

Requirements for nuclear safety-related structures



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Requirements for nuclear safety-related structures



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Technical Committee on Concrete Containment and Safety-Related Structures for Nuclear Power Plants

J. Tchnerer	Mississauga, Ontario, Canada <i>Category: Service Industry</i>	<i>Chair</i>
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X.M. Han	SNC-Lavalin Nuclear Inc., Mississauga, Ontario, Canada <i>Category: Service Industry</i>	
R. Kianoush	Ryerson University, Toronto, Ontario, Canada <i>Category: General Interest</i>	
D. Lim	Canadian Nuclear Safety Commission (CNSC), Ottawa, Ontario, Canada <i>Category: Government and/or Regulatory Authority</i>	
A. Mason	Bruce Power, Tiverton, Ontario, Canada <i>Category: Owner/Operator/Producer</i>	
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P.K. Siriya	Ontario Power Generation Inc, Pickering, Ontario, Canada	<i>Non-voting</i>
T.W. Whyte	Ontario Power Generation Inc, Pickering, Ontario, Canada	<i>Non-voting</i>
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S. van Rassel	Dayton Superior Co., Toronto, Ontario, Canada <i>Category: Supplier/Fabricator/Contractor</i>	
A. Wolf	CSA Group, Toronto, Ontario, Canada	<i>Project Manager</i>

Subcommittee on Requirements for Nuclear Safety-Related Structures

J.P. Brock	RCM Technologies Canada Corp., Pickering, Ontario, Canada	<i>Chair</i>
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A. El Aghoury	Canadian Nuclear Laboratories Limited (CNL), Chalk River, Ontario, Canada	
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R.J. McGrath	Cement Association of Canada (CAC), Ottawa, Ontario, Canada	
D.K. Panesar	University of Toronto, Toronto, Ontario, Canada	
J. Tchnerer	SNC-Lavalin Nuclear Inc., Mississauga, Ontario, Canada	
P.R. Trunk	P R Trunk Ltd, Midland, Ontario, Canada	

T.W. WhyteOntario Power Generation Inc,
Pickering, Ontario, Canada**A. Wolf**CSA Group,
Toronto, Ontario, Canada*Project Manager*

Preface

This is the third edition of CSA N291, *Requirements for nuclear safety-related structures*. It supersedes the previous edition published in 2015 under the title, *Requirements for safety-related structures for nuclear power plants* and 2008 under the title, *Requirements for safety-related structures for CANDU® nuclear power plants*. The title has been changed to reflect more accurately the scope.

Note: CANDU® (CANada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited (AECL).

There have been many changes throughout this edition; the most significant changes are as follows:

- clarification of the scope, specifically for storage of radioactive waste material;
- addition of new clauses on testing of welding materials and rebar splice materials;
- addition of new clauses on beyond design basis and design extension conditions;
- addition of new clauses on personnel qualifications for: visual inspection, non-destructive examination, welding, concrete construction inspection, and non-metallic liner and coatings inspection.
- modification and addition of new clauses to clarify the requirements for a formal, detailed construction inspection and testing program;
- addition of new clauses on aging management; and
- updates to tests and test frequencies tables for concrete materials, concrete, and grout.

This Standard specifies requirements for the material, analysis and design, construction, fabrication, inspection, examination, and aging management of safety-related structures constructed of structural steel, reinforced concrete, and reinforced masonry. The minimum design requirements specified in this Standard follow the requirements of CSA A23.3, CSA S16, CSA S304.1, and the *National Building Code of Canada*. Additional requirements reference the CSA N287 series and the CSA N289 series of Standards.

This Standard provides a general definition of safety-related structures rather than a comprehensive listing of all safety-related structures. The analysis and design of structures cover static and dynamic loads, and the loads, load factors, load combinations, and safety criteria cover service loads and abnormal/environmental loads. This Standard also covers the design and analysis of irradiated fuels and radioactive waste storage structures.

The CSA N-Series of Standards provides an interlinked set of requirements for the management of nuclear facilities and activities. CSA N286 provides overall direction to management to develop and implement sound management practices and controls, while the other CSA Group nuclear Standards provide technical requirements and guidance that support the management system. This Standard works in harmony with CSA N286 and does not duplicate the generic requirements of CSA N286; however, it may provide more specific direction for those requirements.

The users of this Standard are reminded that an authority having jurisdiction (AHJ) such as the Canadian Nuclear Safety Commission might impose additional requirements to those specified in this Standard.

This Standard was prepared by the Subcommittee on Requirements for Nuclear Safety-Related Structures, under the jurisdiction of the Technical Committee on Concrete Containment and Safety-Related Structures for Nuclear Power Plants and the Strategic Steering Committee on Nuclear Standards, and has been formally approved by the Technical Committee.

Notes:

- 1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*

- 2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*
- 3) *This Standard was developed by consensus, which is defined by CSA Policy governing standardization — Code of good practice for standardization as “substantial agreement. Consensus implies much more than a simple majority, but not necessarily unanimity”. It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of this Standard.*
- 4) *To submit a request for interpretation of this Standard, please send the following information to inquiries@csagroup.org and include “Request for interpretation” in the subject line:*
 - a) *define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;*
 - b) *provide an explanation of circumstances surrounding the actual field condition; and*
 - c) *where possible, phrase the request in such a way that a specific “yes” or “no” answer will address the issue.*

Committee interpretations are processed in accordance with the CSA Directives and guidelines governing standardization and are available on the Current Standards Activities page at standardsactivities.csa.ca.
- 5) *This Standard is subject to review within five years from the date of publication. Suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to inquiries@csagroup.org and include “Proposal for change” in the subject line:*
 - a) *Standard designation (number);*
 - b) *relevant clause, table, and/or figure number;*
 - c) *wording of the proposed change; and*
 - d) *rationale for the change.*

CSA N291:19

Requirements for nuclear safety-related structures

1 Scope

1.1

This Standard specifies requirements for the material, analysis and design, construction, fabrication, inspection, examination, and aging management of nuclear safety-related structures. Nuclear safety-related structures covered in this Standard are

- a) structures that support, house, or protect safety systems in nuclear power plants;
- b) structures or their elements, where failure of the structures or their elements, would impede the function of safety systems;
- c) structures and their elements that are required for the safe operation and/or safe shutdown of the reactor in nuclear power plants;
- d) structures for the storage of wet irradiated fuel; and
- e) structures for the storage of dry irradiated fuel and other radioactive waste material as agreed with the AHJ.

Notes:

- 1) *Not all elements of the structures described in Item e) are necessarily considered safety-related and therefore such elements are not governed by this Standard.*
- 2) *The structures described in Item e) can include, but are not limited to structures for storage of high-level radioactive waste material, where “high-level” is as described in Clause A.7 of CSA N292.0, and where the structure requires a design life greater than 50 years.*

1.2

This Standard does not apply to concrete containment structures covered in the CSA N287 series or the pressure-retaining systems and components covered in CSA N285.0/N285.6.

1.3

In this Standard, “shall” is used to express a requirement, i.e., a provision that the user is obliged to satisfy in order to comply with the standard; “should” is used to express a recommendation or that which is advised but not required; and “may” is used to express an option or that which is permissible within the limits of the Standard.

Notes accompanying clauses do not include requirements or alternative requirements; the purpose of a note accompanying a clause is to separate from the text explanatory or informative material.

Notes to tables and figures are considered part of the table or figure and may be written as requirements.

Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

2 Reference publications

This Standard refers to the following publications. For dated references, only the edition cited shall apply. For undated references, the latest edition of the referenced document (including any amendments) shall apply.

Note: *These references include all amendments up to and including January 2019.*

CSA Group

A23.1-14/A23.2-14

Concrete materials and methods of concrete construction/Test methods and standard practices for concrete

A23.3-14

Design of concrete structures

A179-14

Mortar and grout for unit masonry

A283-06 (R2016)

Qualification code for concrete testing laboratories

A371-14

Masonry construction for buildings

CAN/CSA-A3000-18

Cementitious materials compendium

CAN/CGSB 48.9712-14

Non-destructive testing — Qualification and certification of NDT personnel

G30.18-09 (R2014)

Carbon steel bars for concrete reinforcement

N285.0-17/N285.6-17

*General requirements for pressure-retaining systems and components in CANDU nuclear power plants/
Material Standards for reactor components for CANDU nuclear power plants*

N286-12 (R2017)

Management system requirements for nuclear facilities

N287 series of Standards

N287.1-14 (R2019)

General requirements for concrete containment structures for nuclear power plants

N287.2-17

Material requirements for concrete containment structures for nuclear power plants

N287.3-14 (R2019)

Design requirements for concrete containment structures for nuclear power plants

N287.4-09 (R2014)

Construction, fabrication, and installation requirements for concrete containment structures for CANDU nuclear power plants

N287.5-11 (R2016)

Examination and testing requirements for concrete containment structures for nuclear power plants

N287.6-11 (R2016)

Pre-operational proof and leakage rate testing requirements for concrete containment structures for nuclear power plants

N287.7-17

In-service examination and testing requirements for concrete containment structures for nuclear power plants

N287.8-15

Aging management for concrete containment structures for nuclear power plants

N289 series of Standards

N289.1-18

General requirements for seismic design and qualifications of nuclear power plants

N289.2-10 (R2015)

Ground motion determination for seismic qualification of nuclear power plants

N289.3-10 (R2015)

Design procedures for seismic qualification of nuclear power plants

N290.16-16

Requirements for beyond design basis accidents

N292.0-14

General principles for the management of radioactive waste and irradiated fuel

N294-09 (R2014)

Decommissioning of facilities containing nuclear substances

N299 Series of Standards

N299.1-16

Quality assurance program requirements for the supply of items and services for nuclear power plants, Category 1

N299.2-16

Quality assurance program requirements for the supply of items and services for nuclear power plants, Category 2

N299.3-16

Quality assurance program requirements for the supply of items and services for nuclear power plants, Category 3

N299.4-16

Quality assurance program requirements for the supply of items and services for nuclear power plants, Category 4

CAN3-Z299 Series of Standards

Note: *The Z299 Series of Standards is the intellectual property of Ontario Power Generation Inc.*

CAN3-Z299.0-86 (withdrawn)

Guide for Selecting and Implementing the CAN3-Z299-85 Quality Assurance Program Standards

CAN3-Z299.1-85 (withdrawn)

Quality Assurance Program — Category 1

CAN3-Z299.2-85 (withdrawn)

Quality Assurance Program — Category 2

CAN3-Z299.3-85 (withdrawn)

Quality Assurance Program — Category 3

CAN3-Z299.4-85 (withdrawn)

Quality Assurance Program — Category 4

S16-14

Design of steel structures

S304.1-14

Design of masonry structures

W47.1-09 (R2014)

Certification of companies for fusion welding of steel

W48-14

Filler metals and allied materials for metal arc welding

W59-13

Welded steel construction (metal arc welding)

W178.2-18

Certification of welding inspectors

W186-M1990 (R2016)

Welding of reinforcing bars in reinforced concrete construction

ACI (American Concrete Institute)

RPMN-13

Concrete Repair Manual (4th edition)

309R-05

Guide for consolidation of concrete

ANSI/ASTM (American National Standards Institute/American Society for Testing and Materials)

D1293-12

Standard Test Methods for pH of Water

D4327-17

Standard Test Method for Anions in Water by Suppressed Ion Chromatography

ASCE (American Society of Civil Engineers)

ASCE/SEI 7-16

Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASTM (American Society for Testing and Materials)

A193/A193M-16

Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications

A194/A194M-17a

Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both

A240/A240M-16a

Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

A276-17

Standard Specification for Stainless Steel Bars and Shapes

A307-14 (E 2017)

Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength

A416/A416M-17

Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete

A421/A421M-15

Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete

A479/A479M-17

Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels

A722/A722M-15

Standard Specification for High-Strength Steel Bars for Prestressed Concrete

C260-10a (R 2016)

Standard Specification for Air-Entraining Admixtures for Concrete

C311-17

Standard Test Method for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete

C494/C494M-17

Standard Specification for Chemical Admixtures for Concrete

C618-17

Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

C637-14

Standard Specification for Aggregates for Radiation Shielding Concrete

C1017/C1017M-13e1

Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

C1240-15

Standard Specification for Silica Fume Used in Cementitious Mixtures

C1603-16

Standard Test Method for Measurement of Solids in Water

D512-12

Standard Test Methods for Chloride Ion in Water

E70-07 (R 2015)

Standard Test Method for pH of Aqueous Solutions with the Glass Electrode

F3125-15

Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions

AWS (American Welding Society)

A4.2: 2006 (R2014)

Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal

A5.4/A5.4M:2012

Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

A5.9/A5.9M:2017

Welding Consumables-Wire Electrodes, Strip Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat Resisting Steels- Classification

D1.6:2017

Structural Welding Code-Stainless Steel

CNSC (Canadian Nuclear Safety Commission)

REGDOC-2.6.3 (2014)

Fitness for Service: Aging Management

EPRI (Electrical Power Research Institute)

1015108-06

Program on Technology Innovation: The Effects of High-Frequency Ground Motion on Structures, Components, and Equipment in Nuclear Power Plants

3002009564-17

*Seismic Evaluation Guidance: Spent Fuel Pool Integrity Evaluation***IAEA (International Atomic Energy Agency)**

Safety Report series No. 57 – 2008

*Safe long term operation of nuclear power plants***ISO (International Standards Organization)**

9001-15

*Quality management systems***Government of Canada***Nuclear Safety and Control Act, SC 1997, c. 9, and Regulations***NRCC (National Research Council Canada)***National Building Code of Canada, 2015***SAE International (Society of Automotive Engineers)**

AMS-QQ-S-763D (2015)

Steel, Corrosion Resistant, Bars, Wire, Shapes, and Forgings

3 Definitions

The following definitions shall apply in this Standard:

Act — the act, regulation, or ordinance covering boilers and pressure vessels of the province having jurisdiction.

Note: *When reference is made to the Nuclear Safety and Control Act, the full title will be used.*

Abnormal/environmental — a category of events that occurs during a postulated accident or an unusual environmental event, or both.

Acceptance criteria — specified bounds on the value of a functional indicator or condition indicator to assess the ability of a structure and its elements to perform design function.

[Source: Adapted from CNSC REGDOC-3.6]

Additional examination — an examination performed to provide assurance of integrity for a structure or its element that is being used beyond conditions of proven experience.

