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S. K. Fullalove, *Editor*

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Reliability-based evaluation of steel girder bridges

A. A. Czarnecki and A. S. Nowak

Proceedings of the Institution of Civil Engineers, Bridge Engineering, **160**, No. 1, March, 9–15, doi: 10.1680/bren.2007.160.1.9

System reliability can be used as an important tool for the efficient evaluation of existing bridge structures. The traditional element-based approach to bridge design and evaluation does not allow for consideration of interaction between the components that form the structural system and, therefore, it can be conservative. The safety of the structural system also depends on the degree of redundancy (load sharing) and ductility. As a result, it has been observed that the load-carrying capacity of the whole structure can be much larger than that determined by the design of individual components. Therefore, this study was focused on system behaviour. The objective was to identify the load and resistance parameters, formulate the limit state function and develop a system reliability analysis procedure for the whole bridge as a structural system. The reliabilities were also calculated for individual components (girders) and compared with the system reliabilities of the bridge. The resulting system reliability can serve as a basis for the development of a rational bridge design and evaluation procedure.

Going organic: using evolution in civils design

P. Ponterosso and D. Fox

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 1, February, 43–48, doi: 10.1680/cien.2007.160.1.43

Products, buildings and infrastructure are starting to look more natural thanks to recent advances in engineering design, manufacturing and construction technology. Traditional hard, rectilinear structures are being replaced by softer, more organic forms—and not just because they look more natural: millions of years of evolution mean Earth's flora and fauna are engineered to near perfection. But while the enduring design of a mosque might not give us the blueprint for a mosque, engineers can now replicate the natural process of evolutionary design for

their own purposes. This paper introduces the genetic algorithm to civil engineering designers and presents summaries of recent research areas of application, including reinforced earth embankment design, truss optimisation, masonry arch collapse loads and mechanisms, and yield-line analysis of reinforced concrete slabs. Whereas it cannot replace an engineering experience or judgement, the method appears to have great potential as an aid to more creative design.

SCOSS: safeguarding structural safety for 30 years

J. Carpenter

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 3, August, 123–130, doi: 10.1680/cien.2007.160.3.123

The Standing Committee on Structural Safety (SCOSS) was formed 30 years ago to identify trends and practices in the field of structural engineering that are seen as potential causes for concern. During that time it has considered some 200 topics, some of which have led to authoritative guidance or a change in design requirements. Continuing structural failures indicate that civil and structural engineers need to remain vigilant and continue to manage risk carefully. This paper examines the work of the committee to date, the matters of concern and the major issues examined. It emphasises the need for a holistic approach to structural safety which considers the influences of people, process and product. The need to consider that human shortcomings and errors are often the root causes of failure is emphasised and illustrated.

Eurocodes set for global exploitation by UK designers

H. Gulvanessian

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 4, November, 147, doi: 10.1680/cien.2007.160.4.147

The completed set of Eurocodes is on course to become the world's leading suite of structural design standards by 2010. Haig Gulvanessian, chairman of the ICE /IStructE Eurocodes Expert initiative, says design engineers in the UK are better placed than most to exploit them.

Atlantis: a new joined-up world for flood and water engineers

J. Brayshaw and K. Murray

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 4 November, 149 doi: 10.1680/cien.2007.160.4.149

Civil engineers designing flood defence and water-quality schemes in Britain could soon benefit significantly from a nationwide data-interoperability initiative called Atlantis.

Structural failures—the importance of learning from experience

J. Carpenter

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 4, November, 150, doi: 10.1680/cien.2007.160.4.150

Major structural failures continue to occur worldwide. John Carpenter of the ICE /IStructE /HSE Standing Committee on Structural Safety—which has just published its latest biennial report—says design engineers must continue to share and learn from each other's experiences.

Central Park station—engineering a new leaf for Manchester

N. Nicholls and S. Jones

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 4, November, 162–169, doi: 10.1680/cien.2007.160.4.162

Central Park Metrolink station canopy is a dramatic tension structure at the gateway to a new urban regeneration business park in Manchester, UK. Resembling a giant leaf suspended from its stem, it serves both as a transport shelter and an architectural landmark. This paper reports on the organic structure's challenging design and construction, which required the use of sophisticated non-linear analysis techniques as well as two separate wind-tunnel investigations to determine wind loads and likely dynamic behaviour. A complex 16-stage construction sequence also had to be developed and analysed to achieve the required level of cable prestress and to ensure nothing was overstressed during erection.

Engineering design in the time of Thomas Telford

W. Addis

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 4, November, 176–183, doi: 10.1680/cien.2007.160.4.176

Thomas Telford, the Institution of Civil Engineers' first president, was born 250 years ago this year. His career spanned a half-century that saw some of the most remarkable changes in the way European engineers approached the design of buildings, bridges and machines. This paper reviews the development of engineering design, science and education during Telford's era, revealing that Britain was then far behind France, Germany and other European countries. Through the work of Telford and others, Britain's engineers embraced the practical experimental approach that scientists throughout Europe had developed in the eighteenth century to generate new engineering knowledge and understanding. By the early nineteenth century Britain was emerging as a leading engineering nation.

How Roman engineers could have flooded the Colosseum

M. Crapper

Proceedings of the Institution of Civil Engineers, Civil Engineering, **160**, No. 4, November, 184–191, doi: 10.1680/cien.2007.160.4.184

It is known that the Romans staged mock sea battles as well as gladiator contests in some of its numerous amphitheatres. However, there is much speculation as to whether it would have been technically possible to flood the Empire's largest and best-known amphitheatre—the Colosseum in Rome itself—even though contemporary reports suggest it did happen. Using a modern engineering analysis, this paper concludes that while there are a considerable number of missing links in the archaeological evidence, the central 80 m long arena could have been filled in a time of 2–5 h and drained again in a similar timescale.

Modelling compressive strength of eccentrically loaded masonry

T. M. Roberts and T. G. Hughes

Proceedings of the Institution of Civil Engineers, Construction Materials, **160**, No. 1, February, 7–13, doi: 10.1680/coma.2007.160.1.13

A mechanical model for explaining and quantifying the variation of the uniaxial compressive strength of brick masonry with load eccentricity has been developed. The model is based on the development of tensile cracks from shear plane flaws in the bricks and the stress intensity factor resulting from the applied loading and tensile stresses induced by lateral straining of the mortar. Calibration of the model requires knowledge of only the compressive strengths of the bricks, mortar and brick masonry under uniform compression. Theoretical predictions of the lower bound, mean and upper bound compressive strengths of brick masonry under non-uniform loading are compared and show close correlation with test data.

