Under	**THE COMMISSIONS OF INQUIRY ACT 1908**
In the matter of the	**CANTERBURY EARTHQUAKES ROYAL COMMISSION OF INQUIRY INTO THE COLLAPSE OF THE CTV BUILDING**

STATEMENT OF EVIDENCE OF ROBIN SHEPHERD

BUDDLEFINDLAY
Barristers and Solicitors
Christchurch

Solicitor Acting: **Willie Palmer / Kelly Paterson**
Email: kelly.paterson@buddlefindlay.com
Tel 64-3-379 1747 Fax 64-3-379 5659 PO Box 322 DX WP20307 Christchurch 8140

Counsel Acting: **H B Rennie QC**
Harbour Chambers Tel 64-4-4992684 Fax 64-4-4992705 PO Box 10242 Wellington

BRIEF OF EVIDENCE OF ROBIN SHEPHERD

1. My full name is Robin Shepherd. I reside at different times in Tauranga and in Big Bear Lake, California, USA and I am a consulting engineer.

2. In accordance with the requirements of Rule 9.43 of the High Court Rules, I confirm that I have read the Code of Conduct for expert witnesses and that my evidence complies with the Code's requirements.

3. Matters on which I express an opinion are within my field of expertise.

4. I have no interests or relationships with any parties to these proceedings. I have known Dr Reay professionally and personally for many years but our contact is intermittent and I do not believe this affects my impartiality in this matter.

Qualifications and experience

5. I hold a Bachelor of Science (Hons) in Civil Engineering (University of Leeds, UK, 1955) and a Master of Science in Civil Engineering (University of Leeds, UK, 1966). I completed a Doctorate in Civil Engineering at the University of Canterbury in 1971 and was awarded a Doctorate of Science in Civil Engineering by the University of Leeds, UK in 1973. My thesis for my Ph.D in Civil Engineering included computer based nonlinear time history structural analyses.

6. I am an Emeritus Professor of Civil Engineering at the University of California, Irvine, United States of America and now run a private consultancy business. I have previously held a number of directorships, including with Earthquake Damage Analysis Corporation, a California Corporation which I established to provide expert specialised consultancy services in earthquake damage, analysis and mitigation. My employment history includes employment as an assistant structural engineer with the Ministry of Works, Readership at the University of Canterbury and Department Chairman at the University of California, Irvine.

7. I hold a variety of professional memberships including The American Society of Civil Engineers (Fellow and Life Member), The Institution of Civil Engineers (London) (Fellow) and the New Zealand National Society for Earthquake Engineering (Fellow and Life Member). I was registered with the New Zealand Engineers' Registration Board in 1959 and with the Board of Registration for Professional Engineers in California in 1981.

8. My involvement in post-earthquake structural damage assessments extends from the 1968 Inangahua event to California earthquakes including the 1971 San Fernando, the 1989 Loma Prieta and the 1994 Northridge earthquakes.

9. My full resume is **attached** and marked **"A"**.

Instructions

10. I have been instructed by Buddle Findlay, on behalf of Alan Reay Consultants Limited ("**ARCL**"), to provide independent expert advice on issues relevant to the collapse of the CTV Building on 22 February 2011 following an earthquake of magnitude 6.3. In particular, I have been asked to comment on the following issues:

    (a) Forensic Engineering practice;

    (b) The evolution of Seismic Design Standards;

    (c) Cumulative Earthquake Damage;

    (d) Seismic excitation of the Building site; and

    (e) Dynamic Analyses including Non Linear Time History analyses.

11. In preparing this evidence I have referred to and relied upon the principal sources of information set out in an appendix to this statement:

Forensic Engineering Practice

12. Various efforts have been made, most notably in the USA, to standardize best practice structural failure investigations.

13. The National Academy of Professional Engineers (NAFE) was formed in 1982 to advance the art and skill of engineers who serve as consultants to members of the legal profession and as expert witnesses in courts of law. Objects included the provision of continuing education and the promotion of high standards of professional ethics and of excellence in practice.

14. The American Society of Civil Engineers authorized the Technical Council on Forensic Engineers (TCFE) in 1985 with the purpose of developing practices and procedures to reduce the number of failures, to disseminate information on failures and their causes, to provide guidelines for conducting failure investigations, and to provide guidelines for ethical

conduct of forensic engineering. One of the products of the TCFE was the 2003 publication "Guidelines for Forensic Engineering Practice".

15. The objectives of each of the above referenced organizations include the fostering of competent, independent and unbiased applications of engineering principles within the jurisprudence system. Additionally it was anticipated that the practice of engineering would benefit from the Learning from Failure investigations (Shepherd 2010).

16. Clearly the Terms of Reference of the Royal Commission of Inquiry into the Building Failure caused by the Canterbury Earthquakes require that the engineering reports into the collapse of the CTV Building shall be of the highest possible standards which, I interpret, at the very least implies conformance with the NAFE and TCFE recommendations referred to above.

17. In simplistic terms the reports should attempt to answer the questions:

(1) HOW did the CTV Building fail; and
(2) WHY did the CTV Building fail.

In this context "failure" refers to a state or condition of not meeting desirable or intended objectives.

18. The following comments result from my review of the reports made available to me of various investigations undertaken since the February 2011 CTV Building collapse.

19. Dealing first with the HOW question.

20. An excellent effort was made (CTV Building Collapse Investigation for the DBH prepared by Dr Clark Hyland and Ashley Smith dated 27 January 2012 ("**Hyland/Smith report**"), Chapter 6, BUI.MAD249.0189.95) to interview the many eyewitnesses to the collapse and to integrate their memories to produce a most likely actual scenario. With the exception of the observations made by Chartered Engineer Graham Frost, a much less impressive effort was made to record and critically evaluate those portions of the structure remaining after the collapse. Apparently the opportunity was missed to undertake a comprehensive examination of the remains of the south tower or of the north tower before it was demolished. Also many of the column remains were transported to the dump absent a rigorous attempt to identify their position in the building. The impression remains

that after the recovery of survivors and bodies, the work to clear the site took precedence over the opportunity to maximize the information available from that part of the structure that had not collapsed.

21. The WHY aspect first led to the suspicion that the concrete strength of the columns was seriously deficient and this was supposedly substantiated by a few somewhat less than state-of-the-art concrete material tests on column remnants as covered in the Hyland/Smith report. Recent investigations by James Mackechnie, Douglas Haavik, the Cement and Concrete Association of New Zealand and Brendon Bradley have very largely discredited the presumption of concrete column material deficiency. However, the Hyland/Smith investigation appears to have been locked into pursuing the hypothesis that the columns provided the critical failure initiator to the extent that in undertaking the non-linear computer based time history analysis (NTHA) the focus of the modeling was placed on the columns at the exclusion of a possible alternative weakness. The Hyland/Smith report suggests a reluctance to accept the results of the NTHA where these did not agree with the consultants' view of the collapse sequence. It appears probable that the September 2010 earthquake resulted in more deterioration of the CTV Building structure than was assessed immediately following that event. In a somewhat arbitrary decision, those undertaking the NTHA analyses chose to neglect the possibility that the CTV Building might not have been in an essentially undamaged state at the commencement of the February 2011 shaking.

22. The Department and Building's efforts to provide a credible answer to the WHY question, as represented by the Hyland/Smith report, cannot be considered conclusive. By failure to abide by the generally accepted open-minded approach to a Failure Analysis investigation, too many avenues of possible enquiry were neglected.

Evolution of Seismic Design Standards

23. Efforts to ensure quality assurance of constructed facilities have been made from time immemorial. It is recorded that in ancient Babylon the code of Mammurabi held contractors liable for their work, stating that if a man built a house which collapsed and killed a householder, the builder "shall be slain".

24. In the English speaking world building codes can be traced back to those formulated following the rebuilding of London in the seventeenth century after the great fire. A common purpose of early codes was to provide

minimum standards of construction to safeguard personal safety and public welfare. Early seismic resistance standards following earthquakes such as the 1931 Napier and the 1933 Long Beach, California, events were very basic, typically requiring the provision of resistance to static lateral loads of a tenth of the weight of the structure. The overall objectives of such codes were essentially ill defined and, in the absence of reliable quantitative records of seismic ground motion, the choice of the tenth of gravity factor was decidedly arbitrary.

