SMART AND SUSTAINABLE BRIDGE ABUTMENTS - A CASE STUDY

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Abstract- The use of off-site manufactured (OSM) elements is increasing in the Construction industry due to its benefits in terms of cost, site labour and speed of construction. It is commonly acknowledged that off-site production also offers other advantages, that are less evident, but still bring significant improvements on both Health & Safety and Sustainability if compared to more traditional in-situ construction methods. The aim of this paper is to explain how the design and use of OSM reinforced concrete abutment panels contributed to a smarter delivery of the A34 new Overbridge in Perry Barr, Birmingham, UK. After describing the site and project specific constraints, the paper shows the options considered for the new bridge abutments in the early design stages and the factors that contributed to the final choice. Details of the definitive solution are then illustrated with a focus on Health & Safety and Sustainability improvements. The paper then highlights a few key aspects that were considered in the design to ensure accurate production in the factory and efficient assembly on site for the abutment panels. The conclusion then summarises the direct and undirect savings and benefits that the use of OSM abutment panels brought to the project.

Keywords- off-site manufactured (OSM), bridge abutments, embodied carbon, sustainability.

1 Introduction

Modern methods of construction describe different techniques of industry which differ significantly from traditional construction approaches [1,2]. These new techniques include various concepts like novel construction, off-site manufacturing, and pre-fabrication [3]. All these techniques provide opportunities of continuous improvement in the processes of construction industry. This results in reduction of waste and offers improvement in sustainability indicators. Offsite manufacturing includes manufacture and preassembly of elements before execution on a site and is considered as one of the techniques of modern methods of construction [5]. In the study by Davies, 2013[4], it was described how the lack of repetition of end products in the construction industry as compared to other sectors makes off site manufacturing more challenging. There are many benefits of OSM technique which include better quality of product, lower costs, faster construction and reduced labour reworks on site [1]. In addition, OSM technique with reduced site activities also helps to overcome restrictions associated with difficult sites and reduces wastes up to about 90% [6,7,8].

In this paper a case study is considered to explain the benefits of use of OSM abutment units. The case study is based on design and construction of a new overbridge in Perry Barr, Birmingham, UK. Perry Barr is located approximately 4 miles north of Birmingham city centre. The area covered by this scheme is located along the A34, which is part of Birmingham's Strategic Highway Network and provides a key arterial route from the M6 motorway and Walsall into central Birmingham. The aspiration of Birmingham City Council (BCC) was to deliver a programme of infrastructure improvements at Perry Barr to support regeneration of the area.

In section 2 of this paper, it is explained which methodology was used to decide the geometry of OSM abutment units at design stage. Then in the following section, the outcome of final geometry for OSM abutment units is discussed. In the last section, benefits of use of novel OSM abutment units are concluded.

2 Challenges

Implementation of OSM techniques as compared to conventional form of construction poses many challenges. In this case study for a new overbridge in Perry Barr, there were a number of constraints. These included construction of bridge foundations in close proximity to existing structures, strict traffic management restrictions and a tight construction programme. The new bridge had to be designed and subsequently constructed within the limited area enclosed by two existing overbridges and retaining structures. Most of the construction works also had to be undertaken while the junction was operating as per BCC requirements and only occasional lane closures were allowed. Figure 1 below shows a photograph that was taken during the OSM abutment units installation.

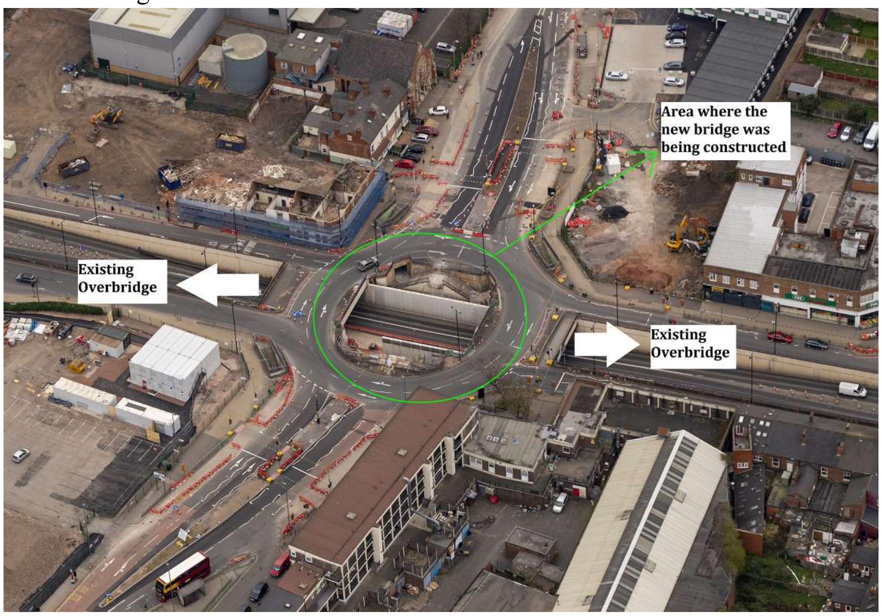

Figure 1 – Construction site for the new overbridge.