Multi-criteria decision aids for sustainable water management

J.-H. Kain, E. Kärrman and H. Söderberg

Proceedings of the Institution of Civil Engineers, Engineering Sustainability, **160**, No. 2, June, 87–93 doi: 10.1680/ensu.2007.160.2.87

This article evaluates three multi-criteria decision aid (MCDA) methods—Regime, Novel Approach to Imprecise Assessment and Decision Environments (Naiade) and Strategic Advisor (Strad)—from a process facilitation perspective. This research shows that Strad has many advantages over the other tools regarding knowledge management, pluralism, functionality, transparency and participation. Concluding recommendations are as follows. (1) Agree explicit aims with stakeholder participation and if the aims change during the process, this is to be communicated. (2) Match methodology with the aims of the process since it is not always necessary to base the ranking on complex mathematical calculations. (3) Participatory processes should be conducted with care as they are resource consuming. Select cases thoughtfully and design them with a reflective attitude. The systematic structure of going through one criterion at a time is perceived as more important than software aggregation of multiple criteria at the end. It was further concluded that MCDAs have to be transparent and

software must be flexible with an understandable user interface.

Characteristic and design soil parameters: use of statistics

S. R. Lo, and K. S. V. Li

Proceedings of the Institution of Civil Engineers, Geotechnical Engineering, **160**, No. 3, July, 141–146, doi: 10.1680/geng.2007.160.3.141

This paper emphasises that the geotechnical parameter governing the occurrence of a limit state is not the point value as measured by a laboratory or field test, and this has important implications for the determination of soil parameters with statistical methods. Two confusing concepts in statistical soil mechanics are discussed: the modelling of innate variability by a random field model, and the distinction between population mean, mean value of a failure domain and sample mean. These two concepts are intrinsically related. This paper demonstrates that most of the confusions or dilemmas associated with the characteristic value and the use of partial material factors may be removed by considering appropriate probabilistic or statistical concepts. It needs to be emphasised that ‘considering’ does not equate to ‘routinely using’. For a sandy soil, it is argued that the methodology of taking a prudently assessed critical state friction angle as the design value is statistically consistent with the definition of the design value in Eurocode 7.

Development of Hairsine method for design of L-shaped walls

J. L. Justo, P. Durand and E. Justo

Proceedings of the Institution of Civil Engineers, Geotechnical Engineering, **160**, No. 3, July, 161–167, doi: 10.1680/geng.2007.160.3.161

Hairsine published a paper in 1972 in the *Proceedings of the Institution of Civil Engineers* entitled ‘A design chart for determining the optimum base proportions of free standing retaining walls’, which has been used ever since for designing L-shaped walls. For small surcharge pressures, the author provides only an approximate method. Hairsine suggests a complicated procedure when surcharge loading represents a large proportion of the wall loading: if this procedure is used, the method loses its effectiveness. This paper sets out to show how, by introducing simple equivalent coefficients, the Hairsine chart may be accurately employed when there is uniform surcharge. In addition, instead of interpolating Hairsine curves, a suggestion is made to draw the curves for the particular design parameters and obtain the envelope directly through the use of a spreadsheet.

Flow nets and textbooks

E. N. Bromhead

Proceedings of the Institution of Civil Engineers, Geotechnical Engineering, **160**, No. 4, October, 203–207, doi: 10.1680/geng.2007.160.4.203

Textbooks in soil mechanics for undergraduate, postgraduate and professional use have been published since 1941. Most of them cover the use of flow nets to illustrate or solve problems in seepage. A review of a number of such textbooks reveals that

the examples of flow nets provided are often few in number, and greatly simplified. Many of the example illustrations contain errors that are of the ‘schoolboy howler’ kind and which have not been corrected from edition to edition of a particular textbook. Perhaps more controversially, there are cases where illustrations from one source appear to have been reproduced in different books by different authors, complete with the errors. The flow net technique predates the first comprehensive textbook on soil mechanics and so has been fully understood throughout the period covered by the review; these inconsistencies are therefore difficult to explain away as the graphical equivalent of the typographical error or as something that was not understood fully at the time of publication.

Modelling water renewal in a coastal embayment

A. I. Stamou, C. D. Memos and M. E. Kapetanaki

Proceedings of the Institution of Civil Engineers, Maritime Engineering, **160**, No. 3, September, 94–104, doi: 10.1680/maen.2007.160.3.93

A hydrodynamic model was applied to calculate the flow field and the renewal time in Salman Bay, a semi-enclosed coastal water body of particular environmental significance in the region of Jeddah, Saudi Arabia. Initially the model was calibrated with field data. It was then applied to assess the effect of a series of engineering modifications of Salman Bay, involving enlarging of the cross-section of a link channel to the Red Sea, dredging of the bay, and reclamation of islands inside the bay, on the flow characteristics and the renewal of waters. Calculations showed that the channel upgrading would significantly improve the renewal of the bay waters. For tidal calculations the renewal time was reduced from 48\$6 days to 12\$7 days, whereas for a wind-driven regime it was reduced from extremely large values to 13–34 days.

Neural network–genetic programming for sediment transport

A. K. Singh MTech, M. C. Deo PhD and V. Sanil Kumar PhD

Proceedings of the Institution of Civil Engineers, Maritime Engineering, **160**, No. 3, September, 113–119, doi: 10.1680/maen.2007.160.3.113

The planning, operation, design and maintenance of almost all harbour and coastal engineering facilities call for an estimation of the longshore sediment transport rate. This is currently and popularly done with the help of empirical equations. In this paper an alternative approach based on a combination of two soft computing tools, namely neural networks and genetic programming, is suggested. Such a combination was found to produce better results than the individual use of neural networks or genetic programming. The ability of the neural network to approximate a non-linear function coupled with the efficiency of the genetic programming to make an optimum search over the solution domain seems to result in a better prediction.

