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Autor: Nilsson, Ingvar

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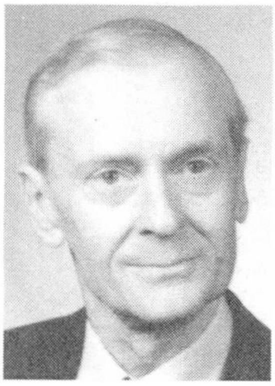
Crack-Free "Surround Concrete" Repairs of the Öland Bridge Piers

Renforcement des piles du pont d'Öland à l'aide d'une enveloppe de béton sans fissures

Rissfreie Betonierung in der Reparaturarbeit der Brückenpfeiler der Ölandbrücke

Ingvar NILSSON
Dr. Eng.
Nordic Construction Co.
Malmö, Sweden



Ingvar Nilsson received his Master's degree in civil engineering in 1963 and Ph.D. in 1973 at Chalmers University of Technology, Göteborg, Sweden. Since 1976 he is at Nordic Construction Company, active in the fields of concrete structures, design, construction methods, materials, durability and repair.

SUMMARY

Damaged bridge piers have been repaired by casting new concrete around them. The use of a sliding layer between an old pier and its surrounding concrete is a new method of obtaining a crack-free structure. Based on measured load-deformation curves for the sliding layer in respect of both normal forces and shearing forces, surround concreting of the piers with a sliding layer can be dimensioned so that no cracks result from the heat of hydration and shrinkage.

RÉSUMÉ

Les piles de pont endommagées ont été réparées en y coulant une enveloppe de béton. Une nouvelle méthode, utilisant une couche de glissement entre la pile existante et le béton frais, a permis d'éviter la formation de fissures. Des courbes charge-déformation sous l'effet de l'effort normal et du cisaillement ont été établies pour cette couche de glissement. Ces courbes ont permis de dimensionner l'enveloppe de béton afin d'éviter la formation de fissures liées à la chaleur d'hydratation et au retrait.

ZUSAMMENFASSUNG

Schäden an den Brückenpfeilern sind mit frischen Betonschalen rund um die Pfeiler repariert worden. Die Benutzung von einem Gleitlager zwischen dem alten Pfeiler und der Betonschale ist eine neue Methode, um eine rissfreie Konstruktion zu erreichen. Die Dimensionierung, die auf abgemessene Last - Deformationskurven (für das Gleitlager unter beide Normalkräfte und Schubkräfte) basiert, wird ausgeführt, so dass die Betonschalen durch Reaktionswärme und Schwinden nicht gerissen werden.

1. INTRODUCTION

With a total length of 6072 m the Öland Bridge in Sweden was the longest bridge in Europe until the Great Belt bridges in Denmark were finished in 1994.
The Öland Bridge was built from 1968 to 1972. From 1990 to 1994 it has been undergoing one of the most comprehensive bridge repairs in the world.
112 of the 156 bridge piers have been repaired.

The piers spalled to a depth of 5-10 cm in the splash zone. The reinforcement was partially exposed in other places. The cause of damage was poor concrete quality. The concrete satisfied the specified strength requirements, but its durability was low. The Öland Bridge was built in accordance with regulations for concrete structures in force in the late sixties. Therefore, many other bridges built at this time also exhibit similar damage.

2. REPAIR METHOD

The piers have been repaired by casting new concrete around them down to the base plate. The existing piers are regarded as ineffective. The concrete shell has a thickness of 40 cm on the long side and 50 cm on the short sides. The work is done mostly below water level in special cofferdams, see Fig 1.