During the Design & Build tender process, in-situ reinforced concrete (RC) abutments on piled foundations had been considered because of the limited information available. During detailed design, on availability of more information, options for OSM abutment units were explored. The key driver for this was the need for ease and speed of construction on one side, and the will to provide a sustainable and innovative solution. The final proposal for the new bridge abutments consisted of OSM RC leaf abutment panels. The original abutments were 1.20m thick and required a series of in-situ concrete pours, while the panels were slimmer and totally precast, which was an added value as they could save time and eliminate risks associated with fixing rebar and concrete casting. As the abutment stiffness is key in the load distribution of integral bridges, a reduced 0.50m thickness was investigated by implementing a preliminary 2D frame model. The subsequent ideas of backfilling the substructures with no-fines concrete and using a void former at the back of the abutments to create a gap also helped reduce the horizontal pressure in favour of a 0.50m thickness.

To finalise the geometry of the OSM abutment units and to decide their width, two main aspects were considered. These included limiting the self-weight of any element to 23 tonnes, due to site lifting constraints, and the type of superstructure, which consisted of 25no. MY5 prestressed beams with 150 mm solid deck cover slab. Figure 2 shows the geometry of a standard unit of pre-cast abutment.

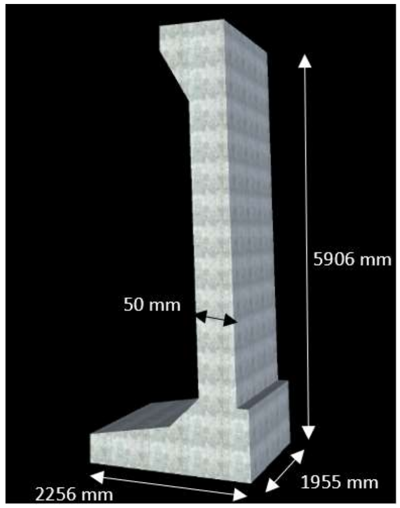

Figure 2 – Pre-cast abutment, standard unit.

As expected, the revised abutments type reduced the amount of moment being transferred to the foundations because a lower stiffness attracts less moment. At that point it was decided to evaluate spread foundations as opposed to piled foundations, since the existing bridges, adjacent to the new structure, sit on spread foundations, suggesting good ground conditions. It was also found that contemporary photos, originating from construction in 1961, show rock cuts in the existing ground and confirming suitability. Spread foundations would be cheaper, quicker to build and less disruptive, hence more sustainable. In Table 1 and accompanying Figure 3, key challenges encountered in the selection of OSM abutment units' spread foundation and resolutions are listed. Figure 4 shows a 3D view of the new bridge.

Table 1 – Challenges and resolutions to enable use of spread foundations.

Challenge	**Our resolution**
Keeping the total vertical action acting on the foundation within its middle-third.	- It was ensured that bending moment being transferred to the foundations was determined appropriately. By applying a full rotational restraint at the base of 2D frame, the bending moment value was overestimated. - Methods for factoring soil stiffness into Finite Elements (FE) bridge models were found. The method proposed by E.C. Hambly in 'Bridge Deck Behaviour' considered to be suitable and considered. - A sensitivity analysis was carried out by using half and twice the provided Young Modulus. - Values of moment and axial force were used that maximised the eccentricity.
Bridging over the existing 1830mm sewer pipe with spread foundations.	- To ensure spread footings could bridge over the existing 1830mm pipe, an in-situ continuity slab at the back of some precast units over the pipe was considered. - Checks were carried out to assess how many units were required to be stiffened, based on a 2D analysis, to help spreading the load from the superstructure onto the areas either side of the pipe.

