

Monitoring the settling of the river pier supporting the Inn valley expressway bridge at Kufstein, Austria

by Martin Aschaber

Erosion of the bed of the River Inn at Kufstein led to the sudden settling of an expressway bridge. The bridge was part of an important international communications link and its prompt repair was eagerly awaited. One problem for the engineers involved in the repair work was the monitoring of the settling of the bridge. The author describes the measuring method used which comprised a differential level monitoring system based on interconnected water vessels.

The bridge over the River Inn at Kufstein was built between 1966 and 1969. As shown in Fig. 1, it consists of three separate reinforced-concrete box girders for the two directions of the Inn valley expressway (A12) and the interstate highway B 175. The bridge spans the River Inn, the Austrian Federal Railway tracks and the B 171 interstate highway.

In plan view the girders are mainly straight and parallel with the exception of the two end spans of the interstate highway bridge which are curved. The overall effective span of the five-span expressway bridge is 450.6 m (1478 ft).

The three superstructures were produced for the first time in Austria using segmental cast-in-place construction. The girders were led over auxiliary supports in the unstressed, reinforced condition. The longitudinal prestress system was later incorporated in the form of a bundled stressed element on the inside of the webs and prestressed via the prestressing blocks on the ends of the girders. A thick layer of gravel, poured in as cement slurry, was applied after stressing for corrosion protection. Severe damage due to corrosion has occurred in all the stressed components over a number of years due to the choice of corrosion protection. This led to the replacing of the complete prestressing system.

Damage to the bridge

On the 11th July 1990 at about 22.00 hours the driver of a car noticed an impact against the wheels of the vehicle as he traveled over the bridge. A step of up to 30 cm (11.8 in) had formed transverse to the direction of travel in the region of the movable joint in the lane in the Innsbruck direction. Luckily, the driver of the car was not injured and he contacted the police. The expressway was immediately completely closed to traffic by the expressway maintenance authorities. After informing the relevant local construction office at Kufstein and the bridge construction department at the state's civil engineering board, all traffic routes in the region of the bridge were closed and barriers set up that same night. This action included the railway tracks, the B 171 and B 175 interstate highways and the river embankment paths.

In the early hours of the next day it was found that the damage had been caused by the settling of the river pier. The pier had sunk about 1 m (3.2 ft) on the downstream side. This value increased during the day to about 1.15 m (3.77 ft). On the upstream side the amount of settling was approximately 22 cm (9 in). The pier had also tilted towards the righthand river span; the degree of tilt was about 60 cm (2 ft) over the pier

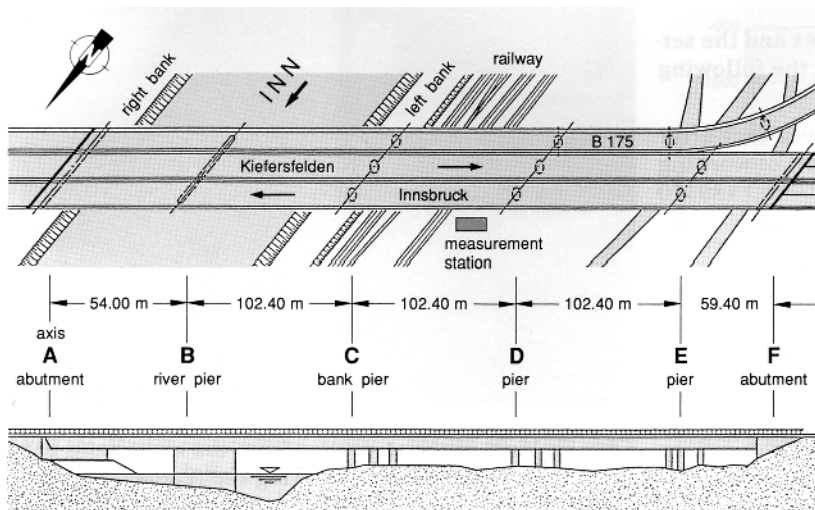


Fig. 1: Plan and elevation of the bridge over the River Inn at Kufstein; the bridge consists of three separate reinforced-concrete box girders



Fig. 2: View of the bridge and river pier from the downstream side after initial safety work had been carried out

height of about 16 m (52.5 ft). In addition, the unreinforced pier shaft had a vertical crack about a third of the way along from the upstream end. **Figure 2** shows a view of the bridge and river pier from the downstream side after the initial preventative measures had been taken.