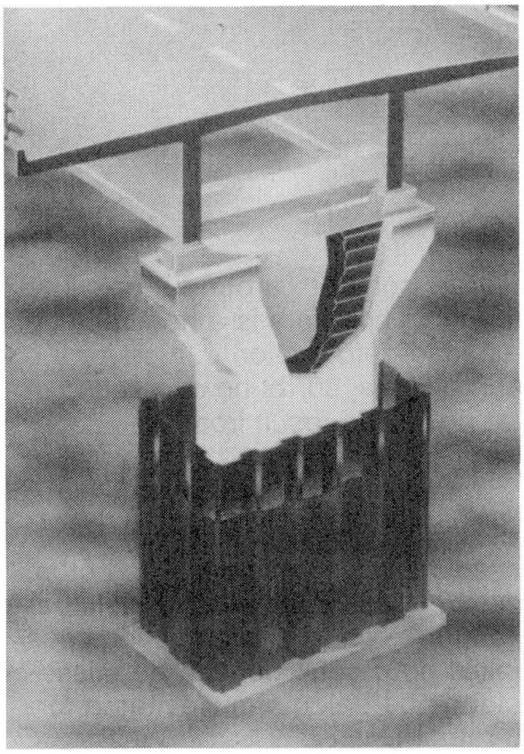
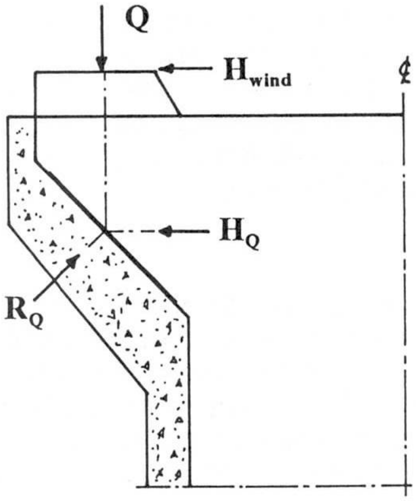


Fig. 1 The work is done under dry conditions in a cofferdam which stands on the base plate.
A sliding layer is placed between the old pier and surround concrete structure.

Fig. 2 Loads on pier top and reaction transferred to surround concrete structure below cantilevered beam.



2.1 Design

The load Q from the bridge bearing (Fig. 2) is transferred in the inclined contact surface. The reaction R_Q is carried by reinforcement in the concrete walls in the direction of the force. The reaction H_Q is a compressive force in the old concrete pier. Epoxy injection into the slit under the inclined surface of the cantilevered beam means that there is contact against the new surrounding pier. The injection is carried out not earlier than half a year after casting when most of the long time deformations have occurred. The rest of the surround concrete structure is separated from the old pier by a sliding layer based on asphalt. Fig. 3 shows the suspension reinforcement in the cantilevered beam.

