account for the time-dependent movements, and a very long discussion of mathematical models. The chapter on mechanisms provides a link with the first part of the book because most of the mechanisms relate to happenings at the microstructural level. The experimental chapter brings a welcome touch of practicality and makes an interesting contrast with the other two chapters of the middle part. The mathematical modelling is important in its demonstration of the relevant and powerful contribution made by the computer, especially in the ability to use numerical methods based on the integration of the effects taken over small time intervals. This is essentially a matter of considering rates of creep and shrinkage and could well be a pointer to future prediction methods based on rates of deformation rather than on the deformations themselves.

The third and last part of the book contains chapters written by C. A. Anderson (Los Alamos National Laboratory, USA), Professor W. H. Dilger (University of Calgary, Canada), and H. G. Russell (Portland Cement Association, USA), B. L. Meyers (Bechtel Power Corporation, USA) and M. A. Daye (Acres America Incorporated, USA). It is the most satisfactory part for the reader in that the coverage has the best balance. Thus the first author provides an example of sophistication in which computer-based constitutive laws are incorporated in a finite element analysis; this is complemented by the second author, who gives an overview of the various methods of

time-dependent analysis available to the structural engineer with some elaboration, including examples of the author's preferred approach. The third chapter returns to reality by describing field observations on structures and by comparing observed and calculated deformations. It is sobering to find, at the end of a book largely concerned with theoretical matters, that existing analytical methods are still unable to produce more than approximate estimates of the behaviour of actual structures.

The reader will find that this volume contains many interesting facts and concepts on the creep and shrinkage of concrete, and on the analysis and measurement of the behaviour of concrete structures. These include ideas for the next generation of methods for estimating the magnitudes of creep and shrinkage, and demonstrations of the mechanics and techniques that can be readily adopted for computer processing. However, as indicated in the last paragraph of the last chapter 'the all inclusive empirical relationship or the complete theoretical formulation for the time-dependent deformation of concrete is as yet unobtainable'. This being so, a comprehensive discussion on the reliability and applicability of existing methods would have been appreciated, daunting though the preparation of such a comparison would be. In the end it may well be that future progress will hinge on the application of the methods described in the two most practical chapters – on experimentation and field observation.

J. M. ILLSTON

Analysis of concrete box beams using small-computer capacity

B. I. Maisel

Wexham Springs, Cement and Concrete Association, A4. Type-set, illustrated, paperback, pp. 87. ISBN 0 7210 1253 1. ISSN 0143-1560. Development Report 5 (publication 41.005). Price: £7.00.

Five Appendices, also A4, in reproduced manuscript corner-stitched, available individually or as a set.

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The second and final report of the Cement and Concrete Association on the analysis of box beams deals with prismatic multi-cell beams and consists of the main report and five Appendices totalling four hundred pages. It is clearly based on a very considerable amount of work of both theoretical and numeri-

cal nature. The report consists of an extensive literature survey, a detailed explanation of Sedlacek's analytical treatment and the results of comparative studies of several box beam structures. The title of the report could be misleading, as 'small-computer capacity', when read in conjunction with the

capacities of micro-computers, might still suggest considerable power and memory capacity. However, abstracting from the report those objectives that seem most appropriate, its aims are to present a method of analysis which is essentially a hand approach with an emphasis on physical insight and which uses a computer or calculator to undertake the numerical work involved in the matrix operations.

The literature survey of the opening chapter lists 329 references, even though some important ones e.g. Dabrowski and the early work of Argyris, are not included there but are to be found in Dr Maisel's earlier reports. It would, however, have been more helpful to the user of the report if the survey had been more selective so that those references particularly relevant to the remainder of the report but not presented in detail in subsequent chapters could have been described more fully.

The chapters that follow on simple bending and torsional warping of multi-cell structures are well worth presenting both for themselves and in order to introduce the treatment of distortional warping after Vlasov and Sedlacek.

The chapter on the analysis of the distortional behaviour of multi-cell box beams will, perhaps, be of most interest. It is also the most difficult part of the theory to deal with. The method described deals explicitly with any number of cells leading to closed solutions and does not rely on the approximation which assumes a simplified mode of behaviour for the anti-symmetric and symmetric deformation patterns respectively. The report sensibly limits the validity of the approach to a maximum of four cells but, of course, the fewer the cells, the less is the need for a general approach. The approach is made general by presenting it in matrix form and the matrix forms of the governing sets of simultaneous differential equations are derived. The governing equations are transformed into a series of independent equations whose variables are the eigen-vectors or characteristic displacement patterns of the distortional deformation components. These deformations can be solved by analogy between the resulting governing equation and that for a beam on an elastic foundation. This physical representation of the solution allows the understanding and available results for such beams to be used without the need for proceeding further with the mathematics. The strength of this approach is that generality is combined with a valuable analogy. However, the number of apparently non-physically connected matrix operations necessary to reach that stage limits the physical insights and understanding to only a part of that which could have been obtained.

The representation of the distortional behaviour of, say, a three-cell box beam by a beam on an elastic foundation is, of course, not only a mathematical analogy. The distortional deflections of the box

produce in-plane curvature of each wall with corresponding bending or distortional warping stresses and also deformation of the cross-section with corresponding distortional reaction. The properties of the box beam are, therefore, physically very similar to those of a simple beam and its foundation.

