S413-94 ***(Reaffirmed 2000)***

Parking Structures

Structures Design

General Instruction No. 2

S413-94

February 1997

Title: *Parking Structures* — originally published December 1994

The following revisions have been formally approved:

Revised	Outside front cover, inside front cover, title page
New	None
Deleted	None

S413-94 originally consisted of **115 pages** (xii preliminary and 103 text) dated **December 1994.** It now consists of the following pages:

iii–xii and **1–103** dated **December 1994;** and
Cover, title page, and **copyright page** dated **February 1997.**

- Update your copy by inserting these revised pages.
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CAN/CSA-S413-94

Parking Structures

Structures Design

A National Standard of Canada
(approved February 1997)

Bien que le but premier visé par cette norme soit énoncé sous sa rubrique Domaine d'application, il est important de retenir qu'il incombe à l'utilisateur de juger si la norme convient à ses besoins particuliers.

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 user to judge its suitability for their particular purpose.

National Standard of Canada
(approved February 1997)

CAN/CSA-S413-94

Parking Structures

Prepared by
Canadian Standards Association

Approved by
Standards Council of Canada

ISSN 0317-5669
Published in December 1994 by Canadian Standards Association
178 Rexdale Boulevard, Etobicoke, Ontario, Canada M9W 1R3

Technical Editor: *Bill Glover*
Managing Editor: *Gary Burford*

(Copyright page replaced February 1997)

General Instruction No. 1
S413-94
December 1994

CSA Standard S413-94, *Parking Structures,* consists of **115 pages** (xii preliminary and 103 text), each dated December 1994.

This Standard, like all CSA Standards, is subject to periodic review, and amendments in the form of replacement pages may be issued from time to time; such pages will be mailed automatically to those purchasers who complete and return the attached card.* Some Standards require frequent revision between editions, whereas others require none at all. It is planned to issue new editions of the Standard, regardless of the amount of revision, at intervals not greater than 5 years. Except in unusual circumstances, replacement pages will not be issued during the last year of that edition.

**This card will appear with General Instruction No. 1 only.*

Although any replacement pages that have been issued will be sold with the Standard, it is for the purchaser to insert them where they apply. The responsibility for ensuring that his or her copy is complete rests with the holder of the Standard, who should, for the sake of reference, retain those pages which have been replaced.

Note: *A General Instruction sheet will accompany replacement pages each time they are issued and will list the latest date of each page of the Standard.*

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S413-94

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S413-94

Parking Structures

Structures (Design)

ISSN 0317-5669
Published in December 1994
by
Canadian Standards Association
178 Rexdale Boulevard,
Rexdale (Toronto), Ontario,
Canada
M9W 1R3

Technical Editor: *Bill Glover*
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Preface

This is the second edition of CSA Standard S413, *Parking Structures*. It supersedes the previous edition published in 1987.

This Standard differs from the previous edition as follows:

(a) Items covered in the latest CSA Standard A23.1 have generally been deleted from this Standard.

(b) Definitions have been added, revised, and deleted.

(c) Emphasis has been added on the need for regular inspection and maintenance.

(d) A requirement has been added to show specified allowances for superimposed dead loads on the drawings.

(e) The requirement for the exposure classification of the concrete in perimeter basement walls has been relaxed.

(f) More stringent requirements have been added for the protection, inspection, acceptance, and repair of damage to the coating of epoxy-coated bars. Epoxy coaters must be certified under the CRSI Certification Program. Plastic-coated vibrators are now required where epoxy-coated bars are used.

(g) A requirement has been added to electrically connect metal items where a future cathodic protection system is contemplated.

(h) Table 1 has been revised to allow more choice in the acceptable protection systems. A sealer on cast-in-place post-tensioned concrete is no longer permitted to be relied upon as a protection system; corrosion protection is required to reinforcement in brackets, corbels, and ledges.

(i) Requirements for steel and concrete stairs have been added.

(j) Exposure designations have been revised to "normal" and "severe", and more description and examples of each have been added to differentiate more clearly between the two. Severe exposure has been subdivided to have different requirements for thin and thick waterproofing systems.

(k) The specified concrete cover has been somewhat revised. Systems which are permitted to have no waterproofing membrane are now required to have 50 mm of concrete cover.

(l) A requirement has been added to apply a sealer to vertical surfaces in splash zones, as well as to vertical surfaces where there is no membrane extending 100 mm up the vertical surface.

(m) Waterstops are now permitted in construction joints in certain locations.

(n) A requirement has been added to show the layout of concrete control joints on the drawings.

(o) Further requirements for control joints in concrete toppings have been added.

(p) A specific design slope for floors has been added.

(q) A requirement for sloping of slabs-on-ground has been added.

(r) A requirement has been added that there be adequate exterior drainage.

(s) Requirements for precast concrete slabs with voids have been added.

(t) A requirement for protection of tendon sheaths where they extend through construction joints has been added.

(u) The foreperson supervising the installation of post-tensioning tendons and the inspectors must now be certified in accordance with a certification program.

(v) A requirement for protection of columns, base plates, and anchor bolts has been added.

(w) Steel deck is now permitted only as a stay-in-place form and is not permitted to be designed to provide tensile strength to the floor.

(x) The requirements for painting of steel structures have been revised.
(y) The appendices have been revised, including
(i) Appendix A, Moisture Barriers, has been rewritten and includes new information about membranes, tests, and performance criteria for sealers.
(ii) Appendix B, Cathodic Protection, has been rewritten and expanded.
(iii) Appendix C, Corrosion Inhibitors, has been completely rewritten and gives information on the determination of dosages.
(iv) A new Appendix G, Structural Considerations, has been added.
(z) An alphabetical index has been added.

The Committee intends to review and update this Standard on a continuing basis and to maintain liaison with other relevant committees.

This Standard has been adopted by the Associate Committee on the National Building Code as the reference Standard for parking structures in Section 4 of the National Building Code for 1995.

This Standard was prepared by the CSA Technical Committee on Parking Structures, under the jurisdiction of the CSA Steering Committee on Structures (Design), and was approved by these Committees.

December 1994

Notes:
(1) *Use of the singular in this Standard 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 publication was developed by consensus, which is defined by* CSA Regulations Governing Standardization *as "substantial agreement reached by concerned interests. Consensus includes an attempt to remove all objections and implies much more than the concept of 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 the publication.*
(4) *CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.*
(5) *All enquiries regarding this Standard, including requests for interpretation, should be addressed to Canadian Standards Association, Standards Development, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3. Requests for interpretation should*
(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) be phrased where possible to permit a specific "yes" or "no" answer.
Interpretations are published in CSA's periodical Info Update. *For subscription details, write to CSA Sales Promotion,* Info Update, *at the address given above.*

Guide for the Use of this Standard

This Standard is a set of minimum design, construction, and maintenance requirements necessary for the structural durability of new parking structures and parts of buildings subject to vehicular traffic or used for parking.

The provisions of this Standard are intended to address both ultimate and serviceability limit states, and specifically to

(a) protect against the deterioration of concrete and steel elements caused by deicing chemicals combined with, where applicable, the effects of freeze-thaw cycling;

(b) protect against damage to vehicles caused by leakage through floors; and

(c) control the flow of water and avoid ponding.

The structural design methods, loadings, and limit states referenced and specified in this Standard are those set forth in the *National Building Code of Canada.*

These requirements are applicable to all parking structures susceptible to corrosion, whether caused by atmospheric conditions or deicing chemicals. In areas where deicing chemicals are not used and are not expected to be used in the foreseeable future, some of the corrosion protection provisions in this Standard may not be warranted.

Some parking structures, or portions of parking structures, may require more than the minimum protection required by this Standard, because of factors such as environmental conditions, the extent of utilization of salt by the municipality, the number of daily vehicle in and out trips, the difficulty of access for repairs, or the desire to minimize maintenance requirements.

For types of construction or construction details not covered by this Standard, the same principles of protection required by this Standard shall apply, including multiple protection systems wherever feasible.

To obtain the intended durability, parking structures designed and constructed in conformance with this Standard must be regularly maintained in accordance with a comprehensive inspection and maintenance program.

Acceptable protection systems are provided in Table 1. The appropriate choices should be made by the designer and specified in the drawings and related documents.

Many of the clauses give only performance requirements. The specific details, materials, and procedures should be shown and specified in the drawings and related documents.

The Commentary (Appendix H) provides explanatory material for the requirements of this Standard, as well as useful supplementary information, and should be read in conjunction with the Standard.

The Standard and Commentary do not cover other important aspects of parking structure design, such as layout, lighting, design loads, etc. Advice on these aspects should be sought from professional sources knowledgeable in the special requirements of parking structures.

There are frequent notes and several appendices in the Standard, which are inserted for guidance, but which may be made mandatory by appropriate references in the drawings and related documents. Footnotes under tables are mandatory.

S413-94
Parking Structures

1. Scope

1.1 General
This Standard specifies special requirements for the durability aspects of the design and construction of new parking structures and parts of buildings subject to vehicular traffic.

1.2 Structure Types
New parking structures constructed of structural steel, reinforced concrete (including prestressed concrete), or a combination of these materials, fall within the scope of this Standard.

1.3 Structural Design
The structural design methods, loadings, and limit states referenced and specified in this Standard are those set forth in the *National Building Code of Canada.*

1.4 Repair of Existing Parking Structures
This Standard does not cover the repair of existing parking structures, and the provisions of this Standard are not necessarily appropriate for the repair and protection of existing structures.
Note: *Repair of concrete structures is covered in CSA Standard S448.1.*

1.5 Reference Standards
In the event of conflict between this Standard and the reference Standards, this Standard takes precedence.

2. Definitions

2.1
The following definitions apply in this Standard:

Anchorage — a device used in post-tensioning to transfer the force from the stressing tendon to the concrete member.

Cathodic protection — the reduction of corrosion rate, usually by shifting the corrosion potential of the protected steel to a less oxidizing potential.

Cementing materials — Portland cement with or without supplementary cementing material, used as the binder to make concrete.

Concrete cover — the distance from the concrete surface to the nearest surface of steel reinforcement, duct, tendon, tendon sheath, mesh, or embedded hardware. The actual distance may be more or less than the specified distance, depending on the allowable tolerance. Concrete covers in this Standard are specified concrete covers, unless otherwise noted.

Construction joint — the surface where plastic concrete is placed against hardened concrete.

Control joint — a tooled, sawcut, or formed groove for the purpose of forming a plane of weakness and inducing a crack, thereby reducing stresses caused by volume changes.

Corrosion — the deterioration of metal due to the formation of oxides; in the case of steel, the formation of iron oxides.

Corrosion inhibitor — a chemical that is added to concrete to delay the onset and reduce the rate of corrosion of reinforcement in the presence of chlorides. A corrosion inhibitor provides protection to embedded reinforcement by chemically influencing the kinetics of the electrochemical corrosion reaction at the reinforcement surface, and not primarily by influencing the concrete matrix, rheology, or permeability.

Designer — the person responsible for the design.

Durable — able to resist over the design service life, significant deterioration due to weathering action, chemical attack, and abrasion, when exposed to the intended uses and conditions of service, provided a comprehensive maintenance program is carried out. The required design service life takes into account the importance of the component and its accessibility for maintenance and replacement.

Expansion joint — a joint that allows for expansion and contraction of the structure without distress.

Hardware — a metal item embedded in, or fastened to, concrete for the purpose of connecting precast elements or attaching adjacent materials.

Membrane — an impermeable material meeting the test requirements of ASTM Standard C957, or CGSB Standard CAN/CGSB-37.50, as applicable.

Mesh — welded steel wire fabric.

Moisture barrier — a sealer or waterproofing membrane.

Parking structure — a building or part of a building subject to vehicular traffic or used for parking.

Protection system — a system intended to decrease the harmful chemical and physical effects of the parking structure environment.

Regulatory authority — the governmental body responsible for the enforcement of any part of this Standard or the official or agency designated by that body to exercise such a function.

Reinforced concrete — cast-in-place or precast concrete, reinforced with not less than the minimum amount of prestressed reinforcement required by Clause 7.3.6 of this Standard, or nonprestressed reinforcement required by CSA Standard A23.3.

Sealant — a material used to exclude water and solid foreign materials from joints.

Sealer — a liquid applied to the surface of concrete to reduce the penetration of water and deicing chemicals.

Sliding joint — a bearing support which allows horizontal movement without distress to the structure.

Tendon — a steel element such as a wire, bar, strand, or a bundle of such elements, used to impart prestress to concrete.

Wearing course — an abrasion-resistant, skid-resistant material used to protect a membrane from damage.

3. Reference Publications

This Standard refers to the following publications and where such reference is made it shall be to the edition listed below, including all amendments published thereto:

CSA Standards

A23.1-94,
Concrete Materials and Methods of Concrete Construction;

A23.2-94,
Methods of Test for Concrete;

A23.3-94,
Design of Concrete Structures;

A23.4-94,
Precast Concrete — Materials and Construction;

CAN3-B79-M79,
Floor Drains and Trench Drains;

CAN/CSA-G164-M92,
Hot Dip Galvanizing of Irregularly Shaped Articles;

CAN/CSA-S16.1-94,
Limit States Design of Steel Structures;

S448.1-93,
Repair of Reinforced Concrete in Buildings.

ACI* Standards

222R-89,
Corrosion of Metals in Concrete;

201.2R-92,
Guide to Durable Concrete;

515.1R-79,
A Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete.

ASTM† Standards

A525M-91a,
Standard Specification for General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process;

C666-92,
Test Method for Resistance of Concrete to Rapid Freezing and Thawing;

C671-86,
Test Method for Critical Dilation of Concrete Specimens Subjected to Freezing;

C682-87 (R1992),
Practice for Evaluation of Frost Resistance of Coarse Aggregates in Air-Entrained Concrete by Critical Dilation;

C957-87,
Standard Specification for High-Solids Content Cold Liquid-Applied Elastomeric Waterproofing Membrane with Integral Wearing Surface;

C1202-91,
Test Method of Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration;

D3963/D3963M-93,
Standard Specification for Epoxy-Coated Reinforcing Steel.

CGSB‡ Standards
CAN/CGSB-37.50-M89,
Hot Applied Rubberized Asphalt for Roofing and Waterproofing;

CAN/CGSB-37.51-M90,
Application of Hot Applied Rubberized Asphalt for Roofing and Waterproofing;

CAN/CGSB-37.65-M89,
Mastic Asphalt (Hot Process) for Flooring;

CAN/CGSB-37.68-M87,
Mastic Asphalt (Hot Process) for Waterproofing;

85-GP-11M-1980,
Painting Steel for Protection Against Continuous Wetting.

Canadian Prestressed Concrete Institute
Metric Design Manual Precast and Prestressed Concrete, 2nd Edition, 1987.

National Research Council of Canada
National Building Code of Canada, 1995;

Supplement to the National Building Code of Canada, 1995.

Post-Tensioning Institute
Specification for Unbonded Single Strand Tendons, July 1993.

*American Concrete Institute.
†American Society for Testing and Materials.
‡Canadian General Standards Board.

4. Corrosion and Leakage Protection

4.1

All parking structures shall be protected against
(a) corrosion; and
(b) water leakage through the floor and roof.

5. Drawings and Related Documents

5.1

The drawings and related documents shall provide the information required by the *National Building Code of Canada* and by CSA Standards A23.3 and CAN/CSA-S16.1, and shall clearly show

(a) concrete cover;
(b) location of drains;
(c) layout of slopes, cambers, if any, and numerical elevations of high and low points of the floor surface;
(d) type of protection systems;
(e) details of termination of membrane at drains, expansion joints, pipe penetrations, doorways, and cladding connections, including sealants at these and other locations; and
(f) specified live loads and allowances for superimposed dead loads.

6. Materials

6.1 Concrete

6.1.1 General

Concrete materials shall be in accordance with CSA Standard A23.1 for cast-in-place concrete and CSA Standard A23.4 for precast concrete, except as specified in Clauses 6.1.2 to 6.1.6.

6.1.2 Class of Exposure and Cementing Materials Content

6.1.2.1

Concrete in perimeter basement walls and nonstructural slabs-on-ground shall be in accordance with the class of exposure requirements of Table 8 of CSA Standard A23.1.

Note: *If the perimeter basement wall is exposed to deicing chemicals, then class of exposure C-1 concrete should be used.*

6.1.2.2

All other concrete shall conform to class of exposure C-1 in Table 8 of CSA Standard A23.1, and shall have a minimum cementing materials content of 320 kg/m^3.

Note: *Class of exposure C-1 concrete should normally be used in structural elements such as floors, columns, shear walls, stair walls, spread footings, and other elements that deicing chemicals can reach.*

6.1.3 Chloride Content

The water-soluble chloride ion content in the concrete before exposure shall not exceed 0.06% by mass of the cementing material.

Note: *Aggregates in some geographic areas, such as Southern Ontario, have high chloride contents such that the chloride content of the concrete will exceed the limit. This is acceptable if it can be shown that no corrosion problems have occurred in the past in concrete structures made with similar materials and exposed to similar conditions.*

6.1.4 Admixtures Containing Chloride

Calcium chloride, or any admixture formulation containing chloride, shall not be used.

6.1.5 Superplasticizing Admixtures

When superplasticizing admixtures are used, the maximum slump as defined in Clause 14.2.3 of CSA Standard A23.1 shall be determined before addition of the admixture.

6.1.6 Aggregate

6.1.6.1

The aggregate abrasion loss specified for exposure classification C-1 in Table 3 of CSA Standard A23.1 shall not exceed 35%.

6.1.6.2

The acceptance or rejection of aggregate for concrete that will be subject to a freeze-thaw environment in service shall be based on its past performance in concrete under similar conditions, or when tested in accordance with one or more of ASTM Standards C666, C671, and C682.

6.1.6.3

Low-density aggregate shall be either expanded shale or expanded clay.

6.2 Reinforcement, Support Chairs, and Ties

6.2.1

When epoxy-coated bars are used, the coating shall conform to ASTM Standard D3963/D3963M, and the bar shall be coated with a primer or a conversion coating to improve adhesion of the epoxy to the bar. The epoxy coating applicator shall be certified under the Concrete Reinforcing Steel Institute's Voluntary Certification Program for Fusion Bonded Coating Applicator Plants.

6.2.2

To avoid steel embrittlement, epoxy-coated bars shall not be bent or welded after coating.

6.2.3

Bar support chairs for uncoated bars shall be either plastic, plastic-tipped for at least the bottom 25 mm, or precast concrete blocks.

6.2.4

Bar support chairs shall be plastic where epoxy-coated bars are used or where the present or future implementation of a soffit cathodic protection system is contemplated.

6.2.5

Plastic ties or plastic-coated wires shall be used for tying post-tensioning tendons and epoxy-coated reinforcement.

6.2.6

Patching material for areas where the epoxy coating is damaged or omitted shall be in accordance with the coating manufacturer's requirements.

6.3 Dissimilar Metals

The use of dissimilar metals shall be avoided where possible. If unavoidable, the metals shall be electrically isolated.

6.4 Exposed Hardware, Embedded Materials, and Railings

6.4.1 Exposed Materials

Exposed connectors and other exposed hardware shall be galvanized or protected from corrosion by an effective and durable coating, or shall be made of corrosion-resistant material.

6.4.2 Embedded Materials

Embedded materials used for floor drains, pipes, sleeves, and other hardware shall be
(a) nonmetallic; or
(b) a low-copper aluminum alloy as designated in CSA Standard CAN3-B79, or an equally corrosion-resistant metal, and coated on surfaces in contact with concrete to prevent galvanic corrosion with steel reinforcement (see Clause 6.3) and chemical reaction between aluminum and concrete; or
(c) protected against the corrosive effects of deicing chemicals by an effective and durable coating.

6.4.3 Railings

Railings and their fastenings exposed to moisture shall be corrosion resistant or shall be coated with an effective and durable coating.

6.5 Welded Steel Wire Fabric

Welded steel wire fabric shall be supplied in flat sheets, or in rolls if the rolls are straightened before placing to lie flat within ±10 mm.

6.6 Post-Tensioning Materials

6.6.1

Bonded and unbonded post-tensioning tendons shall conform to CSA Standard A23.1, Clause 25.

6.6.2

Coating for unbonded tendons shall meet the Post-Tensioning Institute *Specification for Unbonded Single Strand Tendons* in aggressive environments.

6.6.3

For unbonded tendons, the entire assembly including the anchorages and couplers shall be electrically isolated from the reinforcing bars.

6.6.4

The anchorage and coupler surfaces in contact with the concrete shall be coated with an effective and durable dielectric coating.

6.6.5

Grout for filling stressing pockets for tendons shall conform to Clause 25.3.5 of CSA Standard A23.1.

6.6.6

Grout for bonded post-tensioning tendons shall conform to Clause 25.5 of CSA Standard A23.1.

6.7 Structural Steel

Structural steel shall conform to the steel specifications referenced in CSA Standard CAN/CSA-S16.1.

6.8 Steel Deck

Steel floor deck shall have a minimum hot dip galvanized coating of Z275 (275 g/m^2) in accordance with ASTM Standard A525M.

7. Design Requirements

7.1 Code and Reference Standards

The design shall be in accordance with the *National Building Code of Canada* and CSA Standards A23.3 and CAN/CSA-S16.1, except as hereinafter specified. In the event of conflict between this Standard and the referenced Standards, this Standard shall take precedence.

7.2 Volume Change Effects

The design shall take into account volume change effects due to temperature, shrinkage, creep, and elastic shortening.

Note: *Information on volume change effects may be found in the Canadian Prestressed Concrete Institute Publications* Metric Design Manual Precast and Prestressed Concrete, *and* Prestressed Concrete Basics, *M.P. Collins and D. Mitchell.*

7.3 Protection Systems and Concrete Cover

7.3.1 Acceptable Systems

Protection systems shall be as specified in Table 1, except as otherwise permitted by Clause 7.3.2.

Note: *The protection systems are considered adequate when used in conjunction with a regular comprehensive maintenance program. Maintenance information is given in Appendix E.*

7.3.1.2 Low-Permeability Concrete

Low-permeability concrete shall mean a concrete mix with a water/cementing materials ratio not exceeding 0.40, and an average coulomb rating not exceeding 1500 based on a test of 3 specimens tested in accordance with ASTM Standard C1202. The qualification of low-permeability concrete mix shall be established prior to construction. Concrete samples shall be moist cured at 23°C ± 2°C for 28 days prior to testing. The tests shall be conducted on concrete mixes without corrosion inhibitors and on concrete samples without applied sealers or membranes. The constituents and proportions of the qualified concrete mix shall not be changed without the designer's approval.

Note: *At the designer's discretion, coulomb data at ages up to 91 days may be acceptable, provided that the concrete in the structure will not be exposed to deicing salts until later ages. Concrete containing fly ash or supplementary cementing materials typically exhibit reduced coulomb ratings at 56 or 91 days of age.*

7.3.1.3

Reinforcement in brackets, corbels, and ledges shall be protected by epoxy-coating, corrosion inhibitor, or low-permeability concrete.

7.3.2 Alternative Systems

7.3.2.1

Alternative corrosion protection systems are permissible, provided that
(a) provision is also made to protect against water leakage; and
(b) they provide at least the same degree of protection against corrosion as the systems listed in Table 1.

7.3.2.2
Where the present or future implementation of a cathodic protection system is contemplated, all reinforcement and embedded metal items shall be electrically connected, and surface mounted metal hardware shall be either electrically connected or satisfactorily isolated to avoid stray current corrosion. The electrical continuity shall be verified before the concrete is placed.

7.3.3 Stairs
The following protection systems shall be used:
(a) for concrete stairs: all reinforcement epoxy-coated, or corrosion inhibitor in the concrete;
(b) for steel stairs: galvanized steel, or steel with a durable and effective coating system.
Note: *Steel stairs with concrete-filled treads should not be used if they are exposed to weather or subject to frequent washdowns, as water can collect under the fill and corrode the treads.*

7.3.4 Normal Exposure
Normal exposure in Table 1 includes areas not classified as severe exposure. Normal exposure includes areas such as parking areas and adjacent drive aisles, and landscaped areas excluding slabs under surface roadways and walkways.

7.3.5 Severe Exposure
Severe exposure in Table 1 includes the following:
(a) for thick traffic deck waterproofing membrane systems: areas of severe chloride exposure, such as areas of application of deicing chemicals to melt snow or ice, and truck access areas. These include areas such as truck loading or unloading areas, truck access ramps, and grade level roadways and access routes;
(b) for thin traffic deck waterproofing membrane systems:
    (i) areas of severe chloride exposure as specified in Item (a); or
    (ii) areas of heavy wear such as areas of frequent stopping and starting, turning areas, and areas subject to snowplough damage. These include areas such as entrance and exit ramps and helices, floor-to-floor ramps and adjacent turning areas, pay booth aisles, and roofs subject to snowploughing.

Notes:
(1) *Severe exposure protection may also be used wherever additional protection is considered desirable, such as areas difficult or abnormally disruptive to repair (eg, main entrance and exit areas) and areas over habitable space, or where owners wish to minimize maintenance costs.*
(2) *For a description of thick and thin traffic deck waterproofing membrane systems, see Appendix A.*
(3) *Typical areas of normal and severe exposure are illustrated in Figure H12 of Appendix H.*

7.3.6 Prestressed Elements for Table 1
Concrete elements shall be considered prestressed only if the following criteria are satisfied, after allowance for the effect of all restraints and long-term losses:
(a) The extreme fibre stress in tension at the top surface is less than $0.25\lambda\sqrt{f'c}$ under the sum of prestress and dead load, with or without specified live load, whichever is more critical (where λ is as defined in CSA Standard A23.3).
(b) The average prestress on the concrete cross section is not less than 1.4 MPa in each direction, except it is permissible for precast units not exceeding 3.8 m in width to be prestressed in the longitudinal direction only.

Table 1
Acceptable Protection Systems for Floors and Roofs

(See Clause 7.3.)

Concrete system	Acceptable protection systems	
Reinforced (nonprestressed) concrete roofs and floors		
(A1) Nonprestressed, normal exposure (Clause 7.3.4)	1	Membrane
(A2) Nonprestressed, severe exposure (Clause 7.3.5)	2	Membrane + top bars epoxy-coated*
	3	Membrane + corrosion inhibitor
Prestressed concrete roofs and floors		
(B1) Post-tensioned, bonded tendons with steel ducts	4	Membrane + top bars epoxy-coated
	5	Membrane + corrosion inhibitor
	6	Membrane + low-permeability concrete
(B2) Post-tensioned, unbonded tendons, and bonded tendons with non-metallic ducts	7	Protection systems 4, 5, or 6
	8	Corrosion inhibitor + all bars epoxy-coated†
	9	Low-permeability concrete + all bars epoxy-coated†
	10	Corrosion inhibitor + low-permeability concrete†
(C) Precast pretensioned, with or without cast-in-place topping	11	Membrane
	12	Corrosion inhibitor + top bars epoxy-coated
	13	Low-permeability concrete + top bars epoxy-coated
	14	Corrosion inhibitor + low-permeability concrete
	15	Sealer + corrosion inhibitor‡
	16	Sealer + low-permeability concrete‡
	17	Sealer + top bars epoxy-coated‡
	18	Protection systems 11, 14, 15, or 16 when uncoated welded steel wire fabric is used

(Continued)

Table 1 (Concluded)

**At areas of significant slope, such as ramps, where failure of the waterproofing membrane could cause leakage through joints and cracks and flow of chloride contaminated water along the slab soffit, consideration should be given to the use of epoxy-coated bottom bars as well as top bars in this system. See also Clause 7.4.2.6.*
†The use of a membrane shall be considered for post-tensioned floors. Refer to Appendix H.
‡Protective systems that include sealers should be used only where it can be reasonably assured that they will be monitored, and reapplied when necessary.

Notes:
(1) *The corrosion protection in Table 1 applies to bars, mesh, tendons, or ducts within 100 mm of the top surface of the concrete slab or, in the case of a bonded concrete topping, from the top of the topping unless otherwise indicated. Top bars means bars (including stirrups) within 100 mm of the top surface of the concrete slab or bonded concrete topping.*
(2) *Refer to Appendix C for information on corrosion inhibitors generally and calcium nitrite specifically. Refer to Appendix A for information on sealers and membranes. Refer to Clause 7.3.1.2 for low-permeability concrete.*
(3) *The various protection systems in Table 1 are not necessarily equal in effectiveness.*

7.3.7 Specified Concrete Cover

The specified concrete cover for reinforcement, tendon sheaths, ducts, and anchorages shall be in accordance with CSA Standards A23.1 and A23.4, except as follows:

(a) top bars, tendon sheaths, and ducts
- (i) concrete protected by waterproofing membrane ....40 mm;
- (ii) concrete not protected by waterproofing membrane ....50 mm;

(b) top mesh ....40 mm;
(c) bottom reinforcement, tendon sheaths, and ducts ....30 mm;
(d) reinforcement in vertical elements protected by a membrane extending 100 mm above the floor and down to foundation at the lowest floor, or by a sealer in accordance with Clause 7.3.11 .... 40 mm;
(e) the ratio of cover to the nominal maximum aggregate size shall be at least 1.5;
(f) the ratio of cover to nominal bar diameter d_b shall be at least..1.5, but need not exceed 60 mm.

