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**Design and construction of Tongwamen Bridge, China**
Z. Zhang, S.-S. Pan and C. L. Huang
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 1, March, 1–7

Tongwamen bridge is a half-through, concrete-filled steel tubular (CFST) X-type arch bridge with deck width to span ratio of 1/23·8. It is the first time that arch ribs of the plane truss type have been used in the construction of a long-span CFST bridge in China. The rationality of the design for this type of large-span, narrow bridge is justified using a description and discussion of some key issues related to the bridge design and construction, The paper provides an example of the design of a long-span, narrow, CFST arch bridge.

**Whole life cost analysis in concrete bridge tender evaluation**
C. Arya and P. R. Vassie
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 1, March, 9–18

In the UK large sums of money are spent annually on the repair and maintenance of structures. To avoid this problem in future construction, many government and private agencies responsible for asset management have recommended that designers should develop schemes that seek to minimise whole life costs, namely construction plus maintenance costs, rather than just initial construction costs. Currently there is no standard procedure for evaluating tenders in terms of whole life costs and therefore no way of checking that this recommendation is being fully implemented. This paper describes a straightforward model that can be used to assess the whole life costs of concrete bridges exploiting alternative durability options and shows how this model could be incorporated in the tendering process.

**Design of Garrion Bridge, Scotland**
J. Fleck, B. Chalmers and D. Todd
Proceedings of the Institution of Civil Engineers—Bridge Engineering, **157**, No. 1, March, 19–26

The construction of a 50m span *in situ* reinforced concrete arch bridge in central Scotland was completed in the spring of 2002. This paper describes the background, design development and detailed design for this design-and-build scheme. The new Garrion Bridge was designed and constructed to cross the River Clyde 8 km upstream of the town of Hamilton and at the existing junction of the A71 and A72. The bridge forms part of a new junction arrangement to alleviate traffic congestion by forming one arm of a new gyratory system with the other arm utilising the existing three-span masonry arch bridge. Following preparation of various alternative bridge forms, the new arch bridge was designed and constructed in accordance with the outline design approved by The Royal Fine Art Commission for Scotland. The bridge was constructed utilising an *in situ* reinforced concrete construction over the river with the springing point supports founded on and stressed back to the mudstone/sandstone rock strata below the river. The paper describes the background to the scheme, geotechnical issues and the various alternative crossings developed during the tender period as well as describing detailed design issues.

**Design of the New Medway Bridge, England**
D. A. Smith and C. R. Hendy
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 1, March, 27–36

The New Medway Bridge comprises 12 continuous spans of twin-cell box girder with an overall length of 953 m and, at 152·4 m has the longest externally post-tensioned span in the UK. It carries four London-bound lanes and a hard shoulder of the M2 and was constructed as part of the A2/M2 widening project in Kent for the Highways Agency. The need for external post-tensioning was imposed by the client for durability and maintenance reasons. External post-tensioning can lead to a loss in structural efficiency when compared with internal post-tensioning, particularly with respect to anchor zones and overall flexure. There is also an additional cost associated with the provision of deviators. The bridge was built under a Design

and Build contract, which made the need for economic and buildable details all the more acute. This paper identifies the various ways in which a cost-efficient durable design was produced and the way detailing problems specific to such a large externally post-tensioned structure were overcome. Examples include consideration of composite action between formwork and deck in construction, optimization of the permanent flexural design through overall non-linear analysis, design of diaphragms and spanning anchor beams, constraints on placement of external cables and simplification of the details for deviator blocks while maintaining adequate tolerances for construction.

**Evaluation of localised loading on suspension bridges**
T. A. Wyatt
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 2, June, 55–63

The deck girder moments and suspender-cable tensions caused by the application of localised loading to a conventionally articulated suspension bridge with a slender deck girder are expressed in a generalised and normalized form. Comparison with the analogous solutions for localized loading on cable-stayed bridges shows considerable similarity in practical numerical results, despite the disparity between the algebraic forms resulting from the differences of the basic mechanics of the suspension-cable and straight-stay structural systems.

**Bearings for the M2 New Medway Bridge**
P. Boulton and F. Tomaselli
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 2, June, 65–70

The M2 New Medway Bridge was opened on 16th July 2002. The 12-span twin cell concrete bridge deck has a 153 m river span and viaduct spans of up to 84 m. This paper describes the design, manufacture and installation of the unusually large bridge bearings used to support the deck at each of the nine pairs of piers. The design and type of spherical bearings used was influenced by the contractor's temporary works needs. The bearings used were manufactured from up to 13000 kg of solid steel plate per bearing.

