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Two Highway Bridges with High-Grade Steel Reinforcement

Zwei Straßenbrücken mit Bewehrung aus hochwertigen Stählen

Deux ponts-routes en béton avec armatures en acier à haute résistance

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Two reinforced concrete highway bridges, which were recently designed and constructed in Sweden, have been provided with plain reinforcement bars made of high-grade steel ($\sigma_{Y.P.} \approx 100{,}000$ p.s.i.) and with Forssell's anchoring rings (British Patent No. 569.729), see Fig. 1. The anchoring rings and the reinforcement bars were supplied by Halmstads Järnverks AB. The rings had been attached to the bars in connection with the cold drawing of the bars at a rate of about 5 per cent (57,000 p.s.i. $\lessapprox \sigma \lessapprox$ 100,000 p.s.i.).

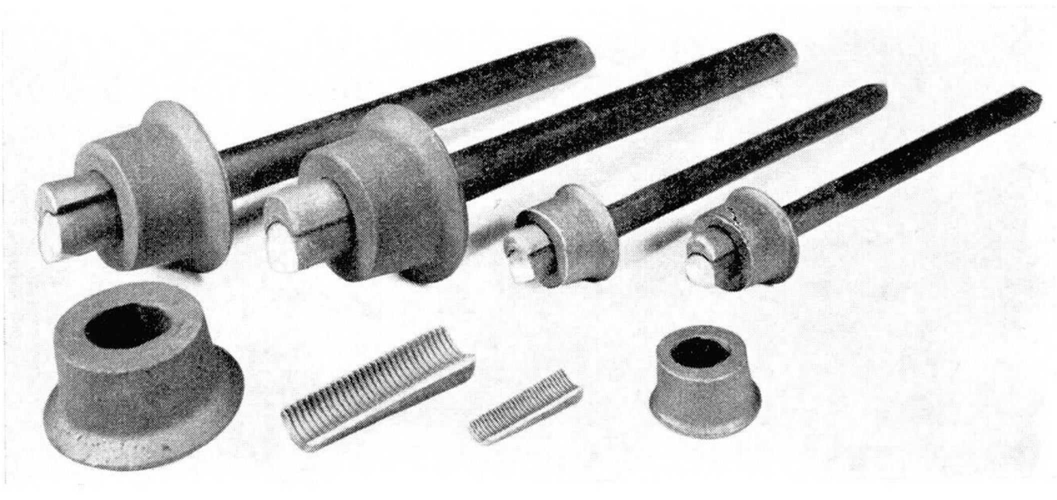

Fig. 1

Both these bridges, which had to comply with the severest requirements for Swedish highway bridges, were designed in accordance with the regulations issued by the Board of Roads and Waterways. The load stipulations were the same as those which are commonly applicable in such cases. The allowable stresses in this type of reinforcement, which has never before been used for bridges, were determined in conformity with the preliminary conditions stated in what follows.

The allowable stress in the reinforcement, which was calculated on the assumption that the concrete in tension was inactive, and that $n = E_{steel}/E_{concrete} = 15$, was fixed at 42,600 p.s.i. (3,000 kg per cm²). However, the allowable stress should not exceed the value determined by

$$\sigma = 0.247 \frac{m \cdot z \cdot \sqrt{d} \cdot E}{W \cdot T} \text{ p.s.i.} \left(\sigma = \frac{m \cdot z \cdot \sqrt{d} \cdot E}{W \cdot T} \text{ kg per cm}^2 \right)$$

where m is the number of reinforcement bars in tension,
z is the lever arm of the internal moment, in. (cm),
d is the mean diameter of the reinforcement bars, in. (cm),
E is the modulus of elasticity of the reinforcement steel, p.s.i. (kg per cm²),
W is the moment of resistance of the concrete cross section for the edge in tension without regard to the reinforcement, cu.in. (cm³),
T is a coefficient equal to 25 for the dead load, and to 15 for the dead load with the addition of half the live load.

