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Serviceability Criteria For Building Codes

Critères d'aptitude au service dans les règlements de construction

Gebrauchstauglichkeitskriterien für Bauwerksnormen

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SUMMARY

The paper presents simple statistical models for processing data for design codes and performance standards. A literature review of the relevant data is made for the cases of serviceability limits related to building deformation, sway, floor vibration and cracking. It is found that the impact of unserviceability parameters on humans is highly variable and is influenced by many non-structural parameters.

RESUME

L'auteur présente divers modèles statiques simples, en vue de traiter les données relatives aux règlements de dimensionnement et aux normes de qualité. A partir de l'étude de publications, il effectue un choix de données essentielles relatives aux états limites de la déformation des ouvrages, du déplacement horizontal des étages, de la vibration des planchers et de la fissuration. Il en résulte que les paramètres d'inaptitude au service ont un effet fort variable sur les hommes et qu'ils sont influencés par de nombreux facteurs non structuraux.

ZUSAMMENFASSUNG

Der Beitrag stellt einfache statische Modelle vor, um Daten für Bemessungsnormen und Güterichtlinien zu bearbeiten. In einer Literaturstudie wird das betreffende Datenmaterial bezüglich Grenzzuständen der Bauwerksverformung, Stockwerksverschiebung, Deckenschwingung und Rissbildung gesichtet. Wie sich herausstellt, ist die Wirkung von Kenngrössen unzulänglichen Gebrauchsverhaltens auf Menschen sehr unterschiedlich und von vielen nicht-baulichen Einflüssen bestimmt.

1. INTRODUCTION

1.1 Serviceability

Because of the increased sophistication in our knowledge on structural strength and the use of higher strength and lighter weight materials, serviceability considerations have become a prime consideration in structural designs. Some idea of this transition can be obtained by noting that whereas the sway in a strong wind of the Empire State building is about 100 mm, the sway of modern skyscrapers such as the World Trade Centre in New York may be as high as 1000 mm.

In this paper, the term serviceability will be taken to refer to all structural behaviour, excluding structural collapse, that renders a building or construction unfit for its intended use. This lack of fitness may relate to human reactions (aesthetic, physiological or psychological), and may range from annoyance to medical trauma; it may also relate to matters that hinder the operations of humans or equipment; it does not include matters related to collapse due to corrosion or fatigue. In concept at least, it is possible to modify an unserviceable building, so that it becomes serviceable.

Some excellent summaries of the state-of-the-art with respect to design for serviceability limit states are to be found in the 1988 symposium/workshop held at Ottawa [2], the report by the ASCE ad hoc committee [11] and the BRANZ study report [10]. Other useful summaries on specific aspects include studies related to deformations [16,20,52], vibration loads [4,5,21,22,23,24,33,50], floor vibrations [5,13,18,35] and cracking [31].

1.2 Codification

The evolution of a structural technology can be divided into three phases as follows. In the first phase, the structural engineering is undertaken successfully only by expert engineers, operating largely through a mixture of past experience and intuition; in this phase, engineering may be considered to be an 'art'. In the second phase, limited research is undertaken to provide these master engineers with information that will assist them in pursuing their art. Eventually a third phase occurs when there is enough information and experience to enable the derivation of design procedures through formal processing of the available data; where possible, this is the preferred option for use in the drafting of codes and standards.

The use of codes and standards within the building industry has been discussed at length in a previous paper [28]. In particular these documents play a role as part of a formal agreement between two or more parties; they define their relative duties and responsibilities in the design and production of a building. Codes and Standards are also useful in that they provide a framework for the collation of data both from research and feedback from field experiences. In addition, it should be noted that codification of design procedures enables engineers of modest ability to execute competent designs of conventional structures.

In the following two simple statistical models of the codification process are presented. They are used as a framework for examining the suitability of available data for the derivation of design criteria related to the specific cases of building deformation, building sway, floor vibration and element cracking.

2. MODELS FOR USE IN CODIFICATION

2.1 General

Because serviceability involves human actions and response, it is a complex matter, involving high variability and nonlinear functions. In the following it will be assumed that for codification purposes, serviceability criteria will take the form of a finite set of simple design decisions. Each such decision will involve an effective cost, and the code recommendation will be based on minimising this cost.

Two types of codes or standards will be considered. The first will be a design code; the second will be an in-service performance standard.

2.2 Design Code

In concept, this will be a design code that is optimised from the viewpoint of the building owner. A statistical model, discussed in a previous paper [29], is used to develop this code and is illustrated schematically in Figure 1; it is stated in terms of an unserviceability parameter such as crack width. The scenario assumed is that a building has an in-service value T of the unserviceability parameter; should this parameter exceed the value of the tolerance level or complaint threshold of the client, denoted by U, then an effective additional cost C_F will be incurred. This cost may be taken to include not only direct costs, such as remedial costs, but also indirect costs that may arise, for example, from bad publicity or the loss of tenants. The aim is to optimise the value of $\bar{T}/\bar{U}$ chosen for the design procedure.

