Long Span Office Construction Using Composite Cellular Beams

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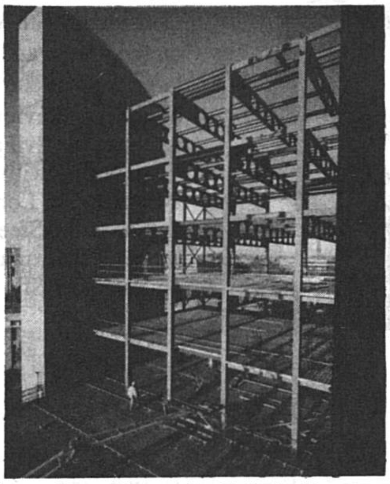
1. Summary

This paper details the development of the cellular beam as a composite floor member from its roots as a castellated section. The paper summarises the aspects of the cellular beam which make it suitable as a composite section before discussing a recent British Steel report (Ref 2) which shows clearly that long span floor construction can be achieved for the same cost as traditional short span methods, using composite cellular beams.

2. Introduction

The development of composite construction in the USA over 25 years ago brought about a revolution in the way modern commercial office buildings are now constructed. By utilising the concrete slab as the compression flange of a steel floor beam, the weight of steel in a typical multi-storey building was reduced by up to 30% when compared to the non-composite equivalent. It was envisaged at that time that long span, column free office space would become the norm, but this was evidently not the case. While composite construction became the most economical method for steel frame construction, the spans remained relatively short, necessitating internal columns.

Cellular Beams were invented and patented by Westok Structural Services Ltd of Wakefield, England in 1987 as a new, flexible form of castellated beam. Their adaptability has led to their use in many structural applications, the most significant of these being long span composite floors. (see photo 1).



Long-Span Composite Cellular Beams

3. Developments in Long Span Floor Construction.

3.1 What defines a long span floor?

A long span floor can typically be defined as an office floor where a client has requested the absence of internal columns, allowing total flexibility for the partition or furniture layout. To achieve this a floor must span from external wall to external wall, or from an internal lift core to external wall, creating spans in the range of 12m-18m.

3.2 Why did long span construction not become the norm?

Due to the work done by the concrete slab of a composite beam, the top flange of the steel beam can be small compared to the bottom tensile flange. Many forms of steel beam have made use of this fact. Stub girders, tapered asymmetric plate girders, lattice girders are commonly designed with a reduced top flange but the cost of production or the weight of steel required make these systems costly.

The cost premiums for long span construction has been evaluated as between 2 and 3% as shown by the British Steel report (Ref 2). Long spans are considered to be desirable but without commercial value. Thus, the extra finance required is seldom provided.

4 Cellular Beam Production Process.

Like their predecessor, the traditional castellated beam, cellular beams are profiled from a hot rolled beam or column section:

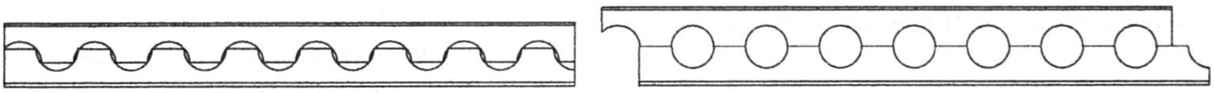


Fig 4.1 Profiling a cellular beam.

After profiling, the two halves are separated (Fig 4.1) and moved relative to each other by half a cell spacing and the beam is then re-welded along the centreline of the cells. The finished depth of the beam is between 1.3 and 1.5 times the depth of the parent section.

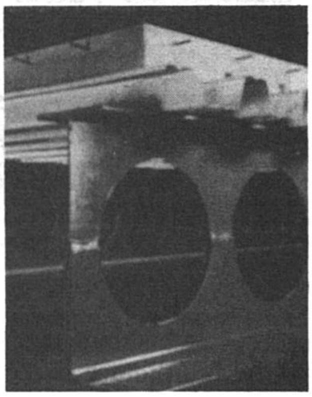
The finished depth is a function of the cell diameter and cell spacing which are varied to suit the structural and geometric requirements of the beam. With exact floor depths being a major consideration for modern commercial office developments, the cellular beam can be designed specifically to fit any given depth of floor. This is achieved using differing combinations of top and bottom section, cell diameter and spacing.