The latter restriction was applicable only in those cases where the tensile stress calculated (without regard to the reinforcement) for the concrete cross section, which was assumed to be homogeneous, exceeded the allowable value given below.

The maximum allowable compressive stress in concrete was 1,780 p.s.i. (125 kg per cm²). In addition, the following correlated values of the compressive strength determined on 8 in. cubes, the allowable compressive stress in bending, and the allowable tensile stress in bending (cf. above) were stipulated for the concrete.

Compressive Strength p. s. i. (kg per cm²)	Allowable Compressive Stress p. s. i. (kg per cm²)	Allowable Tensile Stress p. s. i. (kg per cm²)
5,700	1,780	484
(400)	(125)	(34)
4,980	1,560	455
(350)	(110)	(32)
4,270	1,350	427
(300)	(95)	(30)

It was found most advantageous to use a working stress of 1,350 p.s.i. (95 kg per cm²) in the first of the bridges described in what follows, and a working stress of 1,560 p.s.i. (110 kg per cm²) in the second of these bridges.

When the load comprised all effects, including a certain displacement of the supports and the influence of temperature and shrinkage, the allowable maximum increase in all stresses was fixed at 30 per cent.

Furthermore, an increase of 10 per cent in the allowable compressive stress in concrete was permitted for the moments at the supports.

The investigations published by Forssell in Schweizer Archiv für angewandte Wissenschaft und Technik, Heft 7, 16. Jahrg., 1950, show that these regulations in respect of the reinforcement bars and the anchoring rings are very restrictive. The reason is that the Swedish authorities wished to gain some experience of their own before permitting unconditional use of this method of reinforcement.

The reinforcement of the bridge deck and the secondary reinforcement of the girders in both bridges consisted of deformed bars having an allowable stress of about 27,000 p. s. i. This circumstance is of no interest in the present paper.