**Behaviour of post-tensioned concrete box girders**
R. J. Lark, R. W. Howells and B. I. G. Barr
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 2, June, 71–81

This paper describes the results obtained to date from a study of the strains developed in two post-tensioned, prestressed concrete box girder bridges both during their construction and subsequent service lives. The instrumentation that was used is described and the simplification and representation of the material properties that were required for the subsequent analysis of the data are discussed. Results are presented for both short-term shrinkage strains developed during the construction of the concrete segments, short-term creep strains developed during the construction of the viaducts and long-term creep and service life strains developed over the 17-year period since their construction. It is shown that the assumptions, which are generally accepted for the design of such superstructures, are valid and that satisfactory predictions of the long-term behaviour can be obtained from analyses based on short-term properties, despite the variable environmental conditions that are likely to be experienced by the structures.

**Seismic design of Egnatia Motorway bridges, Greece**
K. Ahmadi-Kashani
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 2, June, 83–91

Egnatia Motorway in Greece is currently one of the largest civil engineering projects in Europe with over 600 bridges on its main axis alone. With the motorway traversing a wide range of seismically active terrains, a variety of bridge forms with different earthquake protection systems are constructed or planned on this project. This paper provides general information on Egnatia Motorway bridges and describes the technical requirements for their seismic design. Measures taken to resist potential seismic forces are outlined for a few major bridges, and computer software developed for seismic hazard risk assessment of the bridges on this project is described.

**Strengthening fatigue-cracked steel bridge decks**
R. C. Battista and M. S. Pfeil
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 2, June, 93–102

In slender orthotropic decks of steel bridges, the dynamic interaction between vehicle tyres on flexible asphaltic pavement and the deck structure plays an important role on stress amplitudes. This involved interaction mechanism is brought into the discussion on the main causes of the pavement disruption and of the observed cracks in a large steel bridge, which has been frequently damaged by fatigue cracks in welded joints and geometric details under random stresses produced by traffic loading. Numerical modelling and experimental strain measurements performed both in situ and in the laboratory on a prototype scale model of the actual steel deck. Proposed solutions include adding a reinforced concrete pavement, either as a sandwich structure with a visco-elastic layer in between the steel plate and the concrete slab, or as a composite deck formed by fixing the concrete slab to the steel plate with stud connectors. It is shown that visco-damping and composite stiffness properties led to substantial reduction of both longitudinal and transverse bending stresses, enhancing the fatigue performance of these bridge decks.

**HSFG bolted connections using weathering steel materials**
R. J. Lark
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 2, June, 103–110

The procedure for designing and making high-strength friction grip (HSFG) bolted joints is relatively simple, but since they work by developing friction, the condition of the faying surfaces has a significant influence on the capacity of the joint. Despite this, there is little data available on the performance of HSFG joints made with weathering steel. The aim of this study was to investigate the slip factors of such joints and to identify the significance of any weathering of the joints between their preparation and assembly. The results demonstrate that the

behaviour of joints made with weathering steel is very similar to that of joints made with similar strength carbon steel and that the effect of weathering of the faying surfaces on the friction that can be developed within such joints is insignificant.

**Assessment testing Mizen Head footbridge, Ireland**
K. D. Ruane and A. Healy
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 117–122

Mizen Head Footbridge in County Cork, Ireland, is a reinforced concrete through-arch structure spanning 50 m. The structure is 95 years old and exhibits typical reinforced concrete defects of spalled concrete, cracking and staining from reinforcement corrosion. An inspection, geometrical survey and a series of material tests were carried out as part of an assessment of the bridge. Petrographic examination of samples removed from the structure gave confidence in the quality of the concrete in the structure. Determination of carbonation and chloride levels in the concrete identified future repair strategies for the structure.

**Strengthening concrete structures using fibre composites**
A.Darby, T. Ibell, J.Clarke, S. Denton, N. Farmer and S. Luke
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 123–129

Rehabilitation of concrete structures using advanced composite fibre-reinforced polymer (FRP) materials has rapidly gained momentum due to the economic and structural benefits offered by such solutions. In 2000, The Concrete Society published its technical report TR55, the world's first best practice guidance on strengthening concrete structures using advanced composite materials in line with British design codes. This document has gained acceptance nationally and in many other parts of the world. Due to the rapid evolution of strengthening techniques, materials and theoretical models of behaviour, the guidelines have been updated for publication in 2004 in order to reflect the current state of the art and best practice. In particular, the chapters dealing with flexural, shear and column strengthening have been substantially revised to reflect latest research findings. Details of the main proposed changes are given in this paper. Design guidance on the use of new techniques such as near surface-mounted (NSM) reinforcement, prestressed FRP and anchorage techniques have also been introduced into the guidelines and are summarised in the paper. The design aspects are backed up with examples of the latest applications of the various strengthening techniques and materials.