Aging management (AM) — engineering, operations, inspection, and maintenance actions to control, within acceptable limits, the effects of physical aging and obsolescence of a nuclear safety-related structure and its elements.

[Source: Adapted from CNSC REGDOC-3.6]

Aging management plan (AM plan) — a set of procedures, arrangements, and activities that provides direction for managing the aging of specific nuclear safety-related structures.

[Source: Adapted from CNSC REGDOC-3.6]

Authority having jurisdiction (AHJ) — the organization having jurisdiction over the design, procurement, fabrication, installation, testing, operation, inspection, maintenance, and decommissioning of a nuclear facility.

Cement — Portland cement, or Portland-limestone cement, with or without a supplementary cementing material that is used as the binder to make concrete.

Condition indicator — a characteristic of a structure and its elements that can be observed, measured, or trended to infer or directly indicate whether a structure and its elements have the current and future ability to function within acceptance criteria.

Note: *Examples of condition indicators for nuclear safety-related structures include*

- a) *Integrated leak test leakage rates;*
- b) *Ingress of harmful substances (e.g., chloride content of concrete);*
- c) *Depth of concrete carbonation;*
- d) *Prestressing force;*
- e) *Structural movement/deflections; and*
- f) *Cracking (extent and magnitude), spalling, delamination, and corrosion products.*

Construction inspection — the inspection of the site condition, preparation, materials, installation method and process, and as-built condition of structures and their elements to ensure adherence to specified requirements during the construction phase of a project.

Constructor — the organization that is responsible for the construction of the structure and the installation of the elements.

Design basis earthquake (DBE) — an engineering representation of potentially severe effects at the site due to earthquake ground motions having a selected probability of exceedance of 1×10^{-4} per year, or such a probability level as is acceptable to the authority having jurisdiction.

Notes:

- 1) *DBE ground motions are usually referred to as an “earthquake”, and can take the form of a response spectrum, or time history of acceleration, velocity, or displacement.*
- 2) *The DBE is used for the seismic qualification of certain SSC. It is used as an input for NPP seismic design, analysis, and testing to produce a design that is adequate for the specified seismic hazard.*
- 3) *The DBE for some older plants was based on an estimated probability of exceedance of 1×10^{-3} per year or was established deterministically (i.e., without probabilistic analysis).*

Design life — the period of time during which a structure is expected to perform according to the technical specifications to which it was produced.

[Source: Adapted from IAEA Safety Glossary]

Designer — the organization or engineer that is responsible for the design of nuclear safety-related structures.

Elastic liner — a continuous membrane that, when applied on a substrate, remains ductile after curing and has a crack-spanning capability for the specified service life.

Embedded part — a part that is in its final location at the time of concrete placement and is permanently anchored in the concrete structure.

Note: *Embedded parts are generally of the following two categories:*

- a) *penetrations that provide openings through the concrete structure for the passage of personnel, material, process piping, ducts, and cables; and*
- b) *non-penetrations that are used primarily as a means of supporting items such as piping, equipment, and platforms for the concrete structure or for the protection of the concrete.*

Engineer — a person in the engineering profession who has knowledge and experience in the specific task and is licensed by the professional association having jurisdiction.

Note: *The engineer can be a designated representative of the operating organization.*

Examination — investigative activities to ensure integrity of structures.

Note: *Examinations can include inspections, non-destructive tests, invasive techniques, and instrumented monitoring of the structure.*

Fabrication — an activity involving cutting, forming, joining, and assembling material to construct the structure, an element, or a portion thereof, but excluding installation.

Inspection — a method of examination performed by direct or indirect visual means.

Note: *An example of inspection performed by indirect visual means is the use of a camera.*

Inspector — a person qualified through professional or technical training who is appointed by the operating organization and who performs examination, measurement, or testing of structures and their elements to ensure adherence to specified requirements.

Life cycle — all phases of the lifetime of a nuclear facility, including design, procurement, construction, commissioning, operation, and decommissioning.

Load —

Dead load — the permanent dead weight of structural and shielding elements and parts, including loads from permanently located equipment, and hydrostatic loads of a permanent nature such as those in pools.

Design accident pressure load — the differential pressure equivalent to the calculated peak value of overpressure for a loss-of-coolant accident or other design basis accident, including dynamic effects.

Differential pressure — the pressure acting across the structural elements, caused by a postulated failure of a minor pipe that has not been designed for the design basis earthquake.

Live load — a floor, roof, or other load that varies in intensity and occurrence.

Note: *Live loads include*

- a) *uniform loads per unit area;*
- b) *movable equipment loads;*
- c) *operational loads from permanent equipment;*
- d) *soil pressures;*
- e) *snow loads;*
- f) *hydrostatic loads of a temporary or variable nature; and*
- g) *temporary installation loads applied during testing or construction.*

Missile load — a load on an element or component caused by the impact of missiles from a tornado, pipe rupture, turbine, or other site-dependent condition.

Pipe rupture load — a load caused by pipe reaction, jet impingement, or pipe impact on an element or component from the rupture of a high-energy system during a postulated accident.

Thermally induced load — a load caused by temperature variations.

Note: *Temperature variations can include*

- a) *the most critical transient or steady-state condition (during start-up and shutdown);*
- b) *linear expansion; and*
- c) *the combination of internal and external ambient temperatures producing the maximum temperature gradient across containment elements.*

Tornado load — a load caused by a tornado and the resultant wind, differential pressure changes, and missile impact.

Load category —

Abnormal/environmental load category — a category of load combinations that occurs during a postulated accident or an unusual environmental event, or both.

Service load category — a category of load combinations that occurs during construction, pre-operational pressure testing, or normal plant operation.

Load combination —

Abnormal load combination — a combination of loads occurring simultaneously during a postulated accident.

Abnormal/environmental load combination — a combination of loads occurring simultaneously during a postulated accident coincident with an unusual environmental event.

Construction load combination — a combination of loads occurring simultaneously during construction.

Environmental load combination — a combination of loads occurring simultaneously during an unusual environmental event, including a design basis earthquake or tornado.

Normal load combination — a combination of loads occurring simultaneously during normal plant operation, including, but not limited to those loads resulting from transient effects during normal start-ups, emergency shutdowns, the site design earthquake, or wind.

Test load combination — a combination of loads occurring simultaneously during the preoperational pressure testing.

Maintenance — the organized activities — both administrative and technical — of keeping a structure and its elements in good operating condition, including both preventive and corrective (or repair) aspects.

Mass concrete — any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of cement and attendant volume change to minimize cracking.

[Source: ACI 207.1]

Mechanical splice — a device for making in-line connections of reinforcing bars or for joining a reinforcing bar to a steel component or part, for the purpose of transmitting tensile or compressive forces, or both.

Nuclear power plant — any nuclear facility that has been constructed to generate electricity on a commercial scale.

[Source: Adapted from CNSC REGDOC-3.6]

Obsolescence — with respect to structures and their elements, the process of becoming out of date in comparison with current knowledge, standards, and technology.

Operating organization — the entity responsible for operating the nuclear facility *under the authority of a licence*.

Note: *In Canada, nuclear facilities are operated under the authority of licences issued pursuant to the Nuclear Safety and Control Act.*

Passivation process — the removal of debris from a stainless steel surface.

Periodic maintenance — a form of preventive maintenance consisting of repair, parts replacement, surveillance, or testing at predetermined intervals.

Planned maintenance — a form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to unacceptable degradation of a structure or its elements.

Predictive maintenance — a form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose, or trend a structure or element's condition indicators; results indicate present and future functional ability or the nature of, and schedule for, planned maintenance.

Preventive maintenance — actions that detect, preclude, or mitigate degradation of a functional structure or element to sustain or extend its useful life by controlling degradation to an acceptable level.

Radiological safety — the measures taken to ensure that radiation hazards associated with nuclear related activities are controlled to achieve an acceptable level of risk resulting in the protection of workers, the public, and the environment.

Rigid liner — a continuous non-metallic membrane that, when applied on a substrate, hardens after curing to form a non-ductile surface for which limited strain damage can be tolerated in the application.

Safety-related structure — a structure, including its elements that, should it fail to perform its intended function, will impede the safe operation and shutdown of the reactor or has the potential to impact the radiological safety of the public or plant staff.

Notes:

- 1) *Safety-related structures can be located inside or outside containment.*
- 2) *Examples of structural and non-structural elements are*
 - a) *steel;*
 - b) *concrete;*
 - c) *reinforcement (pre-stressed and non-pre-stressed);*
 - d) *embedded parts;*
 - e) *metallic liners;*
 - f) *anchors;*
 - g) *masonry;*

- h) *non-metallic liners and coating systems;*
- i) *joint sealants; and*
- j) *elements necessary to support the structure (e.g., foundations).*

Safety-related system — a system, including its components and structures that, by failing to perform in accordance with the design intent, has the potential to impact the radiological safety of the public or plant staff. Safety-related systems are associated with

- a) the regulation (including controlled start-up and shutdown) and cooling of the reactor core under all normal operating and shutdown conditions;
- b) the regulation, shutdown, and cooling of the reactor core under anticipated transient conditions and accident conditions, and the maintenance of the reactor core in a safe shutdown state for an extended period following such conditions; and
- c) limiting the release of radioactive material and the radiation exposure of plant staff and/or the public in accordance with the criteria established by the AHJ during and following normal, anticipated transient, and accident conditions.

Notes:

- 1) *“Safety-related system” covers a broad range of systems, from those having very important safety functions to those with a less direct effect on safety.*
- 2) *The term “safety-related” applies to certain activities associated with the design, manufacture, construction, commissioning, and operation of safety-related systems as well as to other activities that can similarly affect the radiological safety of the public or plant staff, such as environmental and effluent monitoring, radiation protection and dosimetry, and radioactive material handling (including waste management).*
- 3) *The failure of other systems can adversely affect a safety-related system (e.g., through flooding or mechanical damage). The potential for this adverse effect and the necessary means to control it need to be addressed in appropriate phases.*

Safety system — a system provided to ensure the safe shutdown of the reactor or for residual heat removal from the core, or to limit the consequences of anticipated operational occurrences and design-basis accidents.

[Source: Adapted from CNSC REGDOC-2.5.2]

Serviceability — the state for which the intended use of a structure or building is not restricted.

Note: *Serviceability includes deflection, vibration, permanent deformation, cracking, and settlement.*

Service conditions — actual physical states or influences during the life cycle of a structure and its elements, including operating conditions, design basis accident conditions, and conditions following a design basis accident.

Service life — the period from initial operation to final withdrawal from service of a structure and its elements.

Sister splice — a splice that is used to join redundant reinforcement for the purpose of laboratory testing and is prepared in the same position and location as the production splice it is representing.

Site design earthquake (SDE) — an engineering representation of the effects at the site of a set of possible earthquakes with an occurrence rate, based on historical records, of not greater than 1×10^{-2} per year.

Note: *The SDE is retained in this Standard as it is part of the design basis of existing plants, which were designed using previous editions of the CSA N289 series of Standards. The SDE is expressed in the form of response spectra or time histories and is used for the seismic qualification of certain SSC.*

Stressor — an agent or stimulus stemming from pre-service and service conditions that can produce immediate or gradual aging degradation of a structure and its elements.

Note: *Stressors may include*

- a) *percolation of fluid, flowing gases or liquids, and potential abrasives;*
- b) *exposure to alkalis, sulphates, acids, bases, and dissolved salts;*
- c) *cyclic loads and vibration;*
- d) *impact loading and long term loading;*
- e) *thermal cycles and high or low temperatures;*
- f) *electrochemical reactions;*
- g) *irradiation; and*
- h) *foundation consolidation/movement.*

Structures, systems, and components (SSC) —

Structures — a collection of elements, that provide support or enclosure.

Note: *Examples of structures include buildings, racks, retaining walls, dikes, towers, and stacks.*

Systems — a collection of components assembled to perform a function.

Note: *Examples of systems include heat transport system, high-pressure service water, and heating, ventilation, and air conditioning (HVAC) systems.*

Components — mechanical, electrical, or instrumentation and control items.

Notes:

- 1) *Examples of components include piping, pumps, valves, motors, and relays.*
- 2) *Equipment may be used interchangeably with component within this Standard.*

Supplementary cementing material — material that, when used in conjunction with Portland cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both.

Support — a structural element that transfers the loads from the equipment to a structure.

Time-limited aging analysis (TLAA) — an engineering analysis of the remaining design margin to confirm the suitability of a structure and its elements that is developed on the basis of an explicitly stated length of service life.

Note: *Fatigue analysis is an example of a TLAA related to nuclear safety-related structures.*

4 General requirements

4.1 Jurisdictional boundaries

4.1.1

Certain safety-related structures interact with and are attached to structural elements and parts designed and fabricated in accordance with other Codes and Standards. The following definitions, representing portions of components and parts (see Figure 1), shall form the basis for establishing jurisdictional boundaries:

- a) Portion A — the components and parts that conform to the requirements of this Standard;
- b) Portion B — the components and parts that conform to the requirements of CSA N285.0/N285.6 or the CSA N287 series of Standards; and
- c) Portion C — the components and parts that conform to Standards applicable to their function as conventional structural components.