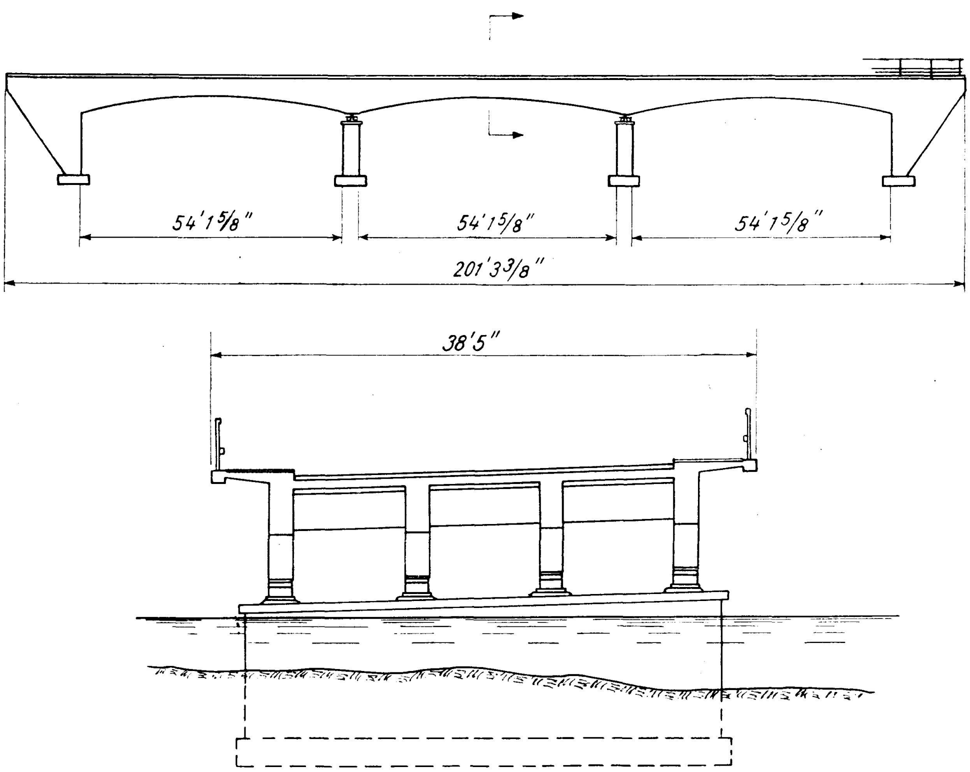

Fig. 2

One of the bridges is a three span girder frame bridge with four main girders, see Fig. 2. The maximum positive moment applied to a girder acts in the end spans of the two girders in the middle. This moment amounts to 1,195 ft. kips (165 tm). The corresponding reinforcement is shown in Fig. 3. The maximum negative moment applied to a girder acts at the external supports of the two middle girders. This moment is 2,320 ft. kips (321 tm). The corresponding reinforcement is shown in Fig. 4. For both of these moments, use has been made of the allowable stresses increased by 30 per cent.