Notes:
(1) *Where the exact positioning of reinforcement is difficult, it may be advisable to increase the specified cover to ensure adequate protection. For post-tensioning tendons, particular caution is warranted.*
(2) *If not protected as specified in Item (d), the covers in CSA Standard A23.1 for corrosive environments apply.*

7.3.8 Minimum Actual Concrete Cover

The slab and the reinforcement (including mesh), tendon sheaths, ducts, and anchorages shall be placed to obtain actual concrete cover within ±12 mm of the specified concrete cover.

7.3.9 Concrete Cover Measure

Concrete cover shall be measured to the base of reveals, grooves, and chamfers.

7.3.10 Membranes

7.3.10.1

Membranes shall meet the test requirements of ASTM Standard C957, or CGSB Standard CAN/CGSB-37.50, as applicable.

7.3.10.2
Membranes on slabs shall be turned up a minimum distance of 100 mm above the top of the wearing surface, at all vertical surfaces, including walls, balustrades, columns, curbs, pipes, and cladding.

7.3.10.3
Membranes shall be extended onto the flange of the body of floor drains to form a waterproof seal with the drain.

7.3.10.4
Where a membrane or nonbreathable sealer is applied to one surface of a concrete slab, the opposite surface shall be free to breathe.

7.3.10.5
Membranes on pedestrian or vehicle traffic surfaces shall be protected by a wearing course.

7.3.11 Sealers

7.3.11.1
A sealer shall be applied to vertical surfaces in any splash zones.
Note: *Splash zones are usually limited to areas exposed to rain or snow outside the garage, where temporary ponding can occur before water drains away.*

7.3.11.2
Where there is no membrane which extends up vertical surfaces in accordance with Clause 7.3.10.2, a sealer shall be applied to reinforced concrete walls, columns, and balustrades, up 600 mm from the top of the concrete slab.
Note: *See Appendix H, Figure H6.*

7.4 Joints

7.4.1 Construction Joints

7.4.1.1
Wherever possible, construction joints shall be located at high points of the floor, and the top of the slab shall slope away on each side.

7.4.1.2
The construction joint between pours shall be made in accordance with Clause 20.1.3 of CSA Standard A23.1.
Note: *Internal waterstops should generally be avoided where possible, because of the difficulty in properly consolidating the concrete adjacent to the waterstop. In some cases, internal waterstops may be desirable in slabs not covered by a membrane, such as stair slabs. If waterstops are used in post-tensioned slabs, they should be located above the tendons so that they do not trap water around the tendon.*

7.4.1.3
Top and bottom reinforcement shall be provided through construction joints in nonprestressed slabs over 130 mm thick, to limit the opening of the joint (due to temperature, shrinkage, and flexural stresses). The reinforcement shall be embedded not less than a development length each side of the joint.

7.4.2 Expansion Joints and Sliding Joints

7.4.2.1

Expansion joints and sliding joints shall be designed to accommodate anticipated short-term and long-term movements.

7.4.2.2

Wherever possible, expansion joints and sliding joints shall be located at high points of the floor, and the top of the slab shall slope away on each side.

7.4.2.3

Expansion joints and sliding joints shall be designed to prevent ingress of water, dirt, or materials that would reduce the effectiveness, or promote the deterioration, of components of the joint or structure.

7.4.2.4

Account shall be taken of horizontal forces that are transferred across sliding joints by friction, shear deformation of bearing pads, or by other actions.

7.4.2.5

Consideration shall be given to the effect of vehicular traffic and snowploughs on the exposed portion of expansion joints.

7.4.2.6

Consideration shall be given to additional corrosion protection to reinforcement at soffits and vertical surfaces adjacent to expansion joints, to protect against corrosion due to possible joint leakage.

7.4.3 Control Joints in Concrete Toppings

7.4.3.1

The layout of control joints shall be shown on the design drawings.

7.4.3.2

Control joints in bonded concrete toppings shall be located adjacent to all vertical surfaces, over joints between precast concrete components, and at other anticipated crack locations.

7.4.3.3

Control joints in unbonded concrete toppings shall be at sufficiently close spacing to reduce stresses due to temperature and shrinkage effects to acceptable limits. Control joints shall be located to relieve stresses at re-entrant corners, and to free unbonded toppings from restraining elements.

7.4.3.4

Control joints in bonded concrete toppings shall be tooled or formed, not sawn.

7.4.3.5

Control joints in bonded and unbonded concrete toppings shall be sealed with flexible joint sealant to prevent the ingress of water.

7.5 Slopes and Drainage

7.5.1

The draining surface shall have sufficient slope, before and after long-term deflection, to provide positive flow of water to drains. There shall be no horizontal areas.

7.5.2

The draining surface shall have a design slope of not less than 2%. At non-ramped floors, the slope to drains shall be not less than 2% in the two principal directions. Where necessary to compensate for short-term and long-term deflection, cambers shall be provided, or a larger design slope shall be used.

7.5.3

Drainage patterns shall be such that water does not flow over the floor edge onto columns, walls, beams, or other structural members.

7.5.4

The draining surface of suspended floors and slabs-on-ground shall slope away from vertical surfaces, and from joints and tendon anchorages.

Note: *See Appendix H, Figures H4, H5, and H6.*

7.5.5

Stair landings and elevator lobbies that open directly onto parking floors shall be above the adjacent floor surface. Stair landings, including intermediate landings, shall be sloped for drainage.

7.5.6

Drains shall be located at all low points. At ramped parking floors, drain(s) shall be provided at the bottom of each ramped floor.

7.5.7

Drains shall have hinged grates with a minimum drainage area of 33 000 mm^2, and a readily accessible sediment bucket.

7.5.8

Where a waterproofing membrane is used on the floor, drains shall have a flange to receive the membrane in accordance with Clause 7.3.10.3.

7.5.9

Where water can penetrate to the membrane level, drains shall have secondary drainage openings at the membrane level. The secondary drainage openings shall be large enough not to be easily obstructed.

Note: *See Appendix H, Figure H10.*

7.5.10

The tops of the floor drains shall have an integral 6 mm anti-ponding feature, or be set at least 6 mm below the floor surface, so that there is no ponding around the drain.

7.5.11
Gratings shall be designed for wheel loads in accordance with the *National Building Code of Canada.*

7.5.12
Drains shall not be located within 1 m of a prestressing anchorage.

7.5.13
Adequate exterior drainage shall be provided around perimeter walls of below grade garages.

7.6 Services

7.6.1
Metal electrical conduits, junction and fixture boxes, and other services that can corrode shall not be embedded within the concrete slab or topping.

7.6.2
Conduits, whether metal or otherwise, shall not be embedded in toppings.

7.6.3
A water supply shall be provided to permit periodic washdown of the parking structure.

7.7 Heating Cables and Pipes
Heating cables, or pipes, and connecting components shall be corrosion resistant, or protected against corrosion.

7.8 Precast Concrete Slabs with Voids

7.8.1
Precast concrete slabs with voids shall have effective drainage holes at low points.

7.8.2
Where the minimum concrete thickness over the void is less than 90 mm, a waterproofing membrane or a bonded concrete topping shall be provided. The topping shall be at least thick enough to provide the reinforcement cover required by Clause 7.3.7, including at corner lap areas of mesh, but not less than 50 mm thick.

Note: *Greater topping thickness may be required to compensate for cambers, or for corner laps of reinforcing mesh.*

8. Additional Requirements for Cast-in-Place, Post-Tensioned Concrete Construction

8.1 Anchorages and Couplers
Post-tensioning anchorages and couplers shall not be located in valleys of the drainage slopes, or anywhere ponding is likely to occur if drainage should become blocked.

8.2 Stressing Pockets
Stressing ends of unbonded tendons shall terminate in a stressing pocket filled with grout as specified in Clause 25.2.14 of CSA Standard A23.1.

8.3 Joints

8.3.1

Joints in a wall, or between a floor and a wall, that could allow penetration of water to a tendon, sheath, stressing pocket grout, coupler, or anchorage shall be made watertight.

8.3.2

Tendons sheaths extending through construction joints shall be protected against damage at the joint surface during construction by an additional split sheath 300 mm long centred on the joint, spirally double taped, and placed with the slit facing down.

8.4 Proximity to Drains

Tendons shall not be located within 300 mm of the edge of drains.

8.5 Qualifications

8.5.1

The foreperson supervising the installation of post-tensioning tendons shall be certified in accordance with a certification program acceptable to the regulatory authority.

8.5.2

Inspectors carrying out inspections in accordance with CSA Standard A23.1, Clauses 25.2.10 and 25.2.11, shall be certified in accordance with a certification program acceptable to the regulatory authority.

9. Additional Requirements for Steel Structures

9.1 Curbs

9.1.1

A concrete curb shall be cast around steel columns at suspended floors and at grade level.

9.1.2

Where curbs are not cast monolithically with the floor slab, the slab surface shall be cleaned by sandblasting or an equivalent method, a cement slurry or bonding agent shall be applied to achieve good bond, and a sealant shall be provided at the junction of the bottom of the curb with the slab.

9.1.3

The top of the curb shall be sloped to shed water away from the steelwork.

9.1.4

The curb shall be reinforced to control cracking. If no membrane turns up the vertical surface of the curb, the reinforcement shall be epoxy-coated, or the concrete shall contain a corrosion inhibitor.

9.1.5

A sealant shall be provided at the junction of the top of the curb and the steelwork.

9.2 Columns, Base Plates, and Anchor Bolts

Column base plates, anchor bolts, and the portion of steel columns located below soil-supported floors shall be protected against corrosion.

9.3 Steel Deck

9.3.1

Steel deck shall be used only as a stay-in-place form and shall not be designed to provide tensile reinforcement to the floor slab.

Note: *See Appendix H, Clause H7.3.10.4.*

9.3.2

The specified concrete cover slab thickness over the steel deck flutes shall be a minimum of 90 mm, but not less than required for strength and serviceability.

9.4 Concrete Encased Structural Steel

For concrete encased structural steel members, the minimum specified concrete cover to the structural steel shall be 70 mm, and the concrete shall be reinforced.

9.5 Water Accumulation

There shall be no inaccessible locations, such as ledges or crevices, where water can collect on steel members.

Note: *Members with flanges should not be used in areas where eventual leakage of salt-contaminated water is likely, such as adjacent to expansion joints.*

9.6 Painting

9.6.1

Exposed structural steel, other than weathering steel, shall be painted.

9.6.2

Painting of interior and exterior structural steel shall meet or exceed the requirements of CGSB Standard 85-GP-11M. In applying the requirements of this Standard to exposed steel in open-air structures near the sea, continuous exposure to a marine environment shall be assumed.

9.6.3

Steel to be painted shall be detailed to eliminate inaccessible areas.

9.7 Weathering Steel

Weathering steel shall not be used in enclosed parking structures.

Note: *Weathering steel does not provide protection against corrosion due to chlorides.*

9.8 Crack Control Over Girders

Sufficient top reinforcement shall be provided in concrete slabs over girders to limit cracks to a width compatible with the membrane's crack bridging properties.

10. Construction

10.1 Reference Standards
The construction shall be in accordance with CSA Standards A23.1 and CAN/CSA-S16.1, except as hereafter specified. In the event of conflict between this Standard and the referenced Standards, this Standard shall take precedence.

10.2 Elevations
Prior to placing concrete, the elevations of forms and screeds shall be checked to verify drainage slopes and cambers.

10.3 Deicing Chemicals
Corrosive deicing chemicals shall not be used on the concrete formwork, or flatbeds of trucks or other containers used to deliver aggregate, or anywhere else in the shipping, storage, or construction process.

10.4 Bar Supports and Side Spacers

10.4.1
Bar support chairs shall be sufficient in number, strength, and stability to maintain the position of the reinforcement within the specified tolerances for the full length of the reinforcement. If spacer bars are used to support the reinforcement, they shall be not less than No. 15.

10.4.2
Side spacers shall be provided to vertical reinforcement.

10.4.3
Uncoated metal tie wires securing reinforcement shall not extend more than 5 mm into the concrete cover.

10.5 Epoxy-Coated Bars and Coated Prestressing Anchorages

10.5.1 Handling

10.5.1.1 Epoxy-Coated Bars
Epoxy-coated bars shall be handled as follows:

(a) Bars shall be unloaded and handled only with systems with padded contact areas.

(b) Bars bundles shall be lifted with a strong back, spreader bar, multiple supports, or a platform bridge, to minimize bar-to-bar abrasion.

(c) Bars shall be stored above ground on timbers or other suitable protective cribbing, spaced to prevent sags in the bundles that could cause coating damage, and of sufficient size to prevent contact of the bars with the ground.

(d) Stacks of bundles of straight bars shall have adequate blocking to prevent contact between the layers of bundles.

(e) Uncoated bars or other materials shall not be piled on top of epoxy-coated bars.

(f) Bars shall not be dropped or dragged.

(g) If the exposure time of partially embedded, exposed, or stored bars is expected to exceed 30 days, they shall be covered with opaque polyethylene or other equivalent protective material draped over the side of the bundle, adequately secured, with provision for air circulation to prevent condensation.

10.5.1.2 Coated Prestressing Anchorages

Coated prestressing anchorages shall be handled to avoid damage, and shall not be dragged or dropped.

10.5.2

Prior to installation, and again after installation, bars and anchorages shall be inspected for visible coating damage and uncoated areas, to identify bars or anchorages to be rejected or repaired.

10.5.3

Bars with coating damage totalling more than 1% of the surface area in any 1 metre length shall be rejected. Anchorages with coating damage totalling more than 1% of the surface area shall be rejected.

10.5.4

Any coating damage or uncoated areas detected on bars or anchorages that are accepted under Clause 10.5.3 shall be repaired.

10.5.5

Any rust shall be removed before repair.

10.5.6

Repair of epoxy coating shall not be carried out when the temperature of the steel or ambient air is 5°C or below, or when moisture is present on the steel.

10.5.7

All coating damage on bars and anchorages shall be repaired. Repair materials and procedures shall be in accordance with the coating manufacturer's instructions.

Notes:

(1) *It has been found that the number of defects in the coating can have a significant effect on its performance.*

(2) *Coating repairs should be completed before permission to place concrete is given.*

10.5.8

Plastic-coated vibrators shall be used to consolidate concrete reinforced with epoxy-coated bars.

10.6 Tendons

10.6.1

During construction care shall be taken to avoid damage to the sheathing as a result of handling and placing of post-tensioning materials, reinforcing steel, and other construction activities.

10.6.2

Tendon sheaths shall be examined immediately upon placing in formwork, and damaged areas of sheaths shall be immediately repaired by restoring the coating in the damaged area and wrapping with moisture-proof tape, spirally wrapped around the sheath to provide at least two layers of tape, and a watertight repair.

Notes:
(1) *A mirror may be required to examine the underside of the sheath.*
(2) *Special-purpose tapes are available for repairing sheaths. Cloth duct tape which is not moisture-proof is not recommended.*

10.6.3
Tie wires shall not be tightened to the extent that the tendon sheath is damaged during installation or tendon stressing.

10.6.4
The high points of all tendons shall be checked for conformance to specified concrete cover prior to concrete placement.

10.7 Slab Finishing
The slab surface shall not be overworked.
Note: *Multiple passes of power floats or trowels can create a fine paste that is subject to scaling. A single pass is not detrimental.*

10.8 Curing

10.8.1
The concrete shall be protected from premature drying and extremes of temperature, and shall be wet-cured at a temperature of at least 10°C for a minimum period of 3 days.

10.8.2
Curing compounds shall not be used on the top surface of slabs.

10.9 Form Removal and Reshoring

10.9.1
Form removal and reshoring shall not commence until the in-place strength of the concrete is at least 75% of its specified 28-day strength, or as otherwise specified by the designer.

10.9.2
Test methods shall be used that provide a realistic assessment of the strength of the concrete in the part of the structure under consideration.

10.9.3
Slabs being stripped shall be immediately reshored so that no large areas remain unshored, unless otherwise specified by the designer.
Note: *See CSA Standard A23.2, Appendix A.*

10.9.4
Additional shores shall be provided if required to prevent temporary overloading of the slab.

10.10 Vehicles
No vehicles which would track in road salts shall be allowed on the structure until the membrane system or sealer is installed and cured.

10.11 Acids

10.11.1

Acid shall not be used as a surface preparation method prior to installation of a moisture barrier.

10.11.2

Acid shall not be used on cast-in-place prestressed structures.

10.11.3

Acid can be used on the concrete surfaces of precast concrete structures to provide an acid-etched exposed architectural finish, provided the process is under plant-controlled conditions, exposed reinforcement and hardware are protected from contact with the acid, and the acid is thoroughly washed off.

10.12 Moisture Barriers

The moisture barrier manufacturer's recommendations shall be followed with regard to ambient air temperature and relative humidity, substrate temperature, preparation and moisture content, treatment of cracks and construction joints, rate of application, curing, and protection.

Notes:

(1) *Further information concerning moisture barriers is provided in Appendix A.*

(2) *For Dryness of Surface Test Method, see Clause 3.4.5.2 of ACI 515.1R.*

10.13 Sealants

The sealant manufacturer's recommendations for treatment of cracks, control joints, and construction joints shall be followed.

11. Inspection and Testing

11.1

Work on the site shall be inspected and materials shall be tested to verify compliance with this Standard.

Note: *Proper workmanship and supervision are critical requirements for achieving the construction of a durable parking structure. Appendix D includes checklists of recommendations for the contractor's quality assurance procedures and for verification procedures to be specified by the designer.*

12. Maintenance

The owner shall be provided with a maintenance program to sustain the durability of the structure. The maintenance program shall include

(a) cleaning;

(b) inspection and repair of the structure, protection systems, and drainage;

(c) recommendations for snow-removal equipment and procedures to minimize damage; and

(d) recommendations for observed conditions which require inspection by a professional engineer.

Notes:

(1) *See Appendix E, Maintenance, and Appendix F, Responsibilities.*

(2) *A comprehensive ongoing inspection and maintenance program is essential to achieve the intended durability. Failure to carry out an inspection and maintenance program may result in premature deterioration of the structure. Appendix E contains maintenance recommendations.*

Appendix A
Moisture Barriers

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

A1. General

A1.1

Moisture barriers can substantially reduce the rate of absorption of moisture and contaminants into concrete, thereby reducing the rate of reinforcing bar corrosion and concrete deterioration. (See Reference (1) in Clause A6).

There are several generic types of moisture barriers in use. Each generic type comprises many products encompassing a wide range of effectiveness.

The basic types addressed herein are membranes and sealers.

A1.2 Membranes with Traffic Wearing Course

A1.2.1 General

Membrane systems, if properly formulated, installed, and maintained, can achieve complete waterproofing of the concrete surface.

The elasticity of membranes allows them to bridge narrow cracks. A disadvantage is that evaluation of the concrete deck condition is more difficult and uncertain.

A1.2.2 Thin Traffic Deck Waterproofing Systems: Elastomeric Membranes with Traffic Wearing Course

These systems consist of

(a) a primer to enhance adhesion to the concrete;

(b) a fluid-applied elastomeric synthetic rubber (polyurethane or neoprene) membrane; and

(c) a wearing course to protect the membrane from the traffic.

The wearing course usually consists of a fluid-applied modified epoxy or polyurethane top coat. Aggregates, generally mineral, are broadcast into the wet wearing course to improve wear resistance, abrasion resistance, and traction. Selection of aggregate should follow the manufacturer's recommendations.

These systems are termed thin systems because the total thickness of membrane and the wearing course is less than approximately 2 mm. Additional thicknesses of the wearing course or larger aggregates, or both, are often used in heavy wear areas such as ramps, turning lanes, ticket and pay booth areas, etc. These systems are vulnerable to damage by snowplough blades. Rubber-edged plough blades reduce damage.

A properly formulated and installed thin membrane should meet the minimum test criteria set out in ASTM Standard C957.

ASTM Standard C957 includes procedures and acceptance criteria for a number of traffic bearing membrane properties. It is intended for use with thin membranes. The tests are summarized in Table A1. In addition to the substrate specified, the Standard permits the specification of other substrates on which the tests can be carried out.

Experience has shown that membranes passing the ASTM C957 tests do not necessarily perform well in actual use. The record of performance of a system should also be investigated, particularly with respect to the special conditions of exposed roof parking slabs.

There are other tests of importance that are not covered by ASTM C957, such as impermeability to chlorides and skid resistance. There is also some concern among waterproofing membrane manufacturers that some of the test procedures are not appropriate. Nevertheless, the Standard provides a basis of reference for comparison of different membranes, and can be useful if it is augmented by other relevant tests.

It is generally considered good practice that the *in situ* bond strength of the membrane to the concrete substrate, and the intercoat adhesion of the total membrane and wear course system, be at least 1.0 MPa.

Table A1
Summary of ASTM Standard C957

Test		Component	Limit
1	Weight loss	Base coat*	40% maximum
2	Low temperature flexibility & crack bridging	Total system (primer, base and top coat, aggregate)	Basecoat should bridge 1.6 mm wide crack
3	Adhesion-in-peal after water immersion	Base coat + primer	875 N/m minimum on concrete
4	Chemical resistance	Base coat and top coat tested separately	Minimum tensile strength retention: 70% in water; 70% in glycol; 45% in mineral spirits
5	Weathering (ultraviolet) resistance and recovery from elongation	Entire system excluding aggregate	Average recovery from elongation 90% minimum; average tensile retention 80% minimum; average elongation retention 90% minimum
6	Abrasion resistance	Entire system excluding aggregate	50 mg maximum weight loss after 1000 cycles with 1 kg weight

**Top coats and primers should also be tested, but they need only meet manufacturer's specification.*

A1.2.3 Thick Traffic Deck Waterproofing Systems: Membranes Covered by Mastic Asphalt, Asphaltic Concrete, or Concrete Topping

These systems usually consist of a bonded, hot or cold applied, rubberized asphalt membrane, or a preformed adhesive sheet membrane, overlaid with a wearing course which protects the membrane. The wearing course usually consists of either mastic asphalt, asphaltic concrete, or concrete topping.

These systems are termed thick systems because the total thickness generally exceeds 15 mm; the membrane thickness is normally in the order of 1.5 mm to 5 mm in thickness, and the wearing course in the order of 15 mm if of mastic asphalt, 25 to 40 mm or more if of asphaltic concrete, and 75 mm to 90 mm or more if of concrete. In some cases rigid insulation is placed between the concrete topping and the membrane.

A properly formulated and installed membrane will be highly impervious and have crack bridging capability. However, because the membrane is concealed by the wearing course, it is sometimes difficult to locate the source of leaks should they develop.

Reference Standards for asphaltic materials and their application are
(a) CAN/CGSB-37.50, *Hot Applied Rubberized Asphalt for Roofing and Waterproofing;*
(b) CAN/CGSB-37.51, *Application of Hot Applied Rubberized Asphalt for Roofing and Waterproofing;*
(c) CAN/CGSB-37.65, *Mastic Asphalt (Hot Process) for Flooring; and*
(d) CAN/CGSB-37.68, *Mastic Asphalt (Hot Process) for Waterproofing.*

(a) Mastic Asphalt Wearing Course

A mastic asphalt wearing course will resist water ingress, thereby imparting water resistance additional to that inherent in the membrane, provided the mastic remains crack-free and any control joints are maintained in a sealed condition.

Mastic asphalt should be formulated to adequately distribute wheel loads and minimize cracking.

The manufacturer should be consulted regarding the suitability of mastic asphalt for use in areas exposed to the heat of the sun, such as roof decks, and for special requirements for stability and skid resistance on sloped surfaces.

(b) Asphaltic Concrete Wearing Course

Asphaltic concrete is permeable to salt-laden water. This water can collect at the interface of the membrane and wearing course, where deicing salts will precipitate after evaporation of the water. This unavoidable condition should cause no harm as long as the membrane remains effective.

Care should be exercised to prevent undue damage to the membrane by the coarse aggregate in the wearing course.

Asphaltic concrete should be formulated and compacted to have adequate stability on sloped surfaces and to distribute wheel loads adequately, without dishing, rutting, or corrugating, and should be adequately cured before traffic is allowed.

(c) Concrete Topping

Concrete topping should be installed with closely spaced control joints. Protection board should be installed on top of the membrane to protect it from damage during concrete placing and to minimize stress on the membrane from thermal movement of the topping. Reinforcement which can corrode should generally be avoided in separate concrete toppings, provided wheel loads do not cause excessive stress.

All control joints, construction joints, and perimeter joints in toppings should be caulked to minimize ingress of water under the topping which may freeze and heave the topping. Ingress of grit into joints, combined with thermal movements, can lead to progressive widening of the joints. As a consequence, in some cases the toppings have pushed against and damaged the perimeter parapets.

If a topping is placed on insulation, the design of the topping to resist wheel loads should account for the elasticity of the insulation. The topping design will likely determine the strength and elastic properties of the insulation to be used. Insulation manufacturers have technical guidelines for these designs, and should be consulted (the manufacturer's recommended allowable compressive stress under vehicle wheel loads may be less than the uniform bearing value given in published catalogues). The insulation should be a moisture-resistant material such as extruded expanded polystyrene (expanded polystyrene that is not extruded is not moisture resistant).

A1.3 Concrete Sealers

A1.3.1 General

Sealers have been used on concrete for many years with varying degrees of success. There are a large number of available products of many different chemical types. Sealer performance is dependent upon the physical properties of the concrete, exposure conditions, surface preparation, and application method.

Sealers are less effective moisture barriers than membranes, but their cost and ease of application may be an advantage in some cases where installation of a membrane is not mandatory. The need for monitoring and future periodic surface preparation and reapplication should be taken into account.

Sealers have a limited ability to seal cracks. Cracks that form after the application of a sealer will not be sealed. Periodic reapplication of the sealer may improve sealing performance at newly formed hairline cracks less than about 0.1 mm wide.

Sealers are not recommended in areas of poor drainage. Linseed oil was recommended for concrete many years ago, prior to the introduction of air-entrained concrete, to improve freeze-thaw durability. There is some evidence that if it is applied at very frequent intervals (annually), it may be effective in reducing chloride ingress. Since such frequent application can seldom be assured, the use of linseed oil is not recommended for protection against chloride ingress.

Test programs for sealers are reported in References (2) and (6).

A1.3.2 Coatings and Penetrants

Sealers can generally be classified either as "penetrants" or film-forming surface "coatings".

Penetrants are usually less viscous, somewhat more compatible with existing moisture in the concrete, more breathable, and generally have greater durability in areas of abrasive wear, than coatings. Penetrants create a hydrophobic (water repellent) condition. Penetrants do not reduce surface skid resistance, which is especially important at ramps and higher speed areas. Penetrants can be resealed with many coating type sealers, but an existing coating type sealer cannot be resealed with a penetrant because the penetrant must be absorbed by the concrete to be effective.

Penetrants should be tested for alkali resistance, which is a measure of durability in the concrete environment.

Tests indicate that some penetrants can reduce the safety factor against scaling if moisture enters the concrete, and this property should be evaluated when resistance to scaling is specifically required. Scaling is usually a problem only with concrete not having a proper air-void structure. Scaling resistance may also be reduced, even with air-entrained concrete, if the concrete contains supplementary cementing materials (slag, fly ash, and silica fume).

Silane is a penetrant that is generally resistant to ultraviolet radiation and other mechanisms of degradation. Siloxane, a more economical version of silane, creates good hydrophobic action but does not generally penetrate as well.

A2. Selection of Moisture Barrier System

A2.2 General

No single system can realize, under various possible exposure conditions, all the desired performance characteristics such as waterproofing, crack bridging, resistance to abrasion and damage (including snowplough damage), longevity, and ease of maintenance and renewability.

The weaknesses and strengths of the different systems have been indicated in Clause A1. If required, specific properties of a system can be improved, for example, by increasing the thickness of the elastomeric membrane, selecting a more durable wearing course, etc.

Product warranty usually does not cover the consequential damages caused by failure of the moisture barrier, or the losses incurred by the closure of the parking facility. For this reason, when selecting a product, undue reliance should not be placed on the product warranty.

The following should be considered when selecting a moisture barrier system:

(a) Exposure to elements:

(i) enclosed or open air garage;

(ii) heated or unheated;

(iii) roof deck and exterior ramps exposed to sun and snow; and

(iv) roof deck snow clearing with snowplough.

(b) Usage:

(i) short-term parking (such as commercial parking) generally leads to a more corrosive environment than long-term parking;

(ii) occupied space directly below parking level; and

(iii) degree of inconvenience that would be caused if the parking facility were closed for repairs (eg, single lane entrance without alternate access, hospital, etc).

Consideration should be given to the performance of specific systems in similar applications, and to any unusual or demanding maintenance or monitoring activities which might be required in order to sustain the manufacturer's warranty. In evaluating existing installations, care should be taken to determine if the manufacturer has since changed the system formulation.

Information for the evaluation of the performance of a moisture barrier in the parking deck environment can be obtained from records of condition surveys of parking structures in which the protection system was installed at the time of construction. Experiences with moisture barriers installed some years after construction may not be relevant.

Useful information can also be obtained from owners and maintenance personnel.

A2.3 Membrane Systems

A2.3.1

Membrane systems should have the following properties under all expected environmental conditions:

(a) Impermeability — The membrane, in the thickness specified for the project, should prevent ingress of water into the substrate;

(b) Adhesion — The membrane should form a strong and lasting bond to the concrete substrate, between membrane coats, and with the wearing course, that will be durable under exposure to environmental conditions and vehicular traffic, including sudden braking, high-speed turns, acceleration, and turning wheels of stationary vehicles during parking manoeuvres;

(c) Mechanical properties — The membrane and wearing course should be able to sustain, without damage, the stresses imposed on it by vehicular traffic and dimensional changes in the structure. The membrane should be able to span cracks up to 1.6 mm wide that may occur after its installation.