After the gradual reduction in the settling of the pier, a more accurate assessment of the damage could be made. It was found that the girders had not only settled, but had also been displaced sideways in the downstream direction by about 30 cm (12 in) at the river pier and by about 15 cm (6 in) at the Kiefersfelden abutment. Furthermore, cracks were noticed in the region of Pier C.

The movement of the river pier had been initiated by erosion of the river bed. A more detailed investigation into the cause of the damage is still in progress. From present knowledge it can however be presumed that the disproportionately deep erosion was caused by the "penetration" of the river bed. Fine sand was found down to a deep level, covered by a layer of relatively coarse-grained gravel.

Preventative measures

Apart from the closing of all traffic routes and the setting up of continuous observation posts, the following immediate measures were taken:

- filling with stones to stabilize the river pier after carefully considering the safety aspects of working under the bridge. In total, about 40,000 t (39370 tons) of stones were placed around the pier;
- setting up of auxiliary supports at Pier C;
- removal from the river area of the remainder of the auxiliary framework which had been erected for previous repair work to the highway bridge.

A number of further measures were necessary to repair the damage and to restore the road and rail connections. These included the setting up of auxiliary supports in the area of the railway, securing the displaced bridge bearings, repositioning the downstream

girder, anchorage of the river pier to the left bank and wrapping tendons around the cracked river pier.

The river pier could be repaired using subsoil grout injections. Following an initial assessment, it was planned to bring the pier back into its original position with high pressure injections spread over a number of phases. This proved to be too optimistic and could not be implemented. However, it was possible to partly rectify the tilted position of the pier using injections.

Connecting ramps were set up from the expressway to the bridge carrying the interstate highway to provide temporary traffic routes. The overall settling of the interstate highway was about 24 cm (9.5 in) and caused almost no damage. Therefore the expressway traffic could be accommodated within a very short time by the girder of the interstate highway.

Work involving water engineering had to be carried out to reduce the rough current conditions in the region of the bridge. This included, for example, filling the erosion channels and making a ground sill on the downstream side.

An important activity was the setting up of an integrated measurement system which was connected to the railway station at Kufstein and to temporary traffic lights on the traffic routes. Using a two-stage alarm scheme, this enabled all of the traffic routes to be closed when a defined limit was exceeded. A comprehensive description of the most important features of this measurement system is given in this article.

Rectifying the damage

All the work involved in repairing the bridge girders and restoring them for further use had to be carried out under pressure of time, because the restoration of the international traffic link was of the highest priority. Since the subsoil consisted of fine sand, the injections were not successful in returning the river pier to its former position. This work did however stabilize the subsoil and stop the movement of the pier. In addition to the pier injections, 136 jetting piles were sunk into the ground below the existing pier foundation in order to secure the river pier.



Fig. 3: View of the river pier from the right-hand bank after lifting the girders, showing the temporary prefabricated bearing stacks

As the subsoil injections progressed, the girder supporting the interstate highway was lifted with hydraulic jacks into its original position and temporarily supported on bearings on the river pier. Soon, on the 31st August 1990, the interstate highway bridge could be brought into operation for the expressway traffic. Both of the expressway girders were then lifted. Here, special safety measures were needed due to the horizontal girder displacement of about 20 cm (7.9 in) at the pier. The girders were tensed like springs. This tension had to be slowly brought under control using hydraulic jacks. The expressway girders are now still lying on temporary bearings on the river pier. The space between the nose of the settled pier and the girder which had been raised to its original position is filled with prefabricated bearing stacks. This situation is shown in Fig. 3 which also illustrates the river pier with raised girders and intermediate bearing stacks as viewed from the right bank. The final positioning will be made on the concreted pier. The work required for this will be carried out while maintaining traffic flow. Since it is not possible to bring the river pier to an upright position, the complete pier will be "jacketed" with a surrounding reinforced concrete apron.

