Commentary K
Application of NBC Part 4 for the Structural Evaluation and Upgrading of Existing Buildings

Introduction

1. This Commentary concerns the structural evaluation and upgrading of an existing building to achieve a level of performance which is appropriate, based on the intent of the current National Building Code requirements. Buildings which satisfy the guidelines provided here should generally be considered acceptable. More stringent criteria may be appropriate for buildings used for post-disaster services.

2. This Commentary does not apply to new additions to an existing building structure or to a review of newly constructed work which was required to be in conformance with the current codes and standards. In both of these applications, NBC Part 4 applies without any of the relaxations described in this Commentary. New additions, however, may increase loads on the existing building structure.

3. Part 4 of the National Building Code and the structural standards referenced by Part 4 are written primarily for the design of new buildings (or new additions), not for the evaluation and upgrading of existing buildings. As a consequence, difficulties have arisen:

- Many current requirements specify quantities and arrangements of materials (such as reinforcing details in masonry and concrete structures) which are economical and practical to implement during initial construction but impractical after a structure is completed. In such cases, alternative solutions are needed
- Many older buildings consist of structural systems, components or materials which are not addressed by the structural design standards referenced by Part 4. When properly connected, however, these old systems can be made to work effectively. Information on the structural properties of such systems is lacking, making evaluation and upgrading difficult. This is especially important for heritage buildings
- Despite their lack of compliance with some aspects of current codes, many old buildings have performed satisfactorily over the years without distress or failure. In addition, some structural parameters, such as dead load and material properties, can be ascertained by measurement or test Such information is not taken into account in the structural criteria of Part 4 and referenced structural design standards.

4. To help overcome these difficulties, this Commentary provides guidance on the application of the requirements of Part 4 to existing buildings, including relaxations where appropriate, and alternatives where available (usually by reference to other documents). NBC Subsection 2.5.2. allows structural alternatives which are equivalent to Part 4 but, except for load testing, they are directed primarily to new construction. Except as recommended in this Commentary, structural equivalence should comply with the requirements of NBC Subsection 2.5.2 and Appendix note A-2.5.2.

5. Earthquake requirements provide the greatest difficulty in the application to existing buildings of Part 4 and referenced structural design standards More specific guidelines to address the seismic evaluation and upgrading of existing buildings have been developed separately from this Commentary, as discussed in Paragraphs 38-42.

6. This Commentary does not specify the circumstances which would require a structural evaluation of an existing building. Typical situations where structural evaluation becomes necessary include change of use of the building, damage or deterioration, and where the safety of the building is a concern because of known or potential defects.

7. After the evaluation and before any upgrading, any life-safety implications of the conclusions of the evaluation should be discussed with the owner and authority having jurisdiction to establish the timetable for the work to be done. Each case must be dealt with taking into account its specific circumstances and the degree of urgency in the requirements for upgrading. Actions to be taken may range from immediate evacuation of the building, to a phased repair program, to monitoring or further evaluation, or to acceptance of the building "as is."

Basic Considerations

8. Structural requirements in Part 4 and referenced structural design standards include general performance requirements and design criteria These requirements are based on the following fundamental considerations:

- life safety
- comfort of occupants
- function of the building for its intended use
- durability
- economics

9. The structural requirements of Part 4 and referenced CSA standards address life safety first and foremost, but they also address comfort, function and economics Life safety is addressed by criteria for the ultimate limit states (strength, stability, integrity) Comfort, function and economics are addressed by criteria for the serviceability limit states. Economics are also taken into account by basing the criteria on appropriate levels of structural reliability, thereby helping to avoid unnecessary consumption of materials.