(d) Durability — The degradation of physical properties during the design service life of the membrane should not adversely affect its performance. The membrane should perform for a significant portion of the design service life of the structure, before major repair of the membrane, or replacement, is required. With some systems, maintenance will be required in areas of heavier wear.

A2.3.2

The selection of a thin or thick membrane system should be made early in the planning so that proper details can be developed and the structural design can account for the weight and headroom implications. Alternatively, the structural design can be based on a thick (and somewhat heavier) system. The added cost of the structure for the extra weight of the heavier system is generally very small.

A2.4 Concrete Sealers

A number of laboratory and field tests have been carried out which confirm the existence of a wide variation in the performance of sealers, even within a generic group. (Some of these reports have been referenced in Clause A6.) Some sealers enhance certain properties of the concrete while degrading others. Therefore, only sealers with a proven performance in field applications and laboratory testing on concrete of similar mix design to that for the structure should be considered.

Alberta Transportation and Utilities (AT&U) has developed a prescreening process in which sealers are evaluated by laboratory tests, followed by *in situ* tests of products to verify compatibility with the specific concrete, to optimize performance, and to develop proper coverage rates. The sealers are classified as Type 1a, 1b, and 1c according to the reduction in weight gain of sandblasted specimens immersed in water. Table A2 has been adapted from the AT&U tests as a guide for the selection of a sealer.

The AT&U test, carried out on a standard reference concrete of 0.5 water/cementing materials ratio, measures the performance before and after abrasion, as simulated by sandblasting the specimen.

The sealer quality is judged by the reduction of moisture absorption by the sealer-coated specimen, with respect to that of uncoated control specimens, on immersion in water for 5 days. (Prior to testing, Type 1a specimens are conditioned to 55%, and Types 1b and 1c to 70%, of their saturated moisture content.) The minimum sealer performance (reduction of absorption) requirements are given in Table A2.

Table A2
Minimum Required Sealer Performance
for AT&U Approval of Type 1 Penetrating Sealers

	Minimum reduction in weight gain, %		
Sealer type abrasion	**Before abrasion**	**After 1st abrasion**	**After 2nd abrasion**
1a	82.5	75.0	n/a
1b	82.5	82.5	n/a
1c	90	90	90

Three 5-day sealer immersion tests are performed on each set of 3 cubes tested, as follows:

(a) before abrasion, by comparing weight gain of treated and untreated cubes during 5-day immersion test;

(b) after abrasion, by abrading surfaces of the same cubes, and repeating 5-day immersion test; and

(c) test for alkali resistance by placing the same cubes in potassium hydroxide solution for 21 days, then retesting in the 5-day sealer immersion test. Sealer performance should be within 3% of that measured after the abrasion performance test.

Breathability is measured by comparing the evaporative weight loss between sealed and unsealed cubes during a 14-day period beginning at the time the sealer is applied. For Type 1b and Type 1c sealers, the minimum vapour transmission requirement is 80% and 75% respectively; no requirement is given for Type 1a sealers since AT&U considers breathability less important in the sheltered locations of bridges where the Type 1a sealers are used.

The Bridge Engineering Branch of AT&U requires a Type 1a sealer in sheltered locations where the deck remains relatively dry, Type 1b in outdoor conditions, and Type 1c where a greater reduction is required in the amount of water the concrete absorbs. Type 1c is designed for low water/cementing materials ratio concrete (0.3 to 0.4). Test cubes for Type 1c are cast from 0.35 water/cementing materials mix.

Table 1 of CSA Standard S413 assumes the use of a sealer at least equivalent to AT&U Type 1b. Current lists of products approved for use on bridges may be obtained from AT&U.

For surfaces not subject to traffic (such as vertical surfaces), the performance after abrasion is not significant, and other Standards and testing procedures developed by recognized authorities can be used for sealer evaluation.

A3. Application of Moisture Barrier

A3.1 Substrate Preparation

For optimum performance of a system, the substrate should be prepared as specified by the manufacturer. This normally involves the removal of laitance and contamination by steel shotblasting, light sandblasting, or high pressure waterblasting. Acid etching should not be used as it has been found to be ineffective for this purpose. Care should be taken to avoid contamination during the various application stages of a system.

A3.2 Moisture Content

The moisture content of the concrete substrate should conform to the manufacturer's specification. In general, the drier the substrate, the fewer problems with membrane pinholing, adhesion, and gas bubbles.

A3.3 Environmental Conditions

Moisture barriers should be applied only when the environmental conditions are favourable. The manufacturer's recommendations should be followed in this regard. Days with high relative humidity, high summer temperature (above 28°C) combined with sunshine, or cold temperature should generally be avoided. Some products are sensitive to rising ambient air temperature during application.

A3.4 Safety Considerations

Flammability or toxicity of some moisture barrier component materials requires special precautions during application. Manufacturer's recommendations should be followed.

A3.5 Coverage and Thickness

The manufacturer's recommended sealer coverage rate or membrane thickness should be followed. These values should be based on the test data criteria used for product selection. Some designers prefer to specify thicker membranes than the manufacturer's recommended minimum. In this case, it should be verified with the manufacturer that there will be no adverse effects.

A4. Field Quality Control

A4.1

It is prudent to have the manufacturer's representative present for a time at the commencement of application of the sealer or membrane to verify that correct procedures are being used.

Cut tests should be performed prior to application of the wearing course to determine membrane thickness, adhesion, and freedom from pinholes and gas bubbles.

In addition, for thick systems, consideration should be given to performing cut tests after application of the wearing course to verify thickness, to check for damage to the membrane caused by the wearing course installation, and to check that the wearing course is generally bonded to the membrane.

Sealer coverage rates should be verified. Appendix D gives further recommendations for inspection and testing.

A5. Maintenance

A5.1 Maintenance Program

The protection system designer should provide for the owner's use a maintenance program specifying the details of the periodic inspections. The instructions should include methods for the detection of possible defects and recommendations for their repair.

A5.2 Log Book

The owner should maintain a log book of the defects discovered on inspection and the details of corrective actions taken.

A5.3 Sealer Renewal

A5.3.1

Sealers require renewal when their effectiveness has diminished. There are no current Standards for the field evaluation of sealers. The manufacturer should be requested to recommend the means by which the effectiveness of a system may be evaluated. This will usually include one or more of the following methods, but it should be recognized that all of these tests have their limitations.

Monitoring tests should be done at sufficient frequency that the end of the sealer's effective life may be detected before the concrete, at the level of the reinforcing steel, becomes chloride contaminated.

The sealer's life should generally not be based solely on the water repellency warranty duration because the performance of the sealer during the years near the end of the warranty period may be at such a diminished level as to permit unacceptably large concentrations of chlorides to penetrate the concrete.

(a) Water uptake test (*In situ*). In this test a graduated tube is sealed to the concrete with an elastomeric sealant. The tube is filled with water, and the decrease in water level that occurs in one hour is measured. This test can be used mainly for determining changes in the water screening effect of the sealer. Therefore, the test should be performed before and shortly after the sealer has been applied and cured, to provide reference values for future investigations. Lack of water uptake may be due to saturation of the concrete, rather than the effectiveness of the sealer. To check for this, the water uptake should be compared with that at a location where the sealer is removed by grinding. If similar results are obtained, then the test is not valid for determining the sealer effectiveness. The water uptake test is not a standardized test.

(b) Water uptake test (cores). The water absorption through the sealer treated surface is determined gravimetrically on cores extracted from the deck. The cores are cut in half, dried, and weighed. The section containing the untreated surface serves as a reference. All surfaces, except the sealer treated surface and corresponding surface of the reference specimen, are waterproofed with an epoxy or similar coating. The samples are weighed and placed in a water bath, with the untreated surface facing up. The water level is maintained about 5 mm above the top surface of the specimens. After a period of time (several days) the samples are removed from the water bath, surface dried and weighed, and the absorption calculated.
(c) Chloride ion concentration profile. The background level of chloride content (see Reference (9)) should preferably be evaluated at the time of the sealer application. The chloride content at the lower horizon levels will normally provide a good indication of the background level, provided samples are taken within about two to three years after construction. When assessing chloride levels in connection with corrosion initiation, care should be taken to differentiate chlorides that are naturally bound within the aggregate, as these are not generally available to cause corrosion.

Usually large variations in chloride content will be found, even within relatively close locations on the floor, making judgements about the sealer's effectiveness uncertain, unless the number of tests is large enough to yield representative values.

A5.3.2

If the water uptake or the chloride concentration increases to a significant degree, the sealer should be reapplied.

A5.4 Membrane Inspection

Membranes should be inspected by qualified personnel, typically at yearly intervals, and significant defects repaired without delay.

A6. References

A6.1

(1) American Concrete Institute (ACI) Report, *Corrosion of Metals in Concrete,* ACI 222R-89, May 1990.
(2) Paul Carter, *Sealing to Improve Durability of Bridge Infrastructure Concrete,* Concrete International, Vol. 13, July 1991.
(3) C.T. Aitken and G.G. Litvan, *Laboratory Investigation of Concrete Sealers,* Concrete International, Vol. 11, November 1989, pp. 37-42.
(4) D.L. Bean, *Surface Treatments to Minimize Concrete Deterioration, Report 1, Survey of Field and Laboratory Application and Available Products,* Technical Report REMR-CS-17, Department of the Army, Waterways Experiment Station, Corps of Engineers, P.O. Box 631, Vichsburg, Mississippi, 39180-0631, p. 59.
(5) R.M. Rollings and R. Chojnacki, *Laboratory Evaluation of Concrete Surface Sealants, (Phase 2),* Ministry of Transportation of Ontario, Report No. M1-127, November 1988.
(6) P.D. Carter and A.J. Forbes, *Comparative Evaluation of the Waterproofing and Durability of Concrete Sealers,* Report No. ABTR/RD/RR-86/09, Alberta Transportation Research and Development Branch, 4999-98 Ave., Edmonton, Alberta, October 1986.
(7) A. Bradbury and B. Chojnacki, *A Laboratory Evaluation of Concrete Surface Sealants,* MI-79, Ministry of Transportation of Ontario, April 1985.
(8) G.G. Litvan, *The Effect of Sealers on the Freeze-Thaw Resistance of Mortar,* Cement and Concrete Research, Vol. 22, No. 6, 1982, pp. 1141-1147.
(9) CSA Standard A23.2-4B, *Sampling Determination of Water-Soluble Chloride Ion Content in Hardened Grout or Concrete.*
(10) G. Halvorsen, *Applying Penetrating Sealers to Concrete,* Concrete Construction, November 1992, pp. 819-823.
(11) P. Mailvaganam and P.G. Collins, *Degradation of Elastomeric Parking Garage Membranes,* Concrete International, October 1993, pp. 58-62.
(12) *Guide for the Design of Durable Parking Structures,* ACI Committee 362 Report, 1994.

Appendix B
Cathodic Protection

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

B1. General

B1.1

Cathodic protection, as applied to reinforced concrete parking structures, is an electrical method of corrosion control designed to reduce the corrosion rate of reinforcing steel in reinforced concrete.

The application of cathodic protection systems to new parking structures is innovative and under development. Consideration should be given to obtaining the advice of an independent corrosion engineer knowledgeable in cathodic protection systems applied to concrete structures.

Corrosion of any electrically isolated metal items may be accelerated by the cathodic protection system.

"Electrical continuity between all reinforcing steel and metallic embedments is necessary for cathodic protection to be effective. Dissimilar metals electrically connected without cathodic protection may cause accelerated corrosion. Care should be taken to avoid this situation" (from Reference (1)).

"It may be appropriate not to cathodically protect certain metal items on, in, or adjacent to the protected structure. Electrical isolation and avoidance of stray current corrosion of such items should be addressed during the cathodic protection system design" (from Reference (2)).

To meet the requirements of Clause 4.1(b) of this Standard, waterproofing membrane and wear course, where specified in Table 1, are required regardless of the installation of cathodic protection.

"Cathodic protection of prestressed concrete must be approached with caution, due to the danger of hydrogen embrittlement in high-strength steel. The presence or absence of plastic sleeves, grout or grease filled ducts, stirrups that are not electrically connected to the stressed steel, anchorage hardware, and many other factors can make the design of a cathodic protection system complex" (from Reference (1)).

"There may be areas of a reinforced concrete structure that appear sound by traditional inspection techniques, that are in fact corroding and experiencing corrosion-related tensile stress near the rupture levels. Such distressed areas may crack, spall, or delaminate subsequent to the application of cathodic protection" (from Reference (2)).

B2. Cathodic Protection Systems

B2.1

The following generic types of cathodic protection systems are available at present (some have been more used on bridges than on parking structures):

(a) conductive overlays, which consist of conductive materials dispersed in a binder which is applied to the top surface of the deck and protected with an asphalt wearing course;

(b) embedded systems, which consist of conductive anode metal (eg, mesh, strips, or wire) either fastened to the structural slab surface and overlaid with protective material or sometimes embedded in the structural slab;
(c) conductive polymer or mastic coatings applied by brush, roller, or spray to the soffit of the deck, beams, and other reinforced concrete members; and
(d) conductive metallic coatings applied to the concrete surface by flame or arc spray.

B3. Design

B3.1

The design should include the following:
(a) adequate concrete cover to reinforcing steel;
(b) electrical continuity of reinforcing bars and other metal whether embedded in, or in contact with, the concrete;
(c) plastic chairs where soffit conductive coatings are used; and
(d) placement or electrical isolation of metal so as not to result in a short circuit between the cathodic protection system and the reinforcing steel. Epoxy-coated bars, if used, should be electrically connected.

Design requirements, as well as a more detailed discussion of cathodic protection, may be found in National Association of Corrosion Engineers (NACE) Standards in References (1) and (2).

B3.2

The effectiveness of any particular cathodic protection system should be evaluated by studying its field performance (parking structure installations under conditions similar to those anticipated in the parking structure under design) as related to effectiveness, durability, maintenance, and monitoring requirements.

B3.3

"Service life of the anode material should be taken into account. For a given current density, the anode life will depend on the electrochemical properties of the anode material, volume, surface area, and geometry" (from Reference (2)).

B3.4

Cathodic protection should not be used if the concrete contains, or is in contact with, high-strength steel with a martensitic crystal structure, unless the high-strength steel can be totally electrically isolated from the concrete. High-strength steel in parking structures includes prestressing tendons.

B3.5

Cathodic protection does not prevent water from seeping through construction joints or the inevitable cracks that form in reinforced concrete. Leakage can debond conductive coatings, and can also cause a low resistance path for current resulting in localized high current density.

The leaking water absorbs lime from the concrete, and is damaging to the finish of cars parked below. For this reason, and to satisfy Clause 4.1(b), a waterproof membrane must also be used. The membrane should be sufficiently permeable to permit venting of gases generated by the cathodic protection system. Some membranes may not be satisfactory in this respect.

B4. Testing

B4.1

The cathodic protection system should be evaluated after initial activation and regularly thereafter to confirm that it complies with the design criteria.

B5. Operation and Maintenance

B5.1

The cathodic protection system should be inspected monthly by the owner or their representative, and an annual inspection and survey should be undertaken under the direction of a qualified inspector.

Note: *The National Association of Corrosion Engineers operates a certification program for the accreditation of cathodic protection specialists.*

B5.2

When the anode material is consumed to the extent that it can no longer perform in accordance with design criteria, it should be removed and replaced.

B6. References

B6.1

(1) National Association of Corrosion Engineers, *Standard Recommended Practice Design Considerations for Reinforcing Steel in Concrete Structures,* RP0187-90, Houston, Texas 77218, April 1987, Reaffirmed September 1990, 7 pp.

(2) National Association of Corrosion Engineers, *Standard Recommended Practice Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures,* RP0290-90, Houston, Texas 77218, April 1990, 25 pp.

(3) Ministry of Transportation of Ontario (MTO), *Design Manual for Bridge Deck Reconstruction,* Part 2, April 1984.

(4) *Corrosion of Steel Reinforcing in Concrete,* 11 papers presented at a NACE Conference in Anaheim, California, 1983.

(5) American Concrete Institute (ACI) Report, *Corrosion of Metals in Concrete,* ACI 222R-89, May 1990.

(6) Federal Highway Administration Report (FHWA), *Cathodic Protection of Reinforced Concrete Bridge Decks,* FHWA-DP-34-2.

(7) *Stopping Bridge Rebar Corrosion,* Engineering News Record, June 14, 1984, pp. 2-5.

(8) Ole Viggo Anderson, *Cathodic Protection of Reinforced Concrete,* ISBN 87-7756-000-0, 1989, Technological Institute, Taastrup, Denmark.

(9) R.A. Gummow, *Evaluating the Performance of Conductive Coating Cathodic Protection Systems Applied to Reinforced Concrete Parking Decks,* NACE Eastern Regional Conference, November 1991.

(10) National Reinforced Concrete Cathodic Protection Association, *Guideline Specification for the Design, Installation, and Evaluation of Conductive Coating Cathodic Protection Systems for Reinforcing Steel in Concrete,* Downsview, Ontario, March 15, 1990, Revised March 2, 1991, 20 pp.

(11) National Reinforced Concrete Cathodic Protection Association, *Users Guide to Cathodic Protection of Reinforced Concrete Parking Structures,* October 1991.

Appendix C
Corrosion Inhibitors

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

C1. General

C1.1 Definition

A corrosion inhibitor is a chemical that is added to concrete to delay the onset, and reduce the rate, of corrosion of reinforcement in the presence of chlorides. A corrosion inhibitor provides protection to embedded reinforcement by chemically influencing the kinetics of the electrochemical corrosion reaction at the reinforcement surface, and not primarily by influencing the concrete matrix, rheology, or permeability.

C1.2 Calcium Nitrite

There are a number of chemical compounds that can act as corrosion inhibitors as defined in Clause C1.1. As calcium nitrite appears to be the most extensively researched and has the most extensive use in structures to-date, this Appendix deals only with calcium nitrite. The calcium nitrite should be incorporated into the concrete mix. Other applications such as surface treatments are considered experimental and are not addressed in this Appendix.

C1.3 Other Corrosion Inhibitors

Other chemical compounds can similarly inhibit corrosion, but their performance in service should be tested to verify that they do not have an adverse effect on the concrete, and to determine the appropriate dosages required to provide the required protection. The testing should be done on concrete of similar quality to that used in the structure.

The corrosion inhibitor should be tested in accordance with ASTM Standard G109, *Test Method for Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environment.* (Note that this is a test method only.)

Other materials are sometimes referred to as corrosion inhibitors, but actually work primarily as pore blockers or by other mechanisms, and do not meet the definition of the S413 Standard.

C2. Mechanism of Calcium Nitrite Protection

Portland cement concrete is highly alkaline (pH approximately 12.5). In this alkaline environment an oxide film, a few molecules thick, forms on steel and protects it from further corrosion. However, there are microscopic areas where the protective film is not present. At these locations, chloride and ferrous ions can form expansive iron chloride complexes. These complexes can migrate from the steel surface, after which the complexes are converted into expansive iron oxides.

Corrosion inhibitors can be anodic or cathodic. Calcium nitrite acts at the anode locations on the surface of the metal, and is therefore termed an anodic corrosion inhibitor.

At locations where the alkalinity of the cement paste has failed to create a complete passive film, the nitrite causes the ferrous ions to be changed to a stable passive film, and prevents the chloride from forming complexes with the iron, thereby completing the protective film.

The nitrite does not enter into the passive film reaction, but rather reacts with the resulting products to form a gas (NO). Since only thin molecular layers of oxides are involved, neither a large volume increase nor a large nitrite depletion occurs.

Nitrite, if present in sufficient quantities, causes the creation of a passive film, even in the presence of chloride levels higher than the normal corrosion threshold for conventional concrete. When the integrity of the passive film is preserved, the half-cell potential of the steel remains in the passive range, no large potential differences develop between different bars or along a bar, and the bar is protected against corrosion.

C3. Ratio of Chloride Ion to Nitrite Ion

Since the nitrite passivates and the chloride depassivates, the ratio of chloride ion to nitrite ion is important. The more the chloride buildup around a bar, the greater is the amount of nitrite required to maintain passivity.

Adequate protection is maintained as chloride is absorbed by the concrete, as long as the chloride to nitrite ratio does not become greater than about 1.5 to 1. This ratio is valid for situations in which the chloride enters from the environment, and is not present in the concrete mix. If chloride is incorporated in the concrete mix (a practice not permitted by this Standard), the chloride to nitrite ratio limitation is 1 to 1.

C4. Calcium Nitrite and Other Materials

Calcium nitrite has been found to provide protection when used in combination with
(a) uncoated steel;
(b) epoxy-coated steel (see Reference (11));
(c) galvanized steel (see Reference (5));
(d) aluminum (see Reference (5));
(e) coated or encapsulated prestressing steel;
(f) high quality conventional concrete and concrete containing silica fume (see Reference (5)), cementitious slag, or fly ash (see Reference (5));
(g) latex-modified grout and concrete (see Reference (10)); or
(h) a combination of these materials.

No information is available on the effectiveness of calcium nitrite if the epoxy coating debonds.

Calcium nitrite does not materially change the quantity of air-entraining agent required, or affect the air-void structure.

C5. Cathodic Protection

Cathodic protection can be installed on concrete incorporating calcium nitrite if the steel is electrically continuous (see Appendix B).

C6. Cracked Concrete

The required dosage of nitrite depends on the quantity of chloride. Since chloride concentration builds fastest at cracks, a severely cracked structure will undergo more distress in a given number of years than an otherwise equal uncracked structure with the same amount of nitrite.

At narrow cracks, any moisture in the crack will be alkaline, and the nitrite will be present in the solution at the reinforcement level. At wide cracks, such will probably not be the case. However, tests by the U.S. Federal Highway Administration (FHWA) with slabs containing more than twice the chloride than the calcium nitrite dosage was expected to protect against showed that the corrosion of the steel was significantly slowed, and other research (see Reference (14)) has found that if an insufficient amount of inhibitor is present, corrosion is comparable to that of concrete with no inhibitor, and is not worsened.

The effectiveness of calcium nitrite corrosion inhibitor has been found not to be significantly reduced at surface crack widths less than about 0.2 mm when the crack is at right angles to the bar. It is thought that the performance will be similar when the crack parallels the bar, but to date all laboratory research on this has been done on cracks at right angles to the bar.

Good design practice should be followed with respect to reducing the causes of cracking (volume changes and restraint) as far as practicable, and to spacing to the reinforcement to control cracking.

C7. Effectiveness versus Time

The mechanism of protection is believed to involve the depletion of the nitrite. However, only microscopic passive films are involved and there is no indication from the long-term laboratory, outdoor exposure, or field studies carried out to date that the protection level in a properly dosed concrete significantly decreases with time. These studies (see References (7) and (15)) show that the nitrite quantities at the reinforcement level are essentially stable with time.

Since the nitrite ion is dissolved in the pore water of the concrete, its concentration will theoretically vary in a concrete subject to different rates of evaporation at different surfaces. Nevertheless, there is no indication to date that there is significant migration of nitrite in an adequately dosed calcium nitrite concrete (see References (7) and (15)) .

C8. Variation of Dosage

If there has been an insufficient dosage (ie, the ratio of chloride to nitrite rises above 1.5) of calcium nitrite at any point along the steel, a large cathode small anode effect will be created, and corrosion may start. Although most long-term studies carried out to date have not shown that corrosion will be promoted or accelerated in concrete with calcium nitrite, even when the ratio of chloride to nitrite significantly exceeds 1.5 (see References (4) and (14)), it is prudent to take care not to underdose.

C9. Effect of Nitrite in Concrete Adjacent to Concrete Not Containing Nitrite

Some elements of a structure may contain corrosion inhibitor while other adjacent elements do not (eg, columns without inhibitor and floors with it). If chlorides remain low and the concrete retains its alkalinity, the adjacent element will not corrode. The decrease in concrete resistivity associated with the use of calcium nitrite has been found (see References (4) and (14)) to be insufficient to cause a large increase in any macrocell which would develop if an adjacent element with interconnected reinforcement became chloride contaminated.

The effect of temperature, moisture content, and the quantity of cathodic steel available for oxygen reduction are the primary factors influencing corrosion. These items are not affected by the presence or absence of calcium nitrite.

For these reasons, calcium nitrite should not cause any significant acceleration of corrosion of adjacent elements, regardless of whether or not large amounts of chloride are present in some or all members.

However, if the adjacent elements will be subject to chloride exposure, they should not be left unprotected, since chloride contamination of these elements could cause corrosion of the reinforcement in them.

C10. Determination of the Calcium Nitrite Dosage

C10.1 Chloride Diffusion Model

The proper dosage is defined based on assessment of

(a) the desired maximum chloride-to-nitrite ratio; and

(b) the maximum chloride concentration expected at the reinforcement level during the design life of the structure.

Item (a) has been determined from research to be 1.5 to 1 for chlorides which enter the hardened concrete (see Figure C3).

Item (b) can be estimated if the following are known:

(i) severity of the environment;

(ii) permeability of the concrete in the structure; and

(iii) specified cover to the embedded steel.

The severity of environment has been estimated from a survey of parking structures in the United States. (Deicing chemical usage per kilometre of road has been collected for various cities in the Unites States and Canada (Ontario) and found to be comparable.) With this data, and diffusion models, an approximate relationship of environment, concrete permeability, and cover has been derived (see Reference (8)). This relation is shown graphically in Figures C1 and C2.

Figure C1 is valid for environments with an annual mean daily temperature not exceeding 10°C. This covers virtually all metropolitan areas in Canada (data are available from Environment Canada). For garages exposed to higher annual mean temperatures, such as heated garages, a higher dosage of corrosion inhibitor is required. Figure C2 is for an average mean daily temperature of 14°C. This approximately corresponds to an indoor garage heated to an average of 10°C for the winter months in Toronto.

In Figures C1 and C2, the relation shown between chloride concentration, environment, permeability, and cover was based on a theoretical 40-year life. Due to the number of variables which cannot accurately be determined, the theoretical life should be considered as an approximation for the purpose of modelling only. Actual life provided by the corrosion inhibitor may be less than the theoretical life. For this reason, as with other protective methods, this Standard requires multiple protection systems when corrosion inhibitors are used.

The graphs in Figures C1 and C2 are presented as bands rather than lines, to allow user judgement in determining the chloride concentration for a particular situation.

C10.2 Dosage from Figures C1 and C2 and Table C1

C10.2.1 General

The required dosage can be determined by reading the design chloride level from the scale at the left side of Figures C1 and C2 as appropriate, and then the corresponding solid calcium nitrite dosage from Table C1. The solid dosage rate so determined should then be converted to a solution dosage rate at the concentration in which the nitrite will be supplied.

The solution dosage rate, in ℓ/m^3, is calculated from the required solid calcium nitrite (kg/m^3), by dividing by the specific gravity of the solution, and by the solution concentration (%). (See Note (3) to Table C1 and Clause C10.2.6.)

Graphs are also available based on coulomb ratings of the concrete. Coulomb ratings determined in accordance with ASTM Test Method C1202 should be based on the concrete mix without the calcium nitrite. Dissolved calcium nitrite has a significant effect on the electrical conductivity of the water-saturated concrete. For this reason, higher coulomb ratings will be obtained from concrete containing calcium nitrite.

C10.2.2 Variation in Cover

In Figures C1 and C2, some allowance has been made for a portion of the reinforcement being closer to the surface than specified. If good placing tolerances cannot be assured, some further allowance should be considered. This can be done by entering the graph at less than the specified cover, or by entering the graph at the specified cover and using the upper portion of the band.

C10.2.3 Concrete Not Protected by Waterproofing Membrane

The required calcium nitrite dosage rates for concrete structures, or elements of structures, not protected by a waterproofing membrane are given in Table C1.

C10.2.4 Concrete Protected by Waterproofing Membrane

Half the dosage listed in Table C1, but not less than 3.8 kg/m^3solid calcium nitrite, may be used for structures protected by a waterproofing membrane that will be maintained in accordance with this Standard.

The reduced dosage is justified on the basis that the concrete will be exposed to chlorides only during the relatively short time periods between failure of the membrane and its repair.

C10.2.5 Increased Dosage

For special situations such as an extended design life, particularly severe exposure to chlorides, or a service temperature above the temperatures on Figures C1 and C2, the design should be based on higher chloride levels. The expected chloride levels should be determined from historical data, diffusion analyses, and discussions with product manufacturers and other technical experts, rather than Figures C1 and C2.

C10.2.6 Examples

Example #1

Given:

(a) cast-in-place nonprestressed slab protected by a waterproofing membrane;
(b) outdoor garage (mean daily temperature less than 10°C);
(c) specified concrete cover = 40 mm;
(d) water/cementing materials ratio = 0.40;
(e) good cover tolerance; and
(f) average exposure to chlorides.

Solution:
From Figure C1, read the chloride concentration as 8.0 kg/m^3, and then from Table C1 read the required solid calcium nitrite dosage as 7.7 kg/m^3. This can be reduced to 3.85 kg/m^3 because of the waterproofing membrane protection. (**Note:** *Dosage should never be reduced to less than* 3.8 kg/m^3, *irrespective of what other protection systems are provided.*) If a 30% solution of calcium nitrite is used, with a specific gravity of 1.27, the dosage is 3.85/1.27/0.30 = 10.1 ℓ/m^3. The graph was read at midband width. If it is known the corrosive conditions are light, it could have been read at the bottom of the band; if more than average corrosive conditions exist, then it should be read at the top of the band.