4.1.2

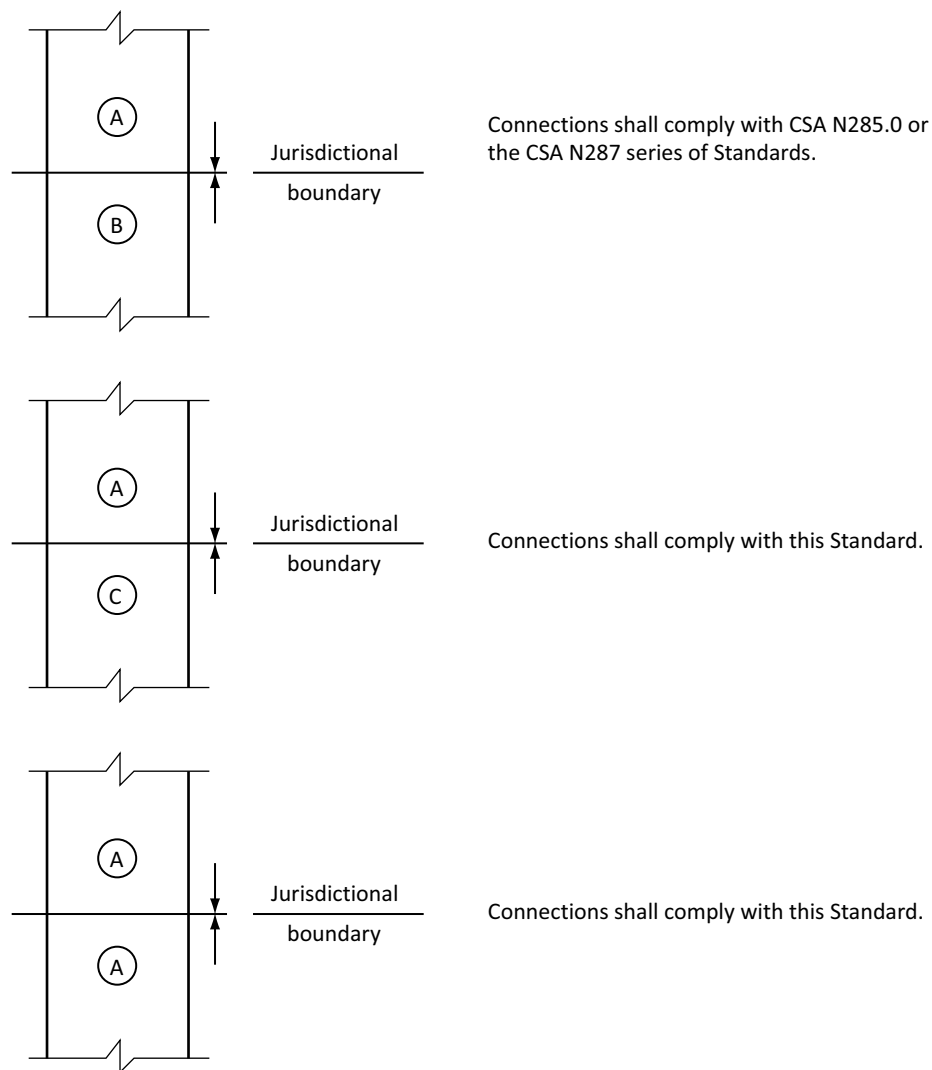
The connection elements at the boundary shall be designed in accordance with Figure 1.

Note: *The intent is to design the connection to the more stringent design requirements of the two standards on either side of the jurisdictional boundary.*

4.1.3

Where the jurisdictional boundary cannot be clearly determined, the operating organization shall establish a boundary to be agreed upon with the AHJ.

Figure 1
Jurisdictional boundaries for connections
 (See Clauses 4.1.1 and 4.1.2.)



Legend:

- Ⓐ = components and parts that conform to the requirements of this Standard
- Ⓑ = components and parts that conform to the requirements of the CSA N285 series or the CSA N287 series of Standards
- Ⓒ = components and parts that conform to Standards applicable to their function as conventional structural components

4.2 Management system requirements

All activities within the scope of this Standard shall be performed in accordance with CSA N286.

4.3 Quality assurance requirements

Quality assurance (QA) requirements applicable to the safety-related structures shall be identified.

Note: Operating organizations have internal procedures which are used to specify QA requirements, in accordance with CSA N286. Historically, operating organizations have specified the QA requirements by reference to a QA Standards (e.g., CSA CAN3-Z299 Series of Standards, 10 CFR 50 Appendix B, etc.). The CSA CAN3-Z299 Series of Standards were withdrawn and replaced by the CSA N299 Series of Standards.

4.4 Operating organization requirements

The operating organization shall be responsible for establishing requirements for

- a) design;
- b) fabrication and construction;
- c) operation;
- d) in-service monitoring, surveillance, and examination;
- e) aging management; and
- f) decommissioning in accordance with CSA N294.

These requirements shall be submitted to the AHJ.

5 Materials

5.1 General

Materials shall be suitable for the application. The selection of materials shall take into consideration full service of the structure and accident scenario exposures.

5.2 Concrete and grout

5.2.1 General

Concrete and grout materials shall be in accordance with the requirements of CSA A23.1/A23.2, except as otherwise specified in this Standard.

5.2.2 Durability

5.2.2.1 Exposure conditions

The exposure conditions shall be specified.

5.2.2.2 Class of exposure

If the class of exposure is specified in accordance with Table 1 of CSA A23.1, as a minimum, the requirements of Table 2 of CSA A23.1 shall apply.

5.2.2.3 Maximum water-to-cementing material ratio

The maximum water-to-cementing material ratio shall be specified.

5.2.2.4 Minimum compressive strength

The minimum compressive strength shall be specified.

Note: Typically compressive strength is specified at 28 days. However, other ages might be more appropriate based on specific requirements. For example, if the heat of hydration is of concern the compressive strength should be specified at 56 or 91 days.

5.2.2.5 Sulphate content and pH in soil and groundwater

The soil and ground water shall be analyzed for sulphate content and pH. When required, measures shall be taken in accordance with CSA A23.1 to protect the below grade concrete structures.

Notes:

- 1) *The designer should review and incorporate the test results when specifying the fill requirements (additional sulphate protection might be required given the long service life).*
- 2) *The designer should indicate which concrete elements require sulphate protection and indicate the appropriate sulphate class of exposure as required in CSA A23.1.*

5.2.2.6 Corrosion-inducing chemicals in grout

The concentrations of corrosion-inducing chemicals in the grout shall be kept as low as is reasonably achievable and shall not exceed the following limits:

- a) for water-soluble chlorides, 250 mg/kg of grout; and
- b) for nitrates, 100 mg/kg of grout.

Note: *Materials conducive to the promotion of corrosion, such as fluorides, sulphites, and sulphides, should not be used in grout unless it can be proven that their presence is not detrimental.*

5.2.3 Materials for concrete

5.2.3.1 Cement

Cement shall be in accordance with CAN/CSA-A3001.

Note: *Certain types of cements that are in compliance with CAN/CSA-A3001 have shown higher heats of hydration. For mass concrete, this should be addressed in accordance with Clause 5.5 of CSA N287.2.*

5.2.3.2 Supplementary cementing materials

Supplementary cementing materials may be used as partial replacement for cement, provided that they meet the requirements of CAN/CSA-A3001

5.2.3.3 Mixing water

Mixing water shall be in accordance with CSA A23.1.

5.2.3.4 Aggregates

5.2.3.4.1 General

Aggregates that have become non-conforming, regardless of cause, during handling and stockpiling shall not be used until they meet specifications.

5.2.3.4.2 High-density aggregates

For concrete having an air dry density greater than 2500 kg/m³, the aggregates required shall be in accordance with ASTM C637.

5.2.3.5 Admixtures

Chemical admixtures shall be in accordance with CSA A23.1. The chloride content of admixtures shall be such that, when used at the manufacturer's recommended addition rate, the admixture contributes no more than 50 mg of chloride to 1 kg of cement. The chloride ion content in admixtures shall be determined in accordance with ASTM D4327.

5.2.4 Materials for grout

5.2.4.1 Cement

Cement shall be in accordance with CAN/CSA-A3001.

5.2.4.2 Mixing water

Mixing water shall be in accordance with CSA A23.1.

5.2.4.3 Aggregates

Aggregate for use in grout shall be fine aggregate (sand), and shall conform to the requirements of CSA A179.

5.2.4.4 Admixtures

Admixtures shall be in accordance with Clause 5.2.3.5.

Notes:

- 1) *The compatibility of different admixtures used in the grout should be assessed.*
- 2) *Aluminum powder and other admixtures may be used to produce expansion, reduce bleeding, and increase the flow rate with reduced water content, provided that tests have been carried out to demonstrate the suitability of these materials for the intended application.*

5.2.4.5 Pre-packaged non-shrink grout

Pre-packaged non-shrink grout may be used, provided that tests have been carried out to demonstrate its satisfactory performance for the intended use.

5.3 Reinforcing steel

5.3.1 General requirements

Materials used in non-pre-stressed reinforcing systems of concrete structures shall be in accordance with CSA G30.18, except as otherwise specified in this Standard.

5.3.2 Certification

Certified mill test reports giving the results of chemical and mechanical tests of the material supplied shall be submitted by the manufacturer to the purchaser or his/her representative.

5.3.3 Identification and marking

5.3.3.1

In addition to the identification and marking requirements of the applicable product Standard, bars shall be identified as conforming to the requirements of Clause 5.3.2.

5.3.3.2

Bars to be spliced by arc welding shall be traceable to their applicable mill test reports. In addition to complying with CSA G30.18, material used in bars shall have the carbon equivalent (CE) clearly indicated by a tag or identifying mark.

5.3.4 Arc-welded splice materials

5.3.4.1

Materials used for splicing reinforcing bars by arc welding shall be in accordance with the requirements of CSA W186, except that the reinforcing bar material to be used shall be in accordance with CSA G30.18 weldable grade.

5.3.4.2

Welding materials shall be in accordance with Clause 5.7.

5.3.5 Mechanical splice materials

Materials used for mechanical splicing of reinforcing bars shall be in accordance with Clauses 6.7.1, 6.7.2, and 6.7.3 of CSA N287.2.

5.4 Pre-stressing steel

5.4.1 General requirements

Materials used in pre-stressed reinforcing systems of concrete structures shall be in accordance with CSA A23.1, CSA A23.4, ASTM A416/416M, ASTM A421/A421M, and ASTM A722/A722M as applicable, except as otherwise specified in this Standard.

5.4.2 Certification

5.4.2.1

Certified mill test reports giving the results of chemical and mechanical tests of the material supplied shall be submitted by the manufacturer to the purchaser or his/her representative.

5.4.2.2

The contractor shall submit the appropriate certified mill test reports or certified batch test reports to the purchaser or his/her representative when the material, heat, or batch is changed.

5.4.3 Identification and marking

5.4.3.1

In addition to the identification and marking requirements of the applicable product Standard, materials or components of the pre-stressing system shall be identified as conforming to the requirements of Clause 5.4.2.1.

5.4.3.2

All materials or components of the pre-stressing system shall be supplied or fabricated from the same heat or batch of material in the manufacturing process to complete the structure. The contractor shall submit the appropriate certified mill test reports or certified batch test reports to the purchaser or his or her representative when the material, heat, or batch is changed.

5.5 Structural steel

5.5.1 Standards

Material and product Standards and specifications shall be in accordance with CSA S16, with the exception that ASTM A307 carbon steel fasteners shall not be used for structural connections. At a minimum, ASTM F3125 carbon steel fasteners shall be used for structural connections.

Note: *ASTM A193/A193M and A194/A194M may be used as applicable when the material or product is not within the scope of ASTM F3125.*

5.5.2 Identification and marking

The materials and products used shall be identified and marked in accordance with Clause 5 of CSA S16 (not including Clause 5.2.2 of CSA S16). Unidentified steel shall not be used for the fabrication of structural members.

5.6 Stainless steel plates and shapes

Plate and shapes shall be fabricated from austenitic stainless steel with a low carbon content suitable for welding. This stainless steel shall be of Type 304 L, 316, or 316 L, in accordance with ASTM A240/A240M. Alternatively, the stainless steel shall be in accordance with ASTM A276 or A479/A479M.

Note: *Existing structures might have been constructed in accordance with any previous editions of SAE AMS-QQ-S-763 (for extrusion only).*

5.7 Welding materials

5.7.1 General requirements

Welding materials shall be in compliance with the requirements of CSA W48, including requirements pertaining to certification and testing, marking, and storage, except as otherwise specified by this Standard.

Electrodes used to weld stainless steel may alternatively be in compliance with AWS A5.4/A5.4M or AWS A5.9/A5.9M.

5.7.2 Certification

5.7.2.1

After compliance has been established, the testing laboratory shall issue a certified material test report for the first delivery that includes the

- a) batch, lot, or heat number;
- b) size of the electrode or rod tested;
- c) date of testing; and
- d) test results.

5.7.2.2

When the manufacturing or formulation of welding materials is revised, recertification shall take place.

5.7.2.3

Deliveries subsequent to the first delivery shall be accompanied by certificates of conformance that identify the batch, lot, or heat number.

5.7.3 Identification and marking

In addition to the identification and marking requirements of the applicable product Standard, welding materials shall be identified as conforming to the certification requirements of Clause 5.7.2.

5.8 Non-metallic liners, coatings, and joint sealants

5.8.1 General

As a minimum, all liners, coatings, and sealants inside containment shall be tested for a DBA scenario and for adhesion due to the potential risk of damage to or interference with safety-related systems if a material detaches from its substrate.

5.8.2 Non-metallic liners

5.8.2.1

Non-metallic liners shall be classified as rigid or elastic types.

Note: See the definitions of “elastic liner” and “rigid liner” in Clause 3.

5.8.2.2

A rigid-type liner shall not be relied on as a membrane against leakage. Such a liner shall meet the requirements of Clause 8 of CSA N287.2 as applicable to meet the design intent with the exception of Clauses 8.6.2 and 8.6.3 of N287.2.

5.8.2.3

An elastic liner that functions as a membrane against leakage shall meet the requirements of Clause 8 of CSA N287.2, as applicable, to meet the design intent.

5.8.3 Joint sealants

Joints in concrete shall be sealed with a joint sealant that satisfies the requirements of Clause 8 of CSA N287.2, as applicable, to meet the design intent.

5.8.4 Coatings for steel

5.8.4.1

Coatings applied to steel located inside containment structures shall be in accordance with the requirements specified in CSA N287.2.

5.8.4.2

Coatings applied to steel located outside containment structures shall be in accordance with the requirements of CSA S16.

5.8.5 Coatings for concrete

5.8.5.1

Coatings applied to concrete structures located within containment structures shall be in accordance with the requirements specified in CSA N287.2.

5.8.5.2

Coatings applied to concrete structures located outside of containment shall be selected to suit the intended use. Material compliance criteria shall be specified or approved by the engineer.

5.9 Anchorage

Anchorage materials shall be in accordance with CSA N287.2, except for adhesive anchors.

Note: See Clause 6.6.6 of this Standard and Annex D of CSA A23.3 for requirements on adhesive anchors.

5.10 Masonry

Masonry materials shall conform to the requirements of CSA A371, except as otherwise specified in this Standard.

5.11 Repair material

Repair materials shall

- a) be suitable for the intended application;
- b) be selected with consideration to the service life of the structure and accident scenario exposure requirements;
- c) be proven, compatible with original construction materials; and
- d) satisfy the requirements of Clause 5, as applicable.

Note: For additional information on concrete repair, see ACI RPMN13.

6 Analysis and design

6.1 General

6.1.1

The analysis and design of safety-related structures shall be conducted in accordance with the requirements of CSA S16 for steel structures, CSA A23.3 for concrete structures, and CSA S304.1 for reinforced masonry structures, except as otherwise specified in this Standard. Unreinforced masonry structural elements shall not be used in safety-related structures.

