Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 64 (1991)

Artikel: High strength concrete for prestressed concrete girders

Autor: Taerwe, Luc

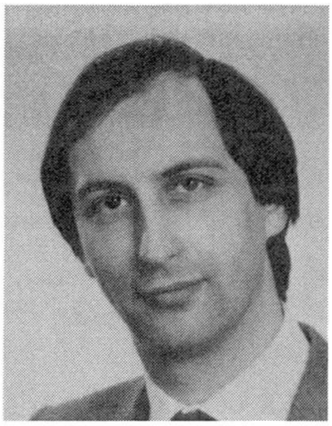
DOI: https://doi.org/10.5169/seals-49332

High Strength Concrete for Prestressed Concrete Girders

Bétons à hautes performances pour les poutres précontraintes

Beton mit hoher Druckfestigkeit für Spannbetonträger

Luc TAERWE
Lecturer
University of Ghent
Ghent, Belgium



Luc Taerwe, graduated as Civil Engineer at the University of Ghent in 1975 where he also obtained his Doctor's degree. At the Magnel Laboratory he is involved in research on non-linear behaviour of concrete structures, high strength concrete, quality assurance and stochastic modelling. He is recipient of several scientific awards among which RILEM's Robert L'Hermite Medal.

SUMMARY

In the paper it is shown that the use of high strength concrete allows increasing the span of prestressed girders with given cross section. It is also indicated that for a given span length, girder spacing can be significantly increased. These benefits are demonstrated by means of numerical examples.

RESUME

L'article montre comment l'utilisation d'un béton à hautes performances permet d'augmenter la portée de poutres précontraintes de section donnée. Pour une portée donnée, la distance entre les poutres peut être augmentée de façon significative. Quelques exemples numériques illustrent les avantages précités.

ZUSAMMENFASSUNG

In diesem Beitrag wird beschrieben wie mit der Anwendung von Beton mit hoher Druckfestigkeit die Stützweite von Spannbetonträgern mit gegebenem Querschnitt erhöht werden kann. Auch wird nachgewiesen, dass für eine bestimmte Stützweite der Querabstand der Träger bedeutend zunehmen kann. Die genannten Vorteile werden anhand einiger numerischer Beispiele erläutert.

1. INTRODUCTION

During the last decade, the use of high strength concrete (HSC) has increased considerably and a lot of research has been devoted to mix design and to the structural behaviour of HSC members. The major part of the applications of HSC concerns particular structures such as

- off-shore platforms in the Nordic countries
- high-rise buildings in North-America (mainly limited to columns).

In these applications, HSC is primarily subjected to compression and thus the beneficial effect of the increased strength is used in the most direct way. With its greater compressive strength per unit cost, HSC is often the least expensive means of carrying compressive forces. In addition, its greater compressive strength per unit weight and unit volume allows lighter and more slender structural elements.

In reinforced concrete members subjected to bending (beams, slabs) the yielding moment is hardly influenced by the use of HSC and possible advantages can only be expected with respect to serviceability [1]. However, as prestressed concrete concerns, potential benefits in using HSC may be expected since the major part of the section is submitted to compressive stresses (full prestressing and allowable stress design).

2. POST-TENSIONED GIRDERS

This section will be mainly devoted to post-tensioned bridges although certain conclusions will also be valid for pre-tensioned girders within the limitations indicated below.

Assuming a fully prestressed section with the prestressing cable placed below the central kernel and located at mid-span of a statically determinate single span girder, it can be shown that the maximum span length is given by the following formula

$$\ell_{max} = \sqrt{8\, I \sigma_{cadm} \cdot \frac{e(a_1+\eta a_2)/r^2 + 1-\eta}{g[ea_1a_2(1-\eta)/r^2+\eta a_1+a_2] + qa_2(1+ea_1/r^2)}} \qquad (1)$$

where I is the moment of inertia, σ_{cadm} the allowable compressive stress in the concrete, e the eccentricity of the centroid of the cable, a_1 and a_2 the distances from the section centroid to respectively the lower and upper fibre, $\eta = \Delta P_t/P_0$ the ratio of the time-dependent loss to the initial prestress, g the load per unit length on the girder at prestressing, q the overload (permanent plus live) assumed to be uniformly distributed. Further it was assumed that the stress conditions related to the limitation of the compressive stress are the most critical which means that q must be sufficiently small with respect to g. For a section with also a horizontal axis of symmetry it was found in [2] that q should be lower than about 0.5 g for the formula to be valid. This condition is generally not fulfilled for pre-tensioned girders with cast-in-place deck (see section 3).

