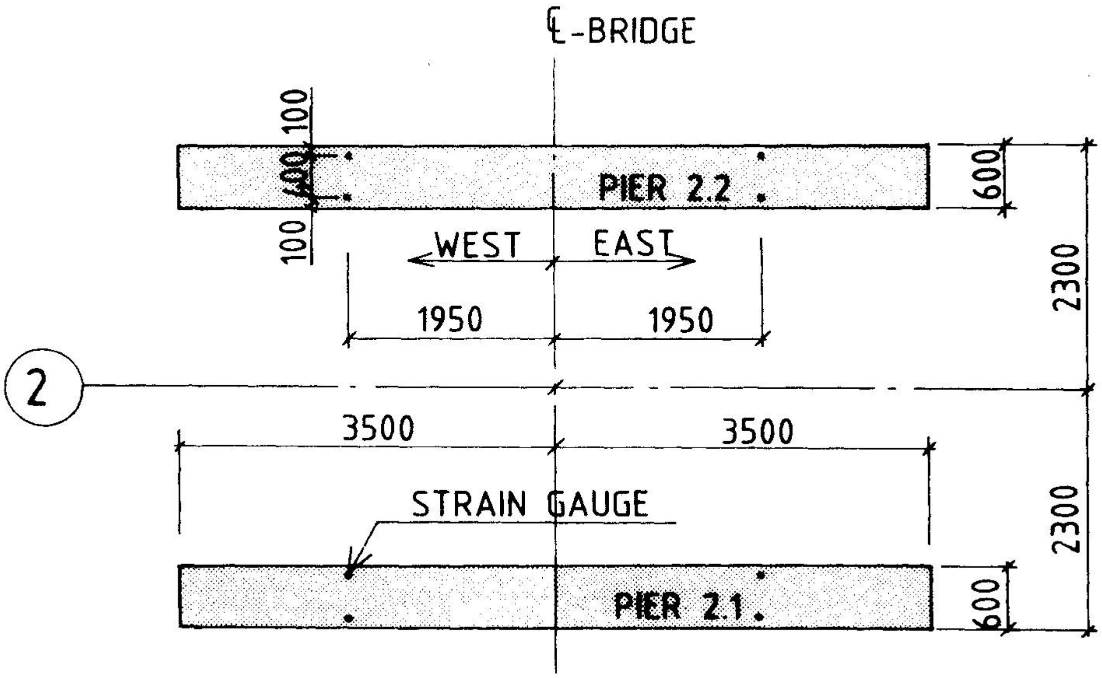


FIG. 2. NORDDALSFJORD BRIDGE. SECTION



TWIN PIERS AXIS 3



TWIN PIERS AXIS 2

FIG 3. LOCATION OF STRAIN GAUGES

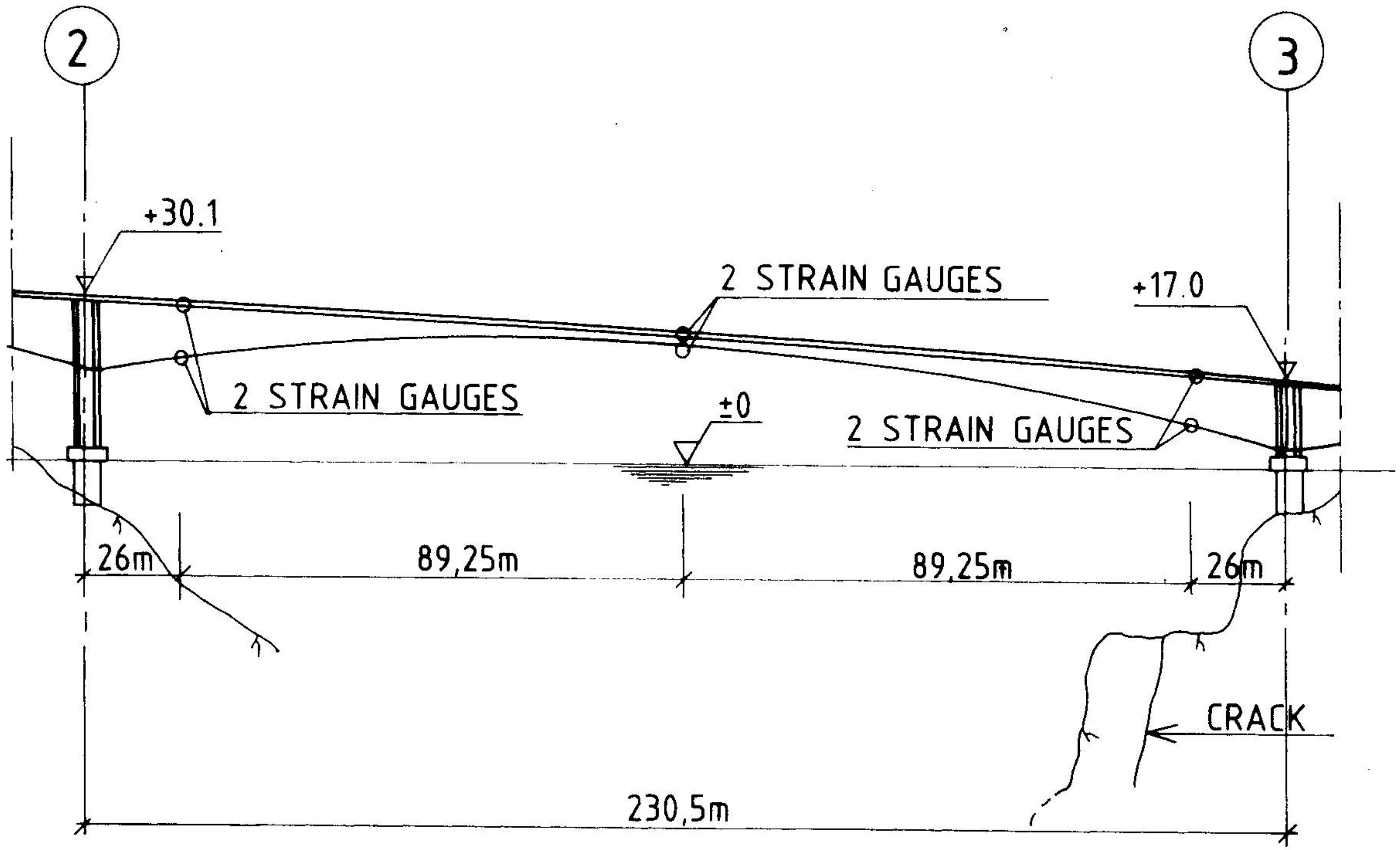


FIG. 4 STRAIN GAUGES IN DECK SLAB AND COMPRESSION SLAB

2.3 Counterweight structures

The counterweight structures filled with rock ballast are vital stabilizing elements. It is of safety reasons necessary to ensure that the total weight is higher than a certain design lower limit. On the other hand, having the bearings in axis 1 and 4 in mind, the total weight must be lower than a certain upper limit. In the actual design, a rather narrow interval was chosen between upper and lower limit. This was compensated by measuring the final load on the bearings by a battery of Enerpack cylinder-jacks. In addition, all the rock ballast was weighed before it was put into the counterweight structures. A little portion of sand and mass concrete was added to the rock to achieve the assumed design weight.

3. THE STRAIN GAUGE

The strain gauge is fabricated by Geonor AS, Norway. The gauge is essentially a vibrating-wire load cell welded to reinforcing steel, see fig. 5. The strain in the steel is a function of the frequency of the vibrating wire, and the frequency is measured by a separate indicator which can easily be connected and disconnected. The strain gauges will hopefully work through the entire lifetime of the structure. After the construction period, readings will be taken at certain intervals.

