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Flisa Bridge, Norway–a record-breaking timber bridge
P. K. Ekeberg and K. Søylund
Proceedings of the Institution of Civil Engineers—Bridge Engineering, **158**, No. 1, March, 1–7

Over the past decade several timber bridges have been built in Norway, particularly in Hedmark County. The unique experience gained from these projects has enabled bridge engineers to build increasingly larger bridges. On 5 June 2003, the new Flisa Bridge opened. It is the world's longest timber bridge designed for full traffic loads with respect to clear span (70·34 m), and one of the longest with respect to total length (196 m). The bridge crosses the river Glomma in Hedmark County, approximately 150 km north of Oslo, and is placed on the foundations of the old bridge. The trusses and parapets are constructed using glued-laminated timber, and the bridge deck is a stress-laminated deck plate of sawn timber. The new superstructure consists of almost 900 m^3 glued-laminated and sawn timber (utilising more than 7000 trees), and more than 200 t of steel. The total cost of the bridge is about 30 million Norwegian kroner (or €3·5 million/£2·4 million). This paper describes the design and construction of this unique project.

Innovative retrofitted reinforcement techniques for masonry arch bridges
S. K. Sumon
Proceedings of the Institution of Civil Engineers—Bridge Engineering, **158**, No. 3, September, 91–99

This paper describes a series of load tests to determine the effectiveness of two innovative repair systems for masonry arch bridges containing the common defect of ring-separation. Two arches were strengthened using the Helibeam system, one using a prototype version and the other using a modified version. Two further arches were strengthened using the masonry arch repair and strengthening (MARS) system, again using a prototype and modified system. The effectiveness of the repair systems is evaluated by comparing the behaviour of the strengthened arches with an unstrengthened arch containing ring separation. For comparison purposes, an additional test was carried out on a fully bonded arch (that is, with no ring-separation). The testing demonstrated that, following some modifications to the initial installation procedures, both retrofitted strengthening systems generated significant increases in load-carrying capacity when compared with the ring-separated and the unstrengthened arch. Some recommendations on practical limitations with particular regard to the safety of the structure during installation of the strengthening system are also given.

Thermal-creep analysis of concrete bridges
Q. Xu and C. Burgoyne
Proceedings of the Institution of Civil Engineers—Bridge Engineering, **158**, No. 3, September, 107–115

The creep effects on sequentially built bridges are analysed by the theory of thermal creep. Two types of analysis are used: time dependent and steady state. The traditional uniform creep analysis is also introduced briefly. Both simplified and parabolic normalising creep–temperature functions are used in the analysis for comparison. Numerical examples are presented, calculated by a computer program based on the theory of thermal creep and using the displacement method. It is concluded that different assumptions within thermal creep can lead to very different results when compared with uniform creep analysis. The steady-state analysis of monolithically built structures can serve as a limit to evaluate total creep effects for both monolithically and sequentially built structures. The importance of the correct selection of the normalising creep–temperature function is demonstrated.

Performance of a stress-laminated-timber arch bridge
A. Kermani and G. Freedman
Proceedings of the Institution of Civil Engineers—Bridge Engineering, **158**, No. 4, December, 155–164

For the past three years the authors have been involved in the optimisation of the performance of stress-laminated timber arch (SLTA) structures by utilising the strength properties of timber in an arching action for use as vehicle and pedestrian bridges. During this time over 20 permanent bridges have been built and eight have been load tested. The overall aim of this extensive research programme has been to develop structural uses for low-grade, UK-grown, timber and it has been shown that arches, using timber in compression, are an extremely effective technique for bridges. Timber structures have a very high

sustainability value while being low cost and employing less early capital. These bridges on public roads can help increase public confidence in timber as a viable structural material. As part of a series of field and laboratory tests on SLTA bridges, a 20 m span arch bridge was designed and constructed at the Glentress Forestry Commission site near Peebles, in August 2004. The bridge has since been subjected to a series of extensive static and dynamic loads evaluating its response to crowd and vandal loadings. The results have confirmed predictions that the strength and stiffness of this type of construction was well beyond the strength normally expected from a slender timber structure. This paper details the construction and compares the analysis, design and load testing of the latest 20 m span full-scale SLTA test bridge at Glentress. The extensive testing programme, augmented by analytical work, aims to develop reliable design guidelines for arch structures using UK softwood.

