Sustainable Construction with Post-Tensioned Slabs

Environmental impact and sustainability have now become global issues. As a result, they are increasingly becoming a deciding factor in commercial decisions for the construction industry. This guidance note informs engineers, contractors and developers of some of the main factors when assessing the environmental impact of post-tensioned structural frames for buildings and demonstrates the savings that can be made when opting for a post-tensioned concrete frame.

Embodied Energy and Embodied Carbon

As buildings become more energy efficient 'in-use', embodied energy (i.e. the energy used to create the building) becomes a more significant part of the total building energy life cycle. The primary factors for assessing the embodied energy of various forms of construction are related to material selection, material source and manufacturing processes. This is often assessed by measuring the embodied carbon content ($kgCO_2/kg$ or $kgCO_2/m_2$). For structural frames this is the embodied carbon required for extracting the raw materials, any secondary manufacture/processing (e.g. steel or cement production, fabrication, etc), transportation to site and final assembly/construction.

Research conducted for the Concrete Centre has highlighted that the difference between frame systems is not substantial. This research also demonstrated that carbon savings are more significantly influenced by how the design and specification are optimised rather than the choice of framing material (see Figure 1).

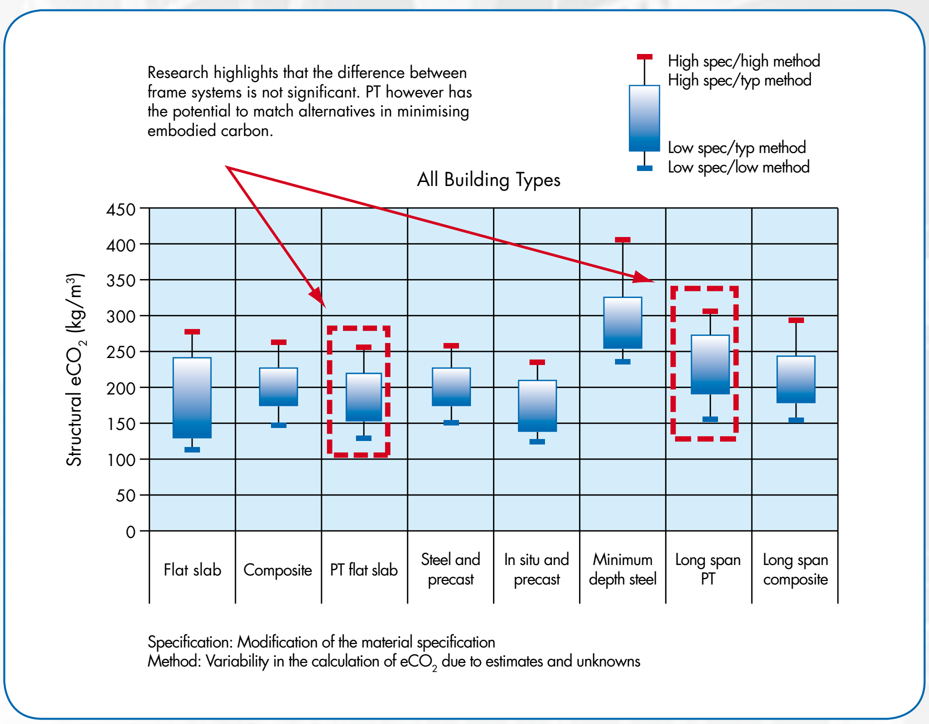

Figure 1 – Embodied CO_2 in Forms of Construction (figure taken from IStructE article, [1]).

The research also shows that the embodied impact of the structural frame of a building is a significant part of a building's construction carbon footprint (50% embodied CO_2 and above) [2]. Therefore, structural frames provide an excellent opportunity to help reduce environmental impact.

Opportunities for the use of post-tensioning

Key sustainability drivers are aimed at reducing construction waste and reducing overall embodied carbon. Post-tensioned construction can deliver savings on both of these aspects. In particular, carefully designed and specified post-tensioned frame solutions can offer the lowest achievable levels of embodied CO_2 for minimum depth. In addition, further sustainability benefits can be achieved as follows:

Resource efficiency

- Typically 20% reduction in concrete volume when compared to its traditional RC counterpart.
- The reinforcement requirement of a typical PT flat slab would be expected to be around 40% of the equivalent RC slab (including strand, duct and anchors).
- The UK concrete industry currently uses almost 50 times more waste than it produces. This waste is used in place of primary material.