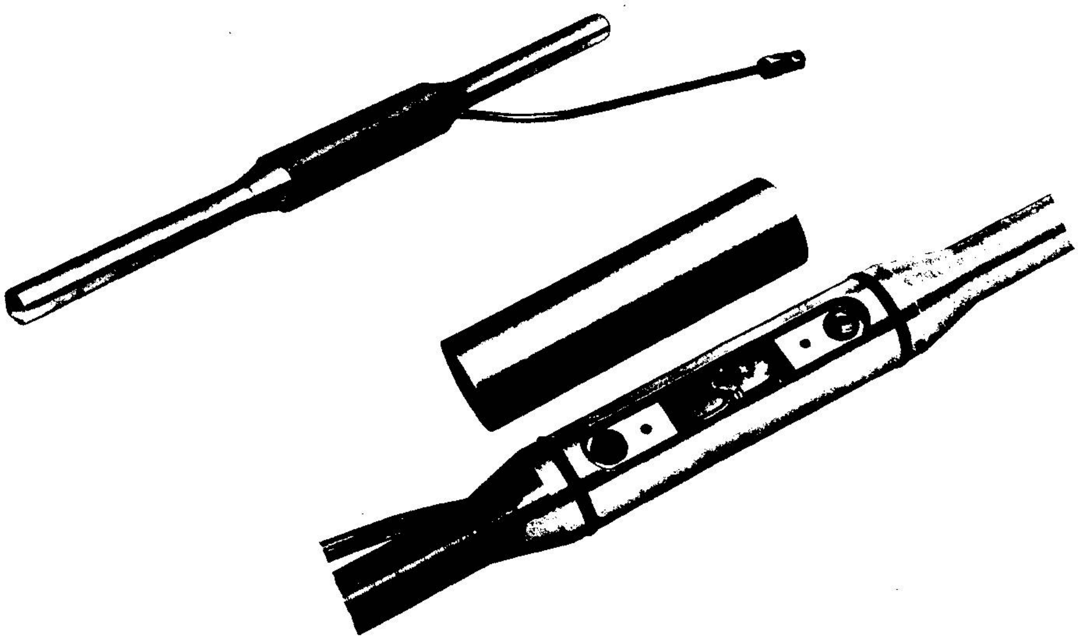


Fig. 5 STRAIN GAUGE

4. RESULTS FROM THE MONITORING INSTRUMENTATION, COMPARED TO CALCULATED VALUES

4.1 Twin wall piers, axis 2

State I: After symmetric free cantilevering, just before connection to the counterweight structure near axis 1.

State II: After completion of remaining unsymmetric free cantilevering until the longest cantilever has reached the middle of the main span.

State III: After jacking down the superstructure 200 mm in axis 1.

State IV: After horizontal jacking and prestressing continuity cables in mid-span.

State V: After installing superimposed dead load.

The strain values include strain due to shrinkage and creep in the concrete and elastic deformation in both reinforcement and concrete. Shrinkage and creep in the concrete is evaluated to account for approximately $\Delta\varepsilon$ = 150 µs in the reinforcement for state I-IV and $\Delta\varepsilon$ = 160 µs for state V. If these $\Delta\varepsilon$-values are subtracted from the measured ε-values, the total compression force in the piers may be computed. This compression force, called "measured force", is compared to the calculated force from the structural analysis.

	Pier 2.1			Pier 2.2		
State	Measured strain ε, (µS)	Measured force N, (MN)	Calcucated force N, (MN)	Measured strain ε, (µS)	Measured force N, (MN)	Calcucated force N, (MN)
I	352	20	21	349	20	21
II	320	17	15	528	38	39
III	457	31	30	364	21	24
IV	453	30	31	348	20	21
V	455	29	29	443	28	28

ε is the mean value of 4 strain gauges
µS = microstrain = 10^{-6}
N is the total axial load (compression) in mega-Newton (mN)

4.2 Twin wall piers, axis 3

State II: After completion of unsymmetric free cantilevering.

State IV: After prestressing continuity cables in mid-span.

State V: After installing superimposed dead load.

Measured force and calculated force are explained in chapter 4.1.

	Pier 3.1			Pier 3.2		
State	Measured strain ε,(µS)	Measured force N,(MN)	Calcucated force N,(MN)	Measured strain ε,(µS)	Measured force N,(MN)	Calcucated force N,(MN)
II	357	21	21	510	36	37
IV	342	19	19	512	36	39
V	468	31	28	543	38	35

ε is the mean value of 4 strain gauges
µS = microstrain = 10^{-6}
N is the total axial load (compression) in mega-Newton (mN)

4.3 Main span

The monitoring of the main span has just begun. The initial values from the six strain gauges are recorded. The development will be checked by taking readings at certain intervals in the future. In addition levelling of the bridge deck will be performed at the same intervals.

4.4 Counterweight structures

The total load on the bearings was checked by a battery of Enerpac cylinder-jacks before continuity in mid-span.

In axis 1 the superstructure was lowered 200 mm in order to stabilize the foundation in axis 2.

Axis	Measured load	Calculated load
1, before vertical jacking	3,60 MN	3,50 MN
1, after vertical jacking	2,82 MN	2,90 MN
4, before continuity	5,76 MN	5,70 MN

5. CONCLUSION, TWIN WALL PIERS

After completion of the bridge (State V), the piers nearest the abutments (piers 2.1 and 3.2) are left with higher compression than their twin pier towards the main span. This was also a design aim.

During construction, there has never been tension in any pier.

The results from the monitoring instrumentation has so far verified the theoretical calculations very well, specially in axis 2. Minor changes in dead load and prestressing force in cables over axis 3 may explain some of the differences between measured and calculated forces in piers 3.1 and 3.2.