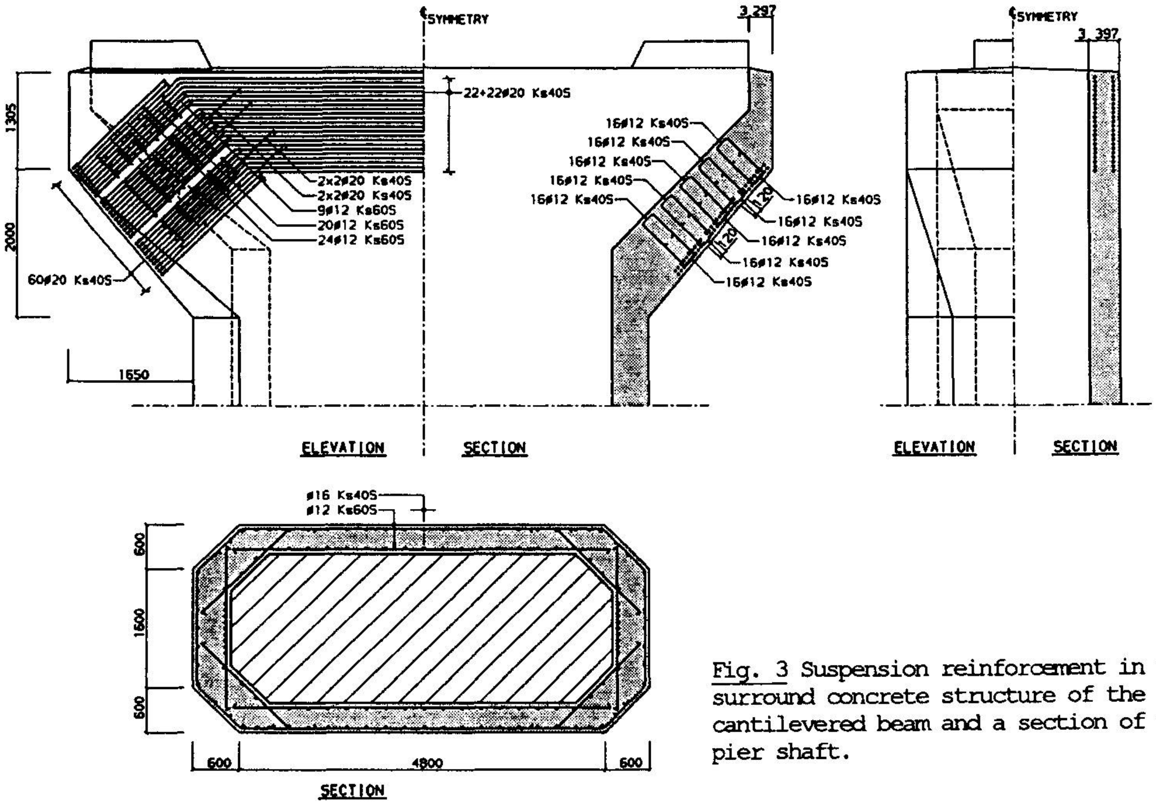


Fig. 3 Suspension reinforcement in the surround concrete structure of the cantilevered beam and a section of the pier shaft.

2.2 Concrete

In order to obtain surround concreting of good durability the following is required: 1. High quality concrete, 2. At least 50 mm concrete cover, 3. Crack-free surround concrete. Durability requirements demand that the surround concreting is crack-free. This is difficult to obtain and special measures are necessary.

The surround concreting is cast with quality K40 (40 Mpa on 15 cm cubes), Swedish cement, 420 kg/m^3 concrete, gravel size 18 mm, water-cement ratio $\leq$ 0.40, 5.5% of air (min 5.0%, max 6.5%), slump 80-100 mm normally without plasticiser.

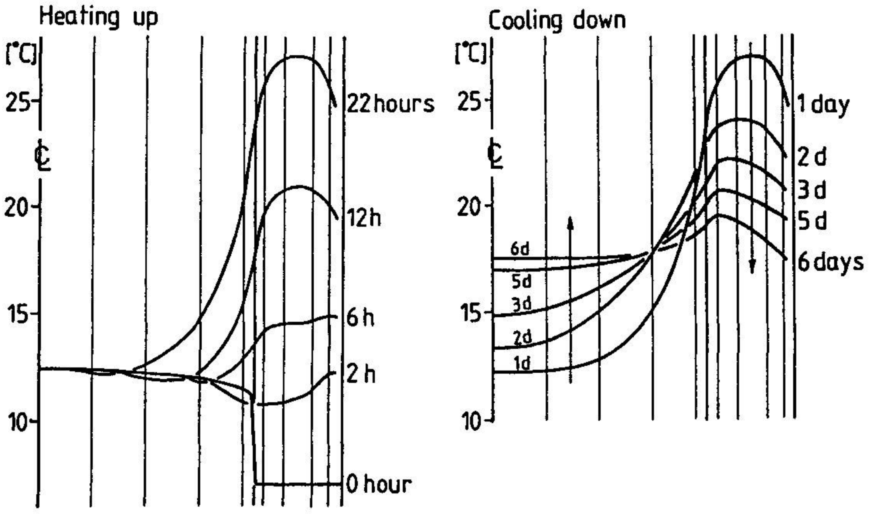
Forms are only allowed to be removed when the new concrete has attained a compressive strength of 28 Mpa and has a temperature not more than 5°C above that of the concrete in the old pier and the ambient air. The aim is to limit the risk of surface cracks. Therefore, forms are usually removed after 15-30 days. Stripped surfaces are protected in temperature controlled environment and water cured continuously with fresh water until the concrete cube strength has reached 40 Mpa. This is reached after 35-55 days, depending on the time of the year. The pier is then painted with a silane. The cofferdam is now removed and the brackish water of the sound comes into contact with the new piers.

3. TEMPERATURE CRACKS

When surround concreting piers there is a risk that the surround concrete will crack. It contracts when the heat of hydration starts to decrease and the surrounding concrete cools. Horizontal contraction is prevented by the old pier. A risk of vertical cracking will then arise. If vertical contraction is prevented there is a risk of horizontal cracking. The cracks will pass through the surrounding concrete.