**The refurbishment of Heyeswood Railway Bridge**
R. Dixon
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 131–137

Heyeswood Railway Bridge was constructed in 1958 and carries the A556 dual carriageway over an over-head electrified spur of the West Coast Mainline railway. The 45° skew deck comprises fabricated steel girders with reinforced concrete slabs at the top and bottom of the deck, forming a complete enclosure. The bridge had suffered deterioration as a result of a variety of factors resulting in significant spalling to both slabs. Interim strengthening was carried out in 1991. Major utilities were very restrictive. The most cost-effective long-term solution was to over slab the top slab, nominally repair the bottom slab and provide a unique load-carrying, glass-reinforced plastic enclosure to the soffit. This aspect of the design is emphasised. The top slab strengthening was carried out in two phases, enabling a contra-flow traffic system to be in place throughout. Work to the soffit had to be carried out under a series of Saturday night railway possessions. The project was carried out as part of the Highways Agency's innovative Construction Management Pilot. It is unlikely that this project could have been successfully concluded under a traditional, more adversarial contract.

**Development of Eirspan: Ireland's bridge management system**
L. Duffy
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 139–146

The road network in Ireland comprises national primary and national secondary roads, and non-national regional roads and local roads. Since 1994 the responsibility for the management and maintenance of the national roads has rested with the National Roads Authority (NRA). In 2001 the Eirspan bridge management system was introduced to coordinate and integrate activities such as inspections, repairs and rehabilitation work to ensure optimal management of the national road structure stock. This paper summarises the reasons for the introduction of the system and gives a review of the distinct activities included in Eirspan. It describes how bridge components are condition rated within principal inspections and outlines how, after the completion of the inventory gathering and first principal inspections, repair works are priority ranked. Future developments within Eirspan are also discussed. Eirspan helps engineers within the NRA to prioritise maintenance needs and maximise the use of available funding. It has proved to be an invaluable tool in helping to maintain the function and safety of bridges throughout the national road network in Ireland.

**Comparison of slab-bridge safety assessment strategies**
D. Imhof and C. R. Middleton
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 147–155

When assessing the safety of existing structures it is often not economic to use the design codes, which may be rather conservative in nature. In this paper, safety is measured in terms of the factor of safety, defined as the ratio of available strength to total load effect. The paper examines the sensitivity of the safety factor of two example concrete slab bridges to: (1) the method of structural analysis and failure criterion; (2) the inclusion of updated strength information; and (3) the application of site-specific loading. It is shown that in certain cases plastic analysis methods can predict the ultimate load capacity more accurately than conventional elastic analysis. Methods are suggested for calculating the material strength values based on test results so as to better reflect the true in situ strength of the bridge. Finally, the use of a bridge-specific load model is suggested which may lead to an increase of the factor of safety.

**Llangollen Railway: refurbishment of Berwyn Viaduct**
J. D. Symonds
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 157–161

This paper sets out the key aspects of the planning, design and construction phases of the refurbishment of Berwyn Viaduct at Llangollen Railway, together with details of the construction of the replica cantilever platform to replace the structure removed following the Beeching cuts in the 1960s. It details how close liaison was required between the client and contractor to ensure the successful conclusion of the project on time and within budget.

**Strengthening rail bridge wingwalls for containment barriers**
S. K. Clubley and M. E. J. Morey
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 163–170

Windsor Branch Railway Bridge carries the busy M4 motorway over a mainline railway and two public footpaths. The route forms the main link from London to South Wales and the south west of England. Constructed in the early 1960s, the bridge consists of five simply supported skewed spans each comprising precast, prestressed concrete beams. The deck is divided longitudinally into two halves by a covered central reserve light-well. A risk assessment identified the bridge as requiring high containment barriers to protect the railway line below. Unfortunately, it was not possible to install these barriers without additional structural strengthening. This paper discusses the use of ground anchors to restrain the wingwalls and capping beams against the collision loads imparted on the structure by the high containment barriers.

**Performance of repairs to concrete bridges**
G. P. Tilly
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 3, September, 171–174

This paper provides an overview of the performance of repairs made to concrete bridges in the field and subjected to the actions of traffic and weathering. Data have been obtained from some 70 case histories having repair lives of up to 33 years on bridges aged from 1908 to the 1990s. It was found that only 45% of the repairs were reported as being wholly successful when last inspected. Perceived causes of failures are considered and ways of making more durable repairs are outlined.

**Portrack—a major railway realignment**
M. J. Hackney, A. Stocks, K. Miller and C. Jencks
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 4, December, 177–186

Crossing the volatile River Nith at Portrack in Dumfriesshire has presented railway engineers with severe problems for over 150 years, at least one previous attempt having been destroyed in a flood. Despite ongoing maintenance and repairs, the existing 11 span wrought iron structure, which carries the increasingly important Glasgow and South West Scotland line over the river, needed urgent replacement to reduce long-term costs and improve the safety and efficiency of the route. Carillion Rail and Scott Wilson Scotland carefully evaluated a number of options before recommending a realignment of the railway, which involved the replacement of two viaducts. Working in an environmentally sensitive location, adjacent to a 'live' railway and to a tight deadline required a tremendous amount of planning, cooperation and ingenuity by all parties; even the local estate owner became the project's architectural advisor. The centrepiece of the scheme is a spectacular 90 m, curved, truss-girder crossing of the river, which was erected using the world's largest mobile crane. The meticulous planning and teamwork paid off with the construction of the entire project being completed on time, within budget and without disruption to the railway.