Waste to low-energy cement substitute
I. Richards
Proceedings of the Institution of Civil Engineers—Civil Engineering, **158**, No. 3, August, 100

A four-year research programme in Wales has found a new, low-energy way to make effective cement substitutes out of ordinary industrial wastes. Ivor Richards of the research team leader Richards, Moorhead & Laing reports.

Understanding novel structures through form-finding
W. Lewis
Proceedings of the Institution of Civil Engineers—Civil Engineering, **158**, No. 4, November, 178

Society expects civil engineers to continue to produce exciting and innovative structures, particularly for landmark buildings and bridges. However, recent high-profile failures call for a review of commonly used design methodologies. Current engineering design practice tends to replace knowledge of mechanics by codes of practice and physical modelling by computer-based calculations. This paper suggests that 'form-finding', a combined physical and mathematical modelling technique used to develop tension and shell structures, should also be applied where innovative designs are envisaged.

Eliminating hazardous materials from demolition waste
N. Strufe
Proceedings of the Institution of Civil Engineers—Engineering Sustainability, **158**, No. 1, March, 25–30

To achieve optimum environmental and economically feasible recycling of construction and demolition waste (C&DW) materials it is paramount to ensure 'clean' (i.e. detoxified) materials. Mixed C&DW requires special treatment and costly disposal of unnecessarily large quantities of materials. A precondition for 'clean' demolition waste is careful sorting of the waste at source as an integrated process of the demolition work. This requires that during the demolition process planned and concise sorting of the different materials be carried out, thereby preventing any mix of the waste with hazardous materials, including materials such as asbestos, lead, mercury, PVCs, solvents and adhesives containing polychlorinated biphenyls (PCBs). Therefore, an initial identification of the presence of these materials in the buildings and structures is required. In this paper examples are given of a hazardous substance, namely PCB, found in buildings.

Building façades: sustainability, maintenance and refurbishment
Y. Kaluarachchi, K. Jones, P. James, M. Jentsch, A. S. Bahaj, D. Clements-Croome and D. Gann
Proceedings of the Institution of Civil Engineers—Engineering Sustainability, **158**, No. 2, June, 89–95

The UK has a fairly mature building stock with between 1 and 5% of new buildings being introduced each year. The development of new façade solutions that can respond to the needs of the occupants of both new and refurbished buildings is, therefore, a key area for development. The built environment is a major consumer of energy across the domestic, industrial and service sectors. The construction and operation of buildings are responsible for about one-third of the energy use and one-half of the electricity use in most industrialised countries. A large share of the energy use is associated with protection from the external climate and operation of systems necessary to give the occupants a comfortable indoor environment. Natural light is seen as a key driver to people's well-being both in the workplace and at home. To realise high daylight factors in offices on overcast days, however, in particular requires highly glazed façades. Single-glazed windows result in high winter-month heat loads, whereas modern double- or triple-glazed units could result in summer overheating without additional solar protection or ventilation. This paper discusses the issue of façade refurbishment or replacement in the UK for multioccupancy buildings in both the commercial and domestic sectors. Sustainability is considered from people, process and product perspectives for traditionally glazed façades in comparison with double-skin façades and climatic envelopes.