Example #2
Given:
Same as Example #1, except garage is heated to 10°C and is located in Toronto.

Solution:
From Figure C2, read the chloride concentration as 9.0 kg/m^3, and then from Table C1 read the required calcium nitrite dosage as 8.6 kg/m^3. This can be reduced to 4.3 kg/m^3 because of the waterproofing membrane. If a 30% solution of calcium nitrite is used, the dosage is 4.3/1.27/0.30 = 11.3 ℓ/m^3.

C11. Concrete Mix Design

Calcium nitrite acts as a concrete accelerator. Mixes incorporating calcium nitrite may require the addition of a retarder in hot weather concreting.

The quantity of mix water should be adjusted to maintain the specified water/cementing materials ratio. The water in the calcium nitrite solution should be counted as mixing water when determining the water/cementing materials ratio.

C12. Test for Presence of Nitrite Plastic Concrete

A test method (see Reference (16)) for nitrite in the plastic concrete enables approximate verification on the job site that the specified dosage has been incorporated into the concrete mix.

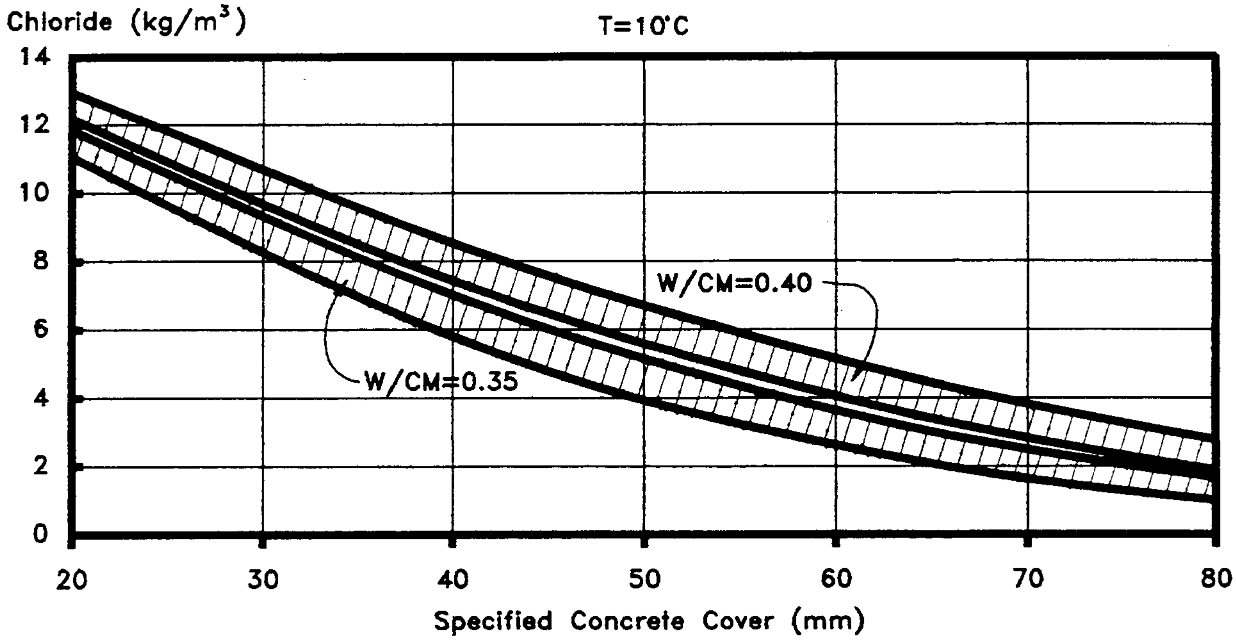
C13. Test for Corrosion Activity

A half cell potential survey may be performed in accordance with ASTM Standard C876 to test for corrosion activity. Rate of corrosion measurements can also be performed (see References (12) and (13)). Both corrosion activity and rate of corrosion tests require grounding to the reinforcement and piercing the waterproofing membrane at test locations, but are otherwise nondestructive.

C14. References

C14.1

(1) A.M. Rosenberg and J.M. Gaidis, *Methods of Determining Corrosion Susceptibility of Steel in Concrete,* Transportation Research Board, Transportation Research Record N692, 1978, pp. 28–34.
(2) W.H. Hartt and A.M. Rosenberg, *Influence of Calcium Nitrite on Sea Water Corrosion of Reinforcing Steel in Concrete,* ACI Publication SP-65, Performance of Concrete in Marine Environment, 1980, pp. 609-622.
(3) A.M. Rosenberg and J.M. Gaidis, *The Mechanism of Nitrite Inhibition of Chloride Attack on Reinforcing Steel in Alkaline Aqueous Environments,* National Association of Corrosion Engineers, November 1979, pp. 45-48.
(4) Y.P. Virmani, *Effectiveness of Calcium Nitrite Admixture as a Corrosion Inhibitor,* Public Roads, Washington, D.C., Volume 54, June 1990, pp. 171-181.
(5) N.S. Berke and A.M. Rosenberg, *Technical Review of Calcium Nitrite Corrosion Inhibitor in Concrete,* Transportation Research Record 1211, Transportation Research Board, Washington D.C., 1989, pp. 18-27.
(6) N.S. Berke, M.P. Dallaire, and M.C. Hicks, *Effect of Calcium Nitrite on the Corrosion Fatigue of Steel Reinforcing in Cracked Concrete,* Corrosion 91 Paper No. 550, National Association of Corrosion Engineers, Houston, 1991, 17 pp.
(7) N.S. Berke and T.G. Weil, *World-Wide Review of Corrosion Inhibitors in Concrete,* CANMET, Advances in Concrete Technology, V.M. Malhotra, Ed., pp. 889-924.
(8) N.S. Berke and M.C. Hicks, *Estimating the Life Cycle of Reinforced Concrete Decks and Marine Piles Using Laboratory Diffusion and Corrosion Data,* Corrosion Forms and Control for Infrastructure, ASTM STP 1137, Victor Chaker, Ed., American Society for Testing and Materials, Philadelphia, 1992.
(9) R.L. Purvis, K. Babaei, K.C. Clear, and M.J. Markow, *Life-Cycle Cost Analysis for Protection and Rehabilitation of Concrete Bridges Relative to Reinforcement Corrosion,* Strategic Highway Research Program, Washington D.C., May 1993.
(10) N.S. Berke, M.P. Dallaire, R.E. Weyers, M. Henry, J.E. Peterson, and B. Prowell, *Impregnation of Concrete with Corrosion Inhibitors,* Corrosion Forms and Control for Infrastructure, ASTM STP 1137, American Society for Testing and Materials, Philadelphia, 1992.
(11) NCHRP 10-37, *Performance of Epoxy-Coated Reinforcing Steel in Highway Bridges,* National Cooperative Highway Research Program Interim Report, April 1992, Revised February 1993.
(12) *Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion, Volume 2: Method for Measuring the Corrosion Rate of Reinforcing Steel,* Strategic Highway Research Program, National Research Council, Washington, D.C., 1992.
(13) *Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion, Volume 8: Procedure Manual,* Strategic Highway Research Program, National Research Council, Washington, D.C., 1992.
(14) F. Tomosawa, Y. Masuda, I. Fukushi, M. Takakura, and T. Hori, *Experimental Study on the Effect of Corrosion Inhibitor in Reinforced Concrete,* Rilem Durability Symposium, 1990, pp. 382-391.
(15) N.S. Berke, M.C. Hicks, and R.J. Hoopes, *Condition Assessment of Field Structures with Calcium Nitrite,* ACI Meeting, Fall 1993.
(16) *Test Method for Quantity of Calcium Nitrite Corrosion Inhibitor in Plastic Concrete,* Michigan Test Method (MTM) 607-86, 1986.



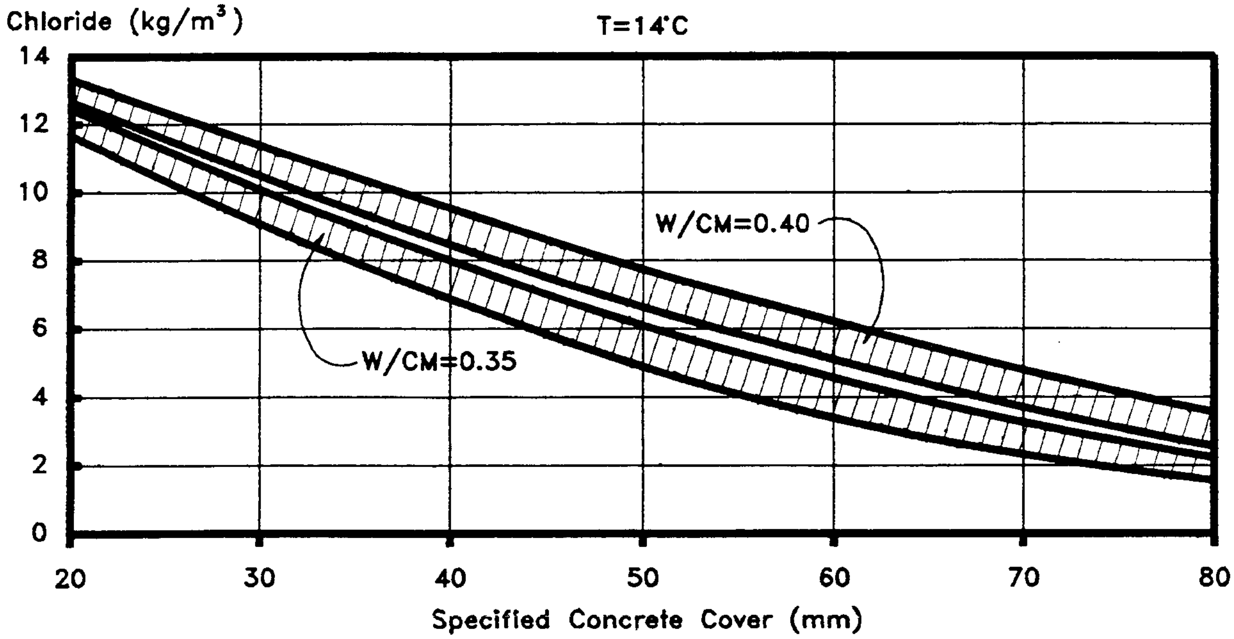
Notes:

(1) *T = mean annual temperature of structure.*

(2) *Refer to Table C1 to determine solid calcium nitrite dosage, and notes under Table C1 to convert to solution dosage.*

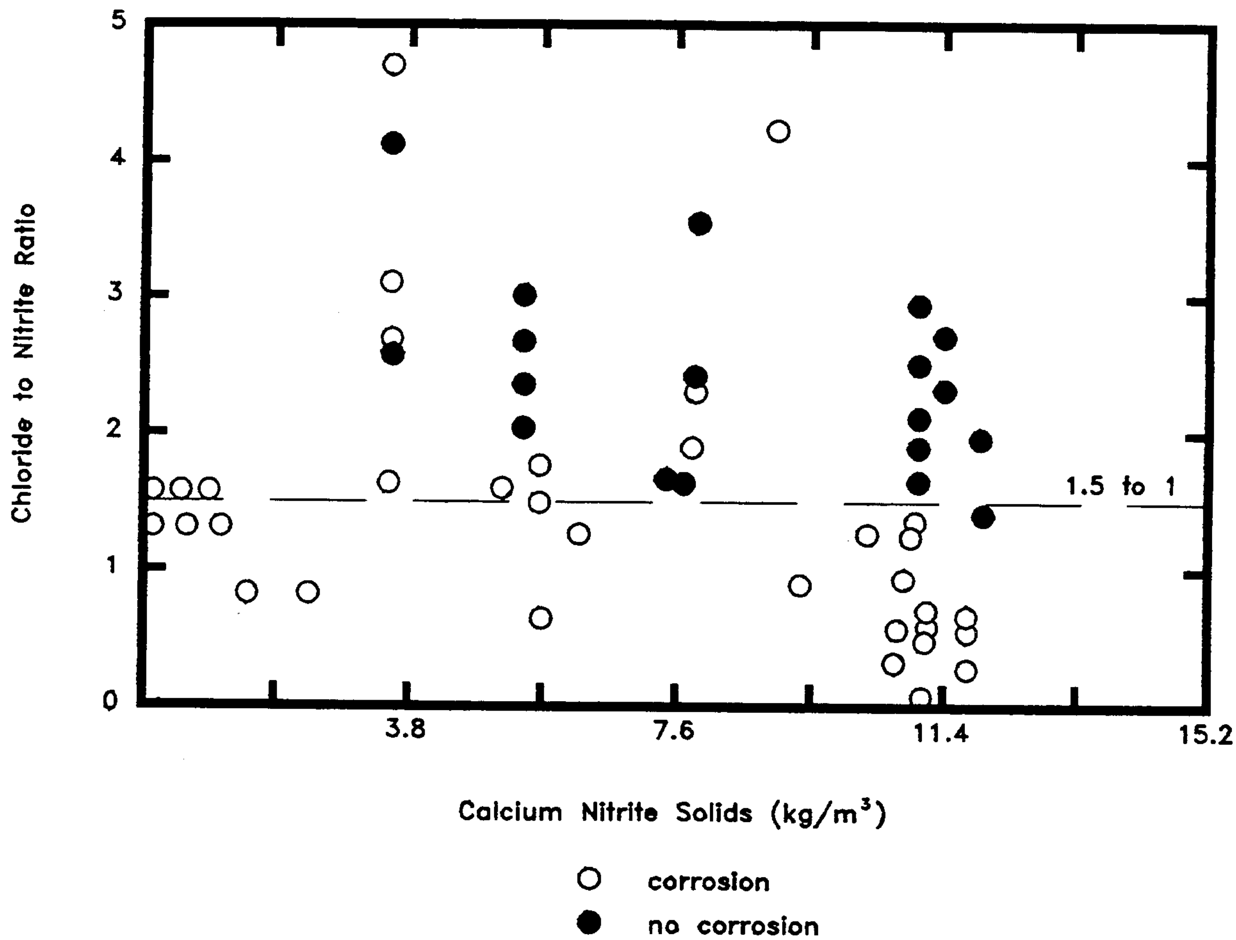
(3) *w/cm = water-to-cementing materials ratio. Graph was developed for concrete without supplementary cementing materials, and will be conservative for concrete containing supplementary cementing materials.*

Figure C1
Estimated Chloride Profiles of Parking Decks for T=10°C
(Adapted from References (8) and (16).)



Notes:
(1) *T = mean annual temperature of structure.*
(2) *Refer to Table C1 to determine solid calcium nitrite dosage, and notes under Table C1 to convert to solution dosage.*
(3) *w/cm = water-to-cementing materials ratio. Graph was developed for concrete without supplementary cementing materials, and will be conservative for concrete containing supplementary cementing materials.*

Figure C2
Estimated Chloride Profiles of Parking Decks for T=14°C
(Adapted from References (8) and (16).)



Note: *Includes data from Grace Washington Research Centre, Solution Tests, Lollipop Tests, and FHWA (Federal Highway Administration) Outdoor Exposure Tests.*

Figure C3
Chloride-to-Nitrite Ratio vs Calcium Nitrite Content (Cl^-/NO_2^-)
(Adapted from Reference (5).)

Table C1
Minimum Calcium Nitrite Dosage Rates
(See Clause C10.2.)

Estimated chloride ion concentration at reinforcement level, kg/m^3	Minimum dosage of solid calcium nitrite, kg/m^3
3.5	3.8
5.0	4.8
6.5	6.2
8.0	7.7
9.5	9.1

Notes:
(1) *Linear interpolation may be used, or the solid calcium nitrite may be determined by the expression* $0.95 \times Cl + 0.075$*, where Cl is the chloride ion concentration. This expression should not be used beyond the range of values indicated in the table.*
(2) *The dosage shall not be less than* 3.8 kg/m^3.
(3) *To convert* kg/m^3 *solid calcium nitrite to the required dosage of calcium nitrite solution, divide by the specific gravity of the solution (generally between 1.25 and 1.35) and divide by the fraction of calcium nitrite in the manufacturer's solution (eg, for a 30% solution of calcium nitrite, to provide* 7.6 kg/m^3 *of solid calcium nitrite requires* 7.6/1.27/0.30 = 20 ℓ/m^3*). See Clause C10.2.6.*

Appendix D
Testing and Inspection

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

D1. General

D1.1
Quality assurance procedures should be established before the commencement of work. These include three components:
(a) the contractor's quality assurance procedures;
(b) inspection and testing by independent agencies; and
(c) the review procedures by the designer, the engineer, or the architect designated to carry out these procedures.

D1.2
The designer should specify the steps to be followed to verify that the contractor has implemented an appropriate quality assurance procedure. This verification may take the form of minutes of an initial project meeting, or may require a formal verification method statement to be provided by the contractor.

D1.3
The following procedures, as a minimum, should be established:
- ☐ procedure for checking shop drawings by the contractor, and coordinating the work of the trades;
- ☐ procedure for the design of formwork, and scheduling, stripping, and reshoring;
- ☐ procedure for ensuring correct placement of formwork, with camber, screeds, and construction joints;
- ☐ procedure for ensuring accurate placing of reinforcement, and that reinforcement is not displaced before or during the placing of concrete;
- ☐ procedure for the protection and repair of epoxy-coated bars and tendon sheaths;
- ☐ procedure for curing concrete;
- ☐ procedure for providing timely investigation for independent inspection and testing agencies;
- ☐ procedure for providing timely notification to the designer, or the engineer or the architect responsible for field review; and
- ☐ documentation for all of the above.

It is recommended that a form be provided which can be signed off by the contractor before concrete is placed in any location. It may also be signed off by the independent inspection and testing company when appropriate, and delivered to the designer as evidence of compliance with the quality assurance procedures.

D2. Checklist

D2.1

The following is a guide for establishing a checklist for inspection and testing. The various items may be the responsibility of an engineer, architect, testing agency, or contractor, as appropriate.

(a) General

- ☐ Retain experienced inspectors and Agencies to carry out inspection and testing.
- ☐ Record results of all inspections and tests.

(b) Concrete Quality

- ☐ Review concrete (Clause 6.1) and stressing pocket grout (Clause 6.6.5), mix design, admixtures (Clauses 6.1.4 and 6.1.5), air entraining agents and aggregates (Clause 6.1.6);
- ☐ Verify dosage of corrosion inhibitor, on delivery ticket.

Test trial mixes to determine

- ☐ permeability of low-permeability concrete (Clause 7.3.1.2);
- ☐ slump (Clause 6.1.5);
- ☐ air content of plastic concrete;
- ☐ air-void structure (spacing factor) of hardened concrete (CSA Standard A23.1, Clause 14.3.4); and
- ☐ water-soluble chloride ion content (Clause 6.1.3).

(c) Formwork

Check

- ☐ that formwork and screed elevations are as shown on the drawings for drainage slopes (Clauses 7.5.1 to 7.5.5, and 10.2);
- ☐ shoring;
- ☐ that the in-place strength of the concrete is at least 75% of the 28-day strength, before removal of formwork (Clause 10.9); and
- ☐ that corrosive deicing chemicals are not used on the formwork (Clause 10.3).

(d) Reinforcement

For epoxy-coated reinforcement, check

- ☐ that the contractor understands the procedures for shipping, handling, storing, and placing epoxy-coated bars to minimize damage to the coating (Clause 10.5).

For reinforcement and prestressing tendons, after trades have finished working on deck, check for

- ☐ quantity;
- ☐ spacing;
- ☐ chaired height;
- ☐ concrete cover (Clauses 7.3.7, 9.3.2, 9.4, and 10.6.4);
- ☐ side cover to reinforcement at vertical and inclined surfaces, and at balustrade dowels (Clause 7.3.7);
- ☐ type of support chairs and spacing (Clauses 6.2.3 to 6.2.5, and 10.4.1);
- ☐ tie wires (Clauses 6.2.5 and 10.4.3);
- ☐ handling, storage, and protection of epoxy-coated bars;

- ☐ damaged or uncoated areas of epoxy-coated bars, before being placed in structure, to determine which are to be rejected and which are to be repaired;
- ☐ damaged or uncoated areas of epoxy-coated bars, after being placed in structure, to determine which are to be rejected and which are to be repaired;
- ☐ surface preparation and adequacy of repair of damaged or uncoated area of coating on epoxy-coated bars (Clause 10.5); and
- ☐ that expansion joint hardware is installed at proper width to accommodate volume change and thermal movements.

For tendons (Clauses 6.6 and 8, and CSA Standard A23.1), check

- ☐ qualifications of foreperson and inspector (Clauses 8.5.1 and 8.5.2);
- ☐ that post-tensioning hardware is protected by an effective and durable coating, and that the coating is not damaged;
- ☐ that tendon sheathing and corrosion protective coating for unbonded tendons conforms with this Standard;
- ☐ that thickness of tendon sheath is not less than 1.5 mm (CSA Standard A23.1);
- ☐ corrosion protective coating application to tendons in shop for complete continuous coverage, with no uncoated portions;
- ☐ placement and plumbness of prestressing anchors;
- ☐ sheaths on unbonded tendons for tears and punctures and subsequent repair;
- ☐ watertight connection of tendon to anchorage;
- ☐ if there is evidence that water has entered the tendon sheath during manufacture, shipping, storage, and construction, and if it has then the tendon is rejected;
- ☐ that voids are filled with grease, including near anchorages;
- ☐ cover to ends of prestressing tendons, ie, to tendon stub;
- ☐ surface preparation and installation procedures for tendon anchor stressing pocket grout;
- ☐ taped double sheath where tendon extends through construction joint (Clause 8.3.2);
- ☐ tendons are not located within 300 mm of the edge of drains (Clause 8.4.1);
- ☐ damage and repair of damage of coating on coated anchorages (Clause 10.5);
- ☐ quantity, placement, chair heights; and
- ☐ protection from weather, of tendons during shipping and storage, and of ends of tendons after placement in formwork until anchors are sealed.

(e) Concrete Placement

Check

- ☐ concrete placement procedures;
- ☐ concrete vibration procedures;
- ☐ environmental conditions;
- ☐ preparation of surfaces where plastic concrete is placed against hardened concrete (Clause 7.4.1.2);
- ☐ slab thickness;
- ☐ that finishing is not started while there is bleed water on the slab;
- ☐ that slab surface is not overworked (Clause 10.7);
- ☐ compaction; and
- ☐ water-soluble chloride ion content from test cylinders (Clause 6.1.3).

(f) Concrete Curing

Check

- ☐ method and duration of curing (Clause 10.8); and
- ☐ that surface is kept continuously moist during curing of cast-in-place concrete, including on weekends.

(g) Protection Systems

Check

- ☐ preparation of surface for application of protection system including treatment of cracks and construction joints in accordance with protection system manufacturer's recommendations (Clauses 10.12 and 10.13);
- ☐ that acid is not used on concrete surfaces as surface preparation for moisture barrier system (Clause 10.11.1);
- ☐ that curing compounds are not used on floor surfaces or other surfaces to receive protection system (Clause 10.8.2);
- ☐ that no acid is used on cast-in-place prestressed structures (Clause 10.11.2);
- ☐ moisture content of concrete before applying protection system, ambient air temperature, and relative humidity (Clause 10.12);
- ☐ application rate of sealers and depth of penetration;
- ☐ height of protection system at vertical surfaces (Clauses 7.3.10.2 and 7.3.11);
- ☐ details where protection system joins drains and expansion joints, and at terminations (Clause 7.3.10.3);
- ☐ adhesion, pinholing, gas bubbles, intercoat adhesion, and effect of wearing course application methods on the membrane, by cut tests; pull tests to check substrate adhesion and intercoat adhesion of thin membrane protection systems;
- ☐ formulation of asphalt wearing course to resist rutting, formulation of mastic wearing course to resist cracking, and hardness tests on mastic;
- ☐ that membrane will not be punctured by aggregates in wearing course;
- ☐ compaction tests and thickness tests on asphalt; and
- ☐ surface preparation and paint coat thicknesses on painted structural steel, including sharp edges and corners.

(h) Joints

Check

- ☐ construction joints (Clause 7.4.1);
- ☐ expansion joints and sliding joints (Clause 7.4.2);
- ☐ that sliding joint bearing material is set back from face of joint, and no concrete bridges across joint (Appendix H, Figure H7);
- ☐ that there is no contact of dissimilar metals (Clause 6.3);
- ☐ that members at sliding joints bear on the sliding material and are not in contact with the concrete of the supporting member;
- ☐ surface preparation and application of joint sealants to control joints (Clause 7.4.3.5); and
- ☐ that expansion joint seals are installed at proper width to accommodate volume change and thermal movements.

(i) Connections

Check

- ☐ that connection hardware for precast members such as balustrades is installed with the hardware surface parallel to the concrete surface, to accommodate movement without binding on the concrete;
- ☐ that at holes slotted to permit movement, there is adequate space from the fastener to the edge of the slot, and the fastener is not tightened to the extent that movement is prevented; and
- ☐ that sliding joints are not seized.

(j) Drainage

Check

- ☐ material used for drains (Clause 6.4.2);
- ☐ drain location (Clauses 7.5.1 and 7.5.12); and
- ☐ drainage and leakage of finished slab surface and drain pipes, by ponding with water, or by spraying with water where ponding is not practical.

(k) Miscellaneous

Check

- ☐ material used for electrical conduits, boxes, portions of drain pipe within slab, etc (Clauses 6.4 and 6.5); and
- ☐ heating cables and pipes (Clause 7.7).

Appendix E
Maintenance

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

E1. Routine Maintenance

Routine maintenance is necessary if the structure is to remain durable throughout its design service life. Inspections should be at regularly scheduled intervals (eg, a walk-through survey annually, and a more extensive condition audit about every three years). Any defects should be immediately repaired. The cost of repair of protection systems is a small fraction of the cost of repairing consequential damage to the structure.

The inspection should be carried out under the direction of personnel knowledgeable in parking garage deterioration and repair.

Table E1 contains recommendations for routine maintenance. Additional information is provided in the References in Clause E6.

E2. Post-Tensioned Structures

Special expertise is necessary in the inspection of post-tensioned structures, as corroding tendons are not necessarily evident from external observations. It has been found that a significant percentage of tendons can fail, without any outward manifestation of tendon failure or structural distress. If tendon corrosion is suspected, detensioning and removal of some tendons for examination may be necessary. This should be done under the direction of a professional engineer experienced in investigation of deterioration of post-tensioned parking structures.

E3. Snowploughing

E3.1

Snowplough blades should have rubber edges, or be equipped with shoes that raise the blade above the floor surface. Ploughing at an angle of 75° or less to the direction of expansion joint can help to reduce damage to the joint and joint hardware (see Reference (3)).

If the roof has not been designed for the weight of piled snow, the snow should be removed from the roof rather than piled. Because of the difficulty in controlling where and how much snow is piled, it is recommended that snow be not piled on the roof.

E4. Deicers

E4.1

Ammonium nitrate and ammonium sulphate, which have been sold as deicers, react chemically with all forms of concrete in the presence of water and cause objectionable disintegration even at room temperature. Their use should be strictly prohibited (see Reference (2)).

E4.2
The use of calcium chloride or sodium chloride to melt snow and ice should be minimized. Wherever possible, urea or calcium magnesium acetate should be used, as these materials are not corrosive to the steel embedded in the concrete structure, or harmful to the concrete.

E5. Need for Expert Advice

E5.1
The following indicate that the structure may be in need of more extensive investigation or repair, or both:

(a) spalled or delaminated floors or columns (delamination is not always visually evident; it can be detected by a chain drag or hammer sounding survey);

(b) deteriorated or leaking expansion joints;

(c) salt deposits or rust stains on the top, edges, or underside of the slabs, or on columns, walls, or balustrades.

If evidence of any of the above is found, an inspection under the supervision of a licensed professional engineer experienced in the design and evaluation of parking structures should be undertaken, and any necessary repairs carried out.

E6. References

E6.1

(1) *Parking Garage Maintenance Manual,* Parking Consultants Council, National Parking Association, 1112 16th Street N.W., Suite 300, Washington, DC, 20006.

(2) *Technical Bulletin No. 2, Parking Facility Maintenance Manual,* Canadian Parking Association, 1993.

(3) A.P. Chrest, M.S. Smith, and S. Bhuyan, *Parking Structures,* Van Nostrand Reinhold, New York, N.Y.

