Sustainability for bridge engineers – Part 2

Bridge scheme lifecycle

Sustainability should be considered at every phase of a development: planning, design, construction, maintenance, change of use (modification), and end of life (demolition) or replacement. The first planning or 'project inception' stage is discussed in Part 1 of this briefing and the rest of the stages discussed below.

This briefing illustrates different approaches to meet sustainability objectives at each stage of the project lifecycle. The points covered here should be treated as ideas for consideration rather than a comprehensive checklist. A full assessment is the only way to understand the trade-offs and significance of each idea within the context of a particular project.

The life cycle of a bridge as discussed below can be seen in the context of CO_2 emissions and global warming potential over its life. In-use emissions associated with the design choices are traffic diversions during maintenance, maintenance itself and finally, demolition. Bridges have a long design life with relatively little lifetime intervention so the initial impacts of the materials represent a major proportion of the total lifecycle emissions. Therefore the focus of design must be on providing a durable structure with minimum initial impacts and minimum maintenance requirements.

Design

Anticipated impacts from every stage of the project need to be considered during design:

Materials: A sustainable approach to materials will include efficiency, responsible sourcing, design to minimise impacts, healthy materials and consideration of end of life.

Efficiency: The materials used determine the amount of embodied energy in a structure so raw construction materials and energy should be minimised. This includes fabrication, transport and construction energy. It has been shown that in general longer span solutions for structures have higher material costs as well as higher embodied energy[1]. 'Architectural' solutions which are not in harmony with the structural form tend towards higher embodied energy.

The quantity of raw materials can be minimised by using a structural form with direct force transfer e.g. elements in pure compression or tension, such as arch or stress ribbon bridges[1, 2]. The use of compressive membrane action will minimise the steel required in concrete decks (BD87/02). Use of reinforced soil in place of rc walls minimises concrete volumes.

Use of innovative materials and forms can reduce the weight of a structure. Lightweight structures minimise foundation size and cost. For example: fibre composite materials[3]; engineered cementitious composites[4]; bridge in a backpack[5], timber and rope[6].

Strategies to minimise waste involve: design for reuse and recovery, offsite construction, materials optimisation, waste efficient procurement, deconstruction and flexibility[7]. Realistic specification, repetitive details, good information and early input from suppliers and contractor will make a significant contribution. Balancing cut and fill increases material efficiency and reduces construction impacts.

Responsible sourcing: Responsibly sourced materials are available to the bridge engineer[8]. Recycled and secondary materials such as aggregates, Portland cement replacements and tyre bales for embankment fill, should be considered but balanced against additional transport distances and technical requirements. (For more information refer to previous sustainability briefings on responsible sourcing, aggregate and a forthcoming briefing on cementitious materials).

Design to minimise impacts: Optimisation on weight is not always the most sustainable option. The material choice should be evaluated against a full set of design constraints including cost, environmental impact and durability. Very high strength concrete can reduce material use[9,] however calculation is needed to show that the weight saving offsets the increased embodied CO_2 of the material. Traditional methods such as masonry construction can be more reliable when using local workforce. Options can be compared using tools discussed in Part 1 of this briefing note.

Design for the full life cycle and health: Durable materials such as concrete, galvanised steel, FRP and weathering steel avoid the need to use coatings. An added benefit of the longer life before maintenance of durable structures is the reduction in traffic disruption and congestion.

In terms of longevity of a bridge, the capacity and condition of bridge substructure will determine if a bridge life can be extended through bridge deck replacement. The design requirements for future proofing balanced against initial impacts merit careful consideration. For elements of the bridge with a shorter design life, use of materials or components that are easily recycled, such as metal parapets, or reused, such as Bailey bridge components, is an end of use benefit.

Material summary: Issues to consider are:
- Avoid overdesign but not at the expense of future proofing
- Prioritise the use of local raw resources and construction methods
- Minimise transport distances and consider suitable size of elements for delivery to the site
- Responsible sourcing for concrete and timber
- Design for balanced earthworks cut and fill

Water and pollution: Water should be addressed at the design stage and in particular the use of water should be minimised as a resource. The designer should also consider drainage provision, water attenuation and catchment and groundwater resources. A sustainable scheme will enhance catchment and minimise runoff to reduce flood risk.

Construction

Early contractor involvement in design (ECI) provides an opportunity to reduce construction impacts. Contractor and supplier input can help develop realistic specifications particularly if extreme exposure and workability is required. The designer can consider ease of access with possible advance enabling works to avoid overrun and delays. Protection from groundwater pollution during construction and in use can be achieved by installing reed beds or petrol interceptors.

ECI will facilitate early discussion of a site waste management plan for waste reduction[10]. The contractor can avoid waste by ordering pre-cut or prefabricated elements and deploying re-usable shuttering or slipforming. This also helps to minimise construction time and improve quality. Quality assurance and control procedures are important tools. Close site supervision will avoid mistakes and rework together with proper storage and site control to avoid damage. Good survey information leads to accurate setting out. Good information for estimating and ordering materials for site helps avoid oversupply and facilitates the design of elements to fit without need for cutting.