Note: Existing unreinforced masonry structural elements may be strengthened to provide adequate capacity.

The design approach and analysis shall include consideration of the following:

- a) the type of structure and the method of construction;
- b) the design life;;
- c) the occupancy;
- d) the impact on the environment; and
- e) aging management.

6.1.2

Alternative methods of design not covered by CSA S16, CSA A23.3, and CSA S304.1 may be used, provided that such methods demonstrate that the design ensures a level of safety and performance commensurate with the requirements of this Standard. The alternative methods shall be approved by the operating organization and shall be acceptable to the AHJ.

6.1.3

For structures subjected to complex dynamic loads such as drop and impact loads, testing, and/or analysis shall be used.

Note: In this case, structural integrity is the criterion that governs the stress limits specified in Clause 6.

6.1.4

Safety-related structures shall be assessed for beyond design basis, including design extension conditions (DEC).

The design of safety-related structures shall consider DEC. The loads, load combinations and the strength/safety requirements shall be defined by the operating organization and submitted to the AHJ.

Note: For information on DEC refer to CSA N290.16 and Annex E of CSA N287.3.

6.2 Symbols

The following symbols apply for loads and load factors for steel and concrete structures:

- D = dead loads, including permanent dead weight of structural and shielding elements and parts, and loads from permanently located materials, elements, and equipment
- L = live loads, including any movable equipment loads, hydrostatic loads (ground water and loads resulting from flooding), snow or rain loads, and other loads that vary in intensity and occurrence, such as soil pressures, operational loads from permanent equipment, and temporary installation loads applied during construction, operation, testing, and maintenance
- P = loads caused by design accident pressure, differential pressure, or pressure test of the containment
- Q_{ed} = loads generated by the design basis earthquake
- Q_{es} = loads generated by the site design earthquake
- Q_t = loads that can be generated by the design tornado specified for the site. Q_t includes the effects of
 - a) tornado wind pressures (Q_{tp});
 - b) differential pressure loads (Q_{td}) due to rapid atmospheric pressure change; and
 - c) tornado-generated missile impact (Q_{tm})
- Q_w = loads generated by the design wind specified for the site
- R = loads generated by the rupture of a high-energy pipe during a postulated accident. R includes the effects of
 - a) jet impingement (R_j); and
 - b) impact of a ruptured pipe (R_m)
- R_a = pipe and equipment reactions during a postulated accident
- R_o = pipe and equipment reactions during construction or normal operating or shutdown conditions, as appropriate
- R_x = impact due to hard objects
- T_a = loads induced due to thermal effects that can be generated by a postulated accident
- T_o = loads induced due to thermal effects that can occur during construction or normal operating or shutdown conditions
- T_p = load effects due to pre-stressing, including losses
- X = loads generated by overpressure from explosion or other similar phenomena dictated by site conditions

6.3 Loads and load factors, load combinations, and limit states

6.3.1 Loads and load factors

All loads shall be defined in the design specifications, with due consideration of loading time history.

Loads shall be determined as follows:

- a) Site-dependent loads:
 - i) Q_{es} and Q_{ed} in accordance with CSA N289.2 and CSA N289.3;
 - ii) Q_w in accordance with the methodology specified in the *National Building Code of Canada (NBCC)*, and with a probability of being exceeded once every 100 years;
 - iii) Q_t as specified for the site;
 - iv) L for snow loads (including snow drifting conditions) in accordance with the methodology specified in the *NBCC*, and based on a 100 year occurrence; and

Note: Where the 100 year occurrence snow load is not available, the 50 year occurrence from the *NBCC* may be used with a 1/0.82 factor from Table C7.2-3 in *ASCE/SEI 7-16*.
 - v) L for hydrostatic loads (ground water) governed by site-specific conditions.

Note: The importance factors from the *NBCC* for post-disaster buildings do not apply. This is due to the inherent conservatism and safety levels incorporated into safety-related structures.
- b) Design-dependent loads:
 - i) L for soil pressures governed by design and for all other loads in accordance with construction and operational requirements; and
 - ii) R , R_a , R_o , R_x , T_a , and T_o for service and abnormal conditions in accordance with analysis approved by the AHJ.
- c) Where site conditions, safety analysis, licensing requirements, etc. give rise to additional postulated loads, the resulting loading effects shall be categorized by extrapolation to a condition covered by this Standard. The applicable load factors and load combinations for other loads shall be developed by analogy.

Note: Loading differs at different stages of a structure's life cycle.

6.3.2 Load combinations

6.3.2.1

All load combinations shall be defined in the design specifications, with due consideration of concurrence probability.

6.3.2.2

Load combinations and load factors shall be determined in accordance with Table 3.

6.3.2.3

Where pre-stressed concrete safety-related structures are used, the load combinations shall be in accordance with Table 7.1 of CSA N287.3.

6.3.2.4

Load factors for structural elements supporting piping or equipment that is designed to the requirements of CSA N285.0/N285.6 shall be in accordance with Table 4. The effects of the loads from CSA N285.0/N285.6 with the factors in Table 4 shall be combined with other applicable loads for designing the structural elements contributing to direct support of the piping or equipment.

6.3.3 Ultimate limit states

6.3.3.1

Structures shall be designed to have sufficient strength and stability, such that factored resistance is equal to or greater than the effect of factored loads where factored resistance is determined in accordance with the requirements of CSA S16 for steel structures, CSA A23.3 for concrete structures, and CSA S304.1 for reinforced masonry structures.

6.3.3.2

The effect of factored loads shall be determined in accordance with the load combinations and the load factors in Table 3.

6.3.3.3

Except as specified in Clause 6.3.3.4, design forces shall be determined by linear analysis, assuming elastic response. Redistribution of the factored member forces shall not be applied.

6.3.3.4

In the case of impact loads from tornado-generated missiles (Q_{tm}), ruptured high-energy pipe (R_m), and hard objects (R_x), consideration of a local plastic deformation due to impact, together with the ability of the structure and the missile to deform beyond yield, may be used to establish the structural capacity.

Note: For information on special provisions for impulse and impact effects for concrete structures, see Annex A.

6.3.4 Serviceability limit states

6.3.4.1

Structures shall be designed to meet the serviceability requirements for the intended use as stated in the design specifications. The serviceability requirements shall include

- a) deflection;
- b) vibration;
- c) permanent deformation;
- d) cracking;
- e) spalling/scabbing; and
- f) settlement.

6.3.4.2

The loads used in checking serviceability requirements shall be the specified loads. The load combinations for checking serviceability requirements shall be as specified in Table 3, with load factors equal to 1.0.

6.4 Foundations

6.4.1

Design and analysis of foundations shall be in accordance with the NBCC, CSA A23.3 and the supplementary requirements specified in this Standard. The requirements shall be defined in the design specifications.

6.4.2

The identification and evaluation of potentially liquefiable soil strata shall be carried out in accordance with CSA N289.3, but in no case shall safety-related structures be on strata that are potentially subject to liquefaction.

6.4.3

The effects from changes in the ground water on foundations that are constructed on soil shall be considered in the settlement analysis and the evaluation of soil capacity.

6.5 Steel structures

6.5.1 General

Safety-related steel structures shall be designed in accordance with the requirements of CSA S16, except as otherwise specified in this Standard.

Note: For seismic analysis, design and dynamic considerations, see Clause 6.10.

6.5.2 Supplementary requirements

6.5.2.1

All bolted connection for members shall be designed in accordance with CSA S16. Where cyclical loads or frequent load reversals are present, the use of slip-critical connections shall be considered according to CSA S16. Rivets shall not be used in safety-related structures.

6.5.2.2

Bolted connections for members that are part of seismic load resisting system, and/or are subjected to dynamic loads, shall be configured such that a ductile limit state in either the member or the connection controls the design.

6.5.2.3

Slenderness ratio requirements shall be established in accordance with CSA S16, with the exception that the slenderness ratio shall not exceed

- a) 120 for main compression members (columns);
- b) 200 for secondary compression members (bracing); or
- c) 240 for all tension members.

6.5.2.4

The designer shall be responsible for identifying connections subjected to dynamic loads and/or vibration. Fasteners at these connections should be installed with locking devices such as lock nuts or pinned threads.

6.6 Concrete structures

6.6.1 General

Nuclear safety-related concrete structures shall be designed in accordance with the requirements of CSA A23.3, except as otherwise specified, and including any additional requirements in this Standard.

Note: For seismic analysis, and design considerations, see Clause 6.10.

6.6.2 Plain concrete

Plain concrete shall not be used for structural purposes in safety-related structures.

Note: Plain concrete to prepare the sub-grade is not excluded from use.

6.6.3 Temperature limitations

6.6.3.1

Except as specified in Clauses 6.6.3.3 and 6.6.3.4, the concrete temperatures shall not exceed the following limitations regardless of the amount of shrinkage and temperature reinforcement:

- a) during normal operating or post-accident conditions over any prolonged periods,
 - i) 65 °C over large areas; or
 - ii) 100 °C over local areas in proximity of penetrations for hot piping; or
- b) during accident conditions or over any short periods on interior surfaces only,
 - i) 175 °C over large areas; or
 - ii) 345 °C over local areas affected by impingements from steam or water jets.

6.6.3.2

Special measures such as cooling pipes, heat exchangers, insulation, or thermal shields may be used to achieve the limitations required by Clause 6.6.3.1.

6.6.3.3

Higher temperatures than the limitations given in Clause 6.6.3.1 a) may be used if it can be demonstrated to the satisfaction of the AHJ that higher limits can be tolerated.

6.6.3.4

Higher temperatures than the limitations given in Clause 6.6.3.1 b) may be used if tests are performed to determine any reduction in concrete strength or stiffness and other deleterious effects, and if the design requirements specified in this Standard are modified accordingly to apply this reduction to design allowables.

6.6.4 Loads induced by thermal effects

For loads induced by thermal effects, consideration of cracked section properties shall be permitted where appropriate provided the following conditions are met:

- a) the tensile stress at any section exceeds the tensile stress at which the section is considered cracked;
- b) redistribution of internal forces and strains due to cracking are included; and
- c) all other loads in the load combinations including thermal loads, as specified in Clause 6.3.2, are considered.

6.6.5 Metallic embedded parts

6.6.5.1

Metallic embedded parts for concrete structures shall be designed in accordance with the requirements of CSA S16, except as otherwise specified in Clauses 6.6.5 through 6.6.6 of this Standard. Anchors for embedded parts shall be designed in accordance with the requirements of Clause 6.6.6 as well as the applicable requirements of Clause 6.6.5.

6.6.5.2

Load factors for metallic embedded parts supporting piping or equipment that is designed to the requirements of CSA N285.0/N285.6 shall be in accordance with Table 4. The effects of the loads from CSA N285.0/N285.6 with the factors in Table 4 shall be combined with other applicable loads for designing the structural elements contributing to direct support of the piping or equipment.

6.6.5.3

The welded joints of metallic embedded parts shall be designed and examined in accordance with CSA W59.

Note: *Certain metallic embedded parts may be governed by the requirements of CSA N285.0/N285.6. The jurisdictional boundaries between this Standard and CSA N285.0/N285.6 should be determined in accordance with the requirements of Clause 4.1.*

6.6.5.4

Metallic embedded parts shall be designed such that deflections resulting from design loads are kept within limits acceptable for the nature of the equipment being supported.

6.6.6 Anchorage to concrete

6.6.6.1

Cast-in and post-installed expansion, undercut, and adhesive anchors shall be designed in accordance with the requirements of CSA A23.3, Annex D with the following exceptions:

- a) Clause D.4.2 of CSA A23.3 does not apply. Load combinations shall be in accordance with this Standard.
- b) Clause D.4.3.3 of CSA A23.3 does not apply. The additional requirements of Clauses D.4.3.4 to D.4.3.8 of CSA A23.3 shall apply.
- c) Clause D.4.3.5.3 d) of CSA A.23.3 does not apply. R_d/R_o shall be equal to 1.0.

6.6.6.2

Load factors for concrete anchorage supporting piping or equipment that is designed to the requirements of CSA N285.0/N285.6 shall be in accordance with Table 4. The effects of the loads from CSA N285.0/N285.6 with the factors in Table 4 shall be combined with other applicable loads for designing the structural elements contributing to direct support of the piping or equipment.

6.6.6.3

Anchorage for non safety-related structures, systems, or components (SSC), whose failure could result in the impairment of adjacent safety-related SSC, shall be designed in accordance with this Standard.

6.6.6.4

Post-installed anchors shall be designed and installed assuming cracked concrete unless it can be demonstrated that the concrete will remain uncracked. Post-installed anchors which are only qualified for uncracked concrete shall not be used in cracked concrete.

6.6.6.5

The impact of operating temperature on anchor properties and performance shall be assessed and accounted for in the determination of anchor capacity. Adhesive anchors shall only be used within the temperature range to which they have been tested.

6.6.6.6

Adhesive anchors shall not be used in applications where they could be exposed to significant levels of radiation unless tested accordingly. The minimum test dosage of radiation shall be equal to the maximum accumulated dosage predicted for the service life of the structure.

6.7 Masonry structures

Unreinforced masonry structural elements shall not be used in safety-related structures.

Note: CSA N289.1 discusses assessment of existing unreinforced masonry, including possible seismic interactions.

6.8 Displacement of structures

Structures or buildings shall not exceed maximum displacement as specified in the design requirements and, as a minimum, as specified in the NBCC. The maximum displacement shall not affect the intended occupancy requirements of the structure, the structure itself, or the adjacent structures.

Note: Displacement can be due to live load, vibratory load, temperature-induced load, seismic load, or settlement.

6.9 Concrete structures with non-metallic or metallic liners

6.9.1 Non-metallic liners

6.9.1.1

For rigid liners, the maximum concrete tensile stress resulting from unfactored loads at the face having the lower tension shall not exceed

- a) $0.17\sqrt{f'_c}$ for the service load category; and
- b) $0.33\sqrt{f'_c}$ for the abnormal/environmental load category.

Note: These formulas are applicable to concrete with a specified compressive strength of 42 MPa or less. For concrete with specified compressive strength greater than 42 MPa, the strength is to be substantiated by test results acceptable to the engineer.

6.9.1.2

For elastic liners that have to function as membranes against leakage, the maximum theoretical crack widths at the liner face shall be in accordance with Clause 12.2 of CSA N287.3.