Achieving sustainability in vibro stone column techniques
C. J. Serridge
Proceedings of the Institution of Civil Engineers—Engineering Sustainability, **158**, No. 4, December, 211–222

As part of achieving environmental sustainability in ground treatment, there is an increasing desire to use recycled materials for vibro stone column techniques. Materials used in stone column construction are required to be free-draining, hard, inert and comply with acceptable criteria in terms of material type, grading, hardness and chemical stability. Spent railway track ballast and crushed concrete probably have the greatest potential for this application in the UK. New European standards for aggregates allow the use of environmentally sustainable materials in a wider range of applications than under the British Standards they replace. However, where such materials are considered for use, as an alternative to natural primary aggregates, it is important that these materials are fit for purpose. Technical requirements for vibro stone column aggregate are discussed. Of particular importance is the fines (clay/silt) content of the aggregate, as this can have a significant effect on the angle of internal friction of the stone column material (and drainage characteristics). This in turn influences both the carrying capacity of the stone column and the settlement characteristics of the stone column–soil composite. Some applications of recycled aggregate in the context of vibro stone columns are presented, including a case history for spent railway ballast and crushed

concrete. Also presented is an innovative technique for avoiding pollutant linkages via stone columns using 'vibro concrete plug' technology.

Quantifying the relative strengths of railway ballasts
W. L. Lim, G. R. McDowell and A. C. Collop
Proceedings of the Institution of Civil Engineers—Geotechnical Engineering, **158**, No. 2, April, 107–111

It is important to be able to distinguish easily between ballasts of poor quality and good quality in terms of strength. For a range of uniformly graded granular materials compacted to the same relative density, there will be two important factors influencing the strength of the aggregate: particle strength and voids ratio (which will be a function of particle shape). Large oedometer tests have been performed in addition to box tests and single particle crushing tests and a new parameter, called the relative strength index, is defined to incorporate the effects of both particle strength and voids ratio. It is found that the relative strength index correlates well with the amount of degradation of ballast in both the large oedometer tests and the box tests, and therefore shows promise as a suitable method for comparing ballast types without having to apply thousands of cycles of load on each ballast.

Pleasure-based design approaches to the built environment
A. Bardill, M. Karamanoglu and K. Herd
Proceedings of the Institution of Civil Engineers—Municipal Engineer, **158**, No. 3, September, 183–193

As an exercise in discipline cross-fertilisation, this paper applies the emergent practice of pleasure-based approaches in product design to the design of the built environment. This analysis provides insight into humans' emotional responses to the environment that is provided for them. Jordan's four pleasures model, composed of physio-, socio-, psycho- and ideo-pleasures, is used to undertake this analysis. From this analytical process it is evident that physio-, socio- and psycho-pleasures are drawn from generic elements that relate to humans as a kind, and that these commonalities are deeply rooted historical and cultural reference points. Understanding these reference points, and the design principles that emerge from them, will enable those who provide the built environment to engage with the 'super-usability' imperative that these pleasure-based approaches have been drawn from and, in so doing, to develop humancentric solutions that engender positive relationships between people and the environment that is provided for them. However, in the absence of a 'market', one area will remain problematic—that of personalised and individually constructed ideo-pleasure.

Design of tension structures: challenges and misconceptions
W. J. Lewis
Proceedings of the Institution of Civil Engineers—Municipal Engineer, **158**, No. 3, September, 231–241

Tension structures, in the form of pre-stressed cable nets and fabric roofs, are becoming a permanent feature of modern architecture. Their popularity can be attributed to their aesthetic appeal, improved durability and the development of computational analysis techniques that facilitate the design process. Despite progress and growing interest in tension structures, their behaviour and complexities of design are not fully understood, except by a few specialists working in the field. This paper introduces the topic, outlines practical difficulties and discusses misconceptions related to the design of tension structures. The main focus of the paper is placed on a process known as form-finding—an issue that affects practically every aspect of design and construction. A way forward, suggested in the closing part of the paper, aims to provoke discussion on the role of engineering education and the division of labour between architect and engineer.