Introducing the following simplifications $a_1 = a_2 = 0.5$ h, $\eta = 1$, $q = \psi g$ and $eh/2i^2 = 2.3$ one finds

$$\ell_{max} \approx \sqrt{\frac{16 A \sigma_{cadm} e}{g} \cdot \frac{1}{2 + 3.3\psi}} \qquad (2)$$

where A is the area of the cross section. From this formula it becomes clear which benefits can be achieved by using HSC.

As σ_{cadm} is proportional to f_c, it follows that doubling f_c allows to increase the span by a factor $\sqrt{2}$ = 1.41. Another substantial saving can be obtained by increasing girder spacing and thus reducing the total number of girders for a given deck width. Reducing the number of girders by a factor 2 approximately corresponds to doubling the factor $\psi = q/g$. From (2) it follows that for $\psi = 0.5$ an increase of f_c by a factor 1.45 is sufficient to reduce the number of girders by a factor 2.

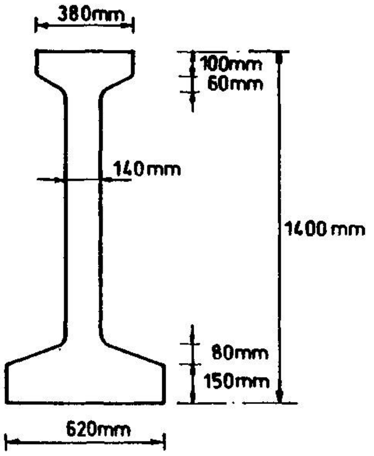


Fig. 1 Girder section investigated.

3. PRECAST PRESTRESSED GIRDERS

3.1 Design assumptions

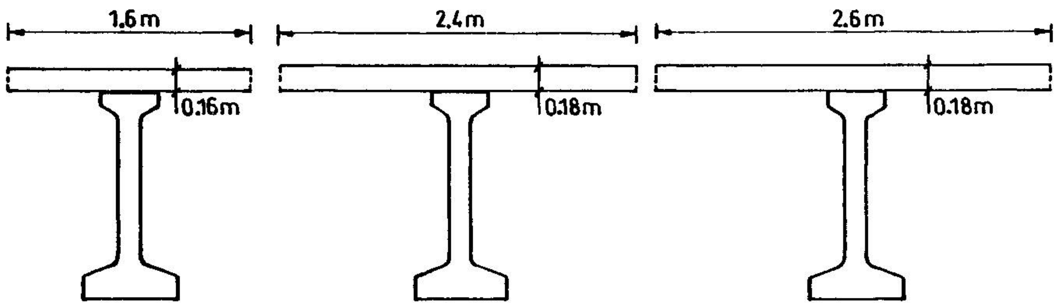
The effect of using HSC in a typical solid section which is currently used in Belgium for road bridges was investigated. The dimensions of the section (designated as I/140/62) are shown in fig. 1. Application to typical girder sections used in the USA is summarized in [3,4,5].

Calculations were made starting from a span of 25 m. A uniformly distributed variable load of 4 kN/m^2 and a standardized convoi of 320 kN, on each 3.5 m wide traffic lane, were considered besides a permanent load of 2.5 kN/m^2 on the bridge deck. The deck was cast in place on the precast girder without shoring, so that the entire dead load of both girder and deck was carried by the girder section alone.

The allowable compression was taken equal to 0.37 f_{ckcub} (characteristic cube strength) and the allowable tension equal to 0. For the reference case A (fig. 2), f_{ckcub} = 50 N/mm^2 was introduced which we term as medium strength concrete (MSC). The high strength concrete (HSC) solutions were calculated with f_{ckcub} = 75 N/mm^2, i.e. an increase by 50 % compared to the reference case with MSC. The manufacturing of HSC requires a considerable additional effort as quality control and material selection concerns but it is deemed that in a precast concrete plant this can easily be achieved. Of course the feasibility of this solution largely depends on the local circumstances.

Time-dependent loss of prestress ΔP_t was introduced on a lump sum basis in the following way : for MSC $\Delta P_t = 0.2\ P_0$ and for HSC $\Delta P_t = 0.15\ P_0$.

The difference is based on the fact that for HSC, creep and shrinkage turn out to be less than for NSC as indicated in section 4. As shown in fig. 2, four different solutions were studied.