All the work on the bridge, which has only been described here briefly, was continuously monitored by measurements to detect the effects of the current activity at each point in time and to call a stop if needed. During the lifting action an alarm point was actually approached, leading to a cessation of lifting. After due consideration a new center for the lifting action of the jacks was found which was only 30 cm (12 in) away from the previous point, but which was nevertheless much more favorable. The measurement equipment is described in more detail below.

Measurement system

The overall concept of the measurement system provided for the passing of all measurements to a central measurement station where they were evaluated by computer. All relevant measurements were acquired and monitored on a continuous basis. A two-stage alarm system was provided which gave advanced warning di-



Fig. 4: The measurement station set up in a builder's trailer on the left bank of the river; the auxiliary supports for the girder can be seen in the left of the picture

rectly on the monitor when the specified limit corresponding to the first alarm stage was reached. This in turn initiated an immediate assessment of the overall situation. On reaching the specified limits for Alarm Stage 2, automatic closure for traffic was provided through appropriately positioned traffic lights. The measurement station was located on the left bank of the river in the measurement trailer shown in Fig. 4.

The significant Parts of the measurement system installed in the region of the river pier comprised an electronic water level system with six measuring vessels on the nose of the pier, two clinometers, inductive displacement transducers and a number of temperature sensors in the box cavity.

Electronic water level system

Immediately following the occurrence of damage an observation post was set up that same night and the progress of the pier settlement was measured using optical means. Figure 5 shows the variation with time of the measurements obtained on the downstream side of the river pier. What was needed for monitoring the pier settlement was an electronic method that automatically acquired the measurements and transmitted them to the measurement station, enabling logging of the results and inclusion of the settlement measurements in the alarm system. It was decided to use an electronic water level system which had already proved useful in settlement measurements.

As illustrated schematically in Fig. 6, a water level system exploits the hydrostatic principle of communicating tubes for making level measurements. In engineering applications the tubes are replaced by measuring vessels. A reference vessel is located on a firm base on the bank. A feed and overflow system maintains a constant level of the measurement fluid in the reference vessel. The levels of the fluid in the separate measuring vessels, which are joined to one another and to the reference vessel by pipes, indicate the same level throughout. If a measuring vessel sinks due to downwards movement on its fixture (settlement of the pier), then the fluid level remains at the same level as before, but the fluid level rises relative to the vessel. The change in level is a measure of the settlement that has occurred. A

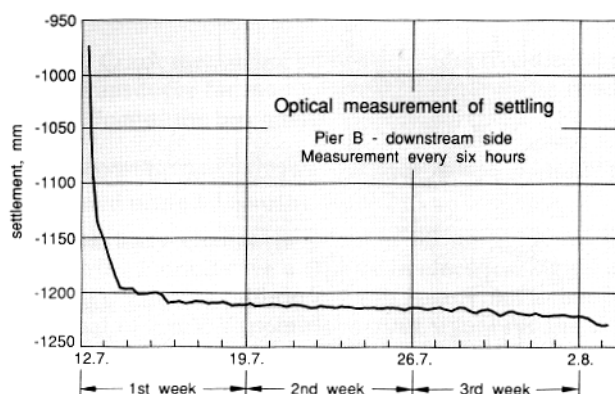


Fig. 5: Results of the optical measurements taken on the river pier which began immediately after damage occurred

change in level also means a change in the quantity of water and the weight of the vessel therefore also changes. This enables the level to be monitored by measuring the weight of the fluid in the vessel. This is technically very easily achieved by fitting each vessel with a load cell which permanently measures the weight of the vessel and passes it as an electrical signal to the measurement station.