Table E1
Recommended Maintenance

	Months	1	3	6	12	Other
Recommended frequency: D = desirable, M = minimum						
1	**Cleaning**					Note (1)
	Sweeping/cleaning localized	D	M			
	Sweeping/cleaning all areas		M			
	Wash parking floors			D	M	
	Clean debris from expansion joints	D	M			
2	**Plumbing**					
	Check floor drain operation; empty sediment buckets	D	M			
3	**Protection systems**					Note (2)
	Check for leaks in (a) joint sealants (b) expansion joints (c) floor membrane areas			D	M	
	Check for deterioration in (a) wearing course (b) sealer			D	M	
	Repair worn spots in membrane and wearing course				M	as needed
	Reapply sealer					Note (3)
4	**Structural system**					
	Check for (a) concrete surface deterioration (b) water leakage (c) concrete cracking or delamination (d) structural steel rusting (e) painted and galvanized metal surface condition			D	M	
	Check exposed tendon stressing pockets for cracks, shrinkage, corrosion products, and dampness			D	M	
5	**For expert evaluation only** (see Clauses B5 and E5)					
	Perform corrosion survey on representative area of top steel					Note (4)
	Check cathodic protection system					Note (5)

(Continued)

Table E1 (Concluded)

Notes:
(1) *In freezing weather heated garages may need more frequent cleaning as a result of melting deposits from the undercarriage of vehicles.*
(2) *Joint sealants generally require localized repairs annually and may need to be completely replaced at 7- to 10-year intervals.*
(3) *Generally reapply at 2- to 6-year intervals. Reapplication period for sealers depends on many factors. High-wear areas may require more frequent reapplication. Tests of* in situ *materials may be required to determine when reapplication is necessary. Refer to Appendix A.*
(4) *Consideration should be given to carrying out a corrosion survey before the warranty on the protection system expires, and periodically thereafter if chloride penetration into the concrete is suspected.*
(5) *See Appendix B for information on cathodic protection system maintenance.*

Appendix F
Responsibilities

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

F1. Structural Designer

F1.1
The structural design, drawings, and specifications for the structural materials and related procedures outlined in this Standard should be prepared by a professional engineer licensed to practise by the province or territory in which the structure is located.

F1.2
The structural drawings should note the type of protection system on which the design is based.

F1.3
The structural designer should be responsible for the field review of structural construction work.

F1.4
The designer should specify the procedures that are to be implemented to audit the contractor's quality control procedures, including the extent of independent inspection and testing.

F2. Protection System Specifier

F2.1
The protection system should be specified by a qualified professional engineer or architect, licensed to practise in the province or territory in which the structure is located.

F2.2
The protection system specifier should prepare the drawings and specifications for the materials, details, and application procedures of the protection system.

F2.3
The protection system specifier should provide to the owner, in writing, the maintenance procedures necessary to maintain the performance of the protection system, based on the information provided by the protection system manufacturer.

F2.4
The protection system specifier should be responsible for the field review of the protection system installation.

F3. Prime Consultant

F3.1

The prime consultant should confirm to the owner and regulatory authority that the requirements of Clauses F1 and F2 have been met.

F4. The Contractor

F4.1

Quality assurance procedures should be established by the contractor to verify that specification requirements are satisfied.

F4.2

The contractor should submit to the prime consultant such documentation as necessary to confirm compliance with the provisions of this Standard.

F5. The Owner

F5.1

Where the structural designer or protection system designer, or both, advise that, as part of their field review activities, an inspection and testing agency should be retained to confirm that the materials and applications comply with the requirements of the contract documents, the owner should commission an agency or agencies acceptable to the designer(s).

F5.2

The owner should be responsible for maintaining the structure in accordance with the maintenance procedures noted in Clause F2.3, and for keeping records of this maintenance in a log book.

Appendix G
Structural Considerations

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

G1. Introduction

The purpose of this Appendix is to highlight some of the special aspects of the structural design of parking garages. More detailed information is available in the specialist literature, including the reference publications listed in Clause G20.

Special structural features of parking garages can significantly influence their overall performance. Long clear spans, ramp systems, corbels and brackets, torsion loading on edge members, and the relationship of stiff elements such as stair and elevator shafts to the main structure require careful consideration. Failure to predict the structural behaviour and interaction of these special features could lead to excessive cracking and, in some cases, insufficient strength. Cracks may occur as a result of normal structural behaviour, restrained volume changes, and stresses induced by corrosion of reinforcing steel.

Crack control for structural members is the implementation of design procedures which reduce the width, but increase the number, of cracks. Some consideration should be given to crack control in parking structures for reasons of corrosion, waterproofing membrane performance, and appearance. However, as noted in ACI 318, "Although a number of studies have been conducted, clear experimental evidence is not available regarding the crack width beyond which a corrosion danger exists. Exposure tests indicate that concrete quality, adequate compaction, and ample concrete cover may be of greater importance for corrosion protection than crack width at the concrete surface" (see Reference (11)). Crack control measures which reduce protection against chlorides (eg, reduced concrete cover) should not be used. No specific crack widths or crack control parameter "z" value (see CSA Standard A23.3) are given in CSA Standard S413. Some engineers limit the crack control parameter "z" to 25 kN/mm, while others apply more restrictive limits.

In the case of cast-in-place concrete toppings, crack control consists of preselecting the crack locations by tooling or sawcutting a joint in the topping.

G2. Loads

Loads are specified in the *National Building Code of Canada* (NBC). Both the specified live load (uniform as well as concentrated if concentrated load governs the design) and allowances for superimposed dead loads (unfactored) should be shown on the drawings (see Clause 5.1).

The concentrated live loads specified in the NBC should be checked, as they may be more critical than the uniform live loads, particularly for short spans. If the garage is accessible to buses and trucks, heavier design live loads are required than if access is limited to passenger cars. Where the structure may be subject to vehicles weighing more than the 9000 kg maximum vehicle gross weight listed in the NBC, reference should be made to CSA Standard S6, *Design of Highway Bridges*. Consideration should be given to the weight of heavy construction equipment, such as asphalt pavers and the like.

Access ramps are sometimes used by heavy vehicles such as garbage trucks, even where the garage is limited to passenger cars. Where appropriate, the ramps should be designed for heavier loading.

The design loadings should be consistent with the proposed maintenance procedures. Where the maintenance includes piling of snow on the roof rather than its removal, the roof should be designed for the snow piling load (refer also to Appendix E, Clause E3.1).

The NBC gives no specific directions on how the wind load force is to be calculated for open air parking structures. In these structures, the wind pressure and suction acts on the solid perimeter as well as the interior elements of the garage. Reference (17) recommends that the garage be considered as totally enclosed for the purpose of determining the surface area on which the wind acts, unless a more rigorous analysis is made.

G3. Normal Structural Behaviour Cracking

A reinforced concrete member loaded in a manner which produces tensile stresses may experience cracks due to flexural stresses, diagonal tension stresses, anchorage/bond stresses, and prestressing anchorage zone splitting and spalling stresses. In addition, cracking can be caused by tensile stresses resulting from volume changes of the concrete due to shrinkage, creep, elastic shortening, and expansion and contraction due to temperature changes.

G4. Flexural Cracking

Flexural cracks, if sufficiently wide, can lead to corrosion when it occurs at surfaces exposed to chlorides, such as the top surface of floors in negative moment regions.

To control cracking in reinforced concrete members it is desirable to have small diameter steel reinforcing bars well distributed in the flexural tensile zones. CSA Standard A23.3 prescribes minimum requirements for the distribution of flexural reinforcement to control cracking. For beams and one-way slabs, CSA Standard A23.3 gives an equation for the crack control parameter "z". No similar crack control parameter "z" is given for two-way slab systems. Nawy and Blair (see Reference (14)) investigated cracking in two-way systems and concluded that crack control equations for beams underestimate the crack widths developed in two-way slabs and plates, and that the cracking mechanism is controlled primarily by the steel stress and the spacing of the bars in the two orthogonal directions. An equation for crack control in two-way slabs and plates is given in Reference (13) in terms of a grid index which combines the effect of the reinforcement in both directions. Recent research (see Reference (7)) has shown that wider cracks occur in concrete reinforced with epoxy-coated bars than with uncoated bars (see Reference (7)). Accordingly, if epoxy-coated bars are used, CSA Standard A23.3 requires that the right-hand side of the equation for "z" be multiplied by a factor of 1.2. The same factor should be used in the two-way slab crack control equation.

G5. Restraints to Volume Change

Volume changes due to drying shrinkage, temperature change, elastic shortening (in post-tensioned construction), and creep can cause cracking if the associated deformations are restrained.

Assumptions made with respect to column stiffness (see Figure G2) and the degree of column base fixity will have a significant influence on calculated forces and moments due to restrained volume changes. In any analysis of deformation due to volume change, assumptions regarding column stiffness and fixity should be consistent throughout the structural analysis, and be reasonable with respect to the actual construction details and structural behaviour.

Stiff elements such as shear walls, stair and elevator cores, walls at entrance ramps, and the like, should preferably be placed near the midlength of the structure (see Figure G3), or separated by expansion joints and the structure provided with lateral strength by other means.

Reference (12) discusses restraints to volume change with respect to post-tensioned structures, but many of the principles apply in varying degrees to pretensioned structures and to nonprestressed structures. Reference (8) includes example calculations of the effects of volume change.

G6. Drying Shrinkage

Drying shrinkage is defined as the decrease over time in the volume of concrete, independent of externally applied loads. Drying shrinkage is mainly due to moisture loss as a result of drying and hydration of the cement and chemical changes which result in the carbonation of the cement hydration products.

For a discussion of the factors influencing drying shrinkage, see Reference (13). The water content of the concrete mix is one of the most important factors determining its shrinkage.

To minimize drying shrinkage, the concrete mix should contain the maximum permissible nominal size of coarse aggregate, have the lowest permissible slump, and a combined grading of coarse and fine aggregate that will give good workability with the minimum amount of water for a given slump.

Guidance for determining drying shrinkage strains is given in a number of publications, including Reference (15).

On average, approximately 40% of the total drying shrinkage of a member occurs in the first 28 days after initial wet curing (see Figure G4).

To allow the initial drying shrinkage to take place, it is desirable that precast prestressed element be at least 28 days old before final field connections are made. In projects where precast prestressed elements have to be placed sooner, it is recommended that the elements not be rigidly connected to the adjacent elements by welding or bolting until the 28-day period has elapsed (see Reference (2)).

Cracking of the thin and lightly reinforced concrete slabs of joist and waffle slab construction, due to differential shrinkage between the slab and webs, is difficult to control. For this reason the use of these types of floor framing systems for parking structures should be carefully considered and avoided if possible.

G7. Thermal Effects

Information on design temperature ranges for coastal, central, and interior regions of Canada is given in Commentary D of the Supplement to the NBC.

Daily and seasonal cycles of temperature changes will cause volume changes in concrete. Increasing temperature causes expansion, which compensates to some extent for the contraction associated with drying shrinkage, elastic shortening, and creep. Conversely, decreasing temperature causes contraction, which is additive to these effects.

Temperature-related volume changes are greatest at a roof directly exposed to the sun, and can be amplified if the roof is covered with a dark-coloured waterproofing system. The temperature of a black roof under a hot sun can rise substantially above the ambient air temperature during the day (see Reference (16)). This will cause roof elements to temporarily camber. Connections should be designed taking into account the rotations and horizontal movements associated with temperature changes. It is recommended that the connections not be so rigid as to restrain temperature-related deformations.

Rigid connections of parapets to vertical elements of the structure (such as walls and columns) should be avoided if possible (see Figure G5), or the structural members should be designed for the additional forces (which can be very substantial) caused by the reduced clear height of the vertical element.

Areas where temperature-related volume changes can have the greatest cumulative effect and should be given special consideration are:

(a) roof level and any other level directly exposed to the sun and the columns and walls directly below;
(b) the first supported level and the columns and walls directly below; and
(c) the southern and western elevations.

G8. Elastic Shortening

Elastic shortening is the deformation that occurs instantaneously when compressive axial force is applied to an element. Elastic shortening is of relevance with respect to cast-in-place post-tensioned concrete structures. Too much post-tensioning in the floor can cause cracking of the supporting walls and columns due to elastic (and creep) shortening of the floor.

G9. Creep

Creep is the inelastic deformation of concrete under sustained load. Creep generally causes increased deflection of the floor. In prestressed concrete, creep also causes increased shortening deformation of the floor.

The forces and moments at rigidly connected columns, caused by drying shrinkage, decrease in time, due to both creep and microcracking of the columns and the connecting horizontal elements.

G10. Incompatible Deflections

When elements of differing lengths, exposure conditions, or stiffness are rigidly connected (see Figure G6), cracking due to incompatible deflections of the joined elements can be expected. This type of cracking can be controlled by the use of isolation joints that permit vertical movement.

At corners of floor slabs connected in both directions to stiff walls or beams, CSA Standard A23.3 requires special corner reinforcement in the slab to control cracking.

G11. Expansion Joints, Sliding Joints, Released Connections, and Pour Strips

Expansion joints permit the separated parts of the structure to contract and expand without adversely affecting the structure's integrity or serviceability. General guidance is given in References (3) and (4) for the spacing of expansion joints.

Sliding joints should be designed to accommodate expected movements and rotations of the structure. The structural elements should not bear near the edge of the joint. Bearing pads may walk from their original position when the dead load bearing stress is less than 2.7 MPa. Sliding joint bearing details are illustrated in Figure H7 of Appendix H.

Released connections are those in which a joint is designed to permit a limited movement of the slab or beam relative to its support. Reference (12) discusses released connections with respect to post-tensioned construction.

In conventionally reinforced concrete and cast-in-place post-tensioned concrete structures, temporary "pour strips" (also known as "closure strips") can be used in conjunction with properly placed expansion joints. Pour strips (ie, a gap between adjacent slabs which is left open for a predetermined time) can overcome some of the problems associated with permanent expansion joints, such as sealing the expansion joint against water penetration, ensuring minimal resistance to horizontal movement, and providing support to the deck slab on each side of the joint. Pour strips accommodate only a part of the expected total movement (see Figure G4), and careful consideration should be given to the effects of the remaining portion of the movement that occurs after the pour strip is closed. Pour strips which are not left open sufficiently long may not serve the intended purpose.

G12. Brackets, Corbels, and Ledges

Reinforced concrete brackets, corbels, and ledges should be designed in accordance with the provisions of CSA Standard A23.3. Care should be taken to fully anchor the reinforcement at both ends of the bracket, corbel, or ledge (ie, at the free end as well as the continuous end, as indicated by the strut-and-tie model). If epoxy-coated bars are used, account should be taken of the increased development lengths required, as well as any measures necessary to control crack widths.

G13. Beam-Column Joint Design

Ramp systems, sloped floors, and relatively long clear spans with columns loaded from one side only can cause high shearing forces in beam-column joints resulting in diagonal tension cracks in the joints (see Figure G1) or in the column between floors. The designer should determine these forces and take them into account in the design of the joint, and of the column. Proper confinement to the concrete should be provided in accordance with CSA Standard A23.3.

G14. Torsion

Long span construction, which is common in aboveground precast concrete parking structures, can cause relatively high torsion loading on supporting edge beams. Chapter 4 of Reference (2) includes a discussion of the torsion design of edge beams of precast concrete structures.

G15. Joist, Waffle, and Precast Tee Slabs

The slab portion of joist, waffle, and precast tee framing systems must have adequate shear and flexural strength to resist the concentrated wheel loads specified in the NBC, and the reinforcement in the slab, whether bars or mesh, should be designed accordingly.

G16. Balustrades

Differential shrinkage between the reinforced concrete balustrade and the floor slab can cause wide cracking of the balustrade. Also, concrete parapets that are integral with roof elements or exposed perimeter elements can experience more and wider cracking at the top due to temperature cambering. As balustrade cracks can be unsightly, consideration should be given to substantially increasing the amount of horizontal reinforcement at the top of parapets and balustrades, or providing closely spaced control joints, or prestressing the spandrels in precast prestressed structures.

G17. Precast Concrete

Chapter 4 of Reference (2) gives useful information on the structural design of precast concrete parking structures. Many of the concepts dealt with in Reference (2) apply, to varying degrees, to cast-in-place concrete parking structures.

G18. Below-Grade Enclosed Structures

There are many restraints to volume change in below-grade enclosed structures, including perimeter walls and shear walls or large columns from any superstructure. As the floor system usually provides lateral restraint to these elements, it is difficult to release the floor from these restraints, and for nonprestressed construction the floors are not generally released from them.

Post-tensioned floors are particularly difficult to properly design for below-grade enclosed structures, and very careful consideration and detailing is required with respect to the release of restraints both before and after prestressing, and the effect of such release on the restraining element. Consideration should also be given to the possibility of water entering the tendon during the life of the structure, either from hydrostatic head against perimeter walls or other sources, and the degree of difficulty in accessing the anchorages to replace tendons should this happen.

G19. Epoxy-Coated Bars

Compared to uncoated bars, epoxy-coated bars require greater development lengths and result in wider cracks where they are stressed to design stresses (see Reference (7)). The design should account for these characteristics.

G20. References

(1) N.P. Mailvaganam, *Repair and Protection of Concrete Structures,* CRC Press, 1992.
(2) Prestressed Concrete Institute, *Parking Structures Recommended Practice For Design and Construction,* 1988.
(3) A.P. Chrest, M.S. Smith, and S. Bhuyan, *Parking Structures Planning, Design, Construction, and Repair,* Van Nostrand Reinhold, New York, 1989.
(4) Portland Cement Association, *Building Movements and Joints,* 1982.
(5) American Concrete Institute, *Guide for the Design of Durable Parking Structures,* ACI Committee 362.
(6) American Concrete Institute, *Environmental Engineering Concrete Structures,* ACI 350R-89, ACI Committee 350.
(7) H.H. Abrishami, W.D. Cook, and D. Mitchell, *The Effect of Epoxy-Coated Reinforcement and Concrete Quality on Cracking of Flat Plate Slab-Column Connections,* submitted to the Structural Journal of the American Concrete Institute, December 1993.
(8) Canadian Prestressed Concrete Institute, *Metric Design Manual Precast and Prestressed Concrete,* second edition, 1987.
(9) American Concrete Institute ACI 362R-85, *State-of-the-Art Report on Parking Structures,* ACI Committee 362.
(10) A.M. Neville, *Properties of Concrete,* Longman Scientific and Technical, Essex, England, third edition, 1990.
(11) ACI 318-89 (revised 1992), *Building Code Requirements for Reinforced Concrete and Commentary,* American Concrete Institute, Detroit, Michigan.
(12) B.O. Aalami and F.G. Barth, *Cracking in Prestressed Concrete Structures,* ACI SP-113, 1989.
(13) ACI 224R-89, *Control of Cracking in Concrete Structures,* American Concrete Institute, ACI Committee 224.
(14) E.G. Nawy and K.W. Blair, *Further Studies on Flexural Crack Control in Structural Slab Systems,* ACI SP-30, 1971.
(15) *Concrete Design Handbook,* Canadian Portland Cement Association, 1985.
(16) *Supplement to the National Building Code of Canada,* National Research Council, 1995.
(17) A.P. Chrest, M.S. Smith, and S. Bhuyan, *Parking Structures,* Van Nostrand Reinhold, New York, N.Y.

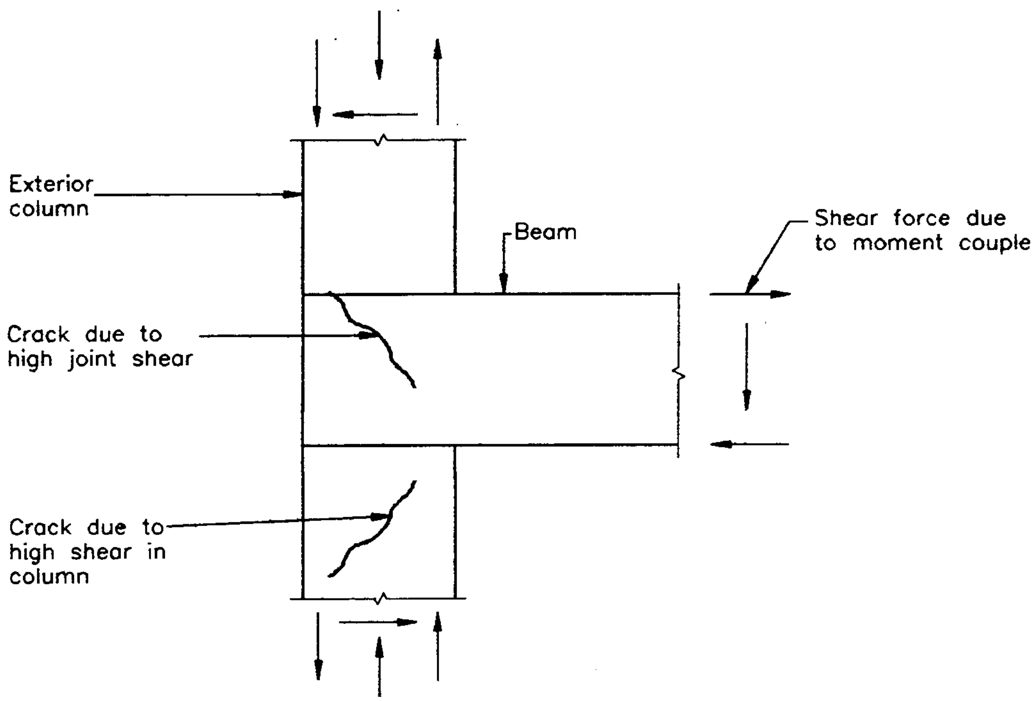


Figure G1
Shear Cracks Due to Beam Moment
(Adapted from Reference (5).)

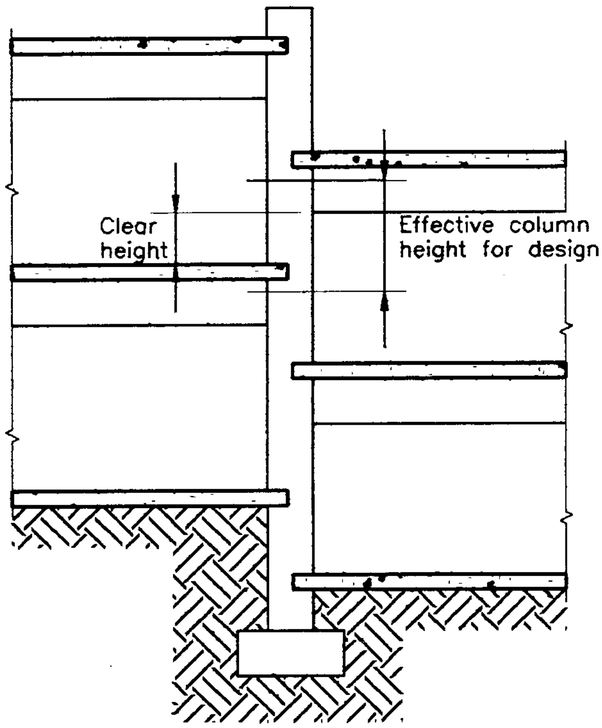


Figure G2
Effective Column Height
(Adapted from Reference (5).)
(See Clause G5.)

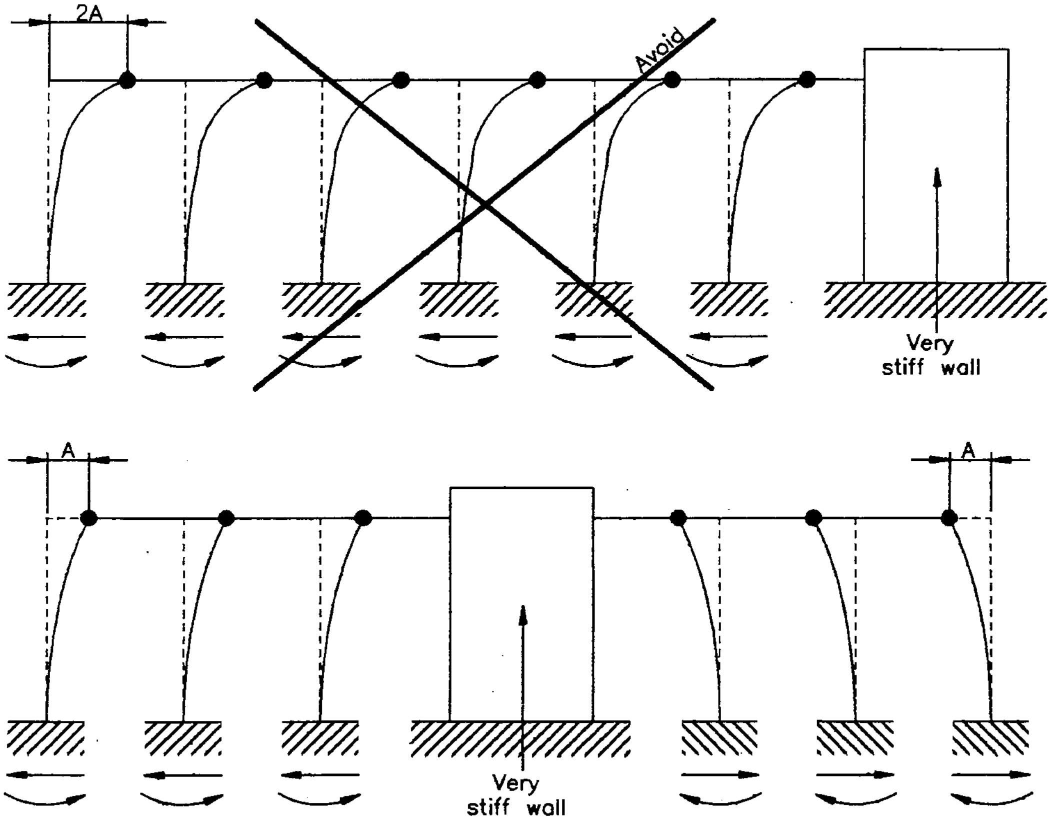


Figure G3
Relative Volume Change Shortening
(Adapted from Reference 9.)
(See Clause G5.)

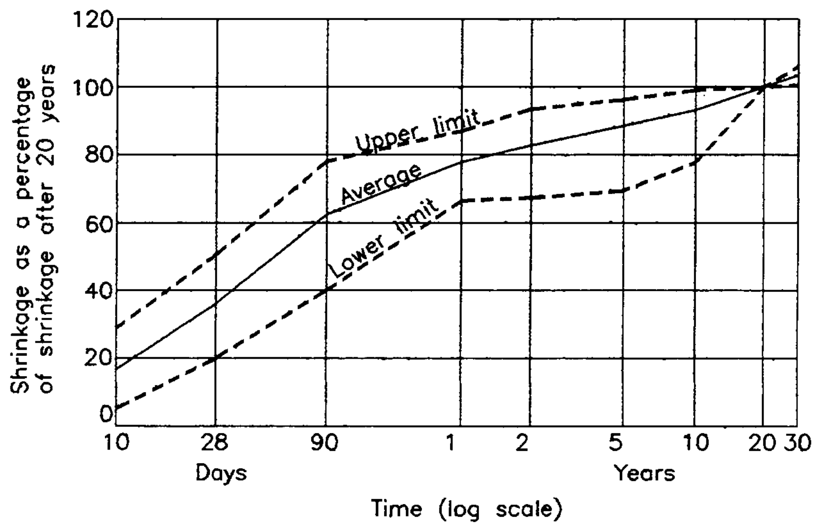


Figure G4
Shrinkage-Time Curves for Different Concretes Stored at Relative Humidity of 50% and 70%
(Adapted from Reference 10.)
(See Clause G6.)

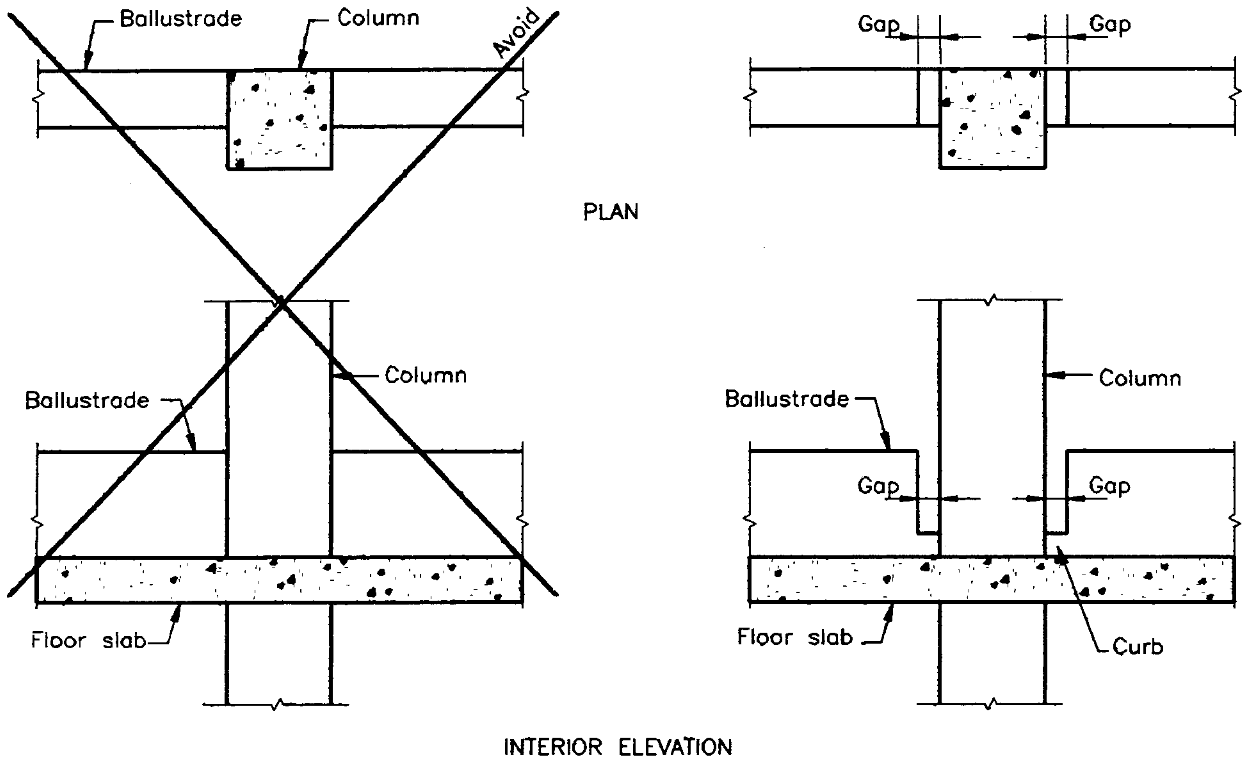


Figure G5
Balustrade-Column Layout
(See Clause G7.)

