High Speed Two (HS2)

Infrastructure Design and Construction

Volume 2

Other titles in the High Speed Two (HS2): Infrastructure Design and Construction series:

High Speed Two (HS2): Infrastructure Design and Construction. Volume 1 - Design, Engineering and Architecture (2022)
High Speed Two. ISBN 978-0-7277-6576-5

ice
Institution of Civil Engineers
Publishing

High Speed Two (HS2)

Infrastructure Design and Construction

Volume 2 Digital Engineering, Environment and Heritage

Published by ICE Publishing, One Great George Street, Westminster, London SW1P 3AA.

Full details of ICE Publishing representatives and distributors can be found at:
www.icebookshop.com/contact.aspx

Other titles by ICE Publishing:

High Speed Two (HS2): Infrastructure Design and Construction. Volume 1 - Design, Engineering and Architecture
High Speed Two. ISBN 978-0-7277-6576-5

Crossrail Project: Infrastructure Design and Construction - 5 volume set
Crossrail. ISBN 978-0-7277-6424-9

Ground Vibrations from High-Speed Railways: Prediction and Mitigation
Victor V. Krylov (ed.). ISBN 978-0-7277-6379-2

www.icebookshop.com
A catalogue record for this book is available from the British Library

ISBN 978-0-7277-6578-9

Cover photo: High Speed Two

Commissioning Editor: James Hobbs
Production Editor: Madhubanti Bhattacharyya
Marketing Specialist: April Nagy
Typeset by The Manila Typesetting Company
Printed and bound in Great Britain by ESP Colour, Swindon

Contents

Heritage and archaeology papers

Foreword

Dr Sonia Zahiroddiny

HS2 Head of Digital Engineering

Digital engineering is changing the way the industry designs and delivers rail and construction projects. As the largest infrastructure programme in Europe, we have a responsibility to lead and set new standards in digital transformation within the industry. To this end, we have set ourselves an ambitious challenge: to be the first to develop and deploy a digital twin of the UK's high-speed rail network.

Our technical papers competition, still in its infancy, has been a great success and I'm delighted that a quarter of all papers submitted were building information management (BIM) and digital engineering themed. The quality of papers has been outstanding with wide-ranging topics that set out exemplar approaches in the adoption of digital engineering in various disciplines. It's fantastic to see the vital role that digital and data are playing in delivering HS2.

This annual competition, open to both HS2 Ltd teams and our supply chain, is a great way to recognise and celebrate our combined achievements and highlight some of the technical challenges to ensure we remain focused on pushing the industry forward.

HS2's digital engineering team take great pride in our innovative approach and fulfilling our strategic commitments to leaving a digital legacy for the industry. I hope you enjoy reading the papers in this volume and find the content relevant and stimulating.

Peter Miller

HS2 Environment and Town Planning Director

Environmental matters have never been as important with the way we manage climate change and nature recovery vital for our future livelihoods. HS2 is a new railway that will enable people to travel super efficiently. Zero-carbon, end-to-end journeys are in prospect and HS2 will make its mark, helping to combat the effects of climate change and enable people to travel well.

We know our plans affect the environment, but our knowledge and vision also recognises our heritage, the places where people live and a landscape that supports biodiversity. We have an obligation to plan and build a new railway that works well for everyone. HS2 provides the opportunity to develop new ways to protect and enhance the environment so everyone will benefit in years to come.

The technical papers in this volume highlight the depth and breadth of our environmental commitment to plan and build better. The knowledge we are gathering will lead to new standards and specifications that will be shared and adopted on projects elsewhere to benefit other people and the environment. As part of this process, the HS2 Technical Papers Competition showcases how we are pushing the boundaries and our willingness to innovate and fulfil our environmental obligations.

All competition submissions are winners in my view and this publication will no doubt spark thoughts and innovation from others in due course. None of us has a monopoly on good ideas, but the power of collaboration demonstrated throughout this competition by colleagues at HS2, our supply chain and academia show how we can make a difference.

I'd like to thank everyone who has contributed. You've set the bar very high indeed and your papers will no doubt be an inspiration to those reading your words.