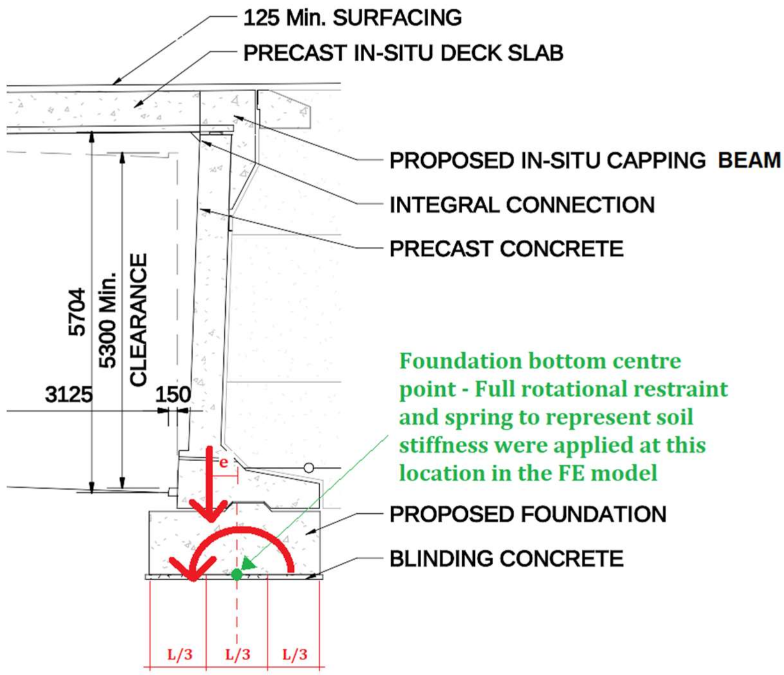

Figure 3 – Main actions being transferred to the foundations.

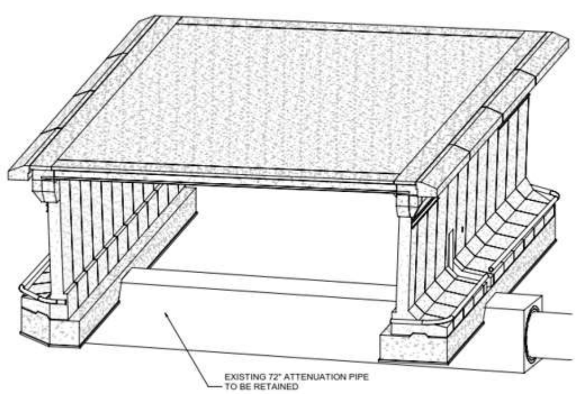

Figure 4 – Bridge Revit model

3 Results and implementation

Following continuous engagement with the contractor, understanding of the site constraints and completion of feasibility checks, the geometry of the OSM abutment units was finalised. The width of standard units was 1955mm and the height of all the units was 5906mm.

Considering the constraints within the site area, 4 different types of OSM abutment units were developed:

1. 19no. Type 1 standard units.
2. 1no. Type 2 unit with an opening to retain access to an existing pump room.
3. 2no. Type 3 units with a corbel on the side to fit the width of the bridge deck required.
4. 2no. Type 4 units with a corbel on the side and a tapered base to fit within existing structures.

Figure 5 below shows the position of the different types of OSM abutment units within the new bridge, while Figure 6 summarises the main construction stages for the new bridge.

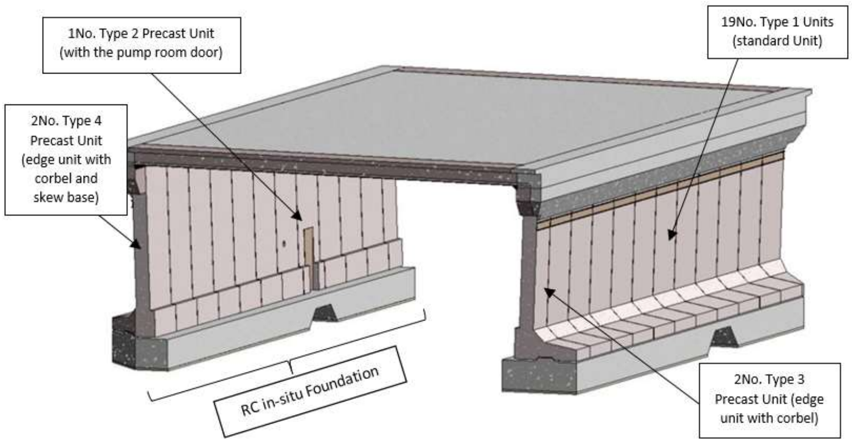

Figure 5 – New bridge, OSM abutment units.

