



H W Chung MSc(Eng)
PhD MICE MIE(Aust)
FHKIE,
reader in civil
engineering at the
University of Hong
Kong. He has
published papers on
concrete technology
and structures in
international journals.

PFA aggregate concrete in prestressed composite structures

by H W Chung

FOR medium to long-span structures, such as highway bridges, the self-weight often absorbs a large proportion of the load-carrying capacity. The use of lightweight concrete effects a considerable reduction in the dead load of the structure, and often results in saving of the construction cost apart from other advantages. The economic advantage is particularly obvious in the case of composite construction where the hauling and handling cost of the precast (and usually prestressed) units is substantial. However, prestressing necessitates high strength concrete which only some lightweight aggregates can produce. Sintered pulverised-fuel ash aggregates, being able to produce concrete with compressive strength of 45N/mm² or even higher, are suitable for this purpose. In Britain, these aggregates are marketed under the trade-name of Lytag.

Sintered pulverised-fuel ash aggregate concrete (hereinafter referred to as Lytag concrete) may be used in a prestressed composite member in two ways: precast prestressed normal weight concrete component with in situ Lytag concrete component, or precast prestressed Lytag concrete component with in situ Lytag concrete component.

The second combination fully utilises the reduction in dead load offered by Lytag concrete, while the first combination avoids the problems associated with prestressing any lightweight concrete.

Laboratory tests and field experience have indicated that conventional design methods are applicable to prestressed lightweight concrete structures, provided that the basic properties of the material are taken into account. The necessary modifications in design have been dealt with in several papers presented at the Second International Congress on Light-

weight Concrete^{1,2,3}. The present paper is concerned with the design considerations related to prestressed composite construction using Lytag concrete.

Losses of prestress

The initial loss of prestress at transfer due to elastic deformation of concrete is proportional to the modular ratio of steel to concrete. The modulus of elasticity of Lytag concrete is 50—60% of that of normal weight concrete⁴, and hence the loss at transfer is about twice as high. It exceeds 10% if the initial concrete stresses are greater than 0.3 of the cube strength at transfer.

The subsequent loss of prestress largely depends on the shrinkage and creep of the concrete which vary considerably with the mix proportions (in particular the cement content) and the conditions of exposure. The drying shrinkage of high-strength (high cement content) Lytag concrete ranges from 350×10^{-6} to 700×10^{-6} ,^{4,5,6} although measurements on full-size bridge beams have shown it to be as low as 200×10^{-6} .⁷ The specific creep of high strength Lytag concrete is around 70×10^{-6} per N/mm².^{5,6}

For estimation of loss of prestress, the following factors should be applied to the concrete properties specified in CP110⁸.

Concrete property	Factor
Modulus of elasticity	0.5
Shrinkage	2.0
Creep	1.5

If relevant data are available from the aggregate manufacturer, a more accurate estimate of loss of prestress may be made.

With the factors proposed, the total loss of prestress due to elastic deformation, shrinkage and creep of Lytag concrete is plotted in Figure 1. At an initial concrete stress equal to 0.3 of the cube strength at transfer, the loss of prestress

due to these three causes amounts to 20% for post-tensioning work and 38% for pre-tensioning work, and it becomes much larger at higher initial concrete stress, especially for pre-tensioning work. To avoid prohibitive loss of prestress, the initial concrete stresses should be limited to 0.3 of the cube strength at transfer.

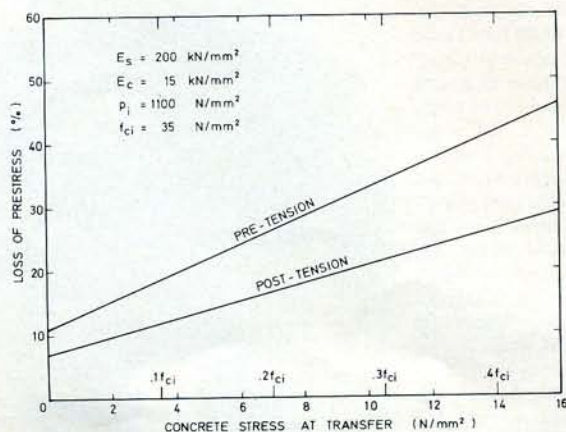
Test results on loss of prestress in prestressed Lytag concrete beams are shown in Figure 2. The loss of prestress was 24% at one month after transfer, increasing to 28% at three months. After one year the loss reached 35% and was still increasing though at a much lower rate. The ultimate value would be in the neighbourhood of 40% which agrees closely with the predicted value.