Improving ductility of non-seismically designed RC columns
J. S. Kuang and H. F. Wong
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 1, February, 13–20

An experimental investigation of the improvement of ductile behaviour of non-seismically designed reinforced concrete (RC) columns with various configurations of transverse reinforcement is presented in this paper. Emphasis is placed on the effects of the configuration of transverse reinforcement on the enhancement of ductility and improvements in seismic performance of RC columns. It has been shown that adopting the combination of traditional non-seismic detailing of links with the proposed transverse ties in the column sections can effectively enhance the ductility capacity and energy dissipation ability, thus improving the seismic behaviour of non-seismically designed RC columns, while the construction cost and difficulty will not be increased significantly.

Diagonally-reinforced beam–column reinforced under cyclic loading
F. T. K. Au, K. Huang and H. J. Pam
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 1, February, 21–40

The beam–column joints in a reinforced concrete frame are vulnerable to damage caused by seismic events. The conventional detailing using transverse hoops usually results in serious joint congestion, which creates contruction problems. This paper introduces a new detail especially developed for low to medium seismicity, which involves the use of additional diagonal bars in the joint. Six half-scale interior beam–column assemblies with different joint details, namely 'empty', nominal transverse reinforcement and diagonal bars, tested under reversed cyclic loading are reported. The empty joint is not suitable even under moderate seismicity. The test results show that the joints containing the newly proposed detail, with or without axial compressive load present in the column, exhibit better behaviour at the lower range of ductility factors in terms of higher load-carrying capacity, greater stiffness and less strength degradation. Therefore, the newly proposed joint detail is suitable for beam–column joints of reinforced concrete buildings located in regions of low to medium seismic risk.

Lateral torsion-flexure buckling of corrugated web steel girders
E. Y. Sayed-Ahmed
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 1, February, 53–69

Resistance to lateral torsion-flexure buckling of steel I-girders with plane webs is a very important design requirement. Codes of practice allow designers to use the critical moment of a simply supported beam subject to a constant moment and relate it to the critical moment of any other loading case via an 'equivalent moment factor'. On the other hand, the compression flange outstand-to-thickness ratio which controls the flange local buckling is another important design parameter. According to most codes of practice this ratio, together with web-to-thickness ratio, defines the I-section class and compactness. Recently, plate girders with corrugated steel webs have been used in different structural applications and bridges. The girder's flanges provide the flexural capacity with no contribution from its corrugated web which provides the girder's shear capacity. Lateral torsion-flexure buckling and local flange buckling of corrugated web girders still need to be investigated. A numerical analysis based on the finiteelement technique was performed on these girders. The critical moment causing lateral instability was numerically determined. The finite-element model results were used to investigate the applicability of the critical moment design equations, currently used for a girder with a plane web, to corrugated web girders. The validity of the equivalent moment factor concept to corrugated web girders was also examined. The numerical model was then used to scrutinise the local buckling behaviour of the compression flange for girders with corrugated webs. The applicability of the currently used limiting values for flange outstand-to-thickness ratio which define the section class to corrugated web girders was also examined.

Shear deformation debonding of adhesively bonded plates
D. J. Oehlers, I. S. T. Liu and R. Seracino
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 1, February, 77–84

Adhesive bonding of fibre reinforced polymer (FRP) and steel plates to the surfaces of reinforced concrete structures is an efficient form of retrofitting, as the plated structure is mechanically efficient, the plate is unobtrusive, and—for FRP plates—the plate is durable and the application is inexpensive owing to the lightness and flexibility of the pultruded or wet lay-up plate. In this paper it is shown: from a comparison of the main FRP plating guidelines, that there is now a general agreement on the major plate debonding mechanisms; that current rules in national standards for the shear capacity of prestressed beams can be used to quantify a major plate debonding mechanism due to beam shear deformations, that is critical diagonal crack (CDC) debonding; and that these developments allow a simple design approach to be used for FRP and steel plated beams and slabs with longitudinal plates.