10. The basic considerations of safety and serviceability apply equally to existing or renovated buildings and to new construction. However, other basic considerations related to construction costs, user disruption and conservation (heritage value, reduction of waste and recycling) may be more critical for existing buildings than for new construction. These other basic considerations usually result in a requirement for minimised structural intervention for the continued use or renovation of an existing building. Therefore, where it can be shown that the resultant life safety (defined as an appropriately low probability of death or injury due to structural failure) is generally equivalent to that required by the National Building Code, and the building is known to be functional, some departure from current code design criteria may be appropriate.

11. Structural criteria in Part 4 and referenced CSA structural design standards are based primarily on the limit states methodology [NBC 4.1.3.]. The working stress methodology [NBC 4.1.4.] is still used as an alternative for some design procedures (masonry, foundations). Criteria recommended in this Commentary are based on the limit states methodology. Appropriate adjustments will be indicated for the working stress methodology, which was applicable at the time of the design of most existing buildings.

12. This Commentary addresses principally criteria for the ultimate limit states, because these limit states directly affect life safety. Criteria for the ultimate limit states include loads, load factors and load combinations specified in NBC Section 4.1., and resistances and resistance factors specified in the CSA structural design standards. Serviceability and durability problems may also occur as a consequence of renovation or change of use or environment, and these are discussed.

Quality Assurance

13. The structural criteria contained in Part 4 and referenced CSA structural design standards are based on a level of quality assurance corresponding to the requirements contained in Parts 2 and 4 of the Code and in the referenced structural design standards. The most important of these are NBC Sentence 4 1 1.2.(2), which requires that the designer be a professional engineer or architect skilled in the work concerned, and NBC Section 2.6., which requires that construction be reviewed for conformance to the design

14. These quality control requirements also apply to structural evaluation and upgrading of existing buildings. The quality assurance may have to be greater for the evaluation and upgrading of an existing building because the uncertainties concerning structural properties of an existing building can be considerably greater than for new construction. More engineering judgment is generally required for structural evaluation and upgrading of existing buildings than for design of new buildings For these reasons the following recommendations are based on the prerequisite that:

- an appropriate structural evaluation of the building has been carried out, and the engineering evaluator has examined construction details which are considered critical by the evaluator,
- field review by the designer will be carried out during any upgrading work.

Recommended Code or Standard

15. Recommendations on the code or standard which may be applied to the evaluation and upgrading of existing buildings are summarized in Table K-1 Sometimes the standard used for the design of the building may be preferred to a current standard; for example, some old buildings were made with products no longer used, such as undeformed reinforcement. Restrictions on the use of earlier versions of standards are given in Notes 1 and 2 of Table K-1.

16. Buildings designed and built in accordance with previous codes may be considered acceptable provided

- the previous code or standard essentially satisfies the life-safety requirements of the current code or standard, and
- the building or its use is not altered in such a way as to affect its structural behaviour or to increase the loadings on the structure.

Table K-1
Recommended Codes/Standards

	1995 Code/Standard			Commentary K	Code/Standard when Built	
	Loads	Load Factors	Material Standards	Load Factors	Loads	Material Standards
Evaluation						
- no change in use or occupancy loads	✓	✓	✓	✓	✓(1)	✓(1)(2)
- change in use or occupancy loads	✓	✓	✓	✓	X	✓(2)
Design of Upgrading	✓	✓(3)	✓	✓(3)	X	X
✓ acceptable			X unacceptable			

Notes to Table K-1:

(1) Acceptable provided the following conditions are met
- no significant damage, distress or deterioration
- designed and built in accordance with recognized codes
- no changes that could impair the performance of the structure
- excludes seismic considerations

(2) Acceptable provided experience does not show serious deficiences in the Standard.

(3) NBC 1995 load factors are preferred (see Paragraph 24).

