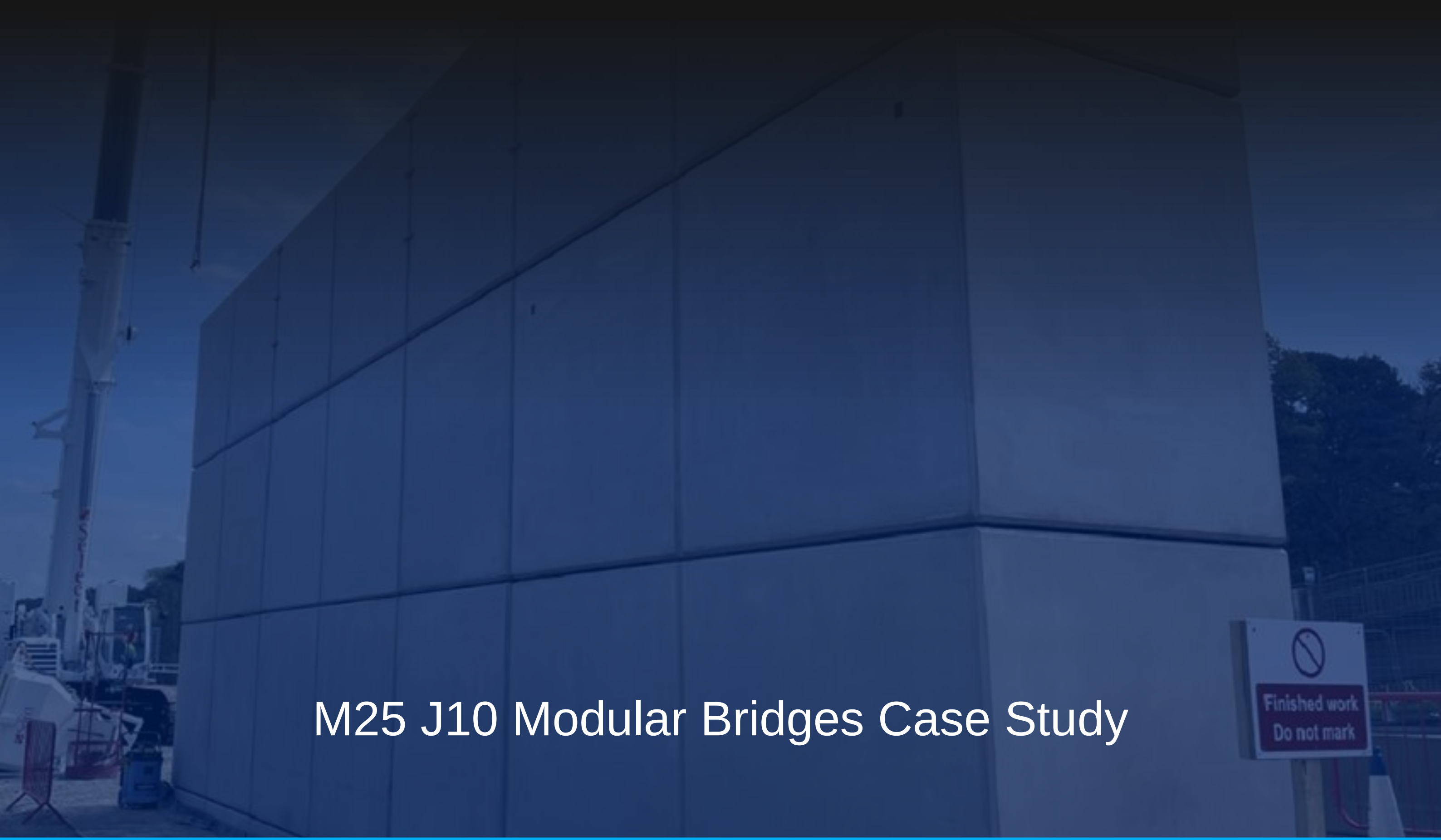
National Highways
CEMC Visit April 2023



M25 J10 Modular Bridges Case Study

expanded

This paper was prepared in response to a request for information from National Highways following a visit to the Centre of Excellence for Modern Construction (CEMC) in April 2023. Specific questions were raised following the visit, and the structure of the paper is framed around each one.

Question 1

Can you please give us a recap on the background how you became involved with this project? We had the distinct impression that the design was already completed when you became involved.

Project introduction

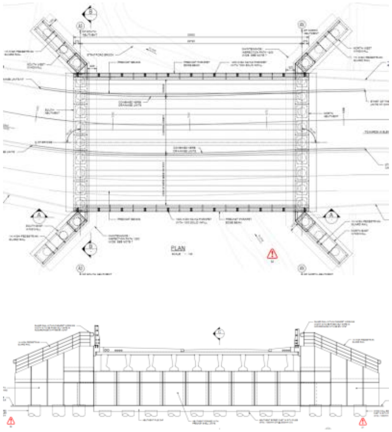
Name of the Project:	M25 Junction 10
Owner of the Project:	National Highways
Modular Solution Adopted	Modular system for abutments, piers and retaining walls
Designer:	Atkins
Main Contractor:	Balfour Beatty
Specialist Supplier	Laing O'Rourke (Expanded and Explore Manufacturing)
Construction Start:	2023

About the project: Junction 10 is reported to be the busiest section of the M25 London Orbital Motorway with over 300,000 vehicles passing through every day[i]. National Highways are undertaking an improvement scheme to reduce congestion, create a smoother flow of traffic and provide safer journeys for thousands of users.

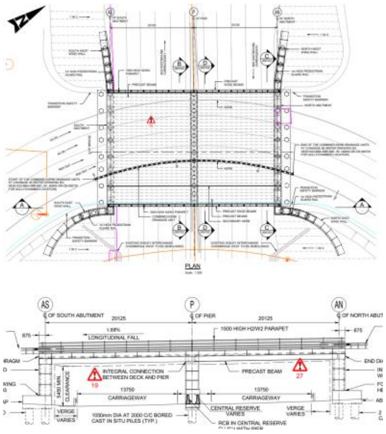
As a specialist supplier to the main contractor, Expanded (Laing O'Rourke) is delivering a bridge package of works comprising eight new bridge structures around the Wisley Interchange, working under a build only contract. A mixture of solutions is being delivered. Three of the bridges are full precast modular builds with in-situ decks on precast beams, three are traditional flexible abutment bridges with reinforced earth walls (by others) but with modular piers, and two of the bridges are Non-Motorised-User (NMU) bridges with steel deck superstructures installed by other subcontractors to Balfour Beatty (BB). One of the bridges adopts full depth, full width precast deck planks as well.

Image Source: National Highways

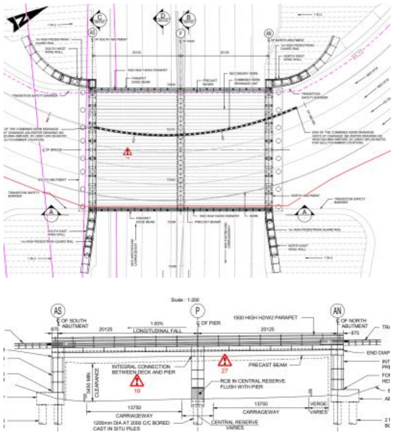
Integral Bridges



Stratford Brook Underbridge

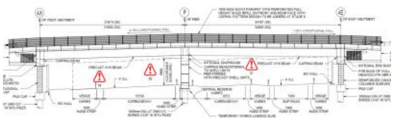


New Wisley Interchange Overbridge West

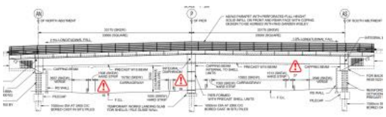


New Wisley Interchange Overbridge East

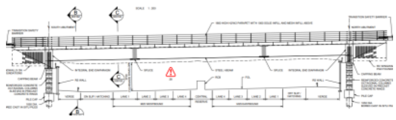
Flexible Abutment Bridges (Reinforced Earth Abutments, Modular Piers)