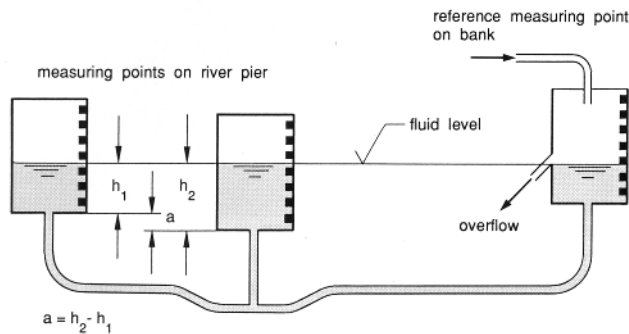


Fig. 6: Diagrammatic representation of the principle of the water level system

Figure 7 diagrammatically illustrates a measuring vessel used in the water level system. Loads cells of the type Z6/10 kg were used. After deciding to install this type of water level system, the utmost speed was needed in setting it up and there was no time for non-essential optimization. Excellent cooperation developed out of the emergency situation between the large number of people, companies and organizations involved. All components for the level monitoring system had to be designed, produced and installed in the shortest possible time. It was thanks to the efficient cooperation between those involved that the water level system was installed and able to supply its first measurements on 1st August

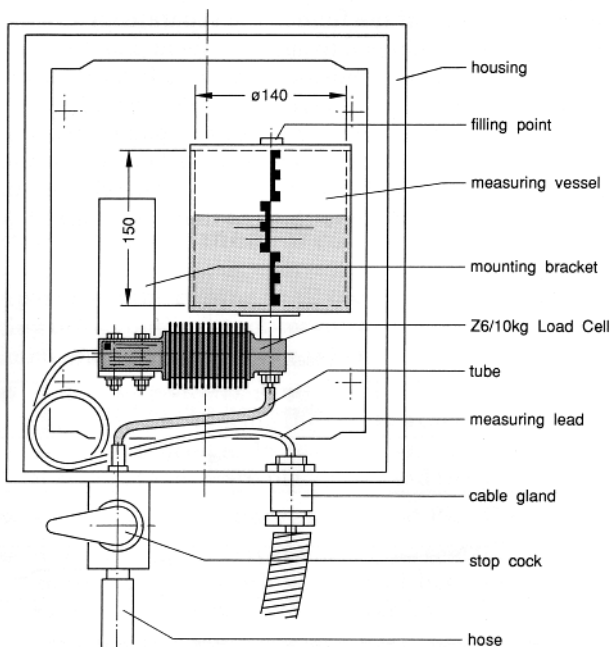


Fig. 7: Arrangement of a measuring vessel in the water level system; the vessel is mounted on a load cell for gravimetric level measurement

1990. **Figure 8** shows a photograph of the reference vessel with the feed and overflow. **Figure 9** illustrates a photograph of the vessel arrangement for Measuring Point No. 1.

A resolution of 0.5 mm (0.02 in) was required from the water level system. This level of accuracy could be obtained without problem with the available load cells in conjunction with a UPM 60 Multipoint Measuring Unit. Load cells were used with a nominal output signal of 2 mV/V at a load of 10 kg (22 lb) and they were operated in the amplifier measurement range of 0.2 mV/V. The possible signal resolution corresponds to a level resolution of approximately 0.1 mm (.004 in). The internal diameter of the measuring vessels was 140 mm (5.5 in) so that a fluid level of about 65 mm (2.6 in) corresponded to a weight of 1 kg (2.2 lb) for a fluid (water) of density 1 g/cm³.