17. A benchmark version of a code or standard is the earliest version which satisfies the life-safety intent of the current requirement. Use and occupancy loads, with one or two exceptions, are essentially unchanged over the years. On the other hand, earthquake requirements have changed considerably over the years and consequently buildings designed to earlier codes often do not provide a level of life safety that meets the intent of current requirements. Table K-2 identifies benchmark versions of NBC Section 4.1. for structural loads. If a structural component was designed prior to the benchmark version in Table K-2, then the current (1995) version should be applied using the load factors recommended in the 1995 NBC or in this Commentary, or the evaluation may be based on satisfactory past performance under the conditions given in Paragraph 18. In the future, each structural design standard referenced in NBC Section 4.3. will provide benchmark versions of the standard for structural resistance. For further guidance see Paragraphs 54-56.

Table K-2
Benchmark Versions of NBC 4.1. (Structural Loads and Procedures)

Load	Benchmark Year	As Modified (with year of modification)
Use and occupancy	1941	guards (1975 and 1995[1]) interior walls over drops (1985)
Snow, ice, rain	1960	snow drifts (1965) ground snow loads (1990) large flat roofs (1995) rain loads – blocked drains (1970)
Wind	1960	flexible structures and canopies (1970)
Earthquake	1970	seismic zones (1985)

Notes to Table K-2:

(1) The 1995 NBC guard loads, which are less stringent than those in the 1975 to 1990 editions of the NBC, should be used for evaluation of all guards and their supports

Evaluation Based on Satisfactory Past Performance

18. Buildings or components designed and built to earlier codes than the benchmark codes or standards, or designed and built in accordance with good construction practice when no codes applied, may be considered to have demonstrated satisfactory capacity to resist loads other than earthquake, provided:

- careful examination by a professional engineer does not expose any evidence of significant damage, distress or deterioration;
- the structural system is reviewed, including examinations of critical details and checking them for load transfer;
- the building has demonstrated satisfactory performance for 30 years or more;
- there have been no changes within the past 30 years that could significantly increase the loads on the building or affect its durability, and no such changes are contemplated.

19. If these conditions are not satisfied, the evaluation should be based on the recommendations in Paragraphs 20-37.

Load Factors and Load Combinations Recommended for Use in Evaluations [NBC 4.1.4. or 4.1.3.]

20. Criteria for the ultimate limit states should be applied in conformity with the basic requirement for life safety. The requirement for life safety, as distinct from structural safety, is based on an acceptable maximum annual probability of death or serious injury as a result of a structural failure in a building. This probability is equal to the probability of structural failure (corresponding to a reliability index of approximately 3 for buildings conforming to Part 4) times the likelihood of death or serious injury if failure occurs. If the likelihood is high, there should be no relaxation in the load factors specified in Sentence 4.1.3.2.(4). Where the likelihood is low, as in the case of storage buildings of low human occupancy, the load factors may be reduced. This is recognised in Sentence 4.1.3.2.(7) by means of an importance factor, γ. For post-disaster buildings, the loads and load factors of NBC Section 4.1. should be applied.

21. Reduced load factors for structural evaluation, incorporating the principle of an importance factor, are recommended in Table K-3. These factors are based on maintaining the level of life safety implied by Part 4 by using the principle described in Paragraph 20. The load factors in Table K-3 are determined by the evaluator based on consideration of three factors which affect life safety - the behaviour of the structure (system behaviour), the likelihood of people being at risk and their number (risk category) and the evidence of safety indicated by past performance. The risk category is addressed in Table K-5.

Table K-3
Load Factors for Structural Evaluation(1)

Reliability Level(2)	Load Factor			Load Combination Factor, ψ
	Dead, α_D	Variable,(3) α_L or α_W	Earthquake,(4) α_E	
5	1.25 (0.85)(5)	1.50	0.6	0.70
4	1.20 (0.88)(5)	1.40	0.6	0.70
3	1.15 (0.91)(5)	1.30	0.6	0.75
2	1.11 (0.93)(5)	1.20	0.6	0.75
1 or 0	1.08 (0.95)(5)	1.10	0.6	0.80

Notes to Table K-3:

(1) This table does not apply to post-disaster buildings.

(2) Reliability Level = sum of the 3 indices for system behaviour, risk category and past performance in Table K-4.