Cockcrow Green Overbridge

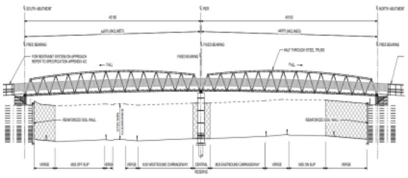


Wisley Lane Overbridge

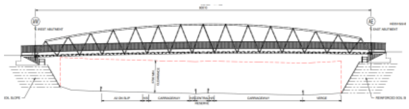


Clearmount Bridge

NMU Bridges



Sandpit Hill NMU Bridge



Redhill NMU Bridge

8 STRUCTURES

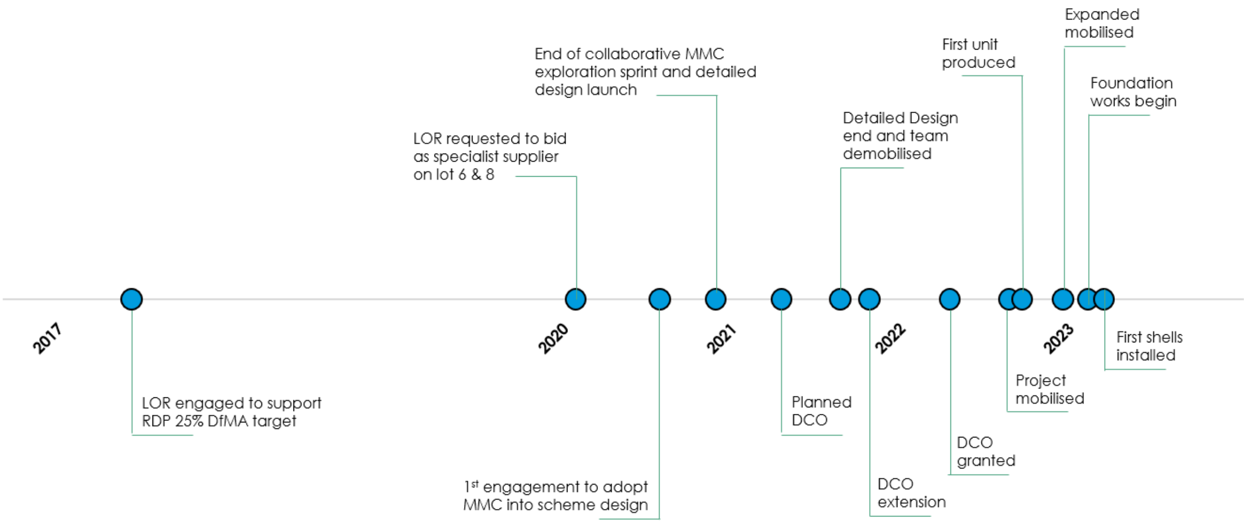
792 PRECAST COMPONENTS

Design: The permanent works were designed by Atkins (Balfour Beatty's design partner). Expanded joined the project in Q3 2020 when the design was at scheme design level, prior to AIP submissions for the structures. Expanded worked collaboratively with Atkins during the early design development, bringing knowledge of the modular bridge approach and learning from previous modular bridge projects to maximise benefits across the structures. To create a safe and integrated solution, Expanded helped inform Atkins' permanent works designs with standardised temporary works designs for the modular kit of parts. This drove engineered safety and the fulfilment of each organisation's CDM responsibilities. Piling design was also conducted by Atkins with the piling works executed by Balfour Beatty Ground Engineering (BBGE).

Expanded scope of works: Expanded is an integrated member of the project delivery team acting as a bridge solution provider. Expanded's scope includes construction of pile caps, manufacture, logistics and assembly of abutments and piers, bridge bearing installation, installation of precast prestressed or steel bridge beams (supplied by BB), concreting of the deck and/or installation of precast deck units and parapet installation.

Project timeline

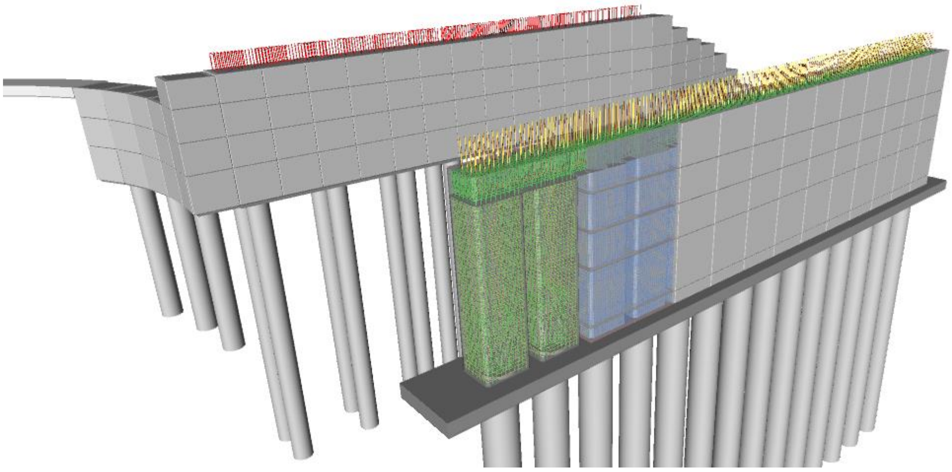
Project timeline:	
2017	• Explore Manufacturing (Laing O'Rourke) begin to support the Balfour Beatty Atkins (BBA) team on Regional Delivery Partnership (RDP) Lots 6 & 8 with a focus on a DfMA[ii] component led approach, specifically to answer the challenge of 25% DfMA by 2025 to support the government's industrial strategy.
2020	• Q1: Expanded (Laing O'Rourke) responded to a request to bid for a position as a specialist supplier of bridges on RDP Lots 6 & 8 to BBA • Q3: Expanded commenced their engagement on M25 RDP Lot 6. When we joined the project, the current design was at scheme design pre-AIP submission. The leadership wanted to change direction and adopt MMC into the scheme • Between July and December Balfour Beatty, Atkins & Expanded worked as a collaborative team to review, explore and maximise the opportunities to change the conforming solution into modular off-site construction • This resulted in 3 structures achieving full conversion and 4 structures with hybrid solutions – part MMC and part conforming design • Detailed design began in December 2020
2021	• Planned DCO was 12th May 2021 but was extended to November 2021 • There was a design demobilisation in September 2021
2022	• DCO Granted May 2022 • Design teams remobilised in May 2022 and preparation of manufacturing information restarting • Project mobilisation for construction in September.
2023	• Expanded construction team mobilised in January • Commenced bridge foundation works in March • First precast units installed in April • **32% of precast units produced** (May 2023)

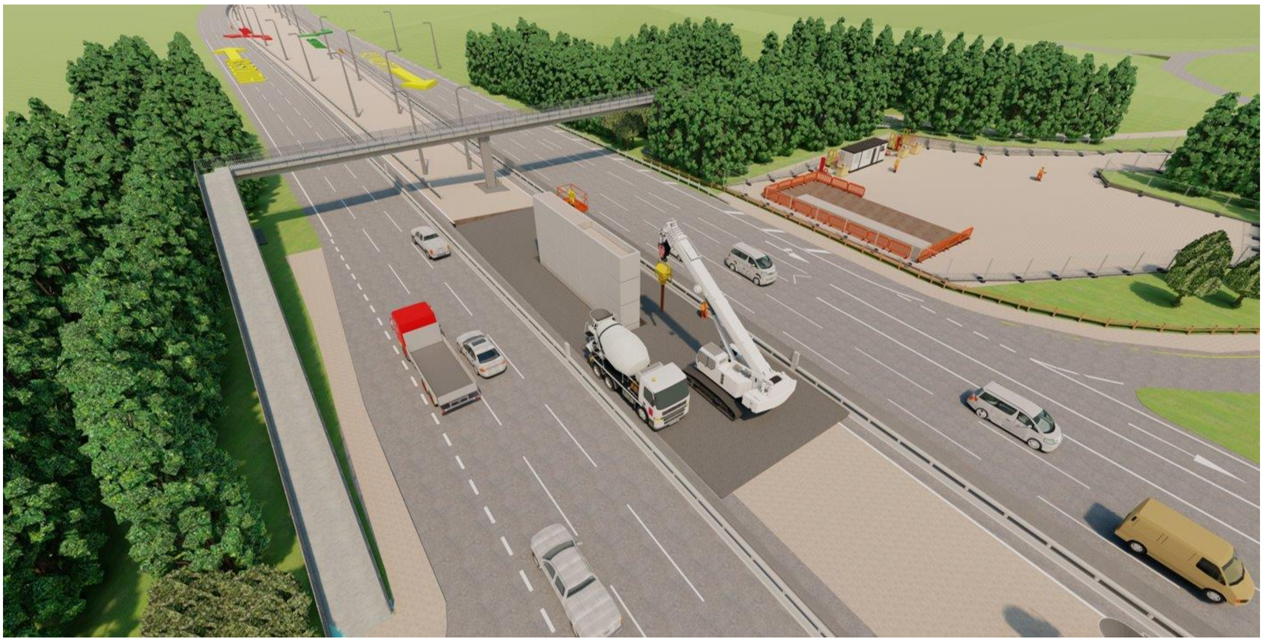


M25 Junction 10 Concept to delivery timeline

Images and Progress Photos

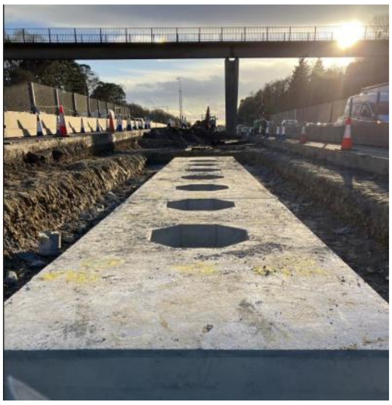
Digital Builds of Modular Assemblies for detailed coordination and site planning





Shell Manufacturing at CEMC

Construction of the combined levelling slab and piling guide-wall, and the central pier at Wisley Lane Overbridge.