**The Tay Rail Bridge disaster revisited**
T. Martin and I. A. MacLeod
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 4, December, 187–192

A view is being expressed that the Tay Rail Bridge disaster of 1879 was not fundamentally due to the action of the wind but was a result of fatigue damage caused by dynamic loading. The paper discusses this proposition and shows that the evidence to support it is weak.

**New bridge technology for sustainable development**
P. R. Head
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 4, December, 193–202

This paper describes a 20-year programme of the development of new advanced composite material applications in bridges to improve durability, lower whole-life cost, lessen disruption to traffic and lower environmental impact. The work is described within and follows the Framework for Effective Innovation set out by the Civil Engineering Research Foundation in the USA in 1996. The paper covers the development of global standards and performance criteria, the building of demonstration projects, examples of cross-disciplinary knowledge sharing and the use of partnering. Many examples are given of applications worldwide. The paper concludes with a brief description of ongoing work to create performance specifications for sustainable development across all disciplines, which builds on the lessons learned from this work.

**Value of shock transmission units for Mumbai Bridge**
D. J. Patel
*Proceedings of the Institution of Civil Engineers—Bridge Engineering*, **157**, No. 4, December, 203–212

The Second Bassein Creek Bridge at Mumbai (formerly known as Bombay) is the first highway bridge in India to have shock transmission units (STUs) installed. The original bridge, which carries the existing two-lane highway adjacent to the second bridge, had faced many problems with caisson foundations during the construction in 1963–1970. During the design of the Second Bassein Creek Bridge the design and proof check consultants realized that, as the site conditions were rather difficult, it was prudent to limit the size of the caisson foundations to a maximum of 12·5m o.d. These, however, would be unable to take full seismic and other short-term

horizontal loads. They resolved this problem effectively by using STUs to distribute seismic loading on various substructure elements of the bridge, thereby limiting the foundation size. This paper describes the difficult site conditions for the construction of caisson foundations and evaluates the usefulness and cost-effectiveness of STUs for the bridge

**Rammed earth: a natural option for walling**
P. Walker and V. Maniatidis
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 1, February, 5

Over two billion people live in earth buildings including quite a few in Britain. Peter Walker and Vasilios Maniatidis of Bath University report on a UK Government-backed project to encourage greater use of this long established and highly sustainable construction method.

**Re-using urban foundations**
T. Chapman, T. Butcher and R. Fernie
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 1, February, 6

Continuing redevelopment of the world's cities is getting more difficult as the earth beneath them fills up with foundations and tunnels. Tim Chapman of Arup, Tony Butcher of BRE and Rab Fernie of Cementation report on an EU-funded research programme that aims to encourage re-use of existing foundations.

**Anderton boat lift: restoring the Cathedral of the Canals**
M. Clarke
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 1, February, 19–25

The Anderton boat lift in north-west England is the world's first boat lift. Built in 1875, the 'Cathedral of the Canals' initially used an innovative system of balanced water rams to transport boats between a navigable river and a 15 m higher canal. It was converted to an electrical pulley system 33 years later but finally succumbed to structural decay in 1983.This paper reports on the complex £7·8 million project to restore and reopen the lift, which has involved installing a modern version of the original hydraulic system within a painstakingly restored iron and steel structure.

**Integer Hong Kong Pavilion: showcasing sustainable construction**
R. Slade
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 1, February, 19–25

Last month a new sustainable energy centre opened in Beijing. It was formerly the Integer Hong Kong Pavilion, a unique British-inspired industry showcase for sustainable high-rise construction that attracted over 100 000 visitors during 2001 and 2002.The pavilion combines a multi-media exhibition and two demonstration apartments known as 'flats of the future'. It also demonstrates many examples of sustainable, low-waste construction techniques in its own design and construction – not least its re-usability.

**Artificial intelligence v. equations**
G. N. Pande and H.-S. Shin
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 1, February, 39–42

Artificial neural networks are increasingly being used by mathematicians and scientists for complex calculations but apparently not by civil engineers. Such networks have many advantages over rigid equations and design codes, not least that they can be continually 'retrained' when new field or research data become available. On the downside, like people, they are not very transparent and not always reliable. This paper shows how a relatively simple neural network can outperform Burland and Burbidge's well-established 1985 ground settlement equation. The advantages and disadvantages of the technique are also discussed.

**European Commission formally recommends Eurocodes**
H. Gulvanessian
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 2, May, 51

European governments have been told to start preparing now for the new structural Eurocodes. But for civil engineers the decision on when to start making the switch is more complex, says Haig Gulvanessian of Eurocodes Expert.

**Sounding it out – advances in ultrasonic testing**
P. Purnell and D. Hutchins
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 2, May, 56

A new generation of ultrasonic equipment could enable us to 'see' reinforcing bars in concrete without even touching the surface. Phil Purnell and Dave Hutchins of Warwick University report on the latest developments in non-destructive testing.