Behaviour of RC column to iTECH composite beam joint
Y.-K. Ju and S.-D. Kim
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 2, April, 77–107

Since the end of twentieth century, the number of highrise buildings in Korea has greatly increased. Due to the imited city area, storey height is a significant factor for tall residential structures. To occupy less storey height, the use of wide reinforced concrete (RC) beams was adopted in some projects such as Trump World and Galleria Palace in Seoul. However, the space for joints between the wide beams and the core walls was too narrow for the reinforcement. In this paper, an alternative composite beam is proposed. The joint with the RC column was experimentally explored through cyclic loading tests. The proposed composite beam is named iTECH (Innovative, Technical, Economical and Convenient Hybrid). It has an asymmetric steel assembly with web openings, where the top plate is welded on top of an inverted structural T-cut 'honeycomb' style. The joint of the RC column–iTECH beam behaved well and may be suitable for field applications.

Experimental study of prefabricated funicular shell units
A. Vafai, H. E. Estekanchi and M. Javidruzi
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 3, June, 167–174

Prefabricated funicular shells were constructed using a stretched membrane as a mould. Forty-five shells with various rises and different types of reinforcement were loaded to failure and their behaviour in the elastic and non-linear range was investigated. The experimental values of membrane and bending stresses in the elastic range along diagonal sections of funicular shells subjected to uniform loading were calculated and compared with the results of numerical analysis. The results are generally found to be in close agreement with theory. Experimental values of vertical deflections along the longitudinal and transverse sections of the shells also compare favourably with the theory. The experimental failure and crack loads are obtained. Empirical equations expressing the relation between rise and reinforcement type with failure and crack loads are given.

The strength of steel end-plated connections
A. G. Kamtekar
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 3, June, 175–190

A yield line approach that uses straight yield lines only is developed to assess the strength of four 'standard' endplated beam-to-column connections. The proposed procedure can be used to analyse the full range of moment connections, including wind moment connections. The strength of the connection can be predicted using relatively simple formulae. The strength predictions are found to agree well with available experimental results. A simple procedure is suggested for designing such connections to provide both adequate strength and adequate ductility. It is used to analyse some standard connection designs contained in a publication by the Steel Construction Institute (the Green Book). The designs in the Green Book appear to be very conservative. Applying the procedure proposed herein to these designs leads to a significant reduction in the end plate thickness though it may require the bolt size to be increased in some cases.

Strength and durability of concrete with ash aggregate
P. A. M. Basheer and Y. Bai
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 3, June, 191–199

A previous investigation to replace natural sand in concrete with furnace bottom ash (FBA) from a coal- fired thermal power plant in Northern Ireland, UK indicated that the water demand of fresh concrete decreases with the increase of the FBA content. Therefore, in the current study the water content was decreased for concretes containing FBA for a given slump and a constant cement content of 382 kg/m^3. The natural sand was replaced with

the FBA at 0, 30, 50, 70 and 100% by mass and three slump ranges, 0–10, 10–30 and 30–60 mm, were considered. The water content of the mixes was determined by carrying out trials. The effect of FBA on water demand, density, compressive strength, pull-off tensile strength, abrasion resistance, drying shrinkage, air permeability, sorptivity, carbonation, chloride diffusion and salt scaling resistance of concretes containing FBA was studied. The results indicated that the water demand of fresh concrete decreases with an increase of FBA content while it has no significant effect on density, compressive strength, pull-off tensile strength or abrasion resistance. The air permeability, sorptivity and drying shrinkage increases beyond 30% FBA content, but the resistance to chloride ingress and salt scaling improves. The depth of carbonation also increases with an increase in the FBA content beyond the 30% replacement level. Overall, FBA content up to 30% as fine aggregate can be incorporated in structural concrete with mostly beneficial effects to various properties of concrete, provided the cement content is kept constant and the water content corresponds to that for low-slump concrete mixes.