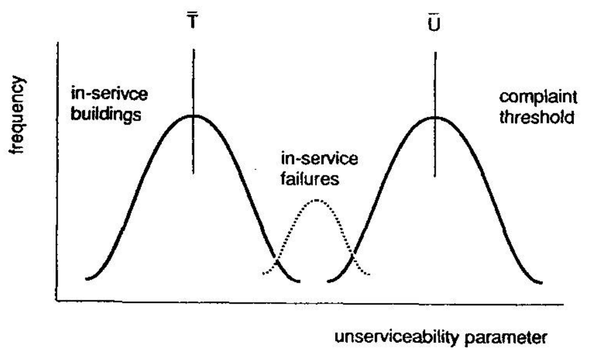


Fig. 1 Statistical model for a design code.

For the building owner, the cost associated with the design denoted by C, can be written

$$C = C_S + C_F\, p_F \tag{1}$$

where C_S denotes the cost of the structure and $p_F = Pr(U < T)$

If it is assumed [29] that

$$C_S = A\bar{T}^{-m} \tag{2}$$

and

$$p_F = B(\bar{U}/\bar{T})^{-n} \tag{3}$$

where A, B, m and n are constant, then optimisation of equation (1) leads to

$$(\bar{T}/\bar{U}) = [n\, B\, C_{FO}/m]^{1/n} \tag{4}$$

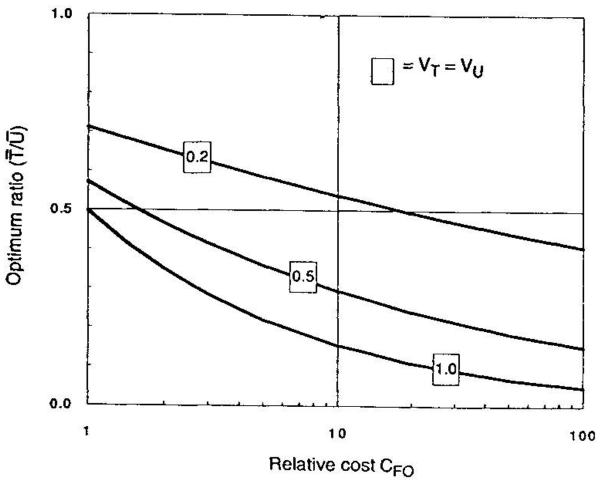
and

$$p_F = m/n\, C_{FO} \tag{5}$$

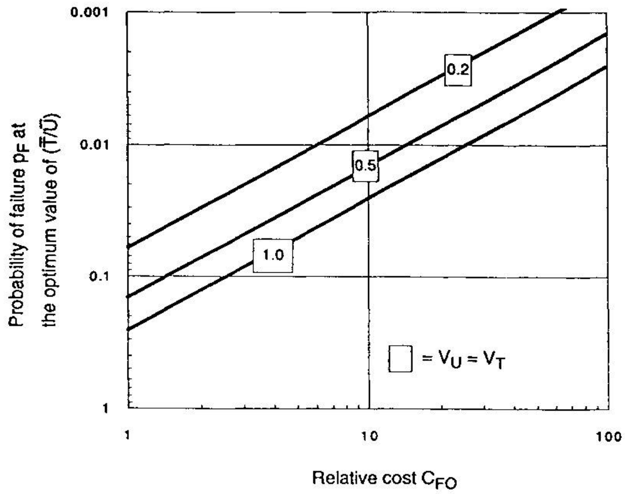
where

$C_{FO} = C_F/C_{SO}$, and C_{SO} denotes the cost of the optimum structure.

Appendix A gives a method for estimating the parameters B and n for use in equations (4) and (5); these parameters are stated in terms of V_T and V_U, the coefficients of variation of T and U respectively. Some typical optimised values of $\bar{T}/\bar{U}$ and p_F based on these assumptions are shown in Figure 2.



(i) Ratio ($\bar{T}/\bar{U}$)



(ii) Probability of failure

Fig. 2 Optimum values for design codes (m = 0.5).

2.3 Performance Standards

The statistical model for this case is illustrated schematically in Figure 3. Here an in-service value L of the unserviceability parameter is specified as a legal limit. If this limit is exceeded, the builder must pay a remedial cost C_F. If the limit is not exceeded, but the unserviceability parameter exceeds the complaint threshold of the owner, then the owner will pay for the costs of remedial action.

The cost to the building owner is

$$C = C_S + C_F\, p_{F1} \tag{6}$$

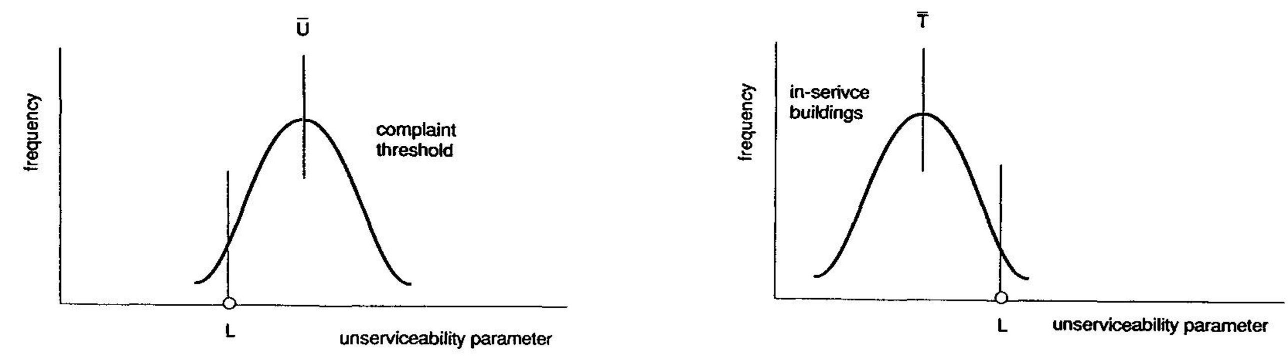
where $C_S = A_1\, L^{-m}$, A_1 is a constant and $p_{F1} = \Pr(U < L)$.