Hydrodynamic analysis of a skirt breakwater

E. V. Koutandos

Proceedings of the Institution of Civil Engineers, Maritime Engineering, **160**, No. 3, September, 121–133, doi: 10.1680/maen.2007.160.3.121

In the present study, wave interaction with a fixed double partially immersed (skirt) breakwater was investigated

numerically and experimentally. The large-scale laboratory experiments concerning the interaction of regular and irregular waves with the breakwater were conducted in the Canal d'Investigació i Experimentació Marítima flume of maritime engineering laboratory at Universitat Politècnica de Catalunya in Barcelona. The experimental results were compared with numerical results obtained with the use of the Cobras model for the regular waves case. The effects of relative width (structure length/wave length) and the relative distance (distance between two barriers/wave length) on the hydrodynamic characteristics (wave transmission, reflection, dissipation, velocity, turbulence kinetic energy) were investigated. The experimental water surface elevation compared satisfactorily with the computed results. Detailed computed velocities and turbulence kinetic energy in the vicinity of the two structures indicate the effects of the breakwater on the flow pattern and the turbulence structure.

Modelling faecal bacteria pathways in receiving waters

I. Schnauder, B. Bockelmann-Evans and B. Lin

Proceedings of the Institution of Civil Engineers, Maritime Engineering, **160**, No. 4, December, 143-153, doi: 10.1680/maen.2007.160.4.143

The two-dimensional finite-volume model 'Hemat' was refined to model the pathways, fate and decay factors of faecal indicator organisms for an integrated river and coastal basin water system. The numerical model was developed, calibrated and tested by modelling faecal indicator organism inputs from river sources. A comprehensive field data set was available including intensive offshore survey data collected during a two-week period; these were used as a time series for the verification of the hydrodynamic model. River discharges and water quality data were used as boundary and initial conditions for the model. The impact of alternative land-use management strategies on the water quality of the receiving estuarine and coastal waters was investigated by modelling a series of 14 scenarios. Generally, the model results show that the faecal indicator organism input from point sources of sewage effluent dominated during dry weather and base flow conditions. On the other hand, riverine sources (such as diffuse catchment sources) significantly dominated the concentrations in the bay both during and after rainfall events. Finally, it was found that a reduction in land used for animal husbandry can considerably reduce the critical peak concentration occurring after heavy rainfall events.

Safety of a deep water marine riser under random loads

R. A. Khan and S. Ahmad

Proceedings of the Institution of Civil Engineers, Maritime Engineering, **160**, No. 4, December, 175-183, doi: 10.1680/maen.2007.160.4.175

The safety of a deep water marine riser subjected to high axial and bending stresses was addressed with respect to potential fatigue failure. A three-dimensional non-linear dynamic analysis of a marine riser was carried out for response calculations. The response histories so obtained were employed for the study of the fatigue reliability analysis of the riser under random wave and random wave plus top vessel motion. A fatigue damage estimation of the riser was made using

Miner-Palmgren's rule (S-N curve approach). A non-linear limit state function based on the above approach was derived in terms of random variables. The advanced first-order, second-moment method (Afosm) and Monte Carlo simulation technique were employed for reliability estimation. The design point important for probabilistic design is located on the failure surface. The influence of various random variables on overall probability of failure was studied through sensitivity analysis. The effect on riser fatigue reliability of uncertainties in various random variables is highlighted.

Axial load behaviour of concrete-filled steel tubular columns

S. De Nardin and A. L. H. C. El Debs

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 1, February, 13-22, doi: 10.1680/stbu.2007.160.1.13

This paper reports an experimental study of concrete-filled steel tubular columns. Six short columns subjected to concentric load were tested. Columns of square, circular and rectangular cross-sections with two steel tube thicknesses were considered. The experimental results showed that the ductility of high-strength concrete increases when confined by a steel tube, but the load-carrying capacity remains the same. The confinement effect does not increase the capacity of the columns because the axial strain of the high-strength concrete core is low up to the point where the column reaches its ultimate load. A model to predict the load against strain behaviour was proposed and the pre-peak and post-peak behaviours of concrete-filled steel columns axially loaded could be predicted from the behaviours of steel tube and concrete core.

Testing and analysis of a traditional oak frame

T. Hill, J. Shanks, J. Stott and P. Walker

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 1, February, 23-29, doi: 10.1680/stbu.2007.160.1.23

Despite the widespread historical use of green oak framing, using all-timber connections, their engineering performance is poorly understood. Restoration of existing structures and design of new buildings are both often reliant on the skills of the carpenter and historical precedents. Structural engineers frequently struggle to validate green oak frame designs using modern codes of practice. The present paper presents findings from a study undertaken to investigate the structural performance of arched-braced green oak sub-frames. The sub-frames were part of a traditional roof structure in a barn that had fallen into disrepair and was to be replaced. To inform the design process and improve engineering understanding, five identical arched-braced sub-frames were commissioned for load testing under laboratory conditions to failure. The experimental results from the sub-frame tests, including deformation and load capacity, are presented. Experimental load capacities are compared with a novel collapse load analysis.

Strut-tie analysis of beams with external tendons

B. El-Ariss

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 1, February, 31–35, doi: 10.1680/stbu.2007.160.1.31

Strengthening of concrete beams by means of external tendons has been increasingly used. Analysis of such beams is more difficult than that of beams with internal bonded tendons because the stress in external tendons depends on the deformations of the whole beam. In the current paper, a simple model based on the strut-and-tie method is presented to predict the capacity of simply supported externally prestressed concrete beams subjected to equal concentrated loads at third-points. The model defines the struts and ties that form a load transfer mechanism in the beams. It predicts the ultimate loads the beam can carry and the force in the tendons at failure using the section method and equilibrium equations. When comparing the results obtained using the proposed model with others in the literature, the model was found to be conservative. The proposed model is intended to help designers in the inspection and structural assessment of beams.