(3) A reduction in load factor may also be justified because of control of the load, as for example, liquid in storage tanks (see Commentary F, Paragraph 18). This may be taken into account in the application of Table K-3, provided that the load factor is not less than the minimum in Table K-3.

(4) See Paragraph 38 and Reference (2) for more specific guidance on the load factor for earthquakes.

(5) The value in brackets applies when dead load resists failure.

Table K-4
Indices for the Calculation of Reliability Level

Items to be Considered for Reliability Level	Index
System Behaviour	
failure leads to collapse, likely to impact people	2
failure unlikely to lead to collapse, or unlikely to impact people	1
failure local only, very unlikely to impact people	0
Risk Category (See Table K-5)	
high	2
medium	1[1]
low	0[1]
Past Performance	
no record of satisfactory past performance	1
satisfactory past performance[2] or dead load measured[3]	0

Notes to Table K-4:

(1) Increase by 1 for loads in assembly areas or for wood structures.
(2) At least 20 years, no significant deterioration.
(3) Apply to dead load factor only.

Table K-5
Risk Category[1]

Category	Description
High	Schools and other occupancies where many people are likely to be exposed to risk associated with the failure (N[2] = 100 or more), buildings of major heritage importance, or industrial or other facilities with hazardous occupancies
Medium	Other occupancies where fewer people are likely to be exposed to risk associated with the failure (N[2] = 5 to 100)
Low	Other occupancies where the floor area or adjacent outside area exposed to the failure is not likely to be occupied by people and, when occupied, by a small number of people only (N[2] < 5)

Notes to Table K-5:

(1) This Table does not apply to post-disaster buildings.
(2) The estimated maximum number of people exposed to risk associated with the failure, N, may be estimated as follows

N = Occupied area exposed to risk, in m^2 · occupancy density · duration factor

where

- for building occupants the occupancy density and duration factor may be estimated using Table K-6,
- duration factor = average weekly hours of human occupancy/100 $\leq$ 1.0, and
- for people outside adjacent to the building these parameters should be assessed approximately, using the same concepts as for building occupants.

Table K-6
Parameters for Estimation of N

Primary Use	Occupancy Density, Persons per m^2	Average Weekly Hours of Human Occupancy
Assembly	1.0	5 – 50
Mercantile and personal services	0.2	50 – 80
Offices, care or detention, manufacturing	0.1	50 – 60
Residential	0.05	100
Storage	0.01 to 0.02	100

22. The choice of the reduced load factor in Table K-3 is made by the evaluator for the specific component addressed by the calculation. The evaluator must consider what will happen if the component fails. Are there protective features of the structural system (including non-structural components) that, given structural failure, reduce the likelihood of people (both outside and inside the building) being injured or killed? Are many people likely to be within the region affected by the failure? For example, failure of exterior building components (such as masonry parapets) overlooking exits or busy streets are a greater risk than failure of components overlooking rarely used areas. Those which fail during earthquake are generally a greater risk than those which fail in very high winds, when fewer people are outside. Finally, if the building is old and its past performance is satisfactory, this evidence of its safety can be taken into account, except for seismic hazards.

23. Table K-5 provides guidance for determining the risk category used in Table K-3, including a procedure for estimating the number of people exposed to risk associated with the failure. In applying this procedure, the engineer should estimate the area of the building which is likely to be affected by the failure mode of the component being evaluated. For example, a punching shear failure of a flat slab building may be likely to cause a major total collapse, whereas a floor joist failure usually affects only a small area.

24. Minimum load factors in Table K-3, while maintaining low risk to life safety, infer an increased risk of building damage due to structural failure. They should be considered as a minimum to require upgrading. They may not be appropriate for use in the design of the upgrading. Where the difference in upgrading cost due to increasing the minimum load factor is small, and the loss due to failure is large, higher load factors, such as those specified in Sentence 4.1.3.2.(4), are recommended for structural design of the upgrading. The level of upgrading should be determined in consultation with the owner.