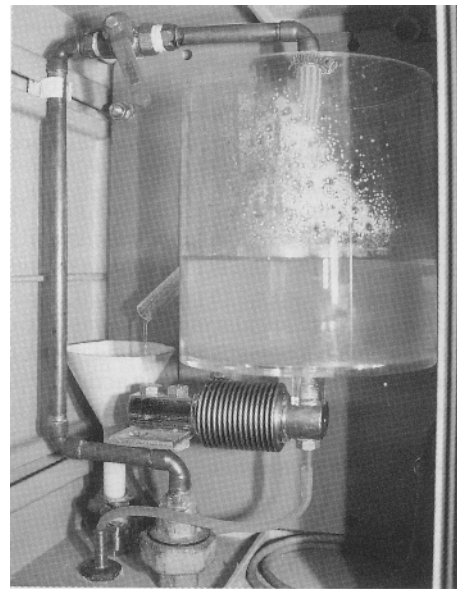


Fig. 8: Reference point measuring vessel with feed and overflow, mounted on firm ground on the river bank



Fig. 9: Vessel arrangement at a measuring point on the river pier

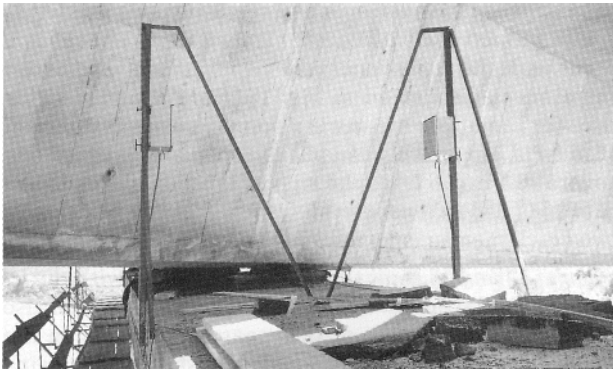


Fig. 10: The measuring points for the water level system on the nose of the pier were mounted on extruded rods

Exact calibration of each measuring vessel, i.e. obtaining the relationship between the transducer signal and the change in level, was made after the complete system had been installed.

The load cells were connected in a six-wire configuration and operated with the 225 Hz carrier frequency amplifier in the UPM 60. The measuring leads were laid in steel conduit to protect the system from lightning. The measuring vessels could not be fixed directly to the pier, because they would have interfered with the lifting work on the girders. Instead they were mounted on extruded rods fitted to the pier as shown in **Fig. 10**. It was therefore possible to change the fixing height if adjustments were needed due to a large degree of settling of the vessels. Changes in the length of the extruded rods due to changes in temperature caused by the weather were slight and did not significantly affect the measurement results. Measuring Point 1 positioned at the south end of the pier (upstream side) was shielded against direct radiation from the sun.

Figure 11 shows the arrangement of the six measuring vessels on the river pier in a plan of the measuring points. Originally, only four points were intended. However, due to the crack in the pier, two extra measuring points (1 and 4) were installed in order to have three points on each segment of the pier. A 1/2" steel pipe provided the hydraulic connection between the reference measurement point on the river bank and Measuring Point 6 on the pier. The ring system connecting the six measuring points consisted of frost-proof garden hose. A mixture of water and glycol was used as the measurement medium.

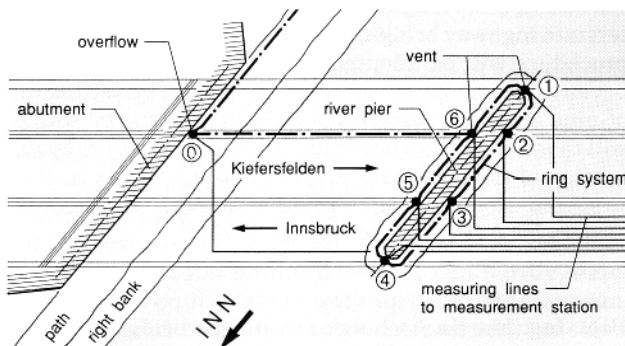


Fig. 11: Plan showing the location of the measuring points in the water level system