Analysis of bending tests on CFRP-stiffened pultruded GRP beams

G. J. Turvey

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 1, February, 37–49, doi: 10.1680/stbu.2007.160.1.37

The equations for the mid-span deflection and end rotations of carbon fibre reinforced plastic (CFRP) stiffened pultruded glass reinforced plastic (GRP) shear deformable beams with semi-rigid end connections are introduced. Two series of three-point flexure tests on simply supported pultruded GRP beams are described. In the first series the beams were tested in the unstiffened state and in the second series the beams were tested with pairs of CFRP strips of varying length bonded to their soffits. A third series of three-point flexure tests on a similar pultruded beam with the CFRP strips bonded over the whole span and with bolted stainless steel and GRP cleat end connections is also described. The shear deformable semi-rigid beam equations are used to predict the loads, deflections, end rotations and surface strains recorded in the three test series. It is shown that the correlation between the measured deflections, rotations and strains is generally good, given the nature of uncertainty surrounding some of the material properties. For example, the largest percentage difference between measured and predicted deflections was about 6% for the first two test series and 12% for the third series. It is concluded that this level of correlation between actual and predicted deformations vindicates the use of refined beam analysis for the more efficient design of CFRP stiffened pultruded GRP beams with practical end connections.

Predicting footfall-induced vibration: Part 1

M. Willford, P. Young and C. Field

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 2, April, 65–72, doi: 10.1680/stbu.2007.160.2.65

The current paper reviews different methods that are presently

available for the prediction of footfall-induced vibration in structures. Five such methods are considered in detail and it will be shown that these vary considerably in formulation, applicability and predicted response. Where possible, the theoretical basis, complexity, robustness, rigour, reliability and limitations of each are considered. This paper is presented in two parts. Part 1 deals with bridges and floors having vertical natural frequencies below 10 Hz, part 2 deals with floors whose first vertical natural frequency is over 10 Hz.

Predicting footfall-induced vibration: Part 2

M. Willford, P. Young, and C. Field

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 2, April, 73–79 doi: 10.1680/stbu.2007.160.2.73

This is the second part of a two-part paper which reviews methods that are currently available for the prediction of footfall-induced vibration in structures. Part 1 considered methods appropriate for floors and bridges with vertical natural modes below 10 Hz. Part 2 considers floors with a first vertical mode over 10 Hz. The theoretical basis, complexity, robustness, reliability and limitations of four different predictive techniques are considered here.

Behaviour of reinforced self-consolidating concrete frames

A. Said and M. Nehdi

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 2, April, 95–104, doi: 10.1680/stbu.2007.160.2.95

Multi-storey reinforced concrete (RC) structural frames represent some of the most congested structural elements. Placing and consolidating concrete in such structural frames imposes substantial challenges. This offers a unique area of application for self-consolidating concrete (SCC) because of its inherent ability to flow under its own weight and fill congested sections, complicated formwork and hard-to-reach areas. Research is, however, needed to demonstrate the ability of SCC structural frames adequately to resist vertical and lateral loads. In the present study, full-scale 3 m high beam-column joints reinforced as per the Canadian Standards CSA A23.3-94 and ACI-352R-02 were made with normal concrete (NC) and SCC. They were tested under reversed cyclic loading applied at the beam tip and at a constant axial load applied on the column. The beam-column joint specimens were instrumented with linear variable displacement transducers and strain gauges to determine load-displacement traces, cumulative dissipated energy and secant stiffness. The current paper compares the performance of reinforced NC and SCC structural frames and discusses the potential use of SCC in such structural elements. Results indicate that reducing the coarse aggregate content in SCC mixtures can reduce the contribution of the aggregate interlock mechanism to total shear resistance, which leads to more rapid deterioration under cyclic loading. Further research is needed to ensure the safety of using low coarse aggregate content in SCC in highly seismic areas and assess the safety of already existing buildings cast using SCC.

Stiffness and damping of infilled steel frames

M. Mohammadi Ghazimahalleh

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 2, April, 105–118, doi: 10.1680/stbu.2007.160.2.105

This paper presents the results of an experimental and numerical investigation on 15 masonry, concrete and multilayer infill specimens. Two types of frames are considered. The first one, having pinned connections, has a small-scale and is composed of very stiff beams and columns. The second has a medium-scale and has rigid connections. The frames represent lower storeys of high- and medium-rise buildings, respectively. The effects of reinforcement and bond beam on masonry infill panels are investigated. It is shown that the efficiency of horizontal reinforcements and bond beams on the behaviour of infill panels depends on the dominant cracking pattern. The results show that adding the steel fibres to the material of infill corners can considerably increase the ultimate strength of concrete panels. It is also concluded that the behaviour of multilayer or fibrous concrete panels is better than single-layer panels and they are preferred when strengthening buildings against lateral loads. A new explanation for infill stiffness, named practical stiffness, is proposed and a new formula is suggested to estimate stiffness of the specimens. Eventually, damping ratios of all specimens are presented. The results show that damping ratios of specimens are indicators of structural damage.

Enhancing ductility of non-seismically designed RC shear walls

J. S. Kuang and Y. B. Ho

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 3, June, 139–149, doi: 10.1680/stbu.2007.160.3.139

Experimental investigation is conducted on the seismic behaviour and ductility enhancement of non-seismically designed reinforced concrete shear walls with various configurations of confinement links. Large-scale squat shear wall specimens are tested under reversed cyclic loads. Emphasis is placed on the effects of the boundary confinement and configuration of confinement links on the improvement of seismic performance and ductility. It has been shown that modification in reinforcement detailing specifications for non-seismic design should be made in order to improve seismic behaviour and enhance ductility capacity, as well as the energy dissipation ability, of reinforced concrete shear walls with non-seismic design for fulfilling the requirements of low to moderate seismicity. This can be achieved by adopting the specific reinforcement detailing, which is proposed based on the results of the experimental study. The proposed reinforcement details include only minor modifications to the detailing techniques of currently practiced non-seismic design, which can lead to an important improvement of ductile response behaviour of the shear walls, but do not result in significant increases in construction cost and difficulty.

Elastic analysis of ground-floor slabs under multiple loads

A. A. Abbas M. N. Pavlovic and M. D. Kotsovos

Proceedings of the Institution of Civil Engineers, Structures and

Buildings, **160**, No. 3, June, 151–164, doi: 10.1680/stbu.2007.160.3.151

The design of ground-floor slabs focuses mainly on single-load cases applied at the centre, edge and corner of the slab. The need for extending existing guidelines that allow for the effect of multiple loads, and for the effect of loads being at some distance from the three aforementioned locations, is fundamental for both safety and economy, and is increasingly recognised in the industry. Some elastic guidelines, which date back nearly a century ago, do exist but they are incomplete, cumbersome and generally little known. In the present paper, a new set of influence lines (previous data really refer to certain stress contours) is proposed for both stresses and deflections owing to loads moving along the centrelines, edges and corner bisectors. These diagrams are based on linear finite element analysis (LFEA), and thus allow the use of direct superposition to accommodate any number of applied loads. Nonlinearities and/or plastic methods are outside the scope of this paper.