The cost to the builder is

$$C = C_S + C_F\, p_{F2} \tag{7}$$

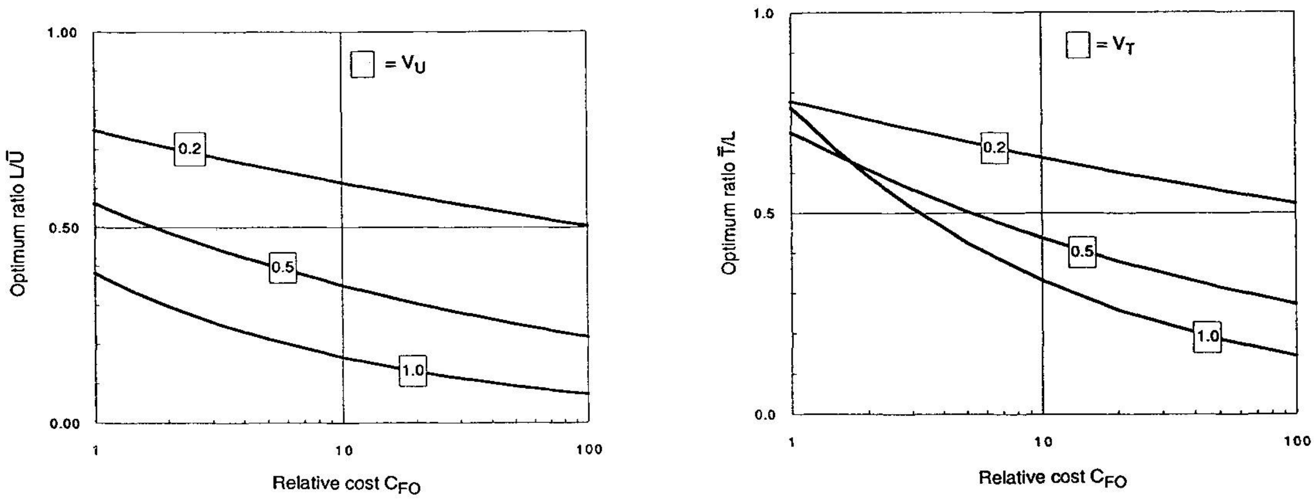
where $C_S = A_2\, L^{-m}$, A_2 is a constant and $p_{F2} = \Pr(T > L)$.

It is now assumed that first the building owner selects the legal limit L so as to minimise his costs, and then the builder selects the target in-service value of $\bar{T}$ so as to minimise his costs. Then the optimisation of equations (6) and (7) leads to equations identical to those for the optimisation of equation (1), except that the coefficients of variation $V_T = 0$ and $V_U = 0$ are to be used in the optimisation of equations (6) and (7) respectively.
Some optimum solutions for these cases are shown in Figure 4.



(i) Selection of a legal limit L (ii) Builder response

Fig. 3 Statistical model for a performance standard.



(i) Selection of a legal limit (ii) Builder response

Fig. 4 Optimum values for performance standards (m = 0.5)

3. BUILDING DEFORMATIONS

3.1 Unserviceability Parameters

Unserviceability parameters for building deformations include deviations from straight lines, distorted right angles, tilt of walls and slopes of floors [20,46].

3.2 Human Response

The impact of these parameters is considerably influenced by additional architectural parameters such as the incident angle of surface lighting, the surface colour and texture, and whether there are any visual references, such as a free-standing cupboard next to a wall, to assess the magnitude of the deviations [44,46].

The writer is unaware of any direct measurements of the statistical characteristics of human response to the above unserviceability parameters.

3.3 In-service Values

With respect to in-service values of the unserviceability parameter, there is an interesting study by Espion and Halleux on the long-term deflection of reinforced concrete beams [14]. They observed a coefficient of variation of 35 per cent in the ratio of actual deformation to predictions by ACI and CEB formulae; this variability is a measure of V_T.

4. BUILDING SWAY

4.1 Unserviceability Parameter

Probably the most common choice for the unserviceability parameter is linear acceleration [32].

4.2 Human Response

When a building sways excessively, humans become aware of linear accelerations, angular accelerations, jerks (rates of change in acceleration), visual stimuli and sound stimuli [7,19,51]. The response ranges all the way from 'feeling refreshed' to nausea to acrophobia.