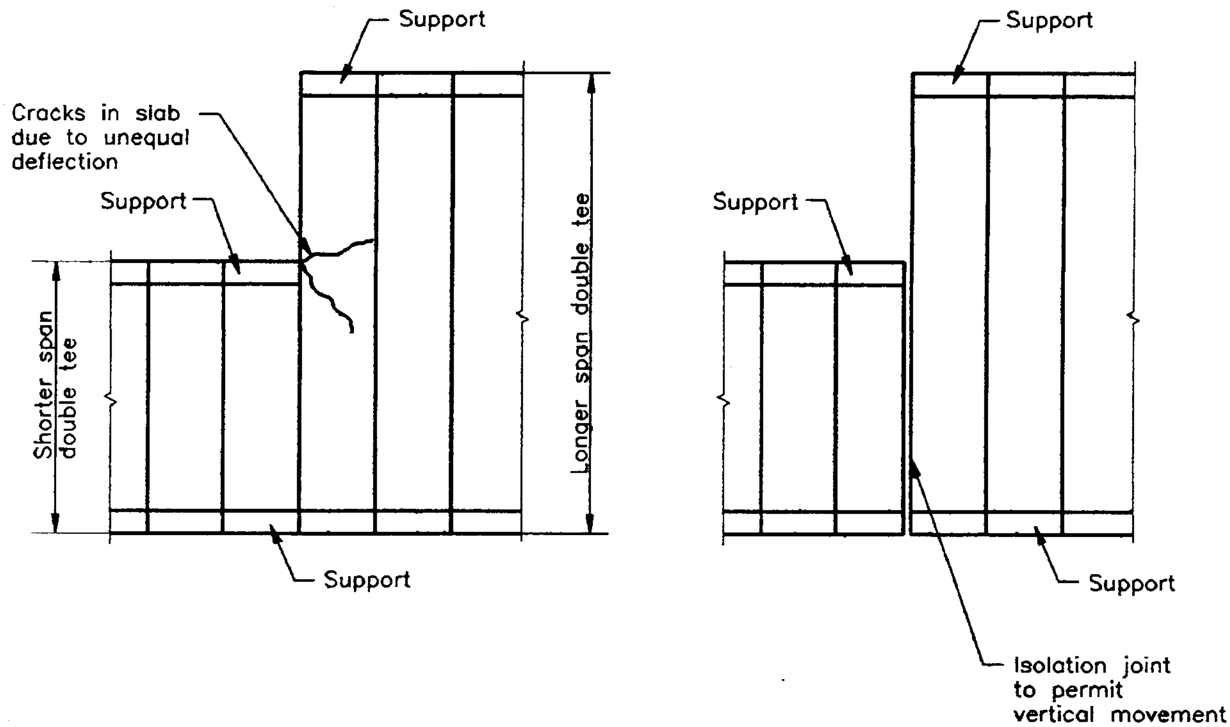


Figure G6
Cracking Due to Incompatible Deflection
(See Clause G10.)

Appendix H
Commentary

Notes:
(1) *This Appendix is not a mandatory part of this Standard.*
(2) *The clause numbers referenced herein, unless otherwise specified, are those of CSA Standard S413. The clause numbers in this Commentary prefaced by the letter "H" correspond to the clause numbers in the Standard.*
(3) *This Commentary was written by the Technical Committee on Parking Structures to explain the intent of various clauses in CSA Standard S413. It also provides additional background information, and a list of references in Clause H13.*

H1. Scope

H1.1 General

This Standard applies to new parking structures, including access ramps, whether located below or above ground, enclosed or exposed to the exterior environment, heated or unheated. They may be constructed of structural steel or reinforced concrete, including prestressed concrete.

Unless otherwise specified, the provisions of this Standard are not mandatory for slabs on ground that are not part of the framing system of the structure. However, to minimize maintenance for such slabs, the prudent designer should provide some corrosion protection to reinforcement (if any) and should specify concrete with resistance to salt scaling and, where necessary, to freeze-thaw action. Slabs on ground are required to slope away from vertical surfaces.

In addition to the requirements of this Standard, the design should be carried out in accordance with other applicable CSA Standards and with the *National Building Code of Canada* (NBC) or the applicable provincial codes and regulations and municipal bylaws.

The provisions of this Standard are intended to provide a structure which will meet a design service life objective for the structural components (such as floor slabs and their supports, stairs, balustrades, walls, and foundations) of 25 to 50 years (see Reference (28)). To achieve this design service life, a program of regular inspection, maintenance, and repair should be carried out by the owner over the life of the structure. Where a longer design service life is required by the owner, consideration should be given to additional protection. Nonstructural components that can be replaced without significant cost or interruption to use of the structure may be designed for a shorter service life, as agreed between the designer and the owner.

Due to the number of variables affecting durability, whose effects cannot be quantified precisely, the predicted service life should be considered an approximation. The provisions of this Standard are those that have been found from experience to contribute to durability. In general, this Standard requires multiple protection systems to protect against structural component failure resulting from corrosion.

Although not structural items, consideration should be given to metal doors and door frames. The bases of doors and frames, when exposed to moisture, have been found to corrode prematurely.

H4. Corosion and Leakage Protection

The causes of parking structure deterioration are known and documented (see References (6), (8), and (16)). One of the principal causes of deterioration is corrosion of the reinforcement and other metals embedded in the concrete. Corrosion of embedded metals in parking structures is an electrochemical process, involving an anode where electrochemical oxidation takes place and rust forms, a cathode where electrochemical reduction occurs, an electrical conductor (the embedded metal), and an electrolyte (the concrete).

Bare reinforcement in concrete is usually protected by the thin oxide film remaining after manufacturing and by the passivating effect of the highly alkaline concrete. However, the presence of free chlorides at the embedded steel, in sufficient concentration, breaks down this protection, allowing corrosion to commence. The corrosion byproducts occupy a volume at least 2.5 times that of the parent metal. This causes high bursting stresses (up to 35 MPa or more) and subsequent cracking and delamination of the concrete (see Figures H1 and H2).

In parking structures, the concrete becomes chloride contaminated when a mixture of deicing chemicals (chlorides) and snow, carried into the garage on the underside of vehicles, is deposited on the floor and melts. If there is no waterproofing system, this chloride contaminated water soaks into the concrete, regardless of whether the concrete is cracked or not, and eventually penetrates down to the embedded steel. For this reason, prestressing the concrete does not prevent corrosion of embedded reinforcement, even though cracking may be eliminated.

In a survey of parking structures constructed before the publication of CSA Standard S413 in 1987, it was found that in some instances deterioration of unprotected structures became evident 5 years after construction, and thereafter the annual delamination rate could be in the order of 3% of the floor area. Major repairs were needed within 10 years of construction. Even in the B.C. lower mainland area, although deicing chemicals are used less than in many areas of Canada, older structures now are in need of repair due to corrosion caused by deicing chemicals.

There are two separate and distinct durability aspects that must be addressed by a protection system. They are

(a) corrosion of reinforcement and embedded hardware due to absorption of chloride ions by the concrete; and

(b) leakage of water through joints or through the inevitable cracks that form, especially in nonprestressed concrete.

Leakage through joints and cracks is deleterious in two respects:

(a) The chloride-laden water runs along the slab soffit and vertical surfaces such as beams, corbels, ledges, and walls, and is absorbed into the concrete, causing corrosion of reinforcement and concrete delamination.

(b) The water dissolves lime from the concrete and drips onto vehicles below, damaging the finish. This occurs even where the water is not chloride contaminated.

Only protection systems that can address both the leakage and corrosion aspects without regular repair are considered adequate. A design which is dependent upon a crack sealing program is not considered to meet the requirements of this Standard.

The corrosion protection provisions of this Standard need not apply where nonmetal reinforcement is used, if it is of a type that will not corrode or degrade, and there are no other metal embedments in the concrete. Some nonmetal reinforcement degrades in the alkaline concrete environment. Currently the design of concrete reinforced with nonmetal material is not included in CSA Standard A23.3.

This Standard covers the following aspects, which have been shown to contribute to durability (see Reference (11)):

(a) Design

- (i) good quality concrete of low permeability with
  - (1) adequate cement content;
  - (2) adequate air-void system;
  - (3) adequate chloride impermeability; and
  - (4) adequate strength;
- (ii) adequate cover to reinforcement;
- (iii) good drainage;
- (iv) good quality expansion joints;
- (v) good quality waterproofing system;
- (vi) good quality sealers replenished regularly;
- (vii) epoxy-coated reinforcing bars;
- (viii) corrosion inhibitors;
- (ix) good protection of prestressing steel and post-tensioning anchors;
- (x) corrosion-resistant floor drains; and
- (xi) good quality sliding bearings.

(b) Construction

- (i) good quality concrete, well placed, compacted, and finished;
- (ii) accurately placed reinforcement and tendons;
- (iii) accurately constructed and aligned connections and hardware for precast concrete;
- (iv) correct cover;
- (v) proper wet curing;
- (vi) proper slope for drainage;
- (vii) no overloading of the floor during construction;
- (viii) good inspection; and
- (ix) good quality control and quality assurance.

(c) Usage

- (i) good maintenance;
- (ii) regularly scheduled detailed inspection by experienced and knowledgeable personnel; and
- (iii) corrective measures when needed.

H5. Drawings and Related Documents

Properly prepared details are critical to achieving durability. Details should be shown on the drawings prepared by the designer, and not left to the contractor to work out. Slopes should be specified by numerical floor elevations shown on the drawings, and not just by the percentage of slope.

H6. Materials

H6.1 Concrete

H6.1.2 Class of Exposure and Cementing Materials Content

The maximum water/cementing materials ratio for Class C-1 exposure is 0.40. For concrete not containing supplementary cementing materials, this results in a 28-day compression strength of about 35 MPa.

The requirement for C-1 exposure applies to all concrete, except in perimeter basement walls and nonstructural slabs on ground. A lesser quality is not permitted, even if there is a surface topping or protective system, or both.

Because of the importance of proper air-entrainment in structures exposed to a freeze-thaw environment, it is recommended that every batch of air-entrained concrete be sampled and tested prior to concrete placement (see Note to Clause 17.4.1.1 of CSA Standard A23.1). Only concrete that has an air content within the specified range should be permitted to be placed in a structure subject to freeze-thaw damage.

H6.1.3 Chloride Content

To test for water-soluble chloride content, a concrete sample is ground and then soaked in water. The chloride content of the water is determined and expressed as a percentage by mass of the concrete or the cement. However, by grinding the sample, chlorides are made available that are not water soluble in the unground concrete. These include up to half the chlorides in the concrete mix constituents which combine chemically with the hydrating cement (see Reference (15)), and chlorides bound up within the aggregate. These chlorides are generally considered not to contribute to corrosion.

H6.1.4 Admixtures Containing Chloride

Editions of CSA Standard A23.1 prior to 1990 allowed the addition of calcium chloride to concrete, of up to 2% by mass of cement. This results in a chloride ion content of more than 6 times the threshold value needed for corrosion to start (see Reference (2)).

H6.1.6 Aggregate

Aggregate with abrasion loss exceeding 35% is not considered desirable for good quality concrete, irrespective of whether the concrete is actually exposed to abrasion.

H6.1.6.3

Semi-low-density concrete (sometimes referred to as semi-lightweight concrete) made using expanded shale or expanded clay aggregate can be as durable as normal density concrete. Although other types of low-density aggregate are available, there are currently no data on their durability.

Because it is essential that low-density aggregate be saturated with water prior to mixing, semi-low-density concrete at early age contains a significant amount of excess water, a condition rendering it vulnerable to freeze-thaw damage. For this reason, semi-low-density concrete should not be placed late in the season when freezing temperatures may occur before desiccation takes place. In most regions of Canada, placement of semi-low-density concrete after September 1 is not recommended.

H6.2 Reinforcement, Support Chairs, and Ties

H6.2.1

Disbondment of the coating on epoxy-coated bars has been found in some existing structures, including Ministry of Transportation of Ontario (MTO) bridges protected by waterproofing membrane. Recent research has resulted in processes that provide improved adhesion of the epoxy coating. The application of a primer to the bar, immediately after cleaning but before the application of the epoxy, is the most common procedure currently in use in Canada to enhance the adhesion. It is believed that enhanced adhesion will improve the life of the coating. It is the intent of this Standard that only bars coated to these new processes, or processes that can be shown to provide at least equivalent protection, are acceptable. Coating properties and application procedures that contribute to durability, the appropriate test procedures to evaluate the coatings, and the expected design life of the coating are matters of much continuing research.

The Ministry of Transportation of Ontario has test procedures and acceptance criteria for cathodic disbondment and salt spray. These are covered in MTO Laboratory Test Methods LS420 and LS421, respectively.

Test Method LS420 determines the resistance to disbonding of an epoxy coating system applied to reinforcing bars after the coated bars, each with an intentional damage site, are placed in a 3% sodium chloride solution at 23°C, and the polarized potential of the steel is maintained at 1.5 volts for 7 days. One bar sample of each size of bar, 200 mm in length, is taken for testing. To maintain certification, the coating applicator must be able to show a disbondment radius of less than 2.0 mm on greater than 95% of the samples tested on a 3-month rolling average.

Test Method LS421 determines the resistance to disbonding of an epoxy coating system applied to reinforcing bars after the coated bars, each with 6 damage sites on the coating, are exposed to water spray containing 5% sodium chloride solution at 35°C for 800 hours. One bar sample, 200 mm in length, is taken for testing for every 24 hours of production. Within every 7-day period, at least one sample representative of each bar produced is tested. To maintain certification, the coating applicator must be able to show a disbondment radius of less than 3.0 mm on greater than 95 percent of the samples tested on a 3-month rolling average.

It is very important for the proper performance of the coating that damage to the coating be minimized or eliminated during handling and placing, and all damage is properly repaired.

H6.2.5

For epoxy-coated reinforcement, the ties should be either plastic or plastic coated to avoid coating damage which could cause the formation of a corrosion cell on the reinforcement at the tie.

H6.3 Dissimilar Metals

Dissimilar metals should be separated or be protected by electrically isolating (dielectric) coatings. To avoid possible contact between dissimilar metals which would cause the formation of a galvanic corrosion cell, a minimum separation of 40 mm is suggested. As dissimilar metals may be inadvertently electrically connected even where a separation is specified, a dielectric coating is the preferred approach.

Stainless steel and plain steel are dissimilar metals, as are galvanized steel and plain steel.

H6.4 Exposed Hardware, Embedded Materials, and Railings

H6.4.2 Embedded Materials

All surfaces of metal drains should be coated with a corrosion-resistant dielectric material, in order to avoid electrical contact between reinforcement and the embedded surface of the drain, and to provide corrosion protection to the exposed surfaces. An example of a corrosion-resistant dielectric coating is fusion-bonded epoxy applied to similar standards as the coating on reinforcing bars.

Where the drain and connecting piping are of different metals, a dielectric material should be used between the piping and the drain to prevent formation of a galvanic corrosion cell.

Where aluminum drains are used, they should be of an alloy conforming to CSA Standard CAN3-B79.

Uncoated cast iron, like other metals, has been found to corrode in the presence of chlorides in parking structures.

Plastic piping or drains may be used only if they meet the requirements of the NBC, including the requirements regarding flame spread and smoke-developed classification.

H6.4.3 Railings

Severe corrosion can occur to railings, particularly where the railing posts enter the concrete. If the post is grouted, a high-quality, low-permeability, noncorrosive grout that does not incorporate calcium chloride should be used. (Most metallic grouts contain calcium chloride.) There should be no depression left around the rail post where water can collect. Caulking around the rail post where it is embedded in the concrete can help to protect the post at this vulnerable location.

H6.5 Welded Steel Wire Fabric

Fabric supplied in rolls does not lie flat when placed, unless straightened with special equipment designed for this purpose.

H6.8 Steel Deck

The zinc coating is intended to protect only against atmospheric corrosion and not against deicing chemicals. Heavier zinc coatings cannot be applied because they crack when the deck is roll-formed.

Little data are available on the performance of steel deck with a membrane protection system on the top surface of parking structure floors. Few such systems are in existence in Canada at this time.

Membranes may tend to debond when the concrete is sealed top and bottom. Some breathability may be obtained at the joints in the steel deck. Approval should be obtained from the membrane manufacturer as to whether this is adequate.

H7. Design Requirements

H7.2 Volume Change Effects

Stiff elements such as walls, stair and elevator shafts, and large columns provide significant restraint against floor expansion and contraction. Such restraints have caused increased cracking in parking structure floors, and unacceptably extensive cracking in the stiff restraining elements.

For this reason stiff elements should be located where their restraining effects are minimized, such as at the midlength of the structure, or, when they are not required to resist lateral loads, they should be isolated from the floor with expansion joints. For below-grade structures, floors are not generally isolated from the exterior walls. In this case, consideration should be given to the effects of the restraint.

H7.3 Protection Systems and Concrete Cover

H7.3.1 Acceptable Systems

The acceptable corrosion protection systems are listed in Table 1. Additional protection may be warranted for special conditions such as greater than average design life requirements, inconvenience of closing the area for repair, occupied space below, difficulty of repair or importance of a structural element, or wherever particularly severe corrosion conditions are expected, including particularly heavy volume of traffic or severe chloride exposure.

Although the various systems listed in Table 1 are all considered acceptable, they do not necessarily provide equal protection.

The low-permeability concrete option is listed only for structural systems that are essentially crack free, such as prestressed systems. For concrete with cracks, such as nonprestressed concrete, the low-permeability concrete would not protect steel at cracks.

Calcium nitrite corrosion inhibitor is able to provide some measure of protection at cracks and is therefore included as an option in both prestressed and nonprestressed concrete.

H7.3.1.2 Low-Permeability Concrete

Low-permeability concrete generally requires all of the following:
(a) low water/cementing materials ratio mix;
(b) good consolidation; and
(c) good curing.

Without good curing, it is unlikely that the concrete will be of low permeability. Although a low water/cementing materials ratio mix is necessary, strength does not contribute to the corrosion protective properties of concrete.

Concrete with a water/cementing materials ratio of 0.35 and without supplementary cementing materials may be able to achieve a 1500 coulomb rating. With a water/cementing materials ratio of 0.40, it will probably be necessary to include supplementary cementing materials in the concrete mix to obtain a coulomb rating of 1500. Silica fume is particularly effective in reducing coulomb ratings at early ages (about 28 days). Slag and fly ash are also effective at reducing coulomb ratings, but their effect occurs at ages greater than 28 days, so that concrete with these materials might be more appropriately tested at 56 or 91 days.

Microcracking of silica fume concrete has been reported to be a problem in some cases. It has been found that use of slag combined with silica fume cement, together with proper mix design and curing, can alleviate this effect.

In some areas of Canada, ground granulated blast-furnace slag may not be available.

Tests on laboratory prepared samples indicate a reduction in deicer salt-scaling resistance of concrete containing large replacement of Portland cement with supplementary cementing materials (see Reference (29)). For surfaces not covered by a membrane and subject to deicer salt scaling, large proportions of supplementary cementing materials should not be used in the concrete mix unless it can be shown the salt-scaling resistance will be adequate.

Low-permeability concrete must be well consolidated and well cured (wet cured). A low water/cementing materials ratio (or high strength) is not sufficient by itself to assure low-permeability concrete. For example, concrete with a water/cementing materials ratio of 0.32 which is improperly consolidated is less resistant to chloride ion penetration than properly consolidated concrete with a water/cementing materials ratio of 0.6 (see Reference 27)). The temperature at which the concrete is cured may also affect permeability (see Reference (26)).

The specified coulomb rating should not be less than 1000, as the distinction in the permeability of concrete based on test results less than 1000 coulombs may be questionable.

It should be recognized that the permeability of concrete is not directly proportional to the coulomb rating, eg, a concrete with a coulomb rating of 3000 is less than twice as permeable as a concrete with a coulomb rating of 1500.

As with any test of concrete properties, there can be considerable variability in the test results. Test results marginally greater than the specified coulomb rating should not necessarily be cause for concern.

Concrete System (A1)

A membrane must be used with this structural system.

Since sealers cannot bridge cracks, this Standard permits reliance on sealers only for precast prestressed concrete (where cracking ought to be minimal).

The practice of using a sealer on a nonprestressed floor and dealing with the cracks by local waterproofing is not permitted. Cracks commence forming within hours of placing the concrete. New cracks form and existing cracks extend in length and width for years after construction. Despite measures to control cracking there will still be many cracks in a nonprestressed structure. Any attempt to deal with cracks by local waterproofing would require continual maintenance and repair, as well as monitoring to discern new crack locations. Leakage and damage to car finishes, and contamination of concrete with chlorides, could occur at new crack locations before the cracks are sealed.

Concrete System (A2)

In a 200 mm thick flat slab, only the top mat, stirrups, and top bars in beams would be required to be epoxy coated. In the case of a 125 mm thick slab, both the top and bottom bars in the slab would be required to be epoxy coated.

Galvanized bars are not considered to be as corrosion resistant as epoxy-coated bars that are properly coated (refer to Clause H6.2.1) and handled. Zinc does not perform well in an alkaline environment. In general it appears that only a slight increase in life will be obtained in severe chloride environments (see Reference (16)).

Concrete Systems (B1) and (B2)

A sealer is no longer considered adequate as a corrosion protection system for reinforcing bars in bonded or unbonded post-tensioned structures, or for metal ducts in bonded post-tensioned structures. If the reinforcing bars or ducts corrode, repair of the resulting concrete spalls and delaminations is likely to cause damage to the tendons and tendon sheaths. For this reason, post-tensioned structures are considered to require more protection against corrosion than structures that are not post-tensioned.

A membrane is recommended for systems 8, 9, and 10 in Table 1, if a longer than normal service life is required, such as where the parking structure supports a significant superstructure, or where the effects of restraint cannot reliably be determined and accounted for in the design. In areas in southwestern British Columbia where deicing chemicals are seldom used, a membrane may not be necessary for systems 8, 9, and 10 if the effects of restraint on the effective prestress can reasonably be determined and taken into account in the design.

A sealer may be used in addition to the protection systems in Table 1, for supplementary protection, but the owner should be advised regarding the requirements for periodic reapplication, including surface preparation.

Plastic duct for bonded post-tensioning is not covered by this Standard. If plastic duct is considered as an alternative to metal duct, tests should be carried out to assess the effects on structural behaviour, fire resistance, and grout penetration. Ducts with concentric (ie, not spiral) grooves have been found to cause voids in the grout.

Concrete System (C)
The requirements of Table 1 are designed to protect steel in the top 100 mm of the slab, unless otherwise noted. Therefore if a 75 mm thick cast-in-place bonded concrete topping is used on a precast unit, and the corrosion inhibitor option is selected, the corrosion inhibitor would be required in the topping but not the precast unit, provided that the steel (bars or mesh) in the flange of the precast unit has at least 25 mm of cover.

H7.3.3(b) Stairs

In some garages, for sanitary or other reasons, it is necessary to wash down the stairs at frequent intervals. In such cases, steel stair treads and landings filled with concrete or other materials should not be used, even when galvanized, because the zinc coating has a limited life. For concrete stairs subject to frequent washdowns, consideration should be given to additional protective measures.

H7.3.5 Severe Exposure

Areas governed by the severe exposure classification include
(a) where the waterproofing membrane is subject to more rapid wear due to high volumes of traffic or snowploughs; and
(b) areas expected to be exposed to relatively large amounts of deicing chemicals, caused either indirectly by being tracked onto the floor by high volume of traffic, or directly by application of deicing chemicals to melt snow or ice from roadways and walks. Granular fill under roadways and walks, regardless of depth, does not diminish the exposure classification, because such material is permeable.

H7.3.6 Prestressed Elements for Table 1

Concrete members are considered prestressed only if the stress limitations in Clause 7.3.6 are met. Criteria (a) and (b) apply in both directions, except as otherwise noted.

For Clause 7.3.6(a), the more critical load combination would generally be prestress load plus dead load plus live load for stress at the support, and prestress load plus dead load for midspan stress. For continuous spans, the live load should be applied on alternate spans to determine the most critical midspan stresses.

The analysis of stresses should be based on the actual tendon profile, including the effects of horizontal lengths of tendon. Approximations of the tendon profile should not be used.

All restraints to dimensional changes, such as those resulting from columns and walls, should be included in the analysis.

The indeterminacy of the precise degree of restraint, concrete tensile strength, member stiffness, and distribution of prestress within the floor warrants the limitation of the extreme fibre tensile stress to a value less than the modulus of rupture of the concrete.

The designer may choose to use a greater degree of prestress than that necessary to satisfy the requirements of this Clause. However, care should be taken not to prestress to a degree that would cause cracking of columns or walls or excessive creep deformation.

To meet the stress limits and concrete cover requirements, deeper members and members with greater prestress force may be necessary than those required to meet the minimum requirements of CSA Standard A23.3.

H7.3.7 Specified Concrete Cover

Increased cover and reduced water/cementing materials ratio each provide resistance to salt penetration, as shown in Figure H3 (see Reference (1)). In these tests, salt was applied daily to unprotected specimens (no membrane), and the time to the start of corrosion of the reinforcement was recorded. The daily salt applications used in the tests do not correspond to the salt applications in actual garages. Therefore, the results show relative times, and cannot be used to predict actual times to corrosion.

H7.3.8 Minimum Actual Concrete Cover

The actual concrete cover is the clear distance to the reinforcement when measured on-site after the concrete is cast.

In a survey of cover over reinforcement in bridges by the Ministry of Transportation of Ontario (see Reference (10), it was concluded that the quality of construction represented by a "diligent" bridge contractor corresponded to a standard deviation of 10 mm. When "tolerance" is defined as 2 standard deviations, this corresponds to a 20 mm tolerance. A study of 36 typical parking structures found even larger standard deviations (see Reference (11)).

Since the variation between specified cover in Clause 7.3.7 and actual cover in Clause 7.3.8 is only 12 mm, it is apparent that the quality of workmanship must be very good to achieve this. Special care during construction and rigorous inspection are needed to meet this tolerance. The bar chairs should be checked and adjusted after the trades have finished their work, and as soon as possible prior to concrete placing. Rigorous and positive control of slab thickness before and during construction is also required.

H7.3.10.1

It is a fundamental distinguishing characteristic of a membrane that it has the capability to span cracks up to a limited width that form in the concrete after the membrane is installed.

H7.3.10.2

Membranes should be extended up vertical surfaces so that water containing deicing chemicals cannot penetrate under the membrane or wick up the vertical surface.

Additional protection to vertical surfaces is also desirable to protect against splashing and, where there is no floor membrane, to prevent water from wicking up the concrete. This can be achieved by applying a sealer to vertical surfaces for 600 mm above the floor (see Figure H5).

Vertical structural elements at their junction with a slab on ground should also be protected (see Figure H6).

H7.3.10.4

All membranes and some surface sealers significantly reduce the vapour transmission rate. Sealing the opposite surface with a nonbreathing coating, steel decking, or other barrier may cause entrapment of moisture and concrete damage due to freeze-thaw, or may cause peeling of membrane or surface sealer, due to vapour pressure. If the soffit of a slab with these protection systems is painted, it should be with a breathable type of paint, so that moisture in the slab can escape.

Paint applied to concrete soffits has not been an effective barrier against corrosion of bottom reinforcement.

H7.3.11 Sealers

A sealer is required only on the vertical surfaces specified in Clauses 7.3.11.1 and 7.3.11.2. Consideration should be given to applying a sealer to vertical surfaces to 600 mm above the floor, at columns and walls supporting multistorey superstructures, where extra protection may be desirable because of the difficulty in shoring and repairing these highly loaded members.

H7.3.11.2
Prestressed concrete structures and nonstructural slabs on ground are permitted to be built without a membrane. The requirements of Clause 7.3.11.2 apply to these cases.

H7.4 Joints

H7.4.1 Construction Joints

H7.4.1.1
Construction joints are frequent leakage areas. In structures with nominally flat floors they should be located at the high points to minimize exposure to moisture and runoff.

H7.4.1.3
Construction joints often open at the top surface, even when located at midspan, because shrinkage and temperature induced tensile stresses can exceed the flexural compressive stress. For this reason, top reinforcement is required to control opening of the top of the joint.

H7.4.2 Expansion Joints and Sliding Joints

H7.4.2.1
References (4) and (21) categorize expansion joints as compression seals, strip seals, and sealant "T" joints. The various types of expansion joints are illustrated in Reference (21).

A compression seal usually consists of extruded neoprene with an internal rib system that deforms when compressed. It is installed by compressing it into the joint, and it must remain in compression to be effective. A lubricant adhesive may be used to install the seal and adhere it to the concrete, or seals with mechanical interlocks may be used. If the joint opens to the extent that there is no compression, the seal will fail.

A strip seal is also usually made of extruded neoprene, but it can work in tension or compression. It is secured to the faces of the joint by mechanical seals embedded in the concrete, or by a polymer concrete. Movement is accommodated by fold(s) or a bulb within the element.

The sealant "T" joint is a thin band of urethane elastomer over a traffic plate. It is chemically bonded into place and works either in tension or compression. Because the seal is of softer rubber, its traffic dimension is larger (typically 150 to 300 mm) than compression or strip seals, and it tends to "hump up" when in compression. As a result it can be damaged by snowploughs or traffic abuse.