Cracking and tension zone behaviour in RC flexural members

K. L. Kong, A. W. Beeby, J. P. Forth and R. H. Scott

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 3, June, 165–172, doi: 10.1680/stbu.2007.160.3.165

This paper presents the results of an extensive programme of research carried out jointly at the University of Leeds and the University of Durham to clarify various aspects of cracking behaviour particularly in the tension zones of flexural members. The results show that concrete cover is the only parameter affecting the transfer length at load levels close to cracking and up to service load. An attempt has also been made to show the bond mechanism at the bar–concrete interface using the technique of ink injection. Unfortunately, this technique failed to reveal internal cracks between two major cracks when the stress in the reinforcement was increased up to approximately 200 MPa; whether this was attributed to their absence or to faults in the testing procedure was unclear. The current paper also proposes an empirical formula to predict the transfer length in slabs. The input data required are more simple and convenient to collect than using a crack width microscope and the predictions from the formula are just as accurate.

Inclined reinforcement around web opening in concrete beams

K.-H. Yang and A. F. Ashour

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 3, June, 173–182, doi: 10.1680/stbu.2007.160.3.173

Twelve reinforced-concrete continuous deep beams having web openings within interior shear spans were tested to failure. The main variables investigated were the opening size and the amount of inclined reinforcement around openings. An effective inclined reinforcement factor combining the influence of the amount of inclined web reinforcement and opening size is proposed and used to analyse the structural behaviour of continuous deep beams tested. It was observed that the end support reaction, diagonal crack width and load capacity of

beams tested were significantly dependent on the proposed effective inclined reinforcement factor. As this factor increased, the end support reaction and increasing rate of diagonal crack width were closer to those of companion solid deep beams. In addition, a higher load capacity was exhibited by beams having an effective inclined reinforcement factor above 0.077 than the companion solid deep beam. A numerical procedure based on the upper-bound analysis of the plasticity theory was proposed to estimate the load capacity of beams tested. Comparisons between the measured and predicted load capacities showed good agreement.

Analysis of São Vicente de Fora church, Portugal

J. R. Correia, F. A. Branco and J. de Brito

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 4, August, 187–196, doi: 10.1680/stbu.2007.160.4.187

The current paper presents a rehabilitation analysis of the sixteenth century church of São Vicente de Fora, where significant damage was observed, particularly in the structure of the barrel vaulted roof above the nave. Having ascertained the main pathology of the church, a numerical model was developed to analyse the behaviour of the structure and to identify the most probable causes of its damage. The numerical model was then used to define possible solutions for the repair and strengthening of the structure of the barrel vaulted roof.

Nonlinear response of a torsionally coupled base-isolated structure

F. Khoshnoudian and N. Azizi

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 4, August, 207–219 doi: 10.1680/stbu.2007.160.4.207

Torsion in base-isolated structures with inelastic elastomeric isolation systems owing to earthquakes is studied under various parametric variations using the finite element method. Parameters include: those that characterise the number of storeys; the ratio of uncoupled torsional fundamental frequency to lateral frequency in a superstructure; the ratio of uncoupled torsional frequency to lateral frequency in an isolation system; and the stiffness eccentricity in the superstructure and in the isolation system. The effect of these parameters on the torsional behaviour of a superstructure is investigated under different ground motions. It is shown that the total superstructure response is reduced significantly owing to the existence of a base isolation system. Torsional amplification significantly depends on: the isolation system and superstructure eccentricities; the lateral and torsional flexibilities of the superstructure; the ratio of uncoupled torsional frequency to lateral frequency of a superstructure; and the isolation system. The results of the parametric study help in the understanding of the behaviour of torsionally coupled base-isolated structures. In addition the study demonstrates that the asymmetric of superstructure cannot be ignored, even if the isolation system is symmetric.

Modelling prop loads during concrete slab construction

X. C. Pintado Llubra and R. J. Carlton

Proceedings of the Institution of Civil Engineers, Structures and

Buildings, **160**, No. 4, August, 221–229 doi: 10.1680/stbu.2007.160.4.221

The current paper presents a study of the behaviour of backprop–floor slab interaction during the construction of a car park in Barcelona. The loads on a series of props and backprops were measured during construction and these measurements are compared with those from a finite-element computer model. The main objectives of this work are to verify if the computer model is able to reproduce with sufficient accuracy the true behaviour of the structure and to determine what proportion of the concrete load is supported by the props, slabs and columns. The final conclusions will be useful to manage the construction of a building using props.

Impulsive loading on a concrete structure

J. I. Siddiqui and S. Ahmad

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 4, August, 231–241 doi: 10.1680/stbu.2007.160.4.231

The current paper deals with the experimental determination of relationships of simultaneous ground shock and airblast parameters against impulsive loading. The empirical relationships of peak air pressure, peak reflected airblast pressure along the height of the structure, peak ground acceleration, arriving shock of ground shock, duration of ground shock and the time lag between ground shock and airblast pressure reaching the concrete structure and so forth on a reinforced cement concrete containment scaled model owing to a surface explosion at a certain distance have been established. Equations have been developed and utilised in software for a structural response analysis of a reactor containment subjected to surface explosions. The generation and the effects of blast wave on the shell structure in the plastic range are discussed. Critical distances have been determined for different amounts of blast charges for a typical shell structure. The developed methodology of analysis may be adopted in order to evaluate the effect of an external explosion on the reinforced concrete containments of other reactors.

Catenary action in steel-framed buildings

M. Byfield and S. Paramasivam

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 5, October, 247–257, doi: 10.1680/stbu.2007.160.5.247

The current paper is of relevance to engineers engaged in the design of buildings in which severe column damage resulting from malicious actions is a design scenario. The tying force method as used for providing robustness to steel-framed buildings relies upon catenary action to redistribute loads following column damage. Fortunately severe column damage is extremely rare and for this reason it is not well understood if this load redistribution mechanism is reliable. The current paper presents results of an investigation into the tying force method by way of a case study of a steel-framed building in which support to a perimeter column is removed. Results indicate that industry standard beam–column connections possess insufficient ductility to accommodate the large floor displacements that occur during catenary action and the factor of safety against collapse is shown to be less than 0.2.