During structural analysis, cells can be varied to adjust the amount of steel around a cell. Thus, if a beam is found fail in shear, the void diameter can be reduced to leave a greater area of web above and below the cell. Likewise, if a webpost is shown to fail in buckling, the cell diameter can be reduced or the cell spacing increased. A good cellular beam design optimises both its structural and geometric requirements.

4.1 Production Advantages for Long Span Cellular Beams.

The two main advantages of the production method for composite floor construction are:

1. The opportunity to mix sections to form asymmetric beams (photo 2).



The Asymmetric Cellular Beam

2. The ability to curve the flexible half beams to produce pre-cambers (Fig. 4.2).

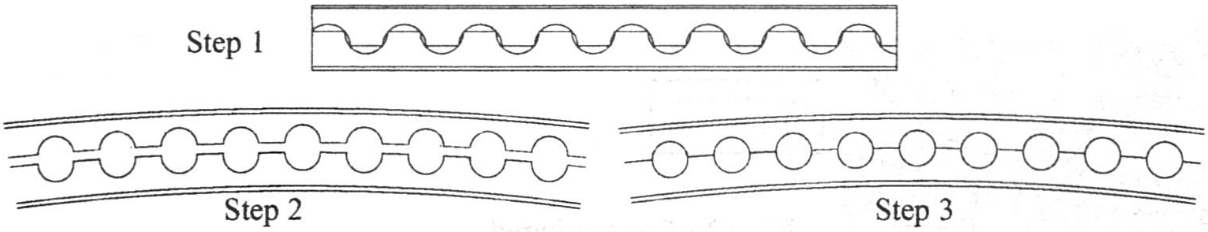


Fig 4.2 - Pre-cambering the cellular beam

As a consequence of the production method, voids are provided for the integration of building services. This allows the floor depth to equal those associated with short span floors (fig. 4.3) maintaining the cost of external cladding and finishes.

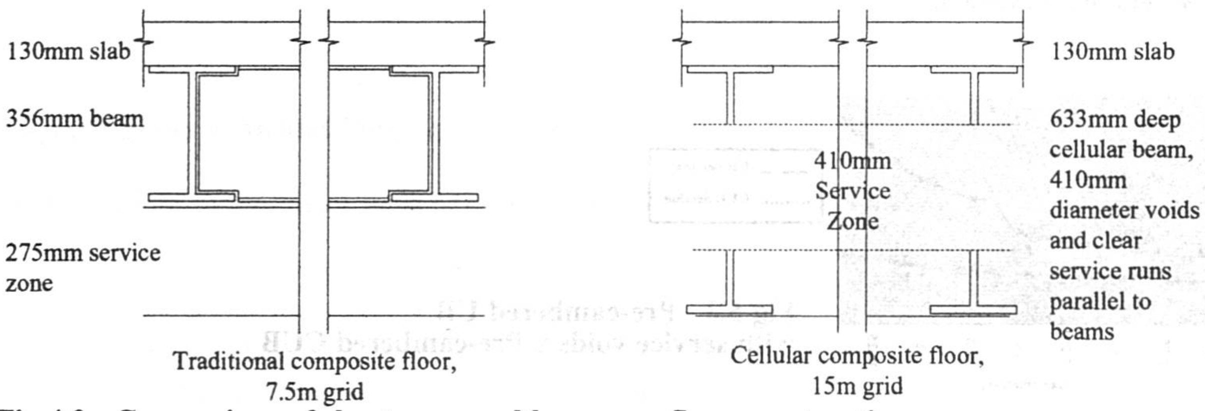


Fig 4.3 - Comparison of short span and long span floor construction.