The adoption of an axial tensile force in the analogous beam to mirror the torsional characteristics which are dependent on the second differential of deflection is understandable, as this is one of the cases dealt with in the standard work on beams on elastic foundations by Hetenyi, which is given as a reference and is widely available. A more satisfying approach would, however, have been to use an elastic foundation with shear connection between the foundation's vertical stiffness properties which has been investigated in depth by Vlasov and Leont'ev, as it would have corresponded more closely to the torsional shear of the actual beam. Whichever is used, the boundary conditions of the analogous beam will be different from those of the actual beam in the vicinity of a concentrated load. The differences are due to changes in both distortional and torsional shear stresses affecting warping deformation. Differences in boundary conditions are not discussed in the report and, since distortional shear is explicitly assumed negligible and coupling of torsional terms between the separate systems in the final form is also assumed negligible, it seems that one is expected to conclude that the boundary conditions do not need further consideration. Section (10)(a) of the main conclusions points out, however, that the coupling and off-diagonal terms are not negligible, but were assumed so 'as was done by Sedlacek in his three-cell example'. It is to be noted that longitudinal stresses are more likely to be affected significantly than transverse bending stresses if the coupling term is included.

Hence the user of the report is left with a difficult decision: whether to follow the same path as the report and Sedlacek or to give the significant 'off-diagonal' terms further consideration. The latter course might have been a little easier if a physical analogy similar to that of the final solution had been used throughout the derivation, i.e. if the initial modes of distortional deformation had been represented as beams with elastic interconnection before deriving the eigen-vectors corresponding to the analogy of the report. The eigen-vectors of such multiple beam systems can be obtained by the following physically derived relationship. If the deflected shape of the transverse structural system acting alone has the same form as the loading applied to it, then it is an eigen-vector of the complete structural system. A similar approach can, of course, be applied directly to the transverse structural system of a multi-cell box beam. The actual arithmetical operations may be best carried out by the matrix

operations described in the report, but without a more physically based derivation the engineering implications of the method cannot be assessed.

The results of the comparisons between the finite strip method and that of the report give the user a method of making a rapid evaluation of the accuracy of the report method, though it is not always possible to separate dead and live load effects. The more detailed results of the Appendices are necessary if a full appreciation is required. In fact, the Appendices are necessary if any part of the report is to be understood at a level which would make it a working document for a design engineer. The report and the extensive Appendices show clearly that 'simple' engineering theories are not at all simple. They contrast strongly with finite element methods for

which powerful computers are necessary for the very large numbers of arithmetic operations, but which are simple in concept and as readily accept a multi-cell beam with a complicated cross-section, as a single I-beam.

It would be difficult to produce a fully automatic computer program to cope with the method of the report in a general way which would avoid an uneconomic amount of pre-processing of data. It is perhaps more likely that programs could be written for specific types of cross-section which could be calibrated against finite element solutions. Once sufficient detail is defined, however, less complex models may be suitable for the degree of accuracy required. Consequently the physical insight given by the report is perhaps its most important attribute.

BRIAN RICHMOND

Pressure on vertical formwork when concrete is placed in wide sections

T.A. Harrison

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The importance of an accurate knowledge of the pressure of concrete on formwork is well known. In fact the very first report of the Civil Engineering Research Association, dealt with this subject in April 1965. CIRIA used the data obtained from CERA Report No. 1 to produce graphs for site use to estimate concrete pressures. Site personnel found the graphs difficult to use and CIRIA produced a revised form of presentation with tables. This is the current information used by the industry in calculating the pressure, but it specifically excludes the use of concrete with cement replacement materials or admixtures and only refers to concreting of parallel-sided formwork. The only other method of calculating formwork pressure is the ACI method, but this is not in general use in the UK.

The publication of Dr Harrison's research report has been long awaited. His new pore-water pressure theory explains simply and concisely the mechanics of concrete pressure applied to formwork. The report explains the basis of the earlier theories and goes on to explain in simple terms the theory of pore-water pressure in concrete. The difference between placing concrete as a continuous fluid member and the site practice of placing in layers is also explained. There are essentially three areas in the construction industry where pressure of concrete on formwork needs serious consideration: firstly in walls on building

contracts, secondly on civil engineering contracts (for large foundation walls and abutments etc.) and thirdly for slender columns and piers. This report is intended only for civil engineering wall applications. On building contracts, walls tend to be relatively thin and this introduces other parameters in the interpretation of the theory; also concrete pressure in single-storey height buildings would rarely exceed 55 kN/m². With regard to pressures on columns, these are a unique case and require separate consideration owing to the higher rates of placing and because the two-dimensional restraint of the section may cause arching and particle support to reduce the concrete pressure. The civil engineer wishing to update his understanding of concrete pressures on a large contract would be well advised to read Dr Harrison's report.

The new theory postulates that the particle structure and the permeability of the formwork (to allow dissipation of the pore-water pressure) are two significant factors in concrete pressure on formwork. In considering the effects of admixtures, plasticizers and cement replacement materials upon the particle structure, the report admits to being inconclusive. Some guidance, though, is given for the use of water-reducers and plasticizers and air-entraining agents, but on the effect of superplasticizers and cement replacements, no conclusions are reached. Perhaps