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Successful delivery of infrastructure projects continues to depend on several key performance indicators, particularly within the context of sustainability. Upgrading or replacing ageing infrastructure with the state of the art requires efficient project management to ensure sustainable delivery.

In this issue of *Civil Engineering*, Shackman and Climie (2016) describe the planning and procurement of the Queensferry Crossing in Scotland, which will largely replace the 1964 Forth Road Bridge when it opens next May. The project includes the delivery of a 22 km long intelligent transport system to manage traffic through the project corridor – which includes the existing bridge. The paper provides valuable insights into the initial scoping through to the award of the construction contracts for the project.

Similarly, innovative use of space is helping to address future infrastructure development needs around the world. The use of below-ground infrastructure, for example, not only helps to conserve space but it also provides a way of using existing sites more effectively. However, the development of such schemes requires a collaborative project delivery environment to ensure their success.

Luk et al. (2016) present the approach used in developing the Happy Valley underground stormwater storage scheme in Hong Kong. The project, which is designed to alleviate flood risk in the Wan Chai district, involves construction of a large stormwater storage tank under the famous Hong Kong racecourse. It is currently the largest NEC3 target cost contract being undertaken in Hong Kong, and is part of the government’s initiative to adopt NEC3 for all public-sector works.

The use of the collaborative-style contract, an equitable risk-sharing mechanism and a ‘one team, one goal’ approach has ensured close collaboration between the employer and contractor, thereby guaranteeing a successful outcome. Another significant contribution to this issue is the work by Pantelidou et al. (2016), who suggest ways for the UK to achieve its Climate Change Act 2007 targets for 2050 transport emissions more effectively. Transport undoubtedly ranks as a significant contributor to global greenhouse gas emissions and as such any measure to reduce the transport-related ‘carbon footprint’ will always contribute to the overall reduction targets.

The paper presents an approach that evaluates the UK government’s 2013 review of carbon dioxide emissions from infrastructure and looks at the country’s present and projected transport emissions in the context of the transport status quo and plans for growth. From this standpoint, the authors identify an urgent need to rebalance the transport modal mix. They also recommend a smart interface for all modes of the transport system and the implementation of drivers for behavioural change.

Brownfield sites continue to provide much-needed additional capacity for rural, urban and regional development. In our final paper, Latham et al. (2016) report on a challenging project to create a new inter-tidal and freshwater habitat on a brownfield site. Situated in north-east England, the Saltersn wetlands in the Tees estuary floodplain is part of the Environment Agency’s flood risk management strategy for the area. Two years on, the site is proving popular with a wide variety of birdlife as well as reducing flood risk to local communities and industry.

The innovative concepts discussed in this issue are highly commendable in that they each reflect engineering efforts and solutions that address the state of the art. From innovative concepts for managing projects, through reducing greenhouse gas emissions to effective use of brownfield sites, it is evident that civil engineers are constantly at the forefront of defining the ‘new normal’ for sustainable infrastructural development.

**References**


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Aligning systemic infrastructure decisions with social outcomes

In the second article from the Institution of Civil Engineers’ thought leadership programme, Tom Dolan and Ellie Cosgrave from University College London propose a new way to ensure that infrastructure investment delivers the desired benefits for society.

The UK Council for Science and Technology (CST) concluded 7 years ago that, ‘We do not believe national infrastructure can continue on its current trajectory’ (CST, 2009). It said delivery and governance were ‘highly fragmented’ and resilience against systemic failure was ‘significantly weakening’.

The UK government responded by creating Infrastructure UK – now the Infrastructure and Projects Authority (IPA), publishing annual national infrastructure plans and, from this year, a 5-year national infrastructure delivery plan (IPA, 2016a).

It also developed and regularly updates an infrastructure pipeline of over 600 projects and programmes costing £425 billion (IPA, 2016b), and launched a National Infrastructure Commission and a consultation on strategic national infrastructure assessment (Dolan, 2015; HMG, 2016).

Social outcomes missing

But while the approaches yield many potential benefits, we believe they are not yet sufficient to address the CST’s warning. The plans, delivery plans and assessments are at risk of failing to capture the opportunity for infrastructure to enable the broad range of social outcomes we know infrastructure can support.

For example, schools, healthcare facilities and other social spaces are considered outside the scope of infrastructure planning, and look set to be excluded from the scope of the national infrastructure assessment (HMG, 2016).

If our infrastructure planning system artificially separates economic and social outcomes – and the requisite investment strategies – we constrain our ability to develop infrastructure capable of enabling the social outcomes expected.

The proposed new toolkit will deliver a clearer vision of the social benefits of future infrastructure projects at a system level.

Systemic challenge

The need to take a whole-system approach has been recognised in government plans, but what this means in practice is less clear. System problems are shared problems: they are caused by no one party in isolation, and can be solved by no one party in isolation.

System problems emerge as a consequence of interaction between system components – including the political, social and economic context in which they are embedded – and are best managed collaboratively.

As part of its thought leadership programme, the Institution of Civil Engineers therefore proposes developing a systemic toolkit comprising a set of transparent, systemic, structured, interconnected and flexible methodologies. They would cover systemic infrastructure visioning, performance and needs analysis, and option identification and selection.

Proposed methodologies

Our methodology will facilitate vision development. We will also develop a methodology to identify infrastructure system ‘performance gaps’. This will help identify infrastructure needs at the system rather than sector level, and frame need in terms independent of possible options to address the need.

A systematic methodology is then needed to identify possible options for improving infrastructure system performance. Finally, selection criteria to evaluate possible options should link to the established vision, ensuring that infrastructure decisions contribute positively to, or have no detrimental impact on the ability to manage system problems.

Benefits and opportunities

The proposed toolkit, if developed and implemented collaboratively, can support systemic decision making. Potential benefits may include improved capability to manage the risk of system problems, opportunities to innovate in response to needs framed at the system rather than sector level, and societal benefits from explicitly aligning infrastructure decision making with social outcomes.

References


For further information please contact: Tom Dolan Tel: +44 740 340 240 Email: thomas.dolan@ucl.ac.uk
Connected and autonomous vehicles: why civil engineers need to act now

Driverless, interconnected cars are just around the corner – and their impact is likely to be huge. All civil engineers involved in the design and operation of transport infrastructure need to start preparing for their introduction now, says John McCarthy of Atkins.

Driverless cars that talk to each other, otherwise known as ‘connected and autonomous vehicles’ (CAVs), are the future of mobility (McCarthy et al., 2015) – and they are now very close to becoming reality. It is a huge field for innovation worldwide and, as technologies converge, will very soon directly impact on civil engineering.

The world’s existing road networks are based on design principles that will need a major review with the advent of CAVs. For example, how will the use of crash barriers, lane width, and capacity optimisation change as CAVs become prevalent on the road network? Civil engineers need to understand the impact of CAVs from an infrastructure perspective and then decide when changes are needed how the transition will be made.

Risk assessments and methodology will need to be reviewed, while modelling of new vehicle behaviours will ensure that safe and operationally efficient infrastructure is designed. Existing communications networks need to be mapped against future needs, and a complete review of legacy equipment and its capability will identify which infrastructure can be exploited and which replaced, with opportunities for early savings on both.

User experiences and services

The safety case for CAVs needs to be fully understood and the implications and benefits associated with improved work–life balance as well as increased productivity need to be borne out fully. It is imperative, for example, that CAVs do not create a two-tier society.

The needs and requirements of the wider community must be matched against the capabilities and opportunities that CAVs can introduce. Cities and authorities should assess the implications of private and public CAV fleets and how these can be made to work for the benefit of all, rather than the few.

In particular, civil engineers need to understand how CAVs can offer new opportunities for independence to a wide user group, including older people and those with mobility constraints, and the impact this may have on demand.

Optimisation and security

CAVs offer the potential for safer, more reliable transport infrastructure. A reduction in the number of accidents and related injuries can directly improve journey time reliability and customer experience.

However, it is vital network operators understand the value that data transmitted to and from CAVs can bring and, as such, understand the requirements this brings for their utilisation. Vehicles that can talk to each other about their journey, the congestion they experience, and other known data points such as weather, offer a valuable resource to network operators. They need to understand how the new systems can link to legacy ones and the data analytics required to make sense of it all.

In addition, there is a need for authorities to accept that the digital world carries with it a new type of operational risk and, as such, understand how the security of the data transmitted is monitored and continuously assessed in real time. It is no longer enough to sit and wait for the inevitable to take place. Actions must be taken now to protect the travelling public and the services they rely upon.

Modelling and rules

It is clear the implications of CAVs for the wider transport network need to be fully understood. There is no clear understanding of what impact such vehicles will have on network capacity. Will CAVs lead to reduced congestion and optimised use of parking spaces? And will the benefits of this be outweighed by an increased use of vehicles?

Modelling of changes in behaviour and driving patterns needs to be undertaken and benchmarked against real-time deployments to create reliable and quantifiable models that underpin future designs and investments.

A rules engine, complementary to both in-vehicle and network operator management strategies, should be developed. This will help not only to define the benchmarked behaviour of individual vehicles but also to create an optimum starting point for network strategies focused on improved customer experience.

In conclusion, all civil engineers involved with designing and operating transport infrastructure need to start preparing for the CAV revolution now.

Reference

Civil engineers urged to facilitate active travel for all

Civil engineers should do more to facilitate walking and cycling in all infrastructure schemes, says sustainability adviser Kate Cairns. The sustainability and social benefits of ‘active travel’ are highlighted in two recent Institution of Civil Engineers journal issues.

Climate change is accelerating, global urban populations are increasing, obesity is escalating and transport carbon dioxide emissions continue to rise. A paradigm shift in the uptake of walking and cycling could therefore make a significant contribution towards a more sustainable, productive and healthier society.

Some barriers to and benefits of so-called ‘active travel’ are addressed in a recent double issue of the Institution of Civil Engineers (ICE) Engineering Sustainability journal.

Younger generation

Targeting the younger generation is critical: active children are more likely to be active adults. Johnson et al. (2016) investigate the effectiveness of cycle training for children, while Lorimer and Marshall (2016) examine other ‘small-wheeled modes’ already adopted by youngsters – such as inline skating, skateboarding and push scooting.

Gaffga and Hagemeister (2016) widen the scope beyond the traditional cyclist – male, young and fit – to include options for the elderly, less-abled or those with goods or children to carry. They show barriers to the use of tricycles and cycles with trailers.

Providing evidence

The benefits of active travel apply to the whole population, not just the participant. More and better tools are being developed to measure such benefits, with increasingly sophisticated cost–benefit analyses. These conclude that investment in active travel infrastructure outweighs other forms of infrastructure investment (DfT, 2014; Parkin, 2016).

It is essential that such evidence be conveyed to those making decisions on major infrastructure investment (HMG, 2016), such as the UK Commissioner for National Infrastructure (currently ICE president John Armitt). This will ensure that active travel is not overlooked as a legitimate investment option, which has often been the case.

Tight (2016) shows that both walking and cycling remain marginalised in favour of motorised modes with respect to provision, priority and planning. Yet the two modes together comprise a means to cover the kinds of distance required for most trips in urban areas. Deegan (2016) provides an example of projects built to meet this urban transport need, demonstrating the successes – and failures – of the London Cycle Network Plus project.

Mutual benefit

Realisation by everyone that each person who chooses to walk, cycle, scoot or skate is making the air cleaner and relieving congestion will also alleviate the divisive attitudes and animosity that often occur between people adopting different modes, which can in turn act as a deterrent to those considering such active modes. Nikitas et al. (2016) show acceptance of the expansion of the Gothenburg bike-hire scheme in Sweden even by those with small (or no) likelihood of using it.

This two-part themed issue explores exciting and innovative areas, stretching imagination and challenging traditional perceptions of the definition of active travel.

When civil engineers recognise their responsibility and take the opportunity to facilitate active travel for all members of society, we are surely engineering sustainability in its true form.

References


International perspectives in managing construction contracts

Civil engineers may operate in a global market but it is far from harmonised or harmonious. International construction law expert Barry Manie reviews a recent themed issue of an Institution of Civil Engineers journal on international perspectives in construction contracts.

A recent issue of the Institution of Civil Engineers (ICE) Management, Procurement and Law journal (Manie, 2015) focused on international perspectives in construction contracts. It will be of interest to anyone engaged in procuring and managing international civil engineering projects, as well as those involved in resolving disputes arising under international construction contracts.

One of the most interesting features of the papers was the different approaches – both good and bad – being taken around the world to managing construction contracts. Some of the topics covered are highlighted below.

Abuse of programmes

Kidd et al. (2015) identify and discuss several ways in which construction programmes around the world are often abused as a result of tensions between their use as a collaborative tool in project delivery and their use in the management of commercial risk.

Examples of common abuses by contractors are over-optimistic or over-pessimistic estimate of time to complete, misrepresentation of time risk, constrained or unnecessary logic and claiming concurrent delay to hide behind an employer delay.

Examples of abuses by employers are non-acceptance of an amended programme, slowing down agreement of an extension of time and reinterpretation of definitions of substantial completion and other dates.

The authors also describe ‘unconscious abuses’ generally arising from a poor understanding of contract or programming techniques. They outline a number of measures that can be taken to protect against abuses of programmes, including developing the right capability, reducing the likelihood of abuse and defending against abuse.

Cultural differences

Webb (2015) addresses some of the difficulties that a European or US contract manager can face in respect of differences in culture and management style when working in Asia, and how they might be overcome.

The author explains the traditional ways of doing business in Asia and highlights particular cultural issues and differences between the eastern and western ways of doing things, showing how these differences can affect contract negotiation and choice of construction contract.

He suggests that the principles underlying the suite of standard forms of contract in ICE’s NEC3 suite, which promote collaboration and partnering, and require the participants in the construction project to act ‘in a spirit of mutual trust and co-operation’, might align more closely with the way in which negotiations are typically conducted in Asia.

He concludes, among other things, that western contract managers need to utilise both ‘soft’ and ‘hard’ skills to undertake their project roles in Asia successfully.

Barriers to BIM

Gibbs et al. (2015) investigate how the Chartered Institute of Building’s Complex Projects Contract 2013 (CPC 2013) addresses the perceived barriers to greater use of building information modelling (BIM) techniques on international construction projects.

The paper considers perceived barriers in four areas: legal and contractual, collaboration, use and management of information, and investment. The authors conclude that CPC 2013 goes some way to facilitate BIM by attempting to overcome these perceived barriers but that some special conditions and amendments to the contract may be required.

A guide to using BIM with NEC3 contracts is available from ICE (NEC, 2013).