**Dismantling the Maureen platform – an overview**
P. Broughton, R. Davies and M. Green
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 2, May, 79–85

Removing, dismantling and recycling the world's largest steel gravity platform has proved that the energy industry can safely and sustainably decommission its vast offshore infrastructure when the oil runs out. Nearly 100% of the 110 000 t Maureen platform and its associated 9000 t loading column was either re-used or recycled–with major structural components being used to build new port facilities and 42 000 t of steel landed ashore for scrapping. This paper reports on the complex and delicate task of cleaning and progressively dismantling the vast structure in a Norwegian fjord. It was the final phase of a £150 million decommissioning project, which has now set a benchmark for over 200 other steel structures currently operating in the British sector of the North Sea.

**Earthquake-proof house shakes bamboo world**
L. Jayanetti and P. Follett
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 3, August, 102

Over 1 billion people already live in houses made from bamboo, the fastest-growing woody plant on the planet. Lionel Jayanetti and Paul Follett of Trada say there is significant further potential for bamboo as a strong and sustainable building material, particularly after the success of a recent fullscale earthquake test.

**Observational method looks set to cut city building costs**
T. Chapman and G. Green
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 3, August, 125–133

Construction of a new 20 m deep commercial building basement in the centre of London involved what is believed to be the first true application of the 'observational method' on a major building project. Use of the ground movement monitoring technique, previously confined to civil engineering projects, allowed the top-down construction sequence on this confined urban site to miss a floor. This made it easier to remove the large concrete base of an existing basement and cut 20 weeks off the construction programme. All observed ground movements were within preset limits, so contingency measures were not needed, resulting in a highly cost-effective solution that could have wide application in the building sector.

**Computer analysis: avoiding the 'black box' syndrome**
A. R. Lamb
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 3, August, 134–139

Recent rapid advances in computer software and hardware have provided civil and structural engineers with increasingly powerful means of processing, storing, retrieving and displaying data. Most engineering consultancy firms now rely heavily on computers and software design packages to provide a competitive edge. However, there is a real danger of blind dependence on automated 'black box' techniques, the results of which may not be checked against engineering experience and intuition. This paper shows how this can happen and proposes a hierarchy of computer-aided design supervision to avoid potentially fatal errors resulting from flawed computer analysis.

**New station brings trains back to Auckland's centre**
M. Maylin and S. Shanmuganathan
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 4, November, 164–171

With a population of just 3·7 million, New Zealand is not exactly renowned for its traffic problems. However the economy of Auckland, its largest city, was starting to suffer from the global bane of traffic congestion and something had to be done. The first step towards a more integrated transport system was to return the main railway station back to the city centre site it vacated 65 years ago, only this time underground. By combining conventional materials with state-of-the-art design and construction methods, the project team was able to deliver a large, safe and attractive transport interchange within a very limited budget and time frame.

**Stress-laminated arches: a stronger case for timber bridges**
G. Freedman and A. Kermani
*Proceedings of the Institution of Civil Engineers—Civil Engineering*, **157**, No. 4, November, 172–178

Timber bridges have been around for a long time but are still viewed with suspicion by design engineers and the public alike. Though not as durable or strong as steel and concrete, timber is nevertheless a sustainable material in plentiful supply and can be combined with other materials to make up for its structural shortcomings. 'Stress-laminated construction', where short planks of low-grade timber are simply bolted together to make large flat slabs, is now a primary design option for secondary road applications in the US. This paper reports on pioneering UK research which has shown such bridges can be even stronger when built with arched rather than flat decks.

**Briefing: The Cement Sustainability Initiative**
H. Klee
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 1, March, 9–11

Klee highlights the environmental impact of the cement industry: 'cement is second only to water as the most consumed substance on the planet and generates 5% of the world's greenhouse gases'. He describes how the industry is recognising its social and environmental responsibilities and the various stakeholder pressures and has established the Cement Sustainability Initiative. Recognising impacts and acting on them is the first step on the journey to a more sustainable future. The briefing note identifies that 'sustainability is not a straightforward issue for any of us (in the cement industry), but we all recognise that our viability and prospects of future existence—let alone growth—are now critically dependent on adopting a responsible approach to the subject'.

**Briefing: Better buildings needed for one-planet living**
R. Napier
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 2, June, 59–60

Robert Napier gives his views, as presented to the Better Buildings Summit, on whether the planet can afford the buildings we are building today and questions who should be responsible for delivering those badly needed buildings in an appropriately sustainable way.

**Crane erection of timber-trussed rafter roofs**
R. Hairstans, A. Kermani and R. Lawson
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 2, June, 89–98

Traditional methods of timber frame construction are labour-intensive and time-consuming. This paper details a study of the crane-erect method of construction which utilises on-site preparatory work and off-site fabrication. The paper also examines the project planning alterations and implications which are required for crane-erect construction to be successful

and the feasibility of crane erect with regard to improved time, cost and safety.