Maintenance and use

Congestion has a very high sustainability cost directly in fuel use but also in social and economic terms. This can influence the choice on whether to replace or strengthen a structure. The following list provides examples of how this can be minimised at initial design stage:

- Provision of access for maintenance without disruption to traffic or services
- Define emergency procedures for major crossings
- Provision for replacement of limited life elements. Easy removal will allow remedial works to a better quality offsite, e.g. provision of jacking points for bearing replacement
- Design to allow replacement, widening or strengthening while maintaining the structure in service. Steel structures are generally easier to strengthen
- Design for robustness or provide generous headroom to avoid damage particularly for steel beams which are more vulnerable to impact damage. Provision of protection or warnings to prevent damage
- Minimise future maintenance requirements: integral bridges with no joints or bearings; good detailing to avoid problems (water path)

Once the bridge is in-use the following examples demonstrate material efficient approaches to maintenance:

- Innovative testing methods to prove structural adequacy or provide accurate estimate of remaining life. Proof load testing[11]
- Relaxed assessment criteria, an accepted departure from standard such as load restrictions or use of less conservative analysis methods, reduce or avoid the need to strengthen or replace. For example, compressive membrane action can be utilised to improve capacity of slab decks BD44/95
- Regular preventive maintenance
- Innovative repair or strengthening options e.g. carbon fibre or heat straightening[12]

Demolition

Demolition should be considered carefully for temporary structures, and a Sustainability Briefing on Design for deconstruction published in *The Structural Engineer,* **89**/4, gives more information on this. Use of materials or components that are easily recycled or reused, such as aluminium parapets and bridge components, is an end of use benefit, e.g. Bailey bridges have significant reusable elements.

References

1 Long, A. E. *et al*.: 'Sustainable bridges construction through innovative advances'. *Proc. ICE – Bridge Engineering,* **161**/4, December 2008, p. 183–188
2 Agrawal, R.: 'Stress ribbon bridges', *The Structural Engineer,* **87**/22, 17 Nov 2009, p.22–27
3 Head, P. C.: 'New bridge technology for sustainable development', *Proc. ICE, Bridge Engineering*, **157**/4, December 2004, p.19 –202
4 Chandler, R. F.: 'Life-cycle cost model for evaluating the sustainability of bridge decks'. *Report No. CSS04-06 2004*. University of Michigan Center for Sustainable Systems
5 Bridge in a Backpack, Advanced Infrastructure Technologies
6 McGlade, D.: Carrick-a-Rede rope bridge, *The Structural Engineer,* **87**/14, 21 July 2009, p. 21–26
7 WRAP web site 'Designing out waste in civil engineering' tools and guidance, available at: http://www.wrap.org.uk/construction/tools_and_guidance/designing_out_waste/dow_civil_eng.html
8 BRE Environmental & Sustainability Standard. BES 6001: ISSUE 2.0 *Framework Standard for the Responsible Sourcing of Construction Products*
9 Martin, A. J.: 'Concrete bridges in sustainable development, *Proc. ICE – Engineering Sustainability,* **157**/4, December 2004, p. 219–230
10 Wrap web site 'site waste management' tools and guidance, available at: http://www.wrap.org.uk/construction/tools_and_guidance/site_waste_management_planning/index.html
11 Clubley, S. K. *et al.*: 'Load distribution of bridge parapet supports in southern England: Re-evaluation, testing and analysis'. *Engineering Failure Analysis 14,* 2007
12 Clubley, S. K., Winter, S. N., Turner, K. W.: 'Heat straightening repairs to a steel road bridge', *Proc. ICE – Bridge Engineering,* **159**/1, March 2006, p. 35–42

Bibliography

- Collings, D.: (2006). 'An environmental comparison of bridge forms'. *Proc. Institution of Civil Engineers*, *Bridge Engineering*, **159**/4, p. 163-168
- Daniel, R. A.: 'Environmental considerations to structural material selection for a bridge'. *European Bridge Engineering Conf. Lightweight Bridge Decks,* Rotterdam, Netherlands, 2003
- Itoh, Y. and Kitagawa, T.: (2003). 'Using CO_2 emission quantities in bridge lifecycle analysis'. *Engineering Structures,* **25**/5, p. 565-577
- Pacheco, P., Adao da Fonseca, A. P., Resende, A. and Campos, R.: (2010). 'Sustainability in bridge construction processes'. *Clean Technology and Environmental Policy*, 12, p. 75-82
- Steele, K., Cole, G., Parke, G., Clarke, B. and Harding, J.: (2003b). 'Highway bridges and environment – sustainable perspective'. *Proc. ICE, Civil Engineering,* **156**/4, p. 176-182
- Willetts, R., Burdon, J., Glass, J. and Frost, M.: (2010). 'Fostering sustainability in infrastructure development schemes. *Proc. ICE, Engineering Sustainability,* **163**/3, p. 159-166
- Zhang, C.: (2010). 'Delivering sustainable bridges to help tackle climate change'. *Proc. ICE, Engineering Sustainability*, **163**/2, p. 89-95

Further Information

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