Figure 5 shows the results of laboratory studies on human perception to horizontal motion undertaken by Chen and Robertson in 1972 [8]; the results indicate a coefficient of variation of about 50 per cent in the perception threshold of horizontal accelerations; there is also an additional factor of 2, depending on whether the subject was seated or standing. This variability is a measure of V_U. Field surveys by Hansen and Reed [19] and by Takeshi Goto [51] in the aftermath of major wind storms has revealed a wide scatter between people with respect to the frequency that is considered to be acceptable for experiencing specific wind storms.

4.3 In-service Values

With regard to in-service performance, a survey of building measurements by Ellis has shown that there is a coefficient of variation of about 30 per cent in the uncertainty associated with predicting the fundamental frequency of vibration of a building [12]. Comments by Jeary indicate that the coefficient of variation of the error associated with prediction of building response is likely to be as high as 100 per cent [25]. These variabilities are indicative of the magnitude of V_T.

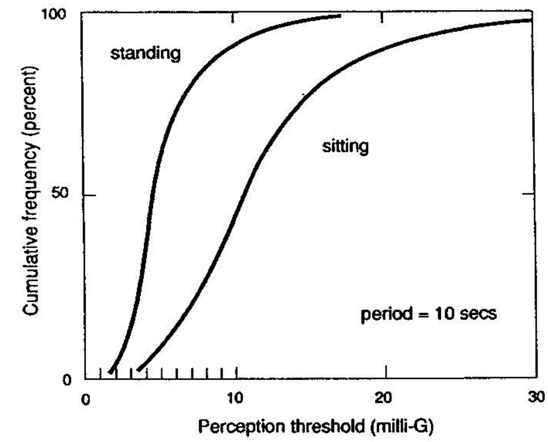


Fig. 5 Perception threshold for horizontal vibrations, after Chen and Robertson [8].

5. FLOOR VIBRATIONS

5.1 Unserviceability Parameters

Choices for unserviceability parameters related to human response to vibrations have included numerous complex functions of displacement, velocity, acceleration, frequency and damping [5]. Murray has compared the GSA, CSA, ISO and modified Reiher-Meister scales for this purpose and found significant discrepancies between them [33].

Even within the narrow topic of wooden floors there is a variety of choices for the unserviceability parameter. For floors with a natural frequency above 8 Hz, Ohlsson uses the peak velocity arising from a 1 N–s impulse [36]; Chui and Smith use the peak acceleration due to a heel-drop loading [9]; Onysko and Russell both use the deflection due to a static load [37,45]. In addition, Smith and Chui make a suggestion that in practice the vibration characteristics of a light weight floor are more likely to be dominated by the disposition of the superimposed loading rather than by the structural characteristics of the floor itself [47].

5.2 Human Response

Some idea of the variability of human response to floor vibrations can be obtained from the studies on 40 persons by Wiss and Parmlee in 1974 [55]. A coefficient of variation of about 30 per cent was obtained both for the threshold value and the strongly perceptible value of the frequency x displacement parameter of transient vertical vibrations.

Another estimate of variability is given in the 1954 research paper by Russell illustrated in Figure 6 [45]. In his study the unserviceability parameter was taken to be the midspan deflection of wood floor systems when subjected to a 1.7 kN midspan point load. For the 225 persons involved, the deflection associated with acceptance involved a coefficient of variation of 35 per cent. Both Russell and Onysko have noted the significance of sound stimuli in the acceptance of a floor system [38,45].

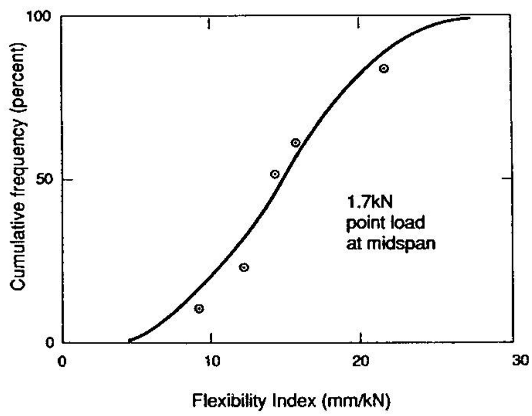


Fig. 6 Rejection threshold for wooden floors,

5.3 In-service Values

For simple floor systems, the variability of deflection and vibration characteristics can be estimated quite accurately from the variability of the materials used. However, there are difficulties. For example, with wooden floors the effects of gaps in the sheeting material and the complex nature of damping introduce many uncertainties [41].

In a study on long span floor systems, Allen and Rainer observed a coefficient of variation of 30 per cent in the ratio between the measured and calculated accelerations due to heel impacts on floor systems [3]; these accelerations are a popular choice for the unserviceability parameter of long span floor systems.

6. CRACKING

6.1 Unserviceability Parameter

The most usual parameter for unserviceability is crack width, although crack length and the number of cracks per unit area have also been considered.

6.2 Human Response

The impression of a crack is considerably influenced by secondary parameters such as the mode of lighting, the surface texture, the occurrence of dirt within the cracks and the viewing distance [6]. Apart from aesthetics, there appears to be a strong psychological element in the human response to cracks. For example, in their survey on human response, Padilla and Robles used attitude scales with questions containing the phrases 'give a bad impression', 'annoy me', 'proof that bad materials were used', 'feeling of danger' and 'fear that the apartment will collapse' [39].