25. The development of strong ground motion measuring instruments, initially of mechanical configuration but subsequently rendered obsolete by electronic devices in the last half century, prompted improved understanding of the dynamic characteristics of both ground motion and superstructure response. As a result, awareness grew of the importance of the matching of structures' dynamic properties with ground vibrations.

26. The first significant strong ground motion time history response record was obtained in 1940 at El Centro near the California/Mexico border. The North/South component of this trace, with a peak acceleration of around 0.3g, was used in early digital computer based analyses of seismic structural response. Simplistic inverted pendulum scratch plate ground motion recorders were developed in New Zealand some fifty years ago and one such instrument indicated a peak horizontal ground acceleration of about 0.28g near to Gisborne in 1960. Such measurements prompted review of the adequacy of the 0.1g static load provision in vogue at that time.

27. In 1968 the Structural Engineers Association of California Lateral Force Code specified the intent that structures designed in conformance should be able to resist minor earthquakes without damage, resist moderate earthquakes without structural damage but with some non structural damage and resist major earthquakes without collapse but with some structural as well as non structural damage. Subsequently the term "earthquake" was replaced by "ground motion" and attempts were made to define the ground motion in terms of a maximum considered event (MCE) with a primary goal of no collapse in the MCE.

28. By 1978 the California Applied Technology Council introduced explicit consideration of risk in seismic resistant design. Recognition was stressed that:

"it is not possible by means of a building code to provide a guarantee that buildings will not fail in some way that will endanger people as a result of an earthquake. While a code cannot ensure the absolute safety of buildings, it may be desirable that it should not do so as the resources to construct buildings are limited. Society must decide how it will allocate the available resources among the various ways in which it desires to protect life safety. One way or another, the anticipated benefits of various life protecting programs must be weighed against the cost of implementing such programs."

29. Prompted by much basic research in seismology and on structural component behaviour more sophisticated design codes in New Zealand and Japan have developed in parallel with those in California. Necessarily the codes became more complex as attempts were made to better represent both the demand (i.e. structural response to ground motion) and the capacity (i.e. the ultimate strength characteristics of the structure's components) and their interaction.

30. A general pattern emerged. As the result of post-earthquake studies of damaged structures and the availability of many more strong ground motion records, refinements to existing codes tended to be enacted most effectively soon after each significant event whilst communities are still receptive to more stringent requirements. Community memories being short, resistance to such changes tend to increase with time. Nevertheless a notable achievement in the developed world has been made by progressively improving seismic design standards thereby reducing dramatically the loss of life due to earthquakes.

31. An inevitable result of stepwise developments in code requirements has been the production of a stock of buildings in any given location with variable seismic resistance capabilities. In general the newer structures respond more closely to their intended behaviour than do older ones. The current trend is to focus in the future on the performance aspects of a proposed structure and to provide a reasonable assurance that serious injury and loss of life will be avoided, that critical facilities will continue to function and that, wherever practicable, repair costs will be minimized.

Cumulative earthquake damage

32. The vulnerability of building structures to damage in successive earthquakes was referred to by Charles Richter, better known to the general public for the magnitude scale that bears his name, in his seminal

work "*Elementary Seismology*" published more than 50 years ago. He referred to "*the weakening effects of repeated shaking on common place construction*" and wrote "*some spectacular failures of old buildings are attributable to progressive weakening in successive minor shaking*".

33. Since then the technical literature contains reports of failure of structures in earthquake aftershocks after being weakened by earlier ground shaking. Much of this is of a colloquial nature, without reliable reference to specific buildings. However, it is clear that as a result of the complex pattern of energy release in successive earthquakes and aftershocks, cumulative damage does occur.

34. Through the Learning from Earthquakes Program of the California based Earthquake Engineering Research Institute multi-disciplinary reconnaissance teams have been dispatched to damaging earthquakes around the world. Their reports, including the observation that buildings that experience successive earthquakes may suffer progressive weakening or eventual collapse, have influenced many aspects of structural design in recent years.

35. Current seismic design anticipates that some non-elastic deformations will occur in selected structural members during strong motion events. When members are subjected to successive excursions each causing plastic deformations, but with insufficient deterioration to cause structural collapse, the structure as a whole is clearly weakened. Such sequences can occur either in the course of one earthquake together with its aftershocks, or over a longer time as a result of successive earthquakes. The damage may be in the form of material deterioration consequent upon repeated cycles of alternating stresses or in the form of residual displacements that can prompt potential instability of the structure.

36. The lateral dynamic response of a multi-storey building to seismic ground movements is critically sensitive to the natural period of vibration. Progressive weakening may lead to greater damage in multiple events as the more flexible structure better matches the input excitation. It is not necessary for the later events to be as energy intense as the earlier ones, but where this is the case the structure is most likely to suffer more damage, even to the point of complete collapse.

37. The ongoing practice of "repairing" cracked reinforced concrete structures by injecting epoxy into earthquake generated cracks and walls and other

elements is undertaken in an attempt to reinstate the strength and stiffness of the degraded member and thereby to restore the structure as near as possible to its original condition. By inference the cumulative nature of earthquake damage is recognised and attempts are made to compensate for it.

38. The CTV Building may well have been damaged more seriously in the September 2010 earthquake than was appreciated immediately following the event.[1] More serious damage could have been consistent with the Compusoft NTHA analyses. For example, see the draft CTV Building Collapse Investigation for the DBH prepared by Dr Clark Hyland and Ashley Smith dated 7 December 2011 ("**Hyland/Smith draft report**"):[2] "*First impressions are that the maximum strains suggest a level of damage somewhat higher than the minor 0.3mm wide cracks that were reported ....after the 4 September Darfield Earthquake*". However, the authors elected to assume that these column cracks had not deteriorated the columns to the extent that they were less able to resist failure in the February 2012 event.

39. It is noted that whereas item 4 of the "Conclusions" section of Appendix D of the Hyland/Smith draft report[3] reads *"[i]t has been difficult to reconcile the damage predicted by the analysis with reports of damage by others after the Darfield earthquake. The analysis generally indicated a higher level of damage than was reported"* the equivalent paragraph[4] of the Hyland/Smith final report reads *"[o]verall the output of the NTHA analyses was not inconsistent with the reported condition of the building after 4 September 2010. The limited available evidence of the building condition after 4 September 2010 leaves room for a range of interpretations of the likely maximum displacements in the 4 September 2010 event. However the conclusions drawn from the analyses are not particularly sensitive to the level of demand assumed by the NTHA, with indications that collapse could have occurred at lower levels of demand."*

40. The modification of the Hyland/Smith draft report wording to the final Hyland/Smith report could be interpreted as recognition by the authors of the problem of forming consistent conclusions based on the generally imprecise nature of quantitative results of NTHA analyses.

[1] Hyland/Smith report, page 49 - Summary of damage reported after the September 10 event, also page 12 "*The limited available evidence...*"
[2] at page 193
[3] at page 204
[4] on page 229

41. I am awaiting the results of the tests on the concrete column remnants tested in Colorado before commenting further on the validity of the view that the September 2010 earthquake did not significantly affect the strength of the CTV columns.

Seismic excitation at the CTV Building Site

42. It is noted that specifically for the CTV Building no records of the site or of the building motions were obtained in any of the Canterbury earthquakes' sequence (September 2010 through February 2011).

43. The response of a structure to an earthquake is critically dependant on the ground motion at foundation level. Both the period and amplitude of this motion can be affected by the characteristics of the near-surface layer. It has been generally accepted that the damage resulting from a major earthquake may vary considerably within a relatively small area in situations where the near-surface geology is inconsistent.

44. The Hyland/Smith report[5] records that Non-linear Time History Analyses were carried out using an input based on records obtained from three of the four sites surrounding the Central Business District ("**CBD**") where strong motion had been recorded, this choice being based on the recommendation of geotechnical specialists (understood to be Tonkin & Taylor).

45. Some confirmation of the appropriateness of this choice, with the possibility of modifying it to better represent the earthquake-induced ground motions at the CTV Building site, could have been undertaken if the site had been instrumented promptly after the earthquake on 22 February 2011. It is probable that the records obtained from the several subsequent significant aftershocks that occurred would have provided available evidence regarding the unique properties of the site.