And to those of you in the HS2 family who are about to come up with the next great idea: sharpen your pencils, fill your pens or get your keyboard ready for HS2's Technical Papers Competition 2021.

Introduction

HS2 is Britain's new high-speed, low-carbon railway, designed to increase capacity on the national network and help rebalance the economy. HS2 is transformative: it is Europe's biggest infrastructure project and has already supported 16,000 jobs. The Project, which is being delivered by HS2 Ltd, is set to support 22,000 jobs during construction of the Phase One route between London and the West Midlands. Phase 2a will extend HS2 to Crewe and Phase 2b will take the railway to the North.

The technical papers provided in this Volume 2 book were submitted as part of the bi-annual HS2 Technical Papers Competition (2020) and include papers categorised as Digital Engineering, Environment and Heritage. Papers categorised as Design, Engineering and Architecture are published in Volume 1.

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

We would like to thank all 180+ authors across 21 organisations within the HS2 family and the supply chain and more than 40 reviewers who have helped to produce the papers and this book.

Aileen Thompson, Director, Communications and Stakeholder Management

Chair, Learning Legacy Oversight Panel

learninglegacy@hs2.org.uk

The HS2 programme

History of the railway

In 1838, when the first trains started running between London and Birmingham, the 112-mile journey took more than five hours. In 2038, two centuries later, High Speed Two trains travelling up to 225mph will take passengers between the same two points on a map in just 45 minutes. The technology has changed radically since the reign of Queen Victoria, with electricity and aerodynamics replacing steam and pistons. Yet there are common threads that unite these landmark railway projects of the 19th and 21st centuries.

HS2, like its predecessor, the London and Birmingham Railway, is at its heart an economic project. The trains, the tracks, the tunnels and the speed are enablers of economic growth. Speed is not an end in itself; it is an agent for change. Time after all is a precious commodity and high-speed travel raises the possibility of "buying" time. If we spend less time travelling – in trains, cars or buses – we have more time to work, to socialise, to live and to flourish. With 345 miles of high-speed track extending to Crewe, Leeds and Manchester, and integrating with the classic network, HS2 will serve more than 25 stations including Glasgow and Edinburgh in Scotland, Liverpool in the North West and Newcastle in the North East.

The national scale of HS2 means opportunity will be unlocked across the country, particularly in the cities and towns of the Midlands and the North. Alongside other projects such as Northern Powerhouse Rail and Midlands Connect, HS2 will help to realise the long-held ambition of rebalancing the British economy, combatting stark regional inequalities in productivity and opportunity that are in part due to rail infrastructure designed for a different age. HS2 will be the backbone on which this transformation will be built, helping Britain to unshackle itself from the last millennium and build anew.

The conception of HS2 began at the turn of the 21st century as population growth and economic expansion was putting the rail network, largely built in the 19th century, under huge strain. A decade after rail privatisation in 1997, passenger journeys soared to 1.13 billion – a 40% increase over a decade before[1]. According to Network Rail at the time, "all credible current projections point to similar growth over the next decade". Iain Coucher, Network Rail's chief executive, argued: "By 2025 many lines will be full up, especially those running to and from the north and west of London." [2]

Major infrastructure investments to address overcrowding included the £8.76 billion modernisation of the West Coast Main Line between London and Edinburgh via Birmingham, which was completed in 2009[3]. However, such interventions were part of the traditional strategy of patching and mending the old infrastructure. They were not going to deliver a transformative, long-term solution for the congested network.