25. The combinations of loads other than earthquake to be used in the application of Table K-3 should, in accordance with Sentence 4.1.3.2.(3), be:

$$\text{Factored Loads} = \alpha_D D + \psi(\alpha_L L + \alpha_W W)$$

where the values of the load factors α_D, α_L, α_W and ψ are given in Table K-3, and D, L and W are defined in Sentence 4.1.2.1.(1). Loads due to movements, T, have not been included for reasons given in Paragraphs 28 and 29. For load combinations including earthquake, α_E in Table K-3 should be used in conjunction with Sentence 4.1.3.2.(8).

26. For the application of Table K-3 to working stress criteria in Subsection 4.1.4., the specified loads can be adjusted by the ratio of the load factor determined from Table K-3 to that corresponding to Reliability Level 5 in Table K-3. For example, if the Reliability Level in Table K-3 is 2 for a floor girder, the dead load is multiplied by 1.11/1.25 and the live load is multiplied by 1.2/1.5 before checking the safety in accordance with Subsection 4.1.4.. An upward adjustment of the load combination factor 0.75 in load combination (b) of Article 4.1.4.2. should also be made in increments of 0.05 similar to that in Table K-3.

Loads Recommended for Use in Evaluations

27. Loads specified in Part 4 concern primarily the ultimate limit states and life safety, and therefore relaxations are generally not recommended. Sometimes, however, as discussed in the following, it may be possible to determine loads for evaluation more accurately than for design. Earthquake loads are discussed in Paragraphs 38 to 42.

Loads Due to Movements, T [NBC 4.1.2.1.(1) and 4.1.2.2.(2)]

28. Loads due to movements caused by temperature change, moisture change and sustained stress (e.g., shrinkage, creep, differential settlement) may usually be neglected for structural evaluation of an existing building provided an inspection of components and connections indicates no damage affecting the safety of the building. This is because past experience with the existing building will show whether such movements cause local damage or displacements which may affect the strength or integrity of the building. Ten years of experience is usually sufficient except for differential settlements of footings on materials such as clay, which can take approximately 30 years.

29. For upgrading, consideration should be given to differential movements between new and old materials.

Dead Loads, D [NBC 4.1.5.]

30. Where dead loads are determined from field measurements, the uncertainty of dead load is reduced compared to design. Tables K-3 and K-4 take this into account by means of a reduction in the dead load factor. Similarly, Note 3 to Table K-3 allows a reduction in dead load factor where the load is highly controlled, as for example hydrostatic load in storage tanks.

31. Due to difficulty in the control of future installations of partitions in office buildings, it is recommended that 1kPa, as called for in Sentence 4.1.5.1.(3), be maintained in those occupancies

Live Loads Due to Use and Occupancy, L [NBC 4.1.6., NBC 4.1.10.]

32. Loads due to people, such as those for assembly, access and exit areas, have a direct effect on life safety. Note 1 of Table K-4 therefore allows less of a reduction in load factor for loads in such areas than for all other loads.

33. It may be possible in an existing building to control some floor loads to a value less than that specified in Subsection 4.1.6. If the analysis of the projected use of the floor clearly indicates that the NBC load, including dynamic effects, will not be approached, then a reduction may be warranted, provided that any future change from the use contemplated is controlled. For example, Article 4.1.6.6. allows a reduction in specified loads for dining areas from 4.8 to 2.4 kPa, provided the floor area is 100 m^2 or less and the floor will not be used for other assembly uses, such as dancing. Generally, however, future use is difficult to control and this provision should be used with caution and only with the approval of the authority having jurisdiction.

34. The requirements of Sentence 4.1.10.5.(1) concerning dynamic analysis of floors supporting rhythmic activities need not be applied if past experience indicates that vibration has not been distinctly noticeable and that a change of use of the floor area is not contemplated.