**Coarse recycled aggregates for use in new concrete**
M. C. Limbachiya
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 2, June, 99–106

The results of a laboratory experimental programme aimed at examining the performance of Portland-cement concrete produced with natural (gravel and sand) and coarse recycled aggregates (RA) are reported in this paper. All concrete mixes were designed for equivalent 28-day compressive cube strengths of 20, 30 and 40 N/mm2. The effects of up to 100% coarse RA on fresh, engineering and durability properties have been established and its suitability for use in a range of designated applications assessed. The results for the fresh concrete showed a reduction in workability of the concrete with increase in RA proportion beyond 30% in the mix, although the slump measurements remained within the allowable margins of ±25mm. The mixes with high proportions of RA were found to be less cohesive and exhibited slight bleeding. Studies of hardened concrete properties, comprising bulk engineering properties (compressive cube strength, flexural strength, modulus of elasticity, drying shrinkage) and durability (initial surface absorption, carbonation rates, freeze-thaw in water and abrasion resistance) showed similar performance for RA and natural aggregate concrete mixes of equivalent strength.

**Reuse of tyre steel fibres as concrete reinforcement**
K. Pilakoutas, K. Neocleous and H. Tlemat
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 3, September, 131–138

To attain economically viable and environmentally friendly tyre recycling, it is necessary to develop new applications and products, which will use tyre by-products (especially the steel cord) as raw materials. The authors demonstrate that the steel fibres recovered from used tyres can be used to reinforce concrete elements. This application has a great potential, as it is estimated that more than 500 000 t of high-quality steel fibres could be recovered annually from used tyres in the EU alone. This paper presents the work carried out as part of various ongoing projects on the use of steel fibres in concrete construction. The first part of the paper deals with waste management issues, the methods used to recover steel fibres from tyres, and existing applications of used tyres. The second part presents the mechanical behaviour of concrete elements reinforced with these steel fibres and discusses the relevant design and economic issues. It is concluded that the use of these steel fibres in concrete construction will benefit not only the construction industry, but also the producers and recyclers of used tyres.

**Using recycled demolition waste in concrete building blocks**
M. N. Soutsos, S. G. Millard, J. H. Bungey, N. Jones, R. G. Tickell and J. Gradwell
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 3, September, 139–148

A study is being undertaken at the University of Liverpool to investigate the potential for using construction and demolition waste (C&DW)-derived aggregate in the manufacture of precast concrete building blocks. Recycled aggregates can be used to replace quarried limestone aggregate, usually used in coarse (6 mm) and fine (4mmto- dust) gradings. Market research has been carried out to determine the economic viability of using C&DW-derived aggregates in blocks. The availability and transportation costs of quarried and C&DW-derived aggregates have been compared and there appears to be scope for investigating the technical as well as the economic aspects of the use of C&DW-derived aggregates in block manufacture.

**Reuse of quarry fines in production of secondary aggregates**
A. M. Padfield, P. J. Carey, C. D. Hills and A. B. Poole
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 3, September, 149–154

Large volumes of wastes are associated with the production of aggregates and dimension stone. Fine-grained wastes are particularly problematic and are deposited in settlement ponds or managed by stockpiling until backfill space becomes available. Although these fine materials have poor engineering properties, when they are mixed with hydraulic binders in a $CO_2$-rich atmosphere, they can be bound together to form pellets suitable for use as aggregates. In the present work, a by-product called hassock, which originates from the quarrying of Kentish ragstone, is investigated for use as secondary aggregate. In excess of 200 000 t of this poor-quality fine-grained material, originating from the Lower Greensand Formation of southern England, are disposed of each year. Hassock waste was blended with other solid waste products, namely cement kiln dust, ground granulated blast furnace slag and pulverised fuel ash, and was pelletised in a $CO_2$-rich atmosphere. The pellets, produced by carbonate cementation; typically have a pH of 9–9·5 and aggregate impact values ranging from 14 to 19.

**Brick recycling and reuse**
R. J. Gregory, T. G. Hughes and A. S. K. Kwan
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 3, September, 155–161

The paper assesses the current brick recycling industry in the UK, and highlights the low rate of brick recycling that is currently achieved. The benefits of increased brick recycling are identified, but it is noted that in order for his to be achieved improved technology to allow more efficient recovery of bricks would be necessary.