[1] Network Rail press release (23 June 2008) https://www.networkrailmediacentre.co.uk/news/meeting-the-capacity-challenge-network-rail-looks-at-the-case-for-new-rail-lines
[2] Ibid
[3] Network Rail Consulting "West Coast Route Modernisation" https://www.networkrailconsulting.com/our-capabilities/network-rail-projects/west-coast-route-modernisation/

The concept of high-speed rail in Britain was part of public discourse due to the ongoing development of High Speed 1 (HS1), a high-speed rail line connecting London with the Channel Tunnel. A study commissioned by the Strategic Rail Authority and conducted by Atkins concluded in February 2003 there was a both a business case and a transport case for a high-speed line between London and the North.[4] This was followed in 2009 by Network Rail's 'New Lines Study' which concluded that the building of a new line was the best answer to providing significant new capacity and that "the strongest and best case was made by making the new line capable of carrying high speed trains."[5]

In January 2009, the Government formed High Speed Two Ltd (HS2 Ltd) to consider the case for new high-speed services from London to Scotland including to develop a proposal for an entirely new line between London and the West Midlands. HS2 Ltd reported its findings in December 2009, and the Government formalised the project in March 2010, publishing a Command Paper 'High Speed Rail'[6] that proposed a core high-speed rail network linking London to Manchester and Leeds via Birmingham. HS2 services would connect directly to other cities in the North and Scotland. Connections to the West and East Coast main lines would enable services to reach additional destinations on the conventional network without passengers having to change trains.

After a decade of design, planning, consultation and securing powers from Parliament, HS2 is being built. For Phase One, which will run between the West Midlands and London, the digging of tunnels, the building of viaducts, the laying of tracks, the delivery of trains and the first live trials lie in the immediate future. Phase 2a, which extends the route to Crewe, achieved Royal Assent from Parliament in March 2021 and enabling works have begun. The Government is considering how best to integrate Phase 2b, which takes the line to Manchester and Leeds, with Northern Powerhouse Rail, the Midlands Rail Hub and other projects to deliver benefits more quickly and efficiently as part of an Integrated Rail Plan for the North and Midlands. In the meantime, HS2 Ltd is proceeding with legislation for the western leg of Phase 2b, which extends the railway to Manchester. A hybrid Bill for the western leg is set to be submitted in early 2022.

The scale of HS2 over-shadows all other national programmes of work in Europe. In recounting the achievements and future challenges of HS2, the term "biggest ever" is frequently used. Much of what has been achieved has meant operating in uncharted territory in terms of design, planning, project management, procurement, environmental practice, public engagement and many other areas of public policy. HS2's team has set new technical standards – from digital engineering, to future-proofed design and engineering, to the environmental mitigations and innovations.

The design, engineering and architecture challenge

HS2's ambition is to set new standards for infrastructure delivery, resilient operations and the passenger experience.

The challenge is significant in terms of scale, technology and the need to adapt as demands and systems improve. We have sought to learn from the reliability and capacity of rail networks

[4] High Speed Line Study, Atkins (2003) https://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/rail/researchtech/research/hspeedlinestudysummaryreport.pdf
[5] Meeting the capacity challenge: the case for new lines, Network Rail (2009), p2
[6] "High Speed Rail" (11 March 2010),

in other countries, such as Japan, and build on the lessons to respond to the longer-term challenges of aerodynamic factors at higher speeds, resilience to changing climate conditions and the needs for maintenance and asset management systems in an emerging age of digital twin technology.

Exemplars such as the reliable European Traffic Control System pave the way, but our ambition is to deliver a railway that is sustainable and faces the challenges of a new era by harnessing technology and design in all their guises, from the benefits of regenerative braking in rolling stock through to BREEAM outstanding architecture and low-carbon energy systems to serve future generations.

The challenge for digital engineering, environment, heritage and archaeology teams

Exponential advances in technology have created new opportunities to collaborate and harness the power of data. With millions of data points yet to be captured, the myriad of design, engineering and construction data will need to be managed, integrated and visualised in a meaningful way, on a scale not seen before. We recognise this is a journey towards an information-centric world; it requires a fundamental shift in ways of working and relies on our supply chains' collective ability to embrace the challenge for a highly complex programme.

The scale of the environmental work at HS2 is staggering. Our assessments and knowledge capital from the first Environmental Statement alone covers 55,000 pages. We will find out more about our past from the largest archaeological excavations ever conducted in Britain. HS2 will leave behind 33 square kilometres of new woodland, wildlife and river habitats along the line from London to the West Midlands, the equivalent of 23 new Hyde Parks across the spine of the country. We are looking to halve the embedded carbon of construction and have ambitions to do more to support the construction industry reach net zero. We'll be publishing our first Environmental Sustainability Report which captures our vison, what we've achieved to date and our specific action plans for the years ahead.