Finished Central Pier at Wisley Lane Overbridge

Beam installation over modular abutments at Stratford Brook Bridge

Question 2

Who were the leading contacts you were dealing with from Balfour Beatty and Atkins and if you had any discussions with National Highways on this project, again names would be useful.

Key People

Project contacts:	
National Highways	• **Jonathan Wade**, Senior PM, M25 • **Laura Christie**, Project manager M25 • **Ian Sandle**, SES
TA Support*	• **Jimmy Barratt -Thorne,** Associate Director, WSP
Balfour Beatty	• **Chris Kennedy**, RDP Engineering lead • **Iain Sutherland**, RDP Framework Director • **Howard Williams**, Project Director • **Ellie Hossack**, Construction lead • **Sarah Jennings**, Procurement highways lead • **Simon Bonser**, Commercial lead
Atkins	• **Scott Shaw**, RDP Lead • **Alastair Moore**, Package RDP package B5 lead • **Robert Petty**, Design Lead
Expanded	• **Mitch Pretious**, Operations Leader • **Phil Robinson**, Technology & Innovation Leader • **Nigel Huxham**, ECI Project Leader • **Andrew Lee**, Commercial Leader • **Adrian Wallace**, Technical Leader • **Ronan O'Rourke**, Construction Project Manager • **Paul Rowland**, Manufacturing Leader • **Tim Rowe,** Pre-construction Project Leader

*WSP functioned as a parallel technical assurance team to support National Highways who undertook the lead TAA role.

Question 3

Clearly, an explanation of the benefits in terms of time, cost and quality, plus those other factors such as carbon savings, safety etc. will all go to telling the story.

Question 4

We also discussed yesterday if a simple visual could be prepared for the M25 scheme representing traditional vs modular construction approach. The supporting information is important because killer facts are what will help the industry make a step change.

Benefits on M25

In October 2020 (before the DCO delay) BBA assessed the benefits from the modular bridge conversions and reported the following:

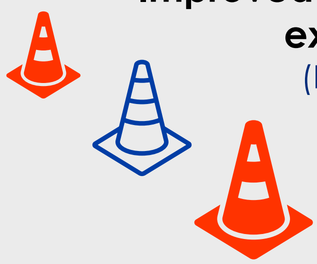
- Commercial savings were made as a result of the significantly increased build speed, pilecap-less construction solutions and the ability to construct in high-risk environments with little to no temporary works
- Meets the 25% offsite by 2025 strategy (and RDP commitment),
- Reduces H&S risk exposure to the workforce in high-risk live traffic environments,
- Offsite construction improves quality control, minimising defects,
- Customer benefit – less disruption to highway users,
- At least 6 months saved from the structures programme from pre-commencement analysis,
- Improvement on critical path provides a saving on full preliminaries,
- Reduced traffic management (TM) requirements improving the road user experience,
- Reduced Temporary works interfaces,
- Virtually no down time due to weather risk.

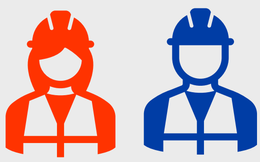
The standardised approach to the modular bridge abutment construction results in **improved safety for operatives and road users.** This is a combination of well-defined risks and mitigation techniques, and the reduction in operatives and plant movements on site over a shorter duration. The repeatable processes provide considerable advantages when employed on a series of bridge builds.

Advantages of the Modular Approach vs Traditional

6 months
saved on programme

Improved customer experience
(Road users)



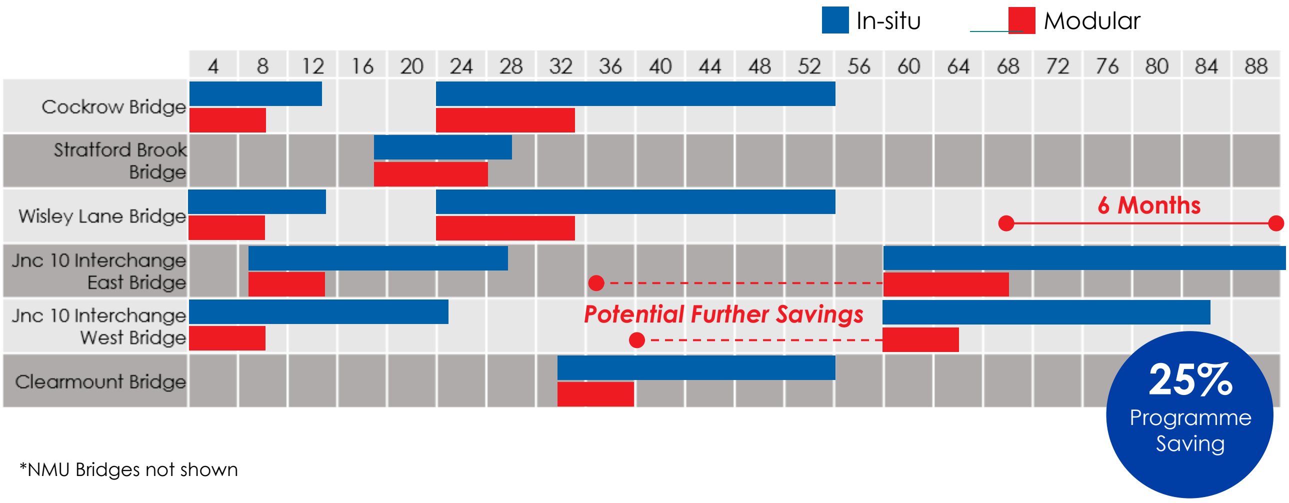


Improved H&S
with reduced risk exposure

DfMA giving
- **25% offsite now***
- High Quality
- High Certainty

* KPI was 25% offsite by 2025

M25 DfMA Pre-Commencement Programme Savings



*NMU Bridges not shown

Deploying new methods of bridge construction offers an opportunity to benefit further projects on the RDP, especially where early engagement is facilitated. There is evidence that the benefits are transferable across projects as identified from our work on HS2 shown in the case study below.

Using case studies from the portfolio of planned and completed projects, more benefits of product-led bridge construction relevant to the M25 J10 solutions can be demonstrated. For a look into workforce efficiency, time and carbon benefits, the HS2 detailed case study below gives notable insight. For cost benefits please see the response to Question 6 and the bridge over the M1 Motorway. Further developments on product improvement and decarbonisation are discussed at the end of this paper in the "Next Steps in innovation" sections.

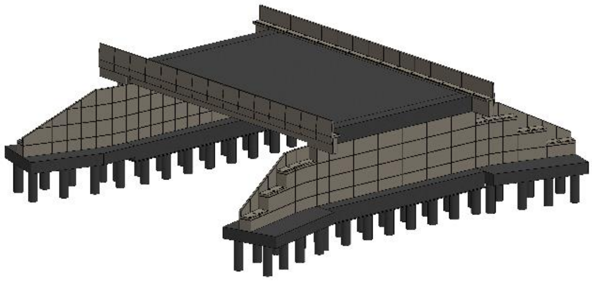
HS2 Case Study

The modular precast concrete shell system for abutments and retaining walls was used to construct four bridges at the Birmingham Interchange Station site near Solihull. The works were heralded as a major success to the delivery of the HS2 enabling works in the area[iii]. The project team have seen first-hand the significant value that modular construction brought to the project in terms of H&S, programme savings, quality, environmental performance and cost certainty.

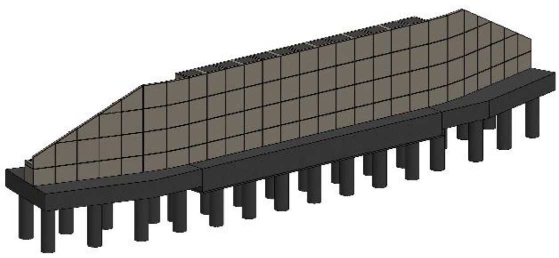
To develop a detailed comparative study of the modular bridge solutions against more traditional construction techniques, Laing O'Rourke commissioned Ramboll UK to fully redesign one of the overbridges as an in-situ reinforced concrete structure with zero offsite construction.