5 Cost Analysis of Long Span Composite Cellular Beams.

To begin the cost analysis of long span versus short span, a comparison can be drawn between two long span floor options. A Unit cost/tonne can be established for plain universal beams (UB) and their equivalent cellular beam (CUB):
Unit cost of UB = total weight x cost per tonne of steel
Unit cost of CUB = total weight x[cost per tonne of (steel + cellular beam production)]

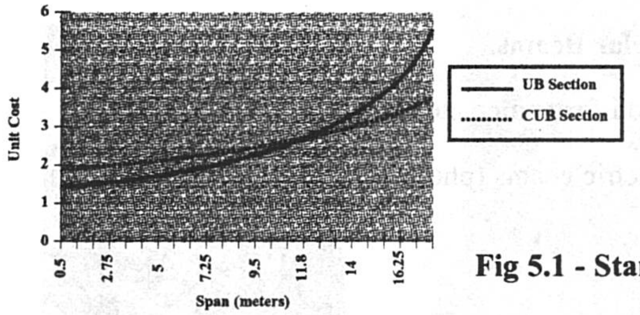


Fig 5.1 - Standard UB v CUB

The first graph shows that the CUB is only economic above spans of 12m. It does not, however, show the full picture as the cost of pre-cambering must be added.

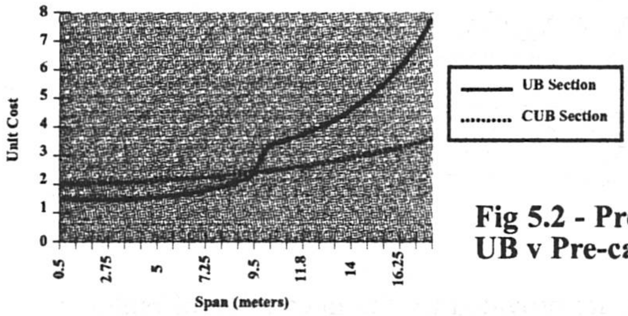


Fig 5.2 - Pre-cambered
UB v Pre-cambered CUB

The cost of pre-cambering the UB is required on spans above 10m. Thus, the difference in unit cost is enlarged on these longer spans. To complete the picture, the cost of providing service integration must be added.

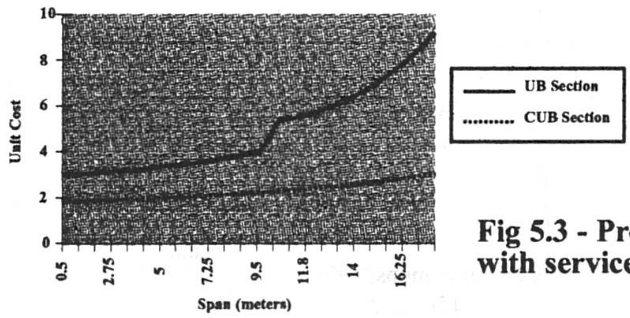


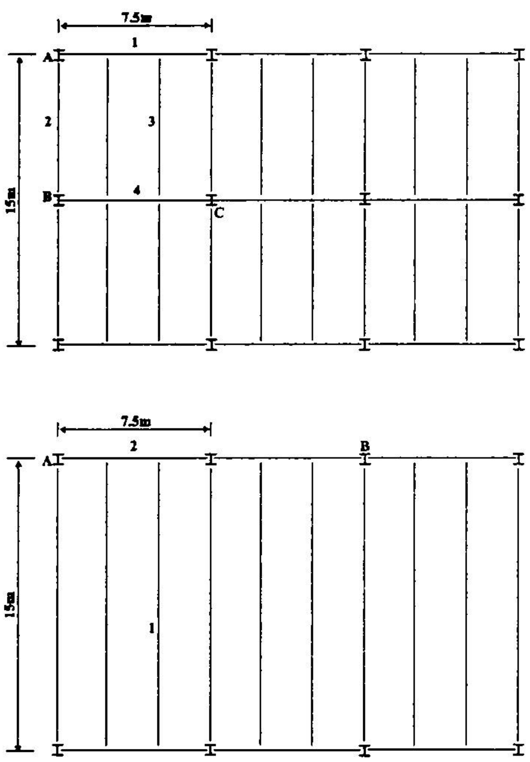
Fig 5.3 - Pre-cambered UB
with service voids v Pre-cambered CUB

The additional cost of providing service integration through a UB has been generalised in this case. Unit costs have been adopted from reference [1], where the BSCA major fabricators provided a rate of 250 GBP/tonne to create 4 service voids in the web of a UB.

Set out below is a model for assessing the true cost comparison of a long and short span option for a typical building.

6 Comparison of TOTAL Building Costs.

As expected, the long span floor has a greater overall steel weight (Fig 6.1).