The depth of thinking and our ability to influence design and policy is leading to positive action that will improve our air quality, deliver enhancements for biodiversity, contain noise and clean up our construction sites. HS2 frames a lasting environmental legacy to support the natural environmental and our well-being – and by accounting for climate change, the high-speed railway will enable a resilient and sustainable future for Britain as it develops through the 2030s and beyond.

HS2: phased delivery of the high-speed rail network

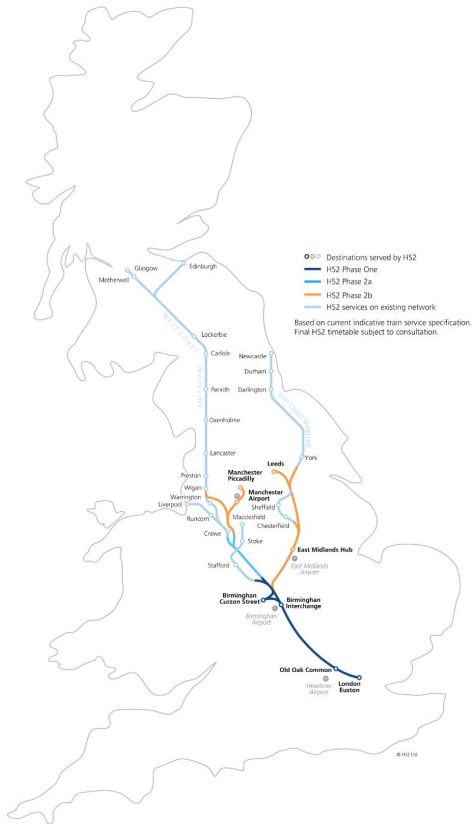

Figure 1: Map of the HS2 line of route

Phase One

The 140-mile Phase One route between London and the West Midlands is being built as the first part of the national high-speed rail network. Construction teams are building hundreds of bridges and viaducts, and creating earthworks for 85 miles of cuttings and embankments. HS2 trains will pass through 32 miles of tunnels between Birmingham and London, delivering quicker journeys and providing more seats. Four new HS2 stations are being built. Phase One has a funding envelope of £35 billion to £45 billion and will open between 2029 and 2033. Notice to Proceed for main works construction was issued in April 2020, marking the point where the Project moved from scheme design and preparatory work to full detailed design and

construction. The first tunnel boring machines for the 10-mile Chilterns tunnel began operating in May 2021.

Phase 2a

The Phase 2a line will extend HS2 from Fradley in the West Midlands to Crewe in Cheshire. The 36-mile route includes two tunnels, 17 viaducts, 65 bridges and 36 embankments.

Services will travel onward from Crewe to places like Manchester, Liverpool, Wigan, Preston and Glasgow. The hybrid Bill for Phase 2a received Royal Assent in March 2021 and the first contracts for early environmental works have been signed.

Phase 2b

Phase 2b forms a Y shape, split into proposed western and eastern legs. The western leg will connect to the high-speed lines at Crewe and run through to Manchester. The proposed eastern leg will connect to high-speed lines in the West Midlands and run through to Leeds. By integrating into the existing East and West Coast main lines, services will also travel onward to places like Glasgow, Edinburgh, Liverpool, Preston, Carlisle and Newcastle. The Government is considering how best to integrate Phase 2b with Northern Powerhouse Rail, the Midlands Rail Hub and other projects as part of an Integrated Rail Plan for the North and Midlands. HS2 Ltd is preparing a hybrid Bill for the western leg to Manchester.

Design and Delivery Framework

The diagram below and subsequent sections set out the organisational structure of the enabling works, main works civils, and main works stations delivered by Integrated Project Teams (IPTs) and Joint Venture (JV) organisations with HS2 Ltd as the client organisation.