An example of a structural sliding joint is shown in Figure H7. Sliding joints should be made of neoprene or other material specifically intended to accommodate movement. Concrete-to-concrete, building paper, or polyethylene and other thin materials that rely upon near perfect flatness and levelness of the bearing surface have not performed well and should not be used.

Shop drawings of joint hardware should be submitted to the designer for review, showing items such as layout, prefabricated corner pieces, intersections, rebates, junctions with vertical surfaces such as walls and columns, interface with the membrane, and installation procedures.

H7.4.2.6
Leaking expansion joints have been a problem in many parking structures. In the majority of the garages studied in one survey, a significant percentage of the total joint length was leaking or otherwise defective (see Reference (11)). Because there can be a considerable length of expansion joint in a parking structure, this can be an expensive item to replace. Inexpensive joint seals have not performed well.

Relative movement across an expansion joint can be perpendicular or parallel to the joint in a horizontal plane, or in a vertical direction, or some combination, depending on the structural design and joint layout. Seals can generally accommodate least movement in a direction parallel to the joint. Wherever possible the direction of joints with seals should be at right angles to the direction of the expected movement of the structure. The expected movements in each direction should be calculated and the specified joint seal selected that can accommodate the movements.

Expansion joint hardware should be set at the proper width, taking into account the temperature of the structure at time of installation, and the expansion and contraction of the structure corresponding to the expected maximum and minimum temperatures of the structure and the expected concrete shrinkage.

H7.4.3 Control Joints in Concrete Toppings

H7.4.3.4

Control joints in bonded toppings are usually tooled rather than sawcut because

(a) tooled joints are open, visible, easily cleaned, and large enough for easy application of the sealant; and

(b) delay in sawing may result in the formation of shrinkage cracks.

In unbonded concrete toppings over waterproofing, because of the number and length of joints in each direction, the joints are usually sawcut. The joint should be sawcut as soon as it is possible to do so without dislodging the aggregate. There are proprietary saws that allow earlier sawcutting than is possible with conventional equipment.

H7.5 Slopes and Drainage

Good drainage is a part of the defence against water and corrosion.

H7.5.1

Neither short-term deflections of the floor system nor long-term deflections (resulting from shrinkage, creep, and thermal and moisture variation) can be predicted with precision. Sufficient allowance should be made in slopes so that deflections do not render drain placement ineffective. The purpose of the slope is to minimize or eliminate ponding of water. Particularly vulnerable to damage from water ponding are unprotected vertical surfaces, tendons at the anchorages, and joints that are difficult to make watertight.

H7.5.2

The design slope is intended to achieve sufficient actual slope in the finished floor, after allowing for finishing tolerances and variations between predicted and actual deflections.

In some cases, the 1.4% minimum slope of the valley will govern the slope of the drainage plane.

Where floors have a single sloping plane from one side of the floor to the other side, a cross fall in a perpendicular direction should be provided, with a minimum 2% slope to direct water to the drain.

Slopes that are too large can sometimes cause problems, such as shopping carts rolling away.

H7.5.4

Vertical construction joints in slabs and horizontal construction joints at the base of walls and columns are vulnerable to water entry.

Although properly encapsulated tendon anchors are theoretically waterproof, as a first line of defence, water should be directed away from the vicinity of anchorages.

Very high chloride concentrations have been found at slab edge faces. This may be caused by water dripping from car bumpers that overhang the perimeter curb, or by leakage at the ends of floor expansion joints, at balustrade expansion joints, at cold joints between balustrade and columns, etc.

A continuous curb should be provided to prevent water from flowing over edges. The joint between floor and curb, and between columns and curb, should be made watertight. Figure H4 shows a suggested detail.

The floor should be sloped to drain water away from the slab edge.

H7.5.6
Typical drain locations are illustrated in Figure H9. In precast structures drains should not straddle the joint between units.

H7.5.7 to H7.5.10
The characteristics of a good drain are illustrated in Figure H10. The antiponding feature is also illustrated.

Hinged grates that close when released are recommended for parking structures. Screw secured grates are difficult to lift to clean the sediment bucket, and consequently the screws are often not replaced.

If the drain has no antiponding feature, then it should be recessed about 10 mm to avoid localized ponding. Larger recess is not recommended in traffic areas, because of possible damage to the grating from wheel impact.

The secondary drainage holes are to permit drainage of water that permeates below the finished surface. Examples are landscaped areas and wear courses that are not bonded to the membrane (eg, separate concrete topping). The drainage holes should be large enough that they are not easily blocked.

The requirement in the previous edition of the Standard, that drains on nonramped floors be spaced so that not more than 400 m^2 of floor be tributary to each drain, has been deleted as it was felt to be unnecessarily restrictive in some instances.

H7.5.12
Drainage should not be directed toward the vulnerable tendon-to-anchorage connection area. Also, ponding due to drain blockage is undesirable in this area.

H7.5.13
Many below-grade garage walls have leakage at construction and expansion joints, at form tie holes, and at shrinkage cracks that inevitably form. This leakage is often traceable to the type of backfill material, or a clogged weeper system. If the on-site material is not granular and free-draining, an imported clean free-draining granular material should be used, or an effective preformed vertical drainage system installed. A geotechnical engineer can advise, based on soil borings, whether the site material is suitable for use as a free-draining backfill.

A perimeter weeper system, draining to a frost-free sump, should be installed with its invert below the underside of the floor. The weeper system should include access provisions for periodic flushing clean. The weepers should be surrounded by a filter medium such as a geotextile filter fabric or 150 mm of pea gravel all around the weeper surrounded by an outer layer of 300 mm of fine aggregate meeting the requirements of CSA Standard A23.1 for fine aggregate for concrete. In some areas of Canada, the native soil is sufficiently free-draining to adequate depth that a weeper system is not required; a geotechnical engineer can advise on this.

Exterior grade should slope away from the building. Consideration should be given to the watertightness of form tie locations.

H7.6 Services

H7.6.1

Embedded metal conduits have had a high incidence of corrosion. In some cases they have become waterfilled.

H7.6.3

In indoor, heated garages, each floor should be provided with a water supply. In open-air and unheated structures, where exposed piping may freeze and burst in winter, other means of providing water, such as hoses from a standpipe, should be employed.

H7.7 Heating Cables and Pipes

Problems with ramp heating have included corrosion of the heating elements (including metal sheathing around electrical heating cables), connecting piping, and electrical conduits, resulting in leaks, electrical breakdown, excessive maintenance, and damage to the ramp surface. Metal components can be protected by various means, including cathodic protection.

H7.8 Precast Concrete Slabs with Voids

The drainage holes in precast concrete slabs with voids (ie, hollow cores) are required to drain out any water that may enter the voids during storage, shipping, or erection.

H8. Additional Requirements for Cast-in-Place, Post-Tensioned Concrete Construction

H8.2 Stressing Pockets

The tendon in the anchorage area has been found to be very susceptible to corrosion. The protection of the anchorage area cannot be overemphasized. There should be multiple protection systems, so that if one system fails, protection will be provided until the failure is detected and repaired.

It has been found that water can enter the grout plugs along the interstitial space that is created between the concrete and the grout plug when the plug shrinks. The sides of the concrete should be roughened to remove the laitance and enhance the bond of the grout. Laitance can be removed by wire-brushing or sand-blasting. However, regardless of the surface preparation and materials used, the grout plug should not be relied upon to be totally watertight. For this reason, CSA Standard A23.1, Clause 25.2.7 requires a watertight fitting to the anchorage to resist a hydrostatic head. The grout plug is then secondary protection.

A typical protection system for tendons and anchorages is shown in Figures H11(a) and H11(b). In the illustrated system, the tendon is placed with the sheath extending through the live end anchor to protect against moisture entry (to the spaces between the wires) before the tendon is encapsulated. The sheath is cut around its circumference to facilitate later removal. Some engineers require that the tendon ends projecting beyond the formwork be covered with plastic caps, or be tied down so that the tendon slopes downward and will not direct rain water into the tendon. When ready to jack, the sheath is removed to the cut point. If the plastic trombone connecting the sheath to the anchor is not tight fitting with no voids, then the plastic trombone should be injected with coating material to fill all voids.

H8.3 Joints

Tendons terminating at exterior walls below grade should be protected against a hydrostatic head of water by backfilling the foundation with clean, free-draining granular material or by a prefabricated geotextile drainage system, and by an effective perimeter drainage system (see also Clause H7.5.13). In addition, the joint and the wall in the vicinity of the joint should be made waterproof.

H8.4 Proximity to Drains

H8.4.1

It has been found that drains sometimes corrode to the extent that replacement is necessary. To permit concrete removal and drain replacement without damaging adjacent tendons, tendons should be located at least 300 mm away from the drain edge.

H8.5 Qualifications

Post-tensioning construction requires good workmanship in order to avoid durability problems. Extra care is needed to achieve good workmanship under job site conditions.

The certification program should include the proper procedures to be followed, as well as the problems that can arise if special care is not taken. At time of publication of this Standard, courses were available at the British Columbia Institute of Technology and the Post-Tensioning Institute.

H9. Additional Requirements for Steel Structures

H9.1 Curbs

A curb is required at steel columns penetrating floor slabs to keep water away from the column, and to facilitate upturning the membrane. If no membrane is used, the joint between floor and curb should be made watertight.

H9.3.1

Composite steel deck, where the deck acts as all or part of the tensile reinforcement, is not permitted because it is subject to corrosion which cannot be repaired without removing the deck and slab.

H9.6.2

The CGSB Standard 85-GP-11M painting requirements allow the designer a wide latitude in system selection. All the systems are suitable for both interior and exterior exposures. In rare instances, where exceptional exterior gloss and colour retention are required, a 1-GP-177M polyurethane can be substituted for the 1-GP-146 epoxy.

The alkyd paint system allowed by 85-GP-11M utilizing the 1-GP-48 primer should be approached with caution. It is not the best exterior system when subject to a seacoast marine environment, or for interior surfaces where prolonged condensation, leakage, or splashing can be expected. The 1-GP-48 primer also contains red lead pigments that eventually will be classified as hazardous both during application and disposal. There are proprietary lead-free primers that can be used as replacements for 1-GP-48, but usually higher film builds are required.

Regardless of which coating system is used, the ultimate success will depend on details incorporated during the design stage. This will include the deliberate elimination of complicated joints, inaccessible areas, flame cut edges, lap joints, stitch welding, and weld splatter. As adequate coating thickness is difficult to achieve at sharp edges, such as at sheared edges of plates, they should be slightly ground to remove the sharpness. Open-web joists should be avoided as they are difficult to clean and paint properly.

H9.7 Weathering Steel

In structures of weathering steel framing, the potential for staining of cladding materials, vehicle finishes, and adjacent structures due to the oxide runoff during the weathering process should be taken into account.

Under suitable conditions, the corrosion rate of weathering steel is significantly less than ordinary structural steel.

For weathering steel to form its protective oxide coating, it must be exposed to intermittent wetting and drying. For this reason, weathering steel should not be used in enclosed structures.

Studies by the Ministry of Transportation of Ontario, and others, indicate that the presence of chlorides prevents the formation of a stable oxide and corrosion will proceed, and that there are difficulties in the cleaning and painting of weathering steel which is contaminated by chlorides and exhibiting pitting corrosion (see References (12) and (13)).

H9.8 Crack Control Over Girders

Recommendations for determining the amount of top reinforcement are given in Reference (18).

H10. Construction

H10.3 Deicing Chemicals

The practice of melting ice and snow on formwork or concrete surfaces with calcium chloride or other corrosive deicers is not permitted because of possible contamination of the concrete. Non-corrosive deicers, such as urea, can be used if deicing is necessary. Chloride deicers have sometimes been placed in trucks delivering materials such as concrete aggregates, so that the aggregates will slide off the truck more readily. This practice is also not permitted.

H10.4.1

Small diameter bars, such as No. 10 bars, are prone to permanent deformation under a person's weight, even with close spacing of bar supports. Consideration should be given to the use of No. 15 minimum size top bars, even if there is some sacrifice in economy.

H10.5.3

This is the criterion used by the Ministry of Transportation of Ontario for epoxy-coated bars.

H10.5.7

Contractors should be familiar with the handling procedures to minimize damage to the epoxy coating, and should have their own quality control program to confirm that these procedures are followed.

H10.6 Tendons

Useful information on single-strand tendon installation may be found in the *Field Procedures Manual For Unbonded Single Strand Tendons,* published by the Post-Tensioning Institute (see Reference (23)).

H10.8 Curing

H10.8.1

Formwork left in place, or curing blankets that are maintained wet, are effective means of curing. Wet burlap is effective if adequate care is taken to monitor and maintain it wet. Covering the burlap with polyethylene is helpful in maintaining the moisture. The maintenance of proper curing procedures for 3 days at 10°C minimum should provide a good cure. Additional curing time would further enhance the durability of the concrete, particularly for structures where early exposure to aggressive conditions may occur, such as structures constructed in the fall. Additional curing beyond 3 days may sometimes be necessary for concrete containing supplementary cementing materials that retard early strength gain.

H10.8.2

Curing compounds are significantly less effective than a wet cure. A wet cure should be used where practicable, such as top surfaces of slabs. However, curing compounds may be the only practical means of curing soffits and vertical surfaces after form removal, where forms are removed before the end of the minimum curing period.

H10.10 Vehicles

Construction traffic may be a source of deicing chemicals as well as oils and other contaminants. Vehicles that would track in road salts, including construction workers' cars, should be kept off the slabs until the protection system is complete. Other contaminants, such as various engine lubricants and fluids, could also be deposited on the slab by vehicles, and may have to be removed before applying the protection system. For this reason, traffic should be restricted to motorized equipment necessary for the construction.

H10.11 Acids

Acid etching should not be used as it has been found not to be a good surface preparation for the application of moisture barriers.

Hydrochloric acid, also known as muriatic acid, will contaminate the concrete with chlorides if not thoroughly washed off the concrete reasonably soon after application.

H11. Inspection and Testing

The designer and the contractor should be aware that more extensive and rigorous quality control and inspection and testing are required for a parking structure than for many other types of structures.

H12. Maintenance

The maintenance program should include
(a) method and frequency for cleaning the floors;
(b) frequency of cleaning drains and sediment buckets;
(c) frequency of checking for ponding water;
(d) frequency of checking for leaks;
(e) frequency of checking membranes for worn areas in wearing course and membrane deterioration;
(f) frequency of sealer reapplication, or method of so determining;
(g) frequency of structural inspections for deterioration such as concrete spalling, delamination, and significant cracks;
(h) equipment for snow removal (such as rubber-tipped blades);
(i) use of deicing chemicals; and
(j) method of cleaning stairs (frequent washing down of steel stairs may accelerate corrosion of steel components).

A recommended maintenance schedule is included in Appendix E.

H13. References

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(6) C.A. Peterson, *Survey of Parking Structure Deterioration and Distress,* Concrete International: Design and Construction, Vol. 2, No. 3, March 1980, pp. 53-61.
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(14) G.T. Suter, *Deterioration of Parking Structures: Extent, Causes and Repair Considerations,* The Research Division, Policy Development and Research Sector, Canada Mortgage and Housing Corporation, October 1985.
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(19) *Specification for Unbonded Single Strand Tendons,* Post-Tensioning Institute, July 1993.
(20) D.G. Manning, *A Rational Approach to Corrosion Protection of the Concrete Components of Highway Bridges,* Ministry of Transportation of Ontario, ME-86-06, October, 1986.
(21) *Guide to Joint Sealants for Concrete Structures,* ACI 504R-77, ACI Manual of Concrete Practice, 1994, Part 5, pp. 504R-1 to 504R-57.
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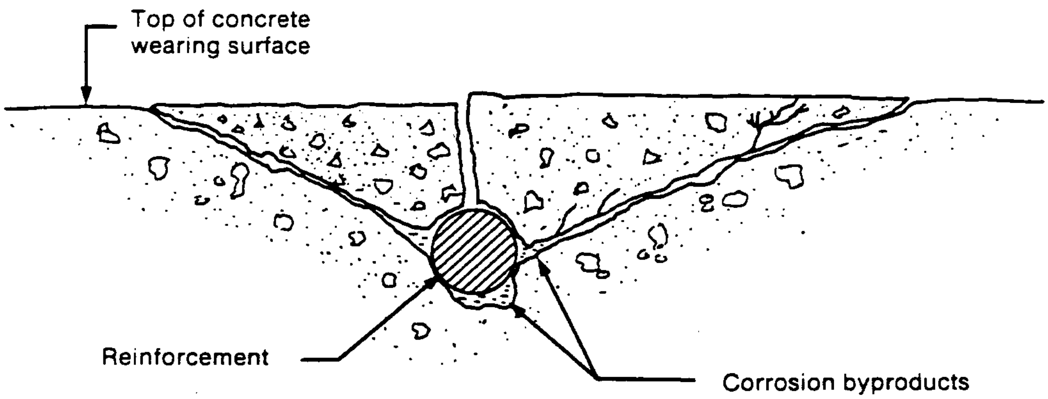


Figure H1
Shallow V-Shaped Fracture Surface at Corroded Reinforcement
(Adapted from Reference (6).)
(See Clause H4.)

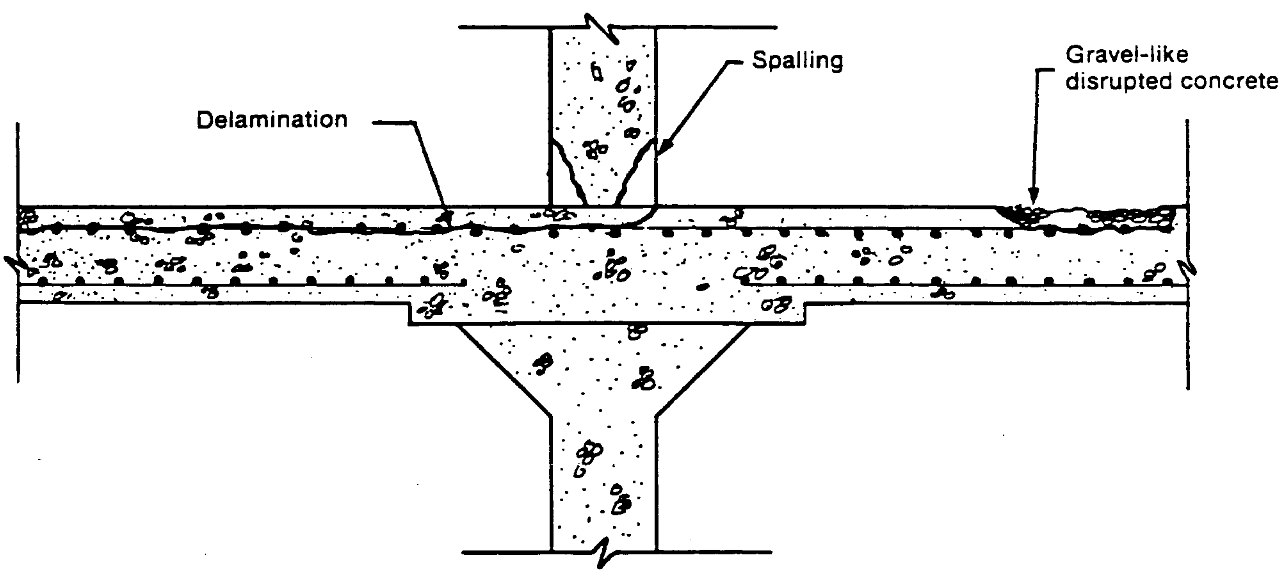


Figure H2
Delamination at Corroded Reinforcement
(Adapted from Reference (6).)
(See Clause H4.)

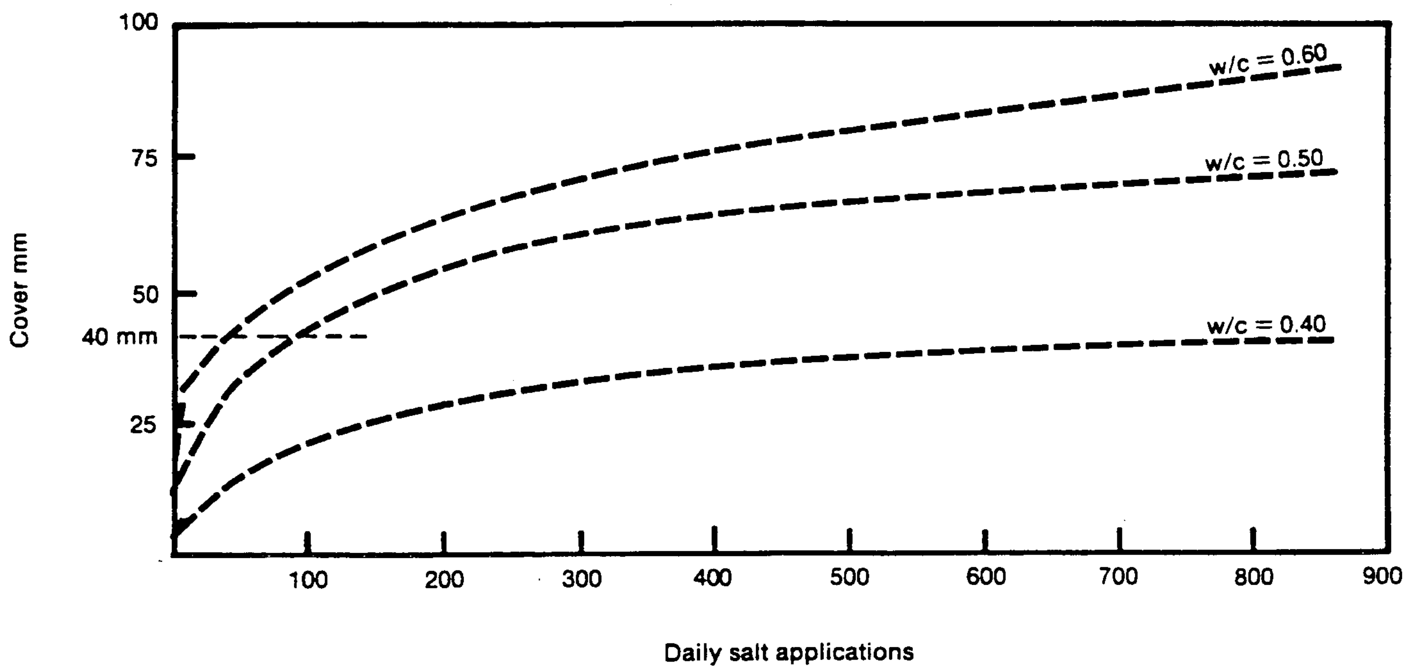


Figure H3
Relative Time to Corrosion for Concrete Containing Normal Portland Cement Without Supplementary Cementing Materials
(Adapted from Reference (1).)
(See Clause H7.3.7.)

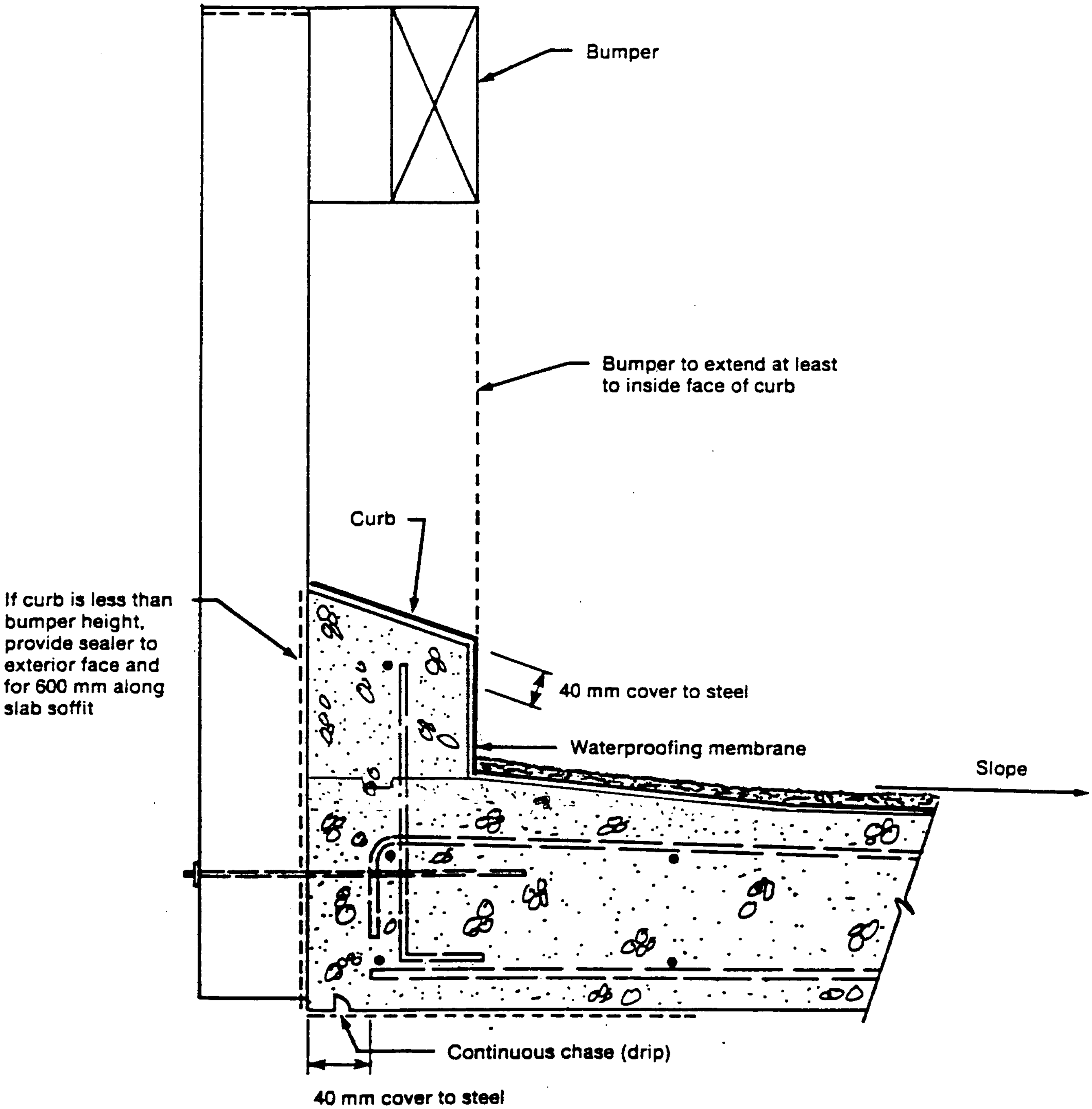


Figure H4
Typical Edge Detail
(See Clause H7.5.4.)

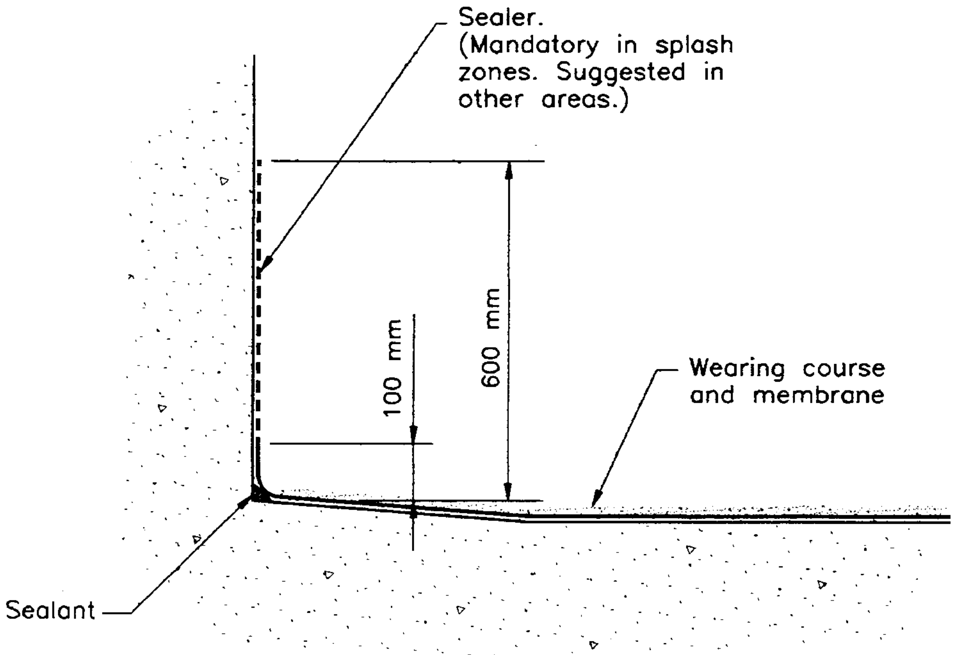


Figure H5
Horizontal to Vertical Transition
(See Clause H7.3.10.2.)