35. For all other use and occupancy loads, it is recommended that Part 4 be followed.

Live Loads Due to Snow, Ice and Rain, L [NBC 4.1.7.]

36. It is generally difficult to justify a reduction in snow, ice or rain loads from those specified in Subsection 4.1.7. and recommended in Commentary H. Despite apparent structural deficiencies according to current Code requirements, however, many years of satisfactory roof performance may indicate a need to better assess actual snow loads on the building. Special studies, including a comparison of local records of ground snow accumulation at the building site with those determined at the Atmospheric Environment Service weather station, as well as special model or analytical studies of snow accumulation on the building in its location, may be used to estimate more closely the site-specific snow load. The assumptions of such studies may not apply, however, if there will be a change in roof geometry or in wind exposure (e.g., due to new buildings). Also a change in snow or ice loads on an existing building can occur due to changes in insulation or indoor heating, or it can occur due to snow sliding off a sloping roof as a result of a change in roofing material. See Commentary H for further guidance.

Live Loads Due to Wind, W [NBC 4.1.8.]

37. It is equally difficult to justify a reduction in wind load from that specified in Subsection 4.1.8. and recommended in Commentary B. Despite calculated structural deficiencies in a building (according to current Code requirements), many years of satisfactory performance may indicate the need to better assess actual wind loads on the building. Special studies, including measurements of wind speeds at the building site (as compared to those measured at the Atmospheric Environment Services weather station), as well as model or analytical studies of wind loads on the building in its location, may be used to estimate the site-specific wind load more closely. The assumptions of such studies may not apply, however, if there is a future change in building shape or local topography. See Commentary B for further guidance.

Earthquakes [NBC 4.1.9.]

38. Current earthquake requirements in Part 4 and referenced structural design standards can present major difficulties for rehabilitation, particularly for heritage or other buildings of unreinforced masonry.

39. Specification-type clauses which cause difficulties include restrictions on structural systems for buildings more than 3 storeys high [NBC 4.1.9.3.(1)], requirement for reinforcement in masonry walls

[NBC 4.1.9.3.(5)], requirements that certain portions of the structure fail before others [NBC 4.1.9.3.(4) and 4.1.9.4.(1)], restrictions related to lateral deflections and pounding [NBC 4.1.9.2.(3) and (4)], as well as restrictions on detailing for earthquakes contained in the referenced structural design standards

40. To help overcome these difficulties it is recommended that the NRC Guidelines for the Seismic Evaluation of Existing Buildings[2] be followed. Information on techniques for seismic upgrading is contained in Reference (3). Reference (4) contains a method of screening buildings prior to detailed seismic evaluations and is essentially a management tool for an owner or authority responsible for a large building inventory.

41. The reduced load factor for earthquakes of 0.6 in Table K-3 should be considered suitable as a triggering criterion for seismic upgrading. For design of the upgrading, the load factor should be increased, preferably to the NBC value, based on considerations of future building use, control of seismic damage (to the building and contents) and the differential in upgrading costs with earthquake force level. An exception is the upgrading of unreinforced masonry buildings covered by the special procedure contained in Appendix A of Reference (2), for which the criteria of Appendix A apply.

42. For many buildings in low to medium seismic zones (Z_a or Z_v of 3 or less), life safety can often be greatly improved at relatively low cost by providing lateral support to masonry and other heavy non-structural components.

Serviceability

43. Serviceability requirements in Part 4 (Articles 4.1.1.5., 4.1.1.6., 4.1.3.3.. and much of Section 4.2.) and referenced structural standards concern human comfort and the function of the building structure for its intended use (operation of equipment, drainage, protection function of the building envelope, etc.).