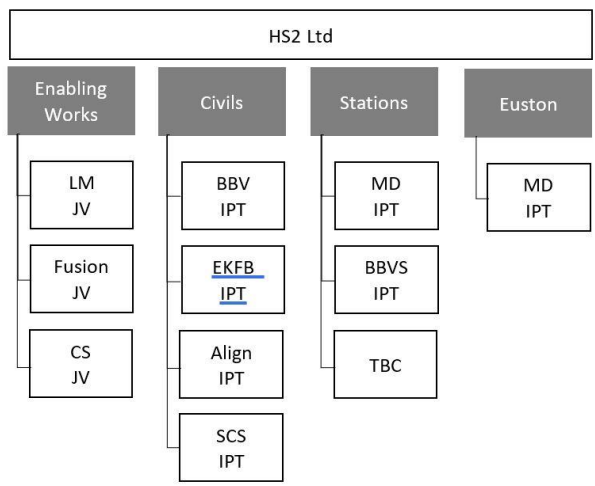

Figure 2: Phase One Contractual Framework

HS2 Ltd

High Speed Two Limited (HS2 Ltd) is responsible for developing and promoting the UK's new high-speed rail network. It is funded by grant-in-aid from the Government. HS2 Ltd is an executive non-departmental public body, sponsored by the Department for Transport.

The company is responsible for procuring and bringing together a supply chain of designers and contractors to deliver billions of pounds worth of contracts, to build, maintain and operate HS2. The company must demonstrate compliance with the requisite technical, safety and environmental standards at all times.

Phase One Enabling Works Contractors

The Phase One Enabling Works Contractors were responsible for preparing the route between the West Midlands and London, ready for the Main Works Civils Contractors to begin building the railway. Phase One enabling works were split into three lots covering the South, Central and North areas of the route, with joint ventures undertaking site preparation works.

As well as archaeology, site clearance and establishing site compounds, enabling works delivered a range of activities including utility diversions, ecology surveys, demolition, ground remediation, watercourse works, highways realignments, monitoring and instrumentation, structural reinforcements and drainage work.

Table 1: Joint Venture organisations delivering the Enabling Works Contracts on Phase One

Joint Ventures (JV)	Enabling Works Contractors	HS2 Contracts
CSjv	Costain Group PLC; Skanska Construction UK	Area South
Fusion JV	Morgan Sindall Construction & Infrastructure Ltd, BAM Nuttall Limited, Ferrovial Agroman (UK) Limited	Area Central
LMJV	Laing O'Rourke Construction Limited, J Murphy & Sons Limited	Area North

Phase One Main Works Civils Contractors (MWCC)

Integrated Project Teams (IPTs) enable integrated delivery and greater collaboration between Main Works Civils Contractors (MWCC) Joint Ventures, Design Joint Ventures (DJVs) and HS2 Ltd. IPTs have been established to deliver works, with clear accountability between client and contractor.

Each IPT is a single, co-located organisation. They are unified with one leader and empowered to make informed, high-quality and timely decisions to achieve aligned objectives. A consistent operating structure underpins each of the four IPTs. However, each is different in scope, risk profile and location.

The MWCCs are the delivery vehicle for the civil engineering works for Phase One. The contracts are split into two-stage, design and build. The Stage 2 contracts feature the delivery of

the civil engineering construction works, following award of the formal Notice to Proceed (NtP) on 14 April 2020. The diagram below shows the geographical marquation of their works whilst the table sets out the organisations involved in each IPT and their contracts which provides context for the papers included in this book.