Cyclic behaviour of beam–column connections in steel portals

C.-M. Yang and Y.-M. Kim

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 5, October, 259–272, doi: 10.1680/stbu.2007.160.5.259

This paper presents an experimental study on the cyclic behaviour of bolted and welded beam-to-column connections in a steel portal frame. The test focuses on: (a) an experimental analysis for investigation of the behaviour of beam-to-column connections under cyclic loading; (b) the failure modes of each connection under cyclic loading; and (c) the capacity of the high-strength bolted angle connections compared with the fully welded counterpart. The behaviour of the high-strength bolted frame under cyclic lateral loading is studied, and it is compared with that of the welded frame subjected to the same loading. The results obtained from six tests on steel portal frames showed that the initial connection stiffness of the specimen composed of top-seat angle and double web angle (TSD) was developed for about 48% of the specimen with welded connection (FW), and the specimen composed of double web angle (DWA) was about 15%. Based on these tests, conclusions are presented.

Long-term response of concrete-encased composite columns

R. Chacón, E. Mirambell and A. Marí

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 5, October, 273–285, doi: 10.1680/stbu.2007.160.5.285

During the last few decades, owing to their several advantages, composite columns have gained acceptance for high-rise buildings as an alternative to steel or reinforced concrete columns. When a composite column is subjected to an eccentrically applied sustained axial load, its structural response must undergo both a short-term and long-term analysis. The study presented in the current paper aims to evaluate the short- and long-term response of concrete-encased composite columns. A numerical model previously developed and experimentally verified is systematically used within this work. This model is capable of developing non-linear and time-dependent analyses on reinforced concrete frame structures. In order to verify the obtained numerical results for this particular case, a series of experimental results on concrete-encased composite columns are compared with those derived numerically. Once verified, the model is used as a simulation tool to analyse in depth the structural short- and long-term response of composite columns. Finally, based on the present study, conclusions about design criteria for concrete-encased composite columns are drawn.

Shear of prestressed concrete beams with steel fibres

J. Thomas and A. Ramaswamy

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 5, October, 287–293, doi: 10.1680/stbu.2007.160.5.287

This study outlines the details of non-linear analysis using the modified compression field theory (MCFT) of 11 shear-critical partially prestressed concrete T-beams having steel fibres over

partial or full depth. Prestressed T-beams having a shear span-to-depth ratio of 2.65 and 1.59 that failed in shear have been analysed using Response-2000. Response-2000 is an implementation of MCFT within the framework of sectional analysis originally developed for reinforced concrete beams having no fibres. The modelling of the various effects of fibre in the concrete matrix using Response-2000 has been illustrated in the current study. The MCFT-based model used for the present analysis accounts for the non-linearities, such as effect of addition of fibres in the post-peak regime of the compressive stress–strain response, the post-cracking tensile stiffness and response of concrete. The load sustenance through the bridging action of steel fibres at the crack interface has been accounted for in the model. The reinforcements such as deformed bars, prestressing wires and steel fibres have been modelled discretely. The capability of the model to capture cracking behaviour, loads and deflections in various types of shear failures in prestressed concrete beams has been illustrated.

Wind-generated interaction between tall buildings

Y.-M. Kim, K.-P. You and N.-H. Ko

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 5, October, 295–303, doi: 10.1680/stbu.2007.160.5.295

To investigate the effect of aerodynamic interference that could increase the dynamic responses of tall buildings to wind loads, a wind tunnel experiment using high-frequency force-balance was conducted to estimate acceleration responses. Root mean square (r.m.s.) acceleration responses of along-wind, across-wind and torsional wind directions and peak resultant accelerations were estimated with and without consideration of the effect of aerodynamic interference, and were then compared with each other. When the effect of aerodynamic interference was included, r.m.s. torsional acceleration response was increased by 82%. For peak resultant acceleration response, the maximum increase was 69%. It was found that dynamic responses could be increased when considering the effect of aerodynamic interference.

A method for estimating fundamental periods of tall buildings

L. Y. Wang and Q. Wang

Proceedings of the Institution of Civil Engineers, Structures and Buildings, **160**, No. 6, December, 327–337, doi: 10.1680/stbu.2007.160.6.327

The objective of the current paper is to develop a simple hand formula to estimate the fundamental vibration period of tall buildings for use in equivalent lateral force analysis specified in building codes. The method based on the Sturm–Liouville differential equation is presented here for estimating the fundamental period of natural vibration. The resulting equation, based on the continuum representation of a tall building braced by coupled shear walls for natural vibration of the building, is proved to be the fourth-order Sturm–Liouville differential equation, and a hand method for determining the fundamental period of natural vibration of the building is presented. Making use of the coupled wall theory for natural vibration, the method is extended to deal with the vibration problem of other tall buildings braced by frame, walls and/or

tube. The method has the merit of being simple in terms of numerical computation and presentation and yet is very versatile when combined with numerical analysis. Once the structural parameters $\bar{A}$, H and $\bar{\rho}$ of a tall building are computed, the fundamental vibration period of the building can be readily obtained. The value of the method is that it will allow a more consistent and accurate use of code formulae for calculating the earthquake-induced maximum base shear in a tall building. Use of the method is economical with respect to both computer time and equipment, for example a hand calculator would suffice to handle the calculations of period of the buildings at concept design stage. It can also be useful to verify the results of the finite-element method where the time-consuming procedure of handling all the data can always be a source of errors.

The evolution of a river modelling system

E. P. Evans, J. M. Wicks, C. D. Whitlow and D. M. Ramsbottom
Proceedings of the Institution of Civil Engineers, Water Management,
160, No. 1, March, 3-13 doi:1080/wama.2007.160.1.13

This paper describes the development of the ISIS rivermodelling system. Solution methods are outlined and examples are provided to demonstrate applications to which practising engineers have applied the software. It is commonplace in much applied research that projects must be directed towards satisfying user needs, and that their benefits must be demonstrable and measurable. This philosophy, however, places limits by its very nature on the imagination of the researcher. This is not to say that the researcher should ignore user needs but rather that a creative dialogue is needed between the innovative idea and its potential users, against a background of advances and cross-fertilisation by ideas from other spheres. It is hoped that, as well as describing the development of the software, the paper will illustrate this point.