44. The serviceability criteria contained in Part 4 and referenced standards are intended for the design of new buildings. For existing buildings, in many cases demonstration of satisfactory performance eliminates the need to apply the serviceability criteria given in Part 4 and referenced structural standards for structural evaluation. Unacceptable deformation, settlement, vibration or local damage will usually be evident to the occupants within a period of 10 to 30 years from construction Examples where serviceability evaluations may be required include change of use, or alteration of building components affecting the properties of the structure.

45. A change of use, for example, might include introduction of activities such as aerobics or jogging into an existing building In such cases, the existing floor structure should be evaluated for such a use either by means of a performance test or by calculation procedures (see Commentary A for further guidance). An evaluation is also recommended for intended uses such as the installation of reciprocating machinery or the use of equipment which is sensitive to vibration, floor smoothness, slope, etc.

46. An alteration of building components affecting the properties of the structure, and therefore its response to loading, might include the removal of partitions, which reduces the damping and stiffness of the floor system and increases its sensitivity to vibration induced by footfalls In this case, it is recommended that the floor construction be reviewed for the intended use before removing the partitions. Similar alterations which may affect structural serviceability include alterations to cladding and partitions in tall buildings, which affects wind sway motions, and the addition of heavy components, which results in increased deflection.

47. In the case of earthquakes, the deflection criteria of Sentence 4.1 9 2.(3) are intended to control damage of non-structural components This will usually not have been tested by experience. For guidance see Reference (2).

Durability

48. Durability is a major factor affecting serviceability and safety requirements which, although not addressed in the general requirements of Part 4, is addressed in Section 4.2. and in the structural design standards referenced in Sections 4.3. and 4.4. (often by reference to other standards, such as CSA A23 1) The CSA standard on parking garages referenced in Subsection 4.4.2. is concerned essentially with durability, as is a CSA standard (CSA S448 1-93) on repair of reinforced concrete in buildings.

49. Corrosion failures of unbonded post-tensioned beams and slabs, reinforced concrete parking structures, supports and connections for precast or other wall panels, masonry wall ties and deep foundations may result in unsafe structures without visible deterioration. References (5) and (6) provide guidance for assessment of such conditions.

50. Change of use (e g , internal environmental conditions) or alteration of the building components (e g., insulation) may result in future deterioration where none had occurred in the past, particularly to exterior wall components Such potential deterioration should be considered in the evaluation.

Structural Integrity

51. In the structural evaluation of an existing building, the ability of the structure to absorb local failure without widespread collapse is an important property, which should be considered by the engineering evaluator. This property can be assessed by considering the likelihood of specific failures due to overloading, accidental damage, defects and deterioration and, if there is such a likelihood, the ability of the building (both structural and non-structural components) to provide alternative paths of support. This consideration, however, is not easily quantifiable and therefore involves considerable engineering judgment. Tables K-3 and K-4 take alternative paths into account by means of a reduction in load factors based on a consideration of system behaviour. See also Commentary C.

Foundations

52. The adequacy of spread footings can generally be demonstrated by satisfactory performance in the past. Consideration should, however, be given to spread footings that will be subjected to a significant increase in loading. Consideration should be given to deep foundations in situations where they may have been weakened by deterioration.

53. Guidance concerning earthquake effects on foundations is given in Reference (2).

Referenced Structural Design Standards

54. In the future each material design standard referenced in Section 4.3. will provide guidance on its application to existing buildings. Until such guidance is available, the evaluator is advised to follow the ultimate limit state requirements for resistance (including resistance factors) contained in each standard referenced in Section 4.3. In the meantime, information contained in Reference (7) may be helpful.

55. Alternatively, the building may be considered adequate on the basis of satisfactory past performance, provided the conditions described in Paragraph 18 are met.

56. Paragraphs 57 to 63 also provide guidance for determining resistance by means of load tests as an alternative to that determined by structural analysis.

Load Testing

57. Load testing can be used for structural evaluation where safety is in doubt (due to lack of drawings or design information, deterioration, fire or possible inherent deficiencies). In some cases, load testing may be used to monitor the effects of deterioration [see Reference (8) for guidance]. Load testing is generally used in the structural evaluation process as a last resort, because it is usually disruptive and costly.