References


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Papers on innovative and recycled materials and novel applications of other materials such as concrete and cement are also encouraged. All aspects of a material’s life are addressed including embodied energy, environmental impact, service life, refurbishment, recycling and reuse.

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Forensic Engineering is currently inviting papers.

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Topics covered also include research and education best practice in forensic engineering and structural pathology, new understanding of the application of engineering principles as a result of unexpected unsatisfactory performance, innovative techniques or equipment used in forensic engineering investigations, and the contribution of forensic engineering and investigation techniques to the role of the expert witness.

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Discussion

1500081 Launching of Leigh Road Bridge, Slough, UK

By Mike O’Connor, Malcolm Attrill, Iain Gibb and Soon Hee Oh (August 2016)

Contribution by Frank Marples

In the paper by O’Connor et al. (2016) on the Leigh Road Bridge launch, I was lead author for the second reference (Marples and Richings, 2014). I was pleased to see the technique described used again but was concerned to see an ‘unforeseen slide incident’ had occurred which could cause Network Rail to object to its use on future UK rail over-bridge projects.

Examining the paper, it seems the incident was entirely foreseeable and preventable if sound engineering principles – as required by the conclusions in our earlier paper – had been used. It seems the adjustment of jacks and self-propelled modular transporter strokes to allow simultaneous contact of both girders on their jacks created a cross-fall. This caused the nose to slide down into the west guides during the subsequent launch.

The skew of the bridge and the transporters being square between edge girders causes a difference in cantilever of approximately 4.1 m (cantilevers of 56.76 m west and 52.66 m east, beyond the leading transporters). Taking the west girder deflection of 422 mm (Figure 3(a)) and pro-rata the cantilevers to the power of four, the east girder deflection is approximately 312 mm. This gives a cross-fall of approximately 0.72% across the polytetrafluoroethylene (PTFE) bearings.

Not only was the cross-fall sufficient to overcome friction of the bearings and produce the transverse movement, the launch force also overcame friction and the nose drifted downhill.

In addition, during launching the west girder was contacting the west guide so the warning signs were evident. Launching ‘unrestrained’ at the transition was inappropriate and should have been stopped by any engineer experienced in slides and launches.

On the A406 bridge launch reported in our paper, PTFE was used to allow the deck to move transversely and longitudinally during jack down to ensure lateral forces went into the guides and not the jack stack. The launch guides were set at ±5 mm to prevent support centrelines being outside the girder webs.

The launch nose should have been jacked to be level across all bearings, the transverse restraint maintained throughout the slide and the installation designed and monitored by engineers experienced in this type of temporary works.

Authors’ reply

We believe the contributor may have misinterpreted some aspects by suggesting that there was an entirely overlooked permanent built-in ‘cross-fall’. There was not.

Simultaneous touchdown of the nose was integral to the three-point support mechanism. Immediately thereafter, vertical jacking and transporter stroking was applied to adjust the structure without stress inducement during the subsequent operations. This addressed any lateral movement tendency of the skewed launch structure, just as the contributor cites should have happened.

However, lateral rotation of a transporter due to the balancing of the hydraulic distribution of the skewed load was a feature which could not be eliminated by adjustments. This also constantly changes as the slide advances, adding to the complexity. This was analysed in the model mentioned in the paper, tested and verified by the team, which included the same specialist launch contractor used for the A406 project.

Nevertheless, no insurmountable lateral movement of the structure occurred in the successful full-scale trial. In addition, the static bearing friction demonstrated in the trial while changing the jack restraints confirmed that no critical cross-fall could have been present at that static stage sufficient to initiate a lateral slide across the PTFE bearings, as concluded by the contributor.

As for the 30 mm and 40 mm clearances we used on the launch restraints and guides, we had taken this into account in devising more robust nose girders to cater for our offset tolerances. We felt these were necessary for sliding this type and size of structure, rather than the potentially constraining 5 mm mentioned by the contributor. This proved very satisfactory until the transition, and during the resumed slide after the repairs.

The authors acknowledge the importance of implementing the recommendations from the paper by Marples and Richings (2014). We also wish to share and highlight for the benefit of the profession the learning points from our own experience of launching a more complex structure.

We believe that implementing the learning points will enhance the application of this method of construction, further increasing the confidence of Network Rail and others in the method as a viable installation technique.

References


NEC3 compared and contrasted (2nd ed.)
edited by Frances Forward, ICE Publishing, 2015, £30, reviewed by Andrew Martin, Cowi, Denmark

The NEC3 suite of contracts has become widely used in recent years, both in the UK and further afield – particularly in Hong Kong, New Zealand and South Africa. This book, now in its second edition, seeks to provide a concise guide to how aspects of NEC3 contracts relate to other contract forms currently in use in Britain and overseas.

It has three main sections: construction contracts, contracts for professional services (i.e. consultancy) and contracts from other parts of the world. The expert author of each chapter describes a particular form and compares it with its equivalent in the NEC3 family.

The main NEC3 Engineering and Construction Contract is compared with the JCT 2011 Standard, Constructing Excellence and Major Project Construction Contracts; the CIOB Complex Projects Contract 2013; the RIBA Building Contracts 2014; and the IChemE Contract. The NEC3 Professional Services Contract is compared with the RIBA SFA 2010; CIC Consultant’s Contract; JCT Consultancy Agreement 2011; ACE Consultancy Agreement; RICS Standard Form of Consultant’s Appointment; and PPC 2000 Project Partnering Contract.

The final chapters have an international perspective, comparing the NEC3 family with Fidic forms and contracts from Australasia, Hong Kong, South Africa and Germany.

This compact book is full of useful information in an easily digestible form. It should provide a useful point of first reference for those familiar with NEC3 contracts and others who are working with contracts in the ever-widening global construction market.

BIM and quantity surveying
edited by Steve Pittard and Peter Sell, published by Routledge, 2016, £24.99, reviewed by Colin Rawlings, HS2 Ltd, UK

This book of 256 pages and 12 chapters provides an introduction to building information modelling (BIM) and its implementation across the construction industry.

While it has been written with quantity surveyors in mind, showing how implementation of BIM will affect the quantity surveying profession, it will prove useful for clients, designers, contractors, building managers and others within the built environment.

The underlying benefit of BIM – which requires collaborative working – in reducing risks and costs by virtual prototyping of projects before construction commences is illustrated by a number of UK-based case histories.

The book notes that it is a much greater exercise to backfill data after the event than taking the time to develop the required data at the outset. Common data environment structures enable effective data management and increased engagement with stakeholders throughout the whole life of a project, including asset management during operation and maintenance.

It also points out that the cultural barriers to implementing BIM should not be underestimated as there is a requirement to make significant changes to well-embedded work processes.

For further reading on BIM for civil engineers see www.ice.org.uk/disciplines-and-resources/information-sheets/building-information-modelling-for-civil-engineers.

From rail to road and back again: a century of transport competition and interdependency
edited by Ralf Roth and Colin Divall, published by Routledge, 2015, £80, reviewed by Phil Renforth, Cardiff University, UK

The Industrial Revolution, which began in Britain in the late eighteenth century, would not have been possible without the great movement of people and materials across transport infrastructure. That infrastructure has evolved organically and artificially as technology and wealth changed.

From Rail to road and back again, edited by Roth and Divall is an ambitious attempt to capture the transformation of transport in Europe and North America from the inception, steaming and fading of rail, to the emergence and dominance of roads.

What is striking is how much infrastructure was created in so little time. By 1870, only 40 years after the first steam passenger railways, there was parallel iron connecting every major city in Europe. In 1940 there were only 50 or so cars per thousand UK inhabitants, by 1970 the number had surpassed 200.

Over the twenty-first century our infrastructure may change again beyond recognition. There has never been a more important time for civil engineers to reflect on where we have come from, to learn the mistakes of the past.

Garden suburbs of tomorrow? A new future for the cottage estates
by Martin Crookston, published by Routledge, 2014, £65, reviewed by Eva Linnell, Atkins, UK
Councils across Britain undertook a mammoth effort in the first six decades of the twentieth century to create a new and optimistic form of housing – the cottage estates. In the 20 years from 1959 there were over 150,000 homes built per annum, generally in the form of well-built houses with spacious gardens.

In this book Martin Crookston describes the perceived issues on cottage estates and whether or not they are significant, drawing on a wide range of research studies by academics, councils and charities as well as his own observations. Through case studies of specific estates, he presents a diverse picture of trends in employment, ethnicity and home ownership using census data, and describes transport connectivity and bus routes.

He gives a detailed, insightful and at times colourful account – for example, quoting a description of the government policy approach to housing under-use as, ‘a sledgehammer to squash a tomato next to the nut’. Most importantly, he stresses the potential offered by the diverse situations of the different estates, not just the problems, and how unrealised potential could be realised in a cost-effective way.

NEW BOOKS

The ICE library maintains one of the most comprehensive collections of civil engineering books in the world, including all titles from ICE Publishing (shown in bold below). New books received in the past 3 months include the following.

- An introduction to geosynthetic engineering by S Shukla, £49.99
- Analysis and design of railway bridges by M Khan, £95.00
- Analysis of structures by M Rohman, £49.21
- Building condition surveys: a practical and concise introduction (3rd ed.) by M Hoxley, £27.00
- Building revolutions: applying the circular economy to the built environment by D Cheshire, £35.00
- Concrete design by P McMullin et al., £21.99
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- Keating on construction contracts (10th ed.) by S Furst, £465.00
- Maintenance, monitoring, safety, risk and resilience of bridges and bridge networks by D Frangopol, £172.00
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ICE review

A review of recent developments at the Institution of Civil Engineers by outgoing ICE president John Armitt. For further information please contact the communications office on +44 20 7665 2107, email communications@ice.org.uk or visit www.ice.org.uk/news-public-affairs.

Leading the Brexit challenge

It quickly became evident after Britain voted to leave the EU that the UK construction industry needed to speak with one voice on the challenges and opportunities ahead, thereby ensuring that international trade negotiators are properly informed. In July, ICE established a built environment leadership group, including experts from Atkins, Pinsent Masons, the Royal Institution of Chartered Surveyors, Skanska, Aecom, KPMG, BSI and the Construction Leadership Council.

The group, which I chair, started by taking a strategic overview of what a ‘post-Brexit’ UK can achieve and our sector’s role in contributing to that vision. This was followed by consideration of what is needed to meet the vision, looking across investment, skills, standards, research, innovation and procurement.

Our contribution – which has been informed by a wealth of knowledge from the industry alongside the expertise of the individuals on the group itself – has been greatly valued by the government and our engagement with negotiators and officials continues. The group has also been feeding into cross-disciplinary work being undertaken by the Royal Academy of Engineering.

Launching new learning hub

ICE’s new infrastructure learning hub will open in November, offering the built environment community a place to tell the story of how they are shaping the world and driving forward human progress.

Located at ICE’s London headquarters, the hub will be home to a series of exhibitions explaining civil engineering in an interactive and engaging way. It will offer insight into how the built environment community is tackling new and complex challenges such as climate change and increasing urban populations. It aims to motivate and engage young people by bringing engineering to life, and supporting thought leadership and skills development.

The first exhibition will be on bridge engineering, delivered with the support of Cemar and Tony Gee. Those visiting the hub will discover the transformative power of bridge engineering on society and learn how bridge building has developed over the centuries.

The hub is supported by Aecom, Atkins, Carillion, Costain, John Laing, Kier, Mace Foundation, Mott MacDonald, Ramboll, Vinci Construction and WSP Parsons Brinckerhoff.

Advising on UK devolution

ICE’s flagship State of the Nation report was launched in June, focussing on devolution and how to ensure this fundamental shift in decision making impacts positively on the UK’s local, regional and national infrastructure networks. The report backs the government’s efforts to rebalance the economy, with the focus on infrastructure as the key driver, and the creation of new combined authorities and transport bodies.

We did however recommend some improvements to the current arrangements to help authorities deliver the maximum benefits of devolution. Our ten-point plan calls for the bodies to be granted greater access to flexible financing streams to supplement central government funding, enabling investment in infrastructure that is transformational, and the skills needed to deliver it.

Furthermore, we believe an infrastructure strategy based on need should be established for every current and emerging economic area so that money is directed towards the right projects. Our report also recommends that all new devolution proposals clearly set out how they will improve environmental sustainability and quality of life, as well as drive growth.

ICE is leading British construction input on trade negotiations following the Brexit vote

An exhibition on bridge engineering opens this month in ICE’s new infrastructure learning hub
Engineering History and Heritage is currently inviting papers.

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Engineering History and Heritage is a high-quality, internationally refereed journal, published four times a year as part of the Proceedings of the Institution of Civil Engineers. Full-length papers or short articles and book reviews on all aspects of the history and heritage of civil engineering and construction are always welcomed. The scope includes the conservation of civil engineering works, infrastructure and buildings as well as histories of the engineering disciplines, engineering science, design methods, individual engineering works, construction firms and biography.

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Cedric Kechavarzi, Kenichi Soga, Nicholas de Battista, Loizos Pelecanos, Mohammed Elshafie and Robert Mair

Price: £ 65.00
ISBN: 9780727760555
Format: Hardbound
Publish Date: August 2016
Number of Pages: 264

This book highlights the main issues and offers guidance on how to correctly and efficiently determine the specifications for a distributed strain sensing system, examines fibre optic data analysis, the conversion to engineering parameters and how to interpret results.

Whole-Life Value-Based Decision-Making in Asset Management
Rengarajan Srinivasan and Ajith Parlikad

Price: £ 45.00
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Publish Date: June 2016
Number of Pages: 96

This best practice guide aims to aid asset management decision-makers to understand better the value generated by assets and the risks associated with this in order to make better informed decisions, and to also have a deeper understanding of the impact of their decision.

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David Rodenas-Herráiz, Kenichi Soga, Paul Fidler and Nicholas de Battista

Price: £ 65.00
ISBN: 9780727761514
Format: Hardbound
Publish Date: July 2016
Number of Pages: 232

The purpose of this guide is to consolidate a generic methodology for the design and implementation of WSNs for monitoring civil engineering infrastructure, coupled with best practice for data management and information valuation.

Bridge Monitoring: A Practical Guide
Campbell R Middleton, Paul RA Fidler and Paul J Vardanega

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ISBN: 9780727760593
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Number of Pages: 136

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Planning and procurement of the Queensferry Crossing in Scotland

Lawrence Shackman BSc, CEng, FICE, FCIHT
Project Manager, Transport Scotland, Rosyth, UK

David Climie BSc, CEng, FICE
Project Director, Transport Scotland, Rosyth, UK

The Forth Road Bridge has carried road traffic across the Forth estuary in Scotland since 1964. It will be replaced at the end of 2016 by the Queensferry Crossing, Scotland’s biggest infrastructure project in a generation. Currently estimated to cost around £1.3 billion, the replacement crossing project consists of a 2.7 km long cable-stayed bridge, associated connecting roads and junction improvements, and a state-of-the-art 22 km long intelligent transport system to manage traffic through the project corridor. All of these elements are key to maintaining the strategically vital link. This paper concentrates on the various stages of the project’s development from initial scoping through to the award of the construction contracts. Construction will be covered in a future paper.