Figure 7 shows data from a study by Haldane involving 400 persons asked to assess cracks in a simulated stub column [17]. The coefficient of variation of crack width corresponding to the rejection limit is about 40 per cent. Some data on field observations of the complaint threshold for cracks in brickwork has been given by Walsh [54].

6.3 In-service Values

In a study by Prakash and Desayi, the ratio of measured to computed crack widths in reinforced concrete beams, slabs and tension members was found to have a coefficient of variation of about 30 per cent. These were cracks due to static loads.

In their monumental study in 1970, Mayer and Rusch measured a coefficient of variation of about 30 per cent in the prediction of building damage due to the deflection of reinforced concrete building components [31].

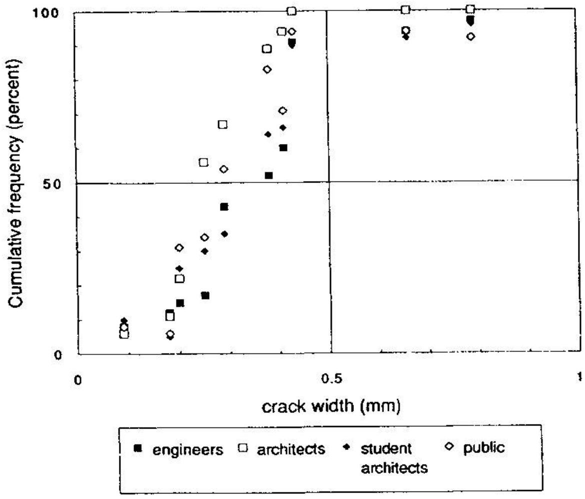


Fig. 7 Rejection threshold for crack widths in reinforced concrete stub columns, after Haldane [17].

Studies related to the prediction of building cracks due to vibrations caused by construction machinery indicate an uncertainty corresponding to a coefficient of variation of 30–60 per cent [15,34].

7. COSTS

The costs associated with resisting unserviceability are easily obtained for any specific theory of resistance. For example, the mass per unit length of Australian universal beams is proportional to $I^{0.414}$, where I denotes the second moment of area [30]. Hence, in the use of these beams, $m = 0.414$ in equation (2) when the unserviceability parameter is related to beam flexibility.

The costs associated with remedial action are not readily available. Some estimates have been given in a previous paper [29]. Interesting examples of costs related to cracking has been published by Kitcher and by Reid and Turkstra [27,43].

8. CODIFICATION

8.1 Data Processing

From this study and a previous one, typical values of parameters for the statistical model are $V_T = 0.2 - 1.0$, $V_U = 0.2 - 1.0$, $m = 0.2 - 1.0$ and $C_{FO} = 1 - 20$ [29].

For most cases a high probability of failure is associated with serviceability limit states, and so the shape and tails of the distributions are not as critical as in the case of analyses of ultimate limit states. Furthermore, if the parameter T turns out to be a complex function of several variables, then simple first order approximations may be used to derive acceptable values of $\bar{T}$ and V_T.

When data is very limited, the coefficients of variation V_T and V_U can be estimated from studies on similar phenomena, the ratio $\bar{T}/\bar{U}$ obtained from the statistical model, and then the mean value of $\bar{T}$ or $\bar{U}$ chosen so as to provide a match for any available data on either successful or unsuccessful inservice structural behaviour as indicated in Figure 1.

8.2 Load Combinations

Load combinations for ultimate limit states are typically estimates of peak loads in a 50-year period; as such they are usually too extreme for use in checking many types of serviceability limit states. For example, the acceptable lateral sway of a building may be stated in terms of events per year [32].

Examples of alternative load combinations for use in checking serviceability limit states are given in the Australian Standard AS 1170.1 [49]; based on the work of Pham and Dayeh, these include the peak load in any one-year period and the mean sustained load, both having a five per cent chance of exceedance [40]; the mean sustained load is intended to be used in creep and settlement estimates.

9 OPERATIONAL CONSIDERATIONS

9.1 Data

The literature search has revealed that for purposes of formal processing, the available data is limited, even with respect to the modest requirements of the statistical models discussed in this paper. Data on the complaint threshold for real buildings is very meagre. However, the use of formal models, as an alternative to simply following the recommendations of master engineers, has several advantages. One reason is the fact that intuitive or heuristic processing of limited statistical data is known to be associated with major bias effects [26]. More importantly perhaps, is that the use of models leads to an awareness of the deficiencies in the existing data bank and provides some idea of the potential benefits to be gained from gathering further data.

One firm conclusion derived from the literature search is that the uncertainties T and U involve high variabilities, and that the optimum failure rates for serviceability limits are high in comparison with that of ultimate limit states.

9.2 Design Codes

It is important that the intent of a design code be transparent; for example, major difficulties frequently arise in the application of many modern codes because it is not clear whether the purpose of deformation limits given therein are related to aesthetic or damage considerations. Ideally, a total scenario should be provided; it should include a description of the relevant failure mode and the associated range of remedial actions. In this regard it is interesting to note that the Australian Standard AS 2870 for residential footings on expansive soils, based on the work of Walsh, includes not only a description of the normal cracking to be expected, but also the reasonable care that the building owner is expected to take in the protection of these footings [48,54].