Carbon/Low Waste

- Concrete mixes with GGBS and PFA replacement in the range of 20-30% are frequently used in post-tensioned structures and mixes of up to 40-50% have been used in recent projects – strength gain requirements are the key constraint – see section on Specification.
- Use of recycled concrete aggregate (RCA) is acceptable up to 20% without further considerations. 50% RCA has been used on a recent PT project [2]. Note that the use of RCA in sustainability terms is limited by the proximity of the source to site – see section on Specification.
- 100% secondary aggregate is also viable as with all concrete structures.
- Reinforcing bar itself is typically from 95-100% recycled sources while the strand content may be as much as 30% recycled.

The Middlehaven CIAC project in Middlesbrough. For more information see [2]. Photo: supplied by CCL.

Flexibility and Adaptability

- Exposed concrete soffits reduce fit-out materials and allow the thermal mass to be used in the heating and cooling strategy – even if not used in original scheme the potential is there for future redevelopments.
- Flat soffits provide the maximum flexibility for services.
- Long spans allow for future flexibility and adaptation, prolonging the life of the building frame.
- Penetrations and remodelling of post-tensioned slabs are common – refer to PTA Guidance Note GN01, [3].
- Contrary to common opinion, demolition of post-tensioned structures is a simple process similar to that of traditional reinforced concrete although it must of course be approached in a professional manner by suitably skilled and experienced professionals.
- Much of the material used in PT structures can be recycled at the end of its design life – refer to PTA Guidance Note GN01, [3].

BREEAM

- BRE Green Guide 'A' Rating achievable in conjunction with the use of power floated finishes (no need for screed).

Durability/Long Life

- Concrete is inherently a robust and durable material with appropriate specification. This allows PT structures to be long lasting with minimal maintenance and therefore maximise the use of their embodied carbon.
- Inherent fire protection, thermal mass and surface quality of PT structures can also help reduce the requirement for secondary surface treatments, again helping to reduce environmental impact.

Additional Benefits

By adopting the thinner, lighter, post-tensioned frame earlier in a project's conception, the structure will have immediate and potentially significant savings in the foundation structure. Reduced slab thickness allows the overall building height to be reduced, translating into a reduced vertical and cladding envelope. For the long-term owners/tenants, the internal volume of a structure is reduced generating savings on the significant life span costs, such as heating and ventilation.

Sustainable Design and Specification of PT Systems

As highlighted above, the key factors in achieving the potential carbon savings available in adopting a PT frame system are careful *design* and *specification*. Below is some preliminary guidance to help highlight issues which should be considered:

Design

The principles required to achieve a more sustainable building structure are the same as those for efficient design – i.e. to optimise the structure – the more optimal the structure the less material is required. Therefore, the driving principles for sustainable PT systems are for efficient design – see TR43 [4]. Key considerations for optimising PT floor systems are as follows:

- **Continuous spans** (three or more is best) – this gives maximum eccentricity of the tendon within the available slab depth.
- **Spans greater than 6m** – shorter spans are generally more economic in conventional RC as there are practical limits on the minimum slab thicknesses. However, there are occasions when PT spans less than 6m are more cost effective.
- **Shorter end spans** – to avoid higher end span moments.
- **Generally uniform loading** (or spans that reflect permanent increased loading) – a uniform moment envelope and span deflections help because tendons are continuous and therefore have the same steel area throughout the span.
- **Overall tendon lengths above 15m** - longer tendons are more economic as fewer anchorages are required for a given area of slab (maximum practical length between movement joints approx 60m with double live ends – longer lengths can be achieved but are less economic due to increasing losses).
- **Simple plan geometry** – complexity can be accommodated but it generally adds to the cost/use of material.
- **Multi-storey** – minimum depth, quicker striking times, reduced weight, floor plate repetition all make PT very economic for mid and high rise developments.
- **Choice of PT system** – bonded or unbonded - refer to PTA Guidance Note GN03 [5].
- **Column spacing vs. structural zone** (span to depth) – TR43 [4] gives typical span to depth ratios for various systems.
- **Location of stiff areas** (e.g. cores, walls, columns) – stiff elements in the floor plate can inhibit the shortening of the slab required to induce pre-compression and therefore their location and detailing must be carefully considered.