1. Introduction

The Forth Road Bridge has successfully carried road traffic across the Forth estuary since 1964. The deteriorating condition of the bridge, particularly in relation to the main suspension cables, and the great difficulty in rehabilitation without massive disruption to traffic, has resulted in the need for a replacement crossing to secure the future of cross-Forth travel. This has been further highlighted recently by a full closure of the Forth Road Bridge for 3 weeks in December 2015 due to problems with the truss end-links.

The Forth replacement crossing is Scotland’s biggest infrastructure project in a generation, which will, by the end of 2016, provide a replacement bridge – to be known as the Queensferry Crossing – for all general traffic which currently uses the Forth Road Bridge.

Currently estimated to cost £1.325-1.35 billion, the project consists of a 2.7 km long cable-stayed bridge; associated connecting roads and junction improvements; and a state-of-the-art 22 km long intelligent transport system to manage traffic through the project corridor. All of these elements are key to maintaining the strategically vital link across the estuary.

This paper concentrates on the various stages of the project’s development from initial scoping through to the award of the construction contracts. The construction phase will be covered in a future paper.

2. The Forth Road Bridge

The Firth of Forth separates the Scottish capital of Edinburgh from the Fife council area to the north. The lowest crossings of the Forth at Queensferry, approximately 12 km west of Edinburgh, are a pair of historic grade A listed bridges – the famous Forth Bridge cantilever rail crossing completed in 1890 (Mackay, 1993) and the Forth Road Bridge, Britain’s first long-span suspension crossing, which was opened in September 1964 (Anderson et al., 1965).

The Forth Road Bridge has a main span of 1006 m and at the start of its life it carried around 4 million vehicles per year. It now carries around 24 million vehicles per year and provides a vital link between Fife, Edinburgh and the east coast of Scotland.

Until June 2015, the Forth Road Bridge was maintained and operated by the Forth Estuary Transport Authority (FETA). The condition of the bridge has gradually deteriorated throughout its lifetime, primarily because of the increased levels of traffic with substantially higher heavy goods vehicle (HGV) axle weights, and the effects of weather. The most serious problem concerns the main suspension cables (Colford, 2008, 2011).

In 2004, FETA undertook an inspection of the main suspension cables which followed American guidelines, as no others existed. This identified a significant number of broken and corroded wires and led to an estimate that the cables had lost around 10% of their strength. From this, predictions indicated that restricting HGVs from using the bridge could be required by 2014, with complete closure by 2017. A further cable inspection in 2008 indicated that the cables may be deteriorating at a slower rate than the most pessimistic estimate, leading to a revised estimate of 2017 to 2021 before any traffic restrictions.

FETA implemented dehumidification of the west cable in 2008 and the east cable in 2009. Subsequent cable inspections indicate that the rate of corrosion of the cables has been reduced. However, the results are uncertain, and no unconditional guarantee can be given about the potential future strength of the cables.
Investigations into replacing or augmenting the cables were also undertaken by FETA, but it was concluded that these works could not be undertaken without unacceptably high levels of disruption to traffic across the Forth.

Closing the bridge to HGVs and potentially other types of vehicles would have a very serious impact on the economy of Scotland as a whole and Edinburgh and the Lothian and Fife council areas in particular. These facts, together with other significant ongoing maintenance issues, led the Scottish government to conclude that the Forth Road Bridge could not continue as the main crossing for all traffic.

The Forth replacement crossing will safeguard this vital connection and also improve the reliability of journey times across the Forth by addressing issues which frequently affect the current Forth Road Bridge. These include its lack of hard shoulders to manage vehicle breakdowns and maintenance activities such as carriageway resurfacing, and lack of wind shielding, which results in closure for certain types of vehicles during high winds.

The existing road and rail bridges, and the proposed Forth replacement crossing to the west, are shown in Figure 1.

3. Forth replacement crossing study

Following FETA’s initial cable investigations, in 2006 Transport Scotland commissioned the Forth replacement crossing study to determine the best solution. This used the Scottish Transport Appraisal Guidance (Stag) methodology, which is an evidence-led, objective-based appraisal process.

Eight transport planning objectives were established at an early stage, based around capacity, accessibility, environment, maintainability, connectivity, reliability, increasing travel choices and sustainable development. A key objective was that traffic capacity should generally remain at 2006 levels and any replacement crossing should not result in a marked increase in cross-Forth traffic levels.

The sensitive location of the crossing necessitated environmental review at an early stage to consider a number of local, national and internationally protected sites and features including

- Ramsar sites – wetlands of international importance
- special areas of conservation (European designated sites) with listed species of flora and fauna
- sites of special scientific interest – areas of national importance for wildlife or geology.

A total of 65 initial options including tunnels, bridges and barrages were sifted against the study objectives and appraised in relation to the Scottish government criteria of economy, environment, integration, safety and accessibility and social inclusion. This led to the assessment in more detail of options along five potential corridors, labelled as A to E as shown in Figure 2.

Corridors A and B were sifted out at an early stage, due to the longer route length and the significant new road connections required on the north side of the Forth, leaving corridors C, D and E, which were deemed to perform well against the objectives. These were then taken forward for further detailed appraisal with bridge and tunnel options being considered for all three corridors.

Benchmarking against the Stag environment objectives and the study-specific planning objectives highlighted the critical issue to be to ‘minimise the impact on people, the natural and cultural heritage of the Forth area’ (Dudgeon, 2007: pp. 55–59).
The bridge proposals in corridors C and E did not perform well due to their proximity to the special protection areas within and adjacent to the Forth. In particular, both of these options were considered to have major adverse impacts on a European designated site, due to the likely loss of special protection area habitat. Therefore, they were unlikely to be permitted when viable alternatives existed that had less or no adverse impact. The bridge in corridor D was considered to avoid this impact.

Further appraisal was, therefore, undertaken on tunnels in all three corridors and a bridge in corridor D. There were two types of bridge options considered, both with 40 m wide decks. The first was a suspension bridge with a 1375 m main span and the second was a cable-stayed bridge with two main spans of 650 m. Initially, only bored tunnels were considered within the study primarily as the topography of the Forth did not lend itself to other tunnel types. However, further work was undertaken in 2007 to establish the feasibility of an immersed-tube tunnel along corridor C and this was considered within part of the overall options appraisal.

A strategic environmental assessment was undertaken on the Forth replacement crossing in 2007 (Ritchie and Walker, 2007). Additionally in 2007, a strategic-level appropriate assessment was undertaken because a new crossing had the potential to affect up to three European designated ‘Natura 2000’ sites (the Firth of Forth and Forth Islands special protection areas and River Teith special area of conservation) and the Firth of Forth Ramsar site.

### 3.1 Tunnel versus bridge options

Comparisons were made between options of tunnel and bridge in order to help determine the most appropriate option. These are summarised in Tables 1 and 2.

In all scenarios analysed in the part 2 Stag appraisal the monetised benefits were greater than the costs (Dodgson, 2007). The corridor D bridge produced the most favourable results, with the lower cost of the cable-stayed variant giving the highest net present value (NPV) and benefit–cost ratio (BCR).

The most favourable tunnel option in economic terms was that of corridor E. This option produced the highest level of monetised benefits, but at a significantly higher level of cost than the corridor D bridge. This resulted in an inferior NPV and BCR. The higher level of benefits was a consequence of the proximity of the southern connections with routes into the city of Edinburgh. However, this was contrary to then current regional and local policies.

### 3.2 Tunnel options

The tunnel in corridor E was determined not to be worthy of further consideration because of environmental impacts; construction risks; impact of drill and blast construction techniques; mine workings on the south side; and high cost.

There was little to choose between the remaining tunnel options in corridors C and D, since they have similar construction periods (7.5 years) and have similar costs (£2.2–2.3 billion). Neither would impact on the special protection areas and the overall environmental benefits of both were similar. Since pedestrians and cyclists would not be permitted into the tunnels for safety reasons, the tunnel options would not be able to provide the same functionality as a bridge crossing.

### 3.3 Bridge options

Of the two types of bridge structure, the cable-stayed bridge was found to have advantages over the suspension bridge, being the cheaper option and capable of being delivered around 6 months earlier. The suspension bridge required complex foundations on the landfalls, which invoked a risk from methane on the southern side of the Forth, whereas the use of a cable-stayed arrangement did not.

A modern cable-stayed bridge provided the opportunity to create a unique situation at the Forth with three different types of bridge construction from three different centuries in close proximity. These are the cantilever structure of the 1890 Forth Bridge carrying rail, the 1964 long-span suspension Forth Road Bridge and the new Forth replacement crossing cable-stayed bridge.

The bridge options were, however, assessed not to perform as well environmentally as the tunnel options in corridors C and D. Direct impacts on the St Margaret’s Marsh site of special scientific interest on the north side of the estuary were likely, and there could also be indirect disturbance to protected species within the special protection areas at both the Forth Islands and the Firth of Forth, which would impose seasonal constraints during construction.

The study concluded that a bridge in corridor D would be significantly cheaper than the tunnel options; could be delivered quicker; had fewer risks associated with construction; and demonstrated the best value for money.

### 3.4 Recommended scheme

A cable-stayed bridge in corridor D, slightly west of the Forth Road Bridge, was recommended as the preferred scheme. This alignment makes use of Beamer Rock, a natural dolerite outcrop in the middle of the Forth, providing a suitable foundation for the central tower of a three-tower cable-stayed bridge.

---

**Table 1. Cost and construction time comparison**

<table>
<thead>
<tr>
<th>Crossing type</th>
<th>Construction time: years</th>
<th>Cost ratio to cheapest</th>
<th>Benefit–cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersed tube tunnel</td>
<td>5-5</td>
<td>1-4</td>
<td>2.91</td>
</tr>
<tr>
<td>Bored tunnel</td>
<td>7-5</td>
<td>1-5</td>
<td>2.23 to 2.7</td>
</tr>
<tr>
<td>Suspension bridge</td>
<td>6-0</td>
<td>1-1</td>
<td>3.83</td>
</tr>
<tr>
<td>Cable-stayed bridge</td>
<td>5-5</td>
<td>1-0</td>
<td>4.31</td>
</tr>
</tbody>
</table>

**Table 2. Crossing type comparison**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Impact on the environmentally protected sites of the Forth</th>
<th>Operating restrictions</th>
<th>Operational risk</th>
<th>Cost</th>
<th>Cost risk</th>
<th>Time to construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Immersed tube tunnel (ITT)</td>
<td>Bored tunnel</td>
<td>Bored tunnel and ITT</td>
<td>Bored tunnel</td>
<td>Bored tunnel</td>
<td>Bored tunnel</td>
</tr>
<tr>
<td>OK</td>
<td>Bridge</td>
<td>ITT</td>
<td>ITT</td>
<td>ITT</td>
<td>Bridge and ITT</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>Bored tunnel</td>
<td>Bridge</td>
<td>Bridge</td>
<td>Bridge</td>
<td>Bridge</td>
<td></td>
</tr>
</tbody>
</table>
Following a comprehensive public consultation exercise in mid-2007, and further consideration of the means to accommodate future travel demand across the Forth, it was determined that the replacement crossing should be ‘multi-modal’ in nature. This meant that the new bridge would be wider than previously envisaged at around 50m to include a corridor which would be utilised for guided buses or a light-rail-based system.

Pedestrians and cyclists would also be accommodated on dedicated facilities, located at the edges of the structure (see Figures 3 and 4). This recommendation was accepted and in December 2007, the Scottish government announced that, ‘the Forth replacement crossing should be a cable-stayed bridge with multimodal capacity on a route slightly to the west of the existing road bridge’ (Scottish Parliament, 2007: col. 4552).

The estimated cost of the project was between £3.2 billion and £4.2 billion and it would be delivered by the end of 2016.

4. Scheme preparation and development

4.1 Selection of consultant

In January 2008, Transport Scotland, by way of a competitive tendering exercise, procured the services of the Jacobs Arup joint venture to assist with the management and delivery of the Forth replacement crossing project.

The scope of the commission included the development and assessment of the project proposals, concept (Hussain et al., 2011) and specimen design (Carter et al., 2011) of the bridge, preparation of an environmental statement, preparation of contract documents, assistance in the procurement and authorisation of the project and subsequent monitoring of construction.

The project is being managed by an integrated team of Transport Scotland and Jacobs Arup staff, and was co-located in Transport Scotland’s Glasgow office up to mid-2011 when the integrated team was relocated to the construction site in Rosyth.

4.2 Initial scheme preparation

Following the ministerial announcement at the end of 2007, the assumption was that the Forth replacement crossing was to provide for all road vehicles, pedestrians and cyclists. No future functional use of the existing road bridge was envisaged. The scheme was planned to incorporate two lanes with hard shoulders plus pedestrian walkways and cycleways in each direction.

Motorway-standard road connections were to be provided principally to join the A90/M90 to the north of the Forth and to the M9 and A90 in the south, for a total approximate length of 22 km.

A multi-modal corridor was to be provided on the new bridge and connect to the adjacent network, to cater for public transport needs, including the possibility of a light rapid transit system or trams in the future.

Scheme preparation was therefore progressed on that basis as shown in Figure 4.

4.3 Future use of the Forth Road Bridge

In early 2008, FETA reported on its second cable investigation which gave an improved prognosis for the rate of cable deterioration. This, together with the removal of general traffic from the Forth Road Bridge (which constitutes some 15% of the loading in the cables), provided some hope that a functional use for the existing road bridge might be possible.

Previously, the view given as part of the Forth replacement crossing was that the existing bridge would not be suitable for future light rail use. However, it was felt within the Forth replacement crossing team that this finding should be challenged, particularly in relation to perceived problems with rotations at expansion joints. A feasibility study was therefore carried out to evaluate the suitability of the suspension bridge to carry a future light rail system (Hussain et al., 2011). This study demonstrated that the Forth Road Bridge could provide a public transport corridor, initially for buses, which could be developed to accommodate light rail or trams if required in the future.