9.3 Performance Standards

If lengthy litigations on failures are to be avoided, then a critical aspect of performance standards is that they specify performance in terms of parameters that can be easily measured in the event of a dispute. Thus the crack width would be considered to be a useful parameter, whereas the lateral sway of a building in a 50-year return wind would not.

9.4 Multiple Limits

The literature review on the impact of unserviceability parameters on humans has revealed that these are strongly influenced by many nonstructural matters such as architectural features, audible and visual stimuli, building usage and the disposition of people. Thus, a strong case can be made that serviceability limits for both design codes and performance standards should not be specified as single values but rather should be specified in terms of sets of limits; this will permit the designer or building owner to choose limits that can be matched to each particular situation, and to the choice of building quality.

10. CONCLUSIONS

Simple statistical models have been presented for a design code and a performance standard. A literature review indicates that even for these simple models the data currently available for formal processing within the framework of these standards is limited. However, these models will become increasingly useful as data accumulates.

The human response to unserviceability parameters is found to be highly variable and to be influenced by many nonstructural parameters. Accordingly, a case can be made that serviceability limit states should be presented not as single values but as sets of values from which choices can be made to suit specific design situations.

Ideally, design codes should be transparent with respect to the failure scenario addressed by the design procedures; similarly performance standards should use criteria that are easily checked in the event of a dispute as to whether or not a serviceability limit state has been violated. The performance standard is probably the best option for countries with intense litigation practices.

11. REFERENCES

1. ALLEN, D.E. (1990). Building Vibrations from Human Activities. *ACI Concrete International: Design and Construction*, **Vol. 12**, No. 6, June, pp. 66–73.

2. ALLEN, D.E. (ed). (1988). *Symposium/Workshop on Serviceability of Buildings*, Ottawa, Canada, Vol. II, May, pp. 1–28.

3. ALLEN, D.E. and RAINER, J.H. (1976). Vibration Criteria for Long-span Floors. *Canadian Journal of Civil Engineering*, **Vol. 3**, No. 2, June, 9 pages.

4. ALLEN, D.E., RAINER, J.H. and PERNICA, G. (1977). Vibration Criteria for Long-span Concrete Floors. *Proc. of ACI Symposium on Vibrations of Concrete Structures*, New Orleans, Louisiana, USA, October, pp. 67–78.

5. BACHMANN, H. and AMMANN, W. (1987). Vibrations in Structures Induced by Man and Machines. IABSE, AIPC and IVBH, Zurich, Switzerland, 176 pages.

6. BEEBY, A.W. (1978). Cracking: What are Crack Width Limits For? *Concrete*, July, pp. 31–33.

7. BROWN, H. and MARYON, J. (1975). Perception of Wind Movements. *Building Materials and Equipment*, August/September, pp. 36–39.

8. CHEN, P.W. and ROBERTSON, L.E. (1972). Human Perception Thresholds of Horizontal Motion. *Journal of the Structural Division, ASCE*, **Vol. 98**, No. ST8, August, pp. 1681–1695.

9. CHUI, Y.H. and SMITH, I. (1987). Proposed Code Requirements for Vibrational Stability of Timber Floors. CIB Working Commission W18, Paper No. 20–8–1, Dublin, Ireland.

10. COONY, R.C. and KING, A.B. (1988). Serviceability Criteria for Buildings. Study Report SR14, Building Research Association of New Zealand, Wellington, NZ.

11. ELLINGWOOD, B. ALLEN, D.E., ELNIMEIRI, M., GALAMBOS, T.V., IYENGAR, H., ROBERTSON, L.E., STOCKBRIDGE, J. and TURKSTRA, C.J. (1986). Structural Serviceability: A Critical Appraisal and Research Needs. *Journal of Structural Engineering, ASCE*, **Vol. 112**, No. 12, December, pp. 2646–2664.

12. ELLIS, B.R. (1980). An Assessment of the Accuracy of Predicting the Fundamental Natural Frequencies of Buildings and the Implications Concerning the Dynamic Analysis of Structures. *Proc. of Institution of Engineers, Part 2*, **No. 69**, September, pp. 763–776.

13. ERIKSSON, P. (1990). Vibration of Low-Frequency Floors – Office Buildings and Shopping Centres. Dept. of Structural Engineering, Chalmers University of Technology, Goteborg, Sweden, 37 pages.

14. ESPION, B. and HALLEUX, P. (1990). Long-term Deflections of Reinforced Concrete Beams: Reconsideration of Their Variability. *ACI Structural Journal*, March/April, **Vol 87**, No. 2, pp. 232–236.

15. FERAHIAN, R.H. and HURST, W.D. (1969). Vibration and Possible Building Damage Due to Operation of Construction Machinery. *Proc. 1968 Public Works Congress and Equipment Show*, Miami Beach, USA, October, pp. 144–155.

16. GALAMBOS, T.V., GOULD, P.L., RAVINDRA, M.K., SURYOUTOMO, H. and CRIST, R.A. (1973). Structural Deflections. A Literature and State-of-the-Art Survey. National Bureau of Standards, US Dept. of Commerce, Washington, DC, USA, October, 66 pages.

