UNDERSTANDING THE CARBON FOOTPRINT OF BOX CULVERTS

1. Synopsis

This factsheet offers an estimate of the Cradle-to-Gate carbon footprint associated with the manufacture of concrete box culverts by members of the Box Culvert Association (BCA). Data from members of BCA, collected as part of the BPCF annual Sustainability Charter scheme, and from the upstream of the supply chain, was used to calculate a carbon footprint which accounts for all the main emission “hot spots” of the manufacturing of box culverts as described in the diagram below. Although a few measures of ISO 14040/44 (such as completeness analysis testing) were not employed, the methodology used was broadly based on the provisions of PAS 2050: 2011.

The carbon footprint of 1 tonne of plain concrete used in the production of box culverts by members of BCA was found to be **104.99 kg CO₂e/t**. Four reinforced box culvert sizes (1,300 x 800 x 2,000mm, 1,500 x 1,500 x 2,000mm, 2,900 x 1,950 x 1,500mm, 3,600 x 2,700 x 2,000mm) were considered. The carbon footprints of the four sizes were 360, 710, 960 and 1,990 kg CO₂e respectively.
2. Introduction

This factsheet offers a basic estimate of the Cradle-to-Gate Carbon Footprint of box culverts. Generic data from members of British Precast, and some members of the Box Culvert Association, was used in order to estimate embodied carbon impacts associated with the supply of raw materials (cement, aggregates, reinforcement steel, and admixtures) and the manufacture (casting, curing, waste management, etc.) of box culverts.

The methodology used broadly complies with the requirements of PAS 2050. However, a few requirements associated with additional requirements (such as sensitivity or completeness analysis) were not carried out. Moreover, some of the assumptions made may need further assessment and justification.

The first functional unit used for GHG emissions reporting will be in 1 tonne of plain concrete used in manufacturing box culverts. This first-stage unit of measurement is applicable only to companies within BCA and is then used to calculate the cradle-to-gate carbon footprint of the following products:

- 1.30 X 0.80 X 2.00 metres of reinforced concrete box culvert (at the factory gate).
- 1.50 X 1.50 X 2.00 metres of reinforced concrete box culvert (at the factory gate).
- 2.90 X 1.95 X 1.50 metres of reinforced concrete box culvert (at the factory gate).
- 3.60 X 2.70 X 2.00 metres of reinforced concrete box culvert (at the factory gate).

3. The carbon footprint of box culverts: Identifying the ‘hotspots’

GHG emissions associated with precast concrete products have been explored and calculated in a number of studies in Europe and North America. In most cases Portland cement production is the main source of carbon dioxide emissions for a concrete product, making around 75% to 85% of the total carbon footprint of a concrete product. This is despite the fact that cement makes no more than 8 to 16% of a concrete product mix. In most cases reinforcement steel comes in second place – the contribution of steel can be between 10 to 25% (based on the source and origin of that steel). Other hotspot processes contributing to the carbon footprint include precast factory impacts (due to energy consumption) and transport sourcing of raw materials. The carbon footprint of concrete can change over time. Concrete is one of the very few products that can have a decreasing carbon footprint during its use due to carbonation. Section 5 of PAS2050 notes that the assessment “shall include the GHG emissions and removals… occurring during the 100 year period following the formation of the product”, which means that any temporary emissions negated by carbonation (even if occurring years after the end-of-life of a product) should not be accounted for.

The following diagram shows the main “unit processes” usually considered to assemble a credible carbon footprint for a box culvert. According to the “Cut-Off” rules of ISO 14044, and Clause 3.33 of PAS 2050, some of the “unit processes” that contribute no more than 1% to the inputs can be eliminated and ignored. Cut off impact can be accounted for by multiplying the impacts calculated by 1.01.
4. Calculation of Carbon emissions for concrete used in box culverts

- The following proportions were used for box culvert production: Coarse Aggregates: 43%, Fine Aggregates: 34%, Cementitious materials: 16%, Water (including moisture content in aggregates): 8%.