Case	A	B	C	D
Beam	MSC	HSC	HSC	HSC
Deck	NSC	NSC	NSC	HSC
ℓ	25m	32m	25m	25m
s	1.6m	1.6m	2.4m	2.6m

Fig. 2 Alternate bridge designs by using HSC

In order to compare creep and shrinkage values of NSC and HSC, two different concrete mixes were studied [7]. Shrinkage and creep tests were performed on prisms (dimensions 150 x 150 x 600 mm) made with NSC (f_{ccub} = 46 N/mm²) and HSC (f_{ccub} = 92 N/mm²). The specimen in NSC was submitted to a compressive stress of 15 N/mm² at 28 days. As HSC concerns, one specimen was loaded to a stress of 15 N/mm² and a second one to a stress of 30 N/mm². All tests were done in duplicate and in table 1, a survey of the mean test results is given. Fig. 3 shows the initial shortening and the creep deformations.

Deformation characteristic	NSC	HSC	
	σ_c = 15 N/mm²	σ_c = 15 N/mm²	σ_c = 30 N/mm²
Shrinkage ϵ_{cs}	560.10^{-6}	420.10^{-6}	420.10^{-6}
φ (2 y., 28 d.)	2.45	1.03	1.10
Time-dependent def.	1880.10^{-6}	770.10^{-6}	1200.10^{-6}
Total deformation	2420.10^{-6}	1110.10^{-6}	1910.10^{-6}

Table 1 Time-dependent deformations until two years age

It can be seen that even for a stress level which is twice as high as that applied to the NSC specimen, the HSC specimen exhibits a substantially lower total and time-dependent deformation. Hence it follows from (3) that time-dependent losses of prestress can be significantly reduced by making use of HSC.

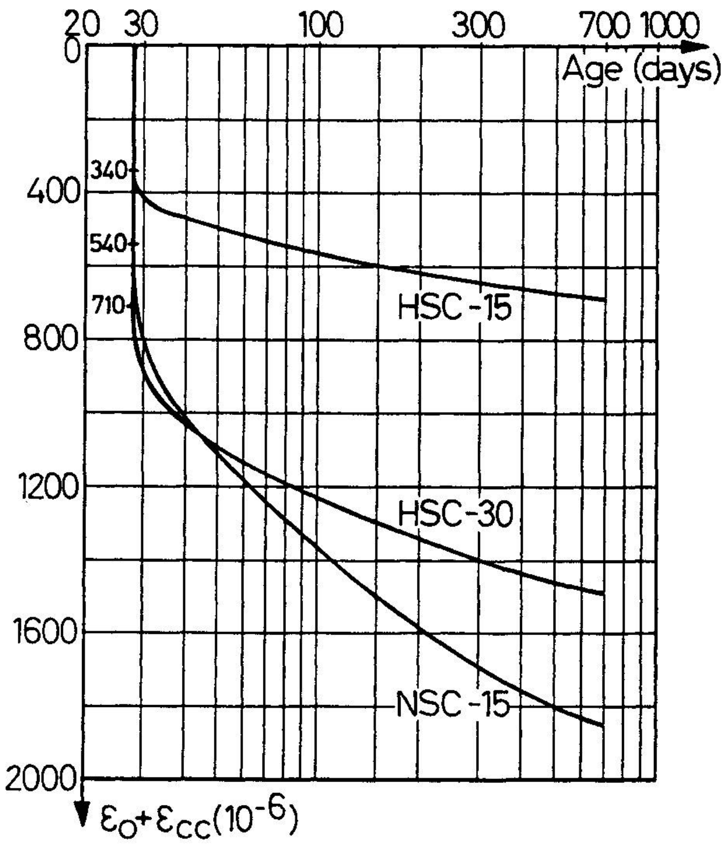


Fig. 3 Experimental initial shorting ϵ_0 and creep deformation ϵ_{cc}

3.2 Case studies

The reference **case** A with the standard MSC corresponds to a span $\ell = 25$ m and a girder spacing s = 1.6 m. The deck thickness equals 0.16 m. In **case B**, HSC is used for the precast girder, whereas the deck is cast in normal strength concrete with $f_{ckcub} = 35$ N/mm^2. By making use of HSC for the girder section considered so far, it is possible to increase the span from 25 m to 32 m (relative increase 28 %). In the HSC **application** C the span length is kept at 25 m but the girder spacing is increased which results in an additional overload on each girder. It follows that it is possible to increase s from 1.6 m to 2.4 m (relative increase 50 %). The deck thickness is slightly increased up to 0.18 m. This solution results in a substantial saving in the number of girders as only 2/3 of the original number are necessary for a given deck width. **Solution D** is comparable to case C except for the fact that HSC is also used for the cast-in-place deck. This makes it possible to achieve and additional increase in girder spacing from 2.4 m to 2.6 m.