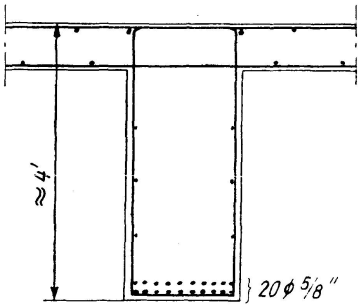

Fig. 3

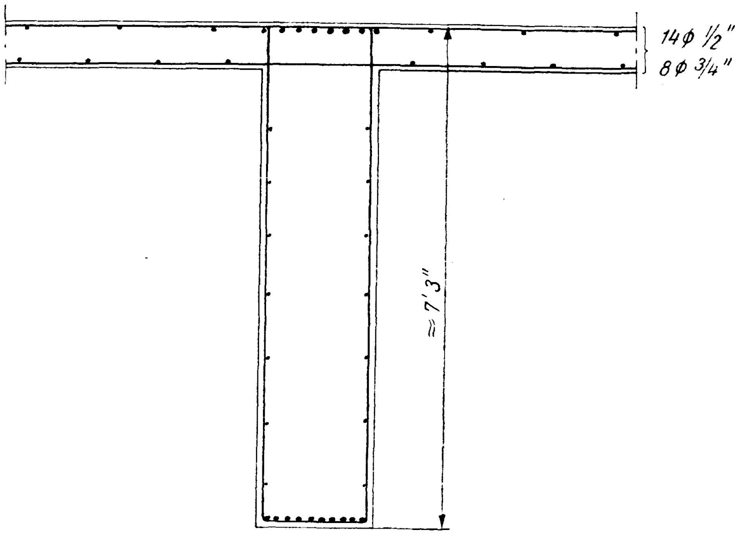

Fig. 4

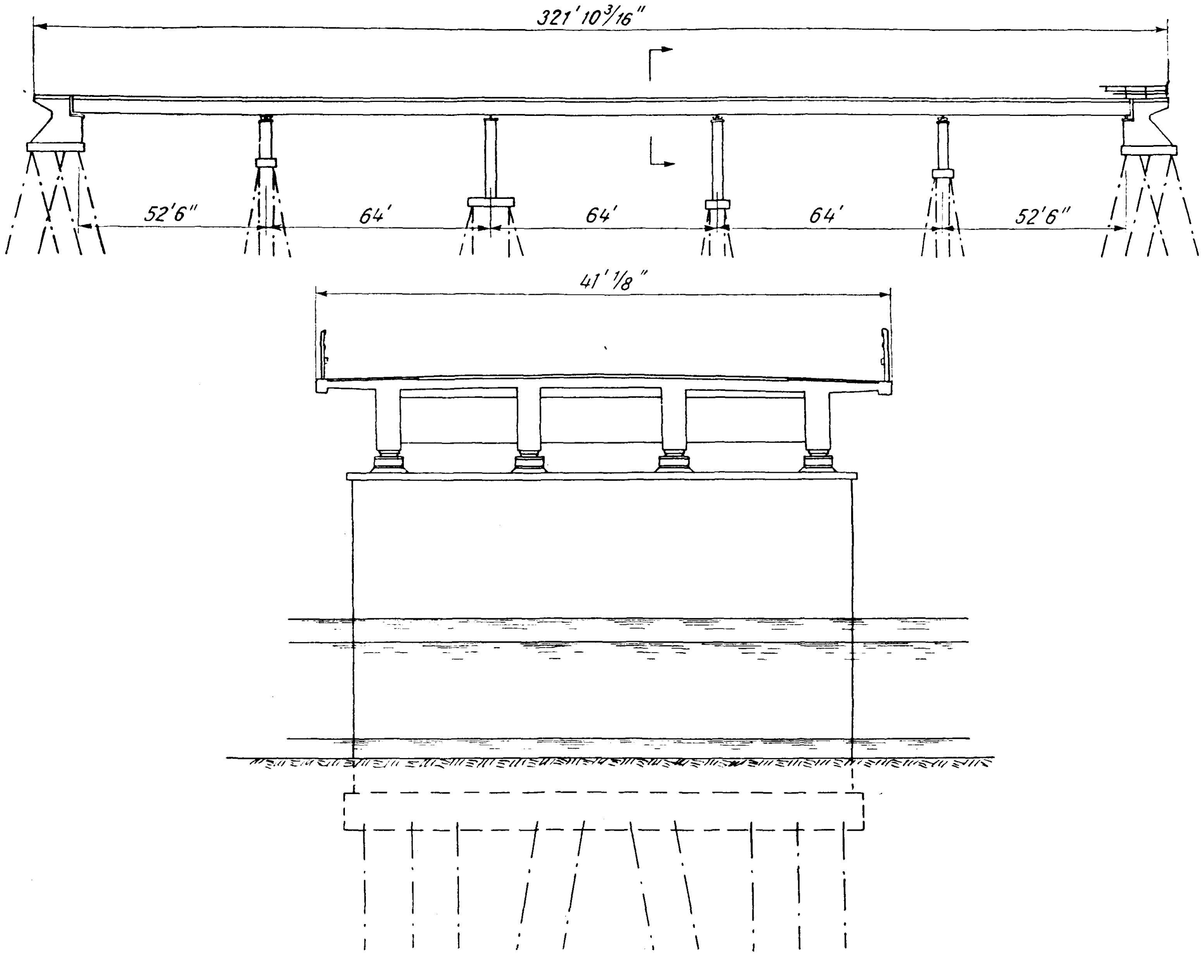

Fig. 5

The other bridge is a five span girder bridge with four main girders, see Fig. 5. The maximum positive moment applied to a girder acts in the end spans of the two outer girders. This moment is 1,340 ft. kips (185 tm). The corresponding reinforcement is shown in Fig. 6. The maximum negative moment applied to a girder acts at the two intermediate supports of the two outer girders. This moment is 1,510 ft. kips (209 tm). The corresponding reinforcement is shown in Fig. 7. For both these moments, use has been made of the allowable stresses without any corrections.