A fair faced exposed PT slab soffit. Photo: supplied by PTA.

Specification

The specification of the concrete provides the greatest scope for influencing the embodied CO_2 of the structural frame. In this respect, the specification of concrete for post-tensioned systems is very similar to that of conventional reinforced frames – the key difference is the early age strength requirements to suit the intended stressing sequence and striking of formwork. Refer to the Concrete Centre's publication 'Specifying Sustainable Concrete' [6]. The following is taken from the front of this publication which provides 'Key Guidance':

"Guidance that balances the desire to specify concrete with low environmental impact, whilst ensuring other performance parameters are optimised, can be summarised as follows:

- Do not over-specify strength.
- Consider the possibility of strength conformity at 56 days rather than the conventional 28 days. This needs to be balanced with strength required at first stressing, strength at transfer and required striking times – this is a key factor when considering cement replacement.
- Specify responsibly sourced concrete and reinforcement.
- Do not specify aggregate sizes below 10mm unless necessary.
- Permit the use of recycled or secondary aggregates but do not over specify.
- Specify that concrete should always contain CEM II/CEM III or an addition.
- Embodied CO_2 (ECO_2) of concrete should not be considered or specified in isolation of other factors such as strength gain.
- Permit the use of admixtures.
- Specify BES 6001 responsibly-sourced concrete and reinforcement to gain maximum credits under BREEAM and the Code for Sustainable Homes.

- The specification of recycled and secondary aggregates is often not the most sustainable option, although it may gain most points. BS 8500 allows producers to use up to 20% of recycled aggregates in concrete, they do this when it is available.
- The BRE Green Guide does not recognise the availability or otherwise of recycled product when incentivising the use of recycled content.
- Recycled aggregates should only be specified when they are locally available, otherwise transportation impacts exceed benefits. Within the current assessment method, this should be discussed with the client or project code assessor to prevent unfair penalisation.
- Use of cementitious additions can reduce the ECO_2 of concrete and influence its visual appearance. When aesthetics are critical, specify the cement/combination to ensure colour consistency.
- Admixtures can be used to enhance sustainability credentials and reduce the ECO_2 of concrete, as well as modifying its physical properties."

Summary

Post-tensioned frame solutions can offer significant opportunities for reducing the environmental impact of the structural frame. When the design and specification are optimised to be resource efficient then PT can represent a leading sustainable framing solution and achieve notable embodied carbon reductions when compared to traditional alternatives – particularly for long span and minimum depth construction. There are good references and guidance available for designers and specifiers to help make informed choices that can have significant benefits for clients and project teams looking to maximise sustainable construction opportunities – see section opposite.

References

1. The Structural Engineer: Volume 90, Issue 5, May 2012, pp32-40.
2. Middlehaven CIAC in Middlesbrough. Contractor – GB Solutions, Frame Contractor – Northfield Construction Ltd, Post-tensioning contractor – CCL, Engineering Consultant – Martin Stockley Associates. This project utilised a locally available stockpile of precast units which could be used to retrieve the aggregates where the quality and properties were known. This project also had a specification for 50% GGBS which was accounted for in the programming on site by Northfield.
3. The Post-Tensioning Association, Post-formed holes through post-tensioned slabs, GN01, 2010.
4. The Concrete Society, Technical Report 43:Post-tensioned concrete floors. Design Handbook, 2nd Ed. 2005.
5. The Post-Tensioning Association, Procurement of post-tensioned slabs, GN03, 2012.
6. The Concrete Centre, Specifying sustainable concrete, 2011.

Further reading:

- The Concrete Centre, Concrete industry sustainability performance report, 5th report, 2011 data, 2012.
- The Concrete Centre, Concrete Credentials: Sustainability, 2010.
- The Concrete Centre, Concrete and the Green Guide, 2009.
- www.post-tensioning.co.uk

The Post-Tensioning Association: Promoting Perfect Post-Tensioning

This Guidance Note has been produced with help from the following members Buro Happold, CCL, MPA The Concrete Centre.

This Guidance Note, as well as a wealth of case studies are available online at:

www.post-tensioning.co.uk