Typical short span floor. Steel S355

Beam

1	305*165*40 UB
2	305*102*33 UB
3	305*127*37 UB
4	356*171*57 UB

Column

A	254*254*73 UC
B	305*305*97 UC
C	305*305*137 UC

Total weight of floor (including columns) 26.4 tonnes.

Typical long span floor. Steel S355

Beam

1	633*152/191*59 CUB
2	533*210*82 UB

Column

A	305*305*97 UC
B	356*368*153 UC

Cell Data - 410mm dia @ 600mm c/c

Total weight of floor (including columns) 32.3 tonnes.

Fig 6.1 - Short Span and Long Span Floor Layouts.

However, four further items must be considered before the true cost comparison is known:

1. The number of elements and connections must be assessed, as they constitute the handling time, fabrication cost and erection period.
2. The foundation arrangement and design must be carefully compared, as fewer columns leads to reduced sub-structure costs.
3. Fire rating of the floor beams, as long span beams have a lower Hp/A value and thus need less material fire protection.
4. The clear-span cellular beam frame reduces the cost of the building services.

6.1. Number of elements and connections:

Short span system = 38 elements, 58 connections.
Long span system = 24 elements, 32 connections.

Two aspects of construction are affected by the reduction in the number of elements and end connections.
1. Production time in factory.
2. Erection program and crane time.

The difference in cost for these items can be calculated in man-hours and crane utilisation time. This calculation will always be conservative as the cost difference is not only a direct capital cost for labour and crane time, but the effect of crane usage on overall program must be assessed. Keeping crane usage to a minimum is an important but often overlooked aspect of steel frame design.

6.2. Reduced foundation costs.

The SCI report [Ref. 1] puts the cost of foundations for a short span system at 21 GBP/m² and for a long span system at 17 GBP/m² for an 8 storey building (m² of net ground floor area). Thus, a reduction of 19% can be achieved in the foundations costs of long span buildings. The sum of the applied forces on the foundations will be equal for both buildings, however, two aspects of long span construction explain this reduction:

1. Rationalisation and reduction in the number of pile caps. On each gridline, the short span system requires 3 pile caps, for long span only 2 are required.
2. Pile groups for short span systems typically utilise three piles per column. The long span system, with higher column loads, requires four piles per column. Thus, for each gridline, the long span system has 8 to the short span 9 piles. A reduction of 11%.

6.3. Reduced fire protection costs.

Taking the secondary steelwork from figure 6.1, the Hp/A values can be calculated:

305*127*37 UB	2.11
633*153/191*59 CUB	18.9

In this case the difference is small, but still in favour of the long span element.

6.4. Reduced service costs.

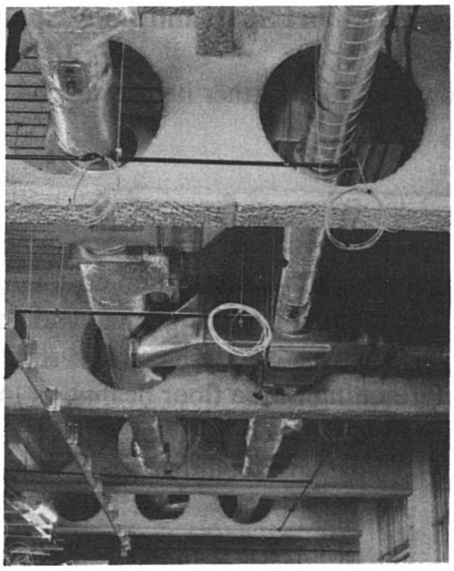
The British Steel report calculates an 8% cost-saving by using circular rather than flat elongated service-ducts. Circular ducting is cheaper to produce and allows more efficient air passage (Photo 3).

7. Conclusion

The adoption of clear-span floor construction has generally been limited to need rather than choice. The recent findings that clear-span steel frames produce a cheaper total building cost will allow the clients preferred layout of clear spans, uninterrupted by columns, to become the norm.

8. References:

1. Steel Construction Industry - 'Costs of Modern Commercial Office Developments' 1992.
2. British Steel - 'Steel or Concrete' 1996.



Integration of Cellular Beams and Services
(Photo 3)