Modular abutment construction

Modular abutment shell



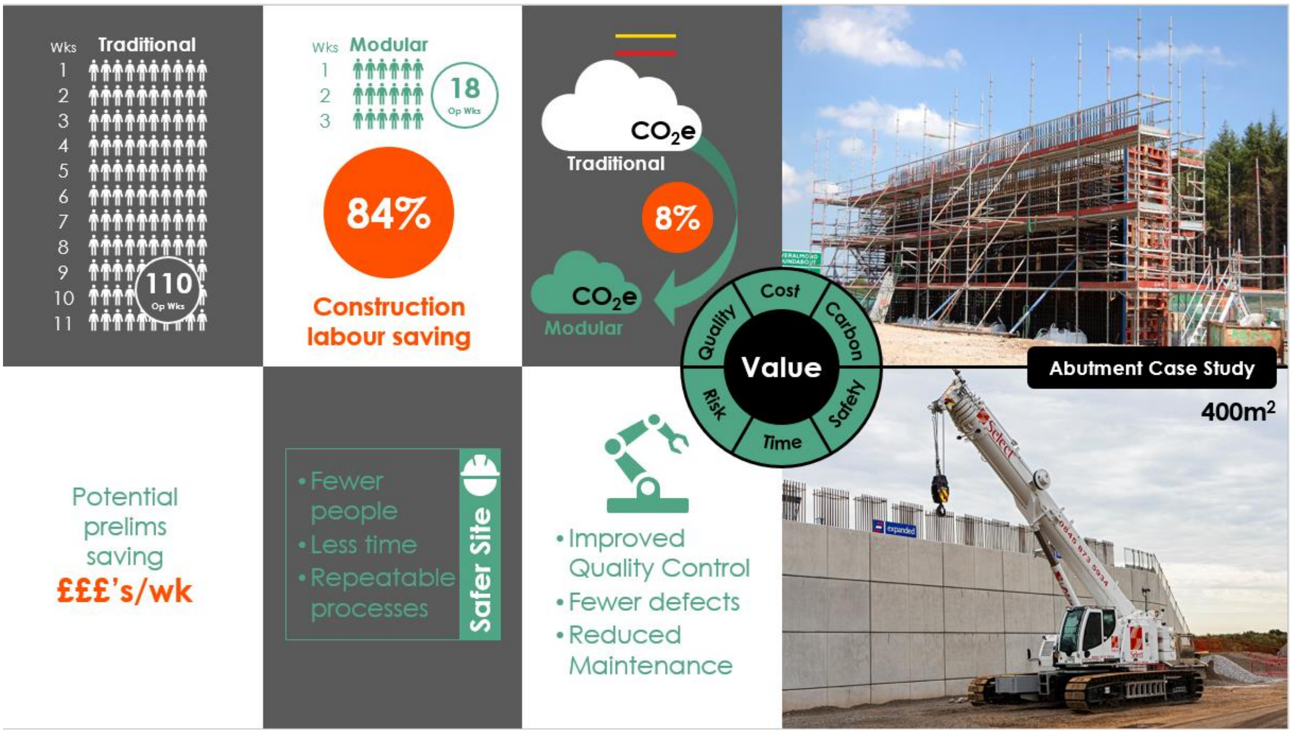
Bridge used for wider carbon case study



Abutment used for this case study

Using the redesign, the original project team prepared a fully detailed project delivery plan. This included temporary works designs, rebar detailing (including splices), preliminaries requirements, craneage, a budget to build and a construction programme.

Case study infographic



The most prominent number from the study is an **84% reduction in operative hours** for the construction of the abutments. This is the result of a reduced number of operatives on site for a shorter time during assembly. **The programme and resource benefits** scale up from each substructure to the whole scheme and this drives significant resource optimisation and preliminaries savings. Approximately **£200,000 was saved for each week** of programme savings on the HS2 BIS bridges in the case study alone.

Scalable benefits of modular bridges

The study showed that the modular approach for abutments and wingwalls helps **reduce embodied carbon** compared to an equivalent, traditionally designed in-situ reinforced concrete abutment. Differences in material content, fuel, waste and transport contribute to this saving. Importantly, our studies are also showing where further effort can be targeted to drive better environmental performance on future schemes (see section in next steps at the end of this paper)

Completed HS2 Integral Bridge structure at Birmingham Interchange near Solihull

The modular system enables the use of a higher percentage of cement replacement within the in-situ core of the modular shells. Traditionally, the in-situ concrete mix for the abutment would be driven towards a higher cement content to achieve rapid strength gain to allow formwork to be stripped early to proceed with the next activity.

Fuel and transport savings are not only a function of the modular approach resulting in fewer deliveries to site, but also due to the significant reduction in on site labour, both in number of people required for assembly and the duration of the works themselves. The study has been published in the CBDG Technical Guide 17 for further reference[iv].

Question 5

It is always useful to identify what did not go to plan and what could have gone better, plus potentially what would have been the greater benefits had you been involved right from the start.

Room for improvement

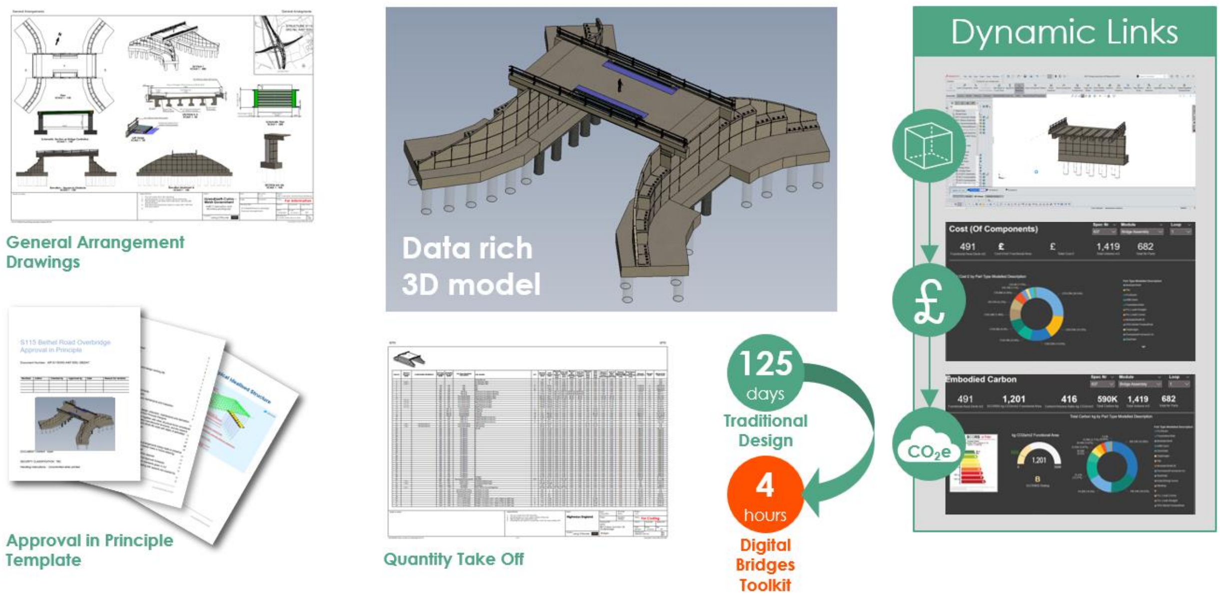
- **Strategic Procurement** – As a Tier 2 contractor, we find that early optioneering has already taken place and that Tier 1 contractors are already on the journey to meet DCO dates. The current point of entry comes too late to maximise benefits of modular solutions. Tapping into the detailed knowledge of the supply chain needs to occur earlier in the design phase to get the best value for the client. Tier 2 suppliers need a procurement route from concept (pre-AIP) through to delivery. Looking at the route developed on LTC roads north, BBA adopted a different approach which was to form an enterprise in advance of the tender. Selected Tier 2 partners were secured to work inside a collaborative enterprise which promotes best outcomes for project solutions.

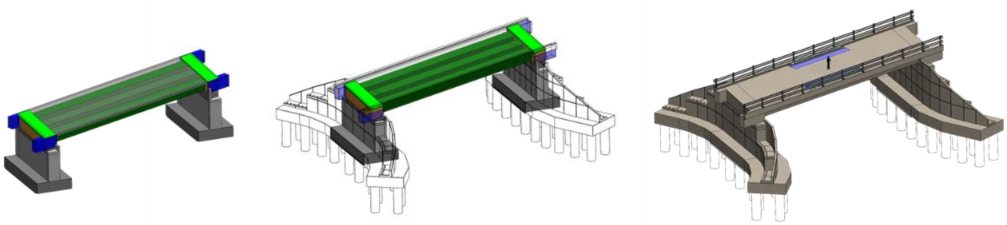
- **Flat line management** would be beneficial; use the tier 2 supply chain to expedite the route to faster decision making – Tier 1, Tier 2, designer and clients working together as a collaborative team.

- **Delay** – the delay to the DCO on the project was unfortunate and led to team demobilisation.

- **Early engagement** is key to maximise the benefits in bridge configuration. For example, we can demonstrate the benefits by using the **digital bridge configuration toolkit** to run multiple options with the bridge kit of parts to select the best ones for desired project outcomes. This will also help to eliminate the cost of design conversions and bespoke componentry. The digital bridge configurator is a Laing O'Rourke product-led tool that takes input parameters (bridge span, skew etc.) and applies suitable component arrangements to rapidly generate high-feasibility bridge configurations with structured output data that can be used to evaluate the cost, carbon and programme of a proposed option. See the final section of this report for further information on the tool.