Assessment of composite column and RC beam joints
Y.-K. Ju, S.-C. Chun and S.-W. Yoon
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 3, June, 201–215

Structural steel reinforced concrete (SRC) composite column to reinforced concrete (RC) beam connections are widely used in South Korea in the top-down construction method. Several joint types have been proposed and implemented for anchorage of the steel reinforcing bars. These anchoring methods can be classified as the passing through type, the wing plate type, and the H-beam bracket type. Their structural performance, however, is not yet clearly understood. In this paper, the experimental exploration of structural characteristics such as strength, stiffness, stiffness degradation, energy dissipation capacity and ductility under monotonic and cyclic loads is described. The test results show that the passing through type connection has the best structural performance of the joint types tested. However, in practice, it is inefficient to make holes in the thick flange of steel columns. With improvements to the passing through type, wide beam type joints were experimentally investigated in a practical application. In the wide beam type joint, the tensile force was resisted by a number of steel reinforcing bars placed at the edge of the slab without intersecting a steel column and without changing its cross-sectional shape. The wide beam type was found to be adequate in the SRC column to RC beam joint not only because of its structural capacity but also for its economic merits.

Enhancing ductility of reinforced concrete frame buildings
J. S. Kuang and A. I. Atanda
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 4, August, 253–265

Two large-scale, two-storey subframes with non-seismic reinforcement detailing and limited seismic detailing were tested under quasi-static cyclic loading to investigate the seismic behaviour and ductility enhancement of reinforced concrete frame buildings for low-to-medium earthquakes. The inherent ductility of an ordinary moment-resisting reinforced concrete frame was experimentally established by testing the subframe specimen in the case where the reinforcement detailing is consistent with that typically adopted for frame buildings in which the design code has not stipulated any requirement for seismic compliance in the steel details. Experimental investigation was then performed on the other subframe specimen to investigate the enhancement to ductile response behaviour following modifications of the reinforcement detailing technique. The modifications were simple and included reducing the spacing between the stirrups while maintaining the ratio of the stirrup area to spacing; the provision of double-U stirrups at the beam–column joint and the addition of inclined bars within the beam at the support region. It is concluded that ordinary moment-resisting frame buildings might not withstand low-to-moderate seismic events. However, the ductility of frame buildings can be significantly improved with minor modification in reinforcement detailing specifications, which do not result in radical changes in currently practiced design and detailing techniques and a significant increase in construction cost.

Designing thin-walled composite-filled beams
K. M. Anwar Hossain
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 4, August, 267–278

Thin-walled composite-filled beams consist of a coldformed open steel box section with an infill of concrete. The strength of such beams is limited by the compression buckling capacity of the steel plate at the top of the open box section. Enhancement of strength is possible by stiffening the compression steel plates at the open end of the box section with various modes of interface connections or strength-enhancement devices. In this paper, the effect of various strength-enhancement devices is correlated to the generation of shear bond between steel and concrete using both experimental and design-oriented analyses. Flexural capacity of such beams can be derived based on either yielding or buckling of steel depending on the generated steel–concrete interface shear bond simulating full or partial shear connections. Design equations are developed and their performance is validated through test results of 24 experimental beams with five different modes of strength-enhancement device. Design procedures for such beams are illustrated with calculated design examples. Such simple design procedures can be adopted in the actual design of thin-walled composite beams with various modes of strength-enhancement devices in practical applications.

Improving RC seismic design through the CFP method
G. M. Kotsovos, C. Zeris and M. Pavlovic
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 5, October, 291–302

Earthquake-resistant design of concrete structures in accordance with the philosophy of current codes of practice can sometimes lead to early collapse that satisfies neither the assumed failure mode nor the ductility requirement of an element. Minor modifications to existing design rules for monotonic loading in accordance with the compressive force path (CFP) method are suggested. On the basis of the test results reported herein, these modifications are proven to ensure both ductile failures and sufficiently high ductility ratios under seismic conditions. Essentially, the modifications consist of increasing the number of hoop stirrups in the compressive zone(s) and extending their

location along the span of the element, as well as increasing the number of stirrups extending throughout the cross-section height at the location of change in the CFP direction when the distance of this location from the load point is smaller than, or equal to, twice the depth of the effective height of the cross section.