Additionally, if the Forth Road Bridge was to be retained then it could also continue to accommodate the pedestrian and cyclist facilities. The Forth replacement crossing could therefore be slimmed down significantly (to around 40m width – see Figure 5).
4.4 New bridge design

Taking the above Forth Road Bridge assumptions into consideration, the design of the new bridge was progressed. A wide range of design issues were addressed including the following:

- Stabilisation of the central tower – with a three-tower cable-stayed bridge exhibiting much larger deflections than those of a two-tower bridge a unique solution incorporating a length of crossed cables at mid-span was developed, helping to provide a slender deck and towers.
- Navigation clearances – provision of at least equivalent clearance to that provided by the Forth Road Bridge and Forth Bridge.
- Wind shielding – to provide almost guaranteed ability to cross in high winds and to maintain views by specifying a transparent barrier.
- Ship impact – extensive investigations into the likely types, weights, speeds and direction of vessels using the Forth to consider the risk and potential outcome of a vessel hitting a tower or pier. The ‘as low as is reasonably practical’ (Alarp) principle was adopted to manage best the engineering and cost implications, and resulted in increased protection to the south tower and adjacent pier as, being located on the outside bend of the main shipping channel, these were deemed more likely to be struck.
- Tower foundations – to inform the foundation design extensive ground and marine investigations were undertaken, split between three contracts to ensure adequacy of resources. Both caissons and piles were considered to be acceptable solutions with the eventual contractor being best placed to choose.
- Deck type/shape – after consideration of various arrangements including truss and vierendeel, a trapezoidal-shaped deck (aerodynamic box with smooth surfaces) was preferred to minimise future maintenance, assist with wind loading and improve aesthetics. However, choice of materials (orthotropic or composite) was left open for the contractor.
- Environmental constraints on construction – including proximity to the special protection areas, setting limiting criteria for construction noise and vibration and preventing interference with cetaceans and other marine life.
- Aesthetics – consideration of the new bridge’s setting and close proximity to the Forth Road Bridge and Forth Bridge greatly influenced the design, particularly in respect of the towers with simple, slender monopoles being adopted to minimise any visual conflict. This met with Architecture and Design Scotland’s approval.

Addressing these issues culminated in a robust, aesthetically pleasing specimen design which tenderers could use to develop into a detailed design. Figure 6 shows an artist’s impression of the intended bridge.

4.5 Road connections and intelligent transport system

In conjunction with the feasibility study on the existing bridge, it was recognised in view of the high cost estimate that the project should be subject to a thorough value-engineering exercise, making best use of existing infrastructure where possible.

The incorporation of an intelligent transport system was first suggested during the Forth replacement crossing study. Use of variable mandatory speed limits combined with variable message signs and other features such as closed-circuit television coverage of the roads concerned had proven to provide operational benefits on roads such as the M42 around Birmingham.

As congestion builds the variable mandatory speed limits displayed on overhead gantries steadily reduce the speeds, smoothing the traffic flow, thus reducing congestion, and reducing emissions. The system has also been shown to improve safety as it helps to avoid stop–start conditions, in particular rear-end shunts into stationary traffic. Use of this technology was deemed to be a pragmatic way of managing the relatively heavy traffic flows along the project corridor and helping to minimise new road construction.

South of the Forth, six principal options were considered to connect the new bridge to the M9 and to the A90 (see Figure 7). All options were assessed in relation to a number of factors including cost, environmental impact, connectivity/traffic routing, design standards (in particular junction spacing) and ground conditions.

The optimum arrangement was to construct a new length of motorway-standard road from the new bridge around the west and south of Queensferry to connect to the A90/M9 spur junction at Scotstoun. A junction with the local network would be provided on the A90. The connection to the M9 would then utilise the recently constructed M9 spur in preference to a new more direct alignment. Better connectivity to the M9 west would be provided by upgrading M9 junction 1a to an all-ways junction and capacity enhancements would be provided by road widening of the M9 itself towards the Newbridge junction. This arrangement was the least costly (in particular by using the M9 spur) and had the lowest environmental impact.

North of the Forth, three main options (see Figure 7) were considered, broadly online, offline and a mix of online/offline. Junction layouts and their spacing, road alignment and ground conditions were principal considerations. Initially it was envisaged that the road should be a three-lane motorway extending up to the M90/A92 interchange at Halbeath.
However, utilising the intelligent transport system to make best use of the existing road space meant that a more considered approach could be adopted. Thus new road construction was to be provided from the new bridge up to the M90 junction 1 at Admiralty with a remodelled junction at Ferrytoll to maintain connectivity to the local road network in and around Rosyth, Inverkeithing and North Queensferry.

The considerations led to a significant reduction in the extent of the road network connections. The incorporation of the intelligent transport system, across a 22 km length from Halbeath to Newbridge, was to be the first such application of this technology in Scotland.

### 4.6 Managed crossing strategy

All of the previously described measures form the ‘managed crossing strategy’, with reuse of the existing bridge and a reduced extent of new road construction being key elements in revising the scope of the project. These changes resulted in a much reduced cost estimate of between £1.7 billion and £2.3 billion.

The strategy was announced by the Scottish government in December 2009 and formed the basis for progressing the project.

### 4.7 Public transport

Further enhancements to the proposed scheme were developed with the key aims to ensure journey time reliability and to enhance public transport services and facilities as far as possible. These included:

- dedicated public transport links to and from the Forth Road Bridge to the A90 with the eastbound link forming a direct connection to the existing A90 Edinburgh-bound bus lane
- additional 1000-space park and ride facility at Halbeath (constructed by Fife Council)
- use of the new bridge’s hard shoulders by public transport when wind prevents them from using the Forth Road Bridge.

Figure 8 indicates the final bridge location and road layout including public transport links.

The ‘managed crossing strategy’, with reuse of the existing bridge and a reduced extent of new road construction, resulted in a much reduced cost estimate of between £1.7 billion and £2.3 billion.

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**Figure 7. Road connection options**

**Figure 8. Forth replacement crossing project: bridge location and road layout including public transport links**
Planning and procurement of the Queensferry Crossing in Scotland
Shackman and Climie

5. Procurement

5.1 Design and build contract

Following a review of interface management and a desire to provide opportunities to a range of contractors, the project was divided into three contracts (see Figure 9). These are the ‘principal contract’, which includes the main crossing and connecting roads, and two smaller contracts: ‘Fife intelligent transport system’ for the intelligent transport system in Fife to the north of the Forth and ‘M9 junction 1a’ for associated road improvement works in and around that junction to the south.

Price certainty is one of the key aims of the project and therefore it was decided to adopt the design-and-build type of contract. Various funding mechanisms were investigated, but in view of the difficulty in obtaining private finance, given the economic crisis prevailing in 2009, it was decided that the project would be funded directly from the Scottish government.

In view of the large size of the project and the likelihood of attracting international consortia to bid, a contract form based on the Fidic standard conditions for turnkey projects (Fidic Silver Book; Fidic, 1999) was adopted. The price was a lump-sum basis with 90% of the inflation risk over the project period being taken by the client and monthly payments made for progress measured against a schedule of milestones.

Two participants were shortlisted for the tender competition for the principal contract. These were Forthspan – a joint venture of Morgan Sindall, Bam Nuttall, Balfour Beatty and Vinci (later replaced by MT Hojgaard) – and Forth Crossing Bridge Constructors, a joint venture of Hochtief, American Bridge, Dragados and Morrison Construction.

5.2 Dialogue period

The competition for the principal contract was undertaken in parallel with the progression of a parliamentary bill. It would normally be desirable to have the legislative powers required in place prior to a tender competition, but the parallel process was necessary due to the time constraints for project delivery.

To provide some comfort to the tendering parties and to encourage them to submit compliant bids, a participation agreement was signed on the basis that

- half of the tender costs up to a value of £5 million would be paid to the unsuccessful tenderer
- full tender costs up to a value of £10 million would be paid to both tenderers should Scottish ministers decide not to continue with the project.

In December 2009, a set of contract documents, including the employer’s requirements and definition drawings were issued to the participants. The definition drawings indicate the minimum requirements that must be followed in terms of the overall form and geometry of the bridge. Also, specimen designs (Carter et al., 2011) were made available to give examples of how the bridge, roads and associated infrastructure may be designed to satisfy the requirements. Throughout 2010 participating consortia prepared their outline proposals for the project and additional ground and marine investigations were undertaken to help inform this.

A formal dialogue process between participants and the Forth replacement crossing team took place through the tender period, to ensure that participants thoroughly understood Transport Scotland’s requirements, and to provide evidence to the Forth replacement crossing team that the participants’ proposals were capable of being developed into acceptable designs.

5.3 Contract award

In early 2011 the preferred bidder was announced to be Forth Crossing Bridge Constructors, and the contract for £790 million (a significant saving on the estimate of between £900 million and £1.2 billion) was signed on 18 April 2011.

The smaller contracts were procured during 2010/2011 and also offered significant savings on the preconstruction estimates.

6. Parliamentary process

Transport Scotland’s road-based projects are normally authorised by way of the Roads (Scotland) Act 1984 (1984). However, because of the provision for possible light rail or trams in the future, it was felt that the scope of this act would not be sufficient and its use could give rise to an increased risk of legal challenge. It was therefore determined that primary legislation, by way of a parliamentary bill, was required.

Scottish ministers introduced the Forth Crossing Bill to the Scottish Parliament on 16 November 2009, outlining proposals for the Forth replacement crossing (Scottish Parliament, 2009). Transport Scotland produced a full suite of accompanying documents to support the Bill and staged public information exhibitions to make this documentation available for public inspection. These documents, as well as all previously published
material, can be found on the project website (Transport Scotland, 2016). This was the first hybrid bill of its type ever taken forward in Scotland.

As part of the parliamentary process there was a 60 d objection period during which objections to the bill could be made to the Scottish Parliament. In total 90 objections were submitted.

Officials from the Forth replacement crossing project team gave evidence at various parliamentary bill committee sessions and, in particular, during the sessions at which the objections were considered in detail in front of an independent assessor.

The bill process ran in parallel with the procurement process and culminated in a final parliamentary debate on 15 December 2010 which confirmed acceptance of the scheme almost unanimously.

On 20 January 2011 royal assent was granted and the Forth Crossing Bill became the Forth Crossing Act 2011 (2011).

7. Conclusions

The Forth replacement crossing project has been developed rapidly since mid-2006. By summer 2011, the necessary legal powers to construct the crossing had been granted by way of the successful passage of the Forth Crossing Bill through the Scottish Parliament and the principal contract (to construct the bridge and immediate connecting roads) and associated contracts had been awarded.

The project is now nearly 5 years into its construction phase (see Figure 10) and the bridge (now known as the Queensferry Crossing) is making highly visible progress. This will be the subject of a future paper once the project is complete.

Key dates for the project are given in Table 3.

![Figure 10. Queensferry Crossing under construction, February 2016](image)

Table 3. Key project stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>Date</th>
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</thead>
<tbody>
<tr>
<td>Forth replacement crossing study</td>
<td>August 2006–June 2007</td>
</tr>
<tr>
<td>Public exhibitions</td>
<td>August 2007</td>
</tr>
<tr>
<td>Scottish government confirms bridge crossing</td>
<td>December 2007</td>
</tr>
<tr>
<td>Consultants Jacobs Arup appointed</td>
<td>January 2008</td>
</tr>
<tr>
<td>Environmental surveys begin</td>
<td>February 2008</td>
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<tr>
<td>Land searches</td>
<td>February 2008</td>
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<tr>
<td>Traffic surveys begin</td>
<td>March 2008</td>
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<tr>
<td>Marine ground investigations</td>
<td>May–August 2008</td>
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<td>Topographical surveys</td>
<td>March–August 2008</td>
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<tr>
<td>Land-based ground investigations</td>
<td>March–August 2008</td>
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<tr>
<td>Scottish government confirms scheme details</td>
<td>December 2008</td>
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<tr>
<td>Public exhibitions</td>
<td>January 2009</td>
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<tr>
<td>Environmental impact assessment concluded</td>
<td>Summer 2009</td>
</tr>
<tr>
<td>Parliamentary bill introduced and statutory consultation</td>
<td>November 2009</td>
</tr>
<tr>
<td>Competitive dialogue process begins</td>
<td>December 2009</td>
</tr>
<tr>
<td>Construction contract (principal contract) signed</td>
<td>April 2011</td>
</tr>
<tr>
<td>Construction begins (all contracts)</td>
<td>Summer 2011</td>
</tr>
<tr>
<td>Queensferry Crossing opens to traffic (target)</td>
<td>December 2016</td>
</tr>
</tbody>
</table>

References


Happy Valley underground stormwater storage scheme, Hong Kong

1. Introduction

Hong Kong’s Wan Chai district has been hit by very heavy rainstorms and typhoons during the rainy season in recent years. These have brought record-breaking levels of precipitation to this fully urbanised and densely populated location, resulting in a flood depth of approximately 1 m in some areas.

The Drainage Services Department (DSD) of the Hong Kong government has therefore developed a long-term solution by constructing an underground stormwater storage tank at the Happy Valley racecourse. It is designed to reduce the risk of flooding posed to the over 150,000 population in the low-lying areas of the Wan Chai district in Happy Valley and Causeway Bay.

The HK$1.07 billion (£96 million) Happy Valley underground stormwater storage scheme comprises construction of a large storage tank. It will temporarily store some of the stormwater and attenuate the peak flow through the stormwater drainage system during heavy rainstorms. When the rainstorm is over, the stored water will be discharged to the sea by way of the existing drainage system. The scheme is designed to withstand rainstorms with an intensity of a 50 year return period.

The scope includes construction of a 60,000 m³ underground stormwater storage tank (equivalent to the size of 24 standard-sized swimming pools), an integrated pumping station, a 650 m long box culvert and associated works, a stilling basin, a fan room, access manholes, the modification of an existing box culvert, and associated drain and sewer diversion works (see Figures 1 and 2).

Project information for the Happy Valley underground stormwater storage scheme is presented in Table 1.

Happy Valley is a premier residential area located just a stone’s throw away from the main shopping streets and the financial 1.