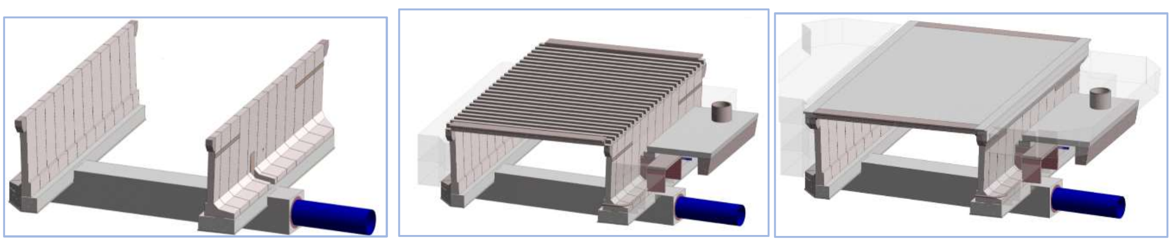

Figure 6 – New bridge, construction stages summary.

The comparison between in-situ concrete abutments and the OSM abutment units was carried out and it was found that the OSM option is a more sustainable solution. They are an environmentally friendly solution, with minimal waste during manufacture and reduced carbon emissions compared to in-situ concrete. Figure 7 shows the comparison between the embodied carbon emissions for traditional in-situ abutments and OSM abutments for the specific case of the new bridge in Perry Barr. In order to determine the carbon footprint for the two solutions, the impact of site machinery, transport to site and labour was considered. Carbon emissions for these three aspects were calculated based on fuel consumption by considering specific mileage for transport and labour and time usage of site machinery.

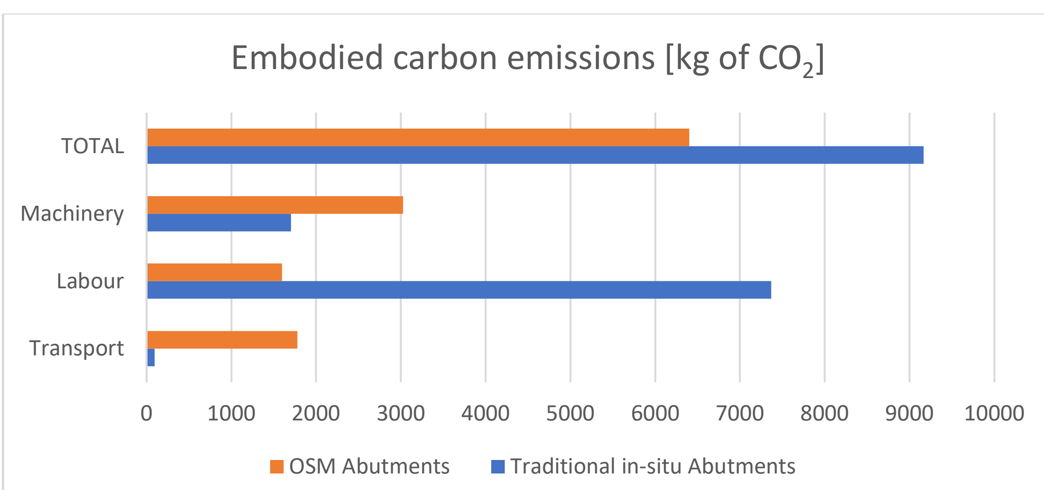

Figure 7 – New bridge abutments, embodied carbon emissions in-situ vs. OSM [Data courtesy of Tarmac]

From a social impact point of view, the time spent in placing these units and disruption to local traffic were considerably less than the ones necessary to cast in-situ concrete abutments. The Contractor had an overall time saving of 2 weeks by using the proposed OSM abutment panels. In addition, the OSM panels were installed within 8 night-time road closures as opposed to the 20-night shifts that would have been necessary for in-situ abutments.
The Health and Safety benefits are also worth mentioning. No site operatives were required to climb down into the layby area to fix rebar cages and work next to live traffic. Risks associated with traffic management were significantly reduced and minimised. On the other hand, the use of OSM abutment units added risks associated to the transport of heavy and large elements. These are however smaller in comparison with the ones that have been eliminated and reduced. In addition, they could be safely managed by competent precast concrete manufacturer and contractor. While OSM elements are generally more expensive to manufacture than equivalent in-situ elements, in this case their use saved significant time. This resulted in labour and traffic management cost savings, which outbalanced the increased manufacturing cost and led to an overall reduced construction cost.
When dealing with OSM elements, the design needs to also focus on production in the factory and installation on site, which are both complex stages for the overall construction process. Supporting the production of high quality OSM elements since design stage is key to minimise waste of resources, optimise timescales, achieve higher quality standards and have a reduced embodied carbon for the asset. In this sense, design approach consisted of:

- Getting early precast manufacturer involvement at preliminary design stage to discuss the construction process and ensure all the parties involved understood the construction sequence.
- Making sure the interface between different structural elements, both precast and in-situ, was clearly and correctly reflected in the new bridge drawing set.
- Ensuring concrete outlines and reinforcement drawings for the precast abutment panels were thoroughly checked by different design engineers and issued to the manufacturer as early as possible.
- Checking the fabrication drawings by the manufacturer and clarifying any doubt on reinforcement detailing before production began.