Digital Bridges Toolkit Capability. Link to video scan QR code to find out more:





- **Management of Intellectual Property (IP)** - The IP drafting in the RDP framework subcontracts is suited to a traditional method of construction i.e., designing from scratch each time. DfMA bridges are constructed from a kit of parts supporting end to end standardisation incorporating lessons learnt. Thus, a different approach to IP was needed. It took a significant amount of time to align IP strategies and update the RDP agreements. The requirements from each party were:
  - National Highways required access to the IP in order to complete the construction of the scheme in the possible event that any of the supply chain are no longer able to deliver the structures. National Highways also need access to the IP to maintain, repair, or replace a bridge in future. These rights should survive termination or expiry of the relevant contracts.
  - Laing O'Rourke (product developers) needed to maintain rights to the IP in the product design (including modifications made during the course of the project) and all related manufacturing and installation knowhow to enable it to use the products for other clients and applications in the future.

  The result of this on the RDP was that National Highways owned any IP developed on the scheme to fulfil the requirements of bullet point one, which was then licensed back to Laing O'Rourke for use on future projects with other clients to fulfil bullet point two.

- **Newer pier and wingwall solutions** – while we deployed successful, time saving solutions for the central reservations and wingwalls, we are continuously improving our products. We have now developed a new precast pier unit which offers a narrower, lighter element which could be deployed to free up more space in the central reserves and with smaller cranes on future schemes. We have also developed retaining wall elements that are taller and we can create more wingwall angles with less material. These units will be used on upcoming structures.

Recommendations

- Using our skill set and that of other Tier 2 suppliers in early optioneering would be beneficial to National Highways when planning projects in the conceptual stages. Having access to the latest technology and construction techniques in time enough to inform the design can only benefit the outcomes.

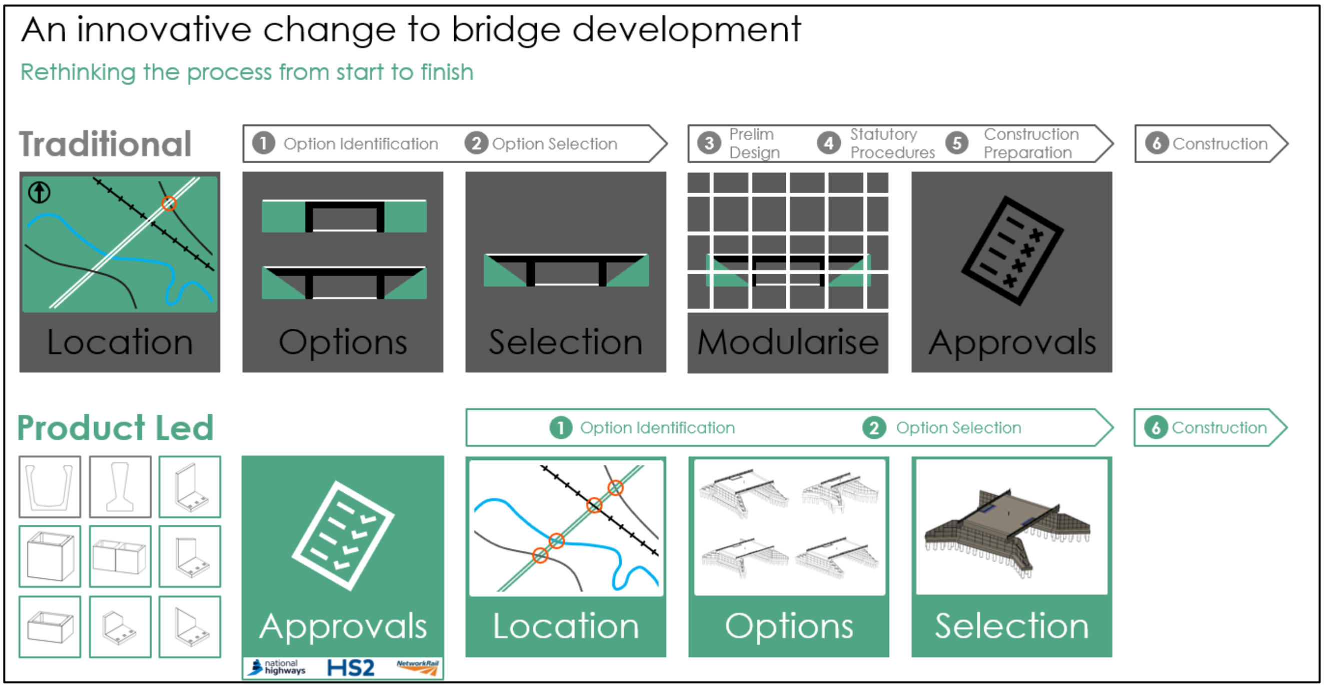
- Introduction of an ECI phase pre-DCO with Tier 2 suppliers would supplement the robustness of the environmental statements and initial assessments i.e., demonstrating more accurate benefits within the examination process.

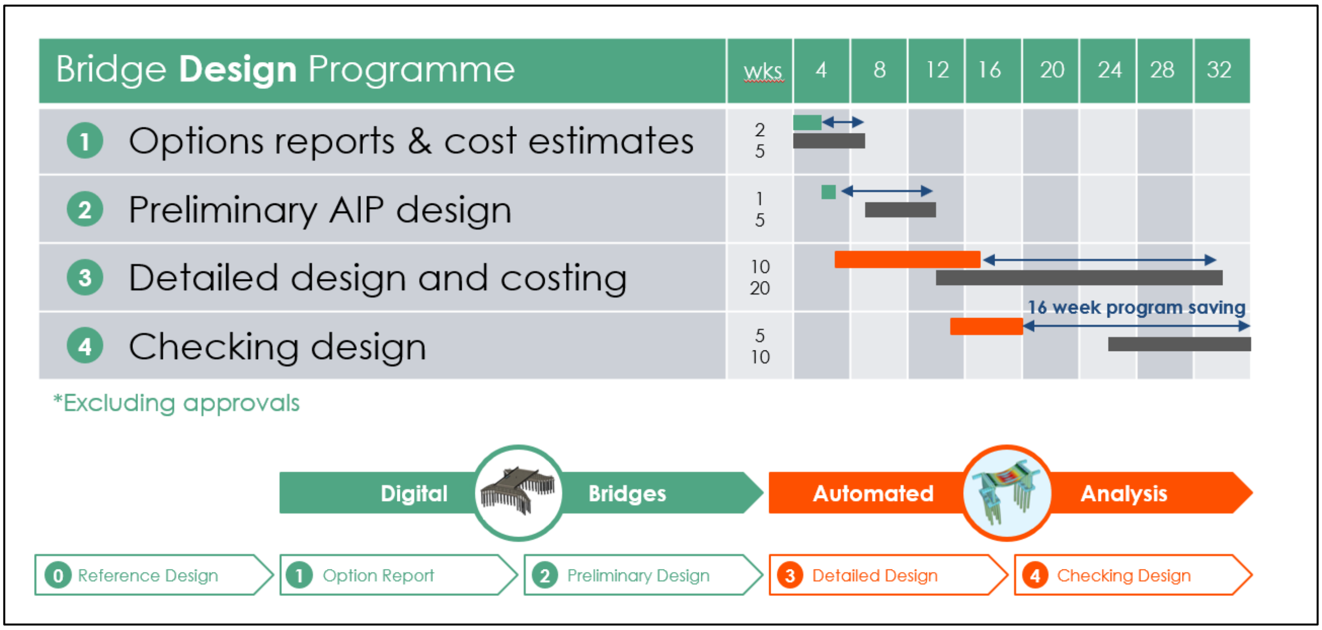
- Promotion of early engagement will unlock the potential of true product-led approaches with the added benefits of digital configuration and design acceleration.

- In late-stage conversion design scenarios, we find that trying to match fixed geometry with modular products leads to inefficiencies in the modular solution, such as the requirement for one-off/bespoke elements. For example, bespoke wingwall units can be required to match the associated earthworks profiles that may have already been fixed. Proposing alterations to the bridge geometry is often limited by the need to revisit stakeholders and seek approvals for an alternative arrangement e.g., resubmission and comment cycles of an AIP (6+ week cycles). If conversion scenarios are unavoidable, the ability to adjust the geometry, where beneficial, requires a suitable approval mechanism to minimise redesign and inefficiency.

- Using pre-approved products and digital configuration tools, like the Laing O'Rourke bridge configurator, accelerates the design and reduces time to construction, with added certainty on cost and programme. There are opportunities for the associated approvals to mirror this.

Product-led design and potential savings in design delivery





Question 6

I understand that you had done cost breakdown of the two different approaches for the M25, so if it easier and possible please send this document through.