Design of FRP strengthening in metal yield zones
W. M. Sebastian
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 5, October, 303–310

Both bond slip and rigid bond analyses of fibre-reinforced polymer (FRP)-plated metallic members are used to hint at recommendations for design of FRP flexural strengthening schemes in zones where the metal yields. The important role played by the stress history of the metal within these yield zones is highlighted. It is demonstrated that although the rigid bond assumption provides a convenient basis for design checks, this assumption can, in zones of metal yield, lead to dramatic over-estimation of the peak shear stresses in the bonding adhesive layer. The extent of this over-estimation is shown to vary with the form of the applied loading. The article ends with suggestions for further work.

The case for air-entrainment in high-performance concrete
M. T. Bassouoni and M. L. Nehdi
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 5, October, 311–319

Freezing–thawing cycles are a major cause of degradation of concrete structures in cold climates. The use of air-entraining admixtures to induce an adequate network of closely spaced air bubbles in concrete has been proven to dramatically decrease its susceptibility to frost action. However, with the advent of high-strength high-performance concrete (HPC), the need for airentrainment in such concrete has become a controversial issue since the 1980s. Some researchers advocate using air-entrainment in HPC, while others argue that this practice is unnecessary owing to the very low porosity and amount of freezable water in HPC. In this paper, an extensive review of the available literature indicates that there is substantial scatter and irreproducibility of data regarding this issue. There is also evidence of vulnerability of HPC to both micro and macrocracking in service and a demonstrated reduction in performance under combined ageing mechanisms. This could make non-air-entrained HPC vulnerable to freezing–thawing degradation even though such vulnerability may not be detected using classical frost durability tests. Moreover, there are practical limitations to the use of very low water/cement ratio concrete in field conditions, which make the production of HPC with negligible freezable water content difficult to achieve in full-scale structures. This paper presents evidence that supports the argument that the use of air-entrainment in HPC is a practice that provides enhanced safety, reliability and serviceability, and is therefore recommended for concrete practitioners.

Development of long-span iron roof structures in Britain
T. Swailes and J. Marsh
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 5, October, 321–329

The aim of this paper is to stimulate a wider interest in the built heritage of industrial Britain amongst civil engineers. Britain has a greater number and variety of iron roofs than found anywhere else in the world. From the tentative iron roofs over the attic workrooms of the first iron-framed factories, this paper traces the development of greater spans using arch and truss forms to meet the needs of a diverse range of building types, among which the railway station passenger train shed is most significant. The confused issue of design and construction responsibilities for some of the great roofs of the nineteenth century is partially unravelled. The paper shows how innovations in iron roofing were at first introduced by a handful of structural ironwork contractors, further advances being made by a small group of specialist engineers expert in the analysis, design and detailing of structural works in iron.

Temperature effects on copper-clad brickwork dome roof
G. I. B. Rankin, A. Thompson and R. D. N. Robinson
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 6, December, 343–353

This paper describes an experimental investigation that involved the monitoring of crack movements in the copper-clad brickwork dome roof of an historic building known as Mussenden Temple—a National Trust property located on the north coast of Northern Ireland. An automatic strain measurement instrumentation system was installed which enabled monitoring of crack movements and temperatures at hourly intervals over a four year monitoring period. The data collected over this period is summarised and some interesting conclusions are drawn. It is hoped that the findings of this research will be useful in the assessment of other historic buildings and structures.

Deficiencies of the normal moment yield criterion for RC slabs
I. M. May and S. H. Lodi
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 6, December, 371–380

Design methods for the ultimate load design of slabs, for example yield line analysis, Hillerborg's strip method and the Wood–Armer equations, require a yield criterion. The criterion usually used is the 'stepped' or normal moment criterion. The sections must also be ductile. A substantial number of experimental tests and theoretical studies have been carried out to verify the criterion for relatively low percentages of reinforcement. However, more recently, experimental studies have shown that the criterion may be unconservative for cases of pure twisting, even with relatively low areas of reinforcement. This paper examines the reasons for the unconservatism. Numerically determined yield criteria are given for a number of isotropically reinforced sections and the loading conditions for which the criterion is unconservative are identified. The implications for current methods of slab design and assessment are discussed. In order to provide safe solutions the sandwich approach method proposed by Morley, combined with the Clark–Nielsen equations, is considered to be a suitable solution.