The described approach enabled the manufacturer to better plan the production of the OSM abutment units and, reduced the chances of having delays to the construction programme. As it is generally acknowledged, precast concrete elements achieve higher quality standards than their in-situ equivalents. This is beneficial for the asset future maintenance, that will likely be reduced for precast elements if compared to in-situ, resulting in an operational carbon reduction. The case study discussed in this paper shows as a collaborative approach between the different parts involved in a scheme can maximise the benefits of using OSM elements.
When it comes to installation of OSM elements on site, generally there are significant benefits in terms of Health & Safety, which have been previously described in this paper. Many common risks related to in-situ reinforced concrete can be eliminated by using OSM elements, on the other hand there are risks which cannot be eliminated and need to be carefully managed. In the case of the new bridge in Perry Barr and the OSM abutment panels, these residual risks were essentially related to the potential instability of the panels during installation and construction. The following measures were adopted to proactively address this hazard and minimise the risk of instability:

- The shape of the panels was designed to be stable on their own during construction.
- Holding down bolts were provided as a further safety measure, in case anything accidentally hit one of the panels during the works.
- A shear key between in-situ foundations and OSM units was provided as a precaution against accidental sliding actions during construction.
- A temporary steel tie at the back of the 3 end units was provided to secure Type 4 units, whose tapered bases would make the 2no. end units unstable if left to stand independently.

Figures 8 to 10 show some key stages of the installation of the OSM abutment panels.

Figure 8 – Installation of OSM abutment panels, preparation [Photo courtesy of Tarmac]

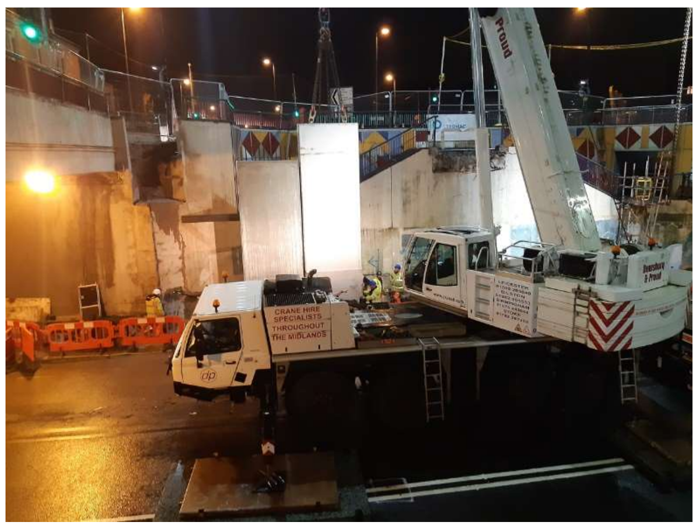

Figure 9 – Installation of OSM abutment panels, panel positioning [Photo courtesy of Tarmac]

Figure 10 – Installation of OSM abutment panels, back view of the panels [Photo courtesy of Tarmac]

4 Conclusion

The case study discussed in this paper for use of OSM abutment units presented several challenges at design and construction stages. The application of strong engineering principles together with great construction capabilities ensured the successful delivery of the new bridge in Perry Barr with an innovative type of OSM abutments. The OSM abutment units represent a solution that, compared with traditional in-situ substructures, is safer and more sustainable due to:

1. OSM abutment units having 34% lower embodied carbon footprint for the new bridge as compared to traditional in-situ construction.
2. The Contractor being able to reduce construction time by approx. 2 weeks by using OSM abutment units.
3. Installation of OSM abutment units being carried out in 8 nights as compared to 20-night shifts for traditional in-situ construction, reducing disruption to local communities.
4. The above reduction leading to reduced construction cost.
5. OSM abutment units carrying a reduced number of risks to Health & Safety associated to production and installation.

The results from this case study showed that the use of OSM abutment units offered great benefit as compared to conventional in-situ construction. This technique needs to be considered and developed for other structural elements in the future.

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