Development of a catchment-wide nutrient model

B. Bockelmann-Evans, I. Schnauder Dr.-Ing, E. Fenrich and R. Falconer

Proceedings of the Institution of Civil Engineers, Water Management,
160, No. 1, March, 35-42 doi:1080/wama.2007.160.1.35

Diffuse-source nutrient pollution remains a major problem within sustainable catchment management. The aim of this study is to provide a decision-support tool that can predict the impact of land-use changes on water quality (WQ) in receiving waters. A linked modelling approach was used to integrate land-use changes with a WQ model and a 2D numerical hydrodynamic model. The linked model was adapted to conditions in estuarine and coastal waters and applied to the catchments of Carmarthen Bay in West Wales, UK. A new set of biochemical reaction rates for nutrients in estuarine waters was found and presented. This approach took into account the assessment of nutrient production rates in the catchment for dry and wet weather conditions, as well as the reactions of constituents passing from the catchment into the coastal basin. The predominant types of land use in the catchment are arable land, improved grassland, rough grazing and woodland. Nutrient loads from these areas were estimated using Geographical Information System (GIS) data and export

coefficients, which characterise the amount of nutrient losses. Furthermore, economical and ecological effects of land-use changes were integrated using an input-output analysis approach. A range of scenario simulations involving different river discharges and reduced nutrient input rates resulting from appropriate measures for land-use changes showed the nutrient pathways and concentration distributions over time throughout the bay. The outcome from these scenario simulations can be used to indicate catchmentwide distribution of diffuse pollution sources and to locate areas that are characterised by high nutrient concentrations and are prone to the occurrence of mass algal growth.

Estimation of burst rates in water distribution mains

J. B. Boxall, A. O'Hagan, S. Pooladsaz, A. J. Saul and D. M. Unwin
Proceedings of the Institution of Civil Engineers, Water Management,
160, No. 2, June, 73-82 doi:1080/wama.2007.160.2.73

The ability to forecast the burst behaviour of pipes in water distribution systems is a fundamental requirement of proactive planning for investment, replacement and rehabilitation strategies. Burst behaviour is, however, a complex function of many uncertain contributing factors. Attempts to develop accurate predictive models have been limited by: data quality and quantity; the lack of associations between individual events and pipes; and the statistical techniques available and applied. Predictive expressions for annual burst rate in cast-iron and asbestos cement pipes are derived for two sample data sets from the UK. The available data were interrogated to make rigorous associations between individual events and pipes and filtered for missing, default and erroneous data. Using statistical analysis, the theory of generalised linear models, it was then possible to derive predictive expressions for burst probabilities. The resulting expressions show strong associations between annual burst rate, diameter and length and a complex association with age. Analysis was also undertaken to investigate associations with available soil data; a relative lack of consistent dependence of burst rate on these data is demonstrated.

Assessing water mains condition using hydraulic transients

D. Misiunas, M. Lambert, A. Simpson and G. Olsson
Proceedings of the Institution of Civil Engineers, Water Management,
160, No. 2, June, 89-94 doi:1080/wama.2007.160.2.89

This paper investigates the potential of using controlled hydraulic transients for non-intrusive assessment of the internal condition of water transmission pipelines. Deterioration of pipelines is a natural process. An effective tool for evaluating the state of pipeline interiors could be extremely useful for planning rehabilitation or identifying critical points in a system. A non-intrusive technique for evaluating the state of the internal surface of a pipeline is introduced. The total length of the pipeline was divided into a number of segments and the condition of each segment assessed based on the transient response corresponding to that interval. In addition to quantification of the deterioration level of different sections of

the pipeline, critical points were identified where closer investigation was suggested. The proposed technique, although in an early stage of development, was tested on a real pipeline.

Optimising water supply and distribution operations

Z. F. Rao PhD, J. Wicks PhD, CEng, MICE and S. West BSc, CEng, MICE, MCIWEM

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 2, June, 95-101 doi:1080/wama.2007.160.2.95

This paper presents an adaptive optimisation system for dynamic operational control of water supply and distribution networks. Based on the combined use of an artificial neural network for predicting the consequences of different pumps and valve settings and a genetic algorithm for optimisation, the energy cost minimisation system (ENCOMS) is designed to assist water distribution system operators to select optimal operating control settings that will best meet not only the current demands but also the projected ones. ENCOMS identifies maximum cost savings by taking into account the electricity tariff and other system operational constraints that prescribe lower and upper limits on nodal pressures and service reservoirs storages, alternative supply sources and so on. The real-time control process operates continually and is updated at short intervals by data transmitted from the SCADA system and the updated demand forecast. The control system is generic in the sense that it can be applied to any distribution network. It is customised for each application to ensure optimal performance. It is extremely powerful and flexible so that the peculiarities of the specific network and/or tariff structure can be accommodated, as well as the preferences of the operator with regard to the time interval between updates, the operating horizon and so on. Multiple sources of treated water with different production costs can also be incorporated, as can various pressure zones and demand districts.

Real-time modelling of a major water supply system

R. Farmani, P. Ingeduld, D. Savic, G. Walters PhD, Z. Svitak and J. Berka

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 2, June, 103-108 doi:1080/wama.2007.160.2.103

Numerical modelling of water supply and distribution systems has become a standard and essential practice in any serious attempt to evaluate hydraulic, water quality and economic aspects of these complex systems. Well-suited models, including advanced technologies such as geographical information system and telemetry systems, accurate fire flow calculations, water quality analysis and leakage reduction have become indispensable tools for water network managers. Application of these advanced techniques in hydraulic and water quality modelling and optimum operation is considered to be a part of master planning for the south-west Moravian water supply system in the Czech Republic. The regional water supply system of south-west Moravia supplies water to two counties (Zdar and Trebic). Two regional control centres manage the whole water supply system. A hydraulic and water quality on-line computational module is installed on the

central control system server. The mathematical model of the water supply system was calibrated and verified for both steady state and extended period simulations. Numerous hydraulic and water quality model scenarios were conducted for both existing and future operations of the system under normal and emergency conditions. Water quality analyses consisted of residual chlorine concentration simulation including detailed water age and source tracing simulations. The main objective in developing the on-line model was to decrease the operational cost of the system by optimizing the operation of pumping stations by improving the rules used to control the inflow into the storage tanks, and by decreasing the time necessary to model required alternatives. The experience from developing the hydraulic and water quality models and optimum scheduling of pumps and valves for the master plan of south-west Moravia as well as the state of the art of the available solutions are discussed in this paper.