46. On the basis of study of past strong motion earthquake records, a "rule of thumb" evolved in which the expected peak vertical acceleration would be of the order of one-half to two-thirds of the peak expected horizontal acceleration. Where the expected worst case horizontal acceleration might be taken as 0.9 g, this led to a corresponding worst case 0.6 g vertical acceleration. Since buildings are designed to resist, with a significant safety margin, normal static gravity loading, it was inferred that expected

[5] 2012, page 13

earthquake generated vertical loads were more than allowed for in gravity resistant design without additional vertical seismic strength provisions.

47. Actual records from the 22 February 2011[6] event showed that at several sites in the CBD the maximum vertical peak ground accelerations were of the order of 1.0 g. In the absence of any records from the CTV Building site, the actual vertical excitation experienced by the CTV structure can only be a matter of conjecture. However, it is clear that it was great enough to apply loads significantly in excess of those typically anticipated in code compliance seismic design. The Hyland/Smith report does not specifically address the possible effect of the exceptional vertical accelerations on the CTV columns.

48. It is noted that in March 2012 ARCL installed instrumentation on the CTV Building site. The results of the analysis of ground motion so recorded are awaited with considerable interest.

Dynamic Analyses

49. The availability of digital computers over the last half century has prompted their use to predict the response of structures to various dynamic excitations, including earthquakes. Initial applications were restricted to the assumptions that buildings behaved essentially elastically. In tandem with increasing computational power, techniques have been developed to permit the input of forcing functions representative of seismic ground motion and to model non-linear response properties of selected structural components.

50. Early computer programs tended to be research tools of little practical application. However, more recently, products from UC Berkeley and several derivative companies have been marketed as commercially applicable tools. These include ETABS, Drain 2-D and SAP 2000 from UCB and its offshoots. A notable contribution is the program RUAUMOKO developed by Professor Athol Carr here at the University of Canterbury. Arguably the most sophisticated, this is designed to produce a piece-wise time history response of non-linear general two-dimensional and three-dimensional structures to ground accelerations or time varying force excitations. It may also be used for static or pushover analyses of structures.

[6] Royal Commission Interim Report, October 2011, page 27

51. A common feature of the later programmes is that as the models become more representative of a physical structure, the size of the computation, and its consequent cost, increases to the extent that for practical considerations typically attention is focused on selected elements of the structure, ideally those judged to be the most critical. For similar cost saving reasons, in the case of a time history excitation input the length of the applied input record is frequently limited.

52. Earthquake ground motion is unpredictable. Consequently it is not possible to use forcing functions fully representative of future events appropriate to a given site. Even in post earthquake studies only rarely is a record available of the motion at a place of interest. As was done in the Compusoft analyses forming part of the Hyland/Smith report, recourse is frequently made to the use of records made at nearby locations with the consequent uncertainty of their applicability. In an effort to overcome the lack of naturally occurring time-history site records, researchers have generated artificial records having energy content and frequency characteristics equivalent to those observed in typical natural events for use on computer simulations. All of these approaches are necessarily a compromise.

53. The inherent complexity of the time-history computer simulation earthquake response process, with the necessity to make many judgment calls regarding the selection of the computer model and of the input functions, leads to the view that there are no absolute conclusions possible from such analyses. Rather their products can be considered to be very useful in a qualitative sense whilst leaving open their success in mirroring, with quantitative accuracy, actual events.

54. The limitations on the size of the model used for the computer analyses prevented a comprehensive "global" investigation that would have involved all components of the CTV structure being simulated to the maximum degree of sophistication. This restriction required a judgmental choice to be made of the most probable vulnerable components, which were then modelled in detail, whilst much of the rest of the structure was not subjected to such refinement. The result is that the computer analyses appear to have been made to prove a certain hypothesis rather than to investigate all collapse possibilities without prejudice.

55. An excellent comprehensive summary of the process of computer based earthquake response simulation is available in a Report to the Canterbury

Earthquake Royal Commission on the "*Inelastic Response Spectra for the Christchurch Earthquake Records*" authored by Emeritus Professor Athol Carr, dated 8 August 2011.

56. As pointed out by structural engineer William Holmes in his review of the report of the Hyland/Smith report, the emphasis was placed on drift controlled column failures as defined primarily by concrete strain limits at the exclusion of a wider ranging investigation of other possible critical factors. It is appreciated that time and resource constraints prompted this choice but the restriction required a judgmental choice to be made of the most probable vulnerable components, which were then modelled in detail, whilst the rest of the structure was not subjected to such refinement. This leaves the investigators open to the charge that the computer analyses appear to have been made to prove a certain hypothesis rather than to investigate collapse possibilities without prejudice.

57. There are numerous disclaimers and/or qualifiers throughout the Hyland/Smith report, for example:

    (a) "*Variability and uncertainty in physical properties and analysis procedures do not allow a particular (collapse) scenario to be determined with confidence.*"[7]

    (b) "*It has been difficult to identify a specific collapse scenario with confidence.*"[8]

    (c) "*Estimating the effect on the structure of the very significant ground accelerations is subjected to considerable uncertainty.*"[9]

    Despite these clearly expressed reservations, the authors chose to focus on a particular scenario at the exclusion of in-depth investigations of alternatives. In doing so, in my opinion they called into question the value of their conclusions.

General comment

58. The term "redundancy" as used in structural engineering is possibly open to misunderstanding. Its general definition of "the state of being no longer needed or useful" could mislead if applied to buildings. Aeronautical engineers have typically preferred "fail safe design" rather than structural

---
[7] Page 26
[8] Page 2
[9] Page 12

"redundancy". It is submitted that encouragement should be give to the use of the wording used in the Final Report, Department of Building and Housing "*Technical Investigation into the Structural Performance of Buildings in Christchurch*"[10] which defines alternative load paths or "back up" mechanisms as the preferred manner of preventing disproportionate collapse in the case of failure of a single load bearing element.

NTHA expert panel

59. I am participating in the NTHA expert panel being facilitated by Athol Carr. I reserve the right to modify or add to my evidence following the completion of this process.

Dated this 11th day of June 2012

R Shepherd

[10] 31 January 2012, page19, item 3

Appendix – Principal sources of information

1. CTV Building structural drawings

2. CTV Building structural specification

3. CTV Building structural calculations;

4. Reports by the Department of Building and Housing (including December 2011 drafts), comprising:

   (a) CTV Building Collapse Investigation for the DBH prepared by Dr Clark Hyland and Ashley Smith; and

   (b) Chapter 5 (CTV Building) of the Expert Panel Report on the Structural Performance of Christchurch CBD Buildings in the 22 February 2011 Aftershock

5. Surface Layer Modification of Seismic Waves" Shepherd & Travers ANZAAS Conference 1968

6. NZS 4203: 1984 - pages 1 through 60

7. Evolution of Building Code Seismic Performance Standards for New and Existing Buildings

8. William Holmes' presentation to the Earthquake Engineering Research Institute's Annual Meeting, Salt Lake City, Utah, February 2009

9. Geotechnical Advice, Tonkin Taylor to StructureSmith LImited - July 2011

10. Inelastic Response Spectra - Professor Athol Carr - August 2011 and Royal Commission Staff summary of same

11. Interim Report - Canterbury Earthquake Royal Commission - October 2011

12. "*Seismic Performance of R.C. buildings in the 22/02/11 earthquake*" - Bulletin of the NZEE Society, Vol. 44, #4, 240-242 & 263-264 - December 2011

13. Compusoft - Non Linear Seismic Analysis Report - February 2012

14. Concrete Testing Review by James Mackechnie - April 2012

15. Statement by Ashley Smith regarding Non Linear Seismic Analysis of CTV Building - April 2012

16. Statement by Derek Bradley regarding Non Linear Seismic Analysis of CTV Building - April 2012

17. Submission to the Royal Commission by Cement and Concrete Association of New Zealand being critique of Hyland January 2012 Reports - April 2012

18. Peer Review by Structural Engineer William Holmes of Hyland/StructureSmith Report on Investigation of CTV Building Collapse – 30 April 2012

19. Shepherd R, "*Forensic Earthquake Engineering*" Paper 36, New Zealand Society for Earthquake Engineering, Annual Conference, 2010 Te Papa, Wellington

"A"

ROBIN SHEPHERD

CONSULTING ENGINEER

Retired President, Earthquake Damage Analysis Corporation, a California Corporation providing expert specialised consulting services in earthquake damage analysis and mitigation.

Emeritus Professor of Civil Engineering, University of California, Irvine, U.S.A.