Where applicable, the crack control requirements of Clause 10.6 of CSA A23.3 shall be met.

6.9.2 Metallic liners

6.9.2.1

The structural capacity of the liner shall not be included in the design capacity of the concrete. The interaction of the liner with the concrete shall be considered when determining liner behavior and the liner and its anchorage system shall be capable of withstanding without failure any deformations resulting from the most severe combination of loads.

6.9.2.2

The liner plate shall be of uniform thickness. However, local thickening of the liner may occur, provided that the design incorporates a uniform transition of stress levels.

6.9.2.3

All welded joints in the liner shall be ground to the same surface smoothness as the plates.

6.9.2.4

Brackets and attachments shall be supported by embedded parts designed in accordance with special measures such as cooling pipes, heat exchangers, insulation, or thermal shields which may be used to achieve the limitations required by Clause 6.6.3.1.

6.9.2.5

Corrosion tests shall be performed on the liner material to prove that the liner and the weld filler material meet the performance requirements of the structure.

Note: *Common forms of corrosion include microbial-induced corrosion, crevice corrosion, and chemical corrosion.*

6.9.2.6

Appropriate measures should be taken to minimize the risk of stainless steel impurities by carbon steel elements throughout the fabrication, construction, and operation life.

6.9.2.7

The passivation process shall be applied to the surface of the stainless steel prior to operating the facility.

6.9.2.8

Strain values shall be in accordance with Table 5.

6.10 Seismic analysis and design considerations

6.10.1

Seismic analysis shall be performed in accordance with the analytical methods described in CSA N289.3. Seismic ground motions for the site design and design basis earthquakes shall be determined in accordance with CSA N289.1 and CSA N289.2.

6.10.2

Structures that are subjected to seismic ground motions shall be linearly analyzed, assuming elastic response. However, the members and connections shall be designed and detailed to at least have moderate ductility in accordance with the requirements of CSA A23.3, CSA S16, or CSA S304.

Note: *“Elastic response” means that R_d , R_o , and $R_p = 1.0$, where R_d , R_o , and R_p are defined in NBCC.*

6.10.3

The design function of any safety-related SSC shall not be impeded by seismic interaction with any other SSC. A review of potential seismic interactions involving safety-related SSC's shall be performed based on the seismic forces generated using the design basis for the safety-related SSC. The review, at a minimum, shall consider the following:

- a) out-of-phase motions of any components or elements sharing a common support;
- b) relative deflections, displacements and deformations of the components or elements under investigation; and
- c) the seismic specific interaction of structural and non-structural elements affecting the response of the safety-related SSC to seismic motions.

6.10.4

The computation of seismic forces (Q_{ed} or Q_{es}) shall be based on loads that are expected during an earthquake. The percentage of live loads to be applied for generating seismic forces shall be determined by detailed analysis and shall consider the following:

- a) The mass from the expected live load, but not less than 50% of the specified live load.
- b) For roofs, 25% of the mass from the design snow and rain loads shall be applied.
- c) For stairs, platforms, and laydown areas, the application of live load shall not be required.

7 Construction requirements

7.1 General

7.1.1

The mix proportion, production, forming, placing, consolidating, finishing, curing, and protection of concrete shall conform to the requirements of CSA A23.1, except as otherwise specified in this Standard.

7.1.2

The fabrication and placement of reinforcement in a non-prestressed reinforcing system shall conform to the requirements of CSA A23.1, except as otherwise specified by this Standard.

7.1.3

Construction, fabrication, and installation requirements for the prestressing system shall be in accordance with Clause 6.8 of CSA A23.1, except as otherwise specified in this Standard.

7.1.4

In addition to requirements of this Standard, mass concrete structures where leak tightness is critical shall meet the requirements of CSA N287.4, as applicable.

Note: Examples of mass concrete structures where leak tightness is critical include the Calandria vault structure, spent fuel bay structures, and structures for storage of radioactive waste materials.

7.2 Concrete and grout

7.2.1 Concrete temperature at placing

Concrete temperatures at the time of placing shall be in accordance with the minimum and maximum limits specified in CSA A23.1, except that, under no circumstances shall the concrete temperature be greater than 25 °C, regardless of concrete strength or section thickness.

7.2.2 Internal concrete temperature for mass concrete

7.2.2.1

The heat of hydration shall be controlled such that the temperature requirements of CSA N287.4 are met considering the following:

- a) selection of concrete constituents;
- b) proportioned concrete mix design; and
- c) construction practices.

7.2.2.2

A temperature difference between the middle and the surface of the structure shall not exceed 20 °C.

7.2.2.3

The temperature limits in Clauses 7.2.2.1 and 7.2.2.2 may be exceeded only at the discretion of an engineer if it is proven that the tensile stresses arising from the temperature differences are always less than the current tensile strength of the concrete.

7.2.2.4

The temperature of the concrete shall be monitored during concrete hydration to ensure that at no time are the temperature limits specified in CSA A23.1 and Clause 7.2.2.2 of this Standard exceeded.

An engineer shall approve the type, amount, and location of instrumentation for temperature measurements and the data collection schedule.

Note: *Monitoring instrumentation might not be necessary when repairs, partial replacements, or small placements of concrete are performed and an engineer is satisfied that the heat of hydration is not of concern.*

7.2.3 Waiting periods

Fresh concrete in walls and suspended slabs that are restrained by continuous reinforcement shall not be placed against existing concrete until the temperature differential is no greater than 8 °C between the following:

- a) average ambient temperature during the 48 h period prior to placing the fresh concrete; and
- b) the temperature of the closure pour measured at the centre of the pour.

Notes:

- 1) *The temperature differential may be increased at the discretion of the designer when post-tensioning is used.*
- 2) *Annex B provides recommended waiting periods for the placing of fresh concrete adjacent to hardened concrete to satisfy the requirements of this Clause for various combinations of temperature, types of cements, and placement thicknesses.*
- 3) *The temperature differential may be higher than 8 °C, provided that tests are performed to determine any deleterious effects due to possible cracking of concrete for given geometries. These effects are to be applied to the design requirements given in this Standard.*

7.2.4 Grout temperature

Cement grout shall be placed in accordance with CSA A23.1. In cold weather, the temperature of grout during mixing, pumping, and curing shall be maintained in accordance with Clauses 6.8.7.2 and 6.8.7.3 of CSA A23.1.

7.3 High-density concrete placement

High-density concrete shall be consolidated by controlled vibration that prevents segregation and settlement of the aggregates.

Note: *The method of consolidation of high-density concrete specified in ACI 309R should be used.*

7.4 Stainless steel

Welding procedures shall be qualified in accordance with CSA W47.1, with suitable allowance for welding stainless steel base material and filler material.

7.5 Metallic liners, non-metallic liners, coatings, joint sealants, and waterstops

Construction, fabrication, and installation of metallic liners, non-metallic liners, coatings, joint sealants, and waterstops for structures where leak tightness is critical shall meet requirements of CSA N287.4.

Note: Examples of structures where leak tightness is critical include the Calandria vault structure, spent fuel bay structures, and structures for storage of radioactive waste materials.

8 Inspection and testing during construction

8.1 Responsibilities and qualifications

8.1.1 Designer responsibilities

8.1.1.1

The requirements for the inspection and testing program shall be included in the drawings and specifications prepared by the designer.

8.1.1.2

The designer shall be responsible for identifying critical elements of the structures requiring additional construction inspections, such as elements subjected to cyclic loads or elements difficult to examine in service conditions.

8.1.2 Engineer responsibilities

8.1.2.1

The engineer shall prepare a construction inspection and testing program in accordance with Clause 8.2.

8.1.2.2

An engineer shall

- a) perform a site review/walkdown;
- b) interpret and evaluate the results of the construction inspection and testing program; and
- c) determine any required follow-up actions, as applicable.

8.1.3 Constructor responsibilities

8.1.3.1

The constructor shall ensure that the construction inspection and testing program (Clause 8.2) is prepared.

8.1.3.2

The constructor shall execute the construction inspection and testing program prepared in Clause 8.2.

8.1.4 Operating organization responsibilities

The operating organization shall review and accept the construction inspection and testing program prepared in accordance with Clause 8.2.

Note: Where possible, the designer should be consulted during the review of the construction inspection and testing program.

8.1.5 Personnel qualifications

8.1.5.1 General

Inspectors who perform non-destructive evaluations and inspections shall be qualified as described in Clauses 8.1.5, except that preference and accreditation shall be given to those persons who can establish their competence by evidence of training and experience.

8.1.5.2 Visual inspection personnel

Inspectors who carry out visual inspections shall pass an annual eye examination to demonstrate, either with or without glasses to correct for near-distance acuity, the capability of reading J-1 letters on a standard Jaegar test chart or its equivalent.

8.1.5.3 Non-destructive examination personnel

Personnel performing NDEs shall be qualified to the requirements of CAN/CGSB 48.9712.

8.1.5.4 Welding inspectors

Welding inspectors shall be qualified to the requirements of Clause 9 of CSA W178.2.

8.1.5.5 Concrete construction inspectors qualifications and responsibilities

8.1.5.5.1 Level I inspector

Level I inspectors shall be qualified to perform tests such as aggregate gradation, slump determination, and unit weight.

To qualify as a Level I inspector, a person shall have completed, with passing grades, a minimum 2-year engineering course at a university or technical college, with a minimum of 1 year of practical training and experience and be certified under an industry-recognized program.

Note: Such industry-recognized programs include

- a) CSA A283 or ISO 9001 with equivalent scope to CSA A283; and
- b) ACI Concrete Field Testing Technician Grade 1.

8.1.5.5.2 Level II inspector

Level II inspectors shall

- a) be qualified to
 - i) perform inspections of concrete production facility operations, placement of systems, reinforcing, and formwork; and
 - ii) interpret and evaluate test results; and
- b) be conversant with applicable Codes and Standards.

To qualify as a Level II inspector, a person shall have completed, with passing grades, a 3-year engineering course at a university or technical college, with a minimum of 2 years of experience as a Level I inspector.

Note: In Ontario, Canada the Concrete Ontario Engineer's Certification Course provides qualification to perform inspection of concrete production facilities.

8.1.5.5.3 Level III inspector

Level III inspectors shall

- a) be qualified to
 - i) approve batching and mixing facilities and concrete mix designs within the limits of the construction specifications; and
 - ii) interpret codes, specifications, and test results; and
- b) have sufficient experience in the design of concrete structures to be able to implement inspection and testing programs.

To qualify as a Level III inspector, a person shall have completed, with passing grades, a 3-year engineering course at a university or technical college, with a minimum of 3 years of experience as a Level II inspector.

8.1.5.6 Nonmetallic liner and coatings inspectors

Inspectors shall be qualified by education and experience in the application and quality control of nonmetallic liners and coatings.

To qualify, a person shall be a high school graduate and satisfy the requirements for experience in accordance with one of the following:

- a) a minimum of 2 years of experience where close guidance or supervision, or both, by a qualified expert is readily available; or
- b) a minimum of 5 years of experience where such guidance or supervision, or both, is not readily available.

8.2 Construction inspection and testing program

8.2.1

The construction inspection and testing program should be established prior to the performance of any inspection and testing activities.

8.2.2

The construction inspection and testing program shall meet the requirements of the specifications and drawings.

8.2.3

The construction inspection and testing program shall include the following:

- a) scope of inspection;
- b) inspection and testing requirements;
- c) locations of the structures and their elements to be inspected;
- d) methods of inspection and testing;
- e) frequency and amount (i.e., statistical distribution) of inspections and testing;
- f) acceptance criteria;
- g) recommended corrective actions as applicable; and
- h) reporting and documentation requirements.

The construction inspection and testing program shall address all structural and non-structural elements of safety-related structures.

8.3 Steel structures

8.3.1 General

The inspection and testing of steel structures shall be in accordance with CSA S16 and with the requirements of this Standard.

8.3.2 Inspection of welded joints

Welded joints shall be inspected in accordance with the requirements of CSA W59.

8.3.3 Inspection of bolted joints

Bolted joints shall be inspected in accordance with the requirements of CSA S16.

8.4 Concrete structures

8.4.1 General testing requirements

8.4.1.1

Inspection and testing shall be documented in the construction inspection and testing program in accordance with Clause 8.2 and shall comply with CSA A23.1/CSA A23.2, except as otherwise specified in this Standard.

8.4.1.2

Prior to production of concrete, results from tests specified in the construction inspection and testing program shall be available. The test results may be obtained by the use of historical data.

The engineer shall determine which tests, listed in Tables 1 and 2, need to be conducted based on the materials being used in consideration of the design exposure condition.

8.4.1.3

At production, the first sample from each production run shall be tested in accordance with the construction inspection and testing program (see Clause 8.2).

8.4.1.4

During production, when sufficient test data have been accumulated to establish consistent compliance with the requirements, the test frequency may be reduced at the discretion of the engineer, and with acceptance by the operating organization.

Notes:

- 1) *Where material for concrete production for safety-related structures is kept separate from material for commercial concrete production, the test frequency should be based on the requirements of this Standard.*
- 2) *Where material for concrete production for safety-related structures is not kept separate from material for commercial concrete production, the test frequency should be based to the entire concrete production of the concrete production facility.*

8.4.2 Concrete materials testing

8.4.2.1

Concrete materials shall be tested in accordance with the construction inspection and testing program (Clause 8.2) and Table 1. The cementitious material testing shall be performed as applicable for the

types of cements and supplementary cementing materials to be used in accordance with Tables 1 through 9 of CSA A3001.

8.4.2.2

Terms of reference for tests shall be clearly defined and shall include

- a) the sources of materials;
- b) definitions of batches and lot sizes;
- c) test frequencies; and
- d) organizations responsible for
 - i) performing the tests;
 - ii) reporting test results; and
 - iii) acceptance of the materials.

8.4.2.3

The engineer shall verify the consistency of test results. When deemed necessary by the engineer, additional tests might be required at specified frequencies.

8.4.3 Concrete testing

8.4.3.1

Concrete shall be tested in accordance with the construction inspection and testing program (Clause 8.2) and Table 2.

8.4.3.2

Slump, air content, and temperature determinations shall be carried out on each load or batch of concrete until satisfactory control is established. Satisfactory control shall be established each day for each mix. It is established when concrete from five consecutive loads or batches are within the specified requirements without field adjustments. If any field adjustments are required, testing on each load shall be continued until five consecutive loads or batches meet the requirements with no field adjustment. After satisfactory control has been established, testing shall be carried out on every third load. If testing indicates that a load does not meet the requirements, testing shall resume on each load until satisfactory control is established.

