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High Speed Two (HS2)

Infrastructure Design and Construction

Volume 3 Design and Engineering

Foreword

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This is the second opportunity for the designers and engineers working across the HS2 family to capture the innovation and knowledge that is driving the project. This volume is a compilation of HS2's design and engineering papers and represents another exciting moment in our development. The challenges of delivering HS2 are significant as we combine our vision to be a catalyst for growth – nurturing innovation and new jobs, skills and opportunities – with our commitment to building a world-class railway that meets our Design Vision.

The papers collected here demonstrate the level of theoretical and practical complexity and invention needed to deliver a project of HS2's unprecedented scale. We are designing and building a high-speed railway, complete with modern, sustainable stations, to complement the varied contexts, landscapes and geology of the UK. Our collective work is producing outstanding innovations, learning and development across a range of professions.

The range and quality of the submissions for this publication underlines how mega-projects like HS2 foster new industry research, developments and improvements. It is through the diligence, determination and investigative nature of our expert teams that the project will succeed and respond to evolving standards, climate change, advances in technology and societal demands.

The papers in this volume illustrate the vast array of interdisciplinary engagement required to deliver the UK's first high-speed rail network. The subjects range from ground-breaking engineering analysis techniques to innovations in construction. The papers expand on the complex technical investigation and solution development needed for building tunnels and bridge structures, as well as how HS2 can meet stringent noise, wind and environmental targets while minimising our impact on existing infrastructure.

I'd like to thank everyone who submitted papers to the Technical Papers Competition for providing new insights and knowledge, and contributing to the way HS2 is raising the bar for the industry.

Introduction

Britain's new high-speed railway is being built from the South East to the North West, with HS2 trains connecting the biggest cities in Scotland with Manchester, Birmingham and London. Europe's biggest infrastructure project will transform Britain with high speed trains running across new lines and upgrades to deliver fast, reliable, high capacity travel to major towns and cities. The project is being built to the latest engineering and environmental standards using world-class engineering and is already supporting nearly 30,000 jobs across the UK.

This is the third in a series of books capturing the technical excellence and learning from across the HS2 programme. It is published as part of HS2's Learning Legacy commitment to share lessons, good practice and innovation and help raise the bar across the UK's infrastructure industry and to improve future productivity.

The technical papers provided in volume 3 were submitted as part of the HS2 Technical Papers Competition (2022) and include papers categorised as Design and Engineering. Papers categorised as Architecture, Digital Engineering, Environment and Heritage are published in volume 4.

This book provides a brief history of the original London and Birmingham Railway, which opened in full in 1838. It describes how HS2 came about and the phased design and construction of the route between London, the West Midlands and the North. The route as it stands today and the organisational framework, including HS2 Ltd as the client and the delivery partners, are described to provide context for the technical papers.

We hope you enjoy reading about this fascinating programme to construct a high-speed railway fit for the 21st century and built to last into the 22nd century.

We would like to thank all our authors across 22 organisations in the HS2 family and the supply chain as well as more than 50 reviewers who have helped to produce the papers and this book.

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Figure 8. View of dive-under looking south towards Bridge 7

Following inspections, the masonry abutments and retaining walls were found to be in generally fair condition, but with some long-standing defects and evidence of previous movement. However, the bridge deck and pier trestle were in poor condition with many defects, including widespread loss of section due to corrosion, missing rivets, and distortion of the internal girders. The ends of the main girders had been encased in concrete, obscuring the bearings. The north abutment was leaning significantly, and two rows of ground anchors had already been installed (Figure 7).

It was concluded that the bridge was in a fragile state and vulnerable to damage due to any further settlement or distortion imposed by the HS2 tunnelling works. The bridge is critical to Network Rail's operations, as all six Euston lines run over, under or next to it. It was identified as a priority to keep the bridge open throughout the HS2 tunnel construction works, with appropriate mitigation works if required.

A six-week blockade below the bridge between 16th July to 30th August 2021 was booked two years in advance with the plan to carry out any potential mitigation works. The challenge for the bridge mitigation team was then to develop a methodology for logistics, design, and construction of the mitigations during the six-week blockade below the bridge, but with no interruption to the main lines above.

To inform this process, a detailed ground movement assessment was put in hand.

Ground Movement Analysis

Due to the complex geometry of the HS2 works and the sensitivity of Bridge 7, a finite element (FE) analysis using LS-Dyna software was chosen to model the ground movements

Innovative aspects of twin arch solution

The pre-cast twin arch solution employs novel structural connections between elements of the lining to minimise construction duration of a tunnel ring thus increasing efficiency in the construction of a tunnel.

The arch roof section and supporting arch wall unit are connected by an articulated knuckle type joint, referred to as the pin joint (circled in red in Figure 5), free to rotate with no discreet shear connection other than shear interface between the convex and concave concrete profiles of the joint (Figure 6). The form of the joint allows the roof units to be craned into place and sat on the arch wall section of the lining with no need to install shear keys or dowels to connect the units. This allows for a faster construction rate of individual rings for the green tunnel and reduces the planned construction programme for the tunnel lining.