Address: 68 Myres Street
Tauranga 3110, New Zealand
Telephone 07 576 7343

or 39508 Clinemiller Place, Fawnskin
California 92333, U.S.A.
(909) 866-6076

e-mail: fawnskin@earthlink.net

Citizenship: New Zealand (Naturalised 1975), U.S.A. (Naturalised 1986): born England, 1933

Professional Licenses: Registered, New Zealand Engineers' Registration Board (Number 2797), 1959-1982. Registered , Board of Registration for Professional Engineers in California, (Number C33548), 1981- date.

Work Experience: Employed on Aircraft Structural Dynamic Analysis with the De Havilland Aircraft Company in England (1955-57) before joining the New Zealand Ministry of Works in Auckland as an assistant structural engineer in 1958.

Appointed to a Lectureship at the University of Canterbury in 1959; established the first Earthquake Engineering course in New Zealand. Transferred to a position as Associate Professor of Civil Engineering at the University of Auckland in 1972, where teaching duties involved Structural Analysis and Design, with particular reference to earthquake resistance, for seven years. Active researcher in the field of seismic response of structures throughout twenty years in New Zealand (see publications list).

Accepted the position of founding Director of the New Zealand Heavy Engineering Research Association in 1979; established the activities of this institute in providing technical and marketing services to New Zealand industry.

Joined the faculty of the University of California, Irvine in September 1980. Civil Engineering Curricula Chairman, July 1981 to June 1983. Departmental Chairman July 1983 to February 1984. Other responsibilities included:

Chairman: Engineering Faculty, 1985-86; Irvine Academic Senate Computer Committee, 1982-83; Research Committee, 1985-86; Graduate Council 1988-89.

Member: Committee on Academic Personnel, 1987-88; Academic Planning Council, 1988-89, Committee on Budget and Planning, 1989.

Part-time Faculty Member, Department of Civil Engineering, California Institute of Technology, 1993-1998. Accepted voluntary early retirement from the University of California, June 1994.

Formed Forensic Expert Advisers Inc. in 1989 as an Expert Referral service.

Established the Earthquake Damage Analysis Corporation in 1996.

Professional Activities: Include acting as a specialist consultant on computer applications in Seismic Resistant Design to individual New Zealand consulting engineers, as Consultant to the Engineers' Computer Bureau Limited, as a member of the Seismic Loadings Sub-Committee of the Standards Association of New Zealand, as Chairman of the Management Committee of the New Zealand National Earthquake Society. Expert advisor on building construction problems, including structural failures and personal accidents, to numerous Southern California Attorneys and Insurance Assessors. Extensive experience with deposition and Court testimony. Member of the Los Angeles City Council Metro Rail Project Technical Review Board. Member of the Publications Committee of Earthquake Engineering Research Institute and the Editorial Board of Earthquake Spectra, the Professional Journal of the Earthquake Engineering Research Institute. Member of the American Society of Civil Engineers' Journal of the Performance of Constructed Facilities Editorial Board. Conference Chairman, Fourth U.S. National Conference on Earthquake Engineering, Palm Springs, California, May 1990. Committee member, American Society of Civil Engineers Technical Council on Forensic Engineering. Official representative of the California Universities to the Seismological Committee of the Structural Engineers' Association of California. Member of the SEAOSC committee on Seismic Base Isolation and a member (chairman 1994-5) of the SEAOSC ad hoc Committee on Experimental Testing Procedures to simulate earthquake loading. Member of the Applied Technology Council ATC-33 Task Force charged with the production of standards for the seismic retrofit of timber buildings and of the ATC-50 Seismic Grading and Retrofitting Project Engineering Panel. One of the six person SAC Joint Venture Management Committee responsible for the $M11 FEMA funded focused investigation into the problems of welded moment resistant steel frame buildings following the weaknesses exposed in the Northridge earthquake.

Chairman, Executive Committee, American Society of Civil Engineers' Technical Council on Forensic Engineering.

Academic Qualifications:	B.Sc. (Hons.) Civil Engineering University of Leeds, U.K. 1955	M.Sc. Civil Engineering University of Leeds, U.K. 1966
	Ph.D. Civil Engineering University of Canterbury, N.Z. 1971	D.Sc. Civil Engineering University of Leeds, U.K. 1973

Professional Societies:

Membership, American Society of Civil Engineers 1961
(transferred to Fellowship, 1972, Life Membership awarded 1998)

Membership, Institution of Civil Engineers (London) 1962
(transferred to Fellowship, 1972)

Membership, The New Zealand National Society for Earthquake Engineering 1968, (elected to Fellowship 1985. Life Membership awarded 2005)

Membership, Earthquake Engineering Research Institute, 1976-2009

Membership, Society for Earthquake and Civil Engineering Dynamics (U.K.) 1984

Associate Membership, Structural Engineers' Association of Southern California, 1981, (reclassified - Membership 1996)

Honors:

1969, Holder of an Erskine Fellowship, University of Canterbury, New Zealand; 1972, Recipient, E.R. Cooper Medal and Prize (Royal Society of New Zealand); 1977, Holder of a Fulbright Travel Grant and a Visiting Professorship California Institute of Technology; 1984, Visiting Research Fellow Imperial College of Science and Technology, London, and Visiting Overseas Fellow, St. John's College, Cambridge; 1987, Erskine Visiting Fellow, University of Canterbury, New Zealand. 1996, Recipient, S.B. Barnes Award (Structural Engineers' Association of Southern California).

Director:

Board of California Universities for Research in Earthquake Engineering (CUREe), a California nonprofit public benefit corporation (1988-1992, 1994-6).

Director:

Forensic Expert Advisers Inc., a California Corporation providing an expert referral service to the legal profession (1989-2010).

Director:

Earthquake Damage Analysis Corporation, a California Corporation providing expert specialized consulting services in earthquake damage analysis and mitigation (1996-2008).

Extra Curricula Activities:

Sailboarding, social racquetball, erratic golf;
Rotary (Paul Harris Fellow) – District Governor 5330, 2008-09

Research and Published Papers

The relationship between many of the projects undertaken is the application of structural dynamic analysis procedures to the prediction of earthquake-induced loads and movements in civil engineering structures.

Many of the earlier papers describe normal mode analyses of idealized buildings, using digital computer techniques and leading to the determination of earthquake design criteria. Subsequent publications describe earthquake response predictions based on direct numerical integration techniques developed in parallel with experimental investigation of the dynamic characteristics of prototype structures to enable examination of the validity of the idealizations involved in mathematical modeling to be made.

Additionally, some tests undertaken to verify the integrity under seismic loading conditions of full size steel beam-column joints and of timber wall panels are reported.

The review papers attempted to describe the state-of-the-art at the time of writing and consequently are related chronologically to the other articles.

Earthquake damage assessments arising from on-site investigations are reported in papers 37, 48, 97, 102, 105, 114, 132, 139, 141 and 142.

Papers 1, 17, 22, 36, 52 and 61 were presented at Annual Conferences of the New Zealand Institute of Engineers.

Papers 5, 13, 19, 20, 25, 27, 28, 30, 33, 51, 55, 56, 57, 58, 62, 66, 67, 68, 76, 77, 78, 80, 86, 87, 88, 89, 91, 100, 103, 104, 105, 106, 108, 115 through 131, 133 through 141, 144, 146, 147, 148, 150, 151, 153 through 163 were presented at the corresponding conferences.

1. Shepherd, R. and Wood, J. H., "Dynamic Design of Earthquake Resistant Structures," New Zealand Engineering, 1963, 18 (4), 111-117.

2. O'Driscoll, R. J. and Shepherd, R., "Dynamic Response of Multistory Buildings," New Zealand Engineering, 1963, 18 (9), 307-312.

3. Shepherd, R., "Some Models of Use in the Teaching of Structural Mechanics," Journal of Engineering Education, 1964, 54 (10) 359-363.

4. Shepherd, R., "Strain Measurement Using Vibrating Wire Strain Gauges," Experimental Mechanics, Journal of the Society for Experimental Stress Analysis, 1964, 4 (8), 244-248.

5. O'Driscoll, R. J., Shepherd, R., and Wood, J. H., "The Determination of the Normal Mode Properties of Multistory Rectangular Rigid Framed Structures Using an Electrical Analogy," Proceedings, Third World Conference on Earthquake Engineering, 1965, 2, 421-442.