**Designing buildings to close the material resource loop**
P. Sassi
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 3, September, 163–171

Making use of recycled and reused building materials and products in the building industry is well understood as an effective way of reducing the environmental impacts associated with materials. To facilitate the recycling of materials, buildings should be designed as recyclable Buildings–buildings that enable the dismantling and the reuse or recycling of building elements and materials. However, currently buildings are seldom designed in this way. Environmental benefits have

proved insufficient to encourage the production of recyclable buildings, and other benefits, in particular economic and social benefits, appear to be key in increasing the production of such buildings. This paper reports on a study of the social and economic benefits of recyclable buildings. The study investigates current building materials and components and their ability to be dismantled and reused or recycled. A questionnaire and interviews with building designers were used to investigate the potential and the barriers to the use of recyclable materials and components as well as identifying methods to overcome the barriers and promote the technology. The paper considers how legislation and the provision of information can act as drivers for change and also suggests that to maximise the environmental benefits, buildings should in fact be designed to create a closed-loop material cycle. It concludes by pointing to a few new examples of buildings designed for reuse and recycling, which may suggest a move towards recyclable building in the construction industry.

**Waste minimisation and material reuse at Eden Project, England**
H. Bartlett, A. Cook, C. Hines and R. Hoyes
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 3, September, 173–180

The Eden Project aims to promote the understanding and responsible management of the vital relationship between plants, people and resources, leading to a sustainable future for all. Located in a former china clay pit, the project has welcomed over five million visitors since opening in 2001 and is home to the two largest conservatories in the world. During the early phases of development the Eden Project recognised that its approach to waste was not wholly consistent with its sustainability ambitions and a waste neutral strategy was developed. A new phase of development is now being undertaken and the Waste Neutral Strategy is central to the procurement process. This paper presents a case study of waste minimisation and material reuse at the Eden Project, including the management of construction waste, setting out the experience of the Eden Project and McAlpine Joint Venture, the contractor for the design-and-build contracts under which all phases of development have been procured.

**Re-use of ISF slag in concrete**
C. Morrison and D. Richardson
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 4, December, 213–218

Slag from the imperial smelting furnace (ISF) method of zinc production is an industry by-product that has been investigated for its potential use as an aggregate in concrete. In the UK alone, there is currently a 2·5 million t stockpile of ISF slag that could potentially be used as aggregate in the construction industry. However, the presence of the heavy metals zinc and lead in the slag raises environmental concerns about its reuse. ISF slag is physically suitable for use as an aggregate, although there are several barriers that need to be overcome before it can be used in concrete. Issues relating to the metal ions present have been addressed in other publications. However, the glassy nature of the slag initially raised concerns regarding the potential for alkali–silica reaction (ASR) to occur in concrete. A comprehensive series of accelerated ASR tests have been carried out, which indicate that the material is not susceptible to this type of deleterious reaction. In addition, site trials on a concrete roadway containing ISF slag have proved successful.

**Concrete bridges in sustainable development**
A. Martin
*Proceedings of the Institution of Civil Engineers—Engineering Sustainability*, **157**, No. 4, December, 219–230

Concrete bridges form significant links in most infrastructure schemes, but as a constructional material concrete faces major challenges concerning its sustainability performance. The paper seeks to identify and discuss significant themes in sustainability as they affect concrete bridges and to give a briefing on the subject to bridge owners, designers, constructors, maintainers and users. After introducing the challenge of sustainability to the concrete industry, a structured means of addressing sustainability issues is presented and the role of concrete in bridge construction is described. The four major aspects of sustainable thinking (natural resources, environment, societal issues and economics) are discussed in the context of concrete bridges. Examples of how sustainable principles have been applied to practical situations involving concrete bridges are then presented and discussed. In conclusion, the need for further research to provide practical sustainability assessment tools is identified together with the importance of increased awareness and involvement of all through education and training.

**Settlement of a bridge embankment on soft soils**
U. F. A. Karim, H. van Meekeren and R. Feenstra
*Proceedings of the Institution of Civil Engineers—Geotechnical Engineering*, **157**, No. 1, January, 9–12

This paper presents a method of analysis of monitored settlements of a bridge embankment in Franeker, the Netherlands. Consolidation coefficients (cv), final settlement and duration are calculated from the monitored time–settlement data using a simple linear approach. Reanalysis is made to overcome uncertainties in settlement predictions arising mainly from the presence of soft soil layers, pre-construction drainage and the soil volume affected by net drainage quantities.

**Geotechnical analysis of a retaining wall in weak rock**
D. J. Richards, C. R. I. Clayton, W. Powrie and T. Hayward
*Proceedings of the Institution of Civil Engineers—Geotechnical Engineering*, **157**, No. 1, January, 13–26

The determination of realistic values of stiffness and in situ horizontal stress is challenging in softer materials, but in weak rocks where discontinuities are typically present it is particularly difficult. Such difficulties were encountered during the site investigation for the construction of the A444 Coventry North–South road retaining structures, where the in-situ lateral stress and stiffness profiles of the weathered sandstones and mudstone were determined using a range of investigation techniques. A section of retaining wall incorporating a stabilising base was monitored during construction, and further investigation of the weak rock was undertaken using geophysical techniques. Aspects of the observed performance

of the retaining wall during construction were analysed using a continuum finite element method to provide a computed stiffness and initial horizontal stress profile. The results from these analyses are compared with the site characterization data.