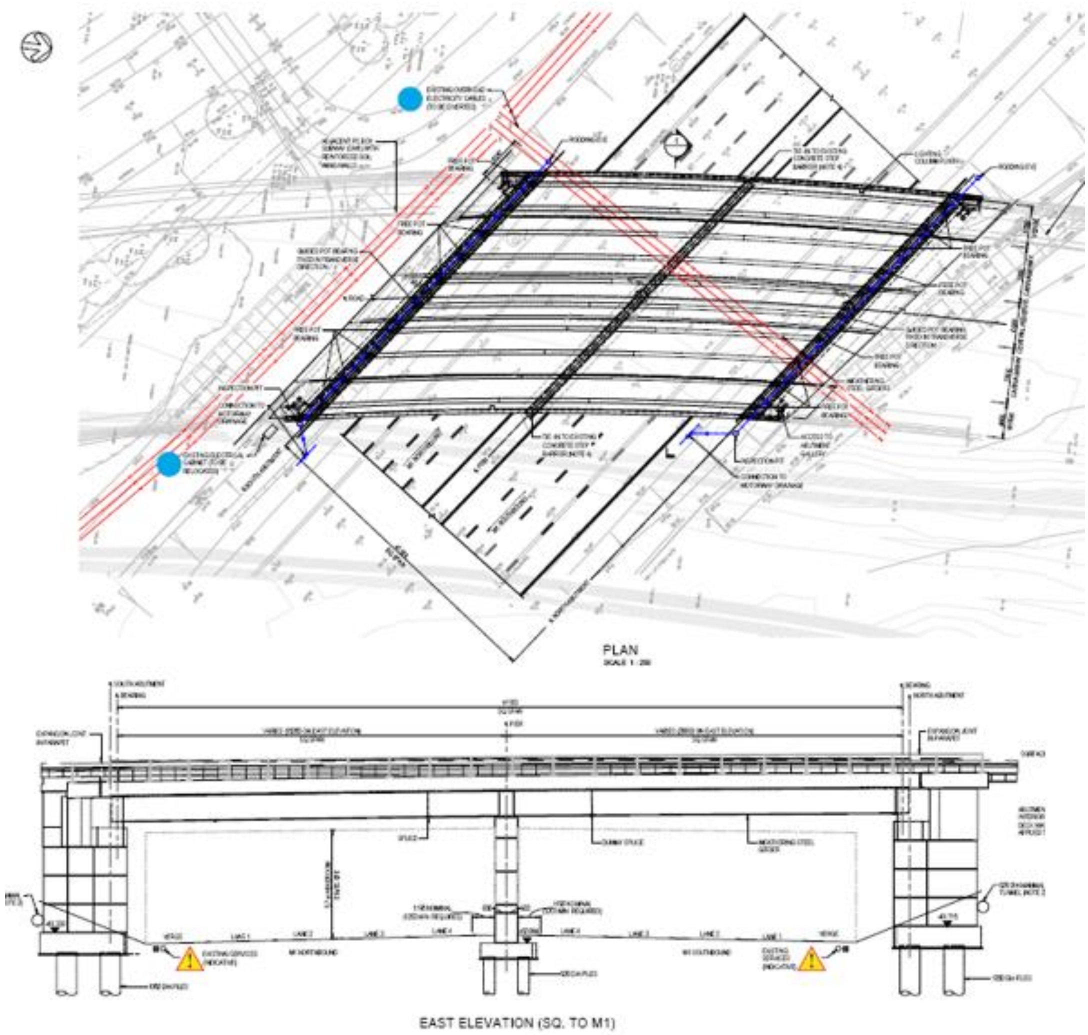
Costing

Expanded is a Tier 2 contractor on the M25 scheme contracted to BBA with a limited scope. To demonstrate the viability of modular schemes we have included one of our most recent conversions of a future National Highways asset from an in-situ to a modular solution on the M1 in Milton Keynes where the scope of works was greater.

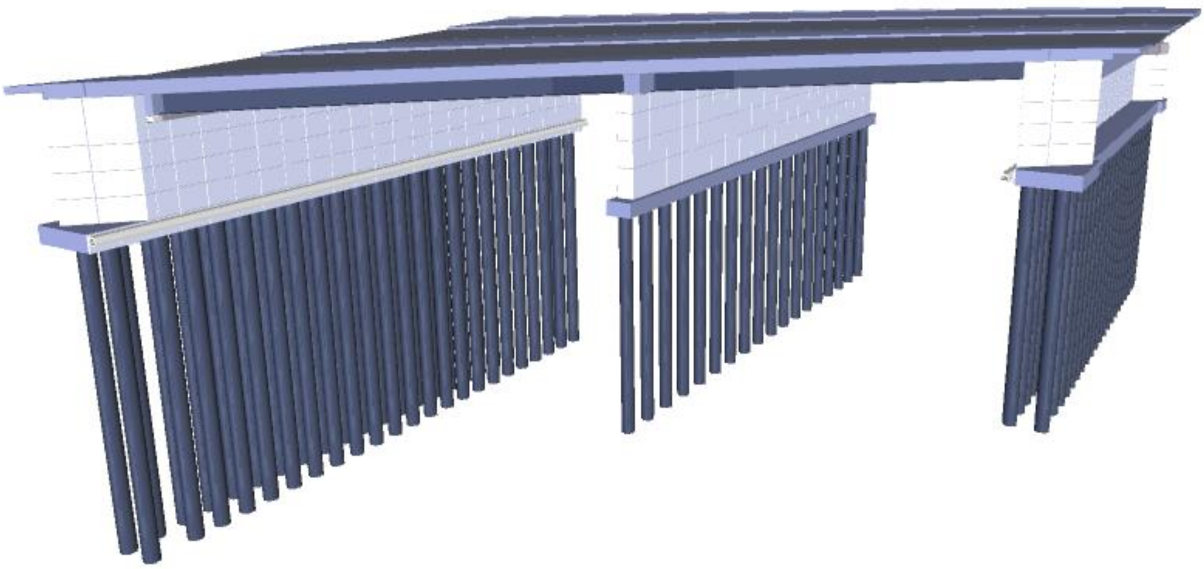
Milton Keynes M1 Bridge Study

The proposed structure is a two-span articulated modular bridge structure over the M1 near Milton Keynes, where we had a wider delivery scope and priced both the conforming design and the MMC converted option. Both the MMC conversion and original design were developed by WSP for consistency. The cost advice below was given by Expanded with programme savings (Expanded preliminaries) applied and **48 weeks less of traffic management** than the original confirming proposal. The modular solution will provide a massive benefit to users of the M1.

Plan and elevation of the M1 bridge



3d Model of the M1 bridge



Expanded Cost Advice (Project Specific)

Item	Modular vs. Traditional Variance	Comment
Series 600 Earthworks	3% savings	Raised pile caps reduce bulk excavation and eliminate sheet piling
Series 1700 Concrete Works (FRC only)	1% more expensive	Higher material cost and design conversion costs
Preliminaries	28% savings	Programme Reduction and Traffic Management saving
Total	5% savings	

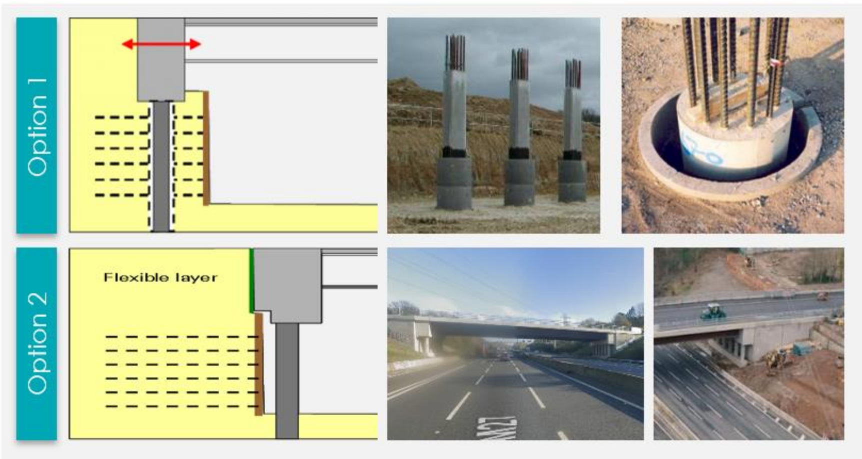
This cost advice demonstrates that while the material costs of the modular solution can be marginally higher, the solution's impact on the wider scope, such as the associated earthworks and temporary traffic management, creates opportunities for overall scheme savings. For example, the conversion on the M1 bridge raised the pile caps to eliminate more expensive excavation and reduced the number of lane closures required to construct the central reservation pier. The preliminaries saved on our scope reported in the table do not consider the wider savings on the entire scheme for the client which are a further benefit on the scheme. The figures do not yet consider any quantification of benefits for the road users (reduced construction time and delay) either.