6. Shepherd, R. and Wensley, L. M., "The Moire-Fringe Method of Displacement Measurement Applied to Indirect Structural-Model Analysis," Experimental Mechanics, Journal of the Society of Experimental Stress Analysis, 1965, 5 (6), 167-176.

7. Shepherd, R., "The Design of Earthquake Resistant Multistory Framed Structures," Journal of the Institution of Engineers, Australia, 1965, 37 (12), 411-425.

8. Shepherd, R. and Walpole, W.R., "The Dynamic Interaction of Structures and Soils," New Zealand Engineering, 1966, 21 (2), 56-62.

9. Shepherd, R., "The Dynamic Analysis of an Apartment Building," Bulletin of the Seismological Society of America, 1966, 56 (1) 13-34.

10. Shepherd, R. and Wood, J.H., "Normal Mode Properties of Multistory Frameworks," Journal of Sound and Vibration, 1966, 3 (3), 300-314.

11. Shepherd, R. and Donald, R. A. H., "The Influence of Floor Flexibility on the Normal Mode Properties of Buildings," Journal of Sound and Vibration, 1967, 5(1), 29-36.

12. Shepherd, R., "Determination of Seismic Design Loads in a Framed Structure," New Zealand Engineering, 1967, 22 (2) 56-61.

13. Shepherd, R. and Donald, R. A. H., "Foundation Deformation Effects in Structural Dynamic Analysis," Proceedings, Fifth Australia-New Zealand Soil Mechanics Conference, Auckland, 1967, 205-212.

14. Shepherd, R. and Sidwell, G. K., "Dynamic Behavior of the Yarra River Bridge," New Zealand Engineering, 1967, 22 (3), 109-111.

15. Shepherd, R., "Strains in a Steel Portal Frame Structure," Journal of the Institution of Civil Engineers, 1967, 36, 595-606.

16. Shepherd, R. and Donald, R. A. H., "Seismic Response of Torsionally Unbalanced Buildings," Journal of Sound and Vibration, 1967, 6 (1), 20-37.

17. Shepherd, R., "Lateral Load Analyses of the Auckland Customs House," New Zealand Engineering, 1967, 22(7), 273-277.

18. Shepherd, R., "Some Measurements of Foundation Bearing Pressures," Strain, Journal of the British Society for Strain Measurement 1967, 3 (3), 32-35.

19. Shepherd, R., "The Determination and Distribution of Lateral Loads in the Design of Tall Buildings," Proceedings of the Third Australian Building Research Congress, Melbourne, 1967, 136-139.

20. Shepherd, R., "Prediction of the Response of a Torsionally Unbalanced Highrise Building to Earthquake Loading," Proceedings, First Australasian Conference on the Mechanics of Structures and Materials, Sydney, August 1967, 16-31.

21. Shepherd, R., "A Comparison of Calculated and Measured Periods of a Tall Building," New Zealand Engineering, 1967, 22 (9), 381-383.

22. Shepherd, R., "Seismic Lateral Load Analysis of a Steel Framed Building," New Zealand Engineering, 1967, 22 (10), 407-413.

23. Shepherd, R. and Reay, A. M., "Some Apparatus for the Small Amplitude Dynamic Testing of Multistory Building," Strain, Journal of the British Society for Strain Measurement, 1967, 3 (4), 16-21.

24. Shepherd, R., "Dynamic Elastic Analyses in the Earthquake Resistant Design of an Office Building," Journal of Sound and Vibration, 1968, 7 (2) 31-40.

25. Shepherd, R. and Travers, J. H., "Surface Layer Modification of Seismic Waves," New Zealand Engineering, 1970, 25 (2), 36-39.

26. Walpole, W.R. and Shepherd, R., "Post-Elastic Seismic Response of a Reinforced Concrete Frame," Bulletin, New Zealand Earthquake Engineering Society, 1968, 1 (1), 102-112.

27. Shepherd, R., "Dynamic Elastic Analyses in the Design of Typical New Zealand High-Rise Buildings," Proceedings, Fourth World Earthquake Engineering Conference, Santiago, 1969, 2, 99-112.

28. Walpole, W. R. and Shepherd, R., "The Inelastic Response of a Steel Frame," Proceedings, Fourth World Earthquake Engineering Conference, Santiago, 1969, 2, 195-204.

29. Walpole, W. R. and Shepherd, R., "Dynamic Elasto-plastic Response of a Reinforced Concrete Frame," Bulletin, Seismological Society of America, 1969, 59,(2), 855-864.

30. Shepherd, R., "Earthquake Resistant Design of Petroleum Storage Tanks," Proceedings, Second Australasian Conference on the Mechanics of Structures and Materials, Adelaide, 1969, 8.1-8.16.

31. Shepherd, R., "Some Limitations of Modal Analysis in Seismic Design," Bulletin, New Zealand Earthquake Engineering Society, 1969, 2 (3), 284-288.

32. Walpole, W. R. and Shepherd, R., "Elasto-Plastic Seismic Response of a Reinforced Concrete Frame," Proceedings, American Society of Civil Engineers, 1968, 95, ST.10, 2031-2055.

33. Shepherd, R., "The Seismic Design of Bridges," Proceedings, Institution of Engineers, Australia, Earthquake Engineering Symposium, Melbourne, 1969.

34. Walpole, W. R. and Shepherd, R., "Seismic Dynamic Analyses of a Railway Bridge," International Association of Bridge and Structural Engineering, 1969, 29/113, 35-46.

35. Shepherd, R. and Bargh, J. K., "Computer Facilities at Canterbury University," New Zealand Engineering, 1969, 24 (11), 346-348.

36. Garden, R. J. P., Shepherd, R., and Sharpe, R. D., "Notes on the Representation of Plastic Hinge Behavior in Dynamic Analysis," New Zealand Engineering, 1969, 24 (12), 386-391.

37. Shepherd, R., Dodd, T. A. H., Sutherland, A. J., Moss, P. J., Carr, A. J., Gordon, D. R., and Bryant, A. H., "The 1968 Inagahua Earthquake: Report of the University of Canterbury Survey Team," 1970 Canterbury Engineering Journal, No. 1, 86 pages, and in summarized form, Bulletin of the Seismological Society of America, 1970, 60 (5), 1561-1605.

38. Blakeley, R. W. C., Park, R., and Shepherd, R., "A Review of the Seismic Resistance of Prestressed Concrete," Bulletin of the New Zealand Earthquake Engineering Society, 1970, 3 (1), 3-23.

39. Shepherd, R. and McConnel, R. E., "An Application of Spectral Techniques to Inelastic Seismic Response Prediction," Bulletin of the New Zealand Earthquake Engineering Society, 1970, 3 (4), 173-178.

40. Reay, A. M. and Shepherd, R., "Steady State Vibration Tests of a Six Story Reinforced Concrete Building," Bulletin of the New Zealand Earthquake Engineering Society, 1971, 4 (1), 94-107.

41. Shepherd, R. and McConnel, R. E., "Some Aspects of the Solution of Equations of Motion Using Numerical Integration Techniques," The Australian Computer Journal, 1971, 3 (1), 20-28.

42. Reay, A. M., and Shepherd, R., "The Use of Models to Determine the Lateral Load Deflection Characteristics of Pierced Shear Walls," Strain, Journal of the British Society for Strain Measurement, 1971, 7 (2), 76-79.

43. Shepherd, R. and Charleson, A. W., "Some Measured Dynamic Properties of Laterally Loaded Piles," Proceedings N.R.B. Roading Symposium, Wellington, 1971, p/1-p/6.

44. Shepherd, R. and Charleson, A. W., "A Method of In-Situ Soil Stiffness Measurement," New Zealand Engineering 1971, 26, (4), 97-101.

45. Reay, A. M. and Shepherd, R., "The Separation of Two Combined Normal Modes," Journal of Sound and Vibration, 1971, 17 (2), 149-155.

46. Reay, A. M. and Shepherd, R., "Dynamic Characteristics of Three Adjacent Reinforced Concrete Buildings," Proceedings of the Institution of Civil Engineers, 1971, 50, 25-47.

47. Shepherd, R. and Charleson, A. W., "Experimental Determination of the Dynamic Properties of a Bridge Substructure," Bulletin of the Seismological Society of America, 1971, 61 (6), 1529-1548.