Modelling the risk of contaminant intrusion in water mains

K. Vairavamoorthy, J. Yan and S. D. Gorantiwar

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 2, June, 123-132 doi:1080/wama.2007.160.2.123

The contamination of water distribution systems is widely recognised in the case of intermittent water supplies, where pipes are empty for many hours each day and thus under negligible or zero pressure. This allows contaminants from pollution sources such as sewers, open drains and surface water bodies to enter into the water distribution pipes through leaks and cracks during non-supply hours. In developing countries, where water supply is intermittent, contamination frequently occurs to the distribution network at unacceptably high levels, posing a threat to public health. The urban poor suffer most from contaminated water supplies and also suffer a far greater health burden, related in part to the consumption of poor quality water. There are no tools currently available to assist engineers in identifying the risks associated with contaminant intrusion into intermittent water distribution systems. This paper introduces a new tool called integrated risk assessment of water distribution systems (IRA-WDS). It is anticipated that the application of such tools will enable engineers to manage water quality more effectively by developing appropriate control measures to minimise the risks of contaminant intrusion. This paper summarises details of the mathematical models that form the basis of IRA-WDS and also describes the application of the tool to a real case study in India. The outputs from IRA-WDS are risk maps showing the risk of contaminant intrusion into the various parts of the water distribution system and an understanding of the main factors that contribute to risk. These risk maps will be invaluable to decision makers in that they can provide a guide to prioritise the operation and maintenance strategy in order to improve water quality.

Linking one- and two-dimensional models for free surface flows

D. Liang, R. A. Falconer and B. Lin

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 3, September, 145-151, doi:1080/wama.2007.160.3.145

This paper presents integration of a one-dimensional (1D) numerical model with a two-dimensional (2D) numerical model for simulating shallow water flows. The dynamic link library (DLL) technique is used to link a 2D research code with a 1D commercial program. The 2D model has been refined to represent ground topography better and the flooding and drying process. Both mass and momentum transfers are allowed between the 1D and 2D solutions. Two test cases were used to verify the linked model. Smooth transitions between wet and dry areas were observed, with accurate mass conservation being achieved during wetting and drying. It has also been shown that the inclusion of momentum transfer between the two models leads to improved results by eliminating the unrealistic variations in the free surface, close to the common boundaries of the models. The combined 1D and 2D model has the capability to simulate hydraulic processes at different spatial scales simultaneously.

Modelling water distribution systems with deficient pressure

M. H. Hayuti, R. Burrows and D. Naga

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 4, December, 215-224, doi:1080/wama.2007.160.4.215

The pressure dependency of withdrawals from water distribution systems under conditions of abnormal stress, such as mains failure or fire fighting, is well accepted. A simple sequential solution seeking iterative approach to obtain a solution for pressure constrained outflows (including leakage) based on repetitive substitution into conventional computational algorithms, where demands are generally predetermined, has been developed. The methods are presently configured to use the computational efficiency and versatility of the widely used EPANET-2 software routine, offering the benefits of full network operational specifications at the level of 'commercial' network applications. Application of the new algorithm to UK water networks under various partial failure conditions has given insight into the 'true' extent and scale of supply deficiency as a consequence of pressure shortfall. The failures of one link of the network at a time have been simulated. The results suggest that, in terms of the nodes (properties) affected by shortfall in pressure, the more rigorous approach reduces the zone of deficient service compared with that flagged by conventional investigations. A case study used the methodology to investigate loss of resilience arising from pressure management and to assess the susceptibility to supply interruption of sensitive customers.

Fuzzy logic model to predict hydraulic jump aeration efficiency

S. Kucukali and S. Cokgor

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 4, December, 225-231, doi:1080/wama.2007.160.4.225

A fuzzy logic model was constructed to predict hydraulic jump aeration efficiency. Fuzzy subsets and rules were created based on experimental observations and measurements carried out in a 0.5m wide flume with upstream Froude and Reynolds numbers of 2.3–6.4 and 1.4–5.4 $\times 10^4$, respectively. A strong correlation was found between the aeration efficiency and Froude number. Upstream Froude and Reynolds numbers were selected as input parameters for the model. In this study, rather than mathematical equations, linguistic expressions were used to relate the upstream Froude and Reynolds numbers with aeration efficiency in an IF–THEN format. The proposed fuzzy model made good predictions and captured the system dynamic behaviour. Experimental observations confirmed the fact that hydraulic jump can be used as an aerator and mixing device in water treatment plants. Estimation of the aeration efficiency of a hydraulic jump could be made by any designer with the help of the fuzzy logic procedure described in this paper.

3-D computation of flood processes in sharp river bends

M. Tritthart, and D. Gutknecht

Proceedings of the Institution of Civil Engineers, Water Management, **160**, No. 4, December, 233-247, doi:1080/wama.2007.160.4.233

Three different three-dimensional computational fluid dynamics codes—SSIIM, Fluent and RSim-3D—were used to predict water surface and flow field during the 100-year flood of August 2002 in a sharp bend of the Danube River near the Austrian municipality of Grein. All models solved the Reynolds-averaged Navier–Stokes equations using a finite-volume approach. For the SSIIM and Fluent models, a structured grid of hexahedral cells was employed, while the basis for the RSim-3D model was an unstructured grid of arbitrary polyhedrons. The non-hydrostatic pressure field was computed using the Simple method and the standard k_ϵ model provided turbulence closure. The position of the water surface was derived from the pressure field. Computed water surface elevations were compared with each other and verified using field data observed during the flood event. It was found that the maximum super-elevation of bank water levels was predicted within an error margin of 10–20% of the observed value. Flow velocity magnitudes were found to vary among the different models, which is primarily credited to different pressure distribution schemes. Strong secondary motions with velocity magnitudes of up to 1 m/s were predicted by the computer codes, contributing to the extreme super-elevations observed.