17. HALDANE, D. (1976). The importance of Cracking in Reinforced Concrete Members. *Proc. of International Conference on Performance of Building Structures*, Glasgow University, Pentech Press, March, pp. 99–109.

18. HANSEN, H. (1958). Deflection Characteristics of Wood-Joist Floors. Norges Bugg forskningsinstitut, Rapport No. 26, 34 pages. National Research Council of Canada Technical Translations 883 by H.A.G. Nathan, 39 pages.

19. HANSEN, R.J., REED, J.W. and VANMARKE, E.H. (1973). Human Responses to Wind-Induced Motion of Buildings. *Journal of the Structural Division, ASCE*, **Vol. 99**, No. ST7, July, pp. 1589–1605.

20. INTERNATIONAL STANDARDS ORGANISATION (1977). ISO 4356 'Bases for the Design of Structures – Deformations of Buildings at the Serviceability Limit States', 18 pages.

21. INTERNATIONAL STANDARDS ORGANISATION (1985). ISO 2631/1 'Evaluation of Human Exposure to Whole Body Vibration – Part 1: General Requirements'. 17 pages.

22. INTERNATIONAL STANDARDS ORGANISATION (1985). ISO 2631/3 'Evaluation of Human Exposure to Whole Body Vibration – Part 3: Evaluation of Whole Body Z–Axis Vertical Vibration'. 6 pages.

23. INTERNATIONAL STANDARDS ORGANISATION (1989). ISO 2631/2 'Evaluation of Human Exposure to Whole Body Vibration – Part 2: Continuous and Shock-Induced Vibration in Buildings (1 to 80 Hz)', 20 pages.

24. INTERNATIONAL STANDARDS ORGANISATION (1990). ISO/DIS 10137 'Bases for Design of Structures – Serviceability of Buildings Against Vibration, 53 pages.

25. JEARY, A.P. (1982). Dynamic Behaviour of Structures. *BRE News*, **No. 56**, Spring, pp. 14–15.

26. KAHNEMAN, D., SLOVIC, P. and TVERSKY, A. (ed). (1982). *Judgement Under Uncertainty: Heuristics and Biases.* Cambridge University Press, Cambridge, UK, 555 pages.

27. KITCHER, J.S.D. (1983). Building Houses on Heavy Clay; Counting the Cost. *South African Builder*, January, pp. 26–29.

28. LEICESTER, R.H. (1991). The Development of Structural Timber Standards. *Proc. of 1991 International Timber Engineering Conference*, London, UK, September, **Vol. 2**, pp. 302–310.

29. LEICESTER, R.H. and BERESFORD, F.D. (1977). A Probability Model for Serviceability Specifications. *Proc. of Sixth Australian Conference on the Mechanics of Structures and Materials*, Christchurch, NZ, August, pp. 407–413.

30. LEICESTER, R.H. and PHAM, L.P. (1987). Serviceability Limits. *Proc. of First National Structural Engineering Conference*, Melbourne, Australia, **Vol. 2**, August, pp. 530–534.

31. MAYER, H. and RUSCH, H. (1967). Building Damage Caused by Reinforced Concrete Building Components. Deutscher Ausschuss Fur Stahlbeton, Heft 193, Berlin 1967, 90 pages. National Research Council of Canada Technical Translation 1412 by J. H. Rainer, Ottowa, Canada, 1970.

32. MELBOURNE, W.H. and CHEUNG, J.C.K. (1988). Designing for Serviceable Accelerations in Tall Buildings. *Proc. of Fourth International Conference on Tall Buildings*, Hong Kong and Shanghai, pp. 148–155.

33. MURRAY, T.M. (1990). Acceptability Criterion for Occupant-induced Floor Vibrations. *Floor Vibration in Buildings – Design Methods*, Australian Institute of Steel Construction, Sydney, Australia, February, pp. 1–9.

34. NORTHWOOD, T.D. CRAWFORD, R. and EDWARDS, A.T. (1963). Blasting Vibrations and Building Damage. *The Engineer*, **Vol. 215**, No. 5601, May, pp. 973–978.

35. OHLSSON, S.V. (1982). Floor Vibrations and Human Discomfort. Div. of Steel and Concrete Structures, Dept. of Structural Engineering, Chalmers University of Technology, Goteborg, Sweden.

36. OHLSSON, S.V. (1988). A Design Approach for Footsteps-induced Floor Vibration. *Proc. of 1988 International Conference on Timber Engineering*, Seattle, USA, September, **Vol. 1**, pp. 722–729.

37. ONYSKO, D.M. (1988). Performance Criteria for Residential Floors Based on Consumer Response. *Proc. of 1988 International Conference on Timber Engineering*, Seattle, USA, September, **Vol. 1**, pp. 736–745.

38. ONYSKO, D.M. (1988). Performance of Wood-joist Floors. Report OPX 120E Study No. OP–052, Eastern Forest Products Laboratory, Ottawa, 24 pages.

