Institution: City University London

Unit of Assessment: 15 General Engineering

Title of case study: Improving the financial and environmental cost of steel framed buildings, whilst raising structural performance

1. Summary of the impact

Some of the most significant and widely used products for steel framed buildings in the global construction market today have been developed by the Structural & Geotechnical Engineering Research Centre at City University London. Our work in this field has permitted a saving of between 25 and 30% in the amount of steel needed for such buildings, making them now on average 9% cheaper than their concrete equivalents. Our research data from this work is now incorporated into at least six Design Guides and two significant industry software suites, published by the Steel Construction Institute (SCI) [text removed for publication]. Steel frame build times have been reduced by up to 13% and the resulting buildings can be 20-50% more energy efficient, helping the industry move towards its 'Target Zero' carbon goals.

The dynamic response of steel members and floor systems has been a key concern in the industry over the last decade. The work undertaken at City has been effective in helping bring new products to market and in improving the application of structural mechanics to real design situations. It has also made a significant contribution to the increasing success of the steel industry in the UK commercial building market.

2. Underpinning research

City's Structural & Geotechnical Engineering Research Centre has been creating better steel and concrete composite structures for over 20 years. Research with the Steel Construction Institute (SCI) and British Steel plc (now part of TATA Steel) has contributed to products such as Slimdek™, Slimflor™ and Bi-Steel™. Further collaboration with the engineering firm Westok Ltd (now ASD Westok Ltd) has led to other innovative products called Cellular Beams and Ultra-Shallow Floor Beams® or USFBs. The work has involved full-scale testing in our Heavy Structures Laboratory and exhaustive analytical and computational studies.

From 1993 to 1998, Professor Laurie Boswell (a member of academic staff since 1972) and Dr Jim Rackham, former City PhD student working for the SCI, developed a new system for constructing long-span composite building floors, consisting of asymmetric steel beams and lightweight permanent steel composite decking used to support the wet concrete. Their innovation came from integrating the majority of the concrete within the depth of the steel beam. This created an opportunity for British Steel to pioneer a new hot roll manufacturing process to create Asymmetric Slimflor Beams or ASBs. A stronger, integral shear connection rolled into the top flange surface, developed and tested during the research, has also meant that thinner steel composite metal decking called Comflor210/225 can be used in the construction of the structural system now known as Slimdek™.[6]

Professor Boswell received funding from the SCI, EPSRC and British Steel in 1995 to investigate a new form of double skin composite construction. The product resulting from that research, Bi-Steel™, was developed by the SCI. Dr Brett McKinley, who was a PhD student at City from 1995 to 2000, tested numerous full scale samples comparing the traditional and new construction methods to investigate their structural integrity and local buckling collapse mechanisms.[1] His research contributed to the seminal reference *Bi-Steel Design and Construction Guide* which was published by British Steel in 1999.

With increases in span length, dynamics and cost became the main concerns. Westok had the solution to cost but lacked a confident solution to engineers' fear of the floors being too "bouncy". Dr Cedric D'Mello (a member of academic staff since 1981, now a Professor), in collaboration with Westok Ltd, tested the longest spans of three new structures during 1999-2000 to compare design predictions of dynamic performance with actual site test results.[2] The research was used by SCI in

the revision of their engineering guidance *Design of Floors for Vibrations.*

Work on subsequent developments to Cellular Beams was carried out in 2007 by Kostas Tsavdaridis, a City PhD student under the supervision of Dr D'Mello. He examined these beams under two critical modes of failure to improve their structural performance. He found that the manufacture of beams with near-elliptical rather than circular cells leads to reduced material waste and allows easier integration of building services without compromising structural integrity.[3] His work led to a patent application filed in 2011.[4]

In 2007, Bing Huo, a City PhD student supervised by Dr D'Mello, was supported by Westok Ltd to investigate a new generation of cellular beam. His work led to the development of another new product, the USFB®, which was intended to extend the existing range of steel options available for the flat slab market and was patented by Westok Ltd in 2011.