Introduction

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Table 1. Project information

<table>
<thead>
<tr>
<th>Project title</th>
<th>Happy Valley underground stormwater storage scheme</th>
</tr>
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<tbody>
<tr>
<td>Contract used</td>
<td>NEC3 Engineering and Construction Contract option C (target contract with activity schedule)</td>
</tr>
<tr>
<td>Employer</td>
<td>Drainage Services Department</td>
</tr>
<tr>
<td>Project manager</td>
<td>Chief Engineer of Drainage Projects</td>
</tr>
<tr>
<td>NEC advisor</td>
<td>Arcadis</td>
</tr>
<tr>
<td>Contractor</td>
<td>Chun Wo Construction &amp; Engineering Ltd</td>
</tr>
<tr>
<td>Start date</td>
<td>3 September 2012</td>
</tr>
<tr>
<td>Completion date</td>
<td>February 2018</td>
</tr>
<tr>
<td>Original total of the prices</td>
<td>HK$ 678 million (£62 million)</td>
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</table>

The Happy Valley underground stormwater storage scheme is designed to alleviate flood risk in Wan Chai, Hong Kong. It involves the construction of a 60,000 m³ stormwater storage tank under the £9 billion a year Happy Valley racecourse, which has to remain operational throughout construction. It is also the largest NEC3 target cost contract undertaken in Hong Kong. The collaborative-style contract is characterised by an equitable risk-sharing mechanism, making it ideally suited for the severe site constraints and highly complex works. This paper describes how use of the NEC3 and a ‘one team, one goal’ approach is helping to ensure close collaboration between the employer and contractor and a successful outcome. Due for final completion in 2018, the project's first phase – completed in 2015 – has already won several local and international awards.
The DSD was faced with the challenge of constructing a large underground stormwater storage tank in this sensitive area. The construction works at the recreation ground and the horse racing track will inevitably affect the residents, sports pitch users and horse racing fans. Therefore, the underground stormwater storage scheme has been separated into two phases. Particular operational requirements are stipulated in the contract to accommodate the daily needs of the public and allow horse racing operations to continue unimpeded during the construction period.

2. Procurement route

DSD has chosen a collaborative contract – the NEC3 Engineering and Construction Contract (ECC) option C (target contract with activity schedule) – to carry out this highly complex project. Traditional procurement is considered less suitable for complex and challenging projects (Challender et al., 2014). The project draws on the invaluable experience gained and the lessons learnt from the DSD’s first ECC option C contract, the Fuk Man Road nullah project, completed in 2012.

The key features of ECC option C are pain–gain share, open-book accounting, risk management, early warning and timely assessment of compensation events. In addition to these benefits, the DSD is also achieving better value from subcontractors in terms of the level of tender prices and quality of post-contract performance through implementation of a special effective subcontractor management procedure.

The procedure involves the selection of subcontractors in a competitive tendering environment, governed jointly by the project manager and the contractor. The competitiveness of the subcontractor’s price maintains the competitive nature of the defined cost. To achieve these benefits in the project, the project manager has taken a more active role in the management of subcontractors than is typical in target cost contracts. This active involvement starts with subcontractor selection and continues through on-site liaison and payment to subcontract completion.

To enhance the NEC’s required ‘spirit of mutual trust and cooperation’, the project manager has implemented some innovative measures to improve communication and embrace collaboration throughout the whole project team, principally through a ‘360° communication network’. This effective and instantaneous communication platform is the essence of the ‘one team, one goal’ approach, and has become the key in achieving the success of this project. The details of these key features are discussed in this paper.

3. Pain–gain share and open-book accounting

The ECC option C contract operates an open-book account to share cost information between the project manager and the contractor that would traditionally have remained confidential in the Hong Kong government’s traditional General Conditions of Contract (GCC).

The availability of real-time project financial data assists decision-making and budgetary control processes and thus allows both the contractor and the project manager to make accurate cost estimates of design changes. This is of paramount importance
to the underground stormwater storage scheme, given its ever-changing site constraints and stakeholders’ requirements.

The desire to achieve common objectives is driven by the pain–gain share mechanism. This is a mechanism where any cost savings and cost overruns are shared between the employer and contractor according to pre-agreed share percentages. This pain–gain share mechanism motivates the contractor to propose innovative or alternative cost-reduction proposals in collaboration with the project manager. Both parties strived for optimal solutions with the least cost and time impact, as well as minimising disruptions to the public, especially horse racing operations.

The benefits of pain–gain share and open-book accounting are demonstrated by the innovative foundations and subsoil drainage system used in the underground stormwater storage scheme.

3.1 Case study 1 – innovative foundations and subsoil drainage system

The original design required 533 pre-bored socketed H-piles from 40 m to 60 m in length for the foundations of the underground storage tank. These piles would hold down the tank against the buoyancy exerted by groundwater.

At the same time, there was an agreement between the DSD and the Hong Kong Jockey Club (HKJC) that spectators’ views would not be obstructed in any situation. Given that the storage tank is located directly adjacent to the horse racing track, the piling sequence and setting of the piling rigs and cranes would require careful planning.

Driven by the cost-saving initiatives under the pain–gain share mechanism, the contractor and the project manager were keen to look for alternative designs with the least implications on cost and horse racing operations.

The contractor proposed an alternative foundation design. This design optimises a series of peripheral water cut-off walls around the storage tank and a proposed subsoil drainage system underneath the footprint of the tank in order to lower the groundwater level around the tank and thus reduce buoyancy (Figure 3).

This swift decision-making process, together with the reduction in foundation construction time, has resulted in substantial time and cost savings. The alternative design works have advanced project completion by 7 months and reduced the construction cost by HK$72 million (£6.6 million), which is equivalent to 10% of the original target cost.

In addition, the new design was able to save approximately 4000 t of structural steel. In environmental terms, this amounts to a reduction of approximately 8000 t of carbon-dioxide-equivalent emissions.

4. Timely assessment of compensation events

A compensation event is NEC terminology for variations, changes to works information, inclement weather and issues outside the control of the contractor, usually resulting in changes in time and cost.

ECC option C contracts operate a swift notification–quotation–assessment–implementation process. The strict time frame for agreeing compensation events (assisted by open-book accounting) leads to the settlement of variations around the time they occur, thereby easing and speeding up the final account process.

A further benefit of timely assessment of compensation events is the subsequent agreement of variations on subcontracts. This allows payment on time and early final account settlement of these subcontracts upon works completion.

In the underground stormwater storage scheme, the process of submission, negotiation and agreement of compensation events is fully documented in accordance with ECC. The process is carefully managed, monitored and reviewed by the project manager. Most importantly, the timely agreement of compensation events maintains confidence in the latest adjusted target cost and eases the project final account settlement process.

The strict response time frame of compensation events has also allowed advantageous alternative designs to be implemented on time and avoided abortive works, as demonstrated by the water harvesting system.

4.1 Case study 2 – water harvesting system

For the purposes of sustainable development in Hong Kong – one of the missions of the DSD – the project manager introduced a new water harvesting system in the underground stormwater storage scheme.

The water harvesting system first collects water from various sources, including groundwater from the subsoil drainage system of the alternative foundation design and rainwater and surplus irrigation water underneath the turf. The system then utilises the...
water collected for general use at the recreational ground instead of discharging it into the sea (Figure 4).

Despite the complexity and innovative nature of the works, the contractor provided cost and time estimates of the proposed system promptly. This enabled the project manager to instruct the changes on time, avoiding both abortive works and impact to the programme.

The water collected from the water harvesting system is approximately 220,000 m³ annually. To reduce the discharge volume to the sea and to make the best use of precipitation, the water collected is used for on-site irrigation of 11 sports pitches and toilet flushing at the Happy Valley recreation ground. The system is now the biggest water harvesting system in Hong Kong.

5. Active subcontractor management

Under traditional contracting arrangements, it is not uncommon to see contractors pursuing their own interests in selecting subcontractors, rather than focusing on the achievement of project objectives.

The underground stormwater storage scheme alleviates this problem by adopting a more active subcontractor management approach. This involves the project manager and the contractor jointly in the selection process of subcontractors.

The project manager and the contractor jointly prepare the subcontract specifications and conduct the tender briefings and tender interviews. A two-way discussion in the tender interviews encourages tenderers to raise questions and put forward innovative ideas using their expertise. This enables the tenderers to have a better understanding of the scope of works and any concerns that the employer and the contractor may have. The potential advantage is the return of a more realistic price that aligns with these parameters.

The underground stormwater storage scheme benefits from ‘active subcontractor management’ by enabling the project manager to capitalise on subcontractors’ expertise. Tenderers are encouraged to raise questions on the tendered works, as well as proposing innovative solutions from their expertise during the tender interviews. An example of such an innovative solution is the alternative turf system.

5.1 Case study 3 – alternative turf system

The conforming design for an artificial turf system comprises a safety pad (the ‘e-layer’) under the turf layer for extra shock absorption. Following further clarification of the usage of the sport pitches by the project manager during the tender interview, some tenderers suggested an alternative artificial turf system that can offer a sufficient level of safety protection for football players without the e-layer. Finally, a new design was accepted with the advantages of a 20% cost saving and a shorter work duration.

6. One team, one goal through 360° communication network

For enhancement of the NEC’s required spirit of mutual trust and cooperation, the project manager has developed various innovative communication measures for improving communication among the whole project team, including the project manager, supervisors, contractor, subcontractors and key stakeholders.

The 360° communication network is the principal innovative communication measure brought by the one team, one goal approach. This enables strong collaboration and efficient communication among the whole project team – the key to achieving success on this project.

The one team, one goal approach was adopted from the commencement of the contract. The project team works towards the achievement of common goals on time, cost, quality, safety and environment, which were agreed and established between the employer, the project manager, the contractor and the stakeholders at the beginning of the contract.

Under the 360° communication network, various communication measures are implemented to ensure timely exchange of information and quick decisions. A joint office, joint organisation chart and regular management meetings are some of the measures adopted to expedite and strengthen communication between the employer and the contractor. Champion group meetings and partnering workshops are held to enhance mutual understanding and working relationships among different parties. A project logo and uniform is used to further nurture a sense of project ownership.

In addition, daily morning briefings are held on site, attended by approximately 30 members comprising the project manager, the contractor and the subcontractors for reviewing the works progress and upcoming activities. This also provides a platform for exchange of updated information or issues of concern among the parties. If any party issues an early warning notice, a risk reduction meeting is arranged to be held within 24 h. The swift response ensures that risk is addressed promptly and that risk reduction measures are implemented without delay.

The highlight of the 360° communication network implemented on the project is the use of different works-specific groups on the Whatsapp social media platform for instant and multi-directional communication. Various groups were set up among the project manager and his delegates, engineers, supervisors, contractor, foremen, subcontractors and stakeholders for instantaneous consultation and immediate notification. A list of these groups is shown in Table 2.
The highlight of the 360° communication network is the use of different works-specific groups on the Whatsapp social media platform for instant and multi-directional communication to the local community, funded by its revenue raised from lotteries and horse racing operations.

The club holds horse racing events every Wednesday evening in Happy Valley during the racing season. The stakeholder is concerned that the construction works, particularly the construction of box culverts under the race track, would impact on the horse racing operations. To address this issue, the project manager, the contractor and the club adopt a ‘multiple-parties collaboration’ approach for expediting the works.

Firstly, the club made a special arrangement for extending the horse racing summer break in Happy Valley in 2014 from 2 months to 4 months. Secondly, the club instructed its contractors to complete their works according to a very tight schedule, providing the DSD’s contractor 2 months for construction of the box culvert and 2 months for the re-turfing works. Thirdly, the DSD’s contractor programmed its part of the box culvert connecting to club’s box culvert at both ends to suit the club’s works programme.

The project manager identified a high risk of traffic blockage during the summer break, due to the high traffic load of both DSD’s and HKJC’s contractors. Both contractors agreed on a gyroratory traffic plan, jointly controlled by personnel of the two contractors. To facilitate the provision of this ‘shared access’, the project manager instructed a compensation event for the contractor to accelerate a section of the box culvert in order to ensure that the common access would be completed on time.

Recognising that the construction works would impact the community as a whole, stakeholder workshops and public briefings with local resident representatives, district council members, nearby schools and other organisations are held by the project manager. This provides opportunities for the stakeholders and the public to express any concerns, as well as for the project manager to explain the rationale and benefits that the underground stormwater storage scheme will bring on completion.

‘Knowing me, knowing you’ workshops are arranged by the DSD to help team members understand their counterparts’ concerns in their duties or management. These workshops are triggered when a downturn in the partnering scores rated by team members is observed. Following the workshops, in almost all cases the partnering score bounces back to the acceptable level. This enhances the team spirit to work towards the achievement of the common goal. On some occasions, an increase in work productivity is also observed.

The 360° communication network, together with the early warning mechanism under the ECC, plays a vital role in risk management on the project. The following case study demonstrates how it works.

6.1 Case study 4 – collaborative box culvert construction with HKJC

Hong Kong Jockey Club is the biggest charity organisation in Hong Kong. Last year, it contributed HK$3 billion (£270 million)
The responses of the Happy Valley recreation ground users and residents of Happy Valley are supportive. Throughout the closure of the jogging facilities, no complaints have been lodged by the public.

7. Conclusion

The Happy Valley underground stormwater storage scheme is the largest NEC target cost contract awarded by the Hong Kong government to date. Further to the Drainage Services Department’s experience on target cost contracts from its first NEC project, the Fuk Man Road nullah, the collaborative techniques under the one team, one goal approach developed under the underground stormwater storage scheme provides a source of experience that can feedback into future similar contracts.

The one team, one goal approach puts collaborative techniques, principally the 360° communication network, into implementation. This provides instantaneous and multi-directional communication across the whole project team. A joint office, a common project logo, uniform and social gatherings attended by the project team members are some other examples of these collaborative techniques. Most importantly, the one team, one goal approach harmonises the common goals on time, cost, quality, safety, the environment and public relations between the employer, the project manager and the contractor.

Although traditional procurement is the most common procurement method in government projects for the reason of cost certainty, deficiencies around the lack of trust between parties, competitiveness on price but not value and limitations on continuous improvement have encouraged a change from traditional procurement to target cost contracts in Hong Kong. The underground stormwater storage scheme also extends the use of NEC3 contracts into the supply chain, as it is the first project in Hong Kong to trial the NEC3 Engineering and Construction subcontract.
7.1 Completion of phase 1 works

Despite a higher than usual number of heavy rainstorms during the construction period, the phase 1 works (30000 m³ storage capacity) were completed 6 months in advance of the contractual completion date and came into operation in March 2015, just before the rainy season (Figure 6).

7.2 Awards

The underground stormwater storage scheme has won a number of green building, safety and environmental management awards since its commencement. Some of these major awards include

- Platinum rating of Beam Plus by the Hong Kong Green Building Council
- Merit award in the Green Building Award 2014
- Considerate Contractors Site Award Scheme 2013: Gold – Considerate Contractors Site Awards (Public Works – New Works); Silver – Outstanding Environmental Management & Performance Awards
- Considerate Contractors Site Award Scheme 2014: Silver – Considerate Contractors Site Awards (Public Works – New Works); Gold – Outstanding Environmental Management & Performance Awards
- Hong Kong Awards for Environmental Excellence 2014 – Silver award (construction industry).

The jewel of these awards was being highly commended for the NEC Large Project of the Year in April 2015. The judges commented

Using NEC with subcontractors supported by the knowing me, knowing you workshop really helped the whole team to collaborate and overcome numerous issues, typhoons and other challenges. Measurement and analysis of partnering scores amongst team members with corrective action taken to keep collaboration on track is considered best practice.