Stiffness and strength of web–flange junctions of pultruded GRP sections
G. J. Turvey and Y. Zhang
Proceedings of the Institution of Civil Engineers—Structures and Buildings, **158**, No. 6, December, 381–391

A simple method of testing pultruded glass reinforced plastic (GRP) wide flange (WF) profiles to determine the rotational stiffness and strength of their web–flange junctions is described. Equal and opposite tensile forces are applied near to the edges of the upper and lower flanges on one side of the section and the separation of the flanges is monitored. Equations are presented for the calculation of the rotations in the web and flange at the web–flange junction. They require only force and displacement data derived from tests on short lengths of WF section. The calculated rotations are used to determine the rotational stiffness of the web–flange junction. Details of two groups of six test specimens for two sizes of WF section are presented. The test set-up and test procedure are outlined. Typical load–displacement responses for each WF section specimen size as well as typical web–flange junction failure modes are presented. How the test results have been used to calculate the rotational stiffnesses of the junctions is explained. Failure loads, failure moments and initial rotational stiffnesses of the web–flange junctions of both sizes of WF section are presented together with values for the transverse elastic moduli of their webs. The average rotational stiffness of the web–flange junction of the smaller WF section was about 70% of that of the larger WF section. The average transverse elastic modulus of the web of the smaller WF section was about 5% lower than that of the larger WF section and both values were between 53% and 61% greater than the manufacturer's stated minimum value.

Assessing heat-adhesive emulsions for track coats
R. Miró Recasens, A. Martínez and F. Pérez Jiménez
Proceedings of the Institution of Civil Engineers—Transport, **158**, No. 1, February, 45–51

The use of conventional emulsions for tack coats can cause problems as they frequently stick to the tyres of construction vehicles. Consequently, the bond between the asphalt layers is inadequate. Recently, new types of emulsions have been developed from very low-penetration bitumen that contain no flux. They are known as 'heat-adhesive' emulsions and they are resistant to construction vehicles. However, the adhesive ability of these new emulsions has not previously been studied closely, particularly at low temperatures. The purpose of this study is to analyse the effect of different heat-adhesive emulsions and to verify their performance in service in comparison with the response of a conventional emulsion. For this reason a new shear test—the LCB test—has been developed. This test is carried out at different temperatures, both on laboratory specimens and on cores extracted from recently constructed pavements, where the same emulsions and dosages have been used. It is the modified heat-adhesive emulsion that performs best over the selected range of temperatures. The conventional heatadhesive emulsion, while performing well at medium temperatures, does not achieve the same resistance at the other temperatures as it is more temperature susceptible.

Effects of surface cracking on responses in flexible pavements
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This paper investigates the effects of surface cracks on the primary responses to wheel loading in a model of a flexible pavement structure. Details of the modelling procedure using finite-element analysis are presented and the effects of different material properties and crack lengths are reported. Results show that in an uncracked flexible pavement structure, the inclusion of horizontal tractions imposed by the wheel load results in narrow regions of horizontal tensile strain at the pavement surface and a high shear strain at the edge of the tyre which could lead to crack initiation. The presence of a surface crack results in a localised region of high horizontal tensile stress and strain at the edge of the tyre, making further crack propagation possible. The predicted horizontal tensile strains increase as the stiffness modulus of the asphalt layer is decreased. The presence of a surface crack results in a high value of shear strain at the crack tip, which increases as the stiffness modulus of the asphalt layer is decreased. The predicted horizontal tensile strain at the base of the asphalt layer is not sensitive to a surface crack until it reaches approximately 50 mm (25% of the layer thickness), after which it increases. The predicted shear strain at the crack tip increases linearly with increasing crack length.