Fig. 12: View in the measurement trailer of the UPM 60 Multipoint Measuring Unit which is connected on-line to a personal computer

The method of allocating scale factors for each measuring point, a method provided by the UPM 60, was used for the calibration. A scale factor was determined for each of the six measuring points and these were stored in the UPM 60, enabling the display and measurement output to be given in millimeter units. During calibration each measuring point was measured for two arbitrary water levels and the difference in signals displayed on the UPM 60 was referenced to the

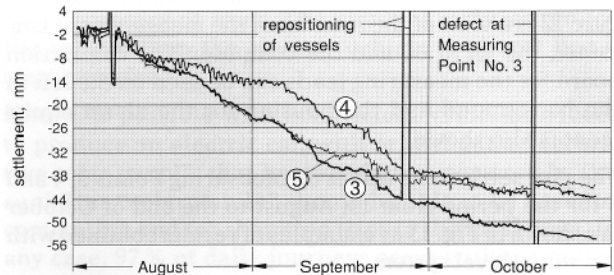


Fig. 13: Results of settling measurements at Measuring Points 3, 4 and 5 in the water level system from the beginning of August to the end of October 1990

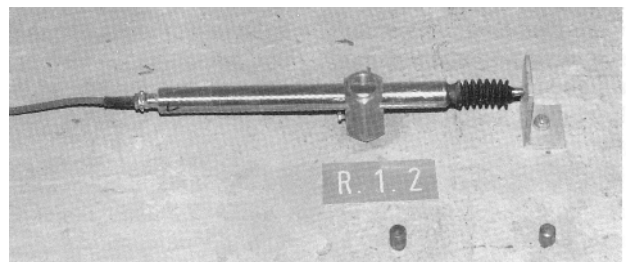


Fig. 14: Crack measuring point with inductive displacement transducer for monitoring the width of the crack on the floor of the box girder

difference in levels. The calibration procedure is explained using Measuring Point 2 as an example.

The arbitrary change in level of 66 mm (2.6 in) at Measuring Point 2 gave a change in electrical signal of 0.224 mV/V during calibration. This means that a change in signal of 2 mV/V (nominal output signal for the Z 6 Load Cell) corresponds to a change in level of 589.29 mm (23.2 in). This set of values is then set on calibrating the UPM 60 for the measurement channel to which Measuring Point 2 is connected. This channel is now set up for a direct measurement display in millimeters to two decimal places. This procedure was used with all the measur-

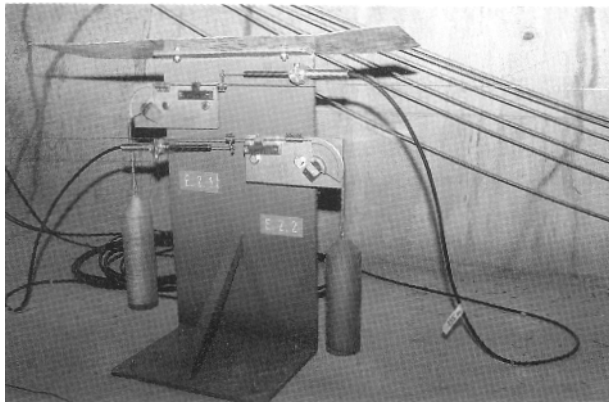


Fig. 15: Wire extensometer measuring point; the changes in the measurement lengths covered by the two Invar wires are measured by two inductive displacement transducers

ing points. The scale factors for the separate measuring points differed slightly due to tolerances in producing the vessels and due to the mounting of the vessels which was not absolutely vertical. The UPM 60 was connected on-line to a computer and to the alarm control unit. **Figure 12** is a view of the interior of the measurement container, the UPM 60 and the computer. The connection board for the measuring leads can be seen on the left in the background and the housing for the alarm equipment is also shown.