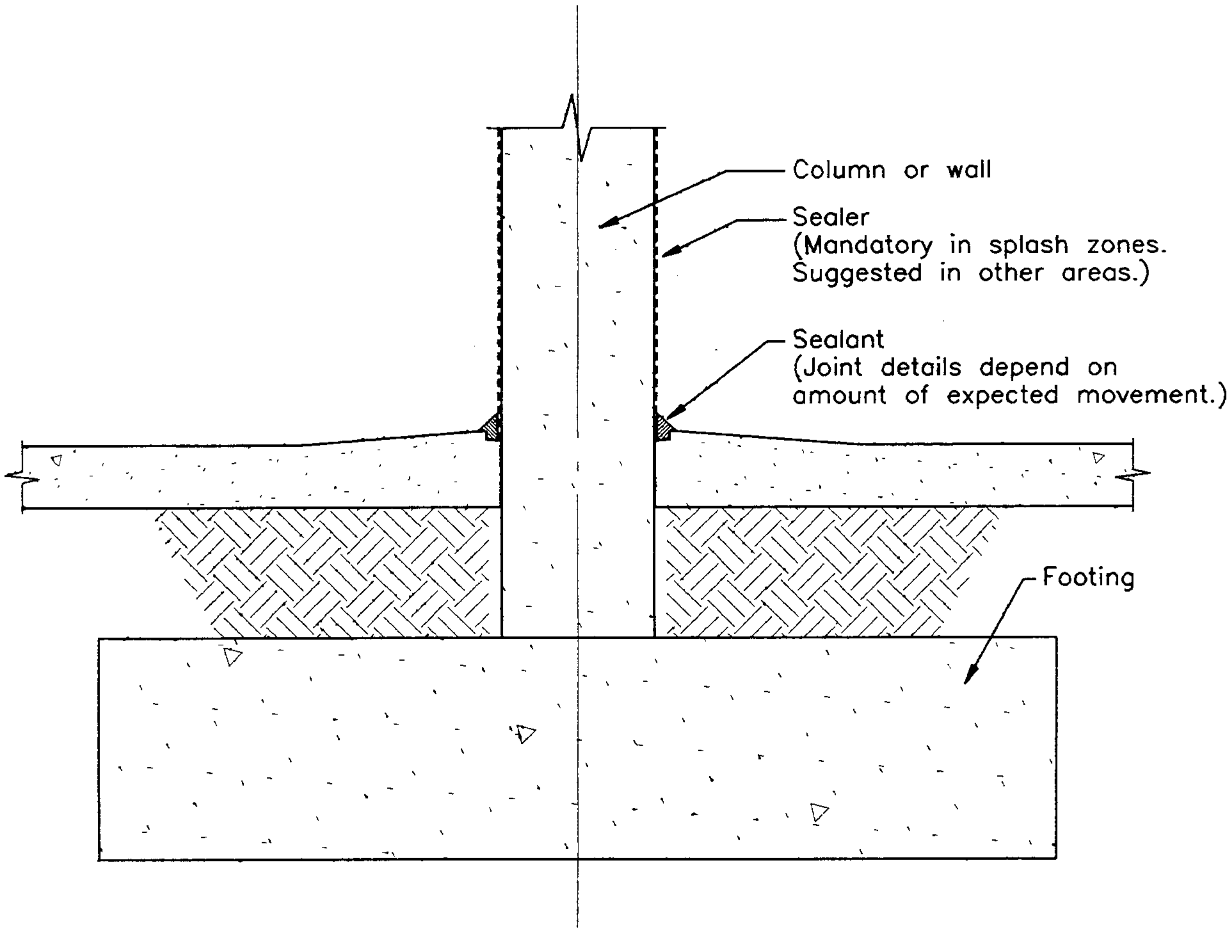


Figure H6
Protection of Vertical Element at Junction with Slab on Ground
(See Clause H7.3.10.2.)

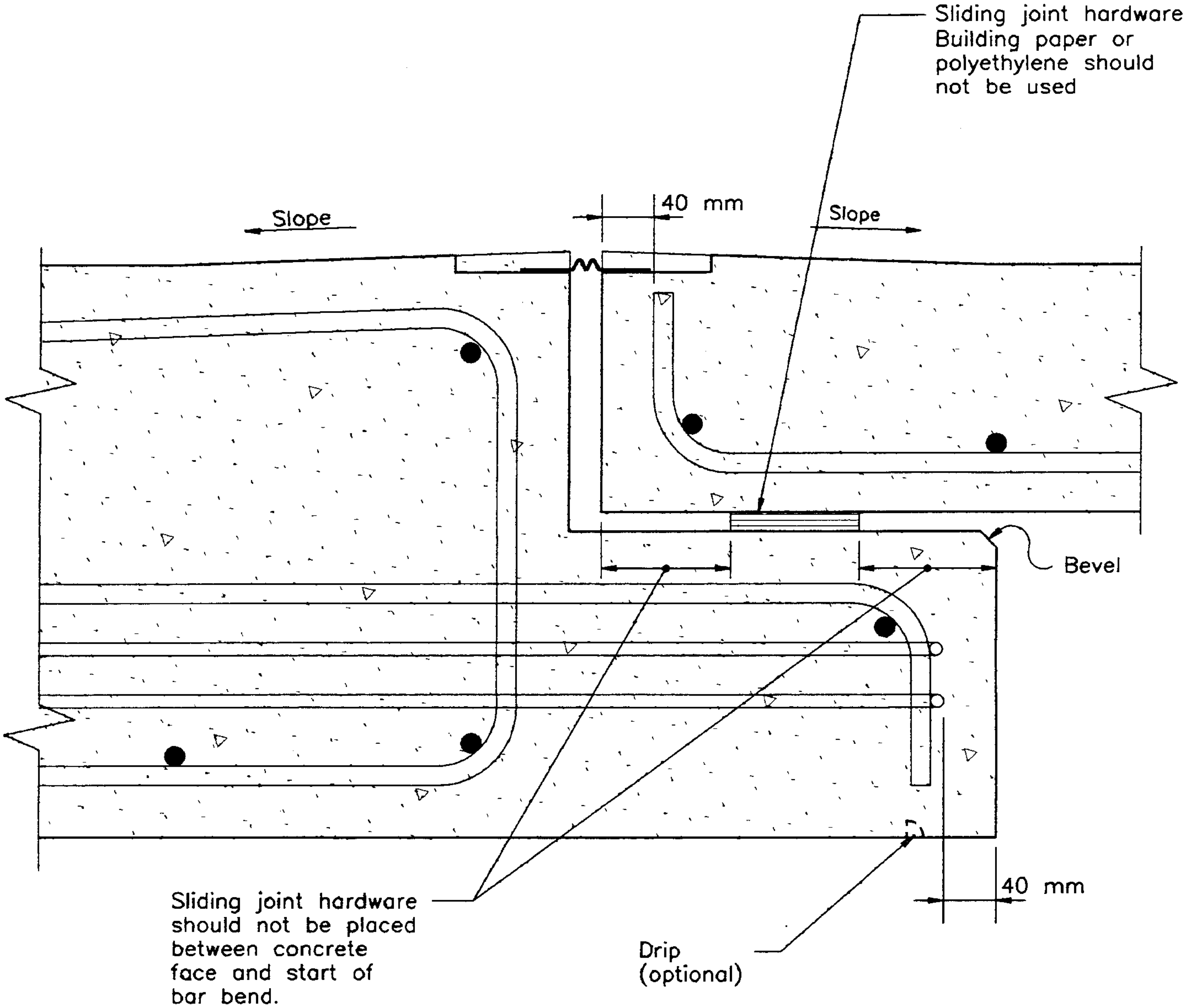
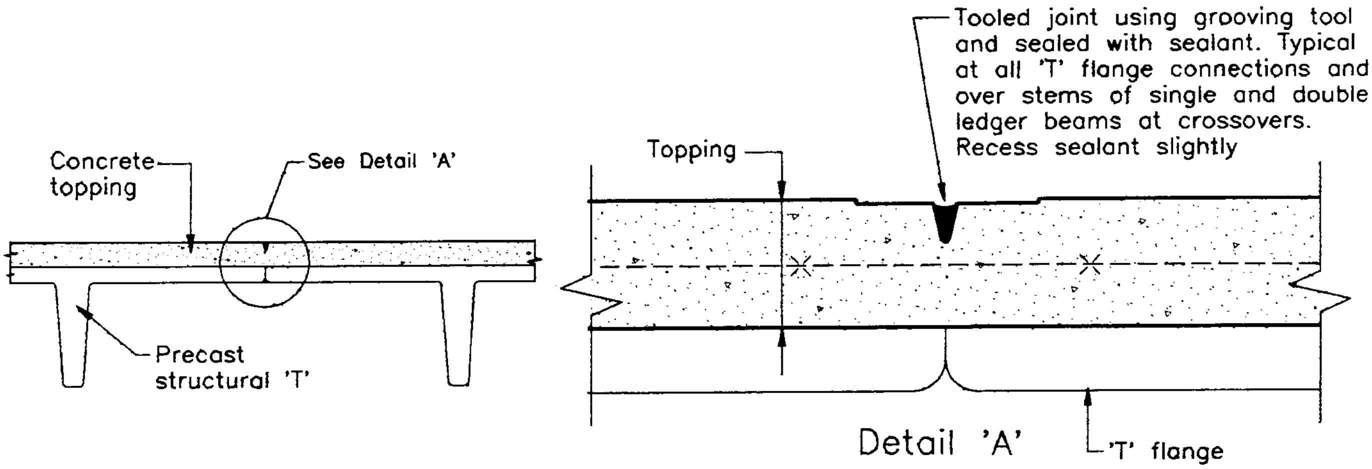
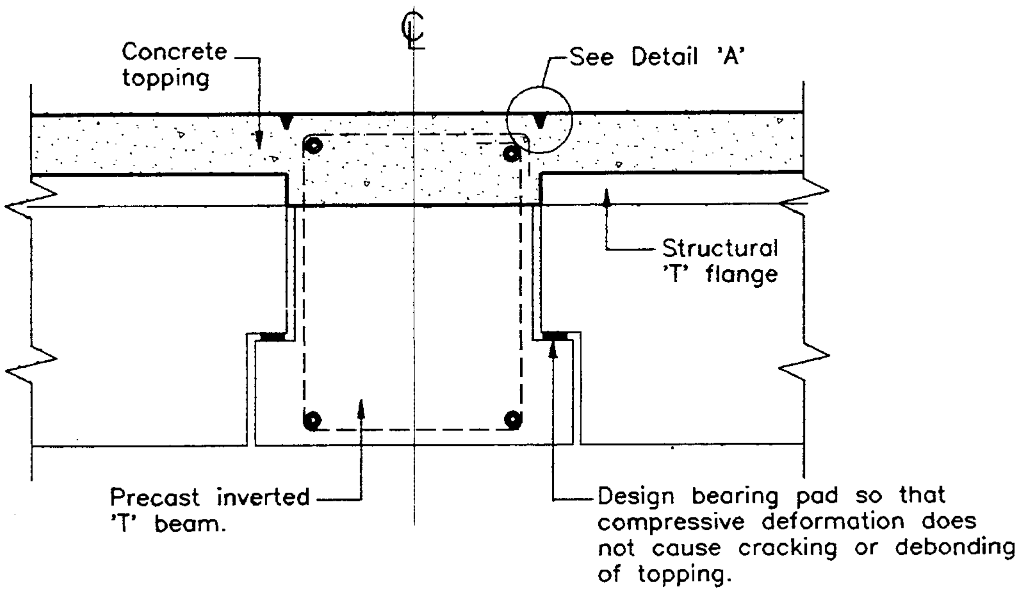


Figure H7
Sliding Joint
(See Clause 7.4.2.)

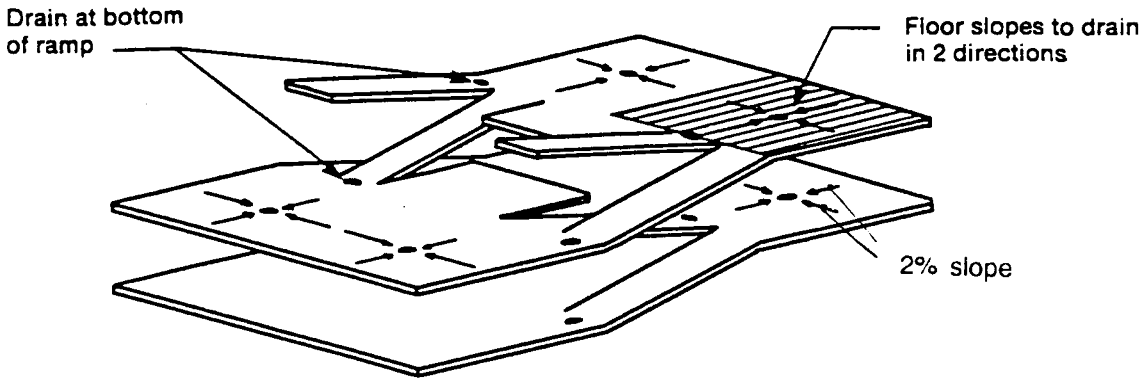


(a) Typical Control Joint Detail in Topping at Precast "T" Flange Connections

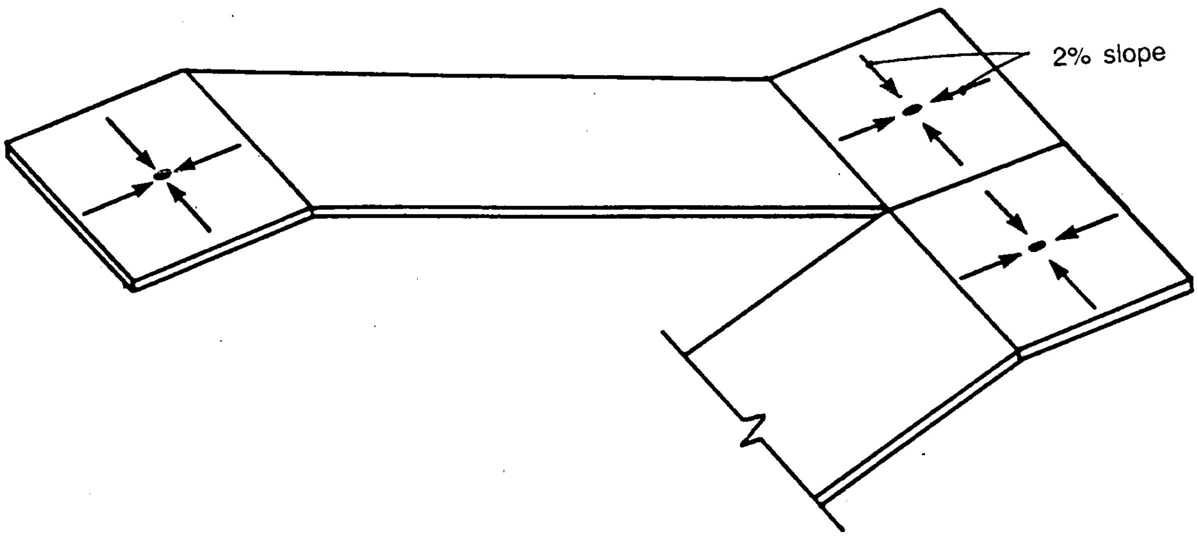


(b) Typical Control Joint Detail in Topping Over Single and Double Ledge Beams of Crossovers

Figure H8
Control Joint Details



(a) Nonramped Floor



(b) Ramped Floor

Figure H9
Typical Drain Locations
(See Clause H7.5.6.)

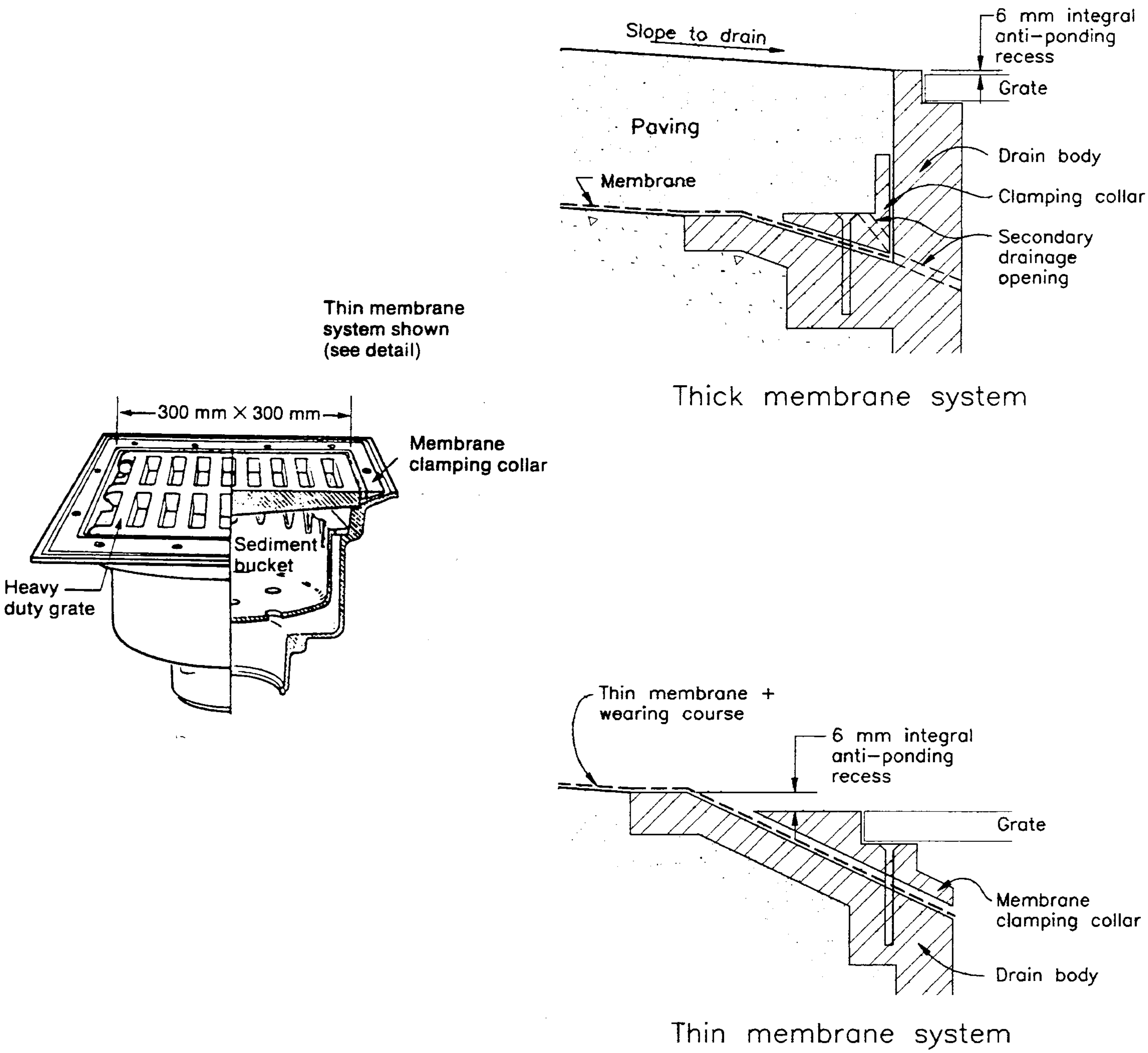
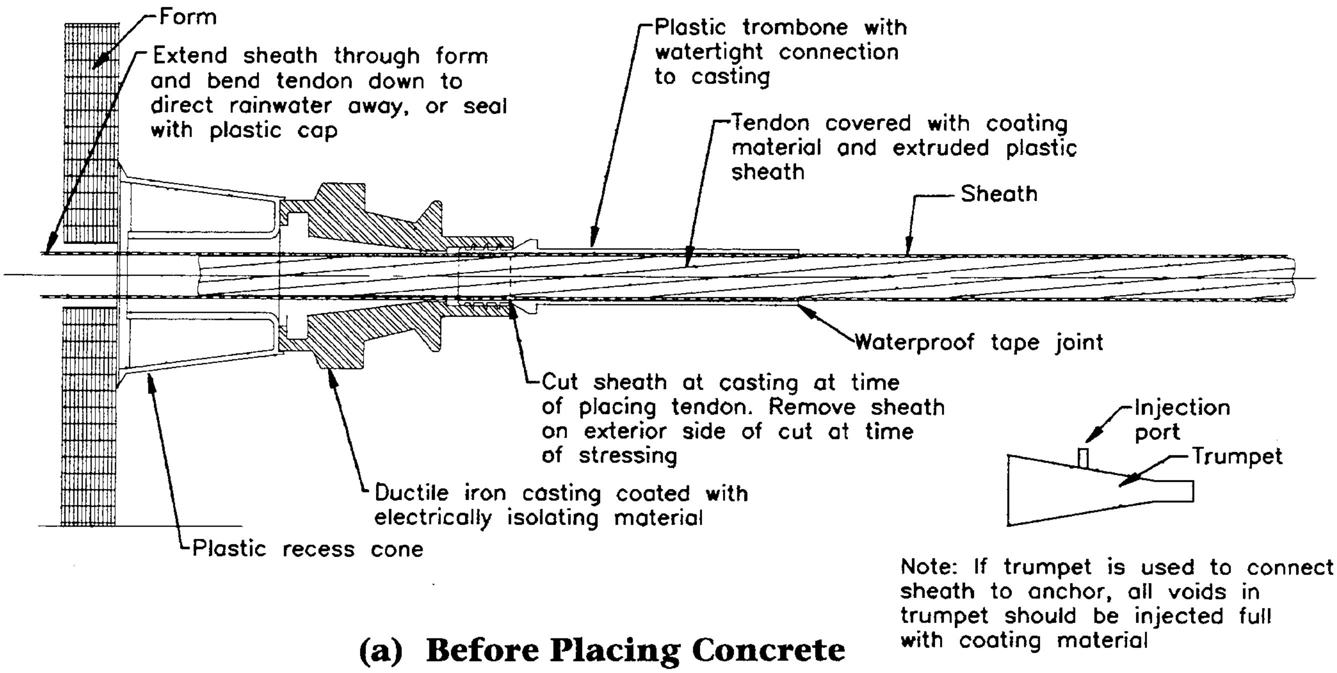
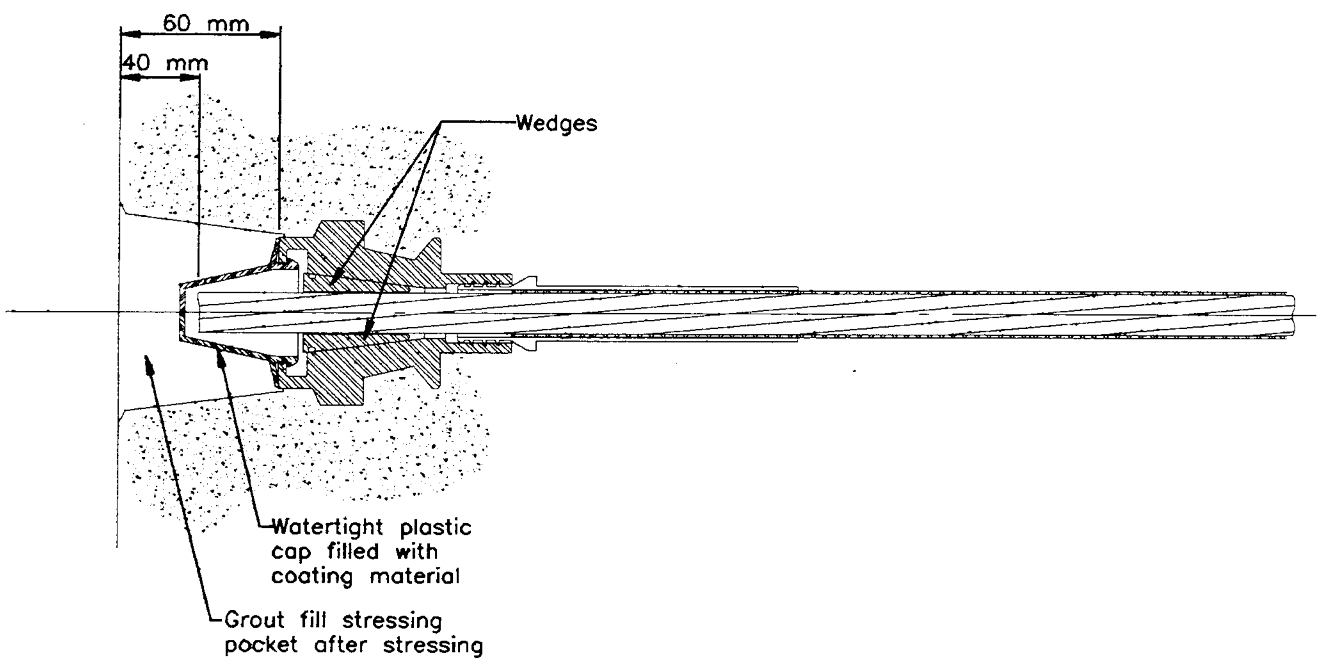


Figure H10
Typical Detail Parking Structure Drain
(See Clauses H7.5.7 to H7.5.10.)

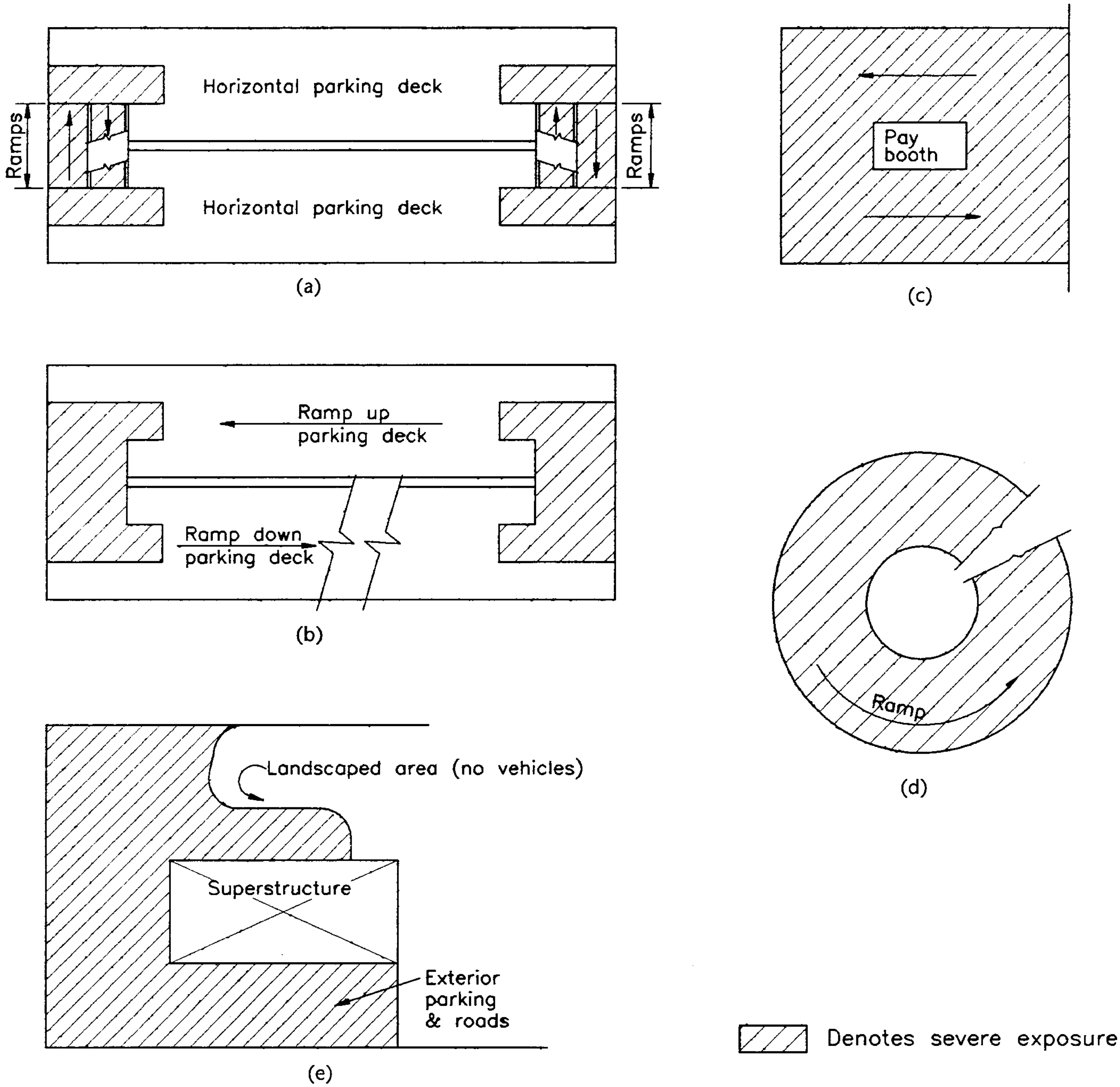


(a) Before Placing Concrete



(b) After Stressing

Figure H11
Prestressing Anchor Assembly
(Stressing End Shown; Dead End Similar;
Reinforcement Not Shown)
(See Clause H8.2.)



Note: *Figures (a) to (d) apply to thin traffic deck waterproofing systems. Figure (e) applies to both thin and thick traffic deck waterproofing systems.*

Figure H12
Areas of Normal and Severe Exposure

Index

Note: *References are to clause numbers. Those in **boldface** are primary references.*

Proposal for Change

To help our volunteer members to assess proposals to change requirements we recommend that each proposal for change be submitted in writing and identify the
(a) Standard number;
(b) Clause number;
(c) proposed wording of the Clause (requirement, test, or pass/fail criterion) using mandatory language and underlining those words changed from the existing Clause (if applicable); and
(d) rationale for the change, including all supporting data necessary to be considered.

The proposal should be submitted to the Standards Administrator at least one month prior to the next meeting of the Committee. It is CSA Committee practice that only those proposals sent out to members prior to a meeting can be the subject of discussion and action. This is to allow the members time to consider the proposal and to do any research they may feel necessary.

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