In addition to the above awards, China’s Minister of Water Resources Chen Lei, Guangdong Governor Zhu Xiaodan and other officials, in the company of the Permanent Secretary for Development Works Hon Chi-keung, Director of the Water Supplies Department Enoch Lam Tin-sing and Acting Director of the Drainage Services Department Mak Ka-wai, visited the site upon successful completion of the phase 1 works.

The successful story of underground stormwater storage scheme will continue until its completion in 2018 (Figure 7).
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1. Introduction

In 2013 the UK government’s Green Construction Board published a report called Infrastructure Carbon Review (GCB, 2013). It was a seminal point in the construction industry’s initiative to lowering the greenhouse gas emissions (measured in carbon dioxide equivalent emissions) of UK infrastructure.

The report had the ambitious aim to inform, motivate and enthuse the industry in actively seeking low carbon dioxide solutions, through policy, design and commitments. This paper reviews the report’s numbers and examines their significance for UK transport infrastructure and the way forward. It aims to suggest the changes that will enable the strategic move to a low carbon dioxide transport in the UK.

Transport is defined by the Oxford Dictionary as, ‘a system for carrying people or goods from one place to another’. It is a critical component of economic development, globally and nationally. Transport availability and efficiency affect development patterns and can be a boost or a barrier to economic growth within individual nations (Krugman, 2009) and more widely. In the context of infrastructure, mobility can be seen as a utility, with decisions to be made on the optimum modal mix and coordination.

By creating links between disparate locations, transport encourages trade, growth and well-being. It provides access to a wider market, adding to economies of scale in production, specialisation, distribution and consumption. It is essential for geographical and social inclusion, spreading prosperity and encouraging development.

By promoting opportunities, transport allows a region to retain its young people who otherwise might move to a big city, draining the countryside of its vitality. Thus the examination of costs and benefits of transport is a complex subject, with many parameters other than just greenhouse gas emissions affecting the wisest choice for a nation (ICE, 2011).

If the underlying vision of government is for continuing national prosperity and growth, it has to ensure that the national and international transport system is fit for purpose, providing connectivity that is efficient, socially enhancing and environmentally positive.

2. National emissions and transport now

The UK has ‘offshored’ much of its manufacturing, which has provided apparent territorial emission reductions, although less control of consumptive emissions, with manufacturing powered by grids elsewhere and contributing to the territorial emissions of others. The Infrastructure Carbon Review provided the latest inventory of carbon dioxide equivalent emissions in the UK, estimating total national emissions to be 981 MtCO2e, a year on
a consumptive basis, including imported emissions that were previously unaccounted for in the strictly territorial assessments.

More than half of the total UK emissions are due to national infrastructure, of which transport is a significant 159 MtCO₂e per annum, accounting for 16% of the total. The majority of transport emissions are from use of transport infrastructure – that is the tail-pipe emissions from cars, trains, ships and aircraft – rather than infrastructure construction and operation. In 2010, over 60% of transport emissions derived from road use, whereas rail was an extremely low 2%, as graphically displayed in Figure 1. Cars were the dominant mode, emitting 52% of the total transport sector, with road freight third, responsible for 11% (Figure 2).

2.1 International transport

International aviation has grown over the last 40 years at an annual rate of 5% (DfT, 2013). Shipping is a dominant force and globalisation of trade has led to significant increases in shipped volumes. Accounting for emissions from international aviation and shipping is problematic due to differing accounting methodologies. The allocation of consumptive emissions enters into the realms of higher-level, international agreements. As a consequence, international aviation and shipping have not yet been included in the UK’s Climate Change Act 2008 (2008), despite the recommendations of the Committee on Climate Change (CCC) for their inclusion.

The Infrastructure Carbon Review recognised the need to move from a territorial methodology to a consumption-based methodology and attempted to reconcile the two by considering international aviation and shipping on the basis of departing journeys. Therefore, emissions from flights and ships that depart from the UK are counted, but those that arrive are not. Thus, international aviation and shipping emissions account for 20% and 6% of total UK transport emissions, respectively (Figure 3).
2.2 Energy waste in transport

Understanding the efficiency of a national transport system requires an understanding of how much energy different transport modes waste and hence how much carbon dioxide they waste. MacKay (2008) presented the efficiency of different passenger transport modes in terms of energy consumption per passenger kilometre travelled and speed of travel – reproduced in Figure 4.

For example, walking and cycling are extremely energy-efficient means of transport, but transport a single passenger over small distances at low speeds. On the other hand, a private car is high on wasted energy for transportation of a small number of passengers, with more luxurious cars even higher.

Per passenger-km travelled, public transport emits less carbon dioxide than a car at average occupancy (Hodges, 2010; Richardson et al., 2008). Shifting away from private towards mass modes of transport will result in reducing wasted energy per passenger-km. However, such transformations can take time to achieve, involve large capital carbon dioxide investment – the emissions associated with construction and decommissioning – and the need to alter city fabric as well as public perception.

Figure 4 comes with some caveats that are extremely important when considering the sustainability of mass-transit systems, requiring a holistic understanding of each transport mode and its sensitivity. Ridership and urban form will have a major impact on the capital carbon and cost of rail (Saxe et al., 2015).

Buses and trains are particularly sensitive to ridership: a bus may have lower operational carbon dioxide – emissions associated with operation and maintenance – when full, but this advantage degrades as ridership decreases. A transport network supported by real-time information that can elastically respond to match supply and demand can bring about large efficiency savings together with reduced wasted energy. The same information network can provide simple knowledge on likely waiting times to potential mobility consumers, which also encourages public transport use over the convenience of immediately available private transport. In time, with autonomous vehicles, there will be a blurring of the strict distinction between public and private transport.

2.3 Freight transport

MacKay (2008) also produced a similar plot comparing different freight transport efficiencies reproduced in Figure 5, which is very informative on the current national strategy of distribution and delivery of goods and resources and its emissions footprint. Road freight, which is the currently dominant form of land transport, is ten times less efficient in transporting the same load of goods over the distance compared to rail freight.

Freight transportation is arguably a bigger generator of emissions and is frequently competing with passenger transportation for capacity on the same roads and railways. Thus a solution for one type of journey should be cognisant of its effects on others, and the big picture is most important in terms of strategic decision making on future expansion of transport and consideration of other technologies in the mix that, to date, have not been seriously considered in the UK (e.g. road freight trains).

2.4 Transport and the city

Urban transport emissions are a significant part of the national total. Urban transport is a super-complex system with socio-economic, political and geographical implications. London accounts for about 13% of the total UK population and its 9.4 MtCO₂ transport emissions (TfL, 2011) are almost 10% of the national total ground-based transport emissions.

The density of a city dictates the energy efficiency of its transport. Barcelona and Atlanta have populations of about 5 million people, but Barcelona’s dense nature and plentiful public transport allows its citizens to expend just a tenth of the carbon dioxide emissions on transport that sprawling Atlanta requires (NCE, 2014).

Jahanshahi and Jin (2015) suggest that there are three types of population density across the UK when considering the passenger transport distribution. They say 20% of the population lives in dense areas with access to good public transport and so can take advantage of it, while 30% live in low-density rural areas where...
private car journeys are probably the only option. It is in the suburban areas of intermediate density, where the remaining half of the UK population lives, where there is an opportunity for significant mode shift to less wasteful modes of transport.

2.5 Policy and perceptions

Recent policy decisions that aimed to reduce transport emissions have had mixed results. The claimed efficiency benefits of diesel have proven to be a double error. First, although lower carbon dioxide emissions are achieved, large amounts of particulate matter have a much greater and more damaging effect on human health in the short term. Second, the improved efficiency has been offset by an increase in travel distances by journeys.

In the recent past, private car ownership had become a status symbol with the run-down of public transport up to the 1980s. The famous apocryphal quote from the Thatcher government era, ‘A man who, beyond the age of 26, finds himself on a bus can count himself as a failure’, best describes the mentality where private cars were prized possessions, irrespective of the practicalities or efficiencies as means of transport.

Public perception is now maturing, with the realities of ever-increasing traffic congestion and cost of owning and running a private car leading to a public understanding of the advantages of mass-transport alternatives.

Furthermore, the nature of private transport is evolving: in congested urban areas like London, walking and cycling are becoming a preferred alternative to short car trips. Recent statistics (TfL, 2012) indicate that one-third of the 4.6 million daily car trips in London are less than 2 km. Based on a very rough calculation, this is equivalent to at least 135,000 t of carbon dioxide per year in heavily congested urban traffic. Two kilometres can be easily covered on foot or by bicycle (Figure 6).

A modal shift from short car journeys would therefore directly eliminate 135,000 t of tail-pipe emissions (1.5% of the total London transport emissions) and, more importantly, relieve the higher stop–start emissions associated with traffic congestion.

Alignment of growth with emissions targets must be realised across all infrastructure sectors, recognising the exceptionally long time for solutions to be implemented.

3. Transport in the future

Large infrastructure schemes have long gestation periods. The Crossrail cross-London railway was first mooted in the 1940s. Hard planning for the current scheme started in 2001, with parliamentary approval in 2008 and full opening expected in 2019. This represents 18 years of continuous work – 7 years of design and planning, some 2 years of enabling works, then about 9 years of main construction.

Likewise, work on the High Speed Two (HS2) north–south national rail route started work in 2009 with a view to phase 1 opening in 2026, a period of at least 17 years. Thus transformational infrastructure projects take about a generation from firm commitment to actual operation.

The Infrastructure Carbon Review made use of projections from 2010 to 2025 and through to 2050 (Figure 7). These are based on the Department for Energy and Climate Change’s pathways to 2050 model (DECC, 2013), using the Markal 3.26 scenario. They considered a wide range of sources including governmental and international reports up to the year 2006, but not beyond that. These projections are not currently aligned with national business and growth aspirations and strategies, as described below.

Figure 6. In London, which accounts for 10% of UK ground-based transport emissions, one-third of car trips are under 2 km – an easy walk or cycle

Figure 7. Current and projected greenhouse gas emissions from UK transport modes
Alignment of growth with emissions targets must be realised across all infrastructure sectors and reflected in the UK Treasury’s infrastructure pipeline – recognising the exceptionally long time for solutions to be implemented.

3.1 National transport

As 2025 approaches, road car emissions are projected to drop dramatically to 33% of transport emissions and international aviation is projected to approach parity with cars.

The projections suggest that rail starts from a very low emissions contribution in 2010, which further reduces by 80% by 2050, predominantly a result of increased electrification using a lower carbon dioxide electricity supply. This is likely to include projects such as the northern hub and Great Western electrification schemes, as well as HS2, HS3 and maybe others. Considering the increased demand due to mode shift plus the electrification of traditional diesel lines, these savings are significant. However, to date Network Rail has assessed that only 60% of its lines offer a good cost–benefit ratio for electrification (Casey, 2014: p. 21).

Of all transport modes, road has the greatest projected emissions savings, with an overall 82% reduction between 2010 and 2050, presumably due to electrification of vehicles and network upgrades. A long-term lower carbon dioxide solution for freight vehicles is yet to be found, so the forecast long-term road freight emissions reduction can only be achieved by strategically shifting freight onto rail or possibly domestic shipping. Road journey times are highly variable and so moving on to infrastructure with less journey time variability will carry low economic risk and likely hold positive economic benefits.

Domestic aviation, although initially small, is projected to increase emissions by 60% by 2050. This is at odds with the general trend of phasing out short-haul flights and a shift towards high-speed rail.

3.2 International transport

The growth in international aviation and shipping is predicted to continue, although at a slower rate. This growth is reflected in an increase of 51% in aviation emissions and a massive 173% in shipping emissions by 2050. Much of this growth will wipe out the hard-earned savings in the road sector and others.

Aviation’s energy requirements make it unsuited for a lower carbon dioxide electricity supply. The power–weight ratio of battery technology is unlikely to offer a viable technical solution for air travel before 2050. However, flights remain the most efficient means of transport per passenger-km over long distance and long-haul passenger travel will continue to be dominated by aviation, although the rate of growth could reduce. Measures such as reducing aircraft fuel consumption on the ground and through glide paths may moderate aviation emission impacts until technology catches.

Shipping is more amenable to technological improvements for increased efficiency. Improvements such as improved hull design, engine and propulsion design can offer 20–30% savings (ABS, 2013) (Figure 8). Research has identified the use of small nuclear reactor systems to power bulk carriers as a means of providing sufficient propulsion at a reduced carbon dioxide output, yet significant investment challenges and regulatory uncertainty pose real barriers (Dedes et al., 2011).

3.3 Subsidies

The role of fossil fuel subsidies on transport modal choice should also be considered. A recent International Monetary Fund working paper (Coady et al., 2015) has put remarkable figures to the scale of the subsidies, at around US$4·9 trillion in 2013 and rising to US$5·3 trillion in 2015. The implications for this on the cost–benefit analysis of transport infrastructure planning are profound and the value of traditionally held modes is set to change following the UN Climate Change Conference in Paris 2015.

4. Strategic transport

Technological advancement is often considered the primary means for resolving the emissions problem. However, the impact of new technologies at the macro scale is difficult to quantify and hence effective policy is difficult to implement. Almost independent from technological changes, a successful long-term national strategy is needed to ensure that transport remains true to its definition and operates as a seamless system transporting people and goods, rather than the sum of different transport modes competing against one another.

If roads and rail are strategically considered as an integral part of a national connectivity system, then transport efficiency can be optimised. This is not currently the case in the UK. The bulk of freight is transported on roads, while rail freight competes with and is constrained by passenger transport on the limited rail routes available.

The government’s recent road investment strategy (DfT, 2014) provides a long-term vision for the strategic road network and a much-needed longer-term investment plan, but still considers the network in isolation from the rest of the transport system. As an example, the strategy plans for improvements of road freight connections for the ports in the south-east, but without making the long-term economic and emissions case compared to a freight rail option.

4.1 Rebalancing the modal mix

Meaningful transport emissions reduction can only result from considered rebalancing of the modal mix, together with smart

Figure 8. Unlike aviation, shipping can be readily made more energy efficient – with small nuclear reactors a possibility
Rail freight is ten times more energy efficient than road freight (Figure 9).

Interfacing between modes that is flexible to optimise ridership and eliminate congestion.

Decarbonisation of road passenger transportation, together with upgrading road infrastructure, will play a major role in the reduction of the single biggest current polluter. This must be assisted by a shift of freight transport off the road network, as it is technologically difficult to decarbonise.