**Approaches to the design of cantilever retaining walls**
N. A. Trenter
*Proceedings of the Institution of Civil Engineers—Geotechnical Engineering*, **157**, No. 1, January, 27–35

Cantilever (stem and pad) retaining walls are among the simplest earth-retaining structures to construct, and accordingly may offer significant economic benefits. Their design involves use of bearing capacity and sliding stability theory, and application of the factors of safety laid down in the code to which the designer is working. Two typical L-shaped cantilever walls founded on and retaining dry cohesionless soil are considered, designed in accordance with the procedures given in CP2:1951 and BS 8002:1994. It is shown that the width of the foundation base depends upon which philosophy of factor of safety, and hence which code, is adopted. It is also shown that BS 8002:1994 produces larger (more conservative) foundation bases than the CP2:1951 it replaces, although the difference is significant only for more steeply sloping backfills and deeper foundations.

**Long-term pile testing in London Clay: a case study**
H. Unwin and R. A. Jessop
*Proceedings of the Institution of Civil Engineers—Geotechnical Engineering*, **157**, No. 2, January, 57–63

This paper describes how a series of large-diameter auger-bored test piles were constructed for the Terminal Five development at London's Heathrow Airport. The piles were tested over a period of one year, prior to the start of the permanent works, to investigate how the shaft resistance within the London Clay varies with time. The test procedure is described, and some of the results are presented and briefly discussed. A further two piles were constructed to investigate the base resistance in the London Clay at depths of up to 47 m. Osterberg Cells were used to generate the testing force, and the construction and testing of these piles is also discussed in the paper.

**Settlement and tilt of low-rise buildings**
J. A. Charles and H. D. Skinner
*Proceedings of the Institution of Civil Engineers—Geotechnical Engineering*, **157**, No. 2, January, 65–75

Where deep foundations are not an economically viable solution, foundation problems may occur at low-rise housing developments on poor ground. It is usually feasible to provide a raft foundation relatively cheaply for lightly loaded buildings. When differential settlement occurs, foundations of adequate stiffness will cause the building to tilt as a rigid body, and will prevent significant distortion of the building and consequent cracking of the walls. A number of case histories of tilted buildings are presented to illustrate the magnitude of tilt that has been observed with different ground conditions, and the remedial actions that have been undertaken. Noticeability is a key factor in assessing the acceptability of tilt for low-rise residential buildings and their occupants, and tilt typically is noticed when it is in the region of 1/250 to 1/200. Where tilts of the magnitude of 1/100 or greater are measured, or the measured rate of increase of tilt indicates that this degree of tilt will be exceeded, some remedial action should be taken, which is likely to include re-levelling the building.

**Non-linear finite element analysis of piled-raft foundations**
D. K. Maharaj and S. R. Gandhi
*Proceedings of the Institution of Civil Engineers—Geotechnical Engineering*, **157**, No. 3, January, 107–113

This paper presents the results of three-dimensional non-linear finite element analysis of raft and piled raft foundations that have been loaded until failure. The raft, pile and soil have been discretised as eight-noded brick elements. The soil has been modelled as a Drucker–Prager elasto-plastic medium. The analyses have been done for a raft, a piled raft, a group of piles and an individual pile. The load–settlement behaviour of all these foundations is presented. The effect of raft thickness and soil modulus on the load–settlement behaviour of rafts and piled rafts is also presented. The axial load distribution for piles in a piled raft foundation is shown, the development of contact stress with increase in loading intensity is presented for rafts, and curves of contact stress against settlement are shown for rafts and piled rafts. The addition of even a small number of piles has been found to increase the load-carrying capacity of a raft foundation. The axial load distribution shows that the piles in a piled raft foundation reach their ultimate capacity earlier than the raft does. The contact stress is found to be minimum at the centre of the raft and maximum at the corner. When the raft reaches its ultimate load-carrying capacity, uniform contact stress is found below the raft except for a very small zone at the corner of the raft. This uniform contact stress is found to be the maximum value that can develop below a raft and a piled raft. The finite element results compare well with the reported literature.

**Deconstruction of the Maureen platform and loading column**
P. Broughton, R. L. Davies and M. Green
*Proceedings of the Institution of Civil Engineers—Maritime Engineering*, **157**, No. 1, March, 3–21

The Maureen Steel Gravity Platform (TSG) and associated concrete articulated loading column (ALC) were both successfully refloated and removed from their North Sea locations in the summer of 2001. The two structures were towed to the Aker construction base at Stord Island (between Stavanger and Bergen) on the west coast of Norway. At this location they were securely moored up in deep water, for the purposes of further decommissioning, which involved internal tank cleaning of the substructure, deconstruction, and partial reuse of large elements of both structures. This process involved many significant marine construction/deconstruction activities. This paper describes the main elements of this decommissioning/deconstruction work, including the reuse of large elements of the steel gravity platform as part of a new quay construction, and the reuse of the column section from the ALC, as a breakwater for a marina development.