Differential shrinkage

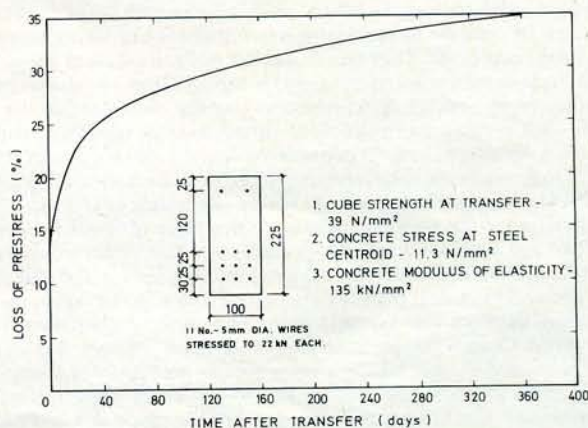
The precast prestressed component of a composite beam is in general substantially cured and mature when it receives the additional concrete at site. Upon hardening and drying, the in situ concrete tends to shrink relative to the precast concrete, and thus induces internal stresses in the composite member. The difference between the shrinkage in the in situ concrete and the shrinkage-plus-creep in the precast concrete occurring after topping is termed in brief the differential shrinkage.

Differential shrinkage in prestressed composite construction does not receive much attention in practice. Design engineers, though fully aware of its existence, tend to ignore it or make a nominal allowance for it, except for unusual structures. According to CP110, "the effects of differential shrinkage are not generally of great importance in simply-supported members".

The use of Lytag concrete in prestressed composite construction, either for the in situ component or for the entire member, enhances the effects of differential shrinkage. This is especially so where



Estimated loss of prestress.



Experimental loss of prestress.

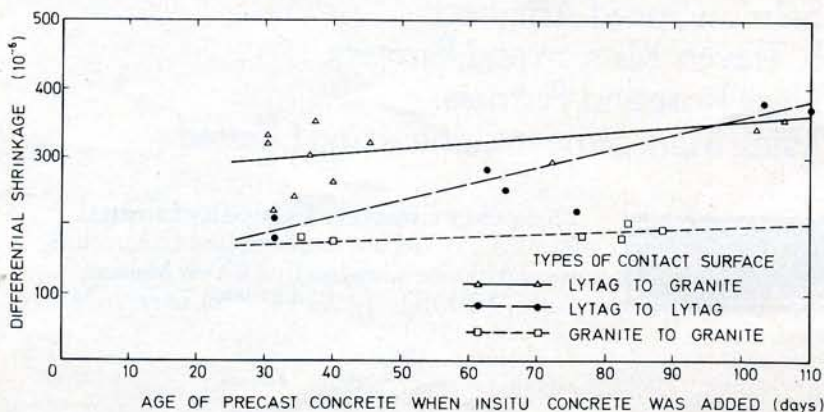
there is an appreciable difference between the age or quality of the concrete in the components.

Tests on prestressed composite beams using Lytag concrete have shown that differential shrinkage in most cases is high enough to justify consideration in design, especially in members incorporating precast prestressed normal weight concrete and in situ Lytag concrete⁹. From the test results summarised in Figure 3, it can be seen that the magnitude of differential shrinkage is not a fixed value, but increases with the period between fabrication of the precast component and casting of the in situ concrete. The reason is obvious. Differential shrinkage depends on, inter alia, the shrinkage-plus-creep strain occurring in the precast concrete after casting of the in situ concrete, which in turn depends on the maturity of the precast concrete when the in situ concrete is added. It is also interesting to note that the beams made entirely of Lytag concrete were subjected to significantly less differential shrinkage than the beams having normal weight concrete as the precast component. This is because the large shrinkage of the in situ concrete was somewhat offset by the also large shrinkage-plus-creep of the precast concrete in the former. In this respect, the use of two different types of concrete in the composite section is objectionable, despite the advantage of reduced loss of prestress of such a combination.

The estimated ultimate values of differential shrinkage, based on the shrinkage of the in situ Lytag concrete being 600×10^{-6} , are shown in Table 1. These values are substantially higher than 100×10^{-6} assumed in CP110 for normal weight concrete. However, the stresses so induced may not be as alarming, owing to the low modulus of elasticity of the Lytag concrete. Such stresses should be computed and the section checked accordingly in each case.