Calculated temperature development in the surrounding concrete and the old pier corresponds well with measured temperatures. The surrounding concrete heats up the old pier. As a consequence the old pier expands at the same time as the surrounding concrete cools down and contracts. This results in dangerous high tensile stresses in the surrounding concrete with a risk of cracks. In order to reduce the cooling and the risk of cracking, the concrete casting temperature is first lowered by cooling with liquid nitrogen.

Initially one pier, No 108, was tested without a sliding layer. The casting temperature was 7°C. Fig.4 shows measured temperatures in a central section. While the surround concrete is cooling, the old pier is heating up.
The accompanying contraction and expansion result in a demand for measures to ensure that the concrete would not crack. Fig.5 shows how pier 108 cracked.



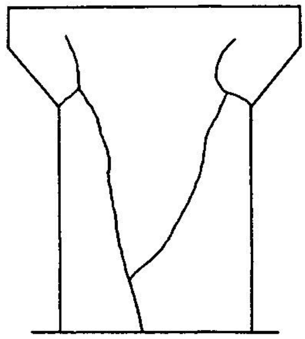


Fig. 4 Measured temperature distribution in a central section of pier No 108 during heating and cooling of the surrounding concrete.

Fig. 5 Crack pattern for test pier No 108.

4. SLIDING LAYER

The use of a sliding layer between an old pier and its surrounding concrete is a new method of obtaining a crack-free result. Cooled concrete is used in order to limit the contraction during cooling.

On the long sides of the piers the sliding layer consists of two layers of 1.6 mm asphalt carpet. On the short sides of the piers where the movement requirements are biggest, a 3.0 mm cellular plastic layer is placed between the asphalt carpets. Sliding layers are not used in the load transfer areas.

Under compressive load the material flows out into pores in the concrete surface which after 20 years exposure has got a rough surface structure. In this way the sliding layer can take up a small movement, even when perpendicular to the surface.

4.1 Movement in the sliding layer

The movements which need to be taken up in the sliding layer are mainly caused by the cooling contraction of the surrounding concrete when the maximum curing temperature is exceeded. That part of the surrounding concrete which is positioned above the water also experiences a slight drying-out shrinkage.

When casting with cooled concrete the difference between max curing temp and curing temp after long time became about 20°C. The cooling contraction coefficient = $8.19 \cdot 10^{-6}$.

Horizontal movement requirements (Fig.6a)

Cooling contraction = $8.19 \cdot 10^{-6} \cdot 20 = 0.16 \cdot 10^{-3}$

Drying out shrinkage = $0.10 \cdot 10^{-3}$

Total = $0.26 \cdot 10^{-3}$

Vertical movement requirements (Fig.6b)

Vertical contraction at 20°C cooling:

For 10 m high pier = 1.64 mm + shrinkage

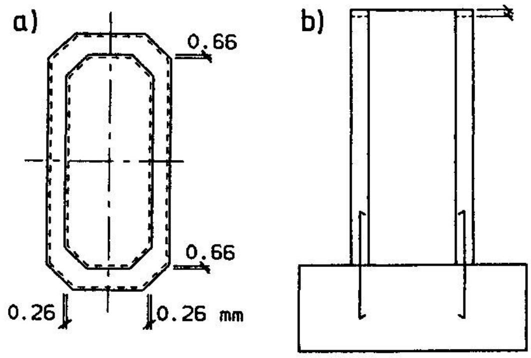


Fig. 6 Horizontal and vertical movement requirements for the surrounding concrete.

4.2 Load-deformation relationship

Which stresses occur in the surrounding concrete when there are movements as outlined above? When the sliding layer is compressed tensile stresses occur. Is there any risk that the surrounding concrete will crack? The load-deformation curves must be determined experimentally for different combinations of normal force and shearing force in order to provide a basis for dimensioning.

5. COMPRESSION ON SHORT SIDES

When the concrete rising rate is 0.6 m/hour there is a concrete pressure of 0.048 Mpa from 2 m concrete before setting. Fig. 7 shows that this corresponds to a compression of 1.34 mm. Cooling and shrinkage need, according to Fig. 6, a 0.66 mm movement requirement, in all 2.0 mm. When the sliding layer is compressed 2.0 mm against the pier side a counter pressure of 0.093 Mpa will occur according to Fig.7. According to Fig. 8 the tensile stress p in the long sides of the surrounding concrete is

$$p \cdot (0.4 + 0.4) = 0.093 \cdot 2.0 \qquad \text{I.e. } p = 0.23 \text{ Mpa}$$

The concrete reaches a tensile strength which is higher than this tensile stress after less than 1 day. Accordingly, it will not crack.