Next Steps in Innovation – Modular Precast Flexible Abutments

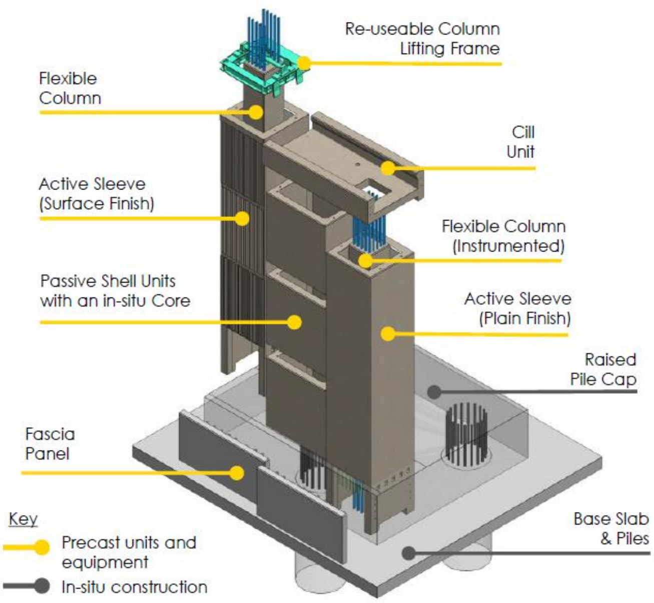
Following a successful demonstrator at CEMC, we are looking to deploy the modular precast flexible abutment on a pilot project as a first of a kind solution. The information below describes the principles of using a product driven solution to construct flexible abutment bridges. The target range of application is for single and multiple span integral bridges with crossing lengths between 30 – 100m and steel or concrete beams. Standard integral bridges of this length generate excessive forces behind the abutments due to the effects of soil strain ratcheting brought about by thermal expansion and contraction of the deck.

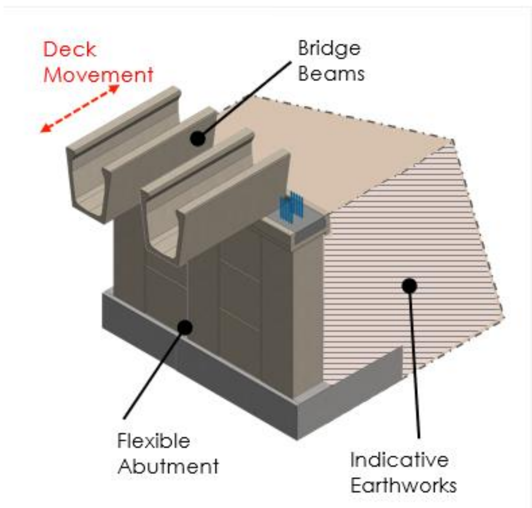
The challenges with current flexible abutment systems (option 1 & 2 in the image[v]) include:

- The need for separate structures on separate foundations to isolate earthwork retention from vertical bridge support (alleviates soil strain ratcheting)
- Typical solutions use reinforced earth wall solutions which are lightweight but slow to construct
- Difficult, if not impossible to inspect the vertical supports if they are encased by earthworks
- The earthworks need to be raised up to the top of abutment level to build the diaphragm and deck, otherwise significant temporary works are needed. Therefore, the earthworks and structures programme are interdependent.



The modular precast flexible abutment, as shown in the diagram below, uses a kit of parts to form a combined support structure and retaining wall for the bridge on a common foundation to address these problems and provide a safe, efficient and rapid DfMA solution. The kit of parts includes a full height precast sleeve (active sleeve), precast flexible columns, precast shells (passive shell units) and precast cill units.





By allowing the column to 'flex' or 'sway' freely in the sleeve without engaging the backfill, the system alleviates the soil-structure interaction effects of long-span integral bridges. The columns still provide a load path from deck to foundations through an in-situ diaphragm cast on the precast cill which sits above the abutment wall. The sleeves and precast shells between the columns provide the retaining function for the structural backfill.

Importantly, the solution decouples the structure programme from the earthworks allowing the works on the critical path to proceed as needed. For example, the solution allows the deck to be constructed before backfilling. The opposite is also possible, the backfill can be lifted to the top of abutment level before the deck is installed because the precast components form a full height retaining wall.

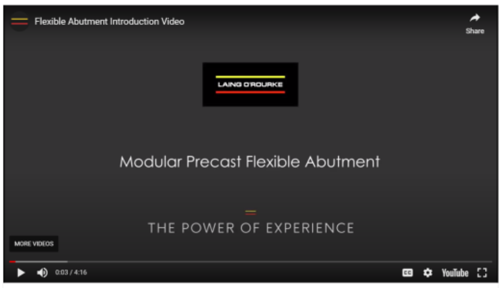
The precast solutions can incorporate inspection access points to allow the condition of the columns to be viewed using non-destructive methods.

Above ground pile caps can be installed to reduce earthwork operations with the novel use of a fascia panel as permanent formwork.

The solution integrates temporary works into the design to drive engineered safety, increase installation speed, and reduce the size of team and the variety of different skills required for installation.

The QR code below is a link to a video of the construction trial at CEMC in June 2022.

Scan for video



Relevance to M25

Abutment Assembly	Op-weeks
Traditional Flexible Abutment	70
Modular Flexible Abutment	24

65% Reduction
(per abutment structure)

Structure only. Assumes a team of 10 for 7 weeks (traditional) vs. a team of 6 for 4 weeks (modular)

Building on the success of the physical trial, a comparison study is underway to review the novel precast flexible abutment against the traditional retained soil wall abutment solutions being built on the M25 Junction 10 scheme.

The case study uses the Cockcrow Green Bridge, a part of the M25 Junction 10 scheme, as a baseline which will be tracked through construction to provide a robust comparison for cost, carbon, and programme. The first part of the review using the trial data and the M25 detailed design information predicts the following benefits for the DfMA approach for the whole bridge:

- Overall cost savings of 5%
- Reduction in overall bridge programme by 12 weeks
- Reduction in overall construction scope carbon by 13%
- 65% reduction in operative hours for abutment construction.

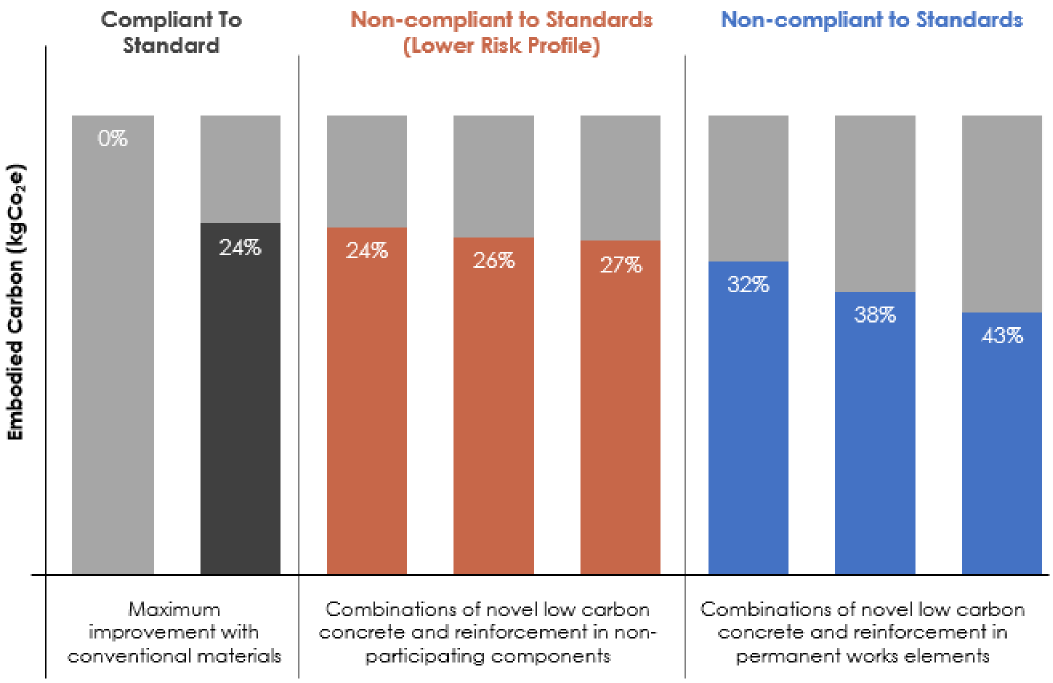
The study is yet to be finalised and includes assumptions that will be validated using site data which will start being gathered when construction of the bridge starts in Q4 2023.