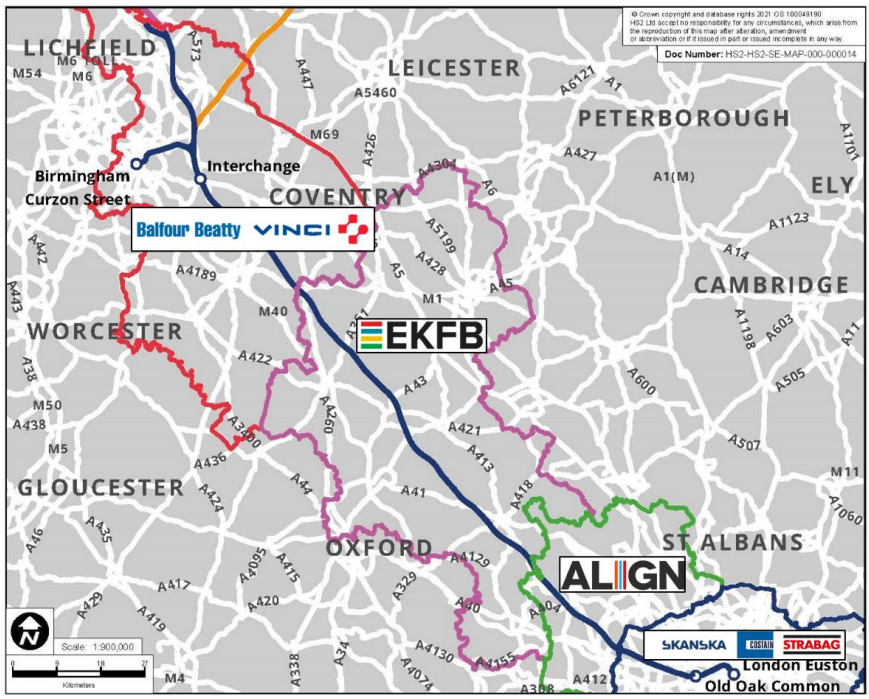

Figure 3: Geographical areas covered by each of the four main works civils contracts

Table 2: Integrated Project Teams delivering the Main Works Civils Contracts on Phase One

Integrated Project Teams (IPTs)	MWCC JVs	DJVs	HS2 Contracts
BBV IPT	Balfour Beatty Group Ltd; Vinci Construction Grands projets; Vinci Construction UK Ltd; Vinci Construction Terrassement	Mott MacDonald; Systra	**Lots N1 and N2** (Area North including Long Itchington Wood Green Tunnel to Delta Junction and Birmingham Spur and the Delta Junction to the West Coast Main Line (WCML) tie-in)

EKFB IPT	Eiffage Geni Civil SA; Kier Infrastructure Oversees Ltd; Ferrovial Agroman; BAM Nuttall	Arcadis; COWI; Sedec	**Lots C2 and C3** (Central Section including the North Portal Chiltern Tunnels to Brackley and Brackley to South Portal of Long Itchington Wood Green Tunnel)
Align IPT	Bouygues Travaux Publics; Volker FitzPatrick; Sir Robert McAlpine	Jacobs and Ingerop	**Lot C1** (Central Section including the Colne Valley Viaduct and Chiltern Tunnels)
SCS IPT	Skanska Construction UK Ltd; Costain Ltd; Skabag AG	Arup and Typsa	**Lots S1 and S2** (Area South including the Northolt Tunnels and the Euston Tunnel and Approaches)

Phase One Main Works Stations Contractors (MWSC)

Phase One Stations is made up of four stations and an automated people mover, which is described below.

Euston

HS2's London terminus integrates high-speed rail connections with conventional rail. High-speed trains will eventually increase the number of peak-time seats out of Euston from 12,100 to 31,200. HS2 Ltd is working with Lendlease, the Master Development Partner for London Euston station, to integrate designs with the requirements of Network Rail and Transport for London to enable comprehensive redevelopment of the Euston estate. This will optimise the new space above the station and tracks and realise opportunities for regeneration of the wider area.

Old Oak Common

This 14-platform rail super-hub in west London features six platforms for HS2 and eight platforms for conventional services, with connections to the Elizabeth Line, the Heathrow Express and the Great Western Mainline. HS2 Ltd is working with the Old Oak and Park Royal Development Corporation (OPDC) on an ambitious vision for the surrounding area – the largest regeneration project in London.

Interchange

Interchange is a four-platform 'through' station with links to Birmingham Airport, Birmingham International station and the NEC. It will be a catalyst for regional economic growth in the Solihull area. Interchange is first station in the world to gain an 'outstanding' BREAAM rating at design stage.