Figure 2. Box culvert concrete mix proportions suggested
4.1 Production of Aggregates

Aggregates have one of the lightest carbon footprints in the construction industry. The impacts are mainly associated with the basic extraction and processing (operations):

- The BRE Environmental Profile reports (considered to be the most accurate in the industry) put the impacts between 6 to 8 kg of CO₂e per tonne. These values are cradle to gate.
- The Bath University “Carbon Footprint Database” offers an average of 5 kg of CO₂e per tonne. It should be noted that the exact boundary conditions were not identified.

In order to produce an accurate carbon footprint it was decided to go for the potentially more comprehensive value of 8 kg CO₂e/t (BRE, 2007). The use of this figure should comply with ISO 14044 requirements for data quality and use of secondary data from reliable and quality sources.

Aggregates GHG emissions per one tonne of generic box culvert = 6.08 kg of CO₂ eq.

4.2 Transport of Aggregates

The Defra standardised average emission conversion factor for >33 artic lorries (published in 2013) is used. For an ongoing trip, a lorry would be fully laden with 20 tonnes of load of aggregates (MPA Aggregates, 2011). However the lorry will be empty for the return trip. DEFRA’s greenhouse gas estimations for a 100% laden +33 tonne articulated lorry would be around 0.91209 kg CO₂ per kilometre. DEFRA’s estimate for a 0% laden return trip is 0.7316 kg CO₂/km. It is assumed that the distance from the quarries is around 43.3 kilometres (MPA, 2011).

Aggregates transport GHG emissions per tonne of generic box culvert = 3.56 kg of CO₂ eq.

4.3 Production of cement

All members of BCA use a combination of cements in their mix: This combination contains differing levels of cement (including CEM I, CEM II/A-V, CEM II/B-V, etc.) along with fly ash added at the factory stage. Data from members reveal that fly ash total content could easily reach 30-35%. The calculations will be based on a simplified mix which includes a 67.5% Portland cement (CEM I) along with a 32.5% fly ash content replacement.

Portland cement (CEM I) greenhouse gas emission secondary upstream information will be taken from MPA Cement’s latest embodied carbon publication: Factsheet 18.

Secondary upstream information for Fly ash GHG differ from one source to another (4 to 8 kg CO₂/t) due to different allocation requirements associated with electricity production and the fact that fly ash is a coal-fired stations’ by-product. The figure used for this factsheet was
sourced directly from the latest MPA factsheet publication on the carbon impacts of cement (MPA, 2012) – Global Warming potential at that profile was 4 kg of CO2eq/t of fly ash.

The upstream greenhouse gas footprint for cementitious content will therefore be around 617.6 kg CO2 eq./tonne of cementitious.

Accordingly, GHG footprint contribution from cement will be around 98.8 kg of CO2 eq. per tonne of box culvert concrete.

### 4.4 Transport of Cement to Factory

The calculation of GHG emissions from transporting cement was based on calculations made by MPA Cement in 2012 (MPA, 2012) which assumes transport impacts reaching around 10 kg CO2e/t of CEM II B-V (the closest mix to cement blends produced by BCA members).

This means that the contribution to the manufactured box culvert product’s GHG footprint would be around 1.6 kg of CO2 eq. per 1 tonne of product.

### 4.5 Production and Use of Reinforcement Steel

The steel used in UK reinforced concrete utilises around 100 percent recycled scrap steel as feedstock (MPA, 2010). Around 80 to 70% of rebar used in concrete reinforcement in the UK is sourced from local mills. A carbon footprint of 450 kg CO2e per tonne for recycled reinforcement steel is used (Hammond & Jones, 2011). The GHG emissions of the reinforcement content for each of the box culvert sizes considered is added to the final carbon footprint (see Table 1)

It will be assumed that 70% of reinforcement is UK sourced, 20% EEA sourced, and 10% imported from a Black Sea port (Turkey, Russia, etc.). Sea travel distance is calculated using sea-distances.org and DEFRA 2013 conversion factors for 5000 to 7999 TEU container ship. An additional 250km land distance is added to the all scenarios to account for any land transport (including transport to the UK’s precast factory).

Impacts from sea travel were found to be 25.07 kg CO2e/tonne of rebar (11 + 14.07 kg CO2e/t). Another 20.55 kg CO2e/tonne is added to account for the 250km land transport.