48. Shepherd, R., "Some Aspects of the San Fernando Earthquake," New Zealand Engineering, 1972, 27 (2), 57-63.

49. Shepherd, R. and McConnel, R. E., "Seismic Response Predictions of a Bridge Pier," Proceedings, American Society of Civil Engineers, 1972, 98, EM3, 609-627.

50. Shepherd, R., "Two Mass Representations of a Water Tower Structure," Journal of Sound and Vibration, 1972, 23 (3), 391-396.

51. Shepherd, R., "Seismic Analyses by Digital Computer Mathematical Modelling," Proceedings, Third New Zealand National Computer Conference, Massey University 1972, 2, 203-236.

52. Shepherd, R., "Seismic Design of Special Structures," New Zealand Engineering, 1972, 27 (12), 389-394.

53. Shepherd, R. and Aves, R. J., "Impact Factors for Simple Concrete Bridges," Proc. (part II) Institution of Civil Engineers, 1973, 55, 191-210.

54. Shepherd, R., "Multiphase Cross Bracing in Earthquake Resistant Structures," International Journal of Earthquake Engineering and Structural Dynamics, 1973, 1 (4), 311-324.

55. Shepherd, R., "The Seismic Response of Elevated Water Tanks Supported on Cross Braced Towers," Proceedings, Fifth World Earthquake Engineering Conference, Rome, 1973, I (paper 71).

56. Shepherd, R. and Travers, J. H., "Wave Propagation and Lumped Mass Analysis Techniques Applied to the Determination of the Response of Multiple Layered Systems to Sinusoidal and Seismic Excitation," Proceedings, Fifth World Earthquake Conference, Rome, 1973, I (paper 36).

57. Shepherd, R. and Sidwell, G. K., "Investigations of the Dynamic Properties of Five Concrete Bridges," Proceedings, Fourth Australasian Conference on the Mechanics of Structures and Materials, Brisbane, 1973, 261-268.

58. Shepherd, R., "New Zealand Earthquake Provisions," Proceedings, Australian and New Zealand Conference on the Planning and Design of Tall Buildings, 1973, Sydney, 82-95.

59. Shepherd, R. and Sidwell, G. K., "Dynamic Characteristics of Composite Steel Beam, Concrete Deck Highway Bridges," Highways and Road Construction, 1973, 41, (1767), 20-25.

60. Croad, R. N., Mead, F. H., and Shepherd, R., "The Cyclic Yield Response of a Steel Star Plate Cruciform Joint," Bulletin of the New Zealand National Society for Earthquake Engineering, 1975, 8 (4), 204-221.

61. Shepherd, R. and Spring, K. C. F., "Racking Load Tests on a Steel Beam-Column Joint," New Zealand Engineering, 1975, 30 (11), 326-331.

62. Shepherd, R. and Ross, D. A., "Inelastic Characteristics of a Reinforced Concrete Frame," Proceedings, South Pacific Regional Conference on Earthquake Engineering, Wellington, N.Z., May 1975.

63. Forrest, E.J. and Shepherd, R., "Dynamic Response of a Seventeen Story Wellington Building", Proceedings, Sixth World Earthquake Engineering Conference, New Delhi, 1977, (3), 416.

64. Shepherd, R., Spring K. C. F., and Mead, F. H., "Tests on Steel Beam-Column Joints," Proceedings, Sixth World Earthquake Engineering Conference, New Delhi, 1977, (9), 184.

65. Shepherd, R., and Greensmith B.M. "Dynamic Characteristics of Grafton No. 1 Motorway Bridge" New Zealand Engineering, 1977, 32, (6), 138-139.

66. Shepherd, R., "The Seismic Response of Tall Chimneys," Proceedings, Canadian Conference on Applied Mechanics, Vancouver, June 1977,297-298.

67. Shepherd, R. and Jennings, P. C., "Experimental Investigations-Correlation with Analysis," Proceedings, Workshop on Earthquake Resistant Reinforced Concrete Building Construction, University of California, Berkeley, July 1977.

68. Shepherd, R. and LeHuu, D., "Some Cyclic Loading Characteristics of Steel Beam-Column Joints," Proceedings, Sixth Australasian Conference on the Mechanics of Structures and Materials, Christchurch, 1977, 299-306.

69. Shepherd, R., "High Earthquake Risk Buildings in New Zealand," International Journal of Earthquake Engineering and Structural Dynamics, 1978, 6 (4), 383-395.

70. Shepherd, R. and Wood, J. H., "Vehicle Induced Vibrations," Proceedings, Seminar on Bridge Design and Research, New Zealand National Roads Board, November, 1978, IV, 1-19.

71. Shepherd, R., Brown, H. E. E., and Wood, J. H., "Dynamic Investigations of the Mohaka River Bridge," Proceedings, I.C.E., Vol. 66, 1979, Part I, 457-469.

72. Shepherd, R., "Seismically Loaded Holding Down Bolts," Proceedings, Seventh World Earthquake Engineering Conference, Istanbul, 1980, 7, 141-148.

73. Gillies, A. G. and Shepherd, R., "Three-Dimensional Inelastic Building Response to Seismic Loading," Proceedings, Seventh World Earthquake Engineering Conference, Istanbul, 1980, 5, 391-399.

74. Gillies, A. G. and Shepherd, R., "Dynamic Inelastic Analyses of a Bridge Structure," Bulletin of the Seismological Society of America, 72, (2), 510-530, April 1981.

75. Gillies, A. G. and Shepherd, R., "Post Elastic Dynamics of Three-Dimensional Frames," Proceedings, American Society of Civil Engineers, 1981, 107, ST8, 1485-1501.

76. Bird, H. W. K. and Shepherd, R., "Wave Interaction with Large Submerged Structures," Proceedings, American Society of Civil Engineers, 1982, 108, WW2, 148-162.

77. Shepherd, R., "Lateral Load Resistance of Panel Houses," Proceedings, Eighth Australasian Conference on the Mechanics of Structures and Materials, Newcastle, New South Wales, August 1982, 37-1 to 37-6.

78. Bird, H. W. K. and Shepherd, R., "Boundary Element Solutions of Wave Structure Interaction," Proceedings, Ocean Structural Dynamics Symposium, Oregon, September 1982, 339-353.

79. Shepherd, R. and Lisieski, L., "The Response of a Bridge to Strong Ground Shaking," Proceedings, Seventh European Conference on Earthquake Engineering, Athens, September 1982, 6, 171-178.

80. Shepherd, R. and Plunkett, A. W., "Analysis of the Imperial County Services Building," Proceedings, American Society of Civil Engineers, 1983, 109, ST7. 1711-1726.

81. Shepherd, R., Pardoen, G. C. and Burridge, P. B., "Analytical and Experimental Dynamic Analysis of a Ten Story Building," Proceedings, Fourth Canadian Conference on Earthquake Engineering, Vancouver, June 1983, 362-371.

82. Gillies, A. G. and Shepherd, R., "Prediction of Post-Elastic Seismic Response of Structures by Mode Superposition Techniques," Bulletin of the New Zealand National Society for Earthquake Engineering, 1983, 16 (3), 222-233.

83. Bird, H. W. K. and Shepherd, R., "On the Interaction of Surface Waves with Immersed Structures," International Journal for Numerical Methods in Fluids, 1984, 4 (8), 765-780.

84. Pardoen, G. C. and Shepherd, R., "Experimental and Analytical Studies of the Imperial County Services Building," Proceedings, Eighth World Conference on Earthquake Engineering, San Francisco, 1984, IV, 807-814.

85. Lee, D. M. and Shepherd, R., "Hazardous Buildings: Aspects of the Los Angeles Building Code," International Journal of Earthquake Engineering & Structural Dynamics, 1984, 12 (2), 149-167.

86. Shepherd, R. and Naeim, K., "An Investigation of Optimum Design of Reinforced Concrete Building Frames," Proceedings, Ninth Australasian Conference on the Mechanics of Structures and Materials, Sydney, 1984.

87. Mazzola, C. A., Reck, R. J. and Shepherd, R., "Dynamic Characteristics of a Space Support Structure," Proceedings, Third International Conference on Space Structures, Guildford, England, 1984, 522-527.

88. Gillies, A. G. and Shepherd, R., "Inelastic Dynamic Modelling of Reinforced Concrete Frame Elements," Proceedings, International Conference on Computer-Aided Analysis and Design of Concrete Structures. Split, Yugoslavia, 1984, II, 1271-1283.