3.3 Prestressing force

If we index the initial prestressing force P per girder by the designation of the three first cases considered, it follows that $P_B = 0.95\ P_A$ and $P_C = 1.49\ P_A$. Making the comparison in terms of the total prestressing force for the complete bridge, it follows that

$$P_{C,tot} = 1.49 \times \frac{1.6}{2.4} \times P_{A,tot} = 0.99\ P_{A,tot}$$

These findings can easily be explained on the basis of the "load-balancing"-concept. Comparing cases A and B, it appears that for a span increase by 28 % the prestressing force remains almost the same or can even be slightly reduced. Holding the eccentricity between the mid- and end sections the same, the upward distributed load is essentially proportional to ℓ^2, the same factor with which the overload is increased. Comparing cases C and A it follows that the total prestressing force remains the same irrespective of the number of girders, which is quite logical.

4. TIME-DEPENDENT LOSSES OF PRESTRESS

Time-dependent losses of prestress are due to creep and shrinkage of concrete and, to a lesser extent, to relaxation of the prestressing steel. A simple way to take account of the interdependence of the three phenomena is provided by the following formula

$$\Delta\sigma_p = \Delta\sigma_s = \frac{\epsilon_{cs}(t,t_0)\ .\ E_s + \alpha\varphi(t,t_0)\ [\sigma_{cg}(t_0) + \sigma_{cp}(t_0)] + \Delta\sigma_{rel}}{1 + \alpha\ .\ \dfrac{A_p + A_s}{A_c}\left(1 + \dfrac{e^2}{r^2}\right)(1 + \chi\cdot\varphi)} \qquad (3)$$

where
- $\Delta\sigma_p$: stress decrease in prestressing steel
- $\Delta\sigma_{rel}$: relaxation of prestressing steel
- $\epsilon_{cs}(t,t_0)$: shrinkage strain between times t and t_0
- $\varphi(t,t_0)$: creep coefficient at time t for loading at t_0
- E_s, E_c : modulus of elasticity of steel and concrete respectively
- α : E_s/E_c
- $\sigma_{cg}(t_0) + \sigma_p(t_0)$: concrete stress at tendon level at t_0
- A_p, A_s, A_c : area of prestressing steel, non-prestressing steel and concrete sections
- e : tendon eccentricity
- r : radius of gyration of uncracked transformed concrete section
- χ : ageing coefficient

The formula is valid for an uncracked prestressed concrete section also containing non-prestressing steel. More details on the background and the field of application of this formula can be found in [6].

5. MISCELLANEOUS ASPECTS

Other advantages of high strength concrete include increased modulus of elasticity and increased tensile strength. Increased stiffness is advantageous with respect to camber and deflections. Increased tensile strength is advantageous for the design in bending when tensile stresses are allowed (not considered in the previous examples) and for shear design on the basis of the principle tensile stress. It is useful to recall that the use of HSC is also particularly beneficial with respect to serviceability and durability.

6. CONCLUSIONS

By making use of high strength concrete (HSC) for prestressed concrete girders, substantial savings can be obtained. In the paper it was shown that for a given girder section the span length is almost proportional to $\sqrt{f_c}$, and hence the use of HSC offers major possibilities to increase span length. Alternatively, for a given span length, girder spacing can be significantly increased in most cases. Time-dependent prestress losses turn out to be less, due to reduced creep and shrinkage. Additional to these purely structural benefits, one obtains a more durable structure.

REFERENCES

1. LAMBOTTE H., TAERWE L., Deflection and cracking of high-strength concrete beams and slabs, ACI Special Publication SP-121, W.T. Hester Ed., Detroit, 1990, pp. 109-128.
2. VANDEPITTE D., Maximum span lengths for highway deck bridges with multiple simply supported prestressed girders, International Congress of Prestressed Concrete, AIG, Gent, 1951, pp. B44.1-B44.2.
3. JOBSE H., MOUSTAFA S., Application of high strength concrete for highway bridges, PCI-Journal, May-June 1984, pp. 44-55.
4. KAUFMAN M., RAMIREZ J., Use of higher strength concrete for prestressed beams in the State of Indiana, PCI-Journal, Vol. 34, No. 3, May-June 1989, pp. 78-93.
5. AHMAD S., SHAH S., Structural properties of high strength concrete and its implications for precast prestressed concrete, PCI-Journal, November-December 1985, pp. 92-119.
6. TAERWE L., Simplified analysis of stress redistribution in partially prestressed concrete sections, ACI Structural Journal, Vol. 87, No. 1, 1990, pp. 93-98.
7. LAMBOTTE H., TAERWE L., The use of high-range water-reducers for high strength concrete, Proceedings ERMCO-Congress 1989, Stavanger, pp. 666-678.