Electrification of existing rail should be considered on the basis of value–benefit ratio, including wasted energy reduction potential as well as capital cost. Increased capacity on passenger rail lines such as HS2 has the potential to free up freight capacity on the classic rail lines it bypasses and thus possibly lead to significant energy savings as a result of enabling that substantial modal shift from road freight to electrified rail freight (Figure 9).

New access provision to major distribution hubs such as ports and airports and new freight capacity should be created using least-energy-wasted means, favouring rail against road. This will reduce the disproportionately large emissions that can be associated with the ‘last mile’ problem.

Freight transport into urban environments should be overhauled, with goods distribution centres located outside the urban perimeter, from where goods are disseminated to urban destinations by means of light rail – possibly underground – or other coordinated and least-polluting modes.

Individual freight companies are optimising their individual journeys; significant savings could be made by strategically connecting across companies in order to increase load factors on all journeys. This would require legislative support, such as taxation on void space in lorries and incentivising of territorial transport rights and shared logistics. As freight transport is dominated by volume and not weight, there are efficiency opportunities through the use of longer and larger vehicles, especially for the trunk part of journeys.

Substantial emissions savings can also be achieved with a shift from short-haul passenger flights to high-speed rail. Airport congestion will then be eased if short-haul aviation is largely phased out, making space for the unavoidable long-haul demand and demoting the need for airport creation and expansion.

Energy-efficient mass-transport passenger options should be developed to and from city centres for the suburban and rural areas that are currently mainly dependent on private transport. More fundamentally, reduction of the underlying need for travel should be addressed by better integrating land use and transport planning, aiming for reduction in demand of both number as well as length of journeys.

4.2 Hard and soft interventions

A strategic optimisation of the transport system will require both hard and soft interventions. The hard interventions will involve a substantial upfront capital investment in upgrading existing and constructing new infrastructure.

The soft interventions should drive changes in the behaviour of transport users. There is a great deal of spare capacity on many sections of the network at different times that can and should be utilised as and when it is possible and appropriate. This second policy aspect will require a drive for behavioural change, resulting from a realistic mapping of human interaction with infrastructure, which should also dictate and influence the engineering interventions. The revolution in large, crowd-based data sources will enable a better understanding, providing data and insights that were previously not possible. More fundamentally, it will also require behavioural change of the users that will drive the modal shift for increased efficiency.

5. Conclusions

The UK Climate Change Act 2008 (2008) was the beginning of the regulatory push to a lower carbon dioxide emissions economy to avoid dangerous climate change. The legislation requires an overarching reduction of 80% in emissions by 2050 compared to 1990 levels, but does not stipulate how or where these savings will come from.

As time has progressed, it has become imperative to identify strategically the sectors that will be required to make savings and plan how those savings will be made. Emissions reduction must take centre stage in the Treasury’s assessments of infrastructure investment in the UK, in line with the traditional economic metrics.

It is now less than 10 years from the fast-approaching 2025 and its interim targets. The encouraging trends observed in 2013 seem to have reversed (GCB, 2015), suggesting that some of them were due to the recent recession. The rate of change must accelerate to achieve the tangible results required. It is of great importance that progress to date and the implications of this for progress into the future are assessed.

The 2013 Infrastructure Carbon Review was an important step in recognising how the significant infrastructure sector will contribute to reaching the 2050 target; given its systemic nature, the types of changes will be different to those proposed and implemented to make buildings more ‘carbon efficient’.

This paper has attempted to put the transport section of the report into context and prime the necessary discussions for the strategic decisions to be made. Strategic decisions on emissions must be made, which will involve major capital investment. Incremental improvements in transport efficiencies are not
enough; considering the entire transport system as a whole and making strategic decisions is paramount. Modal shift is of fundamental importance that cannot be achieved on the scale required if each mode within the transport sector acts without strategic direction.

The control and optimisation of emissions will require the following.

- **Standardisation of the boundaries of life-cycle assessments** (as discussed by Saxe et al. (2015) for rail) – this is now possible following the recent publication of PAS 2080 (BSI, 2016).
- A coherent national strategic plan or ‘roadmap’ for transport for the next 35 years to 2050, setting out the main transformational projects that will be required and identifying a bespoke funding mechanism, recognising that each large transport project will take over half of that period to bring to fruition.
- Within that transport roadmap, prioritisation of infrastructure projects that will bring the largest whole-life emissions improvements in the national infrastructure system.
- Enabling behavioural change on passenger transport choices through a mix of smart infrastructure provision and regulation.

This paper is not simply about the optimisation of the current transport paradigm. Rather, it is about a fundamental change to the modal mix and a transformation of the national transport system to serve national prosperity best while enabling the substantial greenhouse gas emissions reductions required.

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**References**


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Creating inter-tidal and freshwater habitat on a brownfield site

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The Saltern wetlands is a new wildlife habitat in the Tees estuary floodplain near Middlesbrough, north-east England. Created by carefully breaching an existing flood embankment in two places, the managed realignment project is part of the Environment Agency’s tidal flood risk management strategy for the heavily industrialised estuary. Rising sea levels and higher flood defences will lead to a loss of existing mudflats, which are both vital for wildlife and provide a natural system for nutrient dispersal and cycling. This paper explains the challenges faced in recreating inter-tidal and freshwater habitats in a heavily industrialised environment. It analyses the changes in the site over the first 6 months following the breaches, looking in particular at the development and function of the adjacent creek system, the changing use of the site by birds and other wildlife, and the establishment of the target habitat across the freshwater and inter-tidal areas.

1. Introduction

The Environment Agency’s Tees tidal flood risk management strategy published in 2009 (EA, 2009) provides a sustainable plan for the alleviation of flood risk to nationally important infrastructure and residential properties within the Tees estuary.

The Tees estuary supports some of the largest producers of specialist chemicals in the UK and provides an inlet for petrochemicals arising in the North Sea, with the largest deep-water port on the east coast of England. The strategy identifies 560 commercial and 400 residential properties at risk. With climate change these numbers could rise to 900 commercial and 430 residential properties.

In contrast, the estuary is of international importance for nature conservation, particularly for birds, with significant areas designated as special protection areas, Ramsar sites, national nature reserves and sites of special scientific interest. The UK supports a wide variety of species and habitats. A key policy tool for conserving these is the designation and management of protected sites.

Sites known as special protection areas for birds and special area of conservation are of European importance. The sites have been created under the EC birds directive (EC, 1992) and habitats directive (EC, 1992), which are ratified under UK legislation. Ramsar sites are defined under the Convention on Wetlands of International Importance signed by the UK in Ramsar, Iran in 1971 but fully adopted in 1975. Sites that are nationally important for plants, animals or geological or physiographical features are designated as sites of special scientific interest.

The value of the Tees estuary for internationally important numbers of bird species is recognised by the designation of 1247 ha of the estuarine and coastal habitats as the Teessmouth and Cleveland coast special protection area and Ramsar site. The special protection area includes sand and mudflats, rocky shore, saltmarsh, freshwater marsh and sand dunes, which provide feeding and roosting opportunities for important numbers of water birds in winter and during passage periods. In summer, little tern breed on beaches within the site, while Sandwich tern are also abundant.

The Teesmouth national nature reserve includes sand dunes, grazing marsh, inter-tidal sand and mudflats with harbour seals and grey seals using tidal channels. The reserve is split into two main sections. North Gare is an area of dunes and grazing marsh, used by lapwings and curlew, while Seal Sands is one of the largest areas of inter-tidal mudflats on England’s north-east coast, again used by waders, including redshank and dunlin (Figure 1).

Cowpen Marsh site of special scientific interest comprises a large tract of grazed pasture intersected by freshwater channels, lying west of the A178 Tees Road which crosses Greatham Creek. The creek forms the boundary between the boroughs of Stockton and Hartlepool. Greatham Creek and Cowpen Marsh provide important roosting and feeding grounds for the large numbers of migratory wader and wading birds that feed on the inter-tidal flats around the Tees estuary. Species recorded throughout the winter months include wigeon, teal, curlew, redshank, bar-tailed godwit, lapwing, golden plover and dunlin.

The flood risk management strategy identified a potential loss of designated European habitat (i.e. the special protection area and Ramsar sites) attributable to the coastal squeeze effects of the Environment Agency defences over the next 100 years. This loss required creation of compensation habitat. A 77 ha site was purchased by the Environment Agency in March 2009 at Greatham Creek on the Tees estuary, Hartlepool (EA, 2011) to create this compensation habitat through managed realignment.
2. Managed realignment site

A managed realignment allows an area that was not exposed to flooding by the sea to become flooded by removing coastal protection. For the Greatham Creek site, the area does not itself provide a reduction to local flood risk, but compensates for the predicted long-term habitat losses elsewhere in the Tees estuary as a consequence of coastal squeeze.

Coastal squeeze is defined as inter-tidal habitat loss that arises due to the high water mark being fixed by a hard defence (e.g. flood wall or embankment) and the low water mark migrating landwards in response to sea level rise, thereby narrowing the inter-tidal zone. The loss of designated European habitat attributable to the coastal squeeze effects of the Environment Agency defences in the next 100 years identified in the flood risk management strategy was predicted at 12.8 ha (EA, 2008).

A further 7 ha of compensatory habitat as part of the Redcar flood alleviation scheme needed to be met. The requirement at Redcar was enforced by a Town and Country Planning Act 1990 (1990) section 106 agreement within the planning permission, requiring the new habitat to be in place within 5 years of the start of the Redcar scheme. A section 106 provides a legal agreement between the developer (in this case the Environment Agency) and local planning authority to ensure that a planning requirement is met and is used when a standard planning condition is considered to be insufficient. The requirement for compensatory inter-tidal habitat was therefore a minimum of 20 ha covering both elements (EA, 2008).

The purchased site naturally offered considerable benefits as a managed realignment as the original relic system could be linked to the tidal Greatham Creek through the breaches with only minor regrading of the ditches by excavators. Tidal flooding of the site would allow the restoration of natural tidal movement across the site and support the creation of saltmarsh. Mudflats would be created within the restored ditches and low points on site.

The habitat creation at Greatham Creek supports the implementation of the schemes at Redcar, Port Clarence and Billingham that reduce flood risk to nationally significant industry and hundreds of residential properties.

3. Realignment of embankment

The scheme required the creation of approximately 1.2 km of new embankment along the eastern and northern boundaries of the site (Figure 2). The embankment provides flood protection to the A178 road, and protects and maintains dry access to the critically important infrastructure on the northern boundary of the site. The embankment is up to 2.5 m high (approximately 4.4 m above ordnance datum (AOD)) based on the lowest ground levels within the site, and provides the 1-in-30 year protection (3.33% annual exceedance probability) offered by the existing defences that run parallel with Greatham Creek.

The clay material for the embankment was sourced from borrow pits within an adjacent arable field within the land holding originally purchased by the Environment Agency in 2009. An Enkamat geotextile was laid on top of the clay core of the embankment with a thin layer of topsoil placed on top which was seeded with a low-maintenance mix. The roots of the grass combine with the geotextile to stabilise the embankment and reduce the impact of scour by tidal action.

To flood the area between Greatham Creek and the new embankment, two breaches, each 50 m wide at the base increasing to 70 m at the crest, were constructed in the existing embankment. Modelling results suggested that the site topography would allow for the entire site to be inundated by a mean high water spring tide by way of the existing relic ditch system that remained on site. Further information is provided in the paper by Latham et al. (2013).

4. Site remediation strategy

At the time of purchase the site was used for grazing livestock and arable but had an industrial past including salt production. The area is believed to have been used for salt production since Roman times. The mounds that are found across

![Figure 1. Site location with the heavily industrialised Tees estuary area](image1)

![Figure 2. Design of the Greatham managed realignment and borrow pit areas](image2)
the site are locally known as salterns, were created as a result of over-burden from creation of pools used in historic salt-making and are an important heritage feature and provided the final site with its name, Saltern wetlands.

Commercial salt production existed from 1894 until 1971. The commercial salt extraction used wild mining, which involves injecting water into the salt beds (around 300 m below the surface) through a series of brine wells across the site and pumping out the resulting saline solution. When the facility closed the land was used for grazing, although a food-production factory remained on site until 2011 when the buildings were demolished.

Desk study investigations using information from British Geological Survey indicated that 72 brine wells between 270 m and 350 m deep could remain across the site. The Sherwood Sandstone is classified by the Environment Agency as a major aquifer and lies approximately 250 m below the surface. These brine wells had not been decommissioned and the groundwater aquifer had been designated as ‘probably at risk’ from saline intrusion. Without decommissioning, the breaching of the existing embankment and the tidal flooding of the site would pose a further risk to groundwater as seawater had the potential to enter the Sherwood Sandstone aquifer by way of the open well heads.

After detailed geo-physical surveys, ten of the 72 wells were considered to be duplicates or mapping errors, 12 of the remaining 62 were searched for but could not be located. Fifty brine wells were located; only two of these were found to be fully grouted. Forty-two were fully decommissioned during 2012–2013. Two brine wells were considered to be located within a spoil heap, which formed the western boundary of the managed realignment site. The well heads of the remaining four were buried in excess of 5 m from the surface and therefore considered unlikely to provide a pollution pathway after breach. Planning conditions required the decommissioning of the brine wells prior to breaching. Full details of the decommissioning can be found in the paper by Latham et al. (2013).

Remediation of the Saltern wetlands included a large spoil heap that marked the western boundary of the site. Preliminary geo-environmental surveys indicated that the heap was inert and understood to be a mixture of waste from the past industrial uses on site, most probably since the commercial salt production. The steep sides of the heap required regrading to improve stability and seepage from the spoil heap showed some evidence of heavy metals.

It was considered that brine from the two wells thought to be located within the spoil heap seeping into the perched waters and passing through the base of the mound may be mobilising metal compounds. During excavation to determine the location of the two brine wells, fly-tipped material from the salt workings was discovered buried in the spoil heap. Testing of the material showed the presence of asbestos fibres. The discovery of asbestos meant that no further excavation could be undertaken.

Long-term risk management approaches initially comprised the removal of the entire spoil heap or placement of an engineered clay barrier to minimise the potential for leachate generation and prevention of emission of asbestos fibres. These options would be costly and could generate significant health, safety and environmental issues associated with further excavation, material transport and off-site disposal.

Detailed consultation with the Environment Agency’s groundwater and contaminated land team led to the preparation of a contamination risk assessment to consider the risk to the environment from the leachate. Concentrations in existing surface watercourses adjacent to the spoil heap were considerably below the concentrations in the water at the base of the spoil heap, demonstrating the dilution effect of the watercourse with respect to the actual concentrations.