The USFB® allows for the incorporation of passive air cooling/heating inside the floor. By utilising the thermal mass of the concrete floor slab more efficiently, additional savings in energy and CO_2 use are also possible. This energy recycling floor slab is known as TermoDeck®. Huo's PhD research demonstrated that the ducting could be incorporated without loss of structural integrity, providing the ducts were not located near areas of higher vertical shear.[5]

3. References to the research

1. McKinley B. & Boswell L.F. (2002). Large Deformation Behaviour of Double Skin Composite Construction, *Journal of Constructional Steel Research,* 58(10), 1347-1359 10.1016/S0143-974X(02)00015-9
2. Confidential report by C.A. D'Mello (2000) concerning results of tests on dynamic response of floors using Westok Cellular Beams (can be provided on request for REF assessment purposes).
3. Tsavdaridis K.D., D'Mello C. & Huo B.Y. (2013). Experimental and computational study of the vertical shear behaviour of partially encased perforated steel beams. *Journal of Engineering Structures*, 56, 805-822 10.1016/j.engstruct.2013.04.025
4. Tsavdaridis, K.D. & D'Mello, C. (Inventors), City University London (Proprietor). Filed Patent (No GB1112512.7): Perforated Structural Beams. Intellectual Property Office, 2011 http://www.ipo.gov.uk/types/patent/p-os/p-find/p-find-number.htm
5. Huo B.Y. & D'Mello C. (2013). Push-out tests and analytical study of shear transfer mechanisms in composite shallow cellular floor beams. *Journal of Constructional Steel Research*, 88, 191-205 10.1016/j.jcsr.2013.05.007
6. Lawson R. M. *et al*. (1999). 'Slimflor' and 'Slimdek' construction: European developments. Institution of Structural Engineers http://www.istructe.org/webtest/files/87/87428fd8-d23f-40c5-be2b-53ee6bcf9bec.pdf

The articles listed as 1, 3 and 5 are all published in international journals of Elsevier which are well regarded in their specific field and use a rigorous peer review process prior to publication.

4. Details of the impact

The engineering company ASD Westok Ltd manufacture a patented form of castellated beam, using circular openings. At first these beams were used predominantly as roof beams, replacing traditional castellated beams. When used for floor construction, such that the top flange was made to act compositely with the concrete slab, savings of more than 30% in steel weight were achieved, compared to a standard rolled beam also acting compositely with the floor slab.

Floor design

As a result of City's research into steel floor construction, the span of a beam can now be designed to more stringent limits, giving a 25% to 40% reduction in required inertia with 12% reduction in

steel.[7] Additionally the span of the beam has been increased, extending the options available to engineers and architects and reducing the number of beams and connections assembled on site. This allows approximately twice the area to be erected in the same time. As beams can now span further, there are fewer columns and foundations. The longer beam spans enable use of thinner floor slabs, reducing the volume of concrete required (estimated at one concrete mixer truck less per floor), contributing further to material cost savings and reducing road miles and consequent CO_2. This extends a building's potential life span due to unrestricted internal layouts and reduces the number of buildings left empty because their layout does not suit intended use by the owners, providing further environmental benefits.[7, 12]

The results from the tests conducted at City and the follow-up work have had a profound influence on building design in the UK, Europe and the USA as a result of SCI revising their design guidance concerning the dynamic behaviour of floors. Software developed by SCI for ASD Westok Ltd incorporating the City research is used by designers of all cellular beams and is integrated as a component into other widely-used general building design software. The development of long span solutions has led to economical solutions with lower material weight, fewer foundations and faster erection, as there are fewer beams. The beams also meet stringent vibration requirements, including those specified for hospitals. While designers across the world may not be aware of the source of such advances, they are in part directly traceable to this important test work undertaken by City University London.[7]

Cellular Beams

Our work on the Cellular Beam has allowed mechanical and electrical plant equipment to be integrated within the depth of the floor space instead of hung beneath it. As a result Cellular Beams use 25% to 30% less steel than a conventional beam. City's work in this field has more than doubled the tonnage of beams produced by ASD Westok Ltd. [text removed for publication]

Ultra Shallow Floor Beams (USFBs)