89. Balas, G. J. and Shepherd, R., "Dynamics and Control of a Large Deployable Reflector," Proceedings, 26th Structures, Structural Dynamics and Materials Conference, Orlando Florida, 1985, II, p. 729-734.

90. Platt, Christine, M. and Shepherd, R., "Some Cost Considerations of the Seismic Strengthening of Pre-Code Buildings," Earthquake Spectra, 1985, I, 4, 695-719.

91. Shepherd, R., "Dynamic Analysis of Space Structures," Proceedings, Third A.S.C.E. Engineering Mechanics Specialty Conference on Dynamic Response of Structures, U.C.L.A., April 1986.

92. Haroun, Nariman, M. and Shepherd, R., "Inelastic Behavior of X-Bracing in Plane Frames," Proceedings, American Society of Civil Engineers, 1986, 112, ST.4, 2-19.

93. Shepherd, R. and Grimberg, P., "Design Response Spectra at Secondary Locations on Offshore Structures," Proceedings, Fifth International Offshore Mechanics and Arctic Engineering Symposium; Tokyo, 1986, I, 647-654.

94. Shepherd, R. and Platt, C.M., "Economic Aspects Involved in Retrofitting a Commercial Building," Proceedings, Third U.S. National Conference on Earthquake Engineering; Charleston, South Carolina, August, 1986, III, 1947-1958.

95. Shepherd, R. and Adamson, J.W., "Susceptibility of Freeway Systems to Earthquakes," Proceedings, Eighth European Conference on Earthquake Engineering, Lisbon, Portugal, September 1986; V, 10/17 -10/24.

96. Shepherd, R., "Steel-Cross-Bracing in Seismic Resistant Structures." Proceedings, Fifth Canadian Conference on Earthquake Engineering, Ottawa, 1987; 257-264.

97. Shepherd, R., "The October 1, 1987 Whittier Narrows Earthquake," Bulletin of the New Zealand National Society for Earthquake Engineering, 1987; 20, 4, 225-263.

98. Shepherd, R., "Earthquake Induced Building Damage: A Continuing Problem," INTERCIENCIA, Journal of Science and Technology of the Americas, August, 1988; 13, 4, 183-191.

99. Shepherd, R. and Driscoll, M.J., "Building Rehabilitation Using a Knowledge-Based Expert System," Proceedings, Annual Conference, American Society for Engineering Education, Portland, Oregon, June 1988; 1502-1515.

100. Shepherd, R. and Erasmus, L.A., "Ring Spring Energy Dissipators in Seismic Resistant Design," Proceedings, Ninth World Conference on Earthquake Engineering, Tokyo, August, 1988, V, 767-772.

101. Caserio, A.K. and Shepherd, R., "Space Station Structure Modal Selection Criteria," Proceedings, American Society of Civil Engineers, 1989, Journal of Aerospace Engineering, 2, 1, 20-40.

102. Shepherd, R. (Editor), "Loma Prieta Earthquake, October 17, 1989 - Preliminary Reconnaissance Report, Chapter 4, Buildings." Earthquake Engineering Research Institute Report 89-03, November, 1989.

103. Shepherd, R., "Tests on the Seismic Resistance of Panel Walls": Proceedings, Fourth U.S. National Conference on Earthquake Engineering; Palm Springs, California, May 1990, II, 819-828.

104. Shepherd, R. and Billings, L.J., "The Design of Seismic Isolation Systems", Proceedings, Ninth European Conference on Earthquake Engineering, Moscow, U.S.S.R., September 1990; 2, 302-311.

105. Shepherd, R., "Building Damage in the Loma Prieta, California Earthquake", Proceedings, Ninth European Conference on Earthquake Engineering, Moscow, U.S.S.R., September 1990; 9, 206-215.

106. Shepherd, R., and Shepphird, W.R., "Experimental Seismic Qualification of Non-Structural Suspended Ceiling Elements", Proceedings, Applied Technology Council 29 Seminar, Seismic Design and Performance of Equipment and Non-Structural Elements in Buildings and Industrial Structures, Irvine, California, October 1990; 29/1-29/9.

107. Shepherd, R. and Billings, L.J., "Mathematical Modeling of Laminated Bearings", Proceedings, Workshop on Bridge Engineering Research in Progress, Reno, Nevada, October 29-30, 1990, 241-244.

108. Shepherd, R., "Strengthening of Cripple Walls in Traditional Houses", Proceedings, ASCE Structures Congress '91, Indianapolis, April 29 - May 1, 1991; 34-37.

109. Flynn, N.H., Ficcadenti, S., Costley, A., Kazanjy, R., Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Modal Analysis to Determine Response Characteristics of Reinforced Concrete Bridge Components", Proceedings, International Conference on Buildings with Load Bearing Concrete Walls in Seismic Zones, Paris, June 1990.

110. Mowad, S.A., Flynn, N.H., Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Seismic Retrofit of Bridge Pier Walls", Proceedings, Third U.S. Conference on Lifeline Earthquake Engineering, ASCE, Los Angeles, August 1991, 176-185.

111. Shepherd, R. and Billings, L.J., "Mathematical Modeling of Seismic Isolators", Proceedings, Sixth Canadian Conference on Earthquake Engineering, Toronto, June 12-14, 1991, 245-252.

112. Shepherd, R. and Billings, L.J., "Some Design Aspects of Dynamic Isolation of Buildings from Seismic Ground Vibrations", Proceedings, International Conference on Earthquake, Blast and Impact, Manchester, U.K., September 18-20, 1991, Elsevier, London, 121-130.

113. Shepherd, R. and Delos-Santos, E.O., "An Experimental Investigation of Retrofitted Cripple Walls", Bulletin of the Seismological Society of America, October 1991, 81(5), 2111-2126.

114. Shepherd, R., "The June 28, 1991 Sierra Madre, California Earthquake", Bulletin of the New Zealand National Society for Earthquake Engineering, December 1991, 24(4), 279-286.

115. Haroun, M.A., Pardoen, G.C., Shepherd, R., Flynn, N.H., Kazanjy, R.P. and Mourad, S.A., "Strong-axis and Weak-axis Strength of Pier Walls", Proceedings of Bridge Seismic Research Workshop, Sacramento, California, December 1991, 47-56.

116. Haroun, M.A., Pardoen, G.C., Shepherd, R., Flynn, N.H., Kazanjy, R.P. and Mourad, S.A., "Strength of Column Pier at the Base of Elevated Roadways", Proceedings of Bridge Seismic Research Workshop, Sacramento, California, December 1991, 125-134.

117. Shepherd, R. and Billings, L.J., "Mathematical Modeling of Laminated Bridge Bearings", Proceedings 8th US-Japan Bridge Engineering Workshop, Chicago, May 1992, 243-249.

118. Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Shear Strength Capacity of Bridge Column Pins", Proceedings of the Symposium on Seismic Ground Motions, Response, Repair and Instrumentation of Pipes and Bridges, PVP-Vol. 227, New Orleans, June 1992, 41-45.

119. Shepherd, R. and Billings, L.J., "Mechanics of Elastomeric Seismic Isolation Bearings at Large Strains", Proceedings 10th World Conference on Earthquake Engineering, Madrid, Spain, July 19-24, 1992, Vol. 4., 2265-2270.

120. Shepherd, R. and Billings, L.J., "The Modeling of Layered Steel/Elastomer Bearings", Proceedings MARC Users Conference, Monterey, CA, September 1992, 83-97.

121. Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Seismic Ductility and Strength of Pier Walls", Proceedings of the third NSF Workshop on Bridge Engineering Research in Progress, San Diego, CA, November 1991, 285-288.

122. Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Shear Strength of Pinned Columns", Proceedings of the Third NSF Workshop on Bridge Engineering Research in Progress, San Diego, CA, November 1992, 273-276.

123. Billings, L.J. and Shepherd, R., "The Reliability of Simple Design Methods for Rubber Seismic Isolation Bearings", Proceedings ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control, San Francisco, March 1993, 105-111.

124. Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Retrofit of Bridge Pier Walls", Proceedings of the Second Seismic Research Workshop, California Department of Transportation, Sacramento, CA, March 1993, V(3).

125. Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Testing of Pier Walls of Limited Ductility", Proceedings of the Second Seismic Research Workshop, California Department of Transportation, Sacramento, CA, March 1993, V(4).