The proposed carbon footprint of reinforcement steel is 495.6 kg CO2e/tonne

Reinforcement steel content is added to each of the box culvert sizes identified at Section 5.
4.6 Box Culverts Factory Emissions

British Precast possesses generic precast factory energy consumption information submitted by a number of member companies as part of their KPI process. Data for pipeline and box culvert manufacturers from 2012 was used to calculate an average GHG emission value for precast factory activities:

For the purposes of this paper the average for pipes and box culvert manufacturers will be used – this is around 13.72 kg of CO$_2$eq\(^1\) per tonne of box culvert

Fuels delivery, factory consumables, and other impacts
These impacts will likely not exceed 1% of the final footprint and can therefore be accounted for by scaling the final footprint value up by 1%.

Note: Extra proof is needed if such assumption is used in a PAS2050 certified study.

Production waste from factory
A 2.4% concrete waste ratio will be assumed. The carbon footprint of all input materials (except reinforcement steel) will be assumed to be 2.4% higher per 1 tonne of net production.

Note: This is based on an assumption that 90% of all waste generated in factories in 2013 was concrete waste. Further proof (e.g. survey results) is needed to meet PAS2050 requirements.

4.7 Excluding temporary CO$_2$ emissions

The new version of PAS 2050 (2011) accounts for a fixed 100 years assessment period after the formation of the product. Any emissions or removals (not lasting for over 100 years or more after the formation of the product) should be removed. This newly introduced rule can have a significant impact as any temporary emissions absorbed through the carbonation of concrete during 100 years after manufacture will be excluded from calculation: A longer time period may be considered if significant removals/emissions occur afterwards: e.g. at the end-of-life and exhumation, crushing of the box culverts.

Absorption of CO$_2$ at the end-of-life (and 100 years beyond) is estimated based on previous work carried out by BRE (2013). It is assumed that CO$_2$ absorptions by precast concrete: reaches 3.28 kg CO$_2$/m$^3$ during service life, 15.3 kg CO$_2$/m$^3$ at end-of-life if the crushed precast waste is landfill, and 55.6 kg CO$_2$/m$^3$ at end-of-life if the crushed precast waste is reused as graded aggregates. It is assumed that 90% of the crushed box culverts at end of life will be recycled into graded aggregates and 10% will go to landfill:

Total CO$_2$ absorbed due to carbonation =

\[
3.28 + (0.9 \times 55.6) + (0.1 \times 15.3) = 54.85 \text{ kg CO}_2/m^3
\]

\[
= 23.05 \text{ kg CO}_2/\text{tonne of product}
\]

\(^1\) The precast box culvert industry average may be identical.
That absorbed CO₂ is then removed from the Cradle-to-Gate Carbon Footprint of box culverts to produce a footprint more in line with the new PAS 2050 requirements. The cradle-to-gate carbon footprint will therefore be **104.99 kg CO₂/t**.

**5. Final Calculations for reinforced box culvert sizes**

The final Cradle-to-Gate carbon footprint of box culverts are calculated by adding the plain concrete carbon footprint (multiplied by the amount of concrete used) to the carbon footprint of reinforcement steel used in each box design (multiplied by the estimated cradle-to-precast factory carbon footprint of rebar). No cuts, holes or further adjustments to the box culverts are assumed after the product is manufactured. Moreover, the impact of any strips and any material added to seal joints is not accounted for at this stage.

Table 1 shows the calculation results:

<table>
<thead>
<tr>
<th>Cradle-to-Gate Carbon Footprint (kg CO₂e)</th>
<th>1.30 x 0.80 x 2.00 m</th>
<th>1.50 x 1.50 x 2.00 m</th>
<th>2.90 x 1.95 x 1.50 m</th>
<th>3.60 x 2.70 x 2.00 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>360</td>
<td>710</td>
<td>960</td>
<td>1,990</td>
</tr>
</tbody>
</table>

**Table 1. The Carbon Footprint of four box culvert sizes (Cradle-to-Gate) as calculated for members of BCA²**

**6. References**


² For ease of use, values reported are rounded to the nearest 10 kg CO₂e/ product