39. PADILLA, J.D. and ROBLES, F. (1971). Human Response to Cracking in Concrete Slabs. *Cracking, Deflection and Ultimate Load of Concrete Slab Systems*. ACI Publication, SP–30, Detroit, Michigan, USA, pp. 43–54.

40. PHAM, L. and DAYEH, R. (1986). Floor Live Loads. *Proc. of 10th Australasian Conference on the Mechanics of Structures and Materials*, Adelaide, Australia, **Vol. 2**, August, pp. 559–564.

41. POLENSEK, A. (1988). Structural Damping and Its Effect on Human Response to Floor Vibrations. *Proc. of 1988 International Conference on Timber Engineering*, Seattle, USA, September, **Vol. 1**, pp. 746–755.

42. PRAKASH DESAYI (1976). Determination of the Maximum Crack Width in Reinforced Concrete Members. *ACI Journal*, August, pp. 473–477.

43. REID, S.G. and TURKSTRA (1980). Serviceability Limit States – Probabalistic Description. Report ST 80–1, Dept of Civil Engineering and Applied Mechanics, McGill University, Montreal, Canada, June, 94 pages.

44. RIDGE, M.J. (1960). Illumination and Decoration of Flat Surfaces. Report No. L8, Division of Building Research, CSIRO, Melbourne, Australia, 18 pages.

45. RUSSELL, W.A. (1954). Deflection Characteristics of a Residential Wood-joist Floor System. Housing Research paper No. 30, Housing and Home Finance Agency, Washington DC, USA, 64 pages.

46. RYAN, N.M. (1990). Inaccuracy in Locating Partitions and Ceilings and Its Influence on Visual Quality, *Building Research and Practice*, **No. 5**, pp. 297–302.

47. SMITH, I. and CHUI, Y.H. (1991). On the Possibility of Applying Neutral Vibrational Serviceability Criteria to Joisted Wood Floors, CIB W18 Meeting No. 24, Paper No. 24–8–1, Oxford, UK, 9 pages.

48. STANDARDS ASSOCIATION OF AUSTRALIA (1986). AS 2870, Residential Slabs and Footings. Sydney, Australia, pp. 36–38.

49. STANDARDS AUSTRALIA (1989). AS 1170.1 Minimum Design Loads on Structures, Part 1: Dead and Live Loads and Load Combinations'. North Sydney, Australia, 29 pages.

50. STEFFENS, R.J. (1974). *Structural Vibration and Damage.* Building Research Establishment, Dept. of Environment, HMSO, UK, 56 pages.

51. TAKESHI GOTO (1983). Studies on Wind-Induced Motion of Tall Buildings Based on Occupants Reactions. Session 6, *Proc. of 6th International Conference on Wind Engineering*, Gold Coast, Australia, April, **Vol 1**, 12 pages.

52. TNO INSTITUTE FOR BUILDING MATERIALS AND STRUCTURES (1975). Deformation Requirements for Buildings. SG–CUR Report No. 2, Steelbuilding Association (SG), Rotterdam and the Concrete Association (CUR), Zoetermeer, Waltman, Delft, 138 pages. National Research Council of Canada Technical Translation 1969 by A.H.P. Maurenbrecher, Ottawa, Canada, 1980.

53. WALSH, P.F. (1986). Guide to Home-owners on Foundation Maintenance and Footing Performance. Information Service Sheet No. 10–91, Division of Building Research, CSIRO, Melbourne, Australia, 6 pages.

54. WALSH, P.F. (1985). Load Factors and Design Criteria for Stiffened Rafts on Expansive Clays. *Transactions of Institution of Engineers, Australia*, Civil Engineering, **Vol. CE27**, No. 1, pp. 119–123.

55. WISS, J.F. and PARMELEE (1974). Human Perception of Transient Vibrations, *Journal of the Structural Division, ASCE*, **Vol. 100**, No. ST 4, April, pp. 773–787.

APPENDIX A
PROBABILITY OF FAILURE

Because relatively high probabilities of failure are involved in serviceability limit states, the choice of statistical distributions for the variables T and U is not critical. For convenience, log normal distributions will be chosen. The probability of failure is then given by

$$p_F = \Pr(U < T) = \Phi(-\beta) \tag{A1}$$

where

$$\beta = \frac{\ell n(\bar{U}/\bar{T}) + \ell n[(1 + V_T^2)/(1 + V_U^2)]^{1/2}}{\{\ell n[(1 + V_T^2)\,(1 + V_U^2)]\}^{1/2}} \tag{A2}$$

in which $\Phi(\ )$ denotes the cumulative distribution function of a unit normal variate.

To a reasonable approximation, equation (A1) may be written

$$p_F \approx 10^{-\beta} \tag{A3}$$

Equations (A2) and (A3) then lead to

$$p_F \approx B(\bar{U}/\bar{T})^{-n} \tag{A4}$$

where

$$n = 2.3/\{\ell n[(1 + V_T^2)\,(1 + V_U^2)]\}^{1/2} \tag{A5}$$

and

$$B = [(1 + V_T^2)/(1 + V_U^2)]\}^{-n/2} \tag{A6}$$

For coefficients of variation less than 0.3, $n \approx 2.3/\sqrt{V_T^2 + V_U^2}$ and $B \approx 1$.

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