The pier settlement values on Measuring Points 3, 4 and 5 for the period from 1st August to the end of October are shown in **Fig. 13** as examples of results obtained with the water level system.

Inductive displacement measurements

Inductive displacement transducers of the type W 20 TS were installed to monitor the behavior of cracks in the structure at selected points. The transducers were arranged to measure the width of the cracks and **Fig. 14** illustrates a crack measuring point on the floor of the box girder.

Wire extensometers consisting of Invar wires with rollers and freely suspended weights to provide the tension were used to measure changes of length over longer distances in Spans I, II and III. The wires transferred

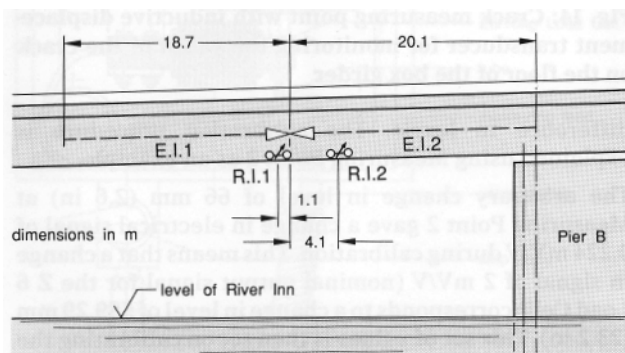


Fig. 16: Example of the arrangement of the extensometers and crack measuring points in the box girder of the lane in the Innsbruck direction

the changes in length over the measurement section to W 20K Inductive Displacement Transducers. The tension point with the transducers for two of these wire extensometers is illustrated in **Fig. 15**. Here the measuring wire for the upper measuring point covers a distance of 18.7 m (61.4 ft) to the left and the wire on the lower one covers 20.1 m (66 ft) to the right. **Figure 16** shows the location of this extensometer system and the position of two crack measuring points in the bridge.

Figures 17 and 18 show the results measured with the inductive displacement transducers. **Figure 17**, which also illustrates the position of the measuring points on the floor of the bridge box girder, clearly shows the closing of the crack which accompanied the girder lifting process. This trend can also be recognised from the results of the two wire extensometers shown in **Fig. 18**.

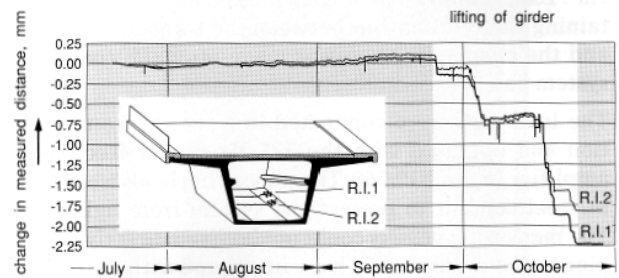


Fig. 17: Measurement results at two crack measuring points using inductive displacement transducers on the floor of the box girder

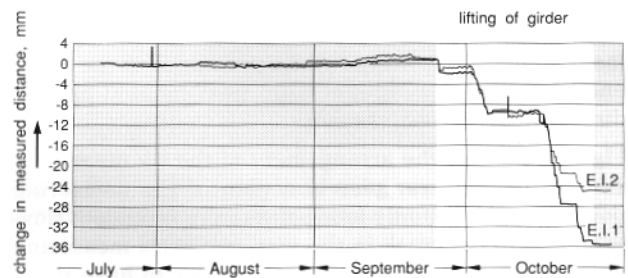


Fig. 18: Changes in length measured with the wire extensometers shown in **Fig. 15**

On-going work

The complete longitudinal prestressing for the interstate highway bridge has been replaced and the same procedure will be adopted for the expressway girders, because the tendons are in part corroded. The setting up of nine auxiliary supports per girder is required which will then take the girder load during the step-by-step extension of the concentrated prestressing elements. It is expected that the final release of both expressway girders for traffic will be in June 1992.

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