8.4.3.3

If multiple plants supply concrete, satisfactory control shall be established for each plant.

8.4.3.4

Air content, slump, and temperature tests shall be carried out whenever compressive test cylinders are cast.

8.4.3.5

The water-soluble chloride-ion content shall be determined in accordance with CSA A23.2-4B for the proposed mix, prior to commencement of work. The test shall be carried out at a minimum concrete age of 28 days.

Notes:

- 1) *For initial correlation, measurements of total chloride-ion content should be made on separate constituents of concrete in accordance with the test methods outlined in Table 1, and the total chloride-ion content of*

concrete should be calculated based on the mix proportions. This value should then be correlated with the water-soluble chloride content.

- 2) Following the correlation test specified in Note 1, the total chloride-ion content of the separate constituents should be monitored in accordance with Table 1 requirements, and the water-soluble chloride-ion content should be monitored in accordance with Table 2 requirements.
- 3) The supplier should provide, for acceptance of the operating organization, acceptance criteria for the comparison between the initial correlation test (see Note 1) and the periodic production tests (see Note 2).

8.4.4 Reinforcement

8.4.4.1 Tensile tests

One tensile test shall be performed of each bar size for each 50 tonnes or less, or for each heat, whichever is smaller.

8.4.4.2 Bend tests

Bend tests shall be in accordance with the requirements of CSA G30.18.

8.4.4.3 Mechanical splice tests

Performance tests for mechanical splices shall be in accordance with Clause 6.8 of CSA N287.2.

8.4.4.4 Visual inspection

Non-pre-stressed reinforcement for reinforced concrete shall be visually inspected for conformance to the specifications and drawings and to the requirements given in this Standard.

8.4.4.5 Inspection of bends for bars partially embedded in concrete

Bars that are partially embedded in concrete and subsequently bent or straightened, or both, shall be inspected for conformance to Clause 6.2 of CSA N287.4.

8.4.4.6 Inspection of arc-welded splices

Arc-welded splices shall be visually inspected for conformance to CSA W186. Arc-welded splices that fail visual inspection shall be repaired or replaced and subsequently re-inspected. Each of the adjacent arc-welded splices shall be similarly inspected.

In the event the re-inspected splices or the adjacent splices fail to meet the requirements of this Clause, the work shall be stopped and corrective action shall be taken to the satisfaction of the engineer.

Note: Unless otherwise specified by the engineer, this Clause applies to the construction inspection of arc-welded splices of principal reinforcement only.

8.4.4.7 Inspection of mechanical splices

The engineer shall be responsible for establishing inspection requirements for mechanical splices, which shall include

- a) inspection methods and procedures;
- b) scope and frequency of inspections;
- c) acceptance criteria and recommended corrective actions;
- d) pre-qualification testing of sister splices;
- e) in-situ testing; and
- f) documentation of test results and corrective actions taken.

8.4.5 Pre-stressing steel

In addition to the requirements of Clause 8.2.3, the inspection and testing program for pre-stressing systems shall include the following:

- a) inspection methods and procedures for the materials, anchorages, sheaths, tendons, grouting of bonded tendons, and protective coating of unbonded tendons;
- b) lift-off tests and re-stressing procedures, if applicable;
- c) the scope and frequency of tests and inspections;
- d) acceptance criteria and recommended corrective actions; and
- e) documentation of test results and corrective actions taken.

8.4.6 Anchorage systems

Inspection and testing of post-installed anchors and inserts shall be in accordance with CSA N287.5.

8.4.7 Metallic liners

Special consideration shall be given to factors such as

- a) the waiting period required for leakage to be detected during inspection;
- b) accessibility problems; and
- c) effectiveness and accuracy of inspection methods.

8.4.8 Non-metallic liners

For structures where leak tightness is critical, inspection and testing of non-metallic liners shall be in accordance with CSA N287.5.

8.5 Grout testing

8.5.1 General

Grout shall be tested in accordance with the construction inspection and testing program (Clause 8.2) and Table 2.

8.5.2 Corrosion-inducing chemicals

The concentrations of corrosion-inducing chemicals in grout shall be kept as low as is reasonably achievable and shall not exceed the following limits:

- a) for water-soluble chlorides, 250 mg/kg of grout; and
- b) for nitrates, 100 mg/kg of grout.

Chlorides shall be determined in accordance with the CSA A23.2-4B test method. When testing for nitrates, the sampling procedure shall be in accordance with CSA A23.2-4B. The nitrates in water, extracted by boiling the grout sample, shall be determined in accordance with ANSI/ASTM D4327.

Notes:

- 1) *When testing for nitrates, the atmosphere described in CSA A23.2-4B is expected to be free of HNO_3 fumes.*
- 2) *Materials conducive to the promotion of corrosion, such as fluorides, sulphites, and sulphides, should not be used in grout unless it can be proven that their presence is not detrimental.*

8.6 Welding material

8.6.1 Testing of weld materials

Testing of welding materials and completed welds shall be in accordance with CSA W48 and CSA W59. Additional testing requirements may be specified by the engineer.

8.6.2 Delta ferrite determination

8.6.2.1

Delta ferrite determination of austenitic stainless steel welding materials, including consumable insert materials, shall be performed in undiluted weld metal using a magnetic measuring instrument calibrated to AWS A4.2.

Alternatively, the delta ferrite determinations for welding materials may be performed using chemical analysis in undiluted weld material in accordance with Figure 5.1 of AWS D1.6.

The minimum delta ferrite number, shall be 5 FN.

8.6.2.2

The results of the delta ferrite determination shall be included in the certified material test report (CMTR).

8.6.3 Tensile and impact tests

8.6.3.1

Where notch-toughness tests are required for both base metals, the welding materials shall be impact tested and the CMTR shall include the results of the impact testing performed at an equal or lower temperature for each heat and lot in the required conditions.

8.6.3.2

The post-weld heat-treatment temperature shall be in accordance with proper metallurgical practices and the temperature shall be maintained for a minimum of 3 h.

8.6.3.3

The tensile and impact tests conducted both in the as-welded and post-welded heat-treated conditions shall meet the minimum values specified in the material specification for the consumable.

8.7 Reinforced masonry structures

Masonry inspection and testing shall comply with CSA A371 and this Standard.

8.8 Documentation and records

The documentation required by this Standard shall remain available during the service life of the facility. Nonconformances and corrective actions shall be recorded and the records kept for the life of the facility. All such records shall include a statement by the engineer that the as-built drawings continue to meet the requirements of this Standard pertaining to quality and safety. They shall be stored in a manner that allows easy access during construction, commissioning, operation, and decommissioning to facilitate on-site inspections, examinations, and audits

Note: *Requirements of CSA N287.1 should be used as guidelines*

9 In-service examination

Notes:

- 1) *Clause 9 specifies requirements for in-service examinations of safety-related structures and their elements during the life of the plant.*

- 2) CSA N287.7 defines requirements for in-service examination of dousing systems.

9.1 General

9.1.1

The examination shall be of sufficient frequency and physical extent to identify deterioration of the structures.

9.1.2

The method, extent, frequency of examinations, and basis of comparison shall be established with consideration to the following:

- a) type and function of the structure;
- b) design and construction history of the structure;
- c) performance records, including those of prior examinations;
- d) design capacity of the structure;
- e) elastic deformation and distortion of the structure, with particular emphasis on those points where maximum structural movement or stress is expected;
- f) provisions for monitoring;
- g) availability of reliable equipment and instrumentation; and
- h) repair history, if any.

Notes:

- 1) *Points of measurement and inspection should be similar to those used in previous examinations, where possible, to facilitate comparison of results and trending.*
- 2) *Basis of comparison should be in accordance with Clause 5.2 of CSA N287.7 as applicable.*

9.1.3

Responsibilities and qualifications of the in-service examination personnel shall be in accordance with the requirements of CSA N287.7.

9.2 In-service examination program

9.2.1

The in-service examination program shall be established to provide assurance of structures' sustained performance. The in-service examination program shall cover general requirements for examination of safety-related structures and their elements. The in-service examination program shall include requirements for additional examination of critical elements identified by the designer in accordance with Clause 8.1.1. The in-service examination program will support the aging management plan as detailed in Clause 10.

9.2.2

The examination program shall include the following:

- a) scope of examination, including
 - i) the identification of the boundaries; and
 - ii) the accessibility limitations, as applicable;
- b) examination requirements;
- c) identified degradation mechanisms;
- d) methods of examination and testing;
- e) frequency and amount (i.e., statistical distribution) of examination and testing;

- f) acceptance criteria; and
- g) reporting and documentation requirements.

Note: *Special consideration should be given to factors such as accessibility, effectiveness, and accuracy of examination methods.*

9.3 Examination frequency

9.3.1

Accessible surfaces of safety-related structures shall be examined at least once every six years, subsequent to the first in-service use of the structure, in accordance with the in-service examination program for the safety-related structures. For areas of safety-related structures that are not normally accessible, the examinations shall be at a frequency agreed upon by the operating organization and the AHJ.

Note: *For large surface areas, an in-service examination could address sample areas that are representative of limiting conditions within the structure. The areas should be selected based on the factors that can affect integrity (e.g., radiation, temperature, humidity, and high stress).*

9.3.2

The frequency of examinations shall be increased for structures and their elements that have exhibited significant deterioration and that might warrant frequent future repair or replacement.

9.3.3

The frequency of examinations may be decreased for structures that have not shown adverse findings or trends as agreed upon by the AHJ. The trend shall be stable for at least the two most recent examinations.

9.4 Examination following abnormal/environmental conditions

Following the occurrence of abnormal/environmental loads that exceeded those specified in the design specification, the safety-related structures shall be subjected to a visual inspection and other methods of examination, as required, to evaluate their integrity.

10 Aging management

10.1 General

10.1.1

An aging management (AM) plan shall be developed, implemented, and maintained by the operating organization to provide for the timely detection and mitigation of aging effects to ensure integrity and functional capability of the structure throughout all stages of its life cycle including design, construction, commissioning, operation, and decommissioning. The AM plan shall be submitted to the AHJ.

Notes:

- 1) *In Canada, CNSC REGDOC-2.6.3 provides the regulatory requirements for managing the aging of SSCs.*
- 2) *CSA N287.8 can be used as guidance for development and implementation of aging management plan for nuclear safety-related structures.*
- 3) *The aging management plan can include surveillance, testing, or other methods that provide assurance of a structure's sustained performance.*
- 4) *In-service inspection, examination, and testing activities form part of the aging management plan.*

10.1.2

Design, fabrication, construction, operation, and decommissioning shall consider the effects of aging on the safety-related structures.

10.1.3

The results from the aging management plan implementation shall be used to assess the rate of degradation and to adjust the aging and in-service examination and testing programs accordingly.

10.1.4

Requirements for organizational arrangements, the aging management team, and data collection and record keeping system shall be in accordance with CSA N287.8.

10.2 Design considerations

10.2.1

A safety margin shall be provided in the design, taking into account relevant aging mechanisms and the potential for age-related degradation in normal operation and accident scenarios.

10.2.2

The design should be provided to facilitate inspection, examination, testing, surveillance, maintenance, repair, and replacement activities, and to keep potential radiation exposures during these activities as low as reasonably achievable.

10.2.3

The operating organization shall ensure that the known stressors and operating conditions are considered during the design phase as well in design of modifications and repairs.

10.3 Operation considerations

10.3.1

Monitoring of operating conditions and parameters that affect aging assumptions used in design shall be recorded and trended.

Note: *Examples of such parameters are temperature, humidity, radiation, pressure, chemistry of water, and the soil that the structure (including its inaccessible areas) is exposed to.*

10.3.2

The effects of changes to operating conditions or modifications to the structure and its elements that affect aging assumptions used in design shall be evaluated and the AM plan shall be updated for all changes identified.

10.3.3

Modifications to the structure and its elements shall not cause accelerated aging.

10.3.4

If aging mechanisms not identified prior to development of the AM plan are discovered, evaluation for aging management shall be performed.

10.4 Maintenance considerations

Preventive and corrective maintenance and management of obsolescence shall be in accordance with requirements of CSA N287.8.

10.5 Evaluation for aging management and condition assessment

Evaluation for aging management and condition assessment shall be performed prior to establishing the AM plan, as shown in Figure 2. Evaluation for aging management and condition assessment shall be performed in accordance with the requirements of Clauses 9 and 10 of CSA N287.8.

10.6 Time-limited aging analysis

10.6.1

Time-limited aging analysis (TLAAs) shall be provided as a part of original design.

Note: For existing structures, TLAAs should be developed later (e.g., as being part of a periodic safety review).

10.6.2

The operating organization shall revalidate the TLAAs when the original design life assumptions are revisited.

Note: An example would be operating conditions exceeding design conditions.

10.6.3

The TLAA shall be revalidated in preparation for life extensions/long term operation (LTO).

Note: Methodologies for such analyses can be found in source documents such as IAEA Safety Report Series No. 57.

Figure 2
Development and optimization of AM plan
(see Clause 10.5.)