Air monitoring testing carried out in the vicinity of the spoil heap and a risk-based analysis of the findings using an industry-leading approach confirmed that the risks presented to future users of the site from the asbestos were not significant. Through agreement with the local authority, Hartlepool Borough Council, the project team was able to agree the premise for a contamination risk model for the area and mitigation.

The spoil heap was covered with Salix Vmax C350 erosion-control matting. It was then seeded at 30 g/m² with a low-maintenance grassland mixture comprising a balanced blend of fescues, bents and nitrogen-fixing legumes. Establishment of the grassland has been satisfactory across the spoil heap. The area was fenced with chestnut paling, but no further risk management measures were required.

Contamination issues have been fully documented in the site construction health and safety file, which will be passed onto the manager of the site under a lease agreement.

5. Habitat creation

5.1 Borrow pits

The borrow pits were active over a period of 20 months. The former arable field was divided into three areas for restoration with a total area of 12.5 ha (Figure 3). The aim was to restore the borrow area to provide a range of freshwater ponds that would complement the inter-tidal habitats.

Area 1 was restored in February 2013, providing a mixture of smaller waterbodies for amphibians and dragonflies (Figure 4). After removal of the clay material the excavated area was levelled and graded to create a basin. This was to increase the overall catchment area as all the waterbodies within the borrow area are fed only by rainfall. The individual ponds were then excavated into the newly formed basin, removing any steep slopes from the excavated areas. The bank side slopes for the ponds were graded to less than 1:5 and in most areas less than 1:20 to provide a shallow edge to aid colonisation. The basin is linked to a swale that joins areas 1 and 2.
Area 2 was restored shortly after area 1. A large wader pool with scalloped edges was created (Figure 5). Clay excavation was shallower than in area 1; however, the pits were still re-profiled to provide a depth of between 1–1.5 m at the deepest sections. Mounds and islands were formed to provide refuge areas within the pool. Shallow margins were created on the edges of the pool to aid colonisation. After re-profiling, the original topsoil from the arable field was returned, covering the bottom of the pool. This would offer a nutrient source to encourage rapid development of invertebrate communities to benefit the feeding waders. The shallow margins would be exposed during the summer providing a muddy edge and a potential food supply for wading birds.

A further wader pond was created in the final compartment, area 3 (Figure 6). This is the shallowest of the excavated areas. No additional excavation was undertaken, although the site was re-contoured and shaped to provide the diversity of edge habitat that would be beneficial for waders and water fowl.

Parts of the former arable field were not excavated and these areas will develop as a grassland transition between the freshwater habitats created in the borrow area and the inter-tidal habitats created in the managed realignment.

The borrow pit area has been seeded with an appropriate mix based on the locally prevalent national vegetation classification targeted at the desired bird species (e.g. wigeon), with a mixture of bents and meadow grasses. The grassland was cut for hay in 2014 to encourage establishment of the sward.

There has been no marginal or aquatic planting in the waterbodies, which have been allowed to develop through natural colonisation. Areas 2 and 3 are fenced and will be grazed; however, it is intended to allow scrub to colonise area 1 to provide cover and over-wintering habitat for species such as great crested newt, common frog and common toad.

All the restored areas in the former borrow area are rainwater fed. A basic level of gravity-fed water management has been introduced between the different compartments through the restored area. The wetlands are linked by a system of swales graded to a contour within the wetlands. As the upper area fills with water, it will spill into the swale and drain into the next area and eventually discharge into the managed realignment area through the existing drainage. The drainage through the site aims to reduce potential nutrient levels from wash-off from the former agricultural areas in to the realignment site. There are no sluices
or penstocks on any of the swales that run through the restored borrow pit.

5.2 Brackish ponds

It had originally been hoped that flooding could be extended to the base of the containment bund of the adjacent petrochemical plant. However, the presence of nationally significant infrastructure and the need to maintain an acceptable new alignment for a public footpath (Latham et al., 2013) required construction of the new flood embankment.

A small area of land of approximately 6 ha remained between the line of the new flood embankment and the containment bund for the adjacent petrochemical plant. Three further ponds were created within this area. These ponds were linked to the surface-water drains that passed through the containment bund and fed into the managed realignment creek system by way of culverts in the new flood embankment (Figure 7).

The culverts were fitted with fish-friendly ‘tilting’ penstock valves, which allowed tidal exchange between the managed realignment site and the additional ponds. The penstock can be manually adjusted to control the volume of water passing through the culvert from the realignment area and, therefore, the inundation of the ponds by the brackish tidal water.

5.3 Breaching

Breaching of the original flood embankment adjacent to Greatham Creek and tidal flooding of the site was only possible once the remediation of the brine wells and spoil heap had been completed, along with a suitable period for establishment of the grass on the new embankment. The establishment of the grass was an important factor for embankment stability as the grass binds with the geotextile.

The existing embankment adjacent to the creek was breached at two locations in May 2014. The timing of the breach was carefully programmed to avoid the seal pupping – when the young seals are most vulnerable and aggressively protected – that occurs along Greatham Creek and the Tees during early summer (June–July) and the over-wintering bird season (October–March). A tidal cycle to provide a sufficient window during low-tide to access the creek side of the existing embankment was also necessary.

Each breach measures 70 m wide at the top of the embankment, 50 m at the base with a 10 m channel excavated at the base of the breach to connect Greatham Creek with the creeks through the managed realignment site. Breach construction was started by removal of material on the dry side of the former flood embankment (Figure 8). Breaching was completed during a period of neap tides, when the creek levels were low enough for machines to gain access to cut back the defences and excavate to the base of the main breach and remove the remaining material.

The breaches were designed to provide a two-stage profile. The base channel of the breach was excavated to 0.5 m AOD matching Greatham Creek with the shoulder
excavated to 2.1 mAOD. Rip-rap was placed on the exposed ends of the embankment. This two-stage design allows tidal inundation across the site over a range of tides. Experience has shown that narrow breaches can lead to entrenched channels across the managed realignment site, resulting in a failure to flood areas of the site during smaller high tides. This can affect the site’s conversion to saltmarsh.

For the western breach, there was no existing drain on the creek side to reconnect the remnant field creeks. Access to the creek was restricted to prevent damage to the existing areas of saltmarsh aligning the creek. This meant that excavation of the base channel was left slightly higher than the design level (1.2 mAOD compared to 0.5 mAOD).

About 8200 t of material was removed from the breaches. The material was retained and re-used on site to reduce waste to landfill. The breaches excavation was completed on 27 May 2014, excavating the material from the channel and connecting the site with Greatham Creek and the Tees estuary for the first time in over 100 years.

5.4 Tidal inundation

To optimise habitat creation for wintering wildfowl and waders, the scheme has aimed to provide the maximum possible area of inter-tidal mudflat, an important feeding resource. Understanding how best to use tidal energy was key to producing this end result, which will significantly enhance the biodiversity potential of the site.

The gradient of the creeks on site was linked to Greatham Creek to ensure a sequence of flooding and emptying of the site during each tidal cycle. Water held in lower areas on site would prevent these areas fully developing as mudflat and saltmarsh, with these areas remaining as semi-saline pools. Ponding would provide fewer opportunities for feeding for the wader species targeted by the habitat creation.

Following observation of the flooding pattern, re-grading and deepening of the field creeks and excavation of a new creek section was required immediately after the breach to ensure emptying of the site adjacent to the spoil heap (Figure 9). This was the lowest point of the site and at a similar elevation to the creek itself. Once the new creek had been constructed, no ponding was observed.

![Figure 9. Plan of western embankment breaches (a) and cross-sections of new graded channel (b)](image)

6. Monitoring of site and habitat development

Colonisation of the wader pools and ponds has been rapid, with reedmace and water crowfoot recorded in the first year. Area 1 has, however, held more water than anticipated and formed a single wader pool, which has been well used by teal particularly during the winter. This area required substantial reworking to form the ponds and this is likely to have resulted in compacting of the clay and reduced infiltration of rainwater.

Initial studies of the creek system have shown a substantial period of natural erosion as the new system re-establishes itself under the new tidal pattern. The erosion was greatest at the western breach where the channel naturally adjusted very rapidly and eroded to the originally desired design level (Figure 10), matching the eastern breach levels. This erosion will settle as the site naturally adjusts itself. It has been observed that the site empties during each tidal cycle and currently there is no evidence to indicate that either breach is dominant. These observations are important in determining the long-term sustainability and resilience of the managed realignment.

The primary aim of the scheme is to compensate for long-term special protection area and Ramsar habitat losses; therefore, the site was targeted for the development of habitat supporting wintering wildfowl and waders. The winter of 2014–2015 was the first opportunity to monitor bird assemblages. Table 1 provides a summary of counts completed by Natural England as the formal Wetland Bird Survey data are not currently available.

The Wetland Bird Survey monitors non-breeding water birds in the UK. The principal aims of the survey are to identify population sizes, determine trends in numbers and distribution, and identify important sites for water birds. Some species (indicated in bold in Table 1) are recorded under article 4.2 of the birds directive (79/409/EEC; EC, 2010) noted on the special protection area details. However, wigeon, teal, curlew and dunlin are also important species for the area. While many of the recorded species were seen using the creek in previous years, the expansion of mud and tidal habitat across the site has seen large numbers of lapwing and dunlin within the managed realignment site.

It will take a number of seasons to determine the benefits the site has for waterfowl and wading species. Food availability for the waders will be a key determinant for the suitability of the site. This will depend on invertebrate availability within the newly created mudflats. Greatham Creek is an important feeding area for waders and the efforts made to link the gradient of the new creeks through the site and to maintain an active tidal regime will support the expansion of the inter-tidal invertebrate populations.

The management and monitoring plan for the site includes annual surveys that will add to the information collected through the Wetland Bird Survey programme administered by the British Trust for Ornithology, the Royal Society for the Protection of Birds (RSPB), the Joint Nature Conservation Committee and the Wildfowl and Wetlands Trust.

The seals seen on the south bank of Greatham Creek prior to the breach are now frequently observed using the creek system within the site, and during high tides are seen moving into the flooded area over 500 m from the breach locations.

Targets set for the site included the establishment of pioneer saltmarsh species within 2 years (5 years at the outside) and characteristic vegetation communities within 10 years. The managed realignment was not rotovated and had not been grazed for 18 months before the breach, leaving an established grass cover when the site...
Figure 10. Initial erosion at the western breach in June 2014

<table>
<thead>
<tr>
<th>Species</th>
<th>Number by date in the 2014–2015 and 2015–2016 over-wintering periods (WeBS data source: English Nature)</th>
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</thead>
<tbody>
<tr>
<td>Black-tailed Godwit</td>
<td>12</td>
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<tr>
<td>Curlew</td>
<td>2</td>
</tr>
<tr>
<td>Dunlin</td>
<td>2</td>
</tr>
<tr>
<td>Golden Plover</td>
<td>950</td>
</tr>
<tr>
<td>Grey Plover</td>
<td>2</td>
</tr>
<tr>
<td>Knot</td>
<td>1</td>
</tr>
<tr>
<td>Lapwing</td>
<td>167</td>
</tr>
<tr>
<td>Oystercatcher</td>
<td>2</td>
</tr>
<tr>
<td>Redshank</td>
<td>3</td>
</tr>
<tr>
<td>Ringed Plover</td>
<td>1</td>
</tr>
<tr>
<td>Shelduck</td>
<td>3</td>
</tr>
<tr>
<td>Teal</td>
<td>13</td>
</tr>
<tr>
<td>Wigeon</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Bird counts for the over-wintering periods 2014–2015 and 2015–2016 at Saltern wetlands – species shown in **bold** are recorded under article 4.2 of the birds directive (79/409/EEC; EC, 2010) noted on the special protection area citation (source: Natural England).
was inundated. No attempt has been made to seed the saltmarsh areas with the establishment of vegetation targeted through natural colonisation. The grassland has been burnt-off by the salt water and the development of species typical of saltmarsh vegetation, including samphire, has been recorded in May 2015, 1 year after breach.

6.1 Management and monitoring plan

A site management plan has been developed jointly by the Environment Agency and the RSPB, with input from Natural England, to agree and secure the long-term management and maintenance arrangements for the site. The management plan covers the site of the managed realignment, the new set-back flood embankment and the additional habitats within the restored borrow area and brackish ponds.

The plan incorporates the programme of ecological monitoring for the site. The plan will be a working document, as subsequent changes to the management of the site may be required as the site develops. Some management and monitoring aspects of the plan are specific to the Environment Agency’s legal obligations under the habitats regulations (HMG, 2010), relating to the securing of 20 ha of functioning inter-tidal habitat to compensate for coastal squeeze habitat losses.

The ecological monitoring therefore primarily focuses on recording the post-breach development of the inter-tidal habitat, and its use by wildfowl and wading bird species, to monitor the success of the compensatory habitat, in particular

- use of the realignment site by wintering birds for the 5 years following the breaches – monthly counts to be undertaken each year during the wintering months
- use of the site by bird species listed within the special protection area citation, to assess the success of the scheme in providing habitat for the affected species (redshank, knot, ringed plover, little tern, Sandwich tern)
- development of the new inter-tidal and transition habitats on the realignment site through surveys, for example national vegetation classification.

The findings of the ecological monitoring will be used to inform and guide the management of the site. The management plan and monitoring results will be reviewed every year with the RSPB and Natural England, so that any subsequent changes to the management arrangements can be discussed, agreed and documented as required.

The ecological monitoring period is scheduled to cover 5 years post-construction. At the end of year five, the monitoring findings as a whole will be reviewed to confirm completion of the ecological monitoring and successful establishment of the site.

7. Stakeholder engagement

Throughout the project’s development the scheme was supported by an environmental steering group made up of the RSPB, Natural England, Hartlepool Borough Council, Teesmouth Bird Club and the Environment Agency. The steering group has been vital in a partnership approach to the development of the preferred option, resolving potential conflicts and gaining widespread support for the scheme.

The paper demonstrates that brownfield sites can be developed successfully as inter-tidal habitats. This is important both for the restoration of industrial estuaries and where the availability of greenfield sites may be more limited or constrained.

8. Conclusions

Post-breach monitoring has and will remain important to provide vital information for future schemes. Initial studies of the creek system showed a substantial period of natural erosion where the channel adjusted very rapidly.

A double-breach design was applied. Neither of the breaches has been shown to be dominant and the inter-tidal areas have flooded and emptied during each tidal cycle.

It will take a number of seasons to determine the benefits the site has for waterfowl and wading species. Initial monitoring undertaken during the winter of 2014–2015 indicates that the expansion of mud and tidal habitat across the site has seen large numbers of lapwing and dunlin within the managed realignment site.

Initial colonisation of saltmarsh vegetation was recorded in May 2015, 12 months after breaching.

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