58. Most load tests of existing building structures consist of proof tests to establish safety. Occasionally it may be useful to carry out destructive ultimate tests of isolated structural components to determine their capacity and mode of failure. Load tests can also be used to determine component forces in a structure where it is difficult to apply a conventional structural analysis.

59. In some situations a load test may not provide sufficient evidence concerning the future safety of the structure. An example is a post-tensioned structure with very little normal reinforcement, where there is hidden corrosion of prestressing. Although such a structure may pass a load test, further deterioration may result in a sudden brittle failure.

60. It is important that in a load test, the structure be exposed and accessible for visual inspection before, during and after the test.

61. For proof tests, the loads should be applied to the structure in a pattern representative of the expected loading and to produce the maximum effects for the critical modes of potential failure as ascertained by the evaluator. The proof test loads should be representative of the effect of factored loads specified in Section 4.1., or some multiple thereof, depending on the type of failure (gradual versus sudden) and whether the whole structure is tested or only a representative portion. For concrete or composite concrete and steel structures, the requirements of Chapter 20 of CAN/CSA A23.3-94 should be followed. In the case of non-composite steel frame structures, an evaluation can normally be done by measurement and calculations. For other materials, a test load (including the weight of the structure tested) representing 1.3 times the total dead load of the renovated building plus 1.6 times the live load should be applied for a minimum of 24 hours. The test should include the measurement of deflections and recovery after the load is removed.

62. In general, the structure is considered to pass the load test if there is no evidence of impending failure during the test. In addition, there may be an indication of serviceability problems under specified loads if there is excessive cracking or deflection (short-term or long-term). This should be evaluated considering past experience with the structure and the contemplated future change of use.

63. For more guidance on load testing see Reference (9).

Further Guidance on Methods of Structural Evaluation

64. Further guidance on methods of structural evaluation is contained in References (10) and (11)

References

(1) D.E. Allen, Criteria for Structural Evaluation and Upgrading of Existing Buildings. Can. J. Civ. Eng., Vol. 17, No. 6, December 1991.

(2) D.E. Allen, J.H. Rainer and A.M. Jablonski, Guidelines for the Seismic Evaluation of Existing Buildings. Institute for Research in Construction, National Research Council, Ottawa, 1992. NRCC 36941.

(3) NEHRP, Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings. Federal Emergency Management Agency, Report FEMA-172, Washington, D.C., June 1992.

(4) J.H. Rainer, D.E. Allen and A.M. Jablonski, Manual for Screening of Buildings for Seismic Investigation. Institute for Research in Construction, National Research Council, Ottawa, 1992. NRCC 36943.

(5) ASCE Standard ASCE11-90, Guideline for Structural Condition Assessment of Existing Buildings. Am. Soc. Civ. Eng., New York, New York, 1991.

(6) N.R. Webster, Evaluation of Unbonded Post-Tensioned Structures. Proc. of Second Canadian Symposium on Cement and Concrete. (Editor Sidney Mindess). University of British Columbia, Vancouver, 1991, pp. 230-241.

(7) Existing Bridge Evaluation. Supplement No. 1 to CSA Standard CAN/CSA S6-88 (Design of Highway Bridges). Canadian Standards Association, Rexdale, Ontario, 1990.

(8) CEB Bulletin 192. Diagnosis and Assessment of Concrete Structures. Comité Euro-International du Béton, Lausanne, Switzerland, 1989.

(9) Load Testing of Structures and Structural Components. Institution of Structural Engineers, London, England, 1989.

(10) Evaluation, Maintenance and Upgrading of Wood Structures: A Guide and Commentary. Am. Soc. Civ. Eng., New York, New York, 1982.

(11) Structural Renovation of Traditional Buildings. Construction Industry Research and Information Association, CIRIA Report III, London, England, 1986.