Automated People Mover

A 2.3km automated people mover will provide fast and frequent connections between Interchange station and Birmingham Airport in just six minutes.

Curzon Station

HS2's seven-platform terminus in Birmingham is a key part of regeneration plans for the city centre around Curzon Street, including potential links to the local tram network.

Euston and Old Oak Common Station Construction Partners

The JV and DJV supply chain partners that form the IPT for Euston and Old Oak Common, alongside HS2 Ltd, are as follows.

Table 3: Integrated Project Teams delivering the Main Works Stations Contracts for Euston and Old Oak Common Stations

Station	JV	DJV	Contracts
Euston IPT	Mace Dragados	Ove Arup & Partners International Limited (working with Grimshaw Architects LLP)	S3
OOC IPT	Balfour Beatty Group Ltd, VINCI Construction UK Ltd, VINCI Construction Grands Projects SAS and SYSTRA Ltd	WSP UK Limited (working with Wilkinson Eyre Architects Limited)	S4

Curzon and Interchange Stations Contracts

Curzon Street and Interchange stations and the Automated People Mover (APM) are procuring Main Works Stations Contractors (MWSC) and will co-create their IPTs with their respective MWSC once appointed.

Table 4: Organisations delivering the Main Works Stations Contracts for Curzon Street and Interchange and the Automated People Mover

Station	Construction Partners	Design Partners	Contracts
Curzon Street	Mace Dragados	WSP UK Limited (working with Grimshaw Architects LLP)	N4
Interchange & APM	MWSC award June 2022 APM Contract award 2024	Ove Arup & Partners International Limited (working with Arup Associates and Wilkinson Eyre Architects Limited)	N3

Phase 2a design contracts

The ERD+ team contains a mix of expertise from across all 3 consultancy organisations and works as an integrated delivery team with HS2. It is led by a blended senior leadership team from the consultants who are accountable for owning the ERD+ scope and delivery.

Table 5: Organisations delivering the Phase 2a design and early works

	Construction Partners	Design Partners	Contracts
Phase 2a Employer's Requirements Design (ERD)	N/A	WSP UK Limited, Arup, Atkins, Jacobs, Sener (working with Grimshaw Architects LLP)	ERD+
Phase 2a Early Works	N/A	Balfour Beatty	EEW (Early Environmental Works)

Phase 2b design contracts

HS2 employs the below consultants to develop and assess the proposed Phase 2b Crewe to Manchester Scheme. The Civil Design and Environmental services (CDES) team focusses on the development and environmental assessment of all civils and environmental works, whilst Railway Systems Application Design Services (RSADS) develop the design of all associated railway systems and ensure the operability of the proposed Scheme. The two consultants work collaboratively under HS2's oversight to produce a fully configurated design in accordance with the Development Agreement. EOC (Environmental Oversight Consultant) play a key role in the production of the environmental assessment and work closely with CDES and RSADS to ensure its validity and quality. Balfour Beatty have been awarded the contracts for the early Ground Investigation (GI) work packages and work closely with CDES to ensure the scope of works aligns with HS2's aspirations.

Table 6: Organisations delivering the Phase 2b hybrid bill design and ground investigation

	Construction Partners	**Design Partners**	**Contracts**
Hybrid Bill development	n/a	Civil Design and Environmental services (CDES) Mott MacDonald/ WSP Joint venture	P2b- Crewe to Manchester: 2DE01 (up to hB), 2PT24 for AP1. Contract codes for later APs TBD
	n/a	Railway Systems Application Design Services (RSADS) WSP	P2 – Both eastern and western legs: 2RS02 (up to hB), 2PT25 for AP1. Contract codes for later APs TBD
	n/a	EOC (Environmental Oversight Consultant) Arup+ (Arup, Foster+Partners, Jacobs, Ramboll, Typsa, Costain)	P2 – Both eastern and western legs: 2EV01
GI WP1b and WP2b	Balfour Beatty		P2b- Crewe to Manchester: 2G005 for WP1b and 2G007 for WP2b