USFB allow more economic shallow floor construction solutions, reducing the structural floor zone and building height or allowing for more floors to be inserted within a prescribed Planning Regulation building height limit. The result is a more efficient use of available building space and volume. By reducing the internal volume to be heated or cooled, savings on construction cladding costs are realised, together with reductions in building life costs. Buildings requiring high light/glazing levels such as schools particularly benefit from the reductions in solar heating that accompany reductions in building cladding height. Following the release of SCI design software for USFB (based on City's research findings), sales increased dramatically [text removed for publication].[7, 8 13]

TATA Steel

TATA Steel is the second largest steel manufacturer in Europe and the seventh largest worldwide.

(i) Asymmetric Slimflor Beams (ASBs)

Slimflor™ and Slimdek™ are products of TATA Steel Europe, developed by City University London.[6] ASBs and Comflor210/225 (a thinner steel composite metal decking), which together comprise the Slimflor system, are sold individually to allow other manufacturers' products, such as precast hollow core concrete panels, to be combined with the ASBs. Slimflor and Slimdek are now regularly designed as steel solution where structural design needs to be kept to a minimum. These beams also contribute to total building cost savings and value through reducing the need for cladding and minimising building height or increasing lettable floor area through more floors for the same height. This research has also been written into a software design suite by the Steel Construction Institute. [text removed for publication]

(ii) TATA Bi-Steel

TATA Bi-Steel is now also marketed as Corefast™ [text removed for publication]. While this product line was affected by the economic downturn of that period, Bi-Steel also forms the basis for an entire range of protective barriers which has generated further business success, achieving [text removed for publication] a prestigious £7M contract to supply security barriers at the Olympic

Park in London in 2012 and the subsequent London Legacy Park. Bi-Steel is also used in the defence and security markets where the inherent blast resistance contributes to niche specialist products associated with hostile vehicle mitigation and blast protective structures.[10, 11]

Steel Construction Institute

SCI has been a trusted source of information and engineering expertise globally for 25 years and remains the leading independent provider of technical expertise and disseminator of best practice to the steel construction sector. Revenue generation to the SCI resulting from the development and sales of design guidance literature and software for all of the above steel products [text removed for publication].[12]

Commercial building market

As a result of research partly conducted by City, TATA and the British Constructional Steelwork Association (BCSA) have recently published an independent study showing that, for the first quarter of 2012, steel options for typical small business park offices (3 storey, c.3200m^2) and city centre office buildings (8 storey, c.16,500m^2) are now 9% cheaper than the concrete equivalents. Steel now allows a 1-13% reduction in construction time and an 18-30% reduction in embodied carbon. This represents a major transformation in the efficiency of the steel construction industry. For multi-storey non-residential buildings, steel construction has had an average market share of 70% over the past few years; a significant success for the industry where the share was around 30% in the early 1980s. This news, published by the BCSA, has been freely disseminated to practitioners via their website and in hardcopy form with industry magazines, thereby helping steel maintain its position in the UK commercial building market.[9, 14, 15]

5. Sources to corroborate the impact

7. Supporting statement provided by Director of Westok Ltd (2002 – 2010)
8. Supporting statement provided by Commercial/Technical Manager of ASD Westok
9. Supporting statement provided by Manager, Construction Market Development, Tata Steel, Construction Services & Development
10. Supporting statement provided by Bid Manager, Bi-Steel, Tata Steel Projects
11. TATA Steel website http://www.tatasteeleurope.com/en/products_and_services/services/business_services/tata_steel_projects/market_sectors/construction/olympic_park_co/
12. Supporting statement provided by Associate Director, The Steel Construction Institute
13. 'ASD Westok Limited Director' report and financial statements for the 10 month period ended 31 December 2010, available at cost from http://www.companiesintheuk.co.uk/ltd/asd-westok or can be supplied
14. British Constructional Steel Association Annual Report 2011-2012 available from http://www.steelconstruction.org/bcsa/annual-review.html
15. BCSA/TATA report on cost comparison of steel (2012) http://www.steelconstruction.org/resources/commercial/cost-comparisons.html