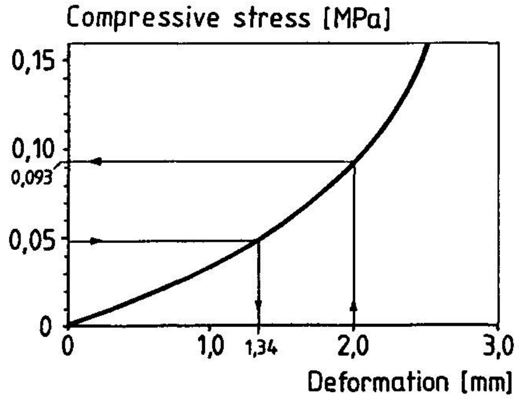


Fig. 7 Measured working curve for a sliding layer with a cellular plastic layer.

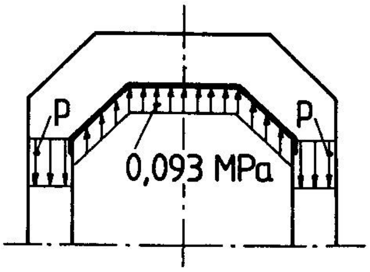


Fig. 8 Tensile stresses in the long sides of the surrounding concrete.

6. COMPRESSION ON LONG SIDES

The concrete pressure is according to the previous chapter assumed to be 0.048 Mpa. Fig. 9 shows that this corresponds to a compression of 0.32 mm. Cooling and shrinkage require according to Fig. 6 a movement need of 0.26 mm, in all 0.58 mm.

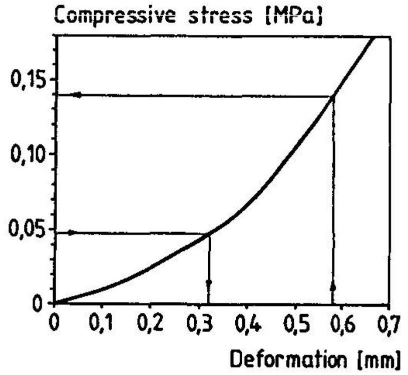


Fig. 9 Measured working curve for a 3.2 mm thick sliding layer on the long sides.

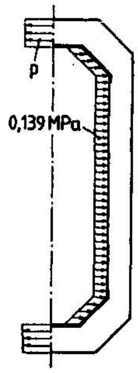


Fig. 10 Tensile stresses in the short sides of the surrounding concrete.

When the sliding layer is compressed 0.58 mm against the pier side a reaction pressure of 0.139 Mpa will occur according to Fig. 9. The tensile stress p in the short sides of the surrounding concrete is according to Fig. 10

$$p \cdot (0.5 + 0.5) = 0.139 \cdot 5 \quad \text{i.e. } p = 0.695 \text{ Mpa}$$

The concrete reaches a tensile strength which is higher than the calculated tensile stress after less than 1 day. Accordingly, it will not crack.

7. SHEARING MOVEMENT

The surrounding concrete structure is anchored to the bottom slab. When the surrounding concrete cools down it contracts vertically. Working curves for shearing force-sliding were measured (not shown here). The shearing stress along the pier decreases against the bottom slab. The calculated tensile stress in the surrounding concrete becomes much less than the concrete tensile strength. Accordingly, it will not crack for vertical sliding.

8. CONCLUSIONS

The use of a sliding and compressible layer between the existing piers and the surrounding concrete opens up possibilities of taking up the movements related to surround concreting. Based on measured load-deformation curves for the sliding layer in respect of both normal forces and shearing forces surround concreting of the piers with a sliding layer can be dimensioned so that there are no cracks resulting from the heat of hydration and shrinkage.

If a cellular plastic layer is included in the sliding layer one must select a material with closed cells and low water absorption, otherwise there is a risk of bursting under freezing conditions. For the Öland Bridge cellular plastic is used only at the pier ends where the movement requirement is greatest. Furthermore, the cellular plastic is enclosed between two watertight asphalt membranes.

REFERENCE

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