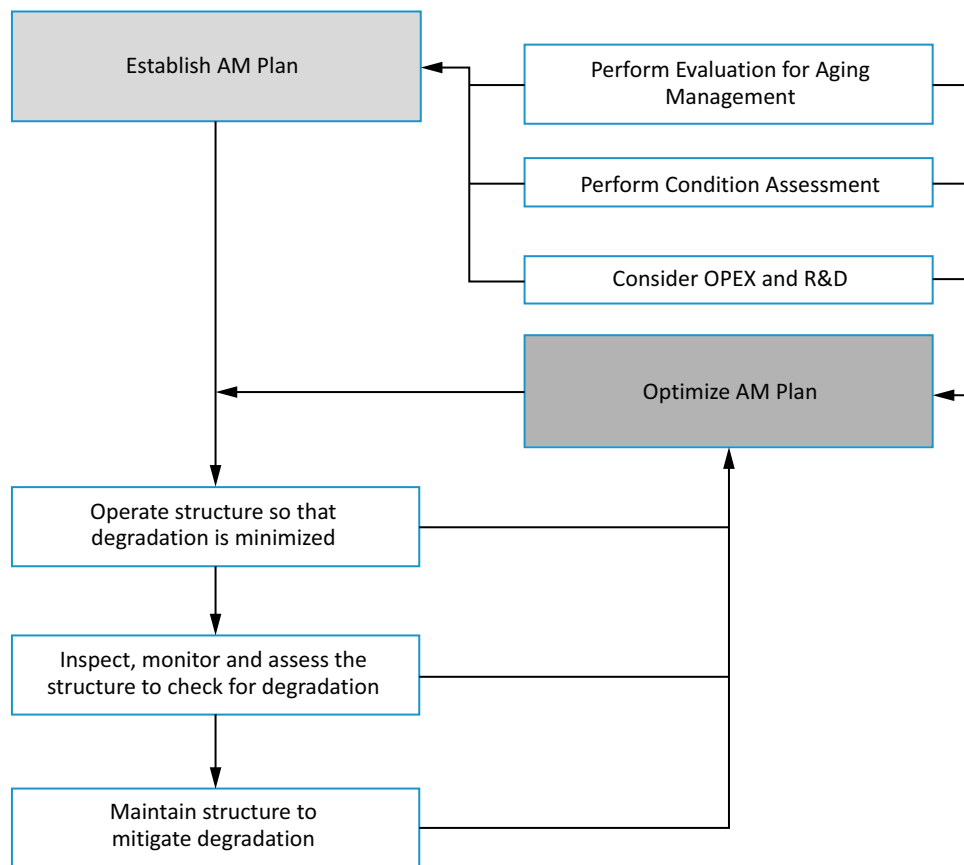


Table 1
Tests and test frequencies for concrete materials
 (See Clauses 8.4.1.2, 8.4.2.1, and 8.4.3.5.)

Material	Test	Test method	Test frequency — Minimum frequency of testing for specified material
Cement			
	Tricalcium aluminate	CSA A3003-12.9	Every 500 t
	Sulphur trioxide	CSA A3003-14.2	Every 500 t
	Other chemicals	CSA A3003-12 and/or -13	Every 1000 t
	Time of set	CSA A3004-B2 and/or -B3	Every 500 t
	Fineness	CSA A3004-A3	Every 500 t
	Strength	CSA A3004-C2	Every 1000 t
	Soundness (autoclave)	CSA A3004-B5	Every 500 t
	Heat of hydration	CSA A3004-B7	Every 500 t
	Sulphate resistance	CSA A3004-C6 and/or -C8	Every 2000 t
	Chlorides	CSA A3003-13.6	Every 2000 t
Supplementary cementing materials			
	Sulphur trioxide		
	Fly ash	CSA A3003-14.2	Every 1000 t or monthly
	Slag	CSA A3003-14.2	Every 1000 t or monthly
	Silica fume	CSA A3003-14.2	Every 1000 t
	Natural pozzolans	CSA A3003-14.2	Every 1000 t
	Soluble alkalis		
	Fly ash	CSA A3003-13.9	Every 1000 t
	Slag	CSA A3003-13.9	Every 1000 t
	Silica fume	CSA A3003-13.9	Every 100 t
	Natural pozzolans	CSA A3003-13.9	Every 100 t
	Loss on ignition		
	Fly ash	CSA A3003-11.3	Every 100 t
	Slag	N/A	N/A
	Silica fume	CSA A3003-11.3	Every 100 t
	Natural pozzolans	CSA A3003-11.3	Every 100 t
	Pozzolanic strength activity index		
	Fly ash	ASTM C311	Every 1000 t
	Slag	N/A	N/A
	Silica fume	ASTM C1240	Every 1000 t
	Natural pozzolans	ASTM C311	Every 1000 t

(Continued)

Table 1 (Concluded)

Material	Test	Test method	Test frequency — Minimum frequency of testing for specified material
	Drying shrinkage**		
	Fly ash	ASTM C311 and CSA A23.2-21C	Every 1000 t
	Slag	CSA A23.2-21C	Every 1000 t
	Silica fume	CSA A23.2-21C	Every 1000 t
	Natural pozzolans	ASTM C311 and CSA A23.2-21C	Every 1000 t
	** The CSA A23.2-21C test is performed on concrete specimens to evaluate the effects of supplementary cementing materials on drying shrinkage for the mix design.		
	Soundness (autoclave)		
	Fly ash	CSA A3004-B5	Every 1000 t
	Slag	CSA A3004-B5	Every 1000 t
	Silica fume	CSA A3004-B5	Every 1000 t
	Natural pozzolans	CSA A3004-B5	Every 1000 t
	Reactivity with alkalis		
	Fly ash	CSA 23.2-28A	Every 1000 t
	Slag	CSA 23.2-28A	Every 1000 t
	Silica fume	CSA 23.2-28A	Every 1000 t
	Natural pozzolans	CSA 23.2-28A	Every 1000 t
	Air-entrained admixture dosage^		
	Fly ash	ASTM C311	Every 1000 t
	Slag	N/A	N/A
	Silica fume	N/A	N/A
	Natural pozzolans	ASTM C311	Every 1000 t
	^ Uniformity of air-entrained admixture dosage tests shall be in accordance to ASTM C618.		
	Fineness^		
	Fly ash	A3004-A3	Every 100 t
	Slag	A3004-A3	Every 100 t
	Silica fume	A3004-A3	Every 100 t
	Natural pozzolans	A3004-A3	Every 100 t
	^ Uniformity of fineness tests shall be in accordance to ASTM C618.		
	Relative density^		
	Fly ash	CSA A3004-A2	Every 1000 t
	Slag	CSA A3004-A2	Every 1000 t
	Silica fume	CSA A3004-A2	Every 1000 t

(Continued)

Table 1 (Concluded)

Material	Test	Test method	Test frequency — Minimum frequency of testing for specified material
	Natural pozzolans	CSA A3004-A2	Every 1000 t
	[^] Uniformity of density tests shall be in accordance to ASTM C618.		
	Slag activity index		
	Fly ash	N/A	N/A
	Slag	CSA A3004-C7	Every 1000 t
	Silica fume	N/A	N/A
	Natural pozzolans	N/A	N/A
	Chlorides		
	Fly ash	CSA A3003-13.6	Every 1000 t
	Slag	CSA A3003-13.6	Every 1000 t
	Silica fume	CSA A3003-13.6	Every 1000 t
	Natural pozzolans	CSA A3003-13.6	Every 1000 t
Aggregates			
	Moisture content ++	CSA A23.2-11A	Twice daily
	++ Determination of moisture content may be completed by alternate means (i.e., moisture probes) as permitted by the operating organization.		
	Gradation	CSA A23.2-2A	Daily
	Organic impurities	CSA A23.2-7A	Daily
	Amount of material finer than 80 µm	CSA A23.2-5A	Weekly
	Flat and elongated particles	CSA A23.2-13A	Monthly
	Relative density	CSA A23.2-6A and/or -12A	Monthly
	Petrographic	CSA A23.2-15A	Monthly
	Clay lumps	CSA A23.2-3A	Monthly
	Low density	CSA A23.2-4A	Monthly
	If the aggregate, when tested according to CSA A23.2-15A, does not show the presence of either clay lumps or low-density granular materials, the requirements for testing in accordance with CSA A23.2-3A and CSA A23.2-4A may be waived.		
	L.A. abrasion	CAS A23.2-16A and/or -17A	Every 6 months
	Potential reactivity	CSA A23.2-14A or CSA A23.2-25A	Every 6 months
	Micro-Deval: Fine aggregates	CSA A23.2-23A	Every 6 months
	Micro-Deval: Coarse aggregates	CSA A23.2-29A	Every 6 months
	Chlorides	CSA A23.2-4B	Monthly
Water and Ice*			
	Total solids	ASTM C1603	Monthly
	Effect on setting	CSA A3004-B2 and/or -B3	Every 6 months

(Continued)

Table 1 (Concluded)

Material	Test	Test method	Test frequency — Minimum frequency of testing for specified material
	Effect on strength	CSA A23.2-8A	Every 6 months
	Chlorides	ASTM D512	Monthly
	* If water is obtained from a potable water supply, tests may be waived.		
Admixtures+			
	Infrared spectrophotometry	ASTM C494/C494M	Every shipment
	pH	ASTM E70	Every shipment
	Solids	ASTM C494/C494M	Every shipment
	Density	ASTM C494/C494M	Every shipment
	Chlorides	ASTM D4327	Every shipment
	+ The test methods should be chosen based on the admixtures used (e.g., air-entraining or super-plasticizer).		

Notes:

- 1) The numbers after the Standard designation show the clause in which the test method can be found. For example, "A23.2-4B" indicates CSA A23.2, Clause 4B.
- 2) Some tests for cement and supplementary cementing materials might not be applicable based on the type of cement and supplementary cementing materials being used. Tables 1 through 9 of CSA A3001 shall be used to establish test applicability. Tests which are not applicable, and therefore not required, shall be documented in the construction inspection and testing program (Clause 8.2.3).
- 3) The constructor's engineer shall seek concurrence from the operating organization for any deviations from this Table. Tests may be deemed not applicable, and test methods and frequencies may be deviated from, only with the concurrence of the operating organization. The deviation(s) shall be documented in the construction inspection and testing program (Clause 8.2.3).

Table 2
Tests and test frequencies for concrete and grout
 (See Clauses 8.4.1.2, 8.4.3.1, 8.4.3.5, and 8.5.1.)

Material	Test	Test method	Minimum frequency of testing
Concrete			
	Slump	CSA A23.2-5C	Every 3rd batch once satisfactory control is established and with every strength test*
	Air content	CSA A23.2-4C	Every 3rd batch once satisfactory control is established and with every strength test*
	Compressive strength	CSA A23.2-9C	Every 100 m ³ , minimum 1 test/day‡
	Density and yield§	CSA A23.2-6C	Minimum of 1 test/day/class
	Temperature	CSA A23.2-17C	Every 3rd batch once satisfactory control is established and with every strength test*
	Uniformity of mixed concrete§	CSA A23.1 Clause 5.2.4.5	Every 6 months
	Water-soluble chloride	CSA A23.2-4B	One test per mix, selected randomly, per year or monthly†
Grout			
	Temperature	CSA A23.2-17C	Each batch
	Compressive strength	CSA A23.2-1B	Daily
	Bleeding	CSA A23.2-1B	Twice daily
	Fluidity	CSA A23.2-1B	For each batch
	Expansion	CSA A23.2-1B	Twice daily
Additional tests for pre-stressing grout			
	Chlorides	CSA A23.2-4B	Before each grouting operation
	Nitrates	CSA A23.2-4B in conjunction with ANSI/ASTM D4327	Before each grouting operation
	Alkalinity	ANSI/ASTM D1293	Before each grouting operation

* Satisfactory control shall be established for each plant supplying concrete.

† Water-soluble chlorides shall be tested monthly per mix if individual constituents tested cannot be calculated based on mix proportions in accordance with Clause 8.4.3.5.

‡ When the frequency of testing stipulated will provide fewer than three strength tests results for a given class of concrete, the strength tests results shall be made from at least three randomly selected batches on a single project.

§ The test may be omitted. The deviation(s) shall be documented in the construction inspection and testing program (Clause 8.2.3).

Table 3
Load combinations and load factors for steel and concrete structures
 (See Clauses 6.3.2.2, 6.3.3.2, 6.3.4.2, and A.6.)

Category	D	L	P	Q_{ed}	Q_{es}	Q_t	Q_w	R	R_a	$R_o^{††}$	R_x	T_a^*	$T_o^{*††}$	T_p	X
Service															
Construction	1.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1.25 [†]	1.5	—	—	—	—	0.4	—	—	1.5	—	—	1.25	1.0	—
	1.25 [†]	0.5	—	—	—	—	1.4	—	—	1.0	—	—	1.25	1.0	—
	1.0	0.5	—	—	1.0	—	—	—	—	1.0	—	—	1.25	1.0	—
Due to containment testing	1.25 [†]	1.5	1.45 [‡]	—	—	—	—	—	—	1.5	—	—	1.25	1.0	—
Normal	1.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1.25 [†]	1.5	—	—	—	—	0.4	—	—	1.5	—	—	1.25	1.0	—
	1.25 [†]	0.5 ^{**}	—	—	—	—	1.4	—	—	1.0	—	—	1.25	1.0	—
	1.0	0.5 ^{**}	—	—	1.5	—	—	—	—	1.0	—	—	1.25	1.0	—
Abnormal/environmental															
Abnormal	1.0	1.0	1.5 [§]	—	—	—	—	1.0	1.0	—	—	1.0	—	1.0	—
	1.0	1.0	—	—	—	—	—	—	—	1.0	1.0	—	1.0	1.0	—
	1.0	1.0	—	—	—	—	—	—	—	1.0	—	—	1.0	1.0	1.0
24 h after accident + SDE	1.0	1.0	1.0	—	1.0	—	—	—	—	1.0	—	1.0	—	1.0	—
Environmental	1.0	1.0	—	—	—	1.0	—	—	—	1.0	—	—	1.0	1.0	—
	1.0	1.0	—	1.0	—	—	—	—	—	1.0	—	—	1.0	1.0	—

* See Clause 6.6 for concrete structures.

† Where the stabilizing effect of dead load counteracts overturning, uplift, sliding, and failure due to stress reversal, and determines anchorage requirements, the load factor for dead load shall be 0.9.

‡ For safety-related structures located inside containment and subject to the test pressure of the containment, 1.45 is the rounded product of a load factor of 1.25 multiplied by the test pressure of 1.15P, where P is the design pressure of the containment (value of test pressure is specified in CSA N287.6).

§ There may be a reduction to 1.0 for pipe failure. In such a case, the dynamic effects shall be considered.

** The factor 0.5 shall be increased to 1.0 for storage areas, and equipment areas and service rooms.

†† Where load factors have been applied in accordance with Table 4, load factors for R_o and T_o in this Table do not apply

Table 4
Load factors for loads from the pipe and equipment supports,
and connections designed in accordance with CSA N285.0/N285.6
 (See Clauses 6.3.2.4, 6.6.5.2, and 6.6.6.2 and Table 3.)

ASME load category	Load factor
A and B	1.50
C	1.20
D	1.00

Table 5
Liner plate strain allowables
 (See Clause 6.9.2.8.)

Strain	Membrane	Combined membrane and bending
Compressive	0.005	0.014
Tensile	0.003	0.010

Note: The types of strain given in this Table are limited to strains induced by deformation or constraint.

Annex A (informative)

Special provisions for impulse and impact effects for concrete structures

Note: This informative Annex has been written in mandatory language to facilitate adoption by anyone wishing to do so.