Table 1. Estimated differential shrinkage

Age of precast concrete when in situ concrete is added	Estimated differential shrinkage	
	Lytag concrete on normal weight concrete	Lytag concrete on Lytag concrete
30 days	320×10^{-6}	220×10^{-6}
60 days	330×10^{-6}	280×10^{-6}
90 days	340×10^{-6}	340×10^{-6}

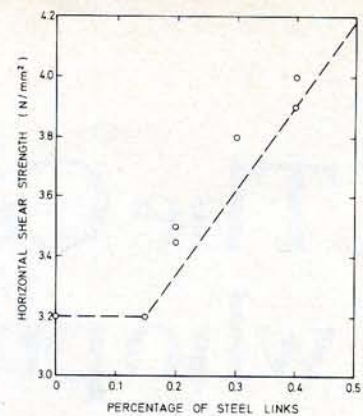


Experimental differential shrinkage.

Horizontal shear connection

The joint between the precast component and the in situ component in a prestressed composite member usually consists of a rough bonded contact surface with steel links extending across it. As the horizontal shear at the interface is resisted by adhesion and interlocking of aggregates, the strength of the aggregates has a direct bearing on the strength of the joint. Owing to the softness of Lytag aggregates, interlocking at the interface is expected to be less effective than that in normal weight concrete, and consequently the horizontal shear strength may be relatively lower. Little information is available in this respect, apart from the author's tests on several prestressed composite T-beams incorporating precast normal weight concrete webs and in situ Lytag concrete flanges¹⁰. The test results are shown in Figure 4 in which the horizontal shear strength is plotted against the percentage of steel across the interface.

The safe limiting line in Figure 4 suggests that the horizontal shear strength is of the order of 3.2 N/mm^2 . The minimum amount of steel links equal to 0.15% of the contact area should be provided. The horizontal shear strength is increased by 2.8 N/mm^2 for each additional area of steel equal to 1% of the contact area. Allowing for a coefficient of variation of 0.2, the characteristic strength (with 5% defective) is estimated to be 2.15 N/mm^2 . Applying a partial safety factor of 1.5, the allowable horizontal shear stress under service load condition is 1.43 N/mm^2 , which compares favourably with the values stipulated in CP110 for a rough bonded contact surface with the minimum amount of steel links. Similarly, the allowable increase for each additional percent of steel links is more than double the allowance by CP110. Consequently, the provisions in CP110 for a rough-bonded contact surface are safe enough for Lytag concrete.



Horizontal shear strength

Conclusions

Loss of prestress in prestressed pfa aggregate concrete may reach 40% or more if the initial concrete stresses exceed 0.3 of the cube strength at transfer.

Differential shrinkage occurring in a prestressed composite pfa aggregate concrete member is enhanced by the large shrinkage of pfa aggregate concrete. It varies considerably with the age of the precast concrete when the in situ concrete is added, and may be over 300×10^{-6} in some cases.

The provisions in CP110 for horizontal shear connection with a rough bonded contact surface are safe enough for pfa aggregate concrete.

References

1. Little, M E R, Design and detailing considerations of lightweight concrete structures generally, *Proceedings of the Second International Congress on Lightweight Concrete*, London, 1980, pp 120-124.
2. Bardhan-Roy, B K. Design considerations for prestressed lightweight aggregate concrete, *Proceedings of the Second International Congress on Lightweight Concrete*, London, 1980, pp 125-140.
3. Kornev, N A, Kramar, V G and Kudryavtsev, A A. Design peculiarities of prestressed supporting constructions from concretes of porous aggregates, *Proceedings of the Second International Congress on Lightweight Concrete*, London, 1980, pp 141-151.
4. Teychenné, D C. Structural concrete made with lightweight aggregates, *CONCRETE*, Vol 1, No 4, April 1967, pp 111-121.
5. Evans, R H and Orangun, C O. The use in p.c. structures of lightweight-aggregate (Lytag) concrete, *Civil Engineering and Public Works Review*, Vol 60, No 702, Jan 1965, pp 90-92.
6. Brooks, J J and Neville, A M. Predicting long-term creep and shrinkage from short-term tests, *Magazine of Concrete Research*, Vol 30, No 103, June 1978, pp 51-61.
7. Tyler, R G. Creep, shrinkage and elastic strain in concrete bridges in the United Kingdom, 1963-71, *Magazine of Concrete Research*, Vol 28, No 95, June 1976, pp 55-84.
8. British Standard Code of Practice CP110: 1972: *The structure use of concrete*, British Standards Institution.
9. Evans, R H and Chung, H W. Shrinkage and deflection of composite prestressed concrete beams, *CONCRETE*, Vol 1, No 5, May 1967, pp 157-166.
10. Evans, R H and Chung, H W. Horizontal shear failure of prestressed composite beams with cast-in situ lightweight concrete, *CONCRETE*, Vol 3, No 4, April 1969, pp 124-126.