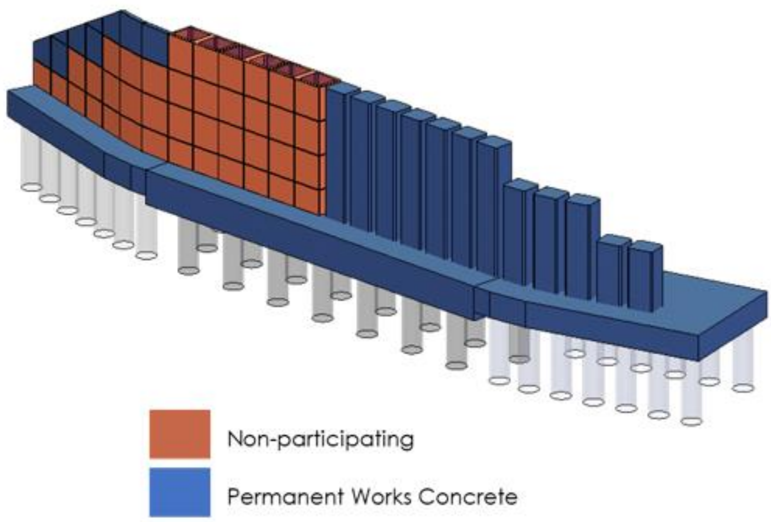
The solution was developed after the M25 J10 design stage. **It is now ready to be deployed on a pilot project. We are actively seeking opportunities to do so.**

The solution has received positive feedback from National Highways representatives that visited CEMC in November 2022, and April 2023, as well as the bridge engineering specialists from HS2 in January 2023. The feedback does not constitute endorsement/pre-approval. Any deployment will be required to follow the due process required by the Overseeing Organization on the chosen project.

Next Steps in Innovation – Decarbonising Precast

Research is underway to achieve our goal of achieving *NetZero concrete* in our products. We are exploring the use of low carbon concrete mixes and alternative reinforcement materials in both the precast and in-situ works. The image below shows a technology roadmap by combining different materials in a staged approach (managing risk) to remove 40% of the carbon in a 400m[2] abutment constructed in 2020.



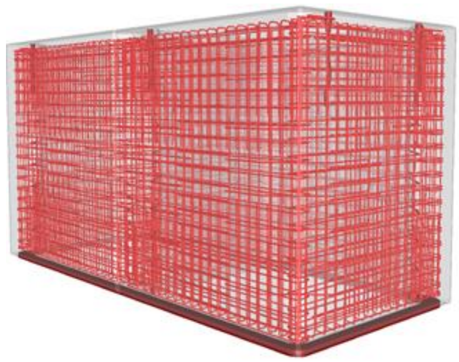


Trials are currently underway to incorporate nonferrous reinforcement into the standard precast shell design as an alternative to steel reinforcement. In addition, the use of low carbon cement replacements in the precast shells and manufacturing process are being trialled with destructive tests planned for Q3 2023 at the Building Research Establishment (BRE).

Because the precast shells are non-participating elements in the permanent works, they are considered to be the right risk profile to trial newer technologies and create a steppingstone to using these technologies on the rest of a bridge structure.

We are also installing instrumentation within some of our units to map real load conditions and performance back to the design, creating a feedback loop that should drive more efficient products.

(Left to right) Low carbon reinforced shell, non-ferrous reinforcement bars at CEMC, Instrumentation in shells



Relevance to M25

The M25 design phase is closed, and the introduction of new technology in the precast is not possible at this stage. However, structures on the M25 are being instrumented in several studies to inform future design practices for the bridges and components.

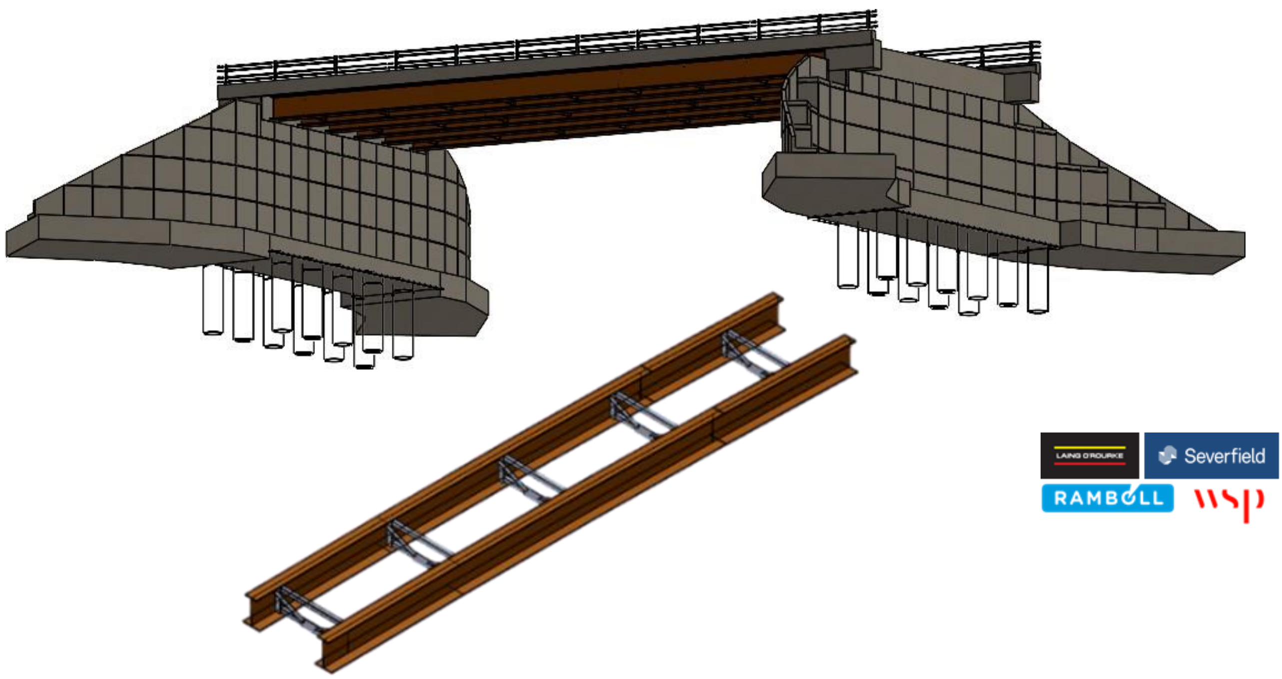
Next Steps in Innovation – Digital Toolkit Expansion

The development of the toolkit in conjunction with the precast kit of parts for bridges was supported through a successful innovation partnership with National Highways. The project, called Digitally Enabled and Assured Product Based Bridges, required strong collaboration across multiple organisations including Ramboll, WSP, National Highways, Solid Solutions and the internal Laing O'Rourke functions.

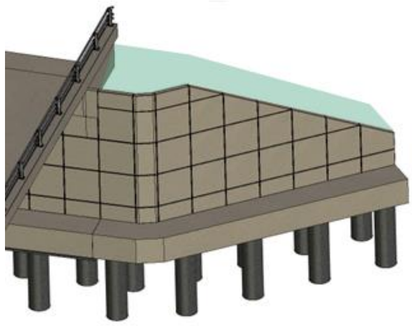
The current version of the digital bridge configuration tool can quickly develop preliminary designs for integral bridges with precast prestressed concrete beams up to approximately 40m in length with skews of 30 degrees. The tool is developed further to enable rapid configuration of a wider range of bridge types including steel beams and multiple spans with use of the modular flexible abutment components, among other updates.

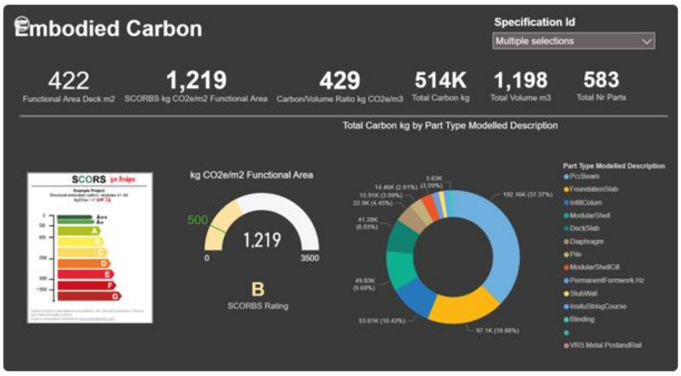
Current toolkit capabilities

Steel Girder Bridges (and project partners)



Added wingwall options and automation of cost, carbon and programme data





Relevance to M25

The use of the toolkit combined with better routes to early engagement will help to speed up optioneering and design for future schemes.

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[i] https://nationalhighways.co.uk/our-roads/south-east/m25-junction-10/
[ii] Design for Manufacturing and Assembly (DfMA)
[iii] https://hs2insolihull.commonplace.is/proposals/improving-the-local-road-network-in-the-interchange-area
[iv] https://www.concretebookshop.com/tg17-precast-concrete-substructure-for-bridge-construction-4519-p.asp
[v] https://www.steelconstruction.info/Integral_bridges