A.1 Symbols

The following symbols shall apply in this Annex:

- A_c = area of core of spirally reinforced column measured to the outside diameter of the spiral, mm²
- A_{ch} = area of rectangular core of column measured out-to-out of hoop, mm²
- A_g = gross area of section, mm²
- A_{xh} = area of rectangular hoop reinforcement in concrete column
- c = distance from extreme compression fibre to neutral axis at ultimate strength, mm
- d = effective depth of section (distance from extreme compression fibre to centroid of tension reinforcement), mm
- f'_c = specified compressive strength of concrete, MPa
- f_y = specified yield strength of non-pre-stressed reinforcement, MPa
- I_a = moment of inertia of section resisting externally applied design loads
- I_{cr} = moment of inertia of cracked section transformed to concrete
- I_g = moment of inertia of gross concrete section about centroidal axis, excluding reinforcement
- ℓ_h = maximum unsupported length of rectangular hoops measured between perpendicular legs of the hoop or supplementary cross ties, mm
- r_F = rotational capacity, radians
- S_h = centre-to-centre spacing of hoops, mm
- ρ = ratio of non-pre-stressed tension reinforcement, equal to A_s/b_d
- ρ' = reinforcement ratio for compression reinforcement, equal to A'_s/b_d
- ρ_s = ratio of volume of spiral reinforcement to total volume of core (out-to-out spirals)
- ρ_x = ratio of volume of rectangular hoop reinforcement to total volume of core (out-to-out of hoops)

A.2 General

A.2.1 Scope

Safety-related structures shall be designed for applicable impulsive and impactive loads. Applicable experimental or theoretical evidence may be applied to justify requirements and acceptance criteria less conservative than those given in this Annex. The impulsive and impactive loads described in this Annex shall be considered in the different defined categories of loading types and levels.

Note: This Annex is intended to be used in DBA loading conditions. The methodologies in this Annex can be applied to BDBA impactive and impulsive loading conditions, provided that the structural failure criteria are determined based on the acceptable analytical or experimental results.

A.2.2 Impulse loads

Impulse loads are time-dependent loads that are determined by an impulsive loading source and are not dependent on target inertial and stiffness properties. Impulse loads are generally force or pressures. These loads shall include, but not be limited to, the following types of loading:

- a) jet impingement;
- b) blast pressure;
- c) compartment pressurization; and
- d) pipe-whip restraint reactions.

A.2.3 Impact loads

Impact loads are time-dependent loads that result from the collision of masses that are associated with finite amounts of kinetic energy. These transient loads are determined by the inertial and stiffness properties of missile and target structures. Impact loads shall include, but not be limited to, the following types of loading:

- a) tornado-generated missiles;
- b) whipping pipes;
- c) aircraft strikes;
- d) fuel cask drop; and
- e) other internal and external missiles.

A.3 Design criteria

A.3.1 General

Clause [A.3](#) defines the criteria for the design of individual structural elements (e.g., beams and slabs) against impulse and impact loads. Due to the severe local nature of these loads, the design may utilize localized inelastic deformation to absorb the input energy.

A.3.2 Material properties

Material properties considered in determining section resistance to impact and impulse loads may include appropriate dynamic increase factors (DIFs) with the maximum values as given in Table [A.1](#).

When the dynamic load factor (DLF) is less than 1.2, the DIF shall be 1.00. The DIF shall be equal to 1.00 when the strain-rate factor has been considered in the applied empirical formulas or material constitutive laws.

A.3.3 Shear strength

A.3.3.1

Flexural-controlled elements shall be designed for shear capacity to exceed flexural capacity to allow for potentially higher energy-absorbing capability.

A.3.3.2

The evaluation of impulse and impact loads shall include both punching shear adjacent to the load and reaction shear at supports. For certain impactive loads, satisfaction of the criteria for perforation of Clause [A.5.2.4](#) may replace the punching shear requirements.

A.3.3.3

Shear requirements shall be determined in accordance with Clause 11 of CSA A23.3, increased by the DIF specified in Clause A.3.2 of this Standard.

A.3.4 Deformation limits

A.3.4.1

Deformation limits are generally specified in terms of permissible ductility ratios for structural elements. The permissible ductility ratio is defined as the maximum acceptable displacement of a structural element to the maximum pseudo-elastic displacement at effective yield for the element. The effective yield point may be found by extending the initial elastic deformation line to its intersection with the maximum resistance line.

A.3.4.2

The limit design method, such as yield line theory, may be used to determine maximum resistance of the structural element.

A.3.4.3

The response of the structural elements or sections shall be with the permissible ductility limits to maintain functionality and structural integrity. The permissible ductility ratios in Table A.2 shall be used, provided that the requirements specified in Clause A.3.5 are met. Less conservative values of ductility ratios and other equivalent failure acceptance criteria may be used if justified by applicable theoretical or experimental evidence.

A.3.5 Special requirements

A.3.5.1

Resistance available for impulse loads shall be at least 20% greater than the steady-state magnitude of an impulse load.

A.3.5.2

The maximum value of $(\rho - \rho')$ shall not exceed 0.5 times the ratio producing balanced conditions in accordance with Clause 10.1.4 of CSA A23.3. Both top and bottom reinforcement for beams shall consist of not less than two bars in each layer and shall have a minimum ρ required by Clause 10.5.1 of CSA A23.3 throughout the length of the beam.

A.3.5.3

At least one-third of the layer amount of the tension reinforcement required at either end of a member shall be continuous throughout the length of the member. At least one-third of the maximum tension reinforcement required in the mid-region of a member shall be continuous throughout the length of the member and fully developed in tension beyond the face of the supports to its specified yield strength. These requirements shall apply to each direction of two-way structural elements.

A.3.5.4

The vertical reinforcement ratio in columns shall be a minimum of 1% and a maximum of 6%.

A.3.5.5

Confinement reinforcement in columns consisting of spiral or hoop reinforcement shall be supplied above and below connections over a minimum length from the face of the connection at least equal to the greatest of

- a) h (the longer dimension in the case of rectangular columns or the diameter of a round column);
- b) 450 mm; and
- c) one-sixth of the clear height of the column.

A.3.5.6

Where a spiral is used, the volumetric ratio ρ_s shall be not less than indicated by Eq. 10-7 of CSA A23.3 and in no case less than 0.12 (f'_c/f_y).

A.3.5.7

Where rectangular hoop reinforcement is used, the required area of the bar shall be calculated as follows:

$$A_{xh} = \frac{\ell_h \cdot \rho_x \cdot S_h}{2}$$

where

ρ_x is the volumetric ratio specified in Clause A.3.5.6 with A_{xh} substituted for A_c and with f_y as the yield strength of the hoop reinforcement. The centre-to-centre spacing, S_h , between hoops or the pitch of continuous hoops shall not exceed 100 mm. Minimum bar size shall be that required for ties by Clause 7.6.5.1 of CSA-A23.3.

Supplementary cross ties of the same bar size as the hoop may be used to reduce the unsupported length, ℓ_h . Each end of the supplementary cross ties shall engage the periphery hoop with a standard semicircular hook, and shall be secured to a longitudinal bar to prevent displacement of the cross tie during construction. The minimum cover of supplementary cross tie reinforcement shall be 13 mm.

A.3.5.8

Special reinforced concrete design, such as lacing reinforcement, may be used. In such case, the ductility ratios of Table A.2 may be increased.

A.4 Analysis and design for impulse loads**A.4.1 Method of analysis****A.4.1.1**

Dynamic analysis shall be performed to evaluate the dynamic effects of the structural system subjected to impulse loads. Non-linear effects or inelastic behaviour shall be accounted for in the analysis. The allowable ductility ratios shall not exceed the values specified in Table A.2 unless justified in accordance with Clause A.3.4.3. In general, the methods in Clauses A.4.1.2 to A.4.1.4 shall be used to determine the structural response.

A.4.1.2

The dynamic effects may be evaluated based on an equivalent static load approach by applying a DLF to the peak impulse load. The DLF shall be based on the permissible ductility criteria, and may be

calculated using a simplified impulse load profile and an idealized bi-linear resistance-displacement function. Limit load may be determined by methods such as virtual work or yield line theory. If this method is adopted, dynamic reactions shall be calculated using equations of force and moment equilibrium consistent with the assumed mode shape.

A.4.1.3

For a load with short duration, impulse can be equated with a change in momentum to find the velocity of the structure. The resulting kinetic energy may be assumed to be absorbed by the available strain energy capacity of the structural system. The available strain energy capacity shall be limited by the permissible ductility ratio and shall be reduced by the amount of work done by other static loads.

A.4.1.4

The dynamic effects may be calculated by time-history dynamic analysis. The mathematical model may be a simplified single degree-of-freedom or multi-degree-of-freedom system. Stiffness degradation of structural elements shall be considered for inelastic analysis. Simplified bilinear representations shall be acceptable. The finite element method shall be used when the accuracy using SDOF or MDOF simplifications cannot be justified.

A.4.2 Concrete stiffness

In calculating the stiffness of reinforced concrete sections, the moment of inertia shall account for cracking of the concrete. The average moment of inertia shall be calculated as follows:

$$I_a = \frac{1}{2}(I_g + I_{cr})$$

In lieu of the above equation, a more rigorous acceptable approach may be used.

A.5 Analysis and design for impact loads

A.5.1 General

Design for impact loads shall satisfy the criteria both for local effect given in Clause [A.5.2](#) and for the overall effect given in Clause [A.5.3](#).

A.5.2 Local effects

A.5.2.1

Local impact effects can include penetration, perforation, scabbing, and punching shear. Applicable formulas derived from pertinent tests may be used to determine concrete thickness required to prevent perforation or scabbing. To prevent scabbing of concrete structural elements, anti-scab plate or another shielding system shall be designed in accordance with applicable formulas or pertinent test data.

A.5.2.2

When it can be demonstrated by applicable formulas or pertinent test data that the concrete thickness is adequate to prevent perforation and hence punching shear failure, design for punching shear in accordance with Clause [A.3.3](#) is not required. For highly deformable missiles, the punching and reaction shear requirements in Clause [A.3.3](#) shall be followed.

A.5.2.3

In general, empirical formulas are applicable over a limited range of missile and target parameters. The designer shall exercise caution in cases where gross extrapolation is required. Such cases include highly deformable missiles, irregularly shaped missiles, oblique impact, near-edge impact, missile rotation, concrete strength, flexural reinforcement, types of shear reinforcement, etc. Adjustment based on pertinent experimental justification may be applied.

A.5.2.4

In the design, the required barrier or wall thickness to prevent perforation shall be at least 20% greater than the calculated thickness from the applicable empirical formulas. The required barrier or wall thickness to mitigate missile penetration shall be at least 50% greater than the calculated thickness from the applicable empirical formula.

A.5.3 Overall effects

A.5.3.1

The deformation characteristics of missiles and targets shall be considered in developing an applied force-time history for the purpose of evaluating the overall response. The structural response may be determined by the methods specified in Clause [A.4.1](#) and [A.4.2](#).

A.5.3.2

When the force-time history is not used (e.g., in the simplified method), the conservation of momentum and energy may be applied to calculate the required target strain energy. The effective size and mass of a missile shall be evaluated and used to determine the structural response.

A.5.3.3

To improve accuracy, detailed nonlinear analysis may be performed to simulate the interactive effect between the missile and its impacted target in the analysis of the finite element method.

A.6 Load combination

Impulse and impact loads shall be considered concurrent and in combination with other applicable loads in accordance with Table [3](#) in abnormal and environmental categories.

Table A.1
Recommended dynamic increase factors
 (See Clause A.3.2.)

Structural material	DIF
Concrete	
Axial and flexural compression	1.25
Shear	1.10
Reinforcing steel	
$f_y = 300$ MPa	1.20
$f_y = 350$ MPa	1.15
$f_y = 400$ MPa	1.10
Pre-stressing steel	1.00
Steel plate	
Carbon steel	1.29
Stainless steel	1.18

Table A.2
Permissible ductility ratios
 (See Clauses A.3.4.3, A.3.5.8, and A.4.1.1.)

Failure mode	Permissible ductility ratio
Flexural*, †, §	$\frac{0.05}{\rho - \rho'} \leq 10$
Compression‡, §	1.30
Shear	
carried by concrete alone	1.30
carried by concrete and stirrups or bent bars	1.60
carried completely by stirrups or bent bars	3.00

* The following requirements shall be met:

- Concrete elements in flexure shall be checked to ensure that the rotational capacity of any plastic hinge shall be limited to $r\phi = 0.0065 (d/c) \leq 0.07$ radians.
- The load-carrying capacity of the element in shear shall be at least 20% higher than that in flexure.
- For loads such as blast and internal pressurization that could affect the integrity of the containment as a whole, the ductility ratio shall not exceed 3.0.

† When the axial compression load does not exceed $(0.1f_c A_g)$ or one-third of what would produce balanced conditions, whichever is smaller.

‡ When compression controls the design, as defined by an interaction diagram.

§ For conditions between those described in Notes † and ‡, the permissible ductility ratio shall vary linearly between the values given in this Table for flexural and compression failure modes.

Annex B (informative)

Waiting periods for placing fresh concrete adjacent to hardened concrete

Note: This Annex is not a mandatory part of this Standard.

B.1

In accordance with the requirements of Clause 7.2.3, Table B.1 takes into consideration

- a) placement thicknesses;
- b) types of cement; and
- c) placing temperatures.

Table B.1
Recommended waiting periods in days for placing fresh concrete adjacent to hardened concrete that is restrained by continuous reinforcement
 (See Clause B.1.)

Placement thickness, mm	7 d heat of hydration of cement, 290 – 310 kJ/kg			7 d heat of hydration of cement, 265 – 285 kJ/kg		
	$T_a-10^{\circ}\text{C}$	$T_a(^{\circ}\text{C})$	$T_a+10^{\circ}\text{C}$	$T_a-10^{\circ}\text{C}$	$T_a(^{\circ}\text{C})$	$T_a+10^{\circ}\text{C}$
	Number of days			Number of days		
500	2.0	2.5	3.0	2.0	2.5	3.0
1000	6.0	6.5	7.0	5.0	5.5	6.0
1500	10.0	11.0	12.0	9.0	10.0	11.0
2000	14.0	16.0	18.0	13.0	15.0	17.0

Notes:

- 1) The above times may be reduced
 - a) where special methods are used to remove the heat of hydration; and
 - b) by 20% where the structure is steel lined.
- 2) T_a = ambient temperature adjacent to concrete.