The stability of the arch is generated through development of compressive axial forces through the roof into the arch walls during the backfilling of the tunnel. The compacted backfill generates sufficient axial compression forces to provide stability to the connection under all rotations anticipated for all temporary and permanent construction and operational stages.

The design of the pin joint considers the development of stress concentrations due to different axial forces and rotations under different load combinations throughout the design life of the structure. The analyses of the pin joint captures the non-linear behaviour under different load stages throughout the backfilling operation and during the long-term behaviour of the tunnel lining. The joint has been analysed under critical load combinations including a fire load case for a 170 minute duration fire with maximum temperature of 1200°C. .

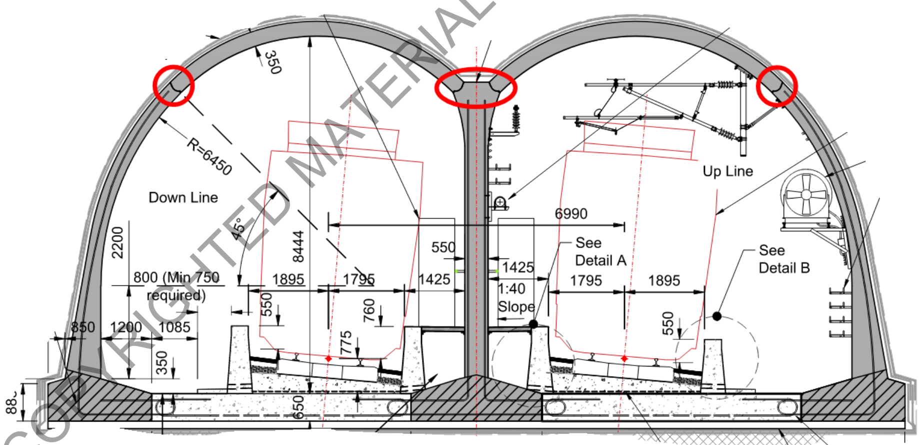

Figure 5. Green Tunnel general arrangement with pin joints circled in red.

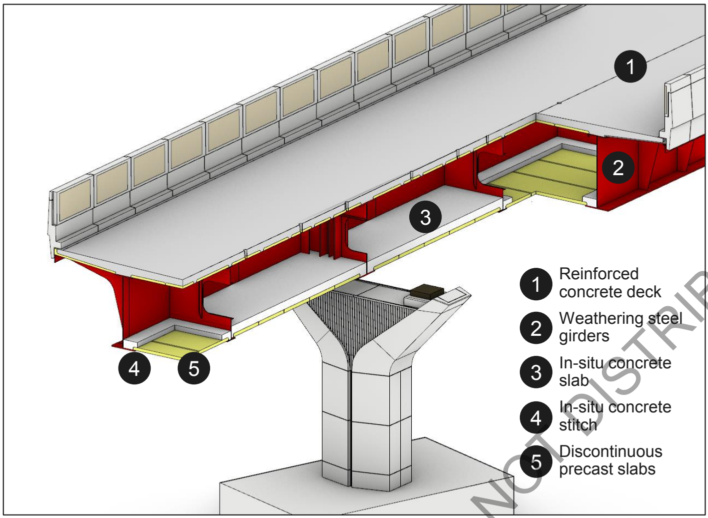

Figure 3. "Strict box" sections along the Small Dean Viaduct's superstructure

From a structural point of view, when compared with the conventional steel-concrete deck, the "strict box" arrangement used for Small Dean Viaduct superstructure, the double composite steel-concrete action along the support regions and the discontinuous precast planks with the in-situ stitch achieves the following main benefits:

- Increased flexural resistance to hogging bending moments
- Enhanced stability for the bottom flange
- Reduced deck deformation and improved dynamic response
- Improved torsional resistance
- Simpler steel fabrication details and increased fatigue resistance.

This results in savings in structural steel, reduction in cross-frame requirements and gains from the additional bracing at midspan due to the bottom precast panels and in-situ concrete stitch. The advantages go further, and additional benefits can be seen for high-speed rail bridges: improved dynamic response (increased damping, heavier deck, enhanced torsional stiffness) and deck end movements due to the increased stiffness; all leading to an increased passenger comfort and a more economical design.
Furthermore, the build-up of steel girders and concrete slab result in a closed box section that brings additional benefits such as:

- Creates a suitable enclosure for services or for the bridge's drainage system. At Small Dean Viaduct the entire drainage system is hidden inside the box to enhance the structure's appearance. This also simplifies the maintenance and inspection of the drainage system.
- The double composite box structure creates less noise as it limits the re-radiant noise coming from wheel-track induced vibrations.