126. Haroun, M.A., Pardoen, G.C. and Shepherd, R., "Shear Strength of Pinned Columns", Proceedings of the Second Seismic Research Workshop, California Department of Transportation, Sacramento, CA, March 1993, VI(6).

127. Shepherd, R., "Things That Fall - Lessons from Some Construction Accidents and Structural Failures", Proceedings ASCE Structures Congress, Irvine, CA, April 1993, Vol. I, 573-578.

128. Shepherd, R. and Billings, L.J., "Mathematical Modeling of Seismic Isolation Bearings", Proceedings 1993 National Earthquake Conference, Memphis, TN, May 1993, Vol. II, 377-385.

129. Shepherd, R. and Haynes, T.E., "Expert System Assessment of Earthquake Hazard Reduction", Proceedings IABSE Colloquium on Knowledge-Based Systems in Civil Engineering, Beijing, PRC, May 1993, 351-360.

130. Allred, B.A. & Shepherd R., "Racking Resistance of Narrow Plywood Shear Panels", Proceedings, 62nd. SEAOC Convention, Scottsdale, Arizona, September 1993.

131. Shepherd, R., "Earthquake Damage Lessons from Big Bear Lake, California, 1992"'. ASCE Journal of Performance of Constructed Facilities, November 1993, Vol. 7, No. 4, 235-248.

132. Haroun, M.A., Pardoen G.C. and Shepherd, R., " Seismic Strengthening of Reinforced Concrete Bridge Pier Walls Designed to Old Standards", Proceedings, Second US-Japan Workshop on the Seismic Retrofit of Bridges, Berkeley, California, January 1994.

133. Allred, B.A., Shepherd, R. & Billings L.J., "Ultimate Restraint Considerations in Base-Isolated Bridges", Proceedings, Third US-Japan Workshop on Earthquake Protective Systems for Bridges, Berkeley, California, January 1994.

134. Haggag, H.A., Haroun, M.A., Pardoen, G.C. & Shepherd, R., "Behavior of Bridge Pier Walls of Modern Design under Cyclic Loads", Proceedings, 5 USNCEE, Chicago, IL., July 1994, Vol. 1, 469-478.

135. Allred, B.A., Billings L.J. & Shepherd, R.,"Ultimate Restraint Control in Base-Isolated Structures", Proceedings, 5 USNCEE, Chicago, IL., July 1994, Vol. 1, 693-702.

136. Haroun, M.A., Pardoen G.C., Shepherd, R. & Haggag, H.A., "Retrofit Strategies for Bridge Pier Walls", Proceedings, 5 USNCEE, July 1994, Chicago, IL., July 1994, Vol. 3, 819-828.

137. Allred, B.A., Billings, L.J. & Shepherd, R., "Ultimate Restraint Control of Seismic Base Isolated Structures", Proceedings, First World Conference on Structural Control, Pasadena, California, August 1994.

138. Shepherd, R., "Performance of Multistory Condominium Buildings in the Northridge Earthquake", Proceedings of Sixth US-Japan Workshop on the Improvement of Building Structural Design and Construction Practices, Victoria, B.C., Canada, September 1994, 5/1 - 5/15.

139. Billings, L.J., Allred, B.A. & Shepherd, R.,"Impact Response of Base Isolated Structures", MARC Users' Conference, Ann Arbor, Michigan, October 1994.

140. Shepherd, R., "California Moment Resistant Steel Frame Connections", Proceedings, Annual Conference, New Zealand National Society for Earthquake Engineering, Rotorua, 1995, 102-109.

141. Shepherd, R., "Condominium Building Performance in the Northridge Earthquake", Proceedings, Annual Conference, New Zealand National Society for Earthquake Engineering, Rotorua, 1995, 118-125.

142. Shepherd, R., "Cyclic Testing of Narrow Plywood Shear Walls", Report R-1, Applied Technology Council, 1995, 64p.

143. Shepherd, R. and Frost, J. D., (Editors), " Failures in Civil Engineering; Structural, Foundation and Geoenvironmental Case Studies", American Society of Civil Engineers, 1995, 92p.

144. Shepherd, R., "Standardized Experimental Testing Procedures for Mixed Material Structural Systems", Proceedings, 64th. SEAOC Annual Conference, 1995.

145. Cluley, N. C. and Shepherd R., " Analysis of Concrete Cable Stayed Bridges for Creep, Shrinkage and Relaxation Effects", Computers and Structures, 58 (2), 1996, 337-350.

146. Shepherd, R., "The SAC Joint Venture Interim Guidelines for Evaluation, Repair, Modification and Design of Welded Steel Moment Frame Structures", Proceedings, IIW Asian Pacific Welding Congress, Auckland, New Zealand, 1996, 725-740.

147. Allred, B.A., Billings, L.J. & Shepherd, R., " Ultimate Restraint Control of Seismic Base-Isolated Structures", Proceedings, 11th. World Conference on Earthquake Engineering, Acapulco, Mexico, June 24-28, 1996

148. Billings, L.J. & Shepherd, R., "Mechanics of Elastomeric Seismic Isolation Bearings", Proceedings, 11th. World Conference on Earthquake Engineering, Acapulco, Mexico, June 24-28, 1996.

149. Shepherd, R., "Standardized Experimental Testing Procedures for Low-Rise Structures", Earthquake Spectra, 1996, 12, 1, 111-127

150. Shepherd, R., "Accurate Assessment of both Demand and Capacity: Progress towards a More Rational Approach to the Seismic Resistant Design of Buildings", Proceedings, Mouchel Centenary Conference, Innovation for Seismic Regions, Cambridge, U.K., 1997, 11-16.

151. Shepherd, R., "Progress with the SAC Joint Venture program for the Evaluation, Repair, Modification and Design of Welded Steel Moment Frame Structures", Proceedings, Mouchel Centenary Conference, Innovation for Seismic Regions, Cambridge, U.K., 1997, 21-26.

152. Shepherd, R., "Construction Site Forensic Problems", Proceedings, American Society of Civil Engineers First Forensic Engineering Congress, Minneapolis, MN, 1997, 16-21.

153. Holmes, W.T., Mahin, S.A. & Shepherd, R., "Current Research Directions and Findings on Steel Moment Resisting Frames - An Update", Proceedings, American Society of Civil Engineers First Forensic Engineering Congress, Minneapolis, MN, 1997, 229-238.

154. Shepherd, R., "Lessons from Recent Seismic Damage Investigations", Proceedings, American Society of Civil Engineers First Forensic Engineering Congress, Minneapolis, MN, 1997, 186-195.

155. Shepherd, R. and Allred, B.A., "Lateral Load Resistance of Narrow Shear Walls", Proceedings, 6th. U.S. National Conference on Earthquake Engineering, Seattle, WA, 1998, 382.

156. Shepherd, R., "The Learning from Failure Process in Structural Engineering," Proceedings, Structural Engineers World Congress, San Francisco, CA, 1998, 848.

157. Shepherd, R., " Field Investigations Following Natural Catastrophe Damage", Proceedings, First Institution of Civil Engineers Conference on Forensic Engineering, London, U.K., 1998, 3 (8).

158. Shepherd, R., "Unacceptable Floor Flexibility Resulting From Earthquake Damage", Proceedings, American Society of Civil Engineers Second Forensic Engineering Congress, San Juan, Puerto Rico, 2000, 200-208.

159. Shepherd, R., "Investigations of the Seismic Response of Welded Steel Moment Frames", Proceedings, American Society of Civil Engineers Second Forensic Engineering Congress, San Juan, Puerto Rico, 2000, 483-492.

160. Shepherd, R., "Post-mortem Seismic Evaluation of an Office Building", Proceedings, Second Institution of Civil Engineers Conference on Forensic Engineering, London, U.K., 2001, 141-148.

161. Shepherd, R., "Steel Moment Frame Buildings - Seismic Issues", Proceedings, 12th. European Conference of Earthquake Engineering, London, U.K., September 9-13, 2002, Paper 636.

162. Shepherd, R., "The St. Francis Dam Failure", Proceedings, American Society of Civil Forensic Engineering Congress, San Diego, California, October 9-21, 2003, 168-177.

163. Shepherd, R., "Forensic Earthquake Engineering", Proceedings, Annual Conference, New Zealand Earthquake Engineering Society, Wellington, N.Z., March 26-28, 2010, Paper 36, 8 pages.