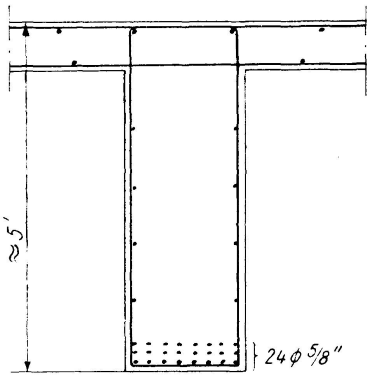

Fig. 6

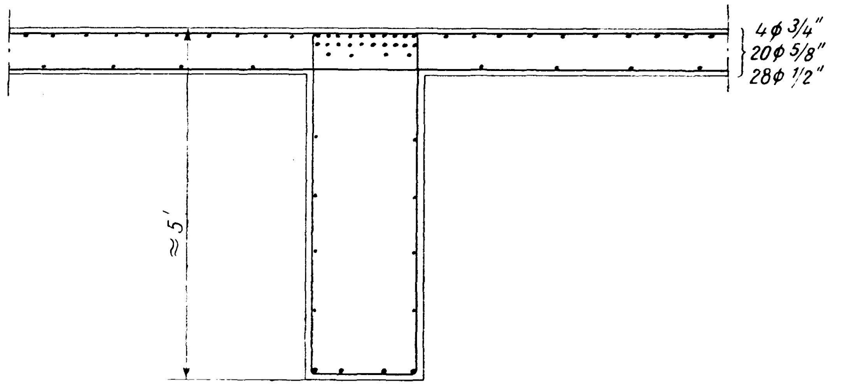

Fig. 7

In addition to the direct advantage derived from the use of this high-grade steel reinforcement, viz. small dimensions, it has resulted in lower weight and reduced rigidity. The former circumstance has yielded small moments due to the dead load. The latter circumstance has led to small moments due to the displacement of the supports and to temperature and shrinkage effects. As a result, both bridges are economical structures. Moreover, since this method of reinforcement is such that it can be used without any special arrangements whatever, and does not require any specially trained labour, it may be expected to find wide applications in the construction of reinforced concrete bridges.

The bridges described in this paper were designed by BYGGNADSRÅD, Nils Centerlöf, Åke Holmberg, Consulting Engineers, the Swedish partners of the Scandinavian Planning and Designing Co., Copenhagen, Denmark. The designer was Erik Gunnerdal, M. Sc.

Summary

A description is given of two reinforced concrete bridges provided with high-grade steel reinforcement ($\sigma_{Y.P.} \approx 100{,}000$ p. s. i.). The use of Forssell's anchoring rings for the anchorage of the reinforcement bars, see Fig. 1, has permitted high allowable stresses, which have resulted in small dimensions

and economical structures. One of the bridges is shown in Fig. 2, while Fig. 3 represents the reinforcement in a girder panel, and Fig. 4 illustrates the reinforcement at a support of a girder. The other bridge is shown in Fig. 5, while the reinforcement in a girder panel is represented in Fig. 6, and the reinforcement at a support of a girder is illustrated in Fig. 7.

Zusammenfassung

Der Verfasser beschreibt zwei Straßenbrücken aus Eisenbeton mit Bewehrung durch hochwertige Stähle (Fließgrenze ca. 70 kg/mm^2). Die Verwendung von Verankerungen durch Ringe nach Forssell (Fig. 1) gestattete, größere zulässige Beanspruchungen vorzusehen, was zu geringeren Abmessungen und größerer Wirtschaftlichkeit führte. In Fig. 2 ist eine der beiden Brücken dargestellt; die Fig. 3 und 4 zeigen das System der Eiseneinlagen eines Balkenquerschnittes in der Mitte einer Spannweite und bei einem Auflager. Die Fig. 5 zeigt die 2. Brücke und die Fig. 6 und 7, Armierungen eines Balkenquerschnittes in der Mitte einer Spannweite und bei einem Auflager.

Résumé

L'auteur décrit deux ponts-routes en béton armé avec armatures en acier à haute résistance (limite d'écoulement env. 70 kg/mm^2). L'emploi d'anneaux de Forssell pour l'ancrage des fers (fig. 1) a permis de prévoir des charges admissibles élevées et corrélativement des dimensions réduites et une construction économique. La figure 2 représente l'un des ponts; les figures 3 et 4 representent le système d'armatures d'une section de poutre au milieu d'une travée et dans la proximité d'un appui. La figure 5 se rapporte au deuxième pont et les figures 6 et 7 aux armatures d'une section de poutre